Managing White-tailed Deer in Forest Habitat From an Ecosystem Perspective

Pennsylvania Case Study

Report of the Deer Management Forum

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Convened by Audubon Pennsylvania and the Pennsylvania Habitat Alliance

to compile and examine the pertinent research, enlist other expertise, weigh the issues, and set forth a vision of what ecosystem-based deer management might entail in large forested areas of the eastern United States, using Pennsylvania as an example.

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This report is available for downloading in portable document format (PDF) at the Audubon Pennsylvania web site (pa.audubon.org). Paper copies may be obtained on request while supplies last, with prepayment of $5 to cover postage, from Audubon Pennsylvania, 100 Wildwood Way, Harrisburg, Pennsylvania 17110.

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Front cover

Painted trillium, redback salamander, white oak, red trillium, hobblebush, and eastern wood-pewee are among the many native species that have been overlooked by traditional approaches to white-tailed deer management. Deer are a valued part of our natural ecosystems, but many other species have declined, sometimes drastically, in areas where deer densities have exceeded the cultural carrying capacity of the forest (see back cover).

Photo credits (clockwise from upper left): Roger M. Latham (painted trillium); Stephen V. Silluzio (redback salamander); John A. Haarstad, courtesy of Cedar Creek Natural History Area (white oak); Roger M. Latham (red trillium); Roger Earl Latham (hobblebush); J. Heidecker, courtesy of VIREO, Academy of Natural Sciences of Philadelphia (eastern wood-pewee); Roger M. Latham (white-tailed deer).

Back cover

Photo credits (clockwise from bottom): Ann Fowler Rhoads (fern carpet, Wyoming County, Pennsylvania); Roger Earl Latham (fenced-unfenced comparison, Susquehanna County, Pennsylvania); Roger Earl Latham (boulder-top “rock garden,” Warren County, Pennsylvania); Tom Kornack (close-up of bluebead lilies).

To Dr. Roger M. Latham (1914-1979),

a pioneering advocate for ecosystem management before the term was created. His work on deer research and management beginning in 1938 still informs our current understanding of Pennsylvania's deer problem. In a lifetime of speaking and writing about his love of nature and the sport of hunting, he educated the public about the need for a scientific basis for managing wildlife, without sidestepping controversy. We dedicate this book to Roger and his vision.

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(See biographical sketches in Appendix A, page 303)

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Preface

In April 2001, the Pennsylvania office of the National Audubon Society and the Pennsylvania Habitat Alliance asked a group of professionals to look at deer management from an ecosystem perspective. The resulting Deer Management Forum, first convened in October 2001, was asked to set forth a vision of what ecosystem-based deer management might entail. In particular, the group was asked to describe how deer management might differ from current practices if deer were managed within an ecosystem framework that aims to conserve native biodiversity. Only with such a vision in hand could decision makers, should they be so inclined, take the steps that will be needed to move deer management in Pennsylvania from a single-species approach to ecosystem management.

The preparation of this report is supportive of a recommendation made by a stakeholder group convened by the Pennsylvania Game Commission (P.G.C.) in July 2002. The group's top-priority recommendation was that deer be managed on an ecosystem basis. This report presents a vision of how that might be done.

Participants in the Deer Management Forum reviewed the scientific literature, visited field sites, heard presentations from other ecosystem and wildlife management experts, and interviewed others (See Appendices B and C for a list of presentations, field sites visited, and interviews).

The report is generally based on consensus. The one exception is the inclusion of material in Chapter 13, which is critical of P.G.C. Two former Game Commission staff members[1] felt that discussion of external critiques of the agency was inappropriate and counterproductive. It was a consensus of the remaining members of the Deer Management Forum, however, that it would be impossible to manage deer from an ecosystem perspective without facing up to and correcting deficiencies identified by external reviews of P.G.C., including reviews commissioned by the agency itself. Presented with an irresolvable impasse, the minority members withdrew their names from the report, although they allowed their contributions to the scientific portions of the report to remain.

By including in Chapter 13 past critiques of P.G.C. (e.g., the so-called MAT review and legislative audits), we do not imply any disrespect for the agency, its commissioners, or staff. We recognize that managing a large resource agency is no easy task, and all agencies have problems. A strong institution will welcome outside critiques as an opportunity for self-improvement.

Two members of the Deer Management Forum are on the staff of the Pennsylvania Department of Conservation and Natural Resources (D.C.N.R.). Their participation does not imply concurrence and endorsement of the report by D.C.N.R. leadership or the administration. To fully explore the issues of policy and structure around the management of deer, D.C.N.R.

permitted staff members participating in the Forum the freedom to openly discuss issues and alternatives from a scientific viewpoint.

The draft version of this report or portions of it have been reviewed by 10 experienced scientists and managers (listed on page ix; also see Appendix D). However, the reviewers were not asked to endorse the conclusions or recommendations, nor have they seen the final report before its release. Overall, the reviewers were very complimentary.[2] In a few cases, as explained in several endnotes and in Appendix D, we did not accept the suggestions or advice of reviewers. In the vast majority of cases, however, we were able to incorporate the suggested improvements. The Pennsylvania Game Commission was also given an advance review copy and senior staff members responded with updates, clarification of their position, and suggestions for revision, many of which are included in the final report.

This document is organized to facilitate its use by a range of readers, including scientists, interested stakeholders, policy analysts, and policy makers. It begins with a brief executive summary. Summary findings and recommendations are placed at the end of each chapter. The most important findings and recommendations appear in a separate chapter at the end of the main report. Supporting material appears in appendices.

Audubon Pennsylvania and the Pennsylvania Habitat Alliance

The mission of the Pennsylvania state office of the National Audubon Society is to conserve and restore natural ecosystems, focusing on birds, other wildlife, and their habitats for the benefit of humanity and the Earth's biological diversity. The state office supports 22 chapters in Pennsylvania with expertise on conservation projects, chapter capability building, fundraising, advocacy, education, and collaboration with other environmental organizations.

Pennsylvania has played a major role in the Audubon Society's history. When John James Audubon first moved to America in 1803, he settled at Mill Grove near Valley Forge. It was in Pennsylvania that he developed his spectacular and unique painting style. In 1896, the Pennsylvania Audubon Society was created as the second state Audubon Society in the country.

The Pennsylvania Habitat Alliance is a coalition of 30 organizations dedicated to conservation issues. It was formed in 1998 with a commitment to conservation of habitat through effective communication and cooperation among conservation organizations, sportsmen's groups, and land trusts.

This report was produced at the request of the Pennsylvania Habitat Alliance, with Audubon Pennsylvania acting as project administrator. The statements, findings and recommendations contained in this report do not necessarily reflect the positions of the member organizations of the Alliance.

Endnotes

[1] Dr. Duane R. Diefenbach and Jerry Hassinger

[2] Complimentary comments from reviewers included the following:

"I will start by complimenting the authors on the wealth of information contained in the report. It is a good reference source for a range of ecosystem topics."

"First and foremost, I want to congratulate all of you on this wonderful document. I know how incredibly hard you worked to produce this, and that work is richly and sometimes eloquently reflected on each page of this document. It is quite unusual in both its breadth and depth, its degree of interdisciplinarity, its readability (no, it's not casual reading, but interested parties from nearly any discipline or interested lay people will gain a great reward for the effort that they put into perusing this volume, and it is accessible to the willing from across that range), and its specific adaptive resource management framework."

"The report of the Deer Management Forum is a fascinating and superb effort to capture deer management in a comprehensive context. The report is an impressive document written by a group of biologists who have rich experience with the issues of deer in eastern forest ecosystems. The adaptive management approach provides the framework for a managing both deer and forests in manner that can build consensus for multiple objectives and incorporate the best scientific knowledge. The synthesis of existing knowledge presented here makes this a valuable document to many readers beyond the intended audience."

"First, I would like to say it was a great read. The task force is to be congratulated on pulling together an amazing amount of information. I have tried to write several chapters like the ones in this plan and I know how scattered the information is. Excellent job."

"I have just spent the last couple hours reading your draft report and I wish to commend you all on a job very well done. I came away from my visit with the Forum feeling overwhelmed with the complexity of the task before you but somehow you seem to have got your arms around it and come up with a credible way forward. Congratulations!"

"In general, I think that this is an excellent publication. I was particularly impressed by the logical, organized presentation of information in the book. I also think that the sections at the end of each chapter on 'Findings' and 'Recommendations' will greatly improve the utility of the publication."

Acknowledgments

We are grateful to those who have provided data, expert knowledge, or logistical support, in particular the reviewers of earlier versions of the manuscript (listed on opposite page). Dr. Duane R. Diefenbach, Pennsylvania State University, Cooperative Fish and Wildlife Research Unit, contributed introductory material on adaptive resource management and the bulk of the chapter on measuring deer population density. He and Jerry Hassinger, Pennsylvania Game Commission, Wildlife Diversity Section (retired) attended most of the Forum meetings, providing valuable guidance on deer management. In addition, we thank: Steve Balzano, formerly Pennsylvania Department of Conservation and Natural Resources; James Bailey, Dr. E. Michael Blumenthal, Mark W. Deibler, Dr. James R. Grace, and Dr. Thomas J. Hall, Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry; Dr. James K. Bissell, Cleveland Museum of Natural History; Robert C. Boyd, Calvin W. DuBrock, Dr. Chris Rosenberry, and Vernon R. Ross, Pennsylvania Game Commission; Dr. Patrick H. Brose and Dr. Susan L. Stout, U.S. Forest Service, Northeastern Research Station, Irvine, Pennsylvania; Dr. James C. Finley, Pennsylvania State University, School of Forest Resources; Dr. Kurt W. Gottschalk, U.S. Forest Service, Northeastern Research Station, Morgantown, West Virginia; Dr. William H. McWilliams, U.S. Forest Service, Forest Inventory and Analysis, Newtown Square, Pennsylvania; Brad Nelson, U.S. Forest Service, Allegheny National Forest; Michael Pechart, Pennsylvania Department of Agriculture; Beth Sanders and Sharon Sherick, Audubon Pennsylvania; Justin Vreeland, Pennsylvania Cooperative Fish and Wildlife Research Unit, University Park; and Paul g. Wiegman, formerly Western Pennsylvania Conservancy. We also thank:

Forum presenters

Dr. Roger C. Anderson, Illinois State University; Dr. Jody W. Enck, Cornell University; Dr. Malcolm Hunter, University of Maine; Dr. Bill Kendall, Patuxent Wildlife Research Center; Dr. James N. McNair, Patrick Center for Environmental Research, Academy of Natural Sciences of Philadelphia; Dr. Karl V. Miller, University of Georgia; Dr. John L. Roseberry, Southern Illinois University, Carbondale; Dr. Michael Soulé, University of California, Santa Cruz (retired); and Dr. Harry Zinn, Pennsylvania State University.

Forum interviewees

Dr. Walter P. Carson, University of Pittsburgh; Dr. David R. DeWalle, Pennsylvania State University; and Dr. William E. Sharpe, Pennsylvania State University.

Field trip hosts and presenters

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EXECUTIVE SUMMARY

Managing White-tailed Deer in Forest Habitat From an Ecosystem Perspective

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White-tailed deer have been a symbol of wild eastern North America throughout the region's history. Deer glimpsed in the woods have thrilled people with their grace and stateliness and venison at the campfire and table has provided savor and sustenance. But the history of deer-human interaction in the last two centuries is one of overexploitation through unregulated hunting, followed by 100 years of overprotection, population increase, and consequent habitat destruction resulting from overbrowsing by growing deer herds.

This report, using Pennsylvania as an example, addresses the seriously degraded ecological condition of forests across much of the East, which has resulted in large part from high deer densities. Forested ecosystems are among the region's most valuable natural resources; they protect our water supply, regulate climate, house a large diversity of organisms, and provide recreational opportunities. Pennsylvania's forests were a major source of timber in the United States in the mid-1800s, and could always be counted on to regenerate naturally. Timber harvesting continues to be a vital industry in the state; however, today when trees die or are harvested, natural replacement no longer follows as a matter of course. In many parts of the state, even where seed supplies are available, regeneration of most tree species does not occur unless the affected areas are fenced to exclude deer.

Deer, a natural and highly valued part of our forested ecosystems, were nearly eliminated from Pennsylvania by the late 1800s due to unregulated hunting. The Pennsylvania Game Commission (P.G.C.) was established in 1895 in part to "bring back" the deer. They were so successful that as early as the late teens and early 1920s concern was expressed about the negative effects of too many deer on forests in some parts of the state. Over time, high deer populations in most of Pennsylvania and across nearby states have greatly altered forest understories. The abundance of native wildflowers and other forest-floor plants has been greatly diminished, shrub species have been dramatically decreased or eliminated, and the variety of tree species has declined. Birds and other wildlife that depend on forest vegetation have also been affected. To the casual observer the woods still look green, but they are much altered. In place of the diverse, multi-storied vegetation that was the norm, there are just a few species, either not preferred by deer or resilient to repeated browsing, for example, hay-scented and New York ferns, striped maple, American beech, and several introduced, invasive species. Once the few tolerant or resistant species spread, their shade makes it difficult for most other members of the native flora to regenerate even if deer numbers are later reduced.

Recognizing that traditional management formulas have been major contributing factors to high deer populations, wildlife agencies are increasingly turning to approaches that focus on the whole ecosystem rather than a single species, taking into account forest structure, diversity of animal and plant species, ecological processes, and ecosystem function in management decisions.

In October 2001 a panel of scientists and experts in natural resource policy was convened by Audubon Pennsylvania and the Pennsylvania Habitat Alliance to review what is known about the impact of deer overabundance and craft a program for approaching deer management from an ecosystem perspective. The group, known as the Deer Management Forum, reviewed relevant scientific research, interviewed a wide range of experts from across the United States, visited field sites, and prepared this report on its findings and recommendations. A draft of the report was reviewed by 10 outside scientists and managers and was discussed with staff of the Pennsylvania Game Commission (P.G.C.). However, the reviewers were not asked to endorse the conclusions or recommendations, nor have they seen the final report before its release.

The major premise of the Deer Management Forum is that restoration and maintenance of fully functional forest ecosystems, containing a full component of native biological diversity at all levels, best serve the long-term interests of the people of Pennsylvania and the region. We recognize that the goal of bringing back the understory vegetation and ensuring the continuation of a rich overstory layer into the future is a values choice.

A switch to ecosystem-based management would involve a program to maintain or restore ecosystem structures and processes, not just healthy populations of deer. It could be carried out using the decision-support concept of adaptive resource management (A.R.M.), which is a science-based way of "learning by doing" that involves five steps:

(1) Set and quantify a resource management goal, based on a set of core values that most stakeholders can agree upon.
(2) Identify competing biological theories that are pertinent to meeting the overall management goal, and the management recommendations that follow from each theory.
(3) Based on past research and experience, pick what is initially believed to be the best combination of management actions (e.g., reducing deer density to 20 per square mile, avoiding the use of herbicides) and implement the combination in an experimental context.
(4) Make quantitative predictions of the results of management actions for each competing biological theory or model and compare the predictions against field data at regular

intervals (e.g., every 3 years), tracking changes in indicator species and other environmental indicators in both managed areas and appropriate comparison areas.

(5) Update the set of management actions, giving preference to the recommendations that flow from those theories (models) that performed best in the comparisons.

A.R.M. does not require consensus on the causes of current forest problems. Managers start by ranking existing theories, using the judgment of a range of experts. Once begun, the A.R.M. process is automatically self-correcting; weights of competing theories are adjusted by applying a formula to indicator data. Based on a comprehensive review of the scientific literature, the authors recommend giving an initial 90% weight to theories that point to deer as a major cause of forest alteration and a 10% weight to theories that say deer have a negligible effect.

Implementing A.R.M. in Pennsylvania depends on the Game Commission, the Department of Conservation and Natural Resources (D.C.N.R.), and private groups building a consensus on goals and assembling the necessary expertise. A.R.M. protocols would be chosen by agency staff with the advice of a broad-based, ad hoc, research advisory committee. An ad hoc, public advisory committee would be formed to represent public constituencies, keep abreast of scientific progress, and provide feedback to managers and researchers to help ensure that choices are made that will be supported by stakeholders and the general public. An example of an A.R.M. program is outlined, with acknowledgment that other approaches to ecosystem management are possible.

The authors further recommend that P.G.C. commissioners update their mission statement and written deer management policy to reflect current understanding of wildlife management principles and recognize the role of deer management in protecting ecosystems and stakeholder values. P.G.C. needs to provide all property owners whose goal includes restoring or sustaining forest structure, diversity, ecological processes, or ecosystem function the ability to manage deer in ways that will enable them to achieve those goals. While still using hunting as the primary management tool, P.G.C. needs to establish new funding sources that represent its broader constituencies and provide its full range of stakeholders an opportunity to participate in management decision processes. Expanding wildlife management from the present single-species approach to an ecosystem focus will require changes in P.G.C. policy, administration, organization, and staffing.

Major Findings Regarding Science and Management of Forests and Wildlife

(1) Pennsylvania's forested ecosystems have been severely altered. Virtually all of the published literature on forest damage in Pennsylvania suggests a major role for high densities of white-tailed deer.

(2) In the areas that have been affected the longest by high deer densities, the diversity of canopy tree species has decreased. Even in some areas that have sustained high deer densities for just a few decades or less, understory tree and shrub layers have been diminished in species diversity, height, and density or completely eliminated, and the formerly diverse ground layer has been reduced to ferns and a few other species that are either not preferred by deer or resilient to repeated browsing.

(3) As a result of the elimination of large predators in the 1700s and 1800s, humans are the only species still present in Pennsylvania capable of maintaining the population density of white-tailed deer in balance with its habitat. Active intervention by humans to keep deer populations below levels that severely alter the composition and diversity of forests will have to be sustained forever, assuming that it is impractical to restore the full complement of predators across the entire range of white-tailed deer in the state. Hunters are critical to the success of deer population management because hunting is currently the only feasible method of regulating deer populations on a large scale.

(4) Adaptive resource management (A.R.M.) is a science-based methodology that is well suited to managing deer from an ecosystem perspective while accommodating disagreements over models of forest dynamics or causes of forest alteration. The A.R.M. approach provides for testing competing scientific models or hypotheses about how forests and wildlife populations function while, at the same time, providing a framework for regular management decisions to be made and implemented based on the best available information.

(5) Two major challenges exist in implementing A.R.M. for deer in Pennsylvania. First, management objectives must be determined in the political arena before A.R.M. can proceed. Second, recovery of the structure, diversity, and function of forest ecosystems may take years or decades. Evaluating progress over a multi-year time frame presents difficulties when deer harvest goals need to be set annually.

(6) The initial commitments involved in preparing A.R.M. alternatives could be made within existing budget authorizations, provided agencies are willing to assign staff to the process. However, because of the great damage that has already been done to the structure of forests and the depletion of the seed supply in many parts of the state, a long-term commitment to the A.R.M. process is needed.

(7) The sooner effective treatments are implemented, the sooner further deterioration will be prevented, saving larger areas of forested land in Pennsylvania from slipping below the threshold for fast recovery.

Major Findings Regarding Policy and Administration

(1) The goal of bringing back the understory vegetation and ensuring the continuation of a self-renewing and diverse forest overstory into the future is not a scientific choice but, instead, a values choice.

(2) With the exception of a vocal minority of hunters, there is a broad consensus that deer densities in Pennsylvania are too high from an ecosystem perspective. In a 2003 survey of Pennsylvanians, the general public ranked managing deer to promote healthy and sustainable forests highest among potential goals (average 7.5 of 10, with 10 meaning complete agreement) and hunters and anglers ranked it even higher (7.8 of 10). Pennsylvania hunters and anglers ranked managing deer to promote healthy and sustainable forests higher than managing deer to promote hunting opportunities (7.8 vs. 7.1 of 10). The stakeholder group P.G.C. convened to recommend goals and objectives for its statewide deer management plan also ranked managing deer to promote healthy forests and ecosystems as its top goal.

(3) P.G.C.'s Deer Management Assistance Program (DMAP) provides for increasing the number of deer harvest permits allocated on specific land units at the owner's request. It is intended as a tool for landowners to manage deer on their own property in line with their values.

(4) In a reevaluation of D.C.N.R.'s state forest system in 2004, Scientific Certification Systems predicted that overabundant deer will continue to decimate the flora and fauna in Pennsylvania's state forests without:

(a) enhanced DMAP regulations that allow more liberal harvest of antlerless deer on state forest lands and are granted to the D.C.N.R. Bureau of Forestry on a continuing and contingency basis by the P.G.C. commissioners; or

(b) legislative fiat, whereby administration and control of deer hunting regulations on District Forests are transferred from P.G.C. to D.C.N.R.; or

(c) merger of P.G.C. with D.C.N.R. in a combined natural resource agency resulting in oversight of hunting regulations by a more balanced representation of natural resource interests. Note: both agencies are on record in opposition to such a merger and there appears to be no real political will to pursue it at this time.

(5) The P.G.C. commissioners, in response to proposals by staff to bring the deer herd more in line with its habitat and to protect commercially valuable trees, set targets for lower deer densities in Pennsylvania in 1979; however, those goals have never been met. In a renewed effort to reduce deer population levels, numerous changes were made in the deer management program from 1998 through 2003. However, the deer herd continued to increase and remains today at 20% above the 1998 level.

(6) Adopting a program of managing deer from an ecosystem perspective would provide both advantages and challenges for P.G.C. Ecosystem considerations would lead to the conclusion that deer densities in some parts of the state should be reduced below levels that would be set solely by considerations of deer health and condition. This would require targets even lower than those P.G.C. has been unable to reach in the past. The reaction of some hunters to lower densities may be negative but the 2003 survey results indicate that the majority of hunters would support the goal of managing deer to promote healthy and sustainable forests.

(7) With the reorganization in 1999 of the Wildlife Management Bureau (with Dr. Gary Alt named chief of the newly formed Deer Management Section) and the support of agency policy makers, P.G.C. is poised to pursue a more aggressive deer management program that, in theory, can effectively reduce deer densities in many parts of Pennsylvania. Its success depends critically on whether the changes are formalized in a way that enables them to last through the turnover of personnel on the staff and Board of Commissioners.

(8) P.G.C. senior staff members argue that they have done all that is possible to manage deer under the current sociopolitical environment. While we find there are many more measures that the P.G.C. staff could and should implement, we do not minimize the sociopolitical constraints under which P.G.C. staff members must operate.

(9) The management of deer is a service provided to all citizens of Pennsylvania, yet P.G.C. is currently funded primarily by license dollars and timber-harvest revenues from game lands. Neither source is predicted to be sustainable in the long term. In the results of a 2003 survey of Pennsylvania residents, 71% of the respondents agreed that a greater proportion of resource agency budgets should go toward non-game wildlife and threatened and endangered species (11% disagreed). Sportsmen supported this concept also, with 70% of hunters and anglers agreeing and 11% disagreeing. A more stable and equitable funding base is required if P.G.C. is to meet broader conservation goals.

(10) Of all the new measures initiated in recent years by P.G.C., the most intricate is DMAP, which shifts some responsibilities away from P.G.C. for choosing deer densities, transferring it to landowners who can apply for additional permits for use solely on their properties. However, most of Pennsylvania's land is privately owned and the vast majority of landowners do not understand the ecological impacts of deer overbrowsing. Thus, most of Pennsylvania's land will not benefit from any science-based application of DMAP.

(11) P.G.C. gives mixed messages about the need for ecosystem considerations. This reflects a mix of *internal* stakeholders with differing views and is evidence of an ongoing debate within the staff and Board of Commissioners about the future of the agency. For instance, P.G.C.'s web site discusses forest damage caused by high deer populations, as does the current deer population management plan. However, P.G.C.'s main strategic planning

document, developed by senior staff members, does not acknowledge that high wildlife populations can be a problem for ecosystems nor does it concede that the agency has failed to bring the deer population in line with past targets.

(12) Although the P.G.C. staff is strong in the areas of deer biology and in implementing and enforcing regulations to make hunting safe, the current staff has limited expertise in the field of general ecology. External reviews have found that P.G.C. operates primarily as a law enforcement agency, with its limited number of biologists isolated and, with few exceptions, not engaged in the core functions of the agency. With resources historically directed mainly at law enforcement, P.G.C. is struggling with making the transition from a law enforcement agency to a natural resource agency — a transition that most state agencies made many years ago.

(13) There is an unusual three-way resource management structure in Pennsylvania with responsibility given by the legislature to P.G.C. for mammals and birds, to the Pennsylvania Fish and Boat Commission (P.F.B.C.) for aquatic animals, and to D.C.N.R. for forests. This situation tends to reinforce single-species management at P.G.C.

(14) State agencies that are responsible for, affect, or have a stake in the management of natural resources in Pennsylvania are not collaborating to ensure that policies by one agency do not adversely affect another's ability to carry out its mission. For instance, at present D.C.N.R. cannot fully implement ecosystem management on its lands because it does not have the necessary authority to manage deer populations in state forests and state parks.

(15) The prevailing wisdom about what the public will support is not always right. For example, there is a perception by some Pennsylvania residents that maintaining the separation between the state agencies managing Pennsylvania's natural resources is strongly supported by the general public. However, the statewide survey of randomly selected Pennsylvania households conducted in December 2003 indicated that 75% of respondents were in favor of combining P.G.C., P.F.B.C., and D.C.N.R. into a single agency provided that the single agency would result in a more efficient or cost-effective system for managing natural resources. Nonetheless the three agencies are on record in opposition to such a merger and, in any case, achieving a change of this magnitude would require an improbably large expenditure of political capital.

Major Recommendations Regarding Science and Management of Forests and Wildlife

(1) Until proven otherwise, policy makers should assume that the consensus view on the impacts of the current high densities of white-tailed deer on forest ecosystems is correct.

(2) Deer management should focus on managing the ecosystems of which deer are a part. Deer densities in Pennsylvania's major forested areas should be brought down to levels that will allow the restoration of full forest structure, diversity, ecological processes, and ecosystem function.

(3) Adaptive resource management (A.R.M.) should be chosen as the framework for implementing management of deer from an ecosystem perspective. The science-based approach of A.R.M. will allow agencies to begin applying remedies based on the best available information while updating their operational theories as new data become available.

(4) Forum members propose a two-tiered A.R.M. program. The first tier would apply to the state as a whole. Its initial treatments would take into account factors that go beyond ecosystem management, for example, budgetary constraints and local traditions. The second tier would apply A.R.M. at a smaller scale, to multiple 10-square-mile forest treatment and comparison areas in all of the major forest regions of the state. In contrast to the first tier, treatments on these forest recovery-monitoring tracts would include a range of deer densities, as well as tests of alternative theories on causes of forest degradation and recovery. The focus would be exclusively on ecosystem management. Lessons learned from these smaller-scale manipulations could be applied to forested areas across the state as a whole in subsequent years.

Major Recommendations Regarding Policy and Administration

(1) The Governor and the General Assembly, in collaboration with P.G.C., should identify a funding base that is more stable and equitable than funding derived exclusively from sources such as license dollars and timber sales on game lands, in order to facilitate the shift from single-species management to ecosystem management.

(2) To identify the most effective way for P.G.C. to achieve its mission, the commissioner system should be reviewed by the Governor and the General Assembly. If the system is retained, it should be changed to ensure that the commissioners represent all the citizens of Pennsylvania, not just those who hunt. Although the Governor now has the power to do this through the appointment process, the General Assembly also should give its approval to broad representation on the Board of Commissioners.

(3) The General Assembly should modify P.G.C.'s enabling legislation to make it unambiguously clear that part of the agency's mission is to resolve wildlife-human conflicts and protect forest ecosystems.

(4) P.G.C. should formally review its staffing capabilities and in-house training. The management of wildlife in Pennsylvania from an ecosystem perspective requires P.G.C. and perhaps other natural resource agencies to employ more wildlife biologists, ecologists, and

other scientifically trained staff members in key positions within central and regional office structures. P.G.C. should also improve training of all staff members on ecosystem issues. To facilitate effective dialogue with hunters, P.G.C. should bring into core positions more people with both strong biological backgrounds and good communication skills.

(5) Until such time as P.G.C. can successfully bring deer densities down to previously approved targets and be well on its way to implementing ecosystem management, an annual review of P.G.C.'s mission, organization, skill mix, policies, funding adequacy, funding sources, and priorities, along with the sociopolitical obstacles it faces, should be conducted by an independent entity appointed by the Governor and the General Assembly. These reviews would build on past reports by the Management Assistance Team, Legislative Budget and Finance Committee, and others, together with input from P.G.C. staff members on recent changes and difficulties.

(6) Public agencies need to lead by example in managing forestlands. P.G.C., in conjunction with D.C.N.R. and with assistance from the Governor, should address the conditions that must be met to maintain continued certification of the state forest system, particularly regarding the adverse effects of deer. In addition, P.G.C. should ensure sustainability of forests on state game lands by developing and implementing an ecologically based forest inventory and forest management plan. When necessary, sections of state game lands should be entered into DMAP.

Looking Forward

The Deer Management Forum hopes that this report and our findings and recommendations will serve to facilitate a partnership between Pennsylvania's natural resource agencies and their public and private stakeholders to bring about significant changes in the way deer are managed in the Commonwealth. Forum members also hope that the report will be useful in other parts of eastern North America where uncontrolled growth of white-tailed deer populations has adversely affected forest structure, diversity, ecological processes, and ecosystem function.

Management on an ecosystem basis is essential to address the threats and stresses on our forests. Resolving the deer impacts will enable us to move forward on effective resolution of other forest health issues. We have shown that ecosystem-based management is feasible and that scientific methodologies exist to achieve it; however, it will require substantial commitment and willingness to adopt new approaches. A partnership among agencies, landowners, and other stakeholders, based on a common vision and goals, is the key to achieving success.

Part I. Introduction to Managing Deer from an Ecosystem Perspective

Chapter 1. Introduction to the Report

Chapter 2. The Adaptive Resource Management Approach

Chapter 3. A Brief History of Penn's Woods

Chapter 4. Some Root Causes of Our Current Ecological Problems

Chapter 1. Introduction

Deer play a role in ecosystems, particularly forests, in various ways including:

(1) Herbivory or predation on the plants they use as food

(2) Altering the physical habitat used by other animal species, plants, and other organisms in the ecosystem

(3) Altering plant species composition, richness (diversity), forest structure (see box on page 34), ecological processes, and ecosystem function

(4) Competing with other animals that use the same food resources

(5) As prey, providing food for large predators

Consequently, deer management has implications that go far beyond recreational hunting.

History of deer management in Pennsylvania

The history of deer management in Pennsylvania is one of overexploitation through unregulated hunting in the nineteenth century, followed by 100 years of overprotection, population increase, and habitat destruction. Deer were rare throughout the eastern United States by 1900[1] but they were scarce in Pennsylvania by 1895, when the Pennsylvania Game Commission (P.G.C.) was formed, in part to restore deer numbers.[2]

Regulated hunting, focusing primarily on protecting antlerless deer, became the hallmark of P.G.C.'s deer management program, which resulted in the herd's rapid recovery.[1] Deer densities were extremely high by the mid-1940s. Escalating alteration of forested habitats due to high-density deer populations was noted by Commission biologists who called for more aggressive antlerless deer harvests.[3] Antlerless deer, however, continued to be under-harvested and the state's deer population continued to grow.

In 1979, P.G.C. adopted deer density goals based on a nutritional carrying capacity model (see box on page 16) that estimated the amount of forage available to deer on a sustained basis in forested habitats. Again, there was a call by biologists to increase antlerless harvests to meet these goals, but instead the Commission maintained deer numbers at 50 to 100% above the recommended goal, where they remained through 1999[4] and then increased a further 20% by 2003.[5] As a result there is widespread concern in the state about severe degradation of deer habitat and negative impacts on Pennsylvania's forested ecosystems, agriculture, wood products industry, and the quality of life for many Commonwealth residents. At the same time, interest in ecosystem approaches to land and wildlife management has increased.

With the reorganization in 1999 of the Wildlife Management Bureau (with Dr. Gary Alt named chief of the newly formed Deer Management Section) and the support of agency policy makers, P.G.C. now has a more aggressive deer management program that, in theory, can effectively reduce deer densities in many parts of Pennsylvania. The challenge now is to tie deer densities to ecosystem management.

Task of the Deer Management Forum

The Deer Management Forum, first convened in October 2001 by Audubon Pennsylvania and the Pennsylvania Habitat Alliance, was asked to set forth a vision of what ecosystem-based deer management might entail in the Commonwealth's large forested areas. In particular, the group was asked to describe in a report how deer management might differ from current practices, if deer were managed within an ecosystem framework that aims to conserve biodiversity. Only with such a vision in hand could decision makers, should they be so inclined, take the steps that will be needed to move deer management in Pennsylvania further in the direction of ecosystem management.

To fulfill its task, Forum members reviewed the literature on deer impacts and management, as well as on the condition of Pennsylvania's forests and the stresses placed upon them. This literature review provides most of the support for the findings. The group also drew upon the experience Forum members have gained in studying and examining the wildlife and forested ecosystems of Pennsylvania. Fifteen meetings were held to prepare the report, many of which included presentations by outside speakers or Forum members with special expertise. Nine outside speakers addressed the group. Several additional scientists were interviewed. In addition, Forum members took several field trips.

Report organizing principle

This report is organized around the decision-support concept of adaptive resource management (A.R.M.).[6] A.R.M. is a science-based way of "learning by doing" that involves five steps:

(1) Set and quantify a resource management goal, based on a set of core values that most stakeholders can agree upon.

(2) Identify competing biological theories that are pertinent to meeting the overall management goal, and the management recommendations that follow from each theory.

(3) Based on past research and experience, pick what is initially believed to be the best combination of management actions (e.g., reducing deer density to 20 per square mile, avoiding the use of herbicides) and implement the combination in an experimental context.

(4) Make quantitative predictions of the results of management actions for each competing biological theory or model and compare the predictions against field data at regular intervals (e.g., every 3 years) using indicator species and other environmental indicators.

(5) Update the set of management actions, giving preference to the recommendations that flow from those theories (models) that performed best in the comparisons.[7]

The Pennsylvania Game Commission, along with wildlife agencies in other states, already relies on A.R.M. indirectly to set the waterfowl season, because the U.S. Fish and Wildlife Service uses A.R.M. to set its yearly targets for waterfowl harvest. Managing deer using an A.R.M. paradigm would be a more complex challenge. Nevertheless, the use of A.R.M. as a decision-support system provides a way to translate an abstract concept, "managing deer from an ecosystem perspective," into step-by-step operations that an agency or coalition of groups can implement. Furthermore, A.R.M. has the added potential to channel controversy into constructive predictions that can be tested and actually help to improve management over time.

Report content

Each chapter is relevant to one of the A.R.M. steps. The chapters in Part I deal with background information related to A.R.M. itself and to the first step in A.R.M., defining and quantifying the management goal. The report starts from the premise that management of white-tailed deer from an ecosystem perspective involves attempting, within the constraints of landowner objectives, to maintain or restore ecosystem structures and processes, not just healthy populations of deer.[8] Pennsylvania is taken as a illustrative example. To define typical ecosystem structures that need to be restored, the report reviews the natural history of Pennsylvania, the current state of the forests, and the extreme alteration of forests that has occurred with increased deer density in certain parts of the state. It concludes with a chapter that explores some of the root causes of our current ecological situation.

Part II begins by exploring the role of white-tailed deer in altering vegetation structure, along with the view that without reductions in deer density, neither recovery of greatly altered forest areas nor prevention of similar change in other areas is likely to be achieved. Alternative theories are discussed. Subsequent chapters go beyond the direct impact of deer to address the full theoretical basis and experience on which A.R.M. must be based, both in choosing yearly management actions and in making the predictions of outcomes that are crucial to updating management strategies for deer. These chapters include consideration of other factors that affect forest ecosystem structure, processes, and the manner and rate at which forests are likely to recover in different locations following reductions in deer browsing.

Part III discusses one of the important quantitative aspects of A.R.M., the measurement of progress. The first chapter presents a practical set of indicators that, if measured in the forests of Pennsylvania, would indicate the progress that was being achieved towards maintaining and restoring ecosystem structure and processes. These same indicators would be used to rank the success of biological theories in making predictions.

When a change in deer numbers is chosen as one of the planned management actions, managers and A.R.M. analysts also need to know whether the implemented deer harvest regulations actually change deer population levels. The second chapter in Part III reviews methods for measuring deer densities, a separate issue from measuring the progress of ecosystem recovery.

Carrying capacity

Much confusion about deer management stems from the fact that more than one definition of "carrying capacity" is used, even among scientists and wildlife managers. The different meanings reflect very different philosophical and practical approaches to deer management.

• ***Ecological carrying capacity***

Ecological carrying capacity focuses on the interaction between a population of herbivores (plant-eaters, such as white-tailed deer) and the plants that they eat. It is defined as "the maximum density of animals that can be sustained in the absence of harvesting without inducing trends in vegetation."[9] At ecological carrying capacity, the rate of browsing is roughly equal to the rate of food-plant regrowth. The definition also implies that there are no major changes in plant species composition resulting from an increase in the density of an animal population to its carrying capacity.

• ***Nutritional carrying capacity***

In contrast, some highly simplified, deterministic models used in managing deer, elk, and moose throughout the United States focus instead on maximum sustained harvest yields (M.S.Y.). These models are used to estimate, from hunter harvest numbers and sometimes the physical condition of deer, where a population lies on the yield curve, which shows the hump-shaped relationship between deer population density and sustainable annual harvest (see Figure 9, page 160). Many managers who use these models believe that deer should be managed to stay near the peak (the nutritional carrying capacity) of the yield

(Box continued on next page.)

Implicit in the use of A.R.M. are the assumptions that (1) a suitable management structure, complete with qualified support staff or consultant expertise, can be put into place, and (2) a consensus among government agencies and stakeholders can be reached on defining a quantifiable goal that will embody the idea of managing deer from an ecosystem perspective. A.R.M. does not require consensus on the means to reach a goal — which is one of its strong points — but the goal itself must be well defined and quantifiable. Part IV takes up the important question of whether Pennsylvania currently has the capability to implement A.R.M. for deer. Can P.G.C., the Pennsylvania Department of Conservation and Natural Resources (D.C.N.R.), and private groups in the state build a consensus on goals and pull together the necessary expertise?

Information collected on management and stakeholder issues is presented in the two chapters that make up Part IV, one on government policy and one on stakeholders, including hunters, non-governmental organizations, and landowners.

(Box continued from previous page.)

curve, because near that point, both overharvest and underharvest (so-called management "errors") theoretically are automatically compensated by population responses of deer. The concept of nutritional carrying capacity disregards plant species composition and considers only the total availability of essential nutrients. From this perspective, the ideal deer habitat is fields of corn and other crops side by side with old fields or clearcuts overgrown with shrubs and tree seedlings. In fact, deer persist in high numbers partly because of the inadvertent input of resources as byproducts of human activity. Artificially high disturbance rates (logging), agricultural fields, and suburban gardens generate high-quality deer food in greater abundance or more consistently, or both, than processes that are not supported by humans, including those that perpetuate forests. The deterministic, single-species approach characterized by M.S.Y. has fallen out of favor with most scientists and many managers.[10]

• ***Cultural carrying capacity***

The maximum number of deer a habitat is physically equipped to support can be much higher than the number that will allow other forest management goals to be achieved. Management goals take more than the number of huntable wildlife into account. Forest management elements that are adversely affected by high deer densities include tree regeneration, conservation of rare plant species, and maintenance of habitat for watchable wildlife, rare animal species, and game other than deer. Cultural carrying capacity is a values choice, which takes into consideration the needs and concerns of a range of stakeholders.

Part V concludes the report with a specific example of how A.R.M. for deer might work in Pennsylvania's forests once an appropriate management structure is in place.

The report is structured to facilitate its use by a range of readers, including scientists, policy analysts, and policy makers. Summary findings and recommendations are placed at the end of each chapter. The most important findings and recommendations are compiled in the final chapter and encapsulated in the executive summary. Supporting material is given in appendices.

Limitations of the report

Although over-abundant white-tailed deer cause problems in agricultural areas and suburban areas, we have focused exclusively on forest tracts in excess of one square mile, consistent with our charge to study ecosystem management. As a result, issues related primarily to less forested areas, such as suburban sprawl, forest fragmentation, and the farm-forest interface, are not discussed. Nevertheless, many of the methods described here can be applied to those other areas.

This report has a tendency to focus on trees and other plants and forestry for a number of reasons. Primarily, the majority of the studies of deer impact on forested ecosystems have measured plants, not animals or other organisms. Plants are more easily located and measured. They do not hide to evade handling, they are attached to the specific sites where an impact is occurring, and they provide the basis of the habitat for the other species inhabiting a site. It is reasonable to assume, because animals are tied to suitable habitat, that the plants providing that habitat can be used as a surrogate measure for the recovery of the community as a whole.[11] Also, plants are generally less susceptible to seasonal or annual population fluctuations than other organisms and thus are better for observing trends in deer impact. In contrast, studies to assess the impact of deer on other wildlife have inherently high variability because the impact of deer on them is indirect, involving the removal of species of plants used for food or cover. Finally, many of the agencies charged with land and forest management that are concerned about the impact of deer on these resources are also charged with native plant management and have no regulatory authority over the animal populations on the lands they manage. A few studies have been done and others are underway to assess deer impacts on species other than plants, but it will take some time to develop the body of knowledge and data to document the definitive impacts of high deer densities on them.

Non-sustainable timber-cutting practices such as high-grading are having a detrimental influence on private forestlands across the state, although they are patchier and intermittent compared to deer overbrowsing. Acid rain is weakening the buffering capacity of soils statewide. We discuss these topics as they relate to deer management; however, consideration of policy measures to reduce non-sustainable timber-cutting and acid rain is outside the scope of this report. Nevertheless, the authors recognize that these are important topics and deserve the kind of policy attention that we in this report have given to the deer issue.

At least one reviewer wanted to see more social science in the report. In response, we added additional material to our discussion of the regulatory structure of deer management in Pennsylvania. Still, we recognize that management of deer from an ecosystem perspective is unlikely to be successfully implemented without the guidance of people with backgrounds in social science areas such as resource economics and sociology.

Endnotes

[1] McCabe and McCabe 1984

[2] Kosack 1995

[3] Latham 1950

[4] Legislative Budget and Finance Committee 2000

[5] M. Grund, unpublished data, 2003

[6] Lindenmayer et al. (2000) suggested that ecologically sustainable forest management requires perpetuating ecosystem processes, including chemical cycling and maintenance of biological diversity at all levels (genetic, species, landscape, and ecosystem). Because of the difficulty of measuring many ecosystem processes directly, they reviewed the use of indicators that could be monitored to determine whether goals were being met. They urged that adaptive resource management be employed to test the validity of any monitoring program.

[7] The theories themselves may be modified from time to time to take into account the results of the comparisons.

Endnotes

[8] Other definitions of ecosystem management are possible. For example, the Ecosystem Management Advisory Committee of the Pennsylvania Bureau of Forestry, D.C.N.R., defined it this way: "Ecosystem management is the implementation of practices that maintain or restore soil fertility, water quality, biological diversity, and other important indicators of ecological health" (from "Definition of ecosystem management for the Pennsylvania Bureau of Forestry," unpublished, November, 1998). Maintaining ecological integrity by protecting biological diversity and ecological processes is the general goal of ecosystem management, according to an extensive review of the historical development of the concept (Grumbine 1994).

[9] Krebs 1978

[10] Holt and Talbot 1978; Mangel et al. 1996

[11] When plant community recovery is successfully achieved in some areas, data can be collected on animals to check this assumption.

Chapter 2. The Adaptive Resource Management Approach

If any program to manage deer is to improve over time it must embrace, rather than ignore, the biological uncertainties. Adaptive resource management (A.R.M.) has been termed "managing in the face of uncertainty, with a focus on its reduction."[1] A more formal definition states that A.R.M. "describes the ability to make a sequence of decisions, in the face of uncertainty, that is optimal with respect to a stated objective, recognizing some constraints."[2] Implied in these definitions is that management can be improved if uncertainty is reduced. In calling for an adaptive management approach to managing deer in national parks, William Porter and Brian Underwood stated, "While the [National Park Service] cannot effectively achieve its goals without better science, neither can it wait for science to fully understand the dynamics of plant-herbivore interactions."[3]

A.R.M. is an alternative to more traditional ways of using scientific data in setting management regulations, namely those that rely solely on expert opinion within an agency or from outside in the form of expert advisory groups. A.R.M. is particularly appropriate in situations where differing interpretation of the scientific data has become a major obstacle to decision making. A.R.M. is not a substitute for broader reforms that have been suggested for wildlife management, such as formally evaluating management decisions against a set of agreed-upon criteria.[4]

An A.R.M. program links three components: (1) management objectives and decisions, (2) models of the system dynamics, and (3) a monitoring program to assess changes in the system being managed. The concept of a model may be unfamiliar to some readers (see box on next page), but its use in this report is essential to explain how management actions are actually adjusted in A.R.M. as new information about forest dynamics is gained.

Management objectives must be specific and quantifiable so that progress towards them can be given numerical ratings and success can be evaluated based on numerical goals. Objectives must be agreed upon by agencies and participating stakeholders as a precondition for A.R.M. to be implemented.[5] The long-term objective of managing deer from an ecosystem perspective is the recovery and maintenance of forest structure and diversity of indigenous animal and plant species, as well as ecological processes and forest ecosystem function. If the native herbaceous vegetation, shrubs, understory trees, and tree canopy are restored and maintained (presupposing that this is consistent with landowner objectives), we assume that other species dependent upon them will have the habitats they need to flourish.[6] We presume that any A.R.M. program for deer will begin with a short-term goal, such as showing improvement in forest structure. The ability to quantify goals, which is necessary for A.R.M., requires the judicious selection of indicators. There are candidate sets of indicators that are appropriate for Pennsylvania's forests (discussed

Definition of "model"

A predictive forest model is a set of verbal rules or mathematical equations that allow quantified predictions of how specific indicators of forest stand conditions will change over time based on a change in a variable of management interest, such as a change in deer density. Usually, forest models are based on a conceptual framework of how forest components interact.

The "input" to a predictive forest model is the starting condition of the stand and relevant variables, such as deer density.

The "output" from the model is a quantitative prediction of how the indicator will change at some time in the future.

For A.R.M. as used in this report, the model output must also include a value for the uncertainty in the prediction, such as a variance or standard deviation.

in Chapter 9). A set of several measures is more reliable than just one or two and those involving multiple species may better reflect broad trends than single-species measures (Lindenmayer et al. 2000); thus, to be effective, A.R.M. requires the simultaneous monitoring of several indicator species and one or more structural indicators (e.g., complexity of vertical layering in the forest, tree seedling density, shrub density). By definition, indicators are surrogates for the complete set of species in a community and the ecosystem processes that sustain them. As a result, research into the long-term appropriateness of the choice of indicators must parallel the monitoring of the indicators themselves.

Success in reaching the short-term goal (improving forest structure) would be declared when a statistically significant improvement in indicators of ecosystem integrity is detected and sustained over time. This by itself is a major challenge given the scientific difficulties in finding trends in complex, ever-changing ecological systems. Based on the analysis presented in subsequent chapters, it may take a decade or more to demonstrate that improvements can be both obtained and sustained.

As for the long-term goals, there exist quantitative indicators for commercially valuable trees that can be used to demonstrate long-term success,[7] but no such target magnitudes of change have been developed for other components of the forest ecosystem. However, it is vital to do so, for instance, by using expert panels such as the one convened for this report. Only with long-term targets in hand can the adequacy of short-term goals be assessed.

Although objectives chosen for A.R.M. should change only when or if new data render them obsolete, disagreement regarding models of the dynamics of the system being managed is permitted at any time. This is one way in which A.R.M. is an improvement over traditional management. Much of the uncertainty regarding managing deer to protect forested ecosystems revolves around how deer directly and indirectly affect the environment. Competing models of the dynamics of forested ecosystems might have different predictions regarding the effect of a specific management action. Those models that do the best job of predicting the outcome of a given management action are given more emphasis when future decisions are considered. This is why monitoring ecosystem responses to management actions is critical.

The form of A.R.M. that we present in this report is based on the model of waterfowl management developed by the U.S. Fish and Wildlife Service.[8] In this form of A.R.M., decision makers give an initial weighting to the models in making quantitative decisions such as how many antlerless deer harvest permits will be authorized in a given year. For instance, if the Pennsylvania Game Commission (P.G.C.) assigned a 90% weight to the consensus view that white-tailed deer are hurting forest structure and a 10% weight to theories that white-tailed deer were relatively unimportant, as we recommend later in the report, then the initial number of permits under A.R.M. would end up close to the recommendation that would be made under the consensus view alone. There are many possible weighting schemes that could be used, including a weighted-average approach (this term will be defined later) when the management action includes quantitative components such as numbers of permits. Alternatively, an all-or-nothing approach could be used in which the agency would fully adopt for a given year the model with the greatest weight. In any case, the assigned model weights would be adjusted in future years based on how well each model did in predicting the outcome of the management action. The adjustments can be made using professional judgment, probability theory,[9] or some combination of the two. The exact values of the initial weights are not crucial, because the system is self-correcting. Furthermore, the weights can be adjusted to account for multi-criteria outcomes that include goals or constraints other than ecosystem management. For example, the rate at which progress in forest recovery occurs can be adjusted by raising or lowering the quantitative decisions (e.g., antlerless permits) to account for agency funding or other constraints.

In many, perhaps most, cases it is desirable to update the models themselves from time to time based on the results of the monitoring program. This could be done after each evaluation was completed, so that models would be optimized for their next evaluation several years later. In addition, totally new models might be proposed, which could also be considered at the start of a new monitoring period.

A quantitative example of applying A.R.M. to deer in large forested areas is presented in Tables 1 and 2 and the next five paragraphs. Those readers not interested in such detail may want to skip to the paragraph following Table 2.

A hypothetical example of A.R.M. in action with two competing models (I and II) is shown in Tables 1 and 2. The area of application is assumed to be a region where 6,000 deer harvest permits have been issued annually for many years, keeping the deer densities above P.G.C. targets. Model I is based on research into the effects of deer on forest structure and processes. If the model is correct, then deer harvest permits should be increased to 12,000 per year in order to start the forest on the way to recovery. In our example, we take Model II to be the “null hypothesis," that is, the theory that no management action under consideration will change anything. Scientists often use the null hypothesis as a standard of comparison against the theory that a particular research effort is designed to test. Under model II, the number of deer harvest permits would be left at 6,000 per year. To begin the A.R.M. process, managers make an initial professional judgment, with the help of expert advice, of the likelihood that each model is

Table 1. Example of updating model weights in adaptive resource management with two competing theories. A highly simplified indicator is used for illustrative purposes only; a real-world A.R.M. program would include the monitoring of a larger set of indicators.

year	measurement of the ratio of *Rubus* cover to fern cover in stands with high levels of light reaching the forest floor, as an indicator of forest recovery [a]	prediction made 3 years previously [a]		model weight [b]	
		Model I	Model II	Model I	Model II
Year 0 (initial yr)	10 ± 3 [a]			0.7 [c]	0.3 [c]
Year 5[d]	12 ± 3	14 ± 5	10 ± 3	0.64	0.36
Year 8	15 ± 3	17 ± 6	10 ± 3	0.68	0.32
Year 11	17 ± 4	16 ± 6	10 ± 3	0.80	0.20
Year 14	19 ± 4	18 ± 6 [e]	10 ± 3 [e]	0.93 [e]	0.07 [e]

[a] The number after the ± is the standard deviation of the listed value. A ratio is used in order to cancel out growth effects in recently thinned stands due solely to increased light reaching the forest floor.

[b] In computing updated weights, Bayes's theorem[10] is used assuming a normal distribution. Let P(M|D) be the desired updated weight (conditional probability), given the most recent monitoring data, D. Bayes's theorem states that $P(M|D) = P(D|M) \times \frac{P(M)}{P(D)}$, where P(M) is the model weight before the new data are obtained (the prior estimated relative probability of the model being correct). P(D|M) is the probability that the data, D, would be obtained, assuming the model is correct, e.g., the normal distribution using the model's mean and standard deviation. P(D) is the net probability of the data occurring. P(D) can be determined by normalizing the updated weights, P(M|D), which must sum to unity over all models.

[c] Subjective relative weight used to start the process. The sum of the model weights is always unity.

[d] Measurements following the first baseline measurements in year 0 are delayed to allow deer populations to catch up to changes caused by an increase in antlerless deer harvest permits.

[d] Model I would do slightly better by the end of year 14, if the standard deviation of its predictions were reduced, whereas Model II would do slightly better if its standard deviation were increased.

correct. In the example considered in Table 1, Model I is considered more likely to be correct and is given an initial weight of 0.7 whereas Model II is given an initial weight of 0.3.

Using the initial weights, the actual number of deer harvest permits allocated for the next 3 years is set to 10,200 (= 0.7 × 12,000 + 0.3 × 6,000). Next, predictions of what will happen to the forest in the management area 3 years after the deer harvest permit allocation is raised from 6,000 to 10,200 are made by each model. In our hypothetical example, we use only one, highly simplified indicator of forest recovery, namely, the ratio of the percent of ground covered by a set of shrub species in the genus *Rubus* (blackberries, raspberries, dewberries), which are highly preferred by deer, to the percent of ground covered by the unpalatable herbaceous species hay-scented fern and New York fern, as measured in stands with high levels of light reaching the forest floor.

Model I predicts that the ratio will increase each year with a magnitude that depends on the average decrease in deer density over the period. Model II predicts that the average cover ratio will be the same after 3 years, that is, the increase in deer harvest permits from 6,000 to 10,200 will make no difference to the ecosystem indicator. As a result, we have a clear difference in predictions that can be tested by *Rubus* and fern monitoring data, which we assume is collected at year 5 and every 3 years thereafter. At the end of year 5, the predictions of the models are

Table 2. Example of changes in allocation of deer harvest permits following updating of model weights (same example as in Table 1)

year	permits that would be allocated if a model were assumed 100% correct		model weights (from Table 1)		allocated permits (based on weighted average) [a]
	Model I	Model II	Model I	Model II	
Year 0	12,000	6,000	0.7 [b]	0.3 [b]	10,200
Year 5[c]	12,000	6,000	0.64	0.36	9,800
Year 8	12,000	6,000	0.68	0.32	10,100
Year 11	12,000	6,000	0.80	0.20	10,800
Year 14	12,000	6,000	0.93	0.07	11,600

[a] The permit allocation is kept the same for 3 years.

[b] Subjective weight used to start the process

[c] Measurements following the first baseline measurements in year 0 are delayed to allow deer populations to catch up to changes caused by an increase in antlerless deer harvest permits.

compared to the data and new weights are assigned to the models (Table 1). The new weights are used to update the number of deer harvest permits allocated for years 6 through 8. In this example, the process continues for 14 years and probability theory is used to update the model weights rather than professional judgment or some combination of the two.

Based on the data collected in year 5, the null hypothesis model, Model II, does better than the biological model, Model I, at predicting the outcome of the chosen, short-term indicator of forest recovery and improves its relative weight (Table 1). As time goes by, however, Model I does better. It recovers its high weight and eventually far outdistances Model II, achieving a (relative) weight of 0.93 by year 14. Note that, in ARM, alternative models do not have to be based on totally different theories. They could have the same basic structure and differ solely in the choice of parameter values.

The way that the model weights affect a management action (allocated deer harvest permits in this example) is shown in Table 2. Based on the initial, subjective weight assigned to the models, the initial allocation of deer harvest permits for a hypothetical zone is set in this example to 10,200. In the following year, the number decreases slightly to 9,800, because Model II did better in predicting the outcome of the monitoring program. However, by the fourth comparison to field data, the allowed number of permits is quite close to that which would be chosen if Model I were assumed to be 100% correct.

The models used in an A.R.M. program do not have to be complicated, in fact, in most cases, the simpler they are, the better. However, each model must include a prediction of its rate of error (e.g., a standard deviation) to be included in the reweighting process. Obviously, for A.R.M. to work, the aim of the monitoring program must be to collect the data required to evaluate the predictions of each model. A.R.M. is an iterative process as subsequent management decisions are made: (1) a management action is proposed based on past model weights, (2) each model predicts the outcome of the management action, (3) data are collected to evaluate the model predictions, and (4) the model that did the best job at predicting prior outcomes is given the greatest influence in guiding the next revision to the management action. Note that weights are assigned to the model, not to the indicator species used to test the model. This is particularly important to bear in mind when multiple species are used as indicators.[11]

Adaptive resource management is not a panacea, and although simple it is not necessarily readily implemented without strong agency commitment. A.R.M. focuses on particular management problems; its contribution to general knowledge usually ranks as a lower priority than is typical in scientific research. Opinions vary on the other ways in which A.R.M. differs from traditional research in science. Many view the quasi-political process of gaining and retaining the support of diverse, often antagonistic groups of stakeholders as an integral part of A.R.M.[12] Some practitioners are willing to accept lower standards of scientific rigor, viewing

Institutional conditions favoring adaptive resource management[15]

- There is a mandate to take action in the face of uncertainty.
- Decision makers are aware that they are experimenting.
- Decision makers care about improving outcomes over biological time-scales.
- Preservation of pristine environments is no longer an option, and human intervention cannot produce desired outcomes predictably.
- Resources are sufficient to measure ecosystem-scale behavior.
- Theory, models, and field methods are available to estimate and infer ecosystem-scale behavior.
- Hypotheses can be formulated.
- Organizational culture encourages learning from experience.
- There is sufficient stability to measure long-term outcomes; institutional patience is essential.

A.R.M. as any systematic attempt to manage natural resources by conducting a series of field trials of alternative management practices, regardless of how rigorously they are carried out.[13] However, as standards of rigor decrease, the risk of erroneously rejecting hypotheses that are actually true increases exponentially. Many, perhaps a majority of practitioners believe that the higher risks of failing to apply rigorous methods of experimental design, data collection, and statistical analysis do not justify the lower costs and are too likely to lead to higher costs and harmful mistakes in the long run.

Achieving an effective institutional framework is one of the challenges of A.R.M. that sets it apart from ordinary research (see box above). In a cautionary note about A.R.M.'s "promises and pitfalls" it has been noted that "An institution's ability to respond to and generate new knowledge is a function of two factors: access to the information and *the will and capacity to utilize that information*"[14] (emphasis added).

Two major challenges exist in implementing A.R.M. for deer in Pennsylvania. First, disagreement over management objectives must be settled in the political arena before A.R.M. can proceed. Second, even though deer harvest regulations are established on an annual basis, vegetation responses may take years or decades. This leads to delayed feedback, which presents difficulties when deer harvest decisions need to be made annually. Feedback is delayed not just because of the lag in the vegetation's response to changes in deer populations, but because the full impact on deer population following changes in permit allocations, particularly antlerless deer harvest allocations, is itself delayed. As a result, major feedback may not be received until 6 years after the start of a deer A.R.M. program, although after the first 6 years, feedback useful for fine-tuning management decisions will be received on a regular basis.

Delays resulting from the use of A.R.M. are to be expected. For example, when the U.S. Fish and Wildlife Service first applied adaptive management to waterfowl, there were two models in competition. One version predicted that reproductive rates would depend strongly on waterfowl density. The other version predicted only a weak relationship between reproduction and density. It took 5 years before one model clearly had outperformed the other.

With delayed feedback, the choice of the initial weights becomes more important than it would be in a situation of rapid feedback. Incorrect weights take longer to subside from the system. In effect, the choice of initial weights represents a 6-year commitment to a particular set of models. Consequently, in the case of deer A.R.M., decision makers cannot relax and pick an arbitrary set of weights, letting the process correct errors in a few years. Decision makers need to listen carefully to the arguments in favor of various theories of forest response to deer populations and make careful judgments about which models deserve the highest weights in setting the level of management action (e.g., annual deer harvest permit allocations). The crucial role of the initial models is a major reason that, in subsequent chapters, we review in detail for the benefit of the reader the literature on deer and forest dynamics.

Despite the complication of delayed indicator response, A.R.M. brings rigor to the decision-making process. It provides a framework for the optimal use of information and the objective evaluation of competing scientific views, such as the importance of deer vs. acid rain in forest ecosystem degradation. This results in a greater understanding of the system being managed and ultimately, better management.

Findings on the adaptive resource management approach

(1) Adaptive resource management (A.R.M.) is a science-based methodology that is well suited to managing deer from an ecosystem perspective while accommodating disagreements over models of forest dynamics or causes of forest alteration. The A.R.M. approach provides for testing competing scientific models or hypotheses about how forests function while, at the same time, providing a framework for regular management decisions to be made and implemented based on the best available information. A.R.M. involves five steps:

- (a) Set and quantify a resource management goal, based on a set of core values that most stakeholders can agree upon.
- (b) Identify competing biological theories that are pertinent to meeting the overall management goal, and the management recommendations that follow from each theory.
- (c) Based on past research and experience, pick what is initially believed to be the best combination of management actions (e.g., reducing deer density to 20 per square mile, avoiding the use of herbicides) and implement the combination in an experimental context.
- (d) Make quantitative predictions of the results of management actions for each competing biological theory or model and compare the predictions against field data at regular intervals (e.g., every 3 years) using indicator species and other environmental indicators.

(e) Update the set of management actions, giving preference to the recommendations that flow from those theories (models) that performed best in the comparisons.

(2) Two major challenges exist in implementing A.R.M. for deer in Pennsylvania. First, management objectives must be determined in the political arena before A.R.M. can proceed. Second, recovery of the structure, diversity, and function of forest ecosystems may take years or decades. Evaluating progress over a multi-year time frame presents difficulties when deer harvest goals need to be set annually.

(3) Managing white-tailed deer in large forested areas from an ecosystem perspective involves attempting, within the constraints of landowner objectives, to maintain or restore ecosystem structures and processes, not just healthy populations of deer. An appropriate short-term goal to use in A.R.M. is the demonstration of a statistically significant improvement in forest structure.

(4) The ability to quantify a goal, which is necessary for A.R.M., requires the judicious selection of indicators. Intermediate to long-term goals must include target magnitudes of change in measurable indicators of ecosystem recovery.

Recommendations on the adaptive resource management approach

(1) A.R.M. should be chosen as the framework for implementing management of deer from an ecosystem perspective. The science-based approach of A.R.M. will allow agencies to begin applying remedies based on the best available information while updating their operational theories as new data become available.

(2) Quantitative guidelines for long-term program success applicable to all components of the forest ecosystem need to be developed, just as they have been for commercially valuable trees. This could be done as part of the A.R.M. process, using an expert panel approach similar to that taken to produce this report.

(3) Research into the long-term appropriateness of the choice of indicators needs to parallel the monitoring of the indicators themselves.

Endnotes

[1] Williams and Johnson 1995

[2] D. R Anderson,National Biological Service, Fort Collins, Colorado, personal communication, 1995 (cited in Williams and Johnson 1995: page 431)

[3] Porter and Underwood 1999

[4] Griese et al. 2000

[5] Kendall 2001

Endnotes

[6] The committee presumes that recovery and maintenance of other species, including vertebrates, invertebrates, and beneficial fungi and other microorganisms will follow if severe stress on plant life is addressed. This assumption can be tested for some organisms (e.g., birds) as part of the long-term monitoring that needs to accompany any set of policy measures implemented with the aim of achieving recovery and maintenance of natural ecosystem structures and processes.

[7] Marquis et al. 1992

[8] Johnson et al. 1993

[9] A Bayesian probability adjustment can may be made as follows. If the monitoring data show a mean value A of a predicted parameter, A, and a model predicted a value, B, with uncertainty characterized by the modeler as normally distributed with standard deviation σ, then the updated relative weight for that model is determined by multiplying the old weight by the normal probability function,

$$\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)^{-\frac{1}{2}\left(\frac{B-A}{\sigma}\right)^2}$$

(Table 1, footnote b, Johnson et al. 2002; Pearl 2000). If there are multiple predictions for all the models, an equivalent multiplier is used for each prediction. The entire process is repeated each time new monitoring data are available. A model that is good enough to make the difference between the measured and predicted value comparable to or smaller than its assigned standard deviation σ will do well in the reweighting, particularly if its is small. In the all-or-nothing approach, it could happen that theories not included in the initial weighting did quite well. In that case, they would have to be given an initialized, post-facto weight before the Bayesian updating was performed.

[10] Pearl 2000; Johnson et al. 2002

[11] In the multiple-indicator case, the simplest approach to weighting models by performance would be to treat all indicators as equal. In this approach, the net weight for a model would be the product of the individual weights computed separately for each indicator, as described in the text for the example of *Rubus*:fern cover ratio. Other variations are possible, for instance, giving special ranking to those indicators that are thought to be the best surrogates for recovery of forest structure and processes. In all cases, the net weights are assigned to the competing models and do not indicate any value assigned to a particular species.

[12] James N. McNair, Head, Quantitative Population Biology Section, Patrick Center for Environmental Research, Academy of Natural Sciences of Philadelphia, personal communication, 2002

[13] James N. McNair, Head, Quantitative Population Biology Section, Patrick Center for Environmental Research, Academy of Natural Sciences of Philadelphia, personal communication, 2002

[14] McLain and Lee 1996, cited in Schaeffer 2001

[15] Lee 1993 and National Research Council 1996, cited in Schaeffer 2001

Chapter 3. A Brief History of Penn's Woods

Our report starts from the premise that the management of white-tailed deer in large forested areas from an ecosystem perspective will involve attempting, within the constraints of landowner objectives, to restore or maintain ecosystem structures and processes and not just healthy populations of deer. To help define the ecosystem structures and processes that need to be restored or maintained, in this chapter we review the relevant natural history of Pennsylvania and the current state of the forests.

The land that greeted the earliest Europeans to arrive in Pennsylvania was primarily forested, broken only by rivers and lakes, clearings associated with Indian villages and occasional large-scale windstorms, and scattered openings of grassland, shrubland, marsh, and shrub swamp. Early accounts of the landscape of the interior of Pennsylvania contain frequent references like this descriptive passage by Fortescue Cumming while crossing Tuscarora Mountain in 1807, "... view to the westward, though extensive, was cheerless and gloomy, over a broken and mountainous or rather hilly country, covered with forests, chiefly of the dark and sombre pine ..." Another passage referred to extensive grasslands and gallery-type forests in which one could "drive a carriage unhindered," apparently the product of Native Americans' regular use of fire to manage the landscape.[1]

Despite its immensity, however, that forest was a fairly recent product of the geological evolution of Pennsylvania's landscape. Eighteen thousand years ago the northeastern and northwestern corners of the state were covered with ice, and tundra and open, boreal woodlands covered the remainder of the state.[2] As the ice receded, species that had lived only to the south during the most recent ice advance began gradually repopulating the state, a process that is still ongoing.

Influence of Native Americans

Fossil pollen and charcoal residues preserved in bogs and lake sediments all across the eastern half of North America show the beginnings of wide-scale burning as far back as 2,000 or 3,000 years ago. Native Americans found they could improve the ease of travel, hunting, and defense and promote the growth of animal and plant species prized as food by wielding fire as a powerful land-management tool.[3]

Evidence exists that Native Americans managed vast areas of forest with fire to create open, park-like forests and also to clear fields where they grew corn, beans and other crops. The oak-dominated forests that persist today and native grasslands, most of which disappeared soon after Native Americans were ousted from the land, almost certainly owe their existence to traditions of large-scale burning among some groups of people for centuries or thousands of years before the arrival of Europeans.[4]

Native American populations were much larger before contact with Europeans introduced smallpox and other diseases, and the extent of land affected by their management was large.[5] When the first European settlers arrived, extensive clearings were described in the Cumberland Valley, Penns Valley in Centre County, the Wyoming Valley, southern York County, and other sites.[6] Later travelers in these same regions described a forested landscape apparently the result of successional growth.[7]

Cutting down the trees

As European settlers claimed the land, taming the wilderness meant cutting down trees and eradicating some forest wildlife, especially large predators, to make room for farms, towns, and villages and assure the safety of settlers and their livestock. Wood not needed for fuel or building material was often burned early in the process of clearing the land — after all, there was a seemingly unlimited supply.

In Pennsylvania, the clearing for farming and cutting trees for commercial uses that began with the first European arrivals had, by 1900, reduced the forest cover from 90 to 95% of the land area to 32%.[8]

Early lumbering

Tall, straight, and suitable for ships' masts, the eastern white pine was the first large-scale target of waves of loggers in Pennsylvania's forests. Beginning in the 1760s, white pine logs 120 feet long and 4 feet in diameter (or larger) were cut in the hills of northeastern Pennsylvania, fastened together in huge rafts, and floated down the Delaware River to Philadelphia to provide masts for British ships.

A second wave of timber harvesting focused on hemlock bark, which was used in the leather-tanning industry. Hemlock logs were cut and the bark stripped. Charcoal making was another forest industry that thrived before the discovery of coal as a fuel. In areas near early iron furnaces, colliers harvested trees (mainly oaks) and stacked them in conical piles built in the woods. The piles of logs were covered with earth and burned to produce charcoal, which was then hauled by wagon to the iron works. Because small trees as well as large were used for charcoal making, timber could be harvested on a 25-year rotation in most areas. An iron furnace required 20,000 to 35,000 acres of forest to support it on a sustainable basis.[9] Today, it is not unusual to come across level circular areas about 40 feet in diameter scattered in forests where charcoal making occurred.

The chemical wood industry and the indiscriminate removal of forests

The invention of the geared logging locomotive set the stage for the removal of forests between 1890 and 1930 across the entire state. The railroad logging era, as it is known, allowed loggers to reach Pennsylvania's vast interior. Rail beds were constructed up every hollow far into forests unreachable by water transport. Today many of the old railroad beds are the basis for a network of hiking trails.

During the railroad logging era, technology was employed not only to harvest vast areas, but also to utilize everything regardless of species or size. What was not usable as lumber was treated by slow heating and distillation in chemical factories, which produced acetate of lime, wood alcohol, wood tar, charcoal, and gases. Wood products including barrel staves, lath, shingles, boxes, and kindling were produced in hastily built factories located in temporary towns that sprang up throughout the northern tier of Pennsylvania. Old photographs record the boom days at Masten, Golinza, Laquin, and many other sites that today are only names on a map, a few old foundations, or perhaps the site of a hunting camp.[10]

The removals were massive and indiscriminate; fires started by sparks from the logging locomotives frequently followed, burning rapidly and fiercely through the slash. The resulting scenes of devastation generated concern by groups throughout the state and led to the formation of the Pennsylvania Forestry Association. A campaign led by Dr. Joseph Rothrock resulted in the formation of a Division of Forestry within the Pennsylvania Department of Agriculture in 1895 and the appointment of Dr. Rothrock as the first Forestry Commissioner.

Development of a system of forest reserves, now known as state forests, began in 1897 with the acquisition of abandoned cut-over lands that were sold at tax sales. By 1904 the system held about a half million acres; today state forest lands total 2.1 million acres.

Impact of pests and diseases

Pennsylvania's forests have been profoundly affected by pests and diseases introduced from different parts of the world. The chestnut blight fungus, first discovered in New York City in 1904, swept through Pennsylvania in less than one decade, reducing American chestnut, which had previously been the most abundant tree across much of the state, to minor status. The gypsy moth, which spread into the state following its accidental release in eastern Massachusetts in 1869, reduced the abundance of oaks by feeding on them in preference to all other species. Beech bark disease, which appeared in Nova Scotia about 1920, still is spreading across the northern and western half of the state. Typically, the largest, oldest trees are the most susceptible; the full impact of beech bark disease has not yet been realized. Dutch elm disease and dogwood anthracnose have taken their toll. The most recent invader, hemlock woolly adelgid, is killing our state tree, the eastern hemlock, in southern and eastern parts of the state. Mild winters have

Vertical structure in forests

In forest ecology and forestry, the term understory refers to all of the forest layers beneath the canopy, or topmost layer. We follow the common practice of dividing the forest into four major vertical layers above the surface of the ground. Shrubs and herbaceous plants are generally confined to the two lowest layers but trees (and woody vines) may be present in any or all layers. In forests with low or moderate deer densities, the understory layers typically include seedlings, saplings, and "pole-size" trees of species that are capable of eventually growing into the canopy. Certain tree species, such as flowering dogwood, striped maple, American hornbeam, eastern hophornbeam, and downy serviceberry, never grow large enough to occupy the canopy of a mature forest.

The four layers (including common synonyms for each) are:

- **canopy**, overstory, dominant trees, upper canopy, upper layer, major trees
- **subcanopy**, understory trees, lower canopy, intermediate canopy
- **shrub layer**, understory shrubs
- **herbaceous layer**, herbaceous flora, herbaceous species, ground layer, ground-layer vegetation, forest-floor plants

allowed the adelgid to spread rapidly westward. (Further discussion of these diseases and insects is in Chapter 6.)

Recent outbreaks of native insects such as elm spanworm, forest tent caterpillar, eastern tent caterpillar, and cherry scallop-shell moth have caused extensive tree death in some parts of the state. Research is ongoing to understand the underlying causes of a recent decline of sugar maple in Pennsylvania.[11] Low levels of magnesium combined with excessive stress, for example from insect defoliation, have been associated with sugar maple decline.[12] On soils with low or intermediate concentrations of base cations, the situation is also worsened by high levels of acidic deposition.[13]

Major forest types

Pennsylvania contains about 16.7 million acres of forestland.[14] Nearly all current forests are second- and third-generation stands that developed after extensive forest removals between 1890 and 1930, when deer densities were very low.[15] Though generally even-aged, many stands contain scattered residuals from the previous generation and some may contain up to four age classes.

The climate, rainfall, and soils support forest growth throughout most of the state with the exception of scattered areas that are too wet, low in soil nutrients, fire-prone, or dry and rocky. From an ecological perspective, 62 tree-dominated natural community types have been described for Pennsylvania.[16] According to the most recent reconstruction of potential natural vegetation (Figure 4B, page 126),[17] the major forest communities represented in the state are beech-maple forest (parts of Erie, Mercer, Lawrence Counties), mixed mesophytic forest (parts of Greene and Fayette Counties), oak-hickory-pine forest (extreme southeastern Somerset and York, southern

Bedford and Fulton, and southwestern Franklin and Lancaster Counties), northern hardwoods (the high plateaus, Allegheny Mountains, and most of northwestern Pennsylvania) and Appalachian oak forest (the remainder of the state, including portions of the northern tier).

In the following descriptions of the major forest types across the state and throughout this report, common names of plants and other organisms are used. The corresponding scientific nomenclature is indexed in Appendix E.

Beech-maple forests, sugar maple-basswood forests

The common canopy trees of beech-maple and sugar maple-basswood forest communities are sugar maple, red maple, American basswood, American beech, white ash, yellow birch, sweet birch, and yellow-poplar. Understory trees and shrubs include flowering dogwood, pawpaw, eastern hophornbeam, spicebush, witch-hazel, and bladdernut. These forests have a rich and diverse herbaceous flora that includes black snakeroot, blue cohosh, wood geranium, hepatica, wild leek, jack-in-the-pulpit, spring-beauty, yellow trout-lily, bishop's-cap, rattlesnake fern, and many others.

Mixed mesophytic forests

The most species-rich forest type represented in the state is the mixed mesophytic forest, which reaches its greatest development in the Great Smoky Mountains and elsewhere in the southern Appalachians. Canopy dominance is often shared by many species, in Pennsylvania most often including yellow-poplar, sugar maple, American beech, American basswood, northern red oak, cucumbertree, yellow buckeye, Ohio buckeye, white ash, and black cherry. Understory trees and shrubs include flowering dogwood, pawpaw, umbrella magnolia, redbud, witch-hazel, and wild hydrangea. If not severely impacted by deer, this forest, which often occurs on sites with rich, limestone-based soils, has an incredibly diverse herbaceous flora that includes large white trillium, Virginia bluebell, wild blue phlox, dwarf larkspur, blue-eyed-Mary, wood anemone, foamflower, wild-ginger, squirrel-corn, Dutchman's-breeches, toadshade, black snakeroot, and many more.

Oak-hickory-pine forests

Oak-hickory-pine forests are most common on dry ridgetops, rocky sites and south-facing slopes. This community is dominated by chestnut oak, scarlet oak, pignut hickory, blackgum, sweet birch, and Virginia pine in the canopy. Before 1910, American chestnut was a dominant and commercially important component of these forests, but the accidental introduction of the chestnut blight fungus in 1904 reduced chestnut to a minor forest understory component in a few decades. Where deer numbers are low, dry oak forests often have a dense shrub layer of black huckleberry, mountain-laurel, lowbush blueberry, and maple-leaf viburnum. Forest-floor plants include teaberry, pipsissewa, trailing-arbutus, Pennsylvania sedge, wild sarsaparilla, bracken fern, pink lady's-slipper, and whorled loosestrife.

Northern hardwoods

The northern hardwood forest occupies the northern third of the state and extends south at high elevations along the Allegheny Front. It also occurs farther south on north-facing slopes and ravines. Major canopy tree species are sugar maple, red maple, and American beech; black cherry is also an important component of many stands. Northern hardwood stands where more than 25% of the total basal area[18] of all trees is in black cherry are referred to as black cherry-northern hardwoods[19] (in the wood products industry, this type is known as Allegheny hardwoods). Associated tree species in northern hardwoods include eastern hemlock, eastern white pine, white ash, yellow-poplar, sweet birch, yellow birch, cucumbertree, American basswood, and northern red oak. Understory trees in northern hardwood forests typically include striped maple, mountain maple, American hornbeam, eastern hophornbeam, American mountain-ash, Allegheny serviceberry, and downy serviceberry. Shrubs formerly abundant in the northern hardwood forest included hobblebush, American yew, mountain winterberry, rosebay rhododendron, and witch-hazel; in most of northern Pennsylvania they have been severely reduced or eliminated by deer. Typical herbaceous species include Canada mayflower, starflower, Indian cucumber-root, painted trillium, purple trillium, large round-leaved orchid, shining clubmoss, and marginal wood fern, but these too have been severely impacted by deer in many areas. New York fern and hay-scented fern, formerly minor components of the northern hardwood forest understory, are not favored deer food and have proliferated where deer have eliminated the normal diversity of species.

Appalachian oak forests

Appalachian oak forests (called Appalachian mixed hardwoods or oak-mixed hardwoods in the wood products industry) are the most common community in the southern two-thirds of the state. Common canopy species include northern red, white, black, scarlet, and chestnut oaks in mixture with pignut, mockernut, shagbark, and bitternut hickory, red maple, yellow-poplar, sweet birch, black cherry, cucumbertree, and eastern white pine. In areas with low deer populations, the subcanopy and shrub layers often include mountain-laurel, black huckleberry, lowbush blueberry, flowering dogwood, beaked hazelnut, redbud, eastern hophornbeam, and maple-leaf viburnum. Common forest floor herbaceous species include bellwort, Solomon's-seal, Solomon's-plume, mayapple, blue cohosh, wood ferns, purple trillium, violets, and yellow trout-lily. The dominance of oaks in these forests is partly the result of long-term, recurring fire discouraging competing tree species, most of which are less tolerant of fire than oaks.[20]

Additional forest types

Several other forest types occur in specialized environments. Although they occupy relatively small areas, they add significantly to the overall biological diversity of Pennsylvania.

Coastal plain forests

In the southeastern corner of the state, in the narrow sliver of the Atlantic Coastal Plain physiographic province that parallels the Delaware River, coastal plain forest canopies contain sweetgum, willow oak, southern red oak, and sweetbay magnolia above a shrub layer of sweet pepperbush, swamp dog-hobble, and pinxter-flower azalea. The herbaceous layer features many coastal plain rarities including Maryland meadow-beauty, New York aster, and coast violet.

Glacial bog forests

In the northeastern and northwestern corners of the state, in areas covered by ice during the most recent glaciation, peat deposits support bog forests of a northern character dominated by black spruce and tamarack. Shrubs include Labrador-tea, highbush blueberry, sweetgale, bog-laurel, bog-rosemary, and northern arrowwood. Characteristic herbaceous species include pitcher plant, round-leaved sundew, many sedges, and rare orchids such as dragon's-mouth, yellow fringed orchid, white fringed orchid, rose pogonia, and grass-pink.

Barrens

Serpentinite rock, which occurs in a band of outcrops stretching across southern Delaware, Chester, and Lancaster counties, supports forests of pitch pine or Virginia pine, eastern redcedar, post oak, blackjack oak, sassafras, scrub oak, and dwarf chinkapin oak interspersed with grasslands dominated by little bluestem, Indian grass, big bluestem, prairie dropseed, moss-pink, barren chickweed, and serpentine aster, with a high diversity of other native grass and forb species.

Shale barrens and limestone barrens of the Appalachian Ridge and Valley physiographic province harbor drought-tolerant species including eastern redcedar, Virginia pine, Table Mountain pine, chinkapin oak, post oak, and hackberry. Redbud and fragrant sumac are frequent in the subcanopy and shrub layers. Herbaceous species include side-oats gramma, Indian grass, little bluestem, hoary puccoon, false-gromwell, bird's-foot violet, and shale-barren ragwort.

Pitch pine-scrub oak barrens occur on ridge tops and other fire-prone sites. Ranging from dry to moist, these habitats have a dense shrub layer that includes sheep-laurel, sweet low blueberry, and rhodora; the herbaceous layer includes the globally rare variable sedge, white fringed orchid, dwarf cornel, and climbing fern.

Riparian forests

Riparian areas throughout the state, where periodic flooding is a limiting factor, are characterized by forests of American sycamore, silver maple, boxelder, American elm, slippery elm, black willow, green ash, red maple, and shellbark hickory. River birch occurs along rivers and streams in the eastern part of the state but not in the west. River floodplains are also rich in shrubs, woody vines, and herbaceous species. Those native to Pennsylvania include silky dogwood, frost grape, spicebush, poison-ivy, spotted jewelweed, pale jewelweed, clearweed, wood nettle, great nettle, and jumpseed. Floodplain forests are especially prone to invasion by introduced species, including multiflora rose, Japanese honeysuckle, Morrow's honeysuckle, Tatarian honeysuckle, Japanese stilt grass, Japanese knotweed, giant knotweed, garlic mustard, and lesser celandine.

Swamp forests

Bottomlands and other areas with a year-round high water table are habitats for several swamp forest types. Red maple and blackgum dominate the most common, widespread swamp type. Swamps dominated by pin oak or swamp white oak are mainly in the southern half of the state and those dominated by eastern hemlock, mainly in the northern half. Red maple and black ash-dominated swamps occur mainly where the groundwater is rich in base cations, overlying calcareous (limestone, dolomite) or mafic (diabase) bedrock. Red spruce swamps occur in glaciated northeastern Pennsylvania. Swamp forests along Lake Erie are the only location where pumpkin ash occurs. Other characteristic tree species in swamp forests include yellow birch, eastern white pine, American elm, slippery elm, and bitternut hickory. The shrub layer often includes highbush blueberry, winterberry, spicebush, northern arrowwood, southern arrowwood, smooth alder, speckled alder, or swamp azalea. Common herbaceous species include skunk-cabbage, cinnamon fern, sensitive fern, arrow-leaved tearthumb, halberd-leaved tearthumb, and sedges.

The forest today

Despite dire predictions by Rothrock and others, Pennsylvania's forests did recover in the years following the devastating removals around the turn of the nineteenth century. Trees came back not only on cut-over lands, but also on abandoned farmland; today second growth forests cover 59% of the state's land area. Only a few fragments of the original forest remain. The Allegheny National Forest in northwestern Pennsylvania includes the only sizeable tract of old-growth forest, 4,080 acres in the Tionesta Scenic and Natural Area. Some 30 smaller fragments are fully or partially protected in state forests, state parks, Allegheny National Forest, and lands owned by public utility companies and conservation land trusts.[21] The Snyder-Middleswarth

State Forest Natural Area preserves over 300 acres of old growth and three tracts in Cook Forest State Park total nearly 300 acres. Several protected stands top 100 acres in size, including Woodbourne Forest and Wildlife Sanctuary (The Nature Conservancy), Otter Creek Natural Area (Holtwood Environmental Preserve, PPL Corporation), Detweiler Run, The Hemlocks, and Alan Seegar State Forest Natural Areas (Pennsylvania Department of Conservation and Natural Resources), and Hearts Content Natural Area (U.S. Forest Service).

Pennsylvania's publicly owned forestlands include 2.1 million acres of state forests and 277,000 acres in 116 state parks. State game lands, administered by the Pennsylvania Game Commission, contain another 1.4 million acres in the public domain. Pennsylvania's only national forest, the Allegheny National Forest, contains just over a half million acres. By far the largest proportion (70%) of forested land in the state is privately owned.

The wood products industry remains an important part of Pennsylvania's economy, totaling nearly $5 billion per year and providing about 100,000 jobs. The most valuable single timber product is black cherry, which is used mainly for veneer by the furniture industry. Oaks and other hardwoods are also important. The resilience of Pennsylvania's forests and their ability to regenerate naturally have long sustained the Pennsylvania wood products industry. But problems resulting from high deer density and fire suppression have affected the abundance of many commercially important species, especially oaks.[22] Extensive burning by Native Americans may have made possible the expansive oak forests found by early Europeans. Fires that followed clearcutting allowed oak forests to become reestablished[23]. But now, oaks are being replaced by red maple in many areas.[24] Research by the Pennsylvania Bureau of Forestry and the U.S. Forest Service suggests that oaks may become reestablished under a regime of deer exclusion followed by fire to reduce competition from faster-growing species such as red maple, sweet birch, black cherry, and pin cherry.[25]

Most forested landscapes in Pennsylvania consist of a mosaic of 70- to 110-year-old stands that originated after catastrophic disturbances, most often heavy logging but also, in some areas, fire and windfall. Stand structure often closely approximates a single cohort (i.e., they are even-aged), although remnant trees from older cohorts are sometimes present. Forest stands typically contain species representing a range in shade tolerance. Stands usually have a stratified canopy (trees occupying both subcanopy and canopy levels) and an irregular diameter distribution.[26] Fast-growing, shade-intolerant species dominate in the larger diameter classes and occupy only the upper layer. In contrast to the situation in most old-growth forests, slower growing, shade-tolerant species are most often concentrated in the smaller diameter classes and understory layers. Woody species composition in second-growth forests can differ from the pre-European-settlement forest composition due to successional status, site conditions, and disturbance history.[27]

The types of disturbances currently affecting second-growth forests differ from those that initiated their development in the nineteenth or early twentieth century. Ordinary windstorms, occasional ice storms and hurricanes, and rare, localized downbursts and tornadoes are still a factor as they have always been,[28] but fire has been drastically reduced. Introduced insects and diseases have altered the successional pathways of some forest types by virtually eliminating certain species, thus creating unprecedented favorable environmental conditions for others.[29] White-tailed deer populations have grown beyond the forest's ecological carrying capacity in most of the state (see box on page 16 and Chapter 11) and have changed species composition and reduced species diversity, mostly in layers beneath the canopy, through selective browsing.

Despite the presence of a diverse overstory, tree regeneration typically is severely limited in Pennsylvania forests.[30] A statewide survey of the regeneration of commercially important species, part of the U.S. Forest Service's recent Forest Inventory Analysis (F.I.A.), concluded that "by every measure, the regeneration picture in Pennsylvania is bleak based on findings for the first panel [year] of regeneration measurements"[31] (see Table 3).

Even where regeneration is ample, the tree seedlings present typically represent fewer species than the overstory due to dense deer populations and the deer's feeding preferences for some species of tree seedlings over others.[32] This is particularly important in stands that may be subject to future canopy thinning or removal by cutting or natural events, because most tree species that grow into the overstory after disturbance must be present as established seedlings before the overstory is removed.[33] Thus, removal of the overstory under present conditions frequently results in regeneration failure or new forests of lower diversity, unless heroic measures are taken. For example, northern hardwood forests frequently regenerate to ferns and grasses, striped maple, or near monocultures of American beech, sweet birch, or black cherry. A

Table 3. Regeneration of trees of value to the wood products industry in Pennsylvania forests.[34] The overall trends are assumed to apply to the majority of native tree species (all of Pennsylvania's indigenous trees are listed in Table 4, with those having significant commercial value marked by an asterisk).

silvicultural region	percent of stands with regeneration of species with high commercial value	percent of stands with regeneration of any species with commercial value
Eastern broadleaf–east	22	50
Plateau	24	45
Central Appalachian	30	44
Eastern broadleaf–west	45	58

monoculture of any species is not a preferred outcome, even if the needs of the wood products industry alone are taken into account, partly because monocultures are much more susceptible to mass mortality from outbreaks of insect herbivores or diseases.

Mixed oaks, in the presence of a high deer density and the absence of occasional fire, frequently regenerate to ferns, mountain-laurel, rosebay rhododendron, flowering dogwood, sassafras, sweet birch, blackgum, red maple, or yellow-poplar. Aside from the commercial losses, a once-magnificent part of Pennsylvania's natural heritage is disappearing as oak forests succumb to a more homogeneous forest dominated by red maple.[35] The vast forests dominated by oaks, American chestnut, and hickories that formerly covered two-thirds of the state sustained a higher total biomass — and in all likelihood a higher diversity — of animal life, with their massive crops of fat-, carbohydrate- and protein-rich nuts and acorns, than the low-diversity woods that are taking their place.

Tree establishment and survival are affected by a variety of factors in addition to deer browsing, including propagule (seed) supply, seedbed conditions, sunlight, competition with other plants, small mammal and insect predation, diseases, non-sustainable forestry, incidence and severity of fire, and soil physical and chemical properties.[36] However, unlike deer overbrowsing, most of these factors rarely limit regeneration of large numbers of species simultaneously over large areas, or for periods of decades or longer. Exceptions may include non-sustainable timber-cutting practices and acidification of soils by atmospheric deposition of pollutants.

In areas such as northwestern Pennsylvania where overbrowsing has been a factor since the 1920s,[37] there may be little in the way of local sources of propagules (seeds, spores, and vegetative reproductive organs such as bulblets) remaining for the shrub and herbaceous species native to the forest understory, which far outnumber tree species in overall diversity. Further exacerbating the situation is the fact that most forest herbs do not have long-distance dispersal mechanisms. The primary means of reproduction for many species is vegetative spread by horizontal roots (rhizomes) or trailing stems (stolons) and the seeds of many others are dispersed by gravity or ants.[38]

Studies of seeds lying dormant in the soil of the region's forests hold out little hope that this "seed bank" will contribute significantly to the recovery of plant species diversity following release from deer overbrowsing.[39] However, there is some hope based on recent work at Hearts Content Natural Area that suppressed individuals of some shrubs and herbaceous species may be present at very low densities even in heavily browsed areas.[40] Some species are still present in local refugia such as large boulders, the tops of which can support small patches of forest floor species,[41] and steep-sided rock outcrops. The prospects for suppressed plant remnants are greater in areas where deer overpopulation is a more recent phenomenon.

Deer threaten the regeneration of all forests throughout the state. Fencing to exclude deer is now a standard practice on state forest lands when timber is harvested. Fencing is necessary to allow new trees to become established and grow beyond the browse line (the height deer can reach, which is about 5 feet). According to the state forester, Dr. James Grace, 20,000 acres of state forest land are fenced at present, but the total could easily be 50,000 if the need were adequately addressed.[42] Optimum timber harvest levels have not been met due to the inability to fence and treat more acres.

Findings on the history of Penn's Woods

(1) Pennsylvania's forests regrew after the massive cutting that occurred between 1890 and 1930. Trees came back not only on cut-over lands, but also on abandoned farmland; today second-growth forests cover 59% of the state's land area. Only a few fragments remain of the pre-European-settlement forest.

(2) Today's forests, most of which are in the 70- to 110-year-old category, differ from the forests that greeted the first Europeans in several important ways. Three hundred- to 400-year-old giants are found in only a few remnant old-growth groves. Oaks and eastern white pine are not as abundant as they once were and American chestnut has been relegated to a minor role in the understory due to the impact of the introduced chestnut blight fungus.

(3) In the areas that have been affected the longest by high deer densities , the diversity of canopy tree species has decreased. Even in some areas that have sustained high deer densities for just a few decades or less, understory tree and shrub layers have been diminished in species diversity, height, and density or completely eliminated, and the formerly diverse ground layer has been reduced to ferns and a few other species that are either not preferred by deer or resilient to repeated browsing.

(4) Pennsylvania's forests also have been profoundly affected by pests and diseases introduced from other parts of the world.

(5) Sixty-two tree-dominated natural community types have been described for Pennsylvania by ecologists. To the wood products industry, the major forest categories of interest are the northern hardwood and Appalachian oak-mixed hardwood forests. The northern hardwood forest is the main forest type in the northern one-third of the state and extends southward at high elevations along the Allegheny Front and down the spine of the Appalachians in western Pennsylvania into Maryland and West Virginia. The main forest type in the southern two-thirds of the state is oak-mixed hardwood.

(6) The U.S. Forest Service's F.I.A. data show that among four tree-harvest regions covering Pennsylvania, desired levels of regeneration were found in only 22 to 45% of the total forest area.

Endnotes

[1] Cumming 1810; Maxwell 1910

[2] Watts 1979; Martin 1958

[3] Maxwell 1910; Day 1953; Thompson and Smith 1970; Webster 1983; Dent 1985; Denevan 1992; Casselberry and Evans 1994; Black and Abrams 2001

[4] Marye 1955; Russell 1983; DeSelm 1986; Abrams 1992; Clark and Royall 1996; Clark et al. 1996; Delcourt and Delcourt 1997, 1998

[5] Dobyns 1966, 1983; Denevan 1992

[6] Bates and Richard 1887; Losensky 1961; Cook 1887; Schoepf 1788; Marye 1955

[7] E.g., Maximilian 1834

[8] deCoster 1995

[9] Bining 1938

[10] Kline et al. 1970-1978; Marquis 1975

[11] Kolb and McCormick 1993; Long et al. 1997; Horsley et al. 2000, 2002

[12] Bailey et al. 2004; Horsley et al. 2000

[13] Drohan and Sharpe 1997

[14] McWilliams et al. 2002

[15] Marquis 1975, 1992

[16] Fike 1999

[17] Küchler 1964

[18] Basal area is the area occupied by tree trunks in an imaginary plane 1.4 m (4 feet 7 inches) above the ground.

[19] Fike 1999

[20] Tome 1854; Abrams and Nowacki 1992; Brose et al. 2001

[21] Erdman and Wiegman 1974; Bjorkbom and Larson 1977; Pennsylvania Bureau of Forestry 1979; Smith 1989

[22] Other forest stresses are discussed in Chapters 5 and 6.

[23] Abrams 1992

[24] Abrams 1998

[25] Van Lear et al. 2000

[26] Oliver and Larson 1996

[27] For example, in a 1940s forest vegetation assessment of old growth in Kentucky's Cumberland Mountains, Braun (1950) estimated that 84% of the overstory consisted of 10 species, dominated by American beech, sugar maple, American chestnut, and eastern hemlock. In 1988, the U.S. Forest Service reported that 10 different species accounted for 83% of the overstory, which is now dominated by oaks, yellow-poplar, hickories, and red maple (Steinman 1999). Disturbances to the late-successional forests observed by Braun, such as chestnut blight and logging, created growing conditions favorable to the early-successional species that currently dominate.

[28] Lorimer 1977, 1980; Runkle 1982; Frelich and Lorimer 1991

[29] E.g., Fajvan and Wood 1996

[30] Marquis et al. 1992

[31] McWilliams et al. 2002

[32] Allegheny National Forest 1995

Endnotes

[33] Grisez and Peace 1973

[34] Data from McWilliams et al. 2002

[35] Abrams 1992, 1998

[36] Kozlowski 2002

[37] Fronz 1930

[38] Bierzychudek 1982; Sobey and Barkhouse 1977; Beattie and Culver 1981

[39] Leckie et al. 2000; Pickett and McDonnell 1989

[40] Ristau 2001

[41] Rooney 1997

[42] Dr. James R. Grace, State Forester, Bureau of Forestry, Pennsylvania Department of Conservation and Natural Resources, personal communication, 2002

Chapter 4. Some Root Causes of Our Current Ecological Problems

The roots of the deer problem

White-tailed deer have been a symbol of wild eastern North America throughout the region's recorded history and even before. From prehistoric Native Americans to twenty-first-century nature enthusiasts and hunters, deer glimpsed in the woods have thrilled people with their grace and stateliness, and venison at the campfire and table has provided savor and sustenance. Unfortunately, deer-human interaction in the last two centuries has a dark side: in the 1800s, overexploitation and near-extinction, and in the 1900s, overprotection and resultant habitat destruction by now-teeming populations.

There is a widespread impulse to blame recent policies and management actions, or inaction, for the current deer situation, but the ultimate causes run much deeper and have been around for a very long time. Profound changes to the landscape and to interactions among wildlife species brought about by humans are responsible for the current high densities of white-tailed deer and their pervasive effects on the rest of the ecosystem. These changes are persistent and difficult to reverse, which means that there is no quick fix. Any remedy for the deer problem will require persevering with carefully targeted efforts indefinitely.

The arrival of Western civilization in Pennsylvania, beginning in 1643 with a small settlement of Swedes in present-day Delaware County, has been more like a geologic force than merely one species' population shift. Within 200 years of arriving, Europeans had cut down most of the forest and converted vast areas to crops and pasture. Industrialization since about 150 years ago has accelerated the pace of change, adding urban sprawl, strip-mining, and other large-scale landscape transformations.

From the deer's perspective, this has been a bonanza. White-tailed deer is an "edge" species. The patchwork of forest fragments interspersed with farmland and suburban lawns and gardens that cover much of present-day Pennsylvania could hardly be more ideal habitat it is capable of supporting far greater deer populations than the mostly forested landscape of 1643.

The increase in Pennsylvania's deer population from the beginning to the end of the twentieth century was mirrored by the buck harvest (see Figure 3, page 122). Statewide, the buck harvest increased nearly 160-fold from 1915 to 2001[1] while the human population grew by a factor of only 1.5 in the same time period.

Although much of present-day Pennsylvania has been transformed into ideal deer habitat over the last few hundred years, major human impacts on Pennsylvania's wildlife, including deer, can be traced back much further, almost as far back as our species' first arrival on the scene at least 13,000 years ago. Contrary to a long-held popular belief, research by paleontologists[2] and recent work by paleoecologists[3] strongly suggest that early human impacts on eastern North American ecosystems were profound. The effect that is most obvious from the fossil remains was the extinction of more than two dozen species of "megafauna" — large mammals — within a few centuries of the arrival of the first humans. An effect not easily detected in the fossil record is a cascade of ecological changes that almost certainly resulted from the removal of the largest herbivores (grazers and browsers) and most of the large carnivores. Megaherbivores and large predators are often keystone species where they survive in present-day ecosystems. A keystone species is one whose effects are much greater than would be expected from its relative population abundance, and whose removal causes the loss of many other species in a community.

Many Pennsylvanians know that gray wolves and mountain lions, before they were exterminated in the nineteenth century, preyed on deer. Fewer are aware that, for millions of years — more than 99% of white-tailed deer's existence as a species — Pennsylvania's native fauna also included American cheetah, Studer's cheetah, jaguar (which survives only in tropical America), dire wolf, Armbruster's wolf, grizzly bear (now confined to western North America), lesser short-faced bear, and giant short-faced bear.[4] The giant short-faced bear was the largest land predator the earth has seen since the demise of the dinosaurs. There is every reason to presume that white-tailed deer were preyed upon by all of these species.

Ironically, *Homo sapiens* — the original cause of large predators' disappearance from Pennsylvania — is the only species still present in the state that is capable of maintaining the population density of white-tailed deer in balance. Deer populations are likely to be reduced most effectively by hunters shooting adult females.[5] However, predation by humans, as currently practiced by hunters and managed by state wildlife agencies, differs in key ways from the predation that regulated deer numbers throughout the species' evolutionary past. Wild predators on deer in North America typically minimize risk to themselves and magnify their chance of success by taking fawns in preference to adults,[6] does in preference to bucks,[7] and deer weakened by age, starvation or injury in preference to robust, healthy individuals.[8] Furthermore, there are two components to predators' effects on deer foraging: numerical and functional. Hunters can reduce the numerical abundance of deer but they are much less effective than predators in shifting deer behavior to avoid large portions of remote areas and reduce foraging times.[9] Recent studies of the effects of wolf reintroduction in Yellowstone National Park have documented cascading effects of the restored carnivore-herbivore interactions. Increased predation risk caused elk to avoid stream corridors, allowing woody plants to regenerate and thus restoring riparian function. Beaver colonies, which had been missing from the area for 50 years, reappeared and aquatic food webs, including birds and other fauna, were reestablished.[10] It is not a trivial challenge and may not be fully practical to find ways in which hunting can be managed in the long term to mimic the way populations have been regulated for millions of years by native predators, and still retain its appeal to hunters.[11] Nonetheless, we assume that until hunters are given adequate tools, it would be premature to conclude that recreational hunting cannot do the job (see Chapter 13).

Findings on the root causes of our current ecological problems

(1) For millions of years — more than 99% of white-tailed deer's existence — the species' population was subject to regulation by a diverse array of predators, including not only the gray wolf and mountain lion but also the American cheetah, Studer's cheetah, jaguar, dire wolf, Armbruster's wolf, grizzly bear, lesser short-faced bear, and giant short-faced bear.

(2) Deer are an "edge" species. The patchwork of forest fragments interspersed with farmland and suburban lawns and gardens that covers much of present-day Pennsylvania could hardly be more ideal habitat, capable of supporting far higher deer populations than the mostly forested landscape of 1643, at the beginning of European settlement.

(3) As a result of the elimination of large predators in the 1700s and 1800s, humans are the only species still present in Pennsylvania capable of maintaining the population density of white-tailed deer in balance with its habitat. Active intervention by humans to keep deer populations below levels that severely alter the composition and diversity of forests will have to be sustained forever, assuming that it is impractical to restore the full complement of predators across the entire range of white-tailed deer in the state.

Endnotes

[1] Pennsylvania Game Commission 2002b

[2] Cope 1871, 1899; Wheatley 1871; Hay 1923; Guilday 1971; Kurtén and Anderson 1980; Williams at al. 1985

[3] Graham and Lundelius 1984; Guthrie 1984; Martin and Klein 1984; McDonald 1984; Owen-Smith 1987; Grayson 1991; Stuart 1991; Zimov et al. 1995; MacPhee and Marx 1997

[4] Cope 1871, 1899; Wheatley 1871; Hay 1923; Guilday 1971; Kurtén and Anderson 1980; Williams at al. 1985

[5] See pages 221 and 222 for discussion of an often-mentioned alternative.

[6] Mech and Karns 1977; Nelson and Mech 1986; Pierce et al. 2000

[7] Nelson and Mech 1986; Bleich and Taylor 1998; Pierce et al. 2000

[8] Mech and Karns 1977; Ackerman et al. 1984; DelGiudice 1998; Pierce et al. 2000

[9] Dr. William J. McShea, Research Scientist, Conservation and Research Center, Smithsonian Institution, personal communication, 2003

[10] Ripple and Beschata 2003, 2004

[11] See Chapter 15 on hunter satisfaction.

Part II. Deer Impact and Forest Recovery

Chapter 5. The Role of White-Tailed Deer in Altering Forest Ecosystems in Pennsylvania

Chapter 6. Factors of Human Origin in Addition to Deer Overbrowsing that Affect Recovery of Pennsylvania's Forests

Chapter 7. Recovery of Pennsylvania's Forest Ecosystems from Deer Overbrowsing

Chapter 8. Predicting Forest Recovery Rates in Pennsylvania

Chapter 5. The Role of White-tailed Deer in Altering Forest Structure in Pennsylvania

To predict the effects of management actions on maintaining or restoring ecosystem structures and processes in Pennsylvania, it is necessary to have a hypothesis (or hypotheses) of the impact of white-tailed deer on forest structure. Adaptive resource management does not require theories to be perfect — they can be improved over time — but they must be quantitative and they must include an estimate of the uncertainty (e.g., rate of error, standard deviation) attached to any prediction. In this chapter, the scientific literature on the impacts of white-tailed deer is reviewed to provide a basis for theoretical predictions to be used in managing deer from an ecosystem perspective.

There is a near unanimous consensus among scientists that the impact of recent high deer populations on forest structure in Pennsylvania is deleterious. Nevertheless, the consensus is not 100%, so the full range of scientific views is discussed in this chapter and in Chapter 6.

Forest plants

Population densities of white-tailed deer have been high enough to cause negative direct and indirect impacts on forest vegetation in many areas of the eastern United States since at least the mid-twentieth century[1] and in some areas, including Pennsylvania, since the 1920s.[2] Effects on woody vegetation have been studied most comprehensively. Exclosure studies comparing zero deer density inside a fence with ambient deer density outside a fence have been the most common method of investigation.[3] Even more useful are enclosure studies where a fixed number of deer are placed inside fences. For example, a 10-year deer enclosure study in northwestern Pennsylvania using a gradient of known deer densities have allowed investigators to study impacts on both vegetation and birds as a function of deer density.[4]

Selective browsing is a well-known characteristic of deer and other forest ungulates (hoofed mammals with an even number of toes, e.g., moose, elk). Food preferences depend partly on what is available to eat. Food variety and availability in turn depend on current local deer density, recent trends in local deer density, availability of alternative forage, human land-use patterns, forest disturbance history, snow cover, and various other factors. Thus, preferred species frequently differ between regions in the same forest type,[5] within regions over long periods of time,[6] at different times during a growing season,[7] and at different deer densities in the same forest type.[8] Early browse preference studies were conducted to help managers foster forests that were better habitat for white-tailed deer, but, as deer numbers skyrocketed, the research focus shifted to encouraging regeneration of tree species of commercial value to the wood products industry (Table 4). Important timber trees represent less than 20% of the native tree species and about 1% of the total native vascular plant diversity in Pennsylvania's forests; however, it is clear that the majority of the state's other native plant species are just as vulnerable to severe depletion or eradication where deer numbers are high.

Over time, selective browsing by densely populated deer results in reduced species richness and altered species composition, with dominance by the few non-preferred and browsing-resilient species.[9] Once unpalatable and resilient species become abundant, they can interfere with the reestablishment of preferred and less browsing-resilient species. Competitive exclusion of some plant species by others is an indirect effect of browsing.[10] For example, non-preferred hay-scented fern and New York fern and browsing-resilient American beech and striped maple interfere strongly with the establishment of most other species.[11] Moreover, as species become scarce, their failure to replenish the seed bank (seeds lying dormant in the soil) affects vegetation dynamics long into the future,[12] another indirect effect of high deer density.

Overbrowsing by deer has eliminated the tree seedling, sapling, and shrub layer in large areas of forest in Pennsylvania. The result is a greatly simplified vertical structure. The herbaceous layer has also been stripped of much of the species diversity that was once there. By the time the density of hay-scented fern exceeds 50 stems per square meter (4.6 stems per square foot), species richness of other forest floor species is significantly reduced.[13]

A 1995 resurvey of a heavily browsed old-growth stand in northwestern Pennsylvania that had been surveyed in 1929 showed a loss of 59 to 80% of the shrub and herbaceous species.[14] A second resurvey of the site,[15] in which the original 160 one-meter-square survey plots from 1929[16] were relocated and remeasured, revealed fewer losses. As in the original survey, it also included a random search of the rest of the tract outside of the original plots, which turned up all but seven of the species tallied in the 1929 survey plots; however, most had severely dwindled in abundance. For example, hobblebush, which was present on 50% of the plots in 1929, was absent from all plots in 2000; it was found only in the wider search of the entire stand and then as small suppressed fragments. In the same timeframe, rhizomatous ferns (hay-scented and New York ferns) increased in abundance in the plots from 3 to 21% on average. Nevertheless, the presence of even small remnants of browsing-sensitive species holds out hope for restoration following future reductions in deer densities.

Native shrubs and understory trees found in Pennsylvania forests that are preferentially grazed by deer include American yew, fly-honeysuckle, hobblebush, pinxter-flower, and mountain maple.[17] Dwarf sand cherry, a plant that is classified as rare in Pennsylvania[18] has declined throughout the Great Lakes ecoregion coincident with heavy browsing by deer.[19] Dwarf sand cherry and bearberry, another low-growing shrub, disappeared from Presque Isle in northwestern Pennsylvania during the period when deer densities increased to the point where vegetation was overbrowsed.[20]

Table 4. The 116 native tree species of Pennsylvania (exclusive of subspecies, varieties, and hybrids)[21] ranked, where known, according to relative browsing preference by deer.[22] The ranking is compiled from multiple, not strictly comparable, sources and is somewhat subjective. However, it can serve as a rough guide to the relative vulnerability among the tree species known to be present at a particular site. The table in its present state is meant to be illustrative; it should be refined (e.g., split into regional tables) based on input from a range of experts. The list includes 13 species that can have either a tree or shrub growth form. An asterisk (*) after the common name indicates species of "medium" to "high" importance to the wood products industry that occur in significant numbers in harvested stands in Pennsylvania.[23] Where cells are left blank under browsing preference, no information was found.

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Abies balsamea	balsam fir		
Acer negundo	boxelder	not preferred	not preferred
Acer nigrum	black maple	low/moderate	high
Acer pensylvanicum	striped maple	low	low
Acer rubrum	red maple*	low/moderate	high
Acer saccharinum	silver maple	low/moderate	moderate
Acer saccharum	sugar maple*	low/moderate	moderate
Aesculus flava	yellow buckeye	(unknown, but toxic to cattle)	(unknown, but toxic to cattle)
Aesculus glabra	Ohio buckeye	(unknown, but toxic to cattle)	(unknown, but toxic to cattle)
Amelanchier arborea	downy serviceberry	(is browsed)	(is browsed)
Amelanchier laevis	Allegheny serviceberry	(is browsed)	(is browsed)
Aralia spinosa	devils-walkingstick	not preferred	not preferred
Asimina triloba	pawpaw	not preferred	not preferred
Betula alleghaniensis	yellow birch*	low/moderate	high (late autumn)
Betula lenta	sweet birch*	low/moderate	high (late fall)
Betula nigra	river birch	low	moderate

(Table continued on next page.)

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Betula papyrifera	paper birch	low/moderate	high (late fall)
Betula populifolia	gray birch	low/moderate	moderate
Carpinus caroliniana	American hornbeam		
Carya cordiformis	bitternut hickory*	low	low
Carya glabra	pignut hickory	low	low
Carya laciniosa	shellbark hickory	low	low
Carya ovalis	sweet pignut hickory (red hickory)	low	low
Carya ovata	shagbark hickory*	low	low
Carya tomentosa	mockernut hickory*	low	low
Castanea dentata	American chestnut		
Castanea pumila	Allegheny chinkapin		
Celtis occidentalis	hackberry	low	low
Celtis tenuifolia	Georgia hackberry (dwarf hackberry)	low	low
Cercis canadensis	eastern redbud		
Chamaecyparis thyoides	Atlantic white-cedar	low	moderate
Chionanthus virginicus	fringetree	low	low
Cornus alternifolia	alternate-leaf dogwood	moderate	high
Cornus florida	flowering dogwood	moderate	high
Crataegus brainerdii	Brainerd hawthorn	low	high
Crataegus calpodendron	pear hawthorn	low	high
Crataegus coccinea	scarlet hawthorn	low	high
Crataegus crus-galli	cockspur hawthorn	low	high

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Crataegus dilatata	broadleaf hawthorn	low	high
Crataegus flabellata	fanleaf hawthorn	low	high
Crataegus intricata	Biltmore hawthorn	low	high
Crataegus mollis	downy hawthorn	low	high
Crataegus pruinosa	frosted hawthorn	low	high
Crataegus punctata	dotted hawthorn	low	high
Crataegus rotundifolia	fireberry hawthorn	low	high
Crataegus succulenta	fleshy hawthorn	low	high
Diospyros virginiana	common persimmon		
Fagus grandifolia	American beech	low	high
Fraxinus americana	white ash*	low/moderate	high
Fraxinus nigra	black ash	low/moderate	high
Fraxinus pennsylvanica	green ash	low/moderate	high
Fraxinus profunda	pumpkin ash	not preferred	not preferred
Gleditsia triacanthos	honeylocust	(is browsed)	(is browsed)
Gymnocladus dioicus	Kentucky coffeetree		
Ilex opaca	American holly	low	low
Juglans cinerea	butternut		
Juglans nigra	black walnut	(is browsed)	(is browsed)
Juniperus virginiana	eastern redcedar	moderate	moderate
Larix laricina	tamarack		
Liquidambar styraciflua	sweetgum	low	low
Liriodendron tulipifera	yellow-poplar (tuliptree)*	high	high

(Table continued on next page.)

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Magnolia acuminata	cucumbertree	low	moderate
Magnolia tripetala	umbrella magnolia	low	low
Magnolia virginiana	sweetbay		
Malus coronaria	sweet crab apple		
Morus rubra	red mulberry		
Nyssa sylvatica	blackgum (black tupelo)*	high	high
Ostrya virginiana	eastern hophornbeam	low	low
Oxydendrum arboreum	sourwood		
Picea mariana	black spruce	not preferred	low
Picea rubens	red spruce	not preferred	low
Pinus echinata	shortleaf pine		
Pinus pungens	Table-Mountain pine		
Pinus resinosa	red pine		
Pinus rigida	pitch pine		
Pinus strobus	eastern white pine*	low	moderate
Pinus virginiana	Virginia pine		
Platanus occidentalis	American sycamore	(is browsed)	(is browsed)
Populus balsamifera	balsam poplar		
Populus deltoides	eastern cottonwood		
Populus grandidentata	bigtooth aspen	(is browsed)	low
Populus tremuloides	quaking aspen	(is browsed)	low
Prunus alleghaniensis	Allegheny plum		
Prunus americana	American plum		

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Prunus angustifolia	Chickasaw plum		
Prunus pensylvanica	pin cherry	high	high
Prunus serotina	black cherry*	low	low
Prunus virginiana	common chokecherry		
Quercus alba	white oak*	moderate	high
Quercus bicolor	swamp white oak	moderate	high
Quercus coccinea	scarlet oak*	moderate	high
Quercus falcata	southern red oak	moderate	high
Quercus imbricaria	shingle oak	moderate	high
Quercus macrocarpa	bur oak	moderate	high
Quercus marilandica	blackjack oak	moderate	high
Quercus montana	chestnut oak*	moderate	high
Quercus muhlenbergii	chinkapin oak (yellow oak)	moderate	high
Quercus palustris	pin oak	moderate	high
Quercus phellos	willow oak	moderate	high
Quercus rubra	northern red oak*	moderate	high
Quercus shumardii	Shumard oak	moderate	high
Quercus stellata	post oak	moderate	high
Quercus velutina	black oak*	moderate	high
Robinia pseudoacacia	black locust	low	low
Salix amygdaloides	peachleaf willow		
Salix caroliniana	coastal plain willow		
Salix nigra	black willow	low	moderate
Sassafras albidum	sassafras	moderate	high
Sorbus americana	American mountain-ash		

(Table continued on next page.)

tree species	common name	browsing preference (spring/summer)	browsing preference (fall/winter)
Sorbus decora	showy mountain-ash		
Tilia americana	American basswood*	(is browsed)	(is browsed)
Toxicodendron vernix	poison-sumac		
Tsuga canadensis	eastern hemlock	low	high
Ulmus americana	American elm	(is browsed)	(is browsed)
Ulmus rubra	slippery elm	(is browsed)	(is browsed)
Viburnum prunifolium	blackhaw	moderate	high

Although primarily thought of as shrub- and small tree-browsers, deer also feed extensively on most herbaceous plants and even fungi. A combination of grasses, sedges, wildflowers, and mushrooms comprised 87% of the summer diet of white-tailed deer in northern Wisconsin.[24] Lilies alone accounted for 12% of the diet by volume in early summer. In late summer asters made up 10% of the diet of deer. Grasses and wild strawberry were also among the most important foods. A study in Missouri revealed that 98 species of herbaceous flowering plants other than grasses, sedges, and rushes accounted for 44.7% of deer food in spring and summer[25] and another in Maine showed that the forest wildflowers bluebead lily and Canada mayflower (also native in Pennsylvania) constituted 50% by weight of all plants eaten by deer during late spring.[26] Overall, herbaceous flowering plants other than grasses, sedges, and rushes made up nearly three-fourth of the diet at that time of the year. Sedges and ferns were also consumed, especially during the summer, although an investigator working in Pennsylvania found that hay-scented fern was not eaten at any time of year.[27]

Other Pennsylvania-native forest herbs that deer graze on preferentially include large white trillium,[28] bluebead lily,[29] Canada mayflower,[30] turtlehead,[31] rose mandarin,[32] and numerous lilies and orchids.[33] Goldenclub, an emergent aquatic plant of shallow water around the margins of lakes in northeastern Pennsylvania, has been grazed to the point where an intact leaf is hard to find by mid-summer at some sites.[34] Wood nettle is browsed so consistently that it has been suggested as an indicator of browsing intensity.[35] Defoliation caused by repeated browsing has been shown to lead to reduction or cessation of sexual reproductive effort or eventual mortality in many plants native to Pennsylvania, including cranefly orchid,[36] turk's-cap lily,[37] glade spurge,[38] jack-in-the-pulpit,[39] Canada mayflower,[40] American yew,[41] Solomon's-plume,[42] and bellwort.[43]

Plants on Pennsylvania's endangered and threatened list that have been negatively impacted by deer browsing include glade spurge, yellow fringed-orchid, showy lady's-slipper, leafy white orchid, and white monk's-hood.[44] Golden puccoon, a state-endangered plant that also grows at Presque Isle, was threatened with extirpation in the state by severe browsing of 51 to 66% of the flowering stems per year and up to 90% reduction in seed production.[45] A deer control program at Presque Isle State Park has since reduced the browsing pressure, allowing golden puccoon to persist.

Because they never outgrow the reach of deer, forest floor wildflowers, other herbaceous species besides the unpalatable ferns, and many shrubs are continually vulnerable to deer impact. Whether a plant species is eaten or avoided by herbivores like deer can be crucial to its success or failure.

Browsing can change the balance between native and introduced species. Those few of the many plant species introduced from other parts of the world that become invasive do so largely because they are unpalatable to local herbivores or resistant to local pathogens.[46] A plant species' population size is regulated in its native range by predation and parasitism by insects and microbes that specialize on particular host plants. The enemy-release principle[47] is based on the observation that a plant introduced into a new region leaves most or all of its specialist herbivores and pathogens behind. For example, in a recent survey of 473 plant species naturalized to the United States from Europe, introduced species were infected by 84% fewer fungal pathogens and 24% fewer viruses in their naturalized ranges than in their native ranges.[48] In some cases a plant population's release enables it to become invasive. In the same study, introduced plants with the fewest pathogen species were found most likely to be listed as serious noxious weeds. Similar results were obtained in another study of the effects of root pathogens and mycorrhizal fungi on five highly invasive plants versus five rare and endangered plants in Canadian old fields and meadows.[49]

In places where deer are densely populated but the density is not so high that the forest herbaceous layer is eliminated, there is a strong potential for selectivity by deer to exacerbate the invasiveness of unpalatable introduced species. Several studies suggest that deer avoid garlic mustard, an introduced herbaceous species invading forests across the eastern United States, in favor of more palatable native species.[50] Japanese barberry, Eurasian species of honeysuckle, and ailanthus are examples of introduced, invasive shrubs and trees that are known to be unpalatable to deer.[51]

It has been shown that deer alter their foraging behavior to correspond with resource availability, nutritional needs, and energy requirements[52] (and large predator distribution and behavior, where species that prey on deer have not been eradicated). Numerous studies of deer food preferences suggest that deer avoid most non-native plants as long as a choice of foods is available.[53] However, the selectivity observed when other foods are available decreases when resources become scarce. Japanese honeysuckle, a non-native invasive plant from Eurasia, was found to be the fourth-most-frequent plant in a study of the contents of deer rumens in Ohio[54] and among the 10 most-frequent foods found in a survey of deer rumens in Indiana.[55] This and other invasive, non-native plants, including Russian-olive, burning-bush, and privets, are browsed during the winter when food resources are scarce.[56]

Studies of indirect effects of overbrowsing by deer species other than white-tails suggest their ability to alter site nutrient cycling by changing plant species composition from species with high-nitrogen, readily decomposable litter (e.g., most hardwoods) to those with low-nitrogen litter that decomposes slowly (e.g., conifers).[57] Recent research conducted in the Adirondack region of New York State documented significant differences in litter composition and rates of nitrogen mineralization between fenced and unfenced forest tracts. The study, conducted at Huntingdon Forest, involved plots inside and outside a 2-acre exclosure originally built in 1939. Significantly more litter was produced in the fenced plot. In addition litter composition differed with more white ash litter in the fenced area and more American beech leaves in the unfenced plot. Total nitrogen mineralization was 64% greater in the unfenced area over the growing season; most of the difference was accounted for by increased ammonification in the unfenced plot.[58] Another overbrowsing effect seen in some parts of the country is the alteration of forest fire regimes through changes in understory species composition from plants that favor surface fires (e.g., grasses, low shrubs) to those that provide fire "ladders," predisposing stands to crown fires (e.g., greenbriers, certain conifers).[59]

Overall, heavy browsing by deer in woody plant communities has the ability to change the trajectory of forest vegetation development. Whether these changes are permanent is a matter of current scientific debate, but it is clear that they are long lasting.[60] A study conducted on a private wildlife preserve in central Pennsylvania where hunting is prohibited compared forest gap dynamics in the preserve with an ecologically similar forest on nearby state game lands. Pellet groups were 6 to 100 times more abundant in the wildlife preserve. Overstory tree composition, stand basal area, and density of trees over 8 inches diameter (breast height) and 51 inches tall were similar at both sites. However, the density of smaller trees was 36 times less in the wildlife preserve (or 240 times less if only trees capable of becoming part of the canopy were considered). The fraction of the tree canopy in gaps was 41% greater in the wildlife preserve and the gaps were older (judged by the degree of decomposition of gap-maker trees). The authors concluded that the forest in the wildlife preserve was being destroyed from the bottom up by excessive deer browsing.[61] It also is clear that regeneration failures and altered species composition as a result of overbrowsing by deer have serious economic consequences, for example, the need to use fencing and herbicide treatments to regenerate forest stands.[62]

Forest animals

Deer have a substantial capacity for preempting limited food resources and altering habitat for other animals.[63] Though research is still limited, available findings demonstrate that deer have both direct and indirect effects on co-occurring animal species in Eastern forests.

Direct effects occur when deer compete with other species for the same limited food resource, for example, acorns and other tree nuts that fluctuate greatly from year to year, also known as mast. Mast is an important food resource for many forest mammals and some birds such as wild turkey and blue jay.[64] For example, reproduction and over-winter survival of gray squirrels[65] and white-footed mice[66] are strongly influenced by the size of the mast crop. Several studies show that competitive consumption of acorn mast by deer has a negative effect on the abundance of the mast-dependent small mammal community the following spring.[67]

Indirect effects occur when deer alter habitat features. Overbrowsing eliminates the shrub layer and greatly reduces the diversity of forest-floor plant species. With the lower layers of the forest thus impoverished, vertical diversity (herbaceous, shrub, subcanopy, and canopy) and horizontal diversity (the patchy mosaic of different plant species across the forest landscape) are greatly diminished. Subcanopy trees tend to be short-lived; where deer eat all of their seedlings, an entire layer is vulnerable to disappearing even though it is beyond the deer's reach. Where overbrowsing of seedlings and saplings halts the regeneration of canopy trees, their contribution to vertical structure diversity at various life stages is lost. Overbrowsing reduces or eliminates species required by animals that are narrowly specialized to eat only one or a few species. It reduces or eliminates critical habitat features such as oviposition sites for insects and other invertebrates. It allows greater wind speed, increases light (and thus temperature), and reduces humidity at the forest floor. These microclimatic effects are especially detrimental to snails, other forest gastropods, salamanders,[68] frogs, and other animals dependent on moist, protected environments. Few, if any, species gain from the increase in the abundance of the few fern and tree species that are unpalatable to deer.

Indirect effects ripple outward to affect animals further removed from deer and their food plants. For example, the reduction of white-footed mouse, deer mouse, chipmunk, gray squirrel, and other small mammal densities due to competition with densely populated deer for mast can lead to reductions in predator populations that feed on them,[69] including owls, hawks, and possibly fishers, martens, and other carnivores. Dense deer populations in New York reduced the density of white-footed mice, presumably by competing with them for their principal food, acorns, and reducing forest-floor cover, exposing the mice to increased predation. White-footed mice are the main predators of gypsy moths, an introduced defoliator of oaks, thus deer in high numbers can facilitate outbreaks of gypsy moths.[70] Deer are the only host of adult deer ticks, which feed on white-footed mice as larvae and transmit the spirochete that causes Lyme disease from the mice to humans. The northeastern subspecies of the white-tailed deer and the known range of the deer tick are virtually identical, and in places such as Nantucket and Martha's Vineyard, where deer were eradicated and then reintroduced, the deer tick appeared only after deer became numerous.[71] In a 3-year study conducted at three sites in southern Maine, deer pellet group density was a consistently significant predictor of adult tick abundance.[72] Even though deer are not susceptible to Lyme disease, the transmission of the disease from mice to humans depends on their presence and increases as deer populations increase.[73]

The total biomass of herbaceous plants (the weight of harvested plants after oven-drying to eliminate water content) has been measured to be three times greater inside a deer exclosure than outside.[74] When whole layers of the forest are severely depleted or lost, the species that depend on those plant strata are also affected. Unlike white-tailed deer, most insect herbivores feed on only a narrow range of species or, in many cases, just one part of a single species.[75] Thus, insect diversity in forests is heavily dependent on the species diversity of the vegetation.[76] For example, in New Hampshire deer browsing threatened a population of blue lupine, the sole larval food of the federally endangered Karner blue butterfly.[77]

Adverse effects of overbrowsing on forest bird communities have been documented repeatedly, although not in every study. In a study in southwestern Pennsylvania, changes in species composition of bird communities were found by comparing a heavily browsed and grazed preserve with the more intact surrounding area.[78] However, the study had poorly matched control stands, a small sample size, and no net changes in the number of birds or bird diversity were found to be statistically significant. A better-designed study compared fenced deer exclosures in northern Virginia with nearby unfenced sites.[79] Reduced understory density outside the exclosures was correlated with increased nest predation and lower overall bird abundance, but not species diversity.[80]

The effect of deer browsing on songbird species richness and abundance was evaluated in a 10-year study in forested enclosures containing four densities of deer — 10, 20, 38, and 64 deer per square mile — in northwestern Pennsylvania.[81] Not only does this study have randomly matched control stands and a large sample size, it looked at effects on birds at four different deer densities. At the end of the 10 years, species richness and abundance of intermediate canopy-nesting birds were, respectively, 27% and 37% lower at the highest deer density than at the lowest. At the scale of the experiment, the threshold for detectable negative effects on species richness of intermediate-canopy-nesters was between 20 and 38 deer per square mile. Abundance in intermediate canopy-nesting birds showed a steady decline from lowest to highest deer densities. Although the effect of deer density on other groups of birds had confidence limits of less than 95%, the trend was clearly the same for birds as a group as for intermediate canopy-nesters.

The few scientific studies to date that have specifically focused on deer overbrowsing and bird communities have either shown that changes in vertical structure caused by deer have a negative impact on bird abundance or diversity, or both, or failed to detect any statistically significant relationship.[82] Meager as they are, the data are consistent with ecological theory, which predicts that deer browsing should change the distribution of bird species in a forest and decrease avian abundance or species diversity by eliminating understory plant species that provide food, cover, and nesting sites.

Impacts of deer overbrowsing on invertebrates so far has been investigated even less than impacts on birds, but the limited available evidence suggests that overbrowsing may severely affect certain groups.[83] The abundance and species richness of web spiders was found to be reduced in forests with deer compared to those without. Because total numbers of insects caught on sticky traps were similar in sites with and without deer, the authors concluded that the decrease in spiders was due to the simplification of habitat structure.[84] In some situations, deer seem to be direct competitors with insect herbivores for plant biomass. However, as with birds much of the impact is likely to be indirect, resulting from changes in the structure, species composition, and quality of the vegetation. Reductions in certain insect populations indirectly affect a host of insectivorous vertebrate species, including shrews, rodents, bats, wood-warblers, flycatchers, other bird groups, frogs, toads, and salamanders. Few studies have addressed this problem in the range of white-tailed deer, but information from studies of other deer species living in temperate forests are instructive. For example, lepidoptera (butterflies, skippers, and moths) were four times more numerous in the absence of red deer browsing in a study in native pine-dominated forests in Scotland.[85] This was a far greater difference than could have been predicted by differences in total plant biomass. The disproportionate effect was attributed to competition between deer and lepidoptera for just the nutritious young growing tips of major food plants.

Deer selectively browse fast-growing, less-well-defended species, which generally produce litter (shed leaves and dead branches) that decomposes faster than litter from the unpalatable species that are left. This causes a shift in plant species composition toward slower-growing species with slower-decaying litter, which in turn affects diverse groups such as springtails (Collembola), mites (Acari), earthworms (Lumbricidae), roundworms (Nematoda), and other animals that are vital to organic matter turnover and soil development and thus influence rates of energy and nutrient flow through the forest ecosystem.[86] A small subset of inverterbrate species dependent on the vegetation that thrives in overbrowsed environments may, like their plant hosts, prosper with high deer densities; however, like understories overwhelmingly dominated by hay-scented fern, their increase would likely represent a simplification of invertebrate communities and overall loss of diversity.

Interaction of deer and silviculture

Forest disturbances, including timber harvests, have profound effects on white-tailed deer populations and vice-versa. Because of the potential for feedback effects, the relationships among these ecological factors and ecosystem management is complex.

Deer populations tend to increase in response to timber harvest or other overstory disturbance, such as large-scale wind events. They grow the fastest following disturbances that increase the abundance of woody and herbaceous vegetation less than 5 feet tall and increase mast production. Forest stands that contain an abundance of browse (buds, twigs, and leaves of woody plants) within 5 feet of the ground are highly preferred by deer. The current year's growth of most hardwood species has a high nutrient content and is among the most highly palatable items in their diet. In Pennsylvania's hardwood forests, germination, survival, and seedling growth are increased by disturbances that open the canopy and increase the amount of light reaching the forest floor, that is, where deer impacts are low enough to allow these responses to occur and where a residual of low, shade-casting plants such as ferns or shade-tolerant small trees are not left behind. Similarly, silvicultural regeneration methods or natural disturbances that remove all or most of the overstory (e.g., clearcutting, shelterwood seed cutting,[87] selection cutting of large groups,[88] windthrow that creates large openings), where advance regeneration (shade-suppressed seedlings) or a seed bank is present, will promote the development of high-density browse. As seedlings grow and a new forest enters the sapling and poletimber (small adult) stages of development, trees grow out of the reach of deer and cast sufficient shade to substantially decrease the abundance of other browse produced. Where deer population density is below some threshold near a given location's ecological carrying capacity (see box on page 16 and Chapter 11), young hardwood stands in Pennsylvania can grow out of reach of deer in 3 to 10 years, depending on the local climate, site conditions, and species composition.[89]

The abundance and diversity of herbaceous plants used as food by deer first increase and then decline after canopy removal. The growth of tree seedlings and shrubs invading a site after disturbance and advance regeneration accelerates in the increased light to form a closed canopy. This canopy substantially reduces the density and growth of herbaceous plants originally stimulated by the disturbance and associated higher light. As trees reach the sapling stage they shade and suppress shrub growth and further seedling recruitment. After closed tree canopies develop, browse production remains low for several decades until trees achieve heights greater than 50 feet. At around that stage, canopy cover generally falls somewhat below 100% due to the death of some trees, fallen branches, and irregularly shaped tree crowns, once again establishing light conditions near the ground that are favorable for woody and herbaceous plant germination, survival, and growth. This stage is referred to as "understory reinitiation".[90] However, understory browse in a forest stand dominated by mature trees is much sparser than the amount of browse available in the first decade after harvesting.

Silvicultural thinning treatments are partial harvests used to increase the diameter growth of trees selected for their mast or timber production value by removing competing trees to encourage crown expansion of the favored trees. Thinnings increase the amount of light reaching the forest floor and can stimulate the growth of understory vegetation, but typically the growth response is short-term, subsiding as the crowns of canopy trees rapidly expand to fill their new growing space. Selective browsing by deer during understory reinitiation suppresses the advance regeneration of certain tree species. At the same time, it promotes the expansion of unpalatable or resilient species, such as hay-scented fern, New York fern, and American beech or striped maple seedlings and saplings, that may slow or prevent later recolonization by trees when the stand is subjected to a harvest that would normally spur regeneration.[91] By exhausting their major food source and fostering conditions that obstruct its regrowth, deer in high numbers can cause a forest's ability to sustain a high deer population to decline, essentially reducing the local ecological carrying capacity. If there is no alternative source of food, the deer population then decreases through malnutrition or reduced recruitment, but typically remains at a high enough density to keep the understory in a depauperate state essentially in perpetuity (see discussion of alternative persistent states on pages 107 and 108).

The supply of mast from oaks and nut trees is an important contributor to the winter diets of deer and many other wildlife species. Because thinning treatments increase the crown size and vigor of residual trees, it results in the production of more seed during good seed years,[92] which serves as a source of future seedlings but also as a rich source of fat, protein and carbohydrate for wildlife.[93] However, because oak seedlings and saplings are highly preferred browse (see Table 4, pages 53-58), overbrowsing delays or even prevents oak regeneration and stand establishment.[94] Depending on the size of the deer population and the availability of other food sources, oaks can change from a dominant to a subordinate component of the newly regenerating forest or disappear altogether.

A dense white-tailed deer population impedes the practice of sustainable forestry in all forest types in Pennsylvania.[95] It also impedes recovery after natural disturbances such as windthrow or tornado damage. If disturbed areas are not fenced to exclude deer, complete regeneration failure can result,[96] especially if woody vegetation is replaced by unpalatable species such as hay-scented and New York ferns.[97] The Pennsylvania Bureau of Forestry spends two million dollars each year on fencing to exclude deer from timber harvest areas so new trees can grow. The

Bureau currently has 800 miles of fencing on state forest land.[98] The Allegheny National Forest and the Pennsylvania Game Commission fence regeneration harvest areas in regions of high deer impact as a matter of course but smaller landowners may not choose to bear the considerable added expense. The cost of fencing varied, for the Bureau of Forestry's 126 fencing projects in 2002 and 2003, from $208 to $596 per acre[99] (average $318) or $1.75 to $2.28 per lineal foot[100] (average $1.98), with the lower part of the range applying only to exclosures of over 40 acres.[101] In addition to fencing, if seed sources, seeds, or seedlings of desired species are reduced or eliminated, third-generation stands will have to be artificially replenished through planting.

Interaction of deer and unpalatable or browsing-resilient plant species

In a forest stand where deer are densely populated, the few plant species that are unpalatable to deer or resilient to deer browsing can become so plentiful that they prevent the establishment and growth of other plant species, including tree and shrub seedlings, even if the stand is later released from overbrowsing.[102] Proliferating unpalatable or resilient species may suppress other plants by producing dense shade on the forest floor,[103] by usurping space in the soil with a dense root mat, or by competing for water and nutrients; there is conflicting evidence about whether allelopathy (releasing chemicals into the soil that are toxic to other plants) might also be a factor.[104] Research on the inhibition of black cherry establishment by hay-scented fern in northwestern Pennsylvania suggests that shade is the most important of these factors.[105]

Deer overbrowsing alone may not be enough to cause non-preferred or browsing-resilient plants to increase to the point where other species can no longer become established. One recent study in central Massachusetts concluded that more than 15 years of intensive browsing following thinning were necessary for hay-scented fern to form continuous shade on the forest floor; neither thinning alone nor overbrowsing alone was sufficient to cause this level of fern proliferation.[106] It is possible that long-term deer overbrowsing alone might cause this condition, for example, if 70 years of overbrowsing caused canopy thinning by preventing the recruitment of new canopy trees. This hypothesis could be tested by quantifying fern dominance and checking timber harvest records for randomly selected sites on state forest lands, where accurate timber harvest data are available.

In overbrowsed forests in Pennsylvania, dense groundcovers of hay-scented fern and New York fern and understories of shade-tolerant striped maple and American beech often form following canopy thinning. Two very different logging practices involve canopy thinning. One is shelterwood seed cutting — removal of enough large trees to open up the canopy and stimulate the germination and establishment of tree seedlings some years prior to their release from shade by clearcutting. When a final harvest is anticipated shortly after canopy thinning or where tree seed sources may be limiting (unless successful regeneration is obtained in conjunction with the thinning), fencing must be included as part of the treatment where deer numbers are high or else most plants, including tree seedlings, will be consumed and one or a few unpalatable or browsing-resilient species will spread and block future regeneration.[107] The other canopy thinning practice is diameter-limit cutting, in which all trees above a certain size are taken. The result of this practice is that sources of tree seeds are often critically reduced due to selective removal of the largest-crowned, best seed-producing trees and thus the probability of successful regeneration declines. Where the deer population is dense, the outcome is often a regeneration failure of desired species (in silvicultural situations) and a decline in diversity. Sometimes, especially on upland sites, low-diversity "fern savannas" can result (see discussion of diameter-limit cutting on pages 82 and 83).

Of the species whose spread is linked to deer overbrowsing, hay-scented fern and New York fern have received the most attention because of their role in both declining biodiversity and dwindling regeneration of trees important to the wood products industry. Deer do not eat these ferns,[108] most likely because the fronds have high levels of defensive compounds that make them inedible to most herbivores.[109] They regenerate from spores where moist mineral soil is present, but their primary mode of spread is by repeated forking and extension of the rhizomes (underground stems). This ability to form a continuous cover over large areas distinguishes them from most native fern species, whose leaves are arranged in rosettes or tufts. In the low light of forests that have not been disturbed for a number of years, the rhizomatous ferns grow slowly. However, in stands where a portion of the overstory has been removed, rhizomes not only grow faster and fork more frequently than in undisturbed forest, but they also form many new rhizome buds.[110] These buds grow out rapidly and greatly expand the area covered by the fern plant. Overstory removal in an overbrowsed area of New Hampshire caused the frequency of hay-scented fern to increase nearly five-fold by the third year after cutting due to vegetative expansion of existing colonies.[111]

It must be noted that the practice of "blaming" ferns for precipitous declines in forest plant species diversity and tree regeneration reflects confusion between intermediate and ultimate causes. Ferns represent a significant component of forest biodiversity; Pennsylvania has 57 native fern species or 5% of the native herbaceous flora in the state,[112] 16 of which are rare and endangered.[113] Only hay-scented fern and New York fern sometimes become invasive, and solely under a narrow range of conditions involving overbrowsing by abnormally abundant deer followed by forest thinning, canopy thinning by natural disturbance, or canopy attrition due to extremely prolonged overbrowsing. In forests not exposed to deer overbrowsing these two Pennsylvania natives behave much as other native ferns and wildflowers do, growing singly or in small patches interspersed with other plant species.

Dense understories of browsing-resilient or unpalatable trees that are also shade-tolerant (in Pennsylvania mainly American beech and striped maple), also severely curtail the establishment of other plants on the forest floor including seedlings of other tree species. Even small stems of shade-tolerant species can deter seedling establishment in partially cut stands because they often develop faster than herbaceous plants and the seedlings of less shade-tolerant tree species, producing enough shade to reduce their survival. There is some evidence that interactions among plant species with different susceptibilities to deer browsing may make the relationship between high deer populations and altered tree species composition more complex than a simple, linear, inverse relationship between deer density and species diversity of tree seedlings.[114] However, the overall pattern is conclusive that the diversity of forest understory herbaceous plants, shrubs, and tree seedlings diminishes as deer densities increase from moderate to high levels, and the apparent "exceptions" represent only small bumps on a clearly downward-sloping line (see the right-hand side of Figure 1, page 68).

Role of alternative forage

Where white-tailed deer living in forest habitat have alternative forage available in nearby logged areas, agricultural fields, or residential areas, high deer densities can occur with less severe impacts on forest ecosystems. This is one reason that not all forests in Pennsylvania show the same impact from deer. Deer usually thrive in a mosaic of crop fields and woodlots. Forest stands interspersed with agricultural lands may not show as much loss of forest structure and species diversity due to deer overbrowsing as larger blocks of forest, which are the primary focus of this report, although forest fragmentation and "edge effects" in such landscapes have detrimental influences of their own.

Deer and diversity

Ecosystem management of deer does not mean elimination of deer. Although no one has ever

Figure 1. Hypothetical relationship between the frequency or severity of natural disturbance, such as browsing by deer, and the number of species an ecological community will support

documented a beneficial effect of deer on the diversity of plants and other animals, ecological theory does indicate that such an effect may well exist at low deer population levels. Many studies have shown catastrophic effects of white-tailed deer on forest understory plants[115] and birds,[116] however, all of this research has been conducted where deer populations are at destructively high levels. The intermediate disturbance hypothesis[117] describes a hump-shaped relationship between species diversity in an ecological community and the frequency or severity of natural disturbances such as fire, windstorm, disease outbreaks, or heavy browsing (Figure 1). The principle is that species diversity is generally maximized when there is a moderate intensity of disturbance; diversity is lower where disturbance is either less intense or more intense. Numerous studies have corroborated the hypothesis for a wide variety of ecosystems and disturbance regimes.[118]

Although the current high deer populations in Pennsylvania appear to have brought forest stands to the right-hand side of the richness curve, especially in portions of northern Pennsylvania where deer have been abundant for a very long time (see Figure 3, page 122), deer at reduced density have a role to play in functioning ecosystems in Pennsylvania. For example, in parts of northern Pennsylvania, low deer density combined with a major disturbance such as timber harvest or severe wildfire or windstorm can lead to pin cherry reducing the survival of seedlings of other species[119] and probably reducing plant diversity, at least for a few years post-disturbance.

Findings on the role of white-tailed deer in altering forest structure

(1) Virtually all of the published literature on forest structure damage in Pennsylvania suggests a major role for high densities of white-tailed deer. An abundance of experimental data supports that view in those areas where data have been collected. Alternative theories (Chapter 6) can be tested as part of adaptive resource management (Chapters 2 and 12).

(2) Deer have direct and indirect impacts on forest plants and animals. Selective browsing and grazing of preferred woody and herbaceous plants reduce species richness, plant density and biomass, height growth, and the development of vertical structure (direct effects). Loss of vertical structure and drastic reduction or elimination of many plant species lead to the decline of animal species that depend on them (indirect effects).

(3) Over time, overbrowsing-induced dominance by unpalatable and browsing-resilient species interferes with the reestablishment of species lost to browsing, even if overbrowsing stops (another indirect effect). Thus, overbrowsing can cause a persistent change in the trajectory of vegetation development. The longer overbrowsing occurs, the more difficult it becomes to restore the original vegetation, in part because seed and other propagule supplies have been greatly reduced or eliminated.

Recommendation on the role of white-tailed deer in altering forest structure

Until proven otherwise, policy makers should assume that the consensus view on the impacts of the current high densities of white-tailed deer on forest ecosystems is correct.

Endnotes

[1] Porter et al. 1994

[2] Fronz 1930; Leopold et al. 1943, 1947; Kosack 1995

[3] Hough 1949; Webb et al. 1956; Grisez 1957; Graham 1958; Grisez 1959; Shafer et al. 1961; Jordan 1967; Ross et al. 1970; Richards and Farnsworth 1971; Marquis 1974; Marquis and Grisez 1978; Anderson and Loucks 1979; Anderson and Katz 1993; Anderson 1994; Alverson and Waller 1997. Exclosure studies are invaluable in understanding the effects of deer on ecosystem processes. However, such studies must be interpreted with the knowledge that plants evolved under some level of deer browsing pressure; eliminating browsing experimentally is not intended to mimic any "natural" situation.

[4] Tilghman 1989; deCalesta 1994; Horsley et al. 2003

[5] Stiteler and Shaw 1966

[6] Hough 1965

[7] McCullough 1984; Healy 1971; Augustine and Jordan 1998

[8] Tilghman 1989; Horsley et al. 2003

[9] Lutz 1930a, 1930b; Winecoff 1930; Park 1938; McCain 1939, 1941; Leopold et al. 1943; Hough 1949; Graham 1954; Dahlberg and Guettinger 1956; Webb et al. 1956; Grisez 1957; Stoeckeler et al. 1957; Graham 1958; Grisez 1959; Beals et al. 1960; Shafer et al. 1961; Hough 1965; Jordan 1967; Behrend et al. 1970; Ross et al. 1970; Richards and Farnsworth 1971; Marquis 1974; Blewett 1976; Snyder and Janke 1976; Marquis and Grisez 1978; Anderson and Loucks 1979; Marquis and Brenneman 1981; Whitney 1984; Frelich and Lorimer 1985; Kroll et al. 1986; Risenhoover and Maass 1987; Tilghman 1989; Allison 1990a, 1990b, 1992; Strole and Anderson 1992; Anderson and Katz 1993; Anderson 1994; Balgooyen and Waller 1995; Ziegler 1995; Waller et al. 1996; Alverson and Waller 1997; deCalesta 1997; Healy 1997; Augustine and Jordan 1998; Fredericksen et al. 1998; Danell et al. 2003; Horsley et al. 2003; Boucher et al. 2004; Cote et al. 2004; Rooney et al. 2004; Whigham 2004

[10] Anderson and Loucks 1979; Horsley and Marquis 1983; de la Cretaz and Kelty 1999; George and Bazzaz 1999a, 1999b; Ristau and Horsley 1999

[11] Horsley 1977, 1993a, 1993b; Horsley and Marquis 1983; Tilghman 1989; de la Cretaz and Kelty 1999; Horsley et al. 2003

[12] Styer et al. 1997

[13] Rooney and Dress 1997a

[14] Rooney and Dress 1997b

[15] Ristau 2001

[16] Lutz 1930b

[17] Allison 1990a, 1990b, 1992; A. F. Rhoads, personal observation; Ristau 2001

[18] Department of Conservation and Natural Resources 1993

[19] Catling and Larson 1997

[20] Dr. James K. Bissell, Curator of Botany, Cleveland Museum of Natural History, personal communication, 2003

[21] Source: Rhoads and Block 2003; common names from Little 1953

Endnotes

[22] Assessment by M. A. Fajvan and A. F. Rhoads based on direct observation and a review of Halls and Ripley 1961; Healy 1971; Knierim et al. 1971; West Virginia University Extension Service 1985; Horsley et al. 2003. As noted above, white-tailed deer food preferences depend partly on what is available to eat. Food variety and availability in turn depend on current local deer density, recent trends in local deer density, availability of alternative forage, human land-use patterns, forest disturbance history, snow cover, and various other factors. Thus, preferred species frequently differ between regions in the same forest type, within regions over long periods of time, at different times during a growing season, and at different deer densities in the same forest type.

[23] Commercial species representing at least 0.05% but less than 0.5% of all live trees 5 inches in diameter at breast height or larger encountered on U.S. Forest Service's Forest Inventory Analysis survey plots (Alerich 1993: pages 15-17)

[24] McCaffery et al. 1974

[25] Korschgen et al. 1980

[26] Crawford 1982

[27] Healy 1971

[28] Anderson 1994; Augustine and Frelich 1998; Knight 2004

[29] Balgooyen and Waller 1995

[30] Rooney 1997

[31] Williams et al. 2000

[32] A. F. Rhoads, personal observation

[33] Miller et al. 1992

[34] A. F. Rhoads, personal observation

[35] Augustine and Jordan 1998

[36] Whigham 1990

[37] Fletcher et al. 2001a

[38] Loeffler and Wegner 2000

[39] Ruhren and Handel 2000; Fletcher et al. 2001b

[40] Rooney 1997

[41] Allison 1990a, 1990b, 1992

[42] Fletcher et al. 2001b

[43] Fletcher et al. 2001b

[44] Loeffler and Wegner 2000; A. F. Rhoads, personal observation; Paul G. Wiegman, formerly Coordinator/Botanist, Natural Areas Program, Western Pennsylvania Conservancy, personal communication, 2003; J. M. Benner, personal observation

[45] Campbell 1993

[46] Keane and Crawley 2002

[47] Keane and Crawley 2002

[48] Mitchell and Power 2003

[49] Klironomos 2002

Endnotes

[50] Anderson et al. 1996; Williams 1996

[51] Ward 2000

[52] Schmitz 1992; Vangilder et al. 1982

[53] E.g., Atwood 1941; Korschgen et al. 1980

[54] Nixon et al. 1970

[55] Sotala and Kirkpatrick 1973

[56] Conover and Kania 1988

[57] McInnes et al. 1992; Pastor and Naiman 1992; Pastor et al. 1993

[58] Didier 2003. Species basal area inside the fence was white ash 44%, American beech 22%, and sugar maple 21%. The unfenced plot had a composition of 62% beech, 25% maple, and 12% ash.

[59] Hobbs 1996

[60] Tilghman 1989; Warren 1991; Stromayer and Warren 1997; Waller and Alverson 1997; Augustine et al. 1998; Coomes et al. 2003; Horsley et al. 2003

[61] Pederson and Wallis 2004

[62] Marquis 1974; Marquis and Brenneman 1981; Horsley et al. 1994

[63] Perkins and Mautz 1987

[64] Martin et al. 1951

[65] Elliot 1978; Nixon and Hanson 1987

[66] Miller and Getz 1977; Gashwiler 1979; Ostfeld et al. 1996

[67] Brooks and Healy 1988; McShea and Rappole 1992; McShea and Schwede 1993; McShea and Rappole 1997

[68] However, one investigator in northwestern Pennsylvania found no difference in surface abundance of salamanders (amphibians) across a range of deer densities 10 years after the introduction of deer in an enclosure study (Thomas Pauley, U.S. Forest Service, Northeastern Research Station, Irvine, Pennsylvania, unpublished data).

[69] Flowerdew and Elwood 2001

[70] Ostfeld et al. 1996

[71] Spielman et al. 1985

[72] Rand et al. 2003

[73] Duffy et al. 1994. In this study, the abundance of deer tick larvae (August) and nymphs (June) was sampled in 1992 at 22 parks and natural areas — some with deer and some without — on Long Island, New York. Significant correlations were found between deer presence and the abundance of both nymphal and larval ticks. Sites without deer had, on average, 1.8% of the larval deer tick population densities and 7% or the nymphal densities found at sites with deer.

[74] Riemenschneider et al. 1995

[75] Strong et al. 1984

[76] Stewart 2001

[77] Miller et al. 1992

[78] Casey and Hein 1983

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[79] McShea and Rappole 1999

[80] Leimgruber et al. 1994

[81] deCalesta 1994

[82] MacArthur and MacArthur 1961; Karr and Roth 1971; Hooper et al. 1973; Roth 1976; DeGraaf et al. 1991a

[83] Stewart 2001

[84] Miyashita et al. 2004

[85] Baines et al. 1994

[86] Pastor et al. 1993; Stewart 2001; Tripler at al. 2002; Ayres et al. 2004; Wardle and Bardgett 2004

[87] Shelterwood cutting involves harvesting in two or more stages. The first harvest — the seed cut — increases light at the forest floor enough to allow seedlings of shade-tolerant species to become established in large numbers. The rest of the canopy is removed when the offspring of the desired tree species have grown robust root systems that allow them to tolerate drought (and, in the case of oaks, fire) and compete with the faster-growing, intolerant species.

[88] Selection cutting of large groups (also called group selection) is the complete removal of the tree canopy in multiple areas dotted across the landscape, each large enough — typically 0.5 to 2 acres — that adjacent uncut trees cannot fill in the gap by lateral growth of crown branches. At present, group selection is not a viable technique anywhere in Pennsylvania unless cut areas are fenced, because of overbrowsing by deer.

[89] Ristau and Horsley 1999

[90] Oliver and Larson 1996

[91] Horsley et al. 2003

[92] Smith et al. 1997

[93] Nutritional content of nuts ("hard mast") native to Pennsylvania forests (U.S. Department of Agriculture 2003):

	mean amounts (g) in 100 g of edible portion		
	protein (N x 5.3)	total lipid (fat)	carbohydrate
Acorns *(Quercus* spp.)	8.10	31.41	53.66
Beechnuts *(Fagus grandifolia)*	6.20	50.00	33.50
Hickory nuts (*Carya* spp.)	12.72	64.37	18.25
Walnuts, black, dried *(Juglans nigra)*	24.06	59.00	9.91
Butternuts *(Juglans cinerea)*	24.90	56.98	12.05
Hazelnuts (*Corylus* spp.)	14.95	60.75	16.70

[94] Kelty and Nyland 1981; Russell et al. 2001; Palmer et al. 2004

[95] Pennsylvania Department of Conservation and Natural Resources 2003

[96] Marquis 1974; Marquis and Grisez 1978

[97] Horsley and Marquis 1983

[98] DiBerardinis 2004

[99] Excludes outlier values for seven of the fencing projects of approximately $180, $989, $878, $851, $725, $674, and $648 per acre.

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[100] Excludes an outlier value for one of the fencing projects of $2.73 per lineal foot.

[101] James Bailey, Forest Genetics/Regeneration Specialist, Silviculture Section, Bureau of Forestry, Pennsylvania Department of Conservation and Natural Resources, personal communication, 2003

[102] Horsley and Marquis 1983; Stromayer and Warren 1997; Waller and Alverson 1997

[103] de la Cretaz and Kelty 2002

[104] Horsley 1993a, 1993b

[105] Horsley 1993a

[106] de la Cretaz and Kelty 2002

[107] Marquis et al. 1975; Cody et al. 1977; Horsley and Marquis 1983; de la Cretaz and Kelty 1999; Horsley et al. 2003

[108] Healy 1971; Waller and Alverson 1997

[109] Bohm and Tryon 1967; Cody et al. 1977

[110] Horsley 1984; Hammen 1993

[111] Hughes and Fahey 1991

[112] Rhoads and Block 2003

[113] Rhoads and Block 2000

[114] For example, in parts of northern Pennsylvania, pin cherry, an early successional tree that survives in forests for 25 to 40 years, can be so abundant after complete timber removal that it slows the regeneration of canopy tree species, unless deer density exceeds about 20 deer per square mile. Above that level, deer herds browse enough pin cherry to allow trees that will eventually dominate the forest to regenerate relatively quickly. However, at the same time, deer restrict the survival of forest tree species to mainly black cherry, American beech, sweet birch, yellow birch, and, in the subcanopy, striped maple. Other components of the northern hardwood canopy and subcanopy, including sugar maple, red maple, white ash, cucumbertree, yellow-poplar, northern red oak, eastern white pine, eastern hemlock, smooth serviceberry, Allegheny serviceberry, mountain holly, and American hornbeam regenerate in significant numbers only where deer densities are considerably lower (Ristau and Horsley 1999; Horsley et al. 2003).

[115] E.g., Anderson and Loucks 1979; Marquis and Brenneman 1981; Tilghman 1989; Miller et al. 1992; Anderson and Katz 1993; Rooney and Dress 1997a; Rooney 2001; Russell et al. 2001; Horsley et al. 2003

[116] E.g., Casey and Hein 1983; deCalesta 1994; McShea and Rappole 1997

[117] Connell 1978

[118] E.g., Reynolds et al. 1993; Collins et al. 1995; Hiura 1995; Bornette and Amoros 1996; Clark 1997; Townsend et al. 1997; Floder and Sommer 1999; Molino and Sabatier 2001. A small fraction of such studies has shown a different pattern (e.g., Schwilk et al. 1997), usually decreasing diversity with increasing disturbance. Various explanations have been proposed for why the relationship between disturbance and diversity is often hump-shaped. A variety of factors may be at play in different ecosystems and at different points along the spectrum of disturbance intensity. In cases where the disturbance is browsing by an animal such as white-tailed deer, the most important factor is clearly plant-plant competition. The best competitors for light, water, and nutrients are species that grow fast and tall, but the faster and taller a plant grows, the more likely it is to be eaten. Where the most

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effective competitors are eaten disproportionately, less-competitive plant species can sustain higher population densities, which are vital to insure pollination, seed production, and long-term persistence. As plant species drop out of the picture either to the left or to the right of the highest point in the curve (see Fig. 2, animal species that depend on them are apt to decline as well. At high levels of browsing, all but a few unpalatable plants are vulnerable and many species decline precipitously or they are exterminated.

[119] Ristau and Horsley 1999; Horsley et al. 2003

Chapter 6. Factors of Human Origin in Addition to Deer Browsing that Affect Recovery of Pennsylvania's Forests

To develop a program for managing deer from an ecosystem perspective it is necessary to consider all of the major factors other than deer that affect forest structure, succession, and other processes. Consideration of these factors is also necessary to make sound predictions about recovery times following reduction in deer browsing pressure, predictions that can be used to test the theoretical understanding on which any management plan must rest. In this chapter, we consider factors pertinent to forest recovery, in addition to deer overbrowsing, that are deliberately or inadvertently influenced by human activity. As in the rest of this volume, we confine our discussion to large forested areas, leaving suburban sprawl, forest fragmentation, the farm-forest interface, and other important topics for examination elsewhere.

Acidic deposition

Acidic deposition is the transfer of strong acids and acid-forming substances from the atmosphere to the surface of the earth. The deposited material includes ions, gases, and particles derived from gaseous emissions of sulfur dioxide, nitrogen oxides, and ammonia and particulate emissions of acidifying and neutralizing compounds.[1] Although the Clean Air Act of 1990 resulted in reduction of sulfur dioxide emissions, there has been little abatement of nitrogen oxide emissions. High emissions in the Northeast result primarily from electrical power generation and heavy manufacturing. Prevailing winds from west to east cause pollutants emitted in the Midwest to be deposited eastward; Pennsylvania is particularly hard-hit. Many of the effects of acidic deposition depend on the rate at which acidifying compounds are deposited from the atmosphere compared with the rate at which acid-neutralizing capacity is generated within the ecosystem. Acid-neutralizing capacity is a measure of the ability of water or soil to neutralize inputs of strong acids. It is largely the result of terrestrial processes such as mineral weathering, cation exchange, and immobilization of sulfur dioxide and nitrogen.[2]

The observation of elevated concentrations of chemically active inorganic aluminum in surface waters has provided strong evidence of soil responses to acidic deposition.[3] Recent studies have shown that deposited material has changed the chemical composition of soils by (1) depleting the availability of cations required by plants in large quantities (calcium, magnesium, potassium), (2) increasing the mobility and chemical activity of aluminum and manganese, and (3) increasing sulfur and nitrogen content. Acidic deposition has increased the concentrations of hydrogen ions and strongly acidic anions (sulfate and nitrate) in the soils of the northeastern United States, which has led to increased rates of leaching of base cations and to the associated acidification of soils.[4] Where the supply of base cations is sufficient, the acidity of the soil water is effectively neutralized. However, where base saturation (exchangeable base cation concentration expressed as a percentage of total cation exchange capacity) is below 20%, atmospheric deposition of strong acids results in the mobilization and leaching of aluminum, and hydrogen ion neutralization is incomplete.[5] About 30% of the soils in Pennsylvania have been classified as sensitive to acidification; these are found primarily in the northern-tier counties, portions of the Ridge and Valley physiographic province, and the extreme southeastern portion of the state.[6] One study, which attempted to duplicate the methods used in earlier studies of northern Pennsylvania sites in order to evaluate change over time, determined that there has been a decrease in base cation concentrations in some soils over the past 20 to 40 years.[7] Attempts to use tree-ring chemistry to evaluate long-term environmental change have been only partially successful. This is because most tree species do not sequester ions solely in the current annual ring; only Japanese larch and, to a limited extent, black cherry have so far shown promise of preserving a chronological record of past soil changes in annual growth rings.[8]

The mechanisms by which acidic deposition can cause stress to trees are only partially understood, but they generally involve interference with calcium and magnesium nutrition and the physiological processes that depend on these elements. The depletion of calcium and magnesium in forest soils raises questions about the health and productivity of northeastern forests, particularly for those containing high base cation-demanding species. Progress on understanding the effects of acidic deposition on trees has been limited by the long response time of trees to environmental stresses, the difficulty in isolating possible effects of acidic deposition from other natural and anthropogenic stresses, and the insufficiency of information on how acidic deposition has changed soils.

To date, investigation of the possible effects of acidic deposition on trees in the Northeast has focused almost exclusively on red spruce and sugar maple. There is evidence that acidic deposition causes dieback of red spruce by decreasing cold tolerance.[9] Where it is an important forest-canopy component in northeastern Pennsylvania, red spruce so far appears to be unaffected, at least superficially,[10] although none of the relevant research has been conducted in the state. Acidic deposition may contribute to episodic dieback of sugar maple by causing depletion of nutrient cations from soils where cation concentrations are already low because of the type of bedrock (parent material) from which the soil is derived. An experimental addition of dolomitic limestone to base-cation-poor soils in north-central Pennsylvania increased calcium and magnesium cation concentration in the soil, decreased the availability of aluminum and manganese, and resulted in significant increases in sugar maple survival, crown vigor, diameter and basal-area growth, and flower and seed production compared with untreated trees.[11] Moreover, strong links have been found between low foliar magnesium, high foliar manganese, insect defoliation stress, and dieback of sugar maple in northwestern and north-central Pennsylvania and southwestern New York.[12]

A dispute has arisen in Pennsylvania over the relative importance of acid rain and deer overbrowsing in altering forests. Disputes of this type about forest dynamics can easily be accommodated within the framework of A.R.M. (see Chapter 2). We return to this issue later in this chapter in the section titled "Impacts of deer and other factors on forest ecosystems — accommodating different views."

Fire suppression in oak-dominated forests

In the cool, moist northern hardwood areas of the Northeast and Great Lakes states, including northern Pennsylvania, fires have historically been infrequent. Wind was the most important disturbance factor.[13] However, in warmer, drier areas occupied by oak forests, including most of the southern two-thirds of Pennsylvania, surface fires occurred relatively frequently, even before the arrival of European settlers.[14] The association of fire with the successful regeneration of oaks has been known for many years. The advent of fire suppression programs in the 1930s and 1940s coincided with the beginning of widespread oak regeneration problems.

Oaks have a different pattern of growth than most of the species with which they compete. Seedlings of northern red oak and white oak, for example, divert most photosynthetic production into root growth at the expense of shoot development.[15] Competitors, including maples, yellow-poplar, birches, and black cherry, favor early shoot growth and relatively little root growth. Over time, these species develop a significant height advantage over the oaks, steadily increasing in both size and number until a multi-storied layer of vegetation develops, including a nearly continuous subcanopy.[16] The added layers of foliage beneath the overstory intercept so much light that often less than 1% of full sunlight reaches the seedling layer, resulting in a negative carbon balance (i.e., metabolism outpaces photosynthesis) for oak seedlings growing under a heavy canopy.[17] In deep shade, oak seedlings often die once acorn reserves are exhausted and, among the survivors, a vigorous root system fails to develop.[18] Even vigorous, nursery-grown northern red oak seedlings survive poorly when planted in mature undisturbed forests on mesic sites (those with moist, loamy soils) and dry-mesic sites. Thus, the presence of a dense understory of competitors often is sufficient to prevent the development of vigorous oak advance regeneration whether or not other limiting factors are present. By contrast, on xeric sites (those with dry, sandy or rocky soils), conditions usually are less hospitable for oak competitors and oak seedlings may persist for 30 to 50 years, developing a strong root system and often a tall shoot.[19] Development of vigorous oak seedlings on mesic sites is feasible, but it has been demonstrated only in cases where understory vegetation has been removed before or at the time of overstory harvest.[20] The bottleneck in developing successful oak regeneration appears to be the need for a low-competition environment in which oak seedlings can develop.

On mesic sites, which include a majority of Pennsylvania forestlands, the presence of frequent surface fires is a key factor promoting oak regeneration.[21] Most oak species have biological traits that suggest adaptation to periodic fire. These include the positioning of resprout buds below the ground surface at the root collar and thick, insulating bark. Such traits protect oaks against fire and allow them to survive even late spring or early summer burns, which are typically high in intensity.[22] In addition, the large oak root with its ample carbohydrate reserves can resprout multiple times. While some oak competitors also can resprout after fire, the rate of resprouting for oaks is higher than that of their more fire-sensitive competitors.[23] Fire has additional benefits for oaks and other nut trees, including hickories: it discourages insect predators of acorns, nuts, and seedlings; exposes the humus or mineral soil layers to drying, which does more harm to seedlings with less-robust root systems than oaks and hickories; improves germination conditions by consuming leaf litter and other forest floor organic matter; and kills seedlings of most other tree species, whose resprouting buds are at or just above the ground surface, allowing oaks to dominate the advance regeneration pool.[24] Thus, where fires occur repeatedly, oaks tend to increase in dominance over competitors.

Recently, the combination of shelterwood cutting to increase light followed in a few years by burning to reduce fire-sensitive oak competitors has been tested and found effective for regenerating oaks.[25] Early results of trials in Pennsylvania appear promising (but only where fencing has been erected to exclude deer).[26]

Silviculture and unsustainable tree harvesting

Impacts of logging on forest understory plant species diversity

There have been surprisingly few studies of the impacts of silviculture and of timber harvesting in general on species diversity in eastern North American forests. Most studies have been relatively short-term in nature (< 20 years). All longer-term studies have taken the chronosequence approach, that is, surveying multiple forest stands of a range of known ages since logging to infer the changes that a single stand might undergo over time. Stands to be compared must be in close proximity to one another, of the same forest type, and with similar soils, slope, aspect, hydrology, and other factors that may influence species composition and the pace of recovery. An experimental approach to questions about logging impacts on diversity is preferable,[27] but because of the great longevity and slow response times of trees, shrubs, and many forest understory herbaceous plants, determining long-term effects would take many decades. A potential pitfall of the chronosequence method is that the observer exerts no control over treatments. As a result, different logging practices or other unknown factors coincidentally confounded with age since logging may lead to a false inference that age caused the differences, or they may obscure the effect of age since logging, resulting in the failure to find differences actually caused by age. Another limitation is shared with most large-scale ecological studies whether they are experimental or observational; the sample size is usually small, which means only large differences can be verified as statistically significant.

A chronosequence study in the southern Appalachians focused on cover and species richness in herbaceous understories of nine old-growth forest stands and nine comparable tracts that had been clearcut 45 to 87 years earlier.[28] The previously logged stands had less herbaceous species diversity compared to nearby uncut stands. Similar results emerged from a study of clearcut, selectively cut, and uncut forest stands in North Carolina.[29] According to a later review,[30] "because of methodological problems, the accuracy of the results have been questioned.[31] Replies to these criticisms[32] and further work[33] by these authors failed to resolve the problems." However, publication of this work did serve to heighten efforts to evaluate the effects of forest management activities on the forest herb layer.

By contrast, a study of four watersheds in the Allegheny Mountains of West Virginia[34] showed little variation in herbaceous species composition or diversity[35] in the herbaceous layers of sites 22 years after clearcutting compared to sites where selective logging had occurred 70 or more years earlier. However, data on the composition of the herbaceous layer (important species were reported as wood nettle, violets, greenbrier, blackberry, seedlings of striped maple and black cherry, and several ferns) make it clear that the forests they worked in were severely depauperate at the ground level, most likely as a result of overbrowsing by deer. In yet another chronosequence study, little difference was found in the spring and summer herbaceous flora of nine forest stands in northern Georgia,[36] encompassing three sites in each of three age categories: 15, 25, and 50 years after clearcutting; no old growth stands were included for comparison. All stands were cove forests with a total of 69 herbaceous species recorded.

In northern hardwood stands in New Hampshire, a team of investigators compared the herbaceous species composition of three 25-year-old clearcuts, three 60-year-old clearcuts, and old (ca. 90 to 120 years) secondary stands adjacent to each former clearcut.[37] Based on differences in abundance between the 25-year-old clearcuts and adjacent old forest stands, they classified species as *insensitive* (7 species showing little difference between clearcuts and adjacent uncut forest); *sensitive* (6 species with lower densities in clearcuts than adjacent uncut forest); *enhanced* (4 species with greater densities in clearcuts than adjacent uncut forest); and *edge-enhanced* (6 species with greatest densities near clearcut edges, decreasing with distance into the clearcut). Interestingly, species found to be sensitive to clearcutting also are sensitive to deer browsing (blue-bead lily, Canada mayflower, Indian cucumber-root, shining clubmoss, rose mandarin, and painted trillium) and clearcut-enhanced species included those that are most deer-resistant (hay-scented fern, New York fern, and sedges). Species in the other categories also were mostly plants sensitive to browsing.

In a comparative study of forested ravines along the lower Susquehanna River in Pennsylvania,[38] sites with successional or highly fragmented forests were missing herbaceous species that were present in older, less-disturbed stands. Herbaceous forest species such as declined trillium and squirrel-corn were notably absent from younger stands even when a closed canopy was present.

While none of the studies cited above are definitive or even directly comparable, they raise questions that require more study. Chronosequence studies in the southern Appalachians suggest that large white trillium, purple trillium, Dutchman's-breeches, dwarf ginseng, Fraser's sedge, black snakeroot, blue cohosh, and hepatica (all species native to Pennsylvania) are slow to recover after logging and members of the lily (Liliaceae), orchid (Orchidaceae), and fumitory (Fumariaceae) families are especially vulnerable to disturbance.[39] A survey of parks and conservation areas throughout the United States documenting instances of deer damage to herbaceous plants found greater sensitivity to browsing, as well, among plants in the lily and orchid families.[40]

Clearly, the relationships among understory plant diversity, anthropogenic disturbances such as logging, and overbrowsing by densely populated deer are not well understood and have only recently begun to be explored in detail.[41]

Impacts of non-sustainable harvesting on forest tree species diversity

Beginning in the 1970s, harvesting became the most widespread disturbance affecting second-generation deciduous forests in Pennsylvania and other Eastern states.[42] On public land, sustainable harvesting — in the form of silvicultural treatments aimed at changing stand development and species composition — usually results in stand regeneration by tree species of commercial value. However, sustainable harvesting frequently is not being practiced on private land,[43] which comprises about 70% of Pennsylvania's forestland ownership.[44] Non-sustainable harvesting practices consist of high-grading, that is, removing all trees with significant commercial value in a single cut without regard for regeneration and future stand condition; trees with little or no commercial value are left standing. One of the most common practices is diameter-limit cutting, in which all canopy trees greater than a certain diameter are removed.[45] Because the smaller trees in a stand are mainly shade-tolerant species, diameter-limit cuts typically are species removals that disproportionately extract the shade-intolerant species while failing to provide conditions suitable for their regeneration.[46]

The accelerated rate of non-sustainable harvesting of second-growth forests on non-industrial private land has concerned scientists and managers in Pennsylvania and nearby states. A series of surveys conducted in response to these concerns unanimously confirmed that diameter-limit harvesting was practiced on the majority of ownerships.[47]

The detrimental effects of diameter-limit harvesting are exacerbated where deer populations are dense. The remaining trees after high-grading typically include species that deer do not prefer or that are resilient to repeated browsing such as striped maple and American beech. With sustained overbrowsing they form a dense understory (along with hay-scented fern and New York fern) that shades the forest floor and hinders the regeneration of trees and most shrubs and herbaceous plants, even if later released from overbrowsing. Because striped maple is a short-lived (about 40 years) understory tree and American beech is currently undergoing an epidemic of beech bark disease, the interaction of diameter-limit cutting and deer overbrowsing may be placing the future forests of Pennsylvania in jeopardy. The development of third-generation forests in the eastern United States almost certainly will deviate from established post-disturbance forest development models.[48] The unprecedented combination of overbrowsing by deer and targeted removal of high-value species that prevails today precludes any definitive predictions of future stand composition.

Introduced pests

Most outbreaks of insect herbivores or diseases in Pennsylvania's forests involve organisms inadvertently introduced to North America from Eurasia. In many cases, the natural enemies of these organisms are absent in their new home and populations of native plants have not had time to develop resistance. In some cases, such outbreaks have caused catastrophic mortality of important species, the most notable example being chestnut blight, a Eurasian fungus that reduced what may have been Pennsylvania's most abundant forest tree, American chestnut, to a sickly understory species in less than a decade.

Insects

Insect infestations occasionally are severe enough to prevent the regeneration of individual tree species, but under most conditions they are just one among a myriad of factors reducing the number of seedlings that become established. Native insect herbivores that undergo outbreak population cycles such as elm spanworm, eastern tent caterpillar, and forest tent caterpillar generally do not cause heavy mortality or major shifts in species composition. The following species were unintentionally introduced.

Cherry scallopshell moth outbreaks occur at about 10-year intervals on the Allegheny Plateau.[49] Outbreaks usually last for 2 or 3 years, repeatedly defoliating large black cherry trees.

While primarily overstory trees are affected, seedlings sometimes are defoliated and killed and seed production may be diminished for several years after defoliation.

Pear thrips are sucking insects whose damage is usually confined to fruit orchards.[50] Since its positive identification in forest environments of the northeastern United States in 1980, pear thrips have occasionally caused damage to overstory trees and seedlings of several species. Wounds of sugar maple seedlings caused by pear thrips have become infected by maple anthracnose, which subsequently has caused seedling mortality.[51] Pear thrips and maple anthracnose do not necessarily occur in synchrony; it is not clear how often these agents are important to sugar maple seedling survival.

The hemlock wooly adelgid, a small insect related to aphids, has caused serious mortality of eastern hemlock trees in southeastern Pennsylvania since about 1995. Saplings and seedlings appear to be less susceptible than larger trees. Even in dense infestations, smaller trees are infested last, appear to recover more quickly, and exhibit lower rates of mortality. This is most apparent along edges where declining trees larger than about six inches in diameter are subtended by vigorous sapling thickets. Reduced seed production in infested areas probably constitutes the major impact on regeneration. Hemlock woolly adelgid infestation has moved slowly from the southeast towards the northwest in Pennsylvania and recently an outlier population appeared in Centre County.[52]

The gypsy moth has become a well-established defoliator of oaks and some other forest, shade, and fruit trees since its accidental introduction into Massachusetts from Europe in the late 1860s. Gypsy moth expansion was slowed by domestic quarantine for many years; the first heavy defoliations did not occur in Pennsylvania until 1969.[53] White oak and chestnut oak appear to be most susceptible.[54] Large numbers of trees (often exceeding 50% of the overstory, with greater percentages in understory trees) are killed when the insect first moves into an area. Subsequent defoliations are episodic with fewer trees killed.

Gypsy moth defoliation can affect the natural regeneration of oak-mixed hardwood stands in several ways.[55] Defoliation significantly reduces acorn production; individual oak trees respond by aborting undeveloped seeds and reducing flower crops in subsequent years.[56] Mortality of oak trees of seed-bearing size also reduces the production of acorns in the long term across entire stands. Defoliation of oak seedlings results in dieback and resprouting and increased mortality, stunting the development of a cohort of seedlings and rendering them less competitive when released from shade.[57] There is also increased interference from other plants, including disturbance opportunists (early-successional species) that respond quickly to the increased light and nutrients present in defoliated stands.[58] Species such as hay-scented fern that are unpalatable to deer increase in density in defoliated stands that are subjected to heavy deer browsing. The growth responses of shade-tolerant tree and shrub species present before defoliation and intolerant species that become established in areas of heavy mortality typically result in a change in species composition of tree seedlings to a mixture with fewer oaks and more red maple, sweet birch, and black cherry.[59] The mortality or reduced vigor of overstory oaks from defoliation results in reduced stump sprouting or none.[60] The net effect is that some oak-dominated stands regenerate to a mix of other tree species that are more resistant to gypsy moth defoliation.

Diseases

Only a few diseases have been identified as impediments to tree regeneration in Pennsylvania forests, all accidentally imported from Eurasia.

Beech bark disease complex, also known as beech scale-nectria canker, is an insect-fungus complex consisting of beech scale (a European insect) and either of two species of canker fungi in the genus *Nectria*, one introduced and one native.[61] Feeding holes made by the scale are colonized by the fungus, which kills cambial tissue (the living, growing, outer layer of wood). Over time, dead cambial patches coalesce, killing the tree. Weakened and dying trees produce abundant root suckers, which form thickets. Dense shade from the highly shade-tolerant beech root suckers interferes strongly with the growth of other plant species, including tree seedlings.

Cherry leaf spot fungus, also known as cherry shot hole fungus, can hamper the regeneration of black cherry.[62] Young seedlings up to about six inches tall are the most affected. Fungal spores are transmitted in rain splash, so the probability of infection is increased when seedlings are closely spaced. In dense stands of young, recently germinated seedlings, whole cohorts sometimes are killed.

Maple anthracnose is a late spring defoliator of sugar maple and red maple, particularly under cool, moist conditions.[63] Maple anthracnose is best known for infecting and killing overstory trees, but it also is active on small seedlings and may contribute to the loss of sugar maple regeneration.

Sudden oak death is a catastrophic disease of oaks caused by a fungus introduced from Eurasia that some experts believe may pose a grave threat to forests in eastern North America.[64] Sudden oak death was first identified in California in 1994. In addition to oaks, it has been found on western North American species of buckeye, maple, and members of the heath family (including rhododendrons, azaleas, blueberries, and huckleberries) but on these hosts the pathogen has not been lethal. Researchers at the University of California at Davis recently reported that seedlings of at least two oak species native in Pennsylvania, northern red oak and pin oak, developed stem cankers after inoculations with the sudden oak death fungus.[65] It is still not known whether mature trees of these or any other Eastern oaks are susceptible.

Presently, efforts are focused on preventing the spread of this pathogen. Quarantines on movement of plant parts of oaks and other host species have been instituted in California.

Restrictions on importing ornamental rhododendrons are still being debated. The ease of spread of this pathogen on shoes or car and bicycle tires means it will be difficult to contain. A recent jump in the range of the disease from California to southern Oregon in an area remote from development, roads, or trails is particularly alarming. Not enough is known about the pathogen to say whether it could survive and spread in Eastern forests. A recent, unpublished risk assessment of Eastern oak forests places the mixed oak forest in the southern two-thirds of Pennsylvania at moderate risk, should the disease arrive in the East.[66] Given the abundance of oaks in many of Pennsylvania's forests, the pathogen could be a serious threat in the future.

Climate change

Global warming also is a potentially severe threat to eastern North American forests. However, so little is known about the likely impacts at a regional scale that only speculative statements can be made about the effects of climate change on forests in Pennsylvania. Across all of eastern North America, forests are projected to "expand under the more moderate scenarios, but decline under more severe climate scenarios."[67] Shifts in species composition and abundance are forecast for particular regions in eastern North America[68] but we did not find any specific predictions in the literature for Pennsylvania. Migration of entire biomes is predicted, but the projected rates depend on uncertain parameters.[69] Forest fragmentation, which is severe across much of the East, is an impediment to migration. Some authors argue that migration will not be fast enough and some forests may be extirpated.[70] Increased fire frequency is predicted to result from an increase in the frequency and duration of droughts,[71] which could positively affect the regeneration of oaks.

Of particular interest are studies that consider herbivory. Some investigators predict climatic effects on some insect and mammalian herbivores and an array of ensuing impacts on biodiversity, outdoor recreation, property values, the wood products industry, and water quality.[72] In their scenario, warmer winter temperatures decrease the food requirements of deer, reducing their per capita impact on forest vegetation. However, because deer population size is governed by winter survival, their populations would most likely increase as a result of warmer winter temperatures, intensifying their collective impact on forests.

In sum, the current state of knowledge gives no reason to expect climate change to mitigate current adverse effects of deer nor to have an overall beneficial effect on the recovery of Pennsylvania's forest ecosystem structure and processes.

Impacts of deer and other factors on forest ecosystems — accommodating different views

The views of forest dynamics presented in the report are based on our review of the literature and thus represent a consensus scientific perspective. Minority or intermediate views are always possible in science. Theories on the effects of silviculture or acid rain can be incorporated into the A.R.M. program that we propose, as long as the proponents are willing to make quantitative predictions, complete with error estimates.

An alternative theory that could be tested as part of A.R.M. is the hypothesis that the effects of deer on forests in Pennsylvania are minor compared to the impacts of acid rain. William Sharpe and Joy Drohan at Penn State University have written, "The controlling factor in the extent of seedling damage is not deer browsing, but the degree of acidification stress and the susceptibility of the particular tree species in question to this stress. Regeneration plans that consider the elimination of only one stress, e.g., deer herbivory, will not successfully regenerate relatively acid-sensitive species such as sugar maple and northern red oak."[73]

If correct, such a view would imply that reductions in deer densities will not assist forests to recover under ordinary soil conditions. This theory goes beyond the null hypothesis discussed in Chapter 2 by predicting that recovery will be good where soil chemistry is favorable or lime is added in the "right" amounts. According to Sharpe and Drohan, "Because root systems on low calcium to aluminum ratio soils [acidic soils] cannot deliver enough nutrients to sustain new growth after deer browsing damage, browsed seedlings do not rapidly replace lost stems and in many cases may not survive this additional stress. In the absence of deer, damage from insects and drought may result in similar consequences."[74] It is a testable hypothesis and the proponents are enthusiastic about including it as part of an A.R.M. protocol.[75]

Another theory that could be tested in the proposed A.R.M. program considers both acid rain and deer as important. Under this theory, predictions about deer impacts would be modified according to soil fertility. According to Dr. David DeWalle at Penn State University, "Although deer browsing pressure is important, the innate fertility of the soil [e.g., acidity] hasn't been considered sufficiently in management thinking. It is important to consider the chemical as well as physical condition of the soil, because a significant percentage of soils in Pennsylvania are poorly buffered."[76]

Under this second theory, soil acidity might also be predicted to have its major impact on vegetation mortality and less impact than deer on regeneration failure. According to University of Göttingen botany professor Dr. Michael Runge, "forest decline always has two aspects: the dying of trees in the overstory and the failure of regeneration. In nearly all cases, the discussion of possible causes focuses on … soil acidification, defoliation, and especially with regard to regeneration failure, browsing by deer and competition by light and nutrients with a dense herbaceous vegetation, particularly the hay-scented fern. ... The negative effect of deer browsing is obvious and can be avoided only by reducing the deer population or by fencing."[77]

As we discuss in the next section, both of these alternate views on acid rain can be incorporated into one heuristic equation, where the dispute is channeled into determining values of a few coefficients. The same process could apply to a dispute about any other factor that influences forest dynamics.

Combining multiple stresses and responses into one equation

A useful way to think about the major theories — (1) deer overbrowsing, (2) other factors, and (3) deer-other factor interactions — is to think of both the stress on, and response of, a component of the forest ecosystem as a summation of four terms:

$$\textit{stress} = S_0 + A \times \textit{deer density} + B \times \textit{other factor level} + C \times \textit{deer density} \times \textit{other factor level} \qquad \text{Eq. 1}$$

where S_0 is the background stress, and A, B, and C are parameters. The last term, the interaction term, is a product of deer density and the level of a second factor, for example, acidic deposition or intensity of forest overstory thinning. The interaction term gets very large when both deer density and the level of the second factor are high.[78]

The actual measurable response of a forest tree, shrub, or herbaceous plant species to the above hypothetical combination of stresses would be some as yet undetermined function of Equation 1 over time. For some ranges of deer density and levels of another factor, the response would be linear. For instance, if deer overbrowsing and acidic deposition are taken as the factors of interest in forest degradation, the biomass of a particular plant species in a stand might be expressed as:

$$\textit{biomass} = B_0 - A_2 \times \textit{deer density} - B_2 \times \textit{acidity level} - C_2 \times \textit{deer density} \times \textit{acidity level} \qquad \text{Eq. 2}$$

In Equation 2, the deer-dominance theory is equivalent to the A-coefficients being much larger than all the others; the acid-rain dominance theory says that the B-coefficients are larger,[79] and the interaction theory says that the C-coefficients are larger.[80]

In some areas of Pennsylvania and for some species it may be possible to show, based on the results of exclosure or enclosure studies and other data, that one or more of the coefficients is near enough to zero that it can be omitted. On the other hand, data might show that all three coefficients are large enough to play an important role in some areas and for some species. The advantage of thinking of ecosystem stresses and responses in this way is that it keeps us from excluding the middle ground. All three theories might have some corner of the truth and be useful in some parts of the state and for some species.

Note that only in the case where the B-coefficients dominate can one discount the effect of deer as an ecosystem stress. Both the deer-dominance theory and the interaction theory predict deer impacts. If the interaction theory is correct, then control of deer is even more urgent in those areas where acid rain may have increased soil acidity.

Findings on other factors affecting forest recovery

(1) Forest recovery in Pennsylvania's remaining large forest blocks is affected by a variety of factors deliberately or inadvertently influenced by human activity. These include deer overbrowsing, acidic deposition from air pollution, logging practices, outbreaks of introduced insects and diseases, the incidence and severity of fire, and climate change. The most important of these is deer browsing. Fire often is required for the release of oak seedlings from competitors.

(2) Pennsylvania receives relatively high levels of acidic deposition. Over time, acidic deposition has decreased soil pH, accelerated losses from soil of the base cations calcium, magnesium, and potassium, and increased the mobilization of chemically active aluminum and manganese. Present evidence shows that one high-base-cation-demanding tree species, sugar maple, responds positively to lime application. There is evidence that some moderate- and low-base-cation-demanding species do not respond to liming.

(3) Non-sustainable timber harvesting methods (such as diameter-limit cutting), which do not ensure the reestablishment of a diverse forest, are in widespread use in Pennsylvania, particularly on forestlands in non-industrial private ownership. Non-sustainable harvesting interacts with deer browsing in ways that severely endanger the long-term health and productivity of Pennsylvania's forests.

(4) The impact of climate change as a result of global warming is uncertain. Research on the topic that pertains specifically to Pennsylvania so far is almost nonexistent.

Recommendations on factors affecting forest recovery

(1) Deer management should focus on managing the ecosystems of which deer are a part. Deer densities in Pennsylvania's major forested areas should be brought down to levels that will allow the restoration of full forest structure, diversity, ecological processes, and ecosystem function.

(2) Serious efforts should be made by Pennsylvania officials to further limit nitrate and sulfate emissions that affect Pennsylvania forests. The role of acidic deposition on forest health and growth should receive increased study.

(3) There should be an increased effort to educate non-industrial private landowners concerning the negative impacts of non-sustainable harvesting methods on the future health and productivity of their own lands and all of Pennsylvania's forestlands. Governmental bodies should take steps to curtail the use of non-sustainable harvesting methods on public lands.

Endnotes

[1] Driscoll et al. 2001

[2] Charles 1991

[3] Driscoll et al. 1980; Cronan and Schofield 1990

[4] Driscoll et al. 2001

[5] Cronan and Schofield 1990

[6] Levine and Ciolkosz 1988

[7] Drohan and Sharpe 1997

[8] DeWalle et al. 1999a, 1999b

[9] Craig and Friedland 1991; Shortle et al. 1997

[10] R. E. Latham, personal observation

[11] Long et al. 1997

[12] Horsley et al. 2000; Drohan et al. 2002

[13] Marquis 1975

[14] Tome 1854; Abrams 1992; Lorimer 1993; Brose et al. 2001

[15] Crow 1988; Dickson 1991

[16] Lorimer 1984

[17] Hanson 1986; Pubanz and Lorimer 1992

[18] Crow 1988

[19] Liming and Johnson 1944; Sander 1972

[20] Johnson and Jacobs 1981; Johnson et al. 1989; Lorimer 1989; Loftis 1990; Nowacki et al. 1990

[21] Nowacki et al. 1990; Lorimer 1993; Brose et al. 2001

[22] Brose and Van Lear 2004

[23] Lorimer 1993

[24] Van Lear and Watt 1993

[25] Brose and Van Lear 1998; Brose et al. 1999; Lanham et al. 2002

[26] Deer Management Forum, personal observation (see Appendix C)

[27] E.g., Hughes and Fahey 1991

[28] Duffy and Meier 1992

[29] Meier et al. 1995

[30] Gilliam and Roberts 2003

[31] Elliott and Loftis 1993; Johnson et al. 1993

[32] Duffy 1993a, 1993b; Bratton 1994

[33] Meier et al. 1995

[34] Gilliam et al. 1995

[35] The study used the Shannon-Wiener index of diversity, which increases both with species richness and with evenness among the species in the number of individuals present.

[36] Ford et al. 2000

[37] Ruben et al. 1999

Endnotes

[38] Bratton et al. 1994

[39] Bratton and Meier 1998

[40] Miller et al. 1992

[41] Gilliam and Roberts 2003

[42] Nyland 1992

[43] Fajvan et al. 1998

[44] Birch 1996

[45] Nyland 1992; Fajvan et al. 1998

[46] Smith and Miller 1987; Niese and Strong 1992; Heiligmann and Ward 1993

[47] Dr. James C. Finley and Josh Pell, School of Forest Resources, Pennsylvania State University, University Park, unpublished data on 1997 Pennsylvania timber harvest assessment; Fajvan et al. 1998; Dr. Ralph D. Nyland, College of Environmental Science and Forestry, State University of New York, Syracuse, unpublished data on 1999 New York timber harvest assessment

[48] E.g., Bormann and Likens 1979; Oliver and Larson 1996

[49] Bonstedt 1985

[50] Hebert 1992; Kolb et al. 1992

[51] Stanosz 1992, 1993, 1994

[52] Dr. E. Michael Blumenthal, Chief, Forest Health Section, and Dr. Thomas J. Hall, Forest Pathologist, Division of Forest Pest Management, Bureau of Forestry, Pennsylvania Department of Conservation and Natural Resources, personal communication, 2003

[53] McManus and McIntyre 1981

[54] Leonard 1981

[55] Gottschalk 1988, 1990

[56] Gottschalk 1990

[57] Allen and Bowersox 1989; Campbell 1981

[58] Collins 1961; Ehrenfeld 1980

[59] Hix et al. 1991

[60] Musika and Twery 1995

[61] Houston 1994; Morin et al. 2001

[62] Hough 1965

[63] Stanosz 1992, 1993, 1994; Hall et al. 1999

[64] Rizzo et al. 2002

[65] Rizzo et al. 2002

[66] Dr. Kurt W. Gottschalk, Research Forester/Project Leader, Northeastern Research Station, U.S. Forest Service, Morgantown, West Virginia, personal communication, 2002

[67] Bachelet et al. 2001

[68] He et al. 2002

[69] Malcolm et al. 2002

[70] Kirilenko et al. 2000

Endnotes

[71] He et al. 2002; Ayres and Lombardero 2000

[72] Ayres and Lombardero 2000

[73] Sharpe and Drohan 1999: p. 200

[74] Sharpe and Drohan 1999: p. 200

[75] Dr. William E. Sharpe, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, personal communication, 2002

[76] Dr. David R. DeWalle, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, personal communication, 2002

[77] Runge 1999: p. 144

[78] If the interaction term is very large, then the coefficient C must be positive. If, on the other hand, the interaction term is less than the sum of the other two terms, then C could be negative, indicating a saturation effect.

[79] Actually, based on the discussion of the acid-rain-dominance theory, there is an allowance for an interaction term as well.

[80] This equation is meant to be illustrative. From a statistical research perspective, one might add terms involving the square of deer density and the square of the acidity level to account for possible nonlinear effects. One might also add terms involving a third measurable stressor, e.g., tree-harvest intensity.

Chapter 7. Recovery of Pennsylvania's Forest Ecosystems from Deer Overbrowsing

A forest is more than trees

Trees are certainly the most conspicuous part of the web of life that comprises a forest ecosystem. But, whereas trees may dominate the structure of a forest, they are intricately linked to the many other living and non-living components. All green plants, from canopy trees to the diminutive mosses on the forest floor, contribute to total primary productivity through photosynthesis, the means by which energy enters the system.

Mycorrhizal fungi, which live on the roots of most plants and have a mutually beneficial relationship with their hosts, increase the uptake of mineral nutrients and water by trees. Squirrels "plant" the seeds of oak, beech, and hickory trees when they cache the nuts and fail to return.[1] Birds are also important in distributing seeds of many species.

Trees such as yellow-poplar, cucumbertree, and flowering dogwood are dependent on insects to pollinate their flowers. Uncounted species of invertebrates, fungi, and bacteria help to decompose organic matter that accumulates on the forest floor, building soil and releasing minerals for recycling. Insects that are predators or parasites of plant-eating insects also contribute to the balance of productivity and herbivory in forests. The adult form of many insect parasitoids, which as larvae help keep populations of destructive insects in check, feed on nectar and pollen produced mainly by herbaceous plants.

Birds feed on insects, helping to keep leaf damage to a minimum and thereby stimulating the growth of trees.[2] Some birds, such as ovenbirds and eastern towhees, nest and feed in the ground layer. Reduced cover in this forest stratum increases nest predation and decreases the ability of birds to raise their young successfully.[3] Other species, such as eastern wood-pewee, indigo bunting, and black-and-white warbler, which use the intermediate layers of the forest, have declined in heavily browsed forests.[4]

All the layers of the forest intercept rainfall, reducing erosion and facilitating percolation and groundwater recharge. Herbaceous plants on the forest floor help to hold soil in place, further reducing erosion. Erosion leads to losses of soil and nutrients from the ecosystem. Herbaceous plants also shade the soil surface, moderating temperature and moisture levels and creating microhabitat for seed germination.

Soil invertebrates, fungi, and microorganisms are also vital links in many food "chains" that make up the forest ecosystem's trophic web. As decomposers of organic debris, they control the accumulation of wastes and recycle minerals. Shifts in species composition in the above-ground vegetation affect the subterranean community by altering the nutrient content as well as the speed at which litter is broken down and thus the thickness of litter and humus accumulation.[5] These in turn affect seed-bed properties, erosion rates, and soil chemistry, including pH.

Each layer of the forest, from the canopy to the soil, provides habitat for a group of specialized plants, animals, and micro-organisms. Canopy trees link it all together, starting as seeds deposited on the forest floor, becoming seedlings in the herbaceous layer, growing into the shrub and subcanopy layers, and eventually reaching the canopy.

Overbrowsing by deer has been shown to impact tree, shrub, herbaceous, bird, and small mammal components of the forest ecosystem and cause major changes in forest structure (see Chapter 5). Although ecosystem function is harder to measure, browsing-caused changes to mineral recycling have also been documented.[6]

Values, forest integrity, and management goals

It is the value judgment of Forum members that the greatest overall benefit to the widest range of stakeholders would be served by restoring forest structure, diversity, ecological processes, and ecosystem function to a state similar to the conditions that prevailed in the relatively recent past. This is the “philosophical” basis for the management goals we outline in this report. The preponderance of scientific opinion attests that the current high densities of white-tailed deer have had highly detrimental effects on forests in Pennsylvania and much of the eastern United States. Moreover, until deer populations are reduced and maintained at lower levels, it will not be possible to restore key elements of forest health. For each of these elements, management goals include (but are not limited to):

(1) **Structure**

- bringing back the missing or impoverished subcanopy, shrub and herbaceous layers
- making it possible for tree seedlings and saplings to establish, survive, and eventually replace dead and fallen canopy trees
- reestablishing habitat for birds, mammals, and other wildlife that depend on the subcanopy, shrub, and herbaceous layers
- recovering levels of forest-floor moisture, humidity, and coarse woody debris that are beneficial to salamanders, frogs, and many other animals dependent on moist, protected environments

(2) **Diversity**

- preventing losses of entire populations of native species, particularly of plants favored as food by deer

(Box continued on next page.)

Prospects for recovery of forest ecosystems

The choice of bringing back the forest understory and ensuring the continuation of a rich overstory layer into the future is not a scientific choice but a values choice (see box above). In our judgment, the greatest overall benefit to the widest range of stakeholders would be served by restoring forest structure, diversity, ecological processes, and ecosystem function to a state similar to the conditions that prevailed in the relatively recent past.

(Box continued from previous page.)

- bringing species that are imperiled by vegetation overbrowsing back from the brink of disappearing
- preserving genetic diversity within individual species, which is essential for them to adjust and survive in the face of changing conditions, by fostering robust, rather than marginal, population numbers
- sustaining the full variety of indigenous forest types

(3) **Ecological processes**

- reestablishing seed sources and replenishing the seed bank
- curtailment of competitive exclusion of seedlings by the few plant species that have proliferated because they are unpalatable to deer or resilient to overbrowsing
- cutting back competition by deer for acorns and nuts that other wildlife species depend on for food, including, indirectly, the predators that feed on mast-consuming animals
- restoration of plant species required by animals whose food or habitat requirements are narrowly specialized
- abatement of probable indirect effects of high deer density, such as heightened severity of gypsy moth outbreaks and Lyme disease infection rates

(4) ***Ecosystem function***

- rebuilding "ecosystem services" adversely affected by vegetation losses, including erosion control, soil development, sediment retention, nutrient assimilation, habitat for other wildlife species, and opportunities for nature appreciation, education, and research

It is not clear how quickly restoration of full forest structure, species diversity, and function can be achieved once deer numbers are reduced to appropriate levels; it certainly will not happen quickly. Nor is it clear how low deer numbers will need to be to achieve recovery of the forest ecosystem. Results of the 10-year enclosure study carried out by the U.S. Forest Service's North-eastern Research Station at Irvine, Pennsylvania, indicated that trees, brambles, and birds exhibited statistically significant increases in either abundance or diversity in reduced-deer-density plots after 10 years.[7] One study in Pennsylvania addressed recovery rate of witch-hazel in fenced exclosures.[8] Another study carried out in West Virginia tracked the recovery of two populations of showy lady's-slipper after exclosures were erected. At one site where deer had removed major portions from 65% to 95% of the stems over 3 years, recovery of pre-herbivory stem heights took 9 to 10 years and recovery of flower production and leaf area required 11 to 12 years. However, even then the number of stems was only 28.5% of the pre-herbivory population size. At the second site where deer had grazed 9% to 46% of the stems over 3 years, flowering ceased for one year and pre-herbivory mean stem height, leaf area, and flower production were restored after only 2 years.[9]

A more-detailed study of the recovery of over-grazed woodlands in Britain involved fenced plots maintained as grazed (one fallow deer per 2.5 acres) and ungrazed (zero deer) treatments.[10] Vegetation in the plots was measured at 6, 14, and 22 years. By 6 years after the fences were installed, there were clear differences between the treatments; in the ungrazed plot the browse line had nearly disappeared and a dense layer of *Rubus* had developed. The ground-layer vegetation in the grazed plot and surrounding forest continued to be dominated by bracken fern, grasses, and sedges. The density and diversity of the lower layer of the forest in the deer-free plot decreased by the later measuring periods as a result of shading by the vigorous layer of tree seedlings and saplings that developed in the absence of grazing. Increases in the species diversity of small mammals and selected invertebrates were detected in the ungrazed plot 20 years after initiation of the study.

The length of time that a forest has been subjected to overbrowsing and the extent to which a dense layer of unpalatable vegetation has developed are major variables that will influence recovery time. Such "legacy effects" of overbrowsing also include declining seed availability and reduced root-sprouting potential. There has been little or no research on certain key biological issues such as how long various native plant species persist as live roots in the face of long-term chronic browsing or how likely such root sprouts are to succeed, if even deer densities were to decrease, especially at the low light levels of closed-canopy stands. Most research related to factors that affect the ecological succession of forest trees has focused on species and forest types of interest to the wood products industry (see Chapters 5 and 6). Thus, to make predictions of the recovery of biological diversity and ecosystem processes, it is fruitful in some cases to draw analogies from the silvicultural research. For example, it has been shown repeatedly that, where a tree seed source remains (adult trees and the soil seed bank), treatments such as fencing deer out to allow tree seedlings to grow above the browse line or herbicide treatment to remove competing ferns can hasten the regeneration of canopy trees.

However, fencing for 6 to 7 years, as is the current practice, does not provide long-term protection for vegetation in the lower levels of the forest. For plants that never outgrow the reach of deer, a more permanent solution to reducing deer impact is required to effect ecosystem recovery. Highly preferred shrub and herbaceous species may require extremely low deer numbers to recover their former levels of diversity and abundance. In a collaborative paper outlining a strategy for restoring old-growth forests in Pennsylvania, foresters from The Nature Conservancy and the Pennsylvania Department of Conservation and Natural Resources cite deer overabundance as one of the problems that will have to be overcome.[11] With the exception of the two studies cited above, little research is available that directly addresses the recovery of forest understory species from overbrowsing. However, research on the recovery of herbaceous components of the forest after natural disturbances or logging suggests that it can be a long, slow process (reviewed in Chapter 6 under "Impacts of logging on forest understory plant species diversity").

Slow growth rates and loss of propagules limit recovery potential

A major impediment to the recovery of the lower layers of the forest is a lack of propagules (seeds, spores, and vegetative reproductive structures such as bulblets). In areas such as northwestern Pennsylvania where overbrowsing has been a factor since the 1920s,[12] there may be few local sources of propagules remaining. Furthermore, most forest herbs do not have long-distance dispersal mechanisms.[13] In one study, at least half of 26 forest herb species investigated in eastern North America relied on vegetative reproduction and only 9 were confirmed to reproduce primarily by seed.[14] The study noted that many deciduous forest herbs lack any specialized seed dispersal mechanisms; many seeds land where the senescing stem falls. Another investigation of seed dispersal adaptations of herbaceous plants in West Virginia forests showed that ant-dispersed species constituted 30% of the herbaceous flora and included some of the most common forest herbs such as spring-beauty, wild-ginger, sharp-lobed hepatica, twinleaf, bloodroot, large white trillium, and perfoliate-leaved bellwort.[15] These species also are all members of Pennsylvania's forest flora.

Slow growth rates

Most forest-floor plants that spread primarily by vegetative means do so through the growth of horizontal underground stems (rhizomes), often at rates that are slow enough to severely limit their recovery potential. A study of the structure and rate of growth of the rhizomes of 412 species of forest herbs and dwarf shrubs in the New Brunswick-Nova Scotia border region revealed that annual growth increments ranged from barely detectable to more than 3 feet.[16] Measurements of rhizome elongation in 11 species of forest herbs in the central and southern Appalachians showed annual rates ranging from 0.06 inch in large white trillium to 3.25 inches in may-apple.[17]

Reduced seed production

In addition to limited seed dispersal mechanisms, rates of seed production are often affected in deer-impacted forests. In one study the forest herbs jack-in-the-pulpit, showy orchis, Solomon's-seal, and bellwort were found to have higher rates of seed production when protected from browsing pressure in exclosures[18] because deer often selectively remove the flowering or fruiting stem even when they do not destroy the entire plant. Reduced sexual reproduction in browsed plants has also been documented in studies of large white trillium,[19] American yew,[20] glade spurge,[21] and Canada mayflower,[22] and has been observed in yellow fringed-orchid, hobblebush, and nodding trillium.[23]

Propagule dispersal from refugia

Local refugia may be an important source of propagules to initiate the recovery of forest-floor species. Boulder tops, cliffs, rock outcrops, and other inaccessible areas such as boulder fields support small patches of plants out of the reach of deer and serve as islands of diversity in an otherwise depleted landscape.[24]

Seed production and dispersal by canopy trees

Propagules come from a variety of sources, including new seed dispersed from overstory trees, seed lying dormant in the forest floor, root suckers, and stump sprouts. Periodicity of seed production by overstory trees varies greatly among species.[25] Sugar maple has good seed crops at 7 to 8-year intervals in the unglaciated northern Allegheny Plateau region of Pennsylvania, compared with 2 to 3-year intervals in New England and the Great Lakes states. Seed supply can be an important barrier to sugar maple regeneration. Yellow-poplar has good seed crops almost annually, but seed viability is seldom more than 5%. American beech has a good seed crop about 1 year in 6, white ash at intervals of 5 or more years, sweet birch and yellow birch at 1 to 3-year intervals, black cherry and red maple at 2 to 3-year intervals, eastern hemlock at 1 to 2-year intervals,[26] and eastern white pine[27] and oaks at 3 to 5-year intervals. However, bumper crops of acorns (called mast years) occur irregularly and may be as infrequent as 10 years apart. It is commonly believed that significant quantities of oak seedlings originate only in mast years, when quantities in excess of those consumed by mammal and insect predators are produced.[28] These seedlings are generally from acorns cached but not retrieved by small mammals. Hickories have good seed crops at 1 to 3-year intervals and are influenced by the same factors as oaks.[29]

Losses to seed predation

Seeds are an important dietary component of various species of mammals, birds, and insects living in Pennsylvania's forests. A large fraction of many plant species' seed production is regularly lost to predation. In fact, seed predation is thought to be the agent of selection that resulted in episodic, synchronous masting by oaks and certain other species.[30] By interspersing several years of low production between each bumper crop, the trees keep populations of animals that specialize on acorns relatively low.

The majority of tests of the effects of seed and seedling predation have been conducted in old fields.[31] These studies show that small mammals have distinct preferences in food choice[32] and predation risk often rises with increased seed size.[33]

Among forest plant seeds, oak acorn predation has been well studied because of the importance of acorns as food for a variety of small mammals, deer, turkeys and other birds.[34] Losses of 90% of a year's seed crop to insects and other animals is typical.[35] Such evidence suggests that destruction of acorns by animals potentially can be a limiting factor for regeneration of oaks in some locations.[36] However, several animal species also benefit the trees in their role as scatter-hoarders. By burying acorns in well-distributed caches, small mammals and blue jays facilitate seed germination.[37] A review of many studies over a large geographic area suggested that a lack of oak seedlings might occur locally in some years, but the lack of seedlings was not the most important factor limiting oak regeneration in a more global sense.[38]

Acorn-infesting insects are the most important and most studied group of pests affecting oak regeneration.[39] One or more of the 22 acorn weevil species in the genus *Curculio* recorded in the United States[40] affects virtually all of Pennsylvania's oak species. Larvae hatching from eggs laid in niches beneath the shell may consume most of the nut within a few weeks. Embryos in infested acorns that escape damage may germinate, but seedlings grow slower than those from uninfested acorns.[41] The rate of infestation is variable, but has exceeded 90% in some northern red oak collections.[42] Infestation rates of filbertworm are much lower than acorn weevils, but filbertworms have been responsible for large losses in low-production years;[43] damage is caused by larval feeding and is usually lethal to infested acorns. The pip gall wasp and stony gall wasp also infest and kill intact acorns.[44] Damaged acorns also may be invaded by other insects; the best known with this mode of action are *Conotrachelus* acorn weevils and the acorn moth.[45] These insects attack otherwise healthy germinating acorns.

Seed banks

Seeds that drop to the forest floor and become buried in decomposing leaves and upper soil layers (collectively called the seed bank) are an important source of regeneration. Seed longevity in the soil varies considerably among species. Most of our knowledge about seed longevity comes from silvicultural research. For example, black cherry, white ash, and yellow-poplar seeds survive in the seed bank for 3 to 5 years. Red maple, sweet birch, yellow birch, cucumbertree, and eastern hemlock seeds live for 1 or 2 years. Sugar maple and American beech seeds have no storage life; the seeds are shed in the fall and either germinate the following spring or not at all. Lack of seed survival in the seed bank beyond the first winter is common to all oaks and hickories. Flowering dogwood, blackgum, and mountain-laurel have little or no storage life. Most species with long-lived seeds are early-successional plants that rarely persist beneath a forest canopy, for example, pin cherry, whose seeds remain viable in the forest floor for periods of 30 to 50 years or more.[46] Almost nothing is known about seed longevity of the majority of Pennsylvania's 103 native tree species, 176 native shrub species, or the rest of the 2,151 kinds of vascular plants native to the state.

The seed bank — live seed that remains dormant in the soil for varying amounts of time — has a potential role in the revegetation of deer-damaged forests. However, studies of the seed bank composition in a temperate, deciduous old-growth forest in Quebec revealed that vernal herbs (spring wildflowers that complete the entire aboveground portion of their life cycle in April and May) were not represented.[47] The most frequent seeds were those of sedges, brambles, white snakeroot, and bush-honeysuckle, all common plants of Pennsylvania forests. Overall, woody species dominated the seed bank in areas with a closed canopy; herbaceous species were more prominent in more open parts of the forest.

In a chronosequence study of the recovery patterns of understory herbaceous plants following 10, 20, and 35 years of forest restoration on former cottage and road sites in southern Ontario, where many years of human use had completely eliminated native understory herbs, native summer and fall-blooming species with wind or vertebrate-dispersed seeds dominated the restored sites.[48] Although total plant species diversity of restored and reference sites was similar, many spring-flowering forest herbs with ant- or gravity-dispersed seeds remained absent from disturbed sites even after 35 years. All but one of the restoration sites in this study were within 65 feet of intact forest. In another comparative study in central New York State, 30 of 39 forest herb species were less frequent in successional forests on abandoned agricultural sites than in adjoining undisturbed forest, and, for several species, frequency declined with distance from a mature forest source area.[49] It is clear that seed dispersal, not seed banking, is the main source of propagules in forests where adult forest-floor plants have been absent or greatly reduced for prolonged periods.

A comprehensive review of the scientific evidence regarding the presence of forest herbs in forest seed banks in eastern North America concluded that they are very rare or completely lacking.[50] Only one study of those reviewed showed any forest herbs to be present in the seed bank and those were species that were present as adults in the immediate vicinity of the samples and thus may not have been long-term components of the seed bank.

Root and stump sprouting

Some tree species, notably American beech, quaking aspen, and bigtooth aspen, reproduce abundantly from root suckers. A few native tree species can reproduce from seedling sprouts and stump sprouts when stems are cut or top-killed.[51] For example, red maple, some oaks, and American chestnut are well known as prolific sprouters, sweet birch and yellow birch seldom have successful stump sprouts, and yellow-poplar is a poor sprouter. Stumps of small trees less than about four inches in diameter sprout more frequently than stumps of larger-diameter trees. The proportion of stumps that sprout decreases as stump diameter increases and is variable among species. For example, among oak saplings, the percentage of sprouting stumps is 100% for chestnut oak, scarlet oak, and northern red oak, 85% for black oak, and 80% for white oak.[52] Because of the oaks' strong sprouting ability, oak seedlings and saplings can survive browsing, breakage, drought, and fire. Top dieback and resprouting of seedlings typically occurs a number of times. Each successive seedling sprout is taller and the root system is stronger. When oak regeneration is successful, seedling sprouts and stump sprouts usually form much of the new stand.

Little research has focused on the dynamics of root and stump sprouting in forest understory shrubs as they recover from disturbance. Shrubs of some species are killed outright by heavy browsing but others may persist for varying lengths of time as roots with gradually declining potential to regrow viable stems and leaves. The study on witch-hazel mentioned earlier is the only one published to date that has addressed this issue for a shrub.[53] In a northern hardwood stand in northeastern Pennsylvania exhibiting regeneration failure of all woody species due to heavy deer browsing, witch-hazel roots sustained their ability to produce viable sprouts after as many as 6 years with no live stems.

Role of infrequent long-distance dispersal events

Although the limited dispersal range of most forest herbs is well documented, occasional exceptions have been found. In a study of a common forest herb, wild-ginger, the mean distance ants (the principal seed-dispersal agent) moved seeds was 5 feet.[54] Given that annual rate of movement, wild-ginger could have moved only 15 miles since the beginning 16,000 years ago of the last glacial maximum from its southern refugia. Even using the single longest seed carry observed in the study (115 feet) as a basis for calculation, the maximum distance that could be accounted for was only around 350 miles. However, the range of wild-ginger today extends 800 miles north of its glacial-era refugia. Infrequent long-distance seed dispersal events that created a steppingstone-like pathway of movement are the most plausible key to this puzzle. Another investigator who created a similar model for tree migration has stressed the importance of the sparse "tail" of the seed shadow, rather than calculated average rates of movement, to account for apparent migration rates.[55]

Infrequent long-distance dispersal events may play a small role in restoring diversity in recovering forests. However this influence is more likely to be felt in large areas and over long time spans than in small isolated sites or short time spans due to the randomness of the effect and the time required to exert its impact.

Site quality limitations on growth rates

The rate of forest recovery depends partly on the rates of survival and growth of the constituent plants. Abiotic environmental stresses limit these rates. In Pennsylvania such stresses include shade, droughty soils, prolonged soil saturation, shallow or rocky soils, low soil-nutrient availability, fire, frost pockets, wind exposure, short growing season, flooding, and ice-scour. These stresses slow the growth and curb the reproductive output of all plants that they fail to kill outright. Many of Pennsylvania's 2,151 kinds of native vascular plants[56] are adapted to survive particular kinds of stress. However, there is a trade-off. Adaptation to stress is normally coupled with inherently slow growth rates.[57] Although stress-adapted plants nearly always grow best in favorable, low-stress sites, they are invariably outcompeted in such sites by faster-growing (but stess-sensitive) species.

The amount of light at the forest floor is one of the most important factors limiting regeneration and recovery rates. The ability to continue photosynthesis at low light levels, termed shade tolerance, determines in what kind of light environments a species is likely to become established.[58] Most herbaceous plants and shrubs adapted to live in forests are moderately to highly shade-tolerant; the same is true of understory trees such as striped maple, flowering dogwood, downy serviceberry, Allegheny serviceberry, American hornbeam, and eastern hophornbeam. Among native trees, eastern hemlock, American beech, and sugar maple are among the most shade-tolerant species and can become established in the low light of uncut stands, if intermediate- and ground-level vegetation are sufficiently sparse or patchy. Red maple, sweet birch, yellow birch, cucumbertree, eastern white pine, oaks, and hickories are examples of tree species that are intermediate in shade tolerance; they tend not to become established or persist where understory plants provide another layer of shade beneath the canopy. Black cherry, white ash, and yellow-poplar are examples of shade-intolerant tree species. They germinate in uncut stands but survive no longer than a few years unless additional light is supplied, so turnover (mortality and new germination) is high in the absence of canopy disturbance.

The seedbed or forest floor condition at the time of germination has an important influence on the ability of seedlings of some species to become established. Most early-successional herbaceous and shrub species and some trees, for example, red maple, white ash, sweet birch, yellow birch, and eastern hemlock, benefit from forest floor disturbance. Over their evolutionary history such species regenerated best in the mineral soil exposed by fallen trees, landslides, scouring by floods, excavations by animals, and fires severe enough to burn away organic soil layers. Many larger-seeded plants are relatively indifferent to seedbed disturbance, establishing nearly as well on disturbed or undisturbed seedbeds as long as surface soil moisture is high. This category includes shrubs such as American hazelnut, beaked hazelnut, dwarf chinkapin oak, and scrub oak, and trees such as black cherry, sugar maple, American beech, eastern white pine, black walnut, butternut, hickories, and oaks. The strong radicle (embryonic root) of these large-seeded species is capable of penetrating soil organic layers to reach mineral soil. However, acorns, nuts, and other seeds on the soil surface are a favored food of a variety of insects, small mammals, wild turkey, other birds, and deer. Most oak and hickory seedlings originate from seeds that are buried by small mammals and not retrieved,[59] often because of the death of the individual that cached them.

Despite the potential importance of soil chemical properties in limiting forest recovery, nutrition of forest plants, including tree seedlings, has received relatively little study.[60] This perhaps is due to the relatively large effects of herbivory, light, and moisture compared with those of nutrition; for example, there presently are no published cases of outright regeneration failure of any eastern North American tree species due to naturally occurring soil chemical properties. Although optimum nutrient requirements are not known for most Eastern forest species, including trees,[61] several observational studies of the distributions of tree and shrub species suggest the relative positions of species along a continuum of soil nutrient status. Sugar maple, white ash, American basswood, flowering dogwood, and hobblebush tend to occupy sites with relatively high levels of exchangeable calcium and magnesium and relatively low levels of aluminum and manganese.[62] Yellow-poplar, yellow birch, eastern hemlock, and American yew occupy sites with moderate calcium and magnesium concentrations. Red maple, northern red oak, white oak, American beech, black cherry, sweet birch, eastern white pine, and striped maple tend to be more abundant on sites with low levels of these two base cations.[63]

Fertilizer studies have been used to evaluate possible deficiencies of soil nutrients on the premise that a response will be obtained only if a nutrient is scarce enough to limit growth. Fertilization will not increase productivity when there are no nutrient deficiencies or when growth is limited by other factors, usually sunlight or moisture availability. Nitrogen, phosphorus, and potassium (the nutrients required by plants in greatest quantity) have been the most widely tested soil nutrient amendments, followed by magnesium and calcium.[64] These studies suggest that nitrogen is by far the primary growth-limiting nutrient in eastern North American forests, but response from phosphorus frequently occurs after the nitrogen deficiency is overcome. For example, fertilization of black cherry with nitrogen and phosphorus resulted in large increases in height of seedlings (4 to 6 feet in the first year) and diameter and basal area growth of dominant and co-dominant overstory trees.[65] Addition of nitrogen increased the survival of eastern hemlock seedlings, but decreased the survival of red maple and eastern white pine.[66] Nitrogen addition reduced the diameter and basal area growth of sugar maple.[67] Few responses to potassium have been found, except in areas of Ontario and Quebec where bedrock levels of calcium and magnesium are very high, creating ionic competition for potassium uptake at the root surface.[68]

Forest liming (addition of calcium and, in some cases, magnesium) has been used to address a variety of nutritional constraints on tree growth and health and to accelerate stand growth.[69] Lime treatments often have been included to moderate soil acidity (thereby reducing chemical activity of potentially toxic aluminum and manganese) or augment supplies of calcium and magnesium.[70] Application rates have ranged from 0.09 to 10 tons per acre, usually of dolomitic limestone (which is high in both calcium and magnesium), and have been evaluated over time periods from 6 weeks to 15 years after treatment. Significant differences in the nutritional status of soils and foliage have been reported following lime application, though reports of positive tree growth responses are less frequent and highly species-specific.[71] For example, in a study in northwestern Pennsylvania, sugar maple survival, crown vigor, diameter and basal area growth, and flower and seed production had significant responses to the addition of 10 tons per acre of dolomitic limestone 8 and 10 years after treatment compared with unlimed trees, but there was no response by black cherry and American beech.[72] In the same study, sugar maple seedlings survived better, but height growth was not significantly improved by lime 10 years after treatment and there were no differences in basal area of black cherry, pin cherry, American beech, striped maple, or sweet birch saplings in the 1- to 4-inch-diameter class compared with unlimed areas 15 years after liming.[73] Significant increases in germination of pin cherry, black cherry, *Rubus*, grasses, and sedges were observed on limed plots in the first growing season,[74] but the response was attributed, in part, to increased production of nitrate nitrogen from organic matter involving calcium- or magnesium-limited microorganisms.[75] Liming of planted and indigenous northern red oak seedlings gave mixed results; liming did not improve survival or height growth of planted seedlings 3 years after treatment.[76] Addition of dolomitic limestone to indigenous northern red oak seedlings on fenced and unfenced plots resulted in increases in seedling height 2 years after treatment on limed plots, however the best treatment (fence + lime) resulted in only 1.6 inches of additional height growth, on average.[77]

Other elements of the forest ecosystem

Forest structure

Another aspect of forest ecosystem recovery, in addition to the restoration of native species diversity, is the reestablishment of a healthy size-class distribution in shade-tolerant canopy trees. Forests that have been reduced to mature canopy trees and a ground layer of herbaceous species that are not preferred by deer are common throughout Pennsylvania and other areas long subjected to heavy browsing. These forests lack the shrub, tree seedling and sapling, and subcanopy components that are important structurally and also provide the replacement trees for the canopy. In a study in northern Wisconsin, it took an estimated 27 years of protection from heavy browsing to reestablish a normal population structure in eastern hemlock.[78] The researchers warned that in areas subjected to longer periods of overbrowsing, where older size classes were missing, recovery could take as long as 70 years before normal population structure was reestablished.

Birds

Alterations in bird species and abundance have been documented in heavily browsed forests.[79] The results of several enclosure and exclosure studies have linked the composition of forest bird communities to structural changes in forest habitat caused by high-density deer populations. In a study comparing enclosures with deer densities of 10, 20, 38, and 64 deer per square mile in northwestern Pennsylvania, species richness of forest understory birds increased in the plots with the lowest deer density within 10 years.

In a study of breeding bird populations at eight sites in Virginia,[80] 5-acre plots were established at each site; half were fenced and half remained unfenced. Vegetation measurements were made three times over a 9-year period; bird population data were collected by mist netting annually in June. Deer density in the region was in excess of 10 deer per square mile throughout the study. Fenced plots responded quickly to deer exclusion by developing increased density in the understory as the grasses that initially dominated the forest floor were replaced by brambles and tree saplings. By as little as 1 to 2 years into the study, bird species composition in the exclosures had shifted from birds such as chipping sparrows that prefer more open understory to indigo buntings, hooded warblers, and ovenbirds, all of which benefit from denser shrub and understory layers. Recovery may have been faster at these sites because they lacked the dense layer of hay-scented fern and New York fern frequently present in stands subjected to canopy thinning and overbrowsing in Pennsylvania.

Amphibians

Among vertebrates, amphibians rival birds and mammals in their importance in forest ecosystems. The biomass of salamanders alone in a northern hardwood forest in New Hampshire was twice that of resident birds during the breeding season and almost equal to that of small mammals.[81] Salamander abundance and species richness increase southward toward the world's center of salamander diversity, the southern Appalachians, where the average salamander biomass per acre is comparable to, or larger than, that of all other vertebrates combined.[82] Amphibians play a key role in ecosystems by exploiting prey that are too small for larger vertebrates, thereby converting large quantities of biomass and energy from small invertebrates into a prey size available to reptiles, birds, and mammals.[83] Because their larval stage is aquatic, they also exploit the high productivity of temporary pools and other wetlands and provide an energy pathway to terrestrial animals and other organisms. Amphibians have attracted much interest as sensitive indicators for monitoring ecosystem integrity in the face of disturbance.[84]

A comprehensive review in 1995 of 18 studies that examined the effects of forest disturbance (clearcutting) on amphibians showed drastic short-term declines in every case, with a median loss of nearly three-quarters of total abundance.[85] The results are more varied among studies of long-term effects. Research in the southern Appalachians demonstrated that recovery times depend in part on temperature and moisture availability. Comparison of salamander abundance in wet, high-elevation forests showed significant effects of forest age since clearcutting up to about 60 years[86] but in dryer, warmer, lower-elevation forests effects of age on both abundance and diversity were significant up to 120 to 200 years.[87] Limited results from studies in the Northeast are consistent with the high-elevation results from farther south; studies in New York,[88] New Hampshire,[89] and southern Quebec[90] suggested recovery times of between 30 and 60 years.

The literature on amphibian recovery from deer overbrowsing is nonexistent.[91] However, one conclusion from studies on post-clearcutting forest succession is highly pertinent to the question of how and to what extent deer overbrowsing affects amphibians. Salamander recovery times varied, not with forest age directly, but with changes in microhabitats that are associated with forest succession.[92] As the forest regrows, there are increases in coarse woody debris, foliage height diversity, amount of canopy cover, and litter depth — all of which tend to foster and stabilize the cool, moist conditions that are essential for all terrestrial amphibians. Deer overbrowsing adversely affects most, if not all, of these elements of forest structure (see Chapter 5).

Other factors that may affect recovery of forest ecosystems

Are nineteenth and twentieth century forest removal and other large-scale disturbances responsible for some or all of the changes in the forests?

Given research reports describing long recovery times following severe disturbance[93] it is necessary to ask to what extent the depauperate condition of much of Pennsylvania's forest might be due to long-term effects of the complete forest removals that occurred in the state around the end of the nineteenth century. One possibility is that the absence of some species is due to the successional status of the forests. Little old growth exists and the bulk of the forests are 70 to 110 years old. It is to be expected that the abundance of species for which old-growth forests are the principal habitat (e.g., certain beetles,[94] fungi,[95] lichens,[96] mosses, and liverworts[97]) would be reduced or species assemblages that are characteristic of long-undisturbed forests (e.g., vascular plants[98] and salamanders[99]) would seldom occur together or in high population numbers.

Although of theoretical interest for some species, the residual impact of the forest removals of the late nineteenth and early twentieth centuries cannot explain the overall trends in forest changes described in this report. Exclosures clearly show that many species that have essentially disappeared from large areas of the forest can be found where deer have been excluded. A one-acre exclosure built in the 1940s on State Game Land 30 in McKean County, Pennsylvania, and maintained through the present[100] provides a vivid contrast with the surrounding browsed forest. Species such as red-berried elder, alternate-leaved dogwood, purple trillium, Solomon's-plume, rose mandarin, white baneberry, ginseng, violets, Canada mayflower, and brambles are abundant within the fence[101] providing evidence that 60 years ago these species existed in the forest in abundance, in contrast to their present-day, extremely sparse distributions. Scattered refugia such as large boulders in the Allegheny National Forest just south of Sheffield, Pennsylvania, and cliffs, rock outcrops, and boulder fields in northeastern Pennsylvania similarly demonstrate the potential for increased plant diversity where deer can't reach. These "rock gardens" contain numerous blooming plants of bluebead lily, Solomon's-plume, fly-honeysuckle, wood fern, mountain maple, wild currants, and American yew, which decades ago practically disappeared from the forest floor.[102]

Has fern dominance created alternative persistent states?

It has been suggested that long-term overbrowsing may create alternative persistent states in forest ecosystems that are to some degree self-perpetuating.[103] The development of a dense cover of unpalatable species such as hay-scented fern, New York fern, striped maple, and root sprouts of American beech has occurred in areas where deer have continually removed other vegetation and the canopy density permits some light to reach the forest floor. Because of their rhizomatous growth habit, the ferns form a dense, continuous foliage layer near the ground surface that is difficult for many other species to penetrate. In such situations decreasing the deer numbers alone does not necessarily result in the recovery of other vegetation, at least not for a long time. A recent study in northern hardwood forests in the Adirondack Mountains of New York concluded that successful establishment of desired tree seedlings requires control of both deer and understory American beech.[104] In such situations, either long recovery times or additional intervention to remove the competing vegetation are required in order for other species to establish successfully.

U.S. Forest Service scientists concluded that white-tailed deer have caused substantial and long-lasting changes in the trajectory of forest vegetation development in northwestern Pennsylvania that will be difficult to reverse in some cases.[105] They cited changes in species dominance, reductions in species diversity, and lack of seed sources as contributing factors. Stands that received complete overstory removal when deer density was high are particularly resistant to recovery because they are where the densest fern layers had developed. Stands cut in a similar manner but with low deer density had low abundance of fern and higher plant species diversity.

On the other hand, the research team noted that plots in their study that received either no overstory removal or partial removal and still had a diverse seed source nearby showed potential for relatively rapid recovery if deer numbers were low enough.[106] They found that sweet birch, common blackberry, eastern hemlock, and eastern white pine were all capable of growing through the ferns. Once other species began to shade the fern layer, it thinned, allowing additional species to grow.

Penetrating and reducing the fern layer sets the stage for other species to repopulate affected areas, either from suppressed remaining fragments, local refugia, or long- or short-distance seed dispersal. However, all of this takes time. In order to decrease the recovery time for the regeneration of commercially valuable tree species, researchers at the U.S. Forest Service have developed protocols that combine canopy thinning with herbicide treatment of the fern, beech, and striped maple layers to speed the recovery process.[107] These methods, coupled with fencing to exclude deer, have made it possible to continue to harvest timber on commercial and state forest lands in many areas, but they may be prohibitively expensive for many small private landowners.

Other effects of deer browsing that may have a long-term impact are potential changes in litter decomposition rates and mineral nutrient cycling due to changes in tree species composition brought about by deer selectively foraging over very long time periods. Differences among tree species in ratios of carbon to nitrogen in leaf litter and the presence and abundance of defensive compounds are important factors affecting both palatability and the quality of soil organic matter. In at least two eastern North American forest ecosystems, changes have been documented in the quantity and chemical properties of litter due to shifts in community structure caused by selective feeding by white-tailed deer or moose.[108]

Further tests of the alternative persistent states hypothesis and other long-term implications of prolonged heavy herbivory should be undertaken to determine whether they are valid and useful models for what is occurring in Pennsylvania’s heavily browsed forests.

Findings on forest recovery from heavy deer browsing

(1) Each layer of the forest, from the canopy to the soil, provides habitat for a specialized group of plants, animals, and microorganisms. Canopy trees link it all together, starting as seeds deposited on the forest floor, becoming seedlings in the herbaceous layer, growing into the shrub and understory layers, and eventually reaching a dominant position in the canopy.

(2) Overbrowsing by deer has damaged forest ecosystems in several profound ways including the widespread loss of forest structure, changes in abundance and diversity of flora and fauna, and interference with processes such as regeneration, succession, and perhaps nutrient cycling.

(3) The choice of bringing back the forest understory and ensuring the continuation of a rich overstory layer into the future is not a scientific choice but a values choice. In our judgment, the greatest overall benefit to the widest range of stakeholders would be best served by restoring forest structure, diversity, ecological processes, and ecosystem function to a state similar to the conditions that prevailed in the relatively recent past.

(4) Although there are indications that the regrowth of forest understories can occur in a few years following the reduction or exclusion of deer, full recovery of the structure and function of forest ecosystems will likely take decades and perhaps require active intervention beyond the mere reduction of deer numbers.

Endnotes

[1] Steele and Smallwood 2002

[2] Marquis and Whelan 1994

[3] Leimgruber et al. 1994; DeGraaf et al. 1991b

[4] deCalesta 1994

[5] Pastor and Naiman 1992

[6] Pastor and Naiman 1992; Didier 2003

[7] Tilghman 1989; Jones et al. 1993; Horsley et al. 2003

[8] Townsend and Meyer 2002; additional studies are underway, but not yet published, on the reduction in reproductive capacity due to browsing and rates of vegetative and reproductive recovery of several forest ground-layer species at the Lacawac Sanctuary in Wayne County, Pennsylvania, including Canada mayflower, Indian cucumber-root, two species of bellwort, Solomon’s-seal, Solomon’s-plume, starflower, teaberry, and white wood aster (Dr. Daniel Townsend, Associate Professor of Ecology, Department of Biology, University of Scranton, personal communication, 2003).

[9] Gregg 2004

[10] Putman et al. 1989

[11] Jenkins et al. 2004

[12] Fronz 1930

[13] Whigham 2004

[14] Bierzychudek 1982

[15] Beattie and Culver 1981

[16] Sobey and Barkhouse 1977

[17] Meier et al. 1995

[18] Fletcher et al. 2001a

[19] Anderson 1994; Augustine and Frelich 1998; Knight 2004

[20] Allison 1990a, 1990b

[21] Loeffler and Wegner 2000

[22] Rooney 1997

[23] A. F. Rhoads, personal observation

Endnotes

[24] Hughes and Fahey 1991; Rooney 1997; A. F. Rhoads, personal observation

[25] Horsley et al. 1994

[26] Godman and Lancaster 1990

[27] Wendel and Smith 1990

[28] Lorimer 1993

[29] Bonner and Maisenhelder 1974

[30] Silvertown 1980; Crawley and Long 1995; Wolff 1996

[31] Reader and Beisner 1991; Ostfeld et al. 1997; Reader 1997

[32] Kantak 1981; Wolff et al. 1985; Bucyanayandi et al. 1990; Ostfeld and Canham 1993

[33] Smith 1972; Wolff et al. 1985; Hulme 1994; Ivan and Swihart 2000

[34] Crow 1988

[35] Arend and Scholz 1969; Marquis et al. 1976; Galford et al. 1991

[36] Lorimer 1993

[37] Thorn and Tzilkowski 1991

[38] Lorimer 1993

[39] Oak 1993

[40] Williams 1989

[41] Oliver and Larson 1996

[42] Gibson 1982

[43] Drooz 1985

[44] Gibson 1982

[45] Galford 1986

[46] Marquis 1975; Peterson and Carson 1996

[47] Leckie et al. 2000

[48] McLachlan and Bazely 2000

[49] Singleton et al. 2001

[50] Pickett and McDonnell 1989

[51] Johnson 1993

[52] Horsley et al. 1994

[53] Townsend and Meyer 2002

[54] Cain et al. 1998

[55] Clark 1998

[56] Source: Rhoads and Block 2003. Vascular plants are all trees, shrubs, vines, wildlfowers, grasses, sedges, rushes, ferns, clubmosses, and related groups. They do not include mosses, liverworts, green algae, or non-plants such as lichens, fungi, cyanobacteria (“blue-green algae”), and photosynthetic microorganisms.

[57] Chapin 1980; Chapin et al. 1993

[58] Baker 1949; Pacala et al. 1994

[59] Steele and Smallwood 2002

[60] Chapin 1980; Demchik and Sharpe 1999a, 1999b; Sharpe and Drohan 1999; Schreffler and Sharpe 2003

Endnotes

[61] Lozano and Huynh 1989; Cote et al. 1993; Cote and Camire 1995

[62] Whitney 1990, 1991; Van Breemen et al. 1997; Finzi et al. 1998; Bigelow and Canham 2002

[63] Hallett and Hornbeck 1997; Van Breemen et al. 1997; Finzi et al. 1998; Whitney 1990, 1991; Bigelow and Canham 2002

[64] Auchmoody and Filip 1973 and references therein

[65] Auchmoody 1982, 1983

[66] Catovsky and Bazzaz 2002

[67] Stanturf et al. 1989; Lea et al. 1979

[68] Ouimet and Camire 1995

[69] Auchmoody and Filip 1973; Safford 1973; Carmean and Watt 1975; Stone and Christenson 1975; Ellis 1979; Stanturf et al. 1989

[70] Mader and Thompson 1969; Leaf and Bickelhaupt 1975; Safford 1973; Czapowskyj and Safford 1979; Lea et al. 1979, 1980; Safford and Czapowskyj 1986; Kedenburg 1987; Ouimet and Fortin 1992; Kolb and McCormick 1993; Cote et al. 1995; Long et al. 1997, 1999; Demchik and Sharpe 1999a, 1999b; Swistock et al. 1999; Moore et al. 2000; Schreffler and Sharpe 2003

[71] Safford 1973; Czapowskyj and Safford 1979; Safford and Czapowskyj 1986

[72] Long et al. 1997, 1999

[73] Horsley et al. 2002

[74] Horsley et al. 2002

[75] Persson et al. 1990/1991; Duggin et al. 1991; Kreutzer 1995; Olsson and Kellner 2002

[76] Demchik and Sharpe 1999a

[77] Demchik and Sharpe 1999b; Schreffler and Sharpe 2003

[78] Anderson and Katz 1993

[79] Casey and Hein 1983; Jones et al. 1993; deCalesta 1994; McShea and Rappole 1997

[80] McShea and Rappole 2000

[81] Burton and Likens 1975

[82] Hairston 1987

[83] deMaynadier and Hunter 1995

[84] deMaynadier and Hunter 1995

[85] deMaynadier and Hunter 1995

[86] Petranka et al. 1993

[87] Petranka et al. 1994

[88] Pough et al. 1987

[89] DeGraaf and Yamasaki 1992

[90] Bonin 1991, cited in deMaynadier and Hunter 1995

[91] The only experimental study found in the preparation of this report focused on one common species exposed to four deer densities (10, 20, 38, and 64 deer per square mile) in enclosures in northwestern Pennsylvania; it

Endnotes

detected no difference among treatments in surface abundance of redback salamanders after 10 years (Thomas Pauley, U.S. Forest Service, Northeastern Research Station, Irvine, Pennsylvania, unpublished data).

[92] deMaynadier and Hunter 1995

[93] Duffy and Meier 1992; Petranka et al. 1993; Bratton and Meier 1998; Singleton et al. 2001

[94] Stork 1990; Chandler and Peck 1992; Niemelä et al. 1993; Nilsson et al. 1995; Neave 1996; Spence et al. 1996, 1997; Werner and Raffa 2000

[95] Czederpiltz 1998, 2001

[96] Selva 1994; Nilsson et al. 1995

[97] Cooper-Ellis 1998; Rambo and Muir 1998

[98] Hughes and Fahey 1991; Duffy and Meier 1992; Bratton et al. 1994; Meier et al. 1995; Ruben et al. 1999; Abrams 2003

[99] Results of 18 studies reviewed in deMaynadier and Hunter 1995

[100] Bonta 2000

[101] A. F. Rhoads, personal observation

[102] A. F. Rhoads, personal observation

[103] Augustine et al. 1998; Stromayer and Warren 1997

[104] Sage et al. 2003b

[105] Horsley et al. 2003

[106] Horsley et al. 2003

[107] Horsley 1994

[108] Pastor and Naiman 1992; Didier 2003

Chapter 8. Predicting Forest Recovery Rates in Pennsylvania

In this chapter, we tie together the various influences on forest structure and diversity discussed earlier into a framework to be used as a basis for predicting forest recovery rates following the reduction of deer browsing. Prior estimation of recovery rates is part of the adaptive resource management process, which we see as key to managing deer from an ecosystem perspective.

Even with strong limitations on deer browsing pressure, forests cannot be expected to return to exactly the same conditions that existed prior to heavy deer browsing in the second-growth forests of the early twentieth century. The successional path of the forest has been changed by waves of introduced tree diseases, insect infestations, and invasive plants. Existing knowledge is sufficient to develop methods of reestablishing the tree component, there is limited knowledge in most of Pennsylvania[1] about exactly what kind of understory layer will return following the reduction of deer browsing pressure, even when actively fostered by restoration efforts. Nevertheless, the return of a diverse native forest understory and dramatic increases in the abundance of many currently rare tree, shrub, and herbaceous plant species can be expected, over varying time frames in different situations across the state. In this report, we call such a process structural recovery, with an important distinction between partial and full structural recovery.

Partial structural recovery consists of the restoration of quick-responding understory species such as blackberries and raspberries and the increase in abundance and height of other woody and herbaceous species that are preferred as food by deer. It can be reached relatively quickly in stands where deer browsing impacts have been low and of relatively short duration. It can be achieved somewhat more slowly, but still within 10 years, after deer density reduction in most overbrowsed stands if the canopy is open enough to allow substantial amounts of light to reach the forest floor. Full structural recovery, which includes the restoration of a suite of full-grown tree, shrub, and herbaceous species now absent from a stand, could take more than 50 years. Its speed depends on how long overbrowsing has taken place on a site and, to a lesser extent, on a site's logging history, soil chemistry, length of the local growing season, presence of introduced invasive species, and other factors influencing propagule availability and growth rates of native plant species. Partial structural recovery denotes the reestablishment of robust shrub and herbaceous understory layers, even if they are composed of relatively few species. With full structural recovery, those layers are not only robust but include a large fraction of the native species that were once present in a given forest type and landscape position.

The challenge for the near term is to demonstrate that partial structural recovery is occurring following reduction of deer densities, so that concerned stakeholders and the general public can have confidence that natural processes are working as predicted. In regions where deer overbrowsing has been occurring for 50 years, it is not reasonable to expect full structural recovery across the region in less than 50 years, although patches within the region may recover fully in a shorter time.

In cases in which a landowner's objectives include periodic removal of wood for sale that requires the use of heavy machinery, then immigration of slow-dispersing forest floor herbaceous plants might regularly be cut off.[2] In such a situation, full structural recovery might not be possible but an intermediate level of structural recovery should be the goal.

Several major factors can influence structural recovery time in forest stands (Table 5). Based on knowledge of these factors and of the characteristics of individual plant species, it is possible to make some predictions about what course of events to expect after release from deer overbrowsing and in what time frame (outlined qualitatively as a flow chart in Figure 2). Quantitative versions of these predictions can be used to test the theoretical understanding on which any ecosystem management plan rests. In particular, they can be used as part of an A.R.M. protocol.

If a seed supply is present and sufficient light is reaching the forest floor, then some species (e.g., *Rubus* spp., seedlings of sweet birch, yellow birch, eastern hemlock, eastern white pine) can grow through a dense fern cover in as little as 5 years,[3] ultimately shading and reducing the ferns to their normal pattern of small, isolated individuals and patches. If light reaching the forest floor is low, then recovery must await the canopy opening up, either as a result of natural aging and mortality of trees, natural disturbance, or commercial logging. Clearcutting or heavy canopy thinning are likely to hasten partial recovery but delay full recovery by engendering dominance first by early-successional species and later by sapling and even-aged small adult trees, which sequentially suppress the growth of plant species characteristic of mature forest understories. If the propagule supply for a plant species is limited, as for many herbaceous plants, then immigration rates or the local availability of refugia may determine the length of time before that species increases to a large enough population to be self-sustaining in the long term. The presence of a dense hay-scented fern or New York fern cover induced by overbrowsing complicates the situation; the ferns may also prosper in conditions of good light, increasing their interference with reestablishment by other plants. A similar problem is associated with the presence of introduced invasive species.

Recovery time

It is possible to estimate the time to structural recovery by breaking the process into a number of steps. First, there is the time it takes for recovery to begin, which we call recovery start time. Recovery start time depends on how long it takes for natural or human processes to allow sufficient light to reach the forest floor to support the reestablishment of a diverse understory.

Table 5. Factors affecting forest recovery time following reduction of severe deer browsing

factor	effect	depends on, or varies with:
Amount of light reaching forest floor	Determines how fast plants can grow and produce seeds or other propagules, including species whose increased cover due to selective avoidance by densely populated deer interferes with reestablishment by other plant species.	Stand structure; stand age; forest type; recent disturbance history
Condition of seed supply in forest floor	Determines whether a species can recover prior to the immigration of new seeds.	Duration of deer overbrowsing; longevity of dormant seeds in soil
Availability of refugia	Speeds up the spread of plants that would otherwise require very long times to immigrate.	Presence of sites inaccessible to deer, e.g., boulder tops, steep slopes
Time since last removal of canopy trees	Recent removal speeds up partial structural recovery by increasing light and soil resources for seed production and growth, but slows full structural recovery after reduction of deer densities because succession after logging can suppress or eliminate some understory plants.	Logging history; history of major natural disturbance
Extent of hay-scented fern or New York fern cover	Interferes with the establishment and growth of many plants.	Duration of deer overbrowsing; presence of ferns at the start of deer overbrowsing and previous thinning of the canopy
Native forest species' growth rates	Some plants, e.g., forest herbs, especially those that rely on vegetative reproduction rather than seed, can grow so slowly that their inherent growth rate can be an important factor in the total time it will take to reach full recovery.	Species' reproductive modes

(Table continued on next page.)

factor	effect	depends on, or varies with:
Soil chemistry	Plant growth is slowed on sites with a low availability of N, Ca, Mg, or possibly K or P, or a high availability of Al or Mn.	Soil parent material (bedrock, glacial till, etc.) supplies (Ca, Mg, K, P); organic matter quality (N, P); pH (Al, Mn)
Soil moisture	Waterlogged soils or dry, sandy or rocky soils restrict recolonization to a subset of the available species and slow their growth.	Soil particle size distribution; topography; hydrology; growing-season droughts and unusually wet years (and their long-term patterns of occurrence)
Disease and insect pest outbreaks	Can change species composition and slow the recovery rate.	Immigration or importation of insects and pathogens; in some cases, prolonged drought or other stress

Once recovery starts, there are other sources of delay to consider. For instance, there is the time it may take for significant numbers of propagules to migrate into the stand if propagules have been lost or greatly depleted — termed propagule lag time.[4] Another delay arises from the time it takes newly released plants to penetrate and overwhelm the fern layer if a dense fern layer is present. We call this the fern-penetration lag time. Finally, there is the time it takes for a newly regenerated species to grow to maturity and compete with any deer-tolerant or deer-resistant species that may be dominating the stand — called the competition lag time.

Under this conceptual framework, the time to reach recovery in a particular stand is a function of the four terms. In many cases, the functional relationship would be a simple sum:

$$\textit{time to recovery} = \textit{recovery start time} + \textit{propagule lag time} + \textit{fern penetration lag time} + \textit{competition lag time} \qquad \text{Eq. 3}$$

In a particular stand, any one or all of these lag times could be zero. Some of them will be different for different species. Some will be different depending on whether or not partial or full recovery is under consideration.

Equation 3 does not account for deer densities that are below current levels but above sustainable levels. The effect of deer on structural recovery time could be parameterized as:

$$\textit{time to recovery} = T_{(deer\,=\,0)} + D \times T_{slope1} + D^2 \times T_{slope2} \qquad \text{Eq. 4}$$

where $T_{(deer=0)}$ is the recovery time from Equation 3, D is deer density, and T_{slope1} and T_{slope2} are parameters to be determined from the literature or professional judgment.

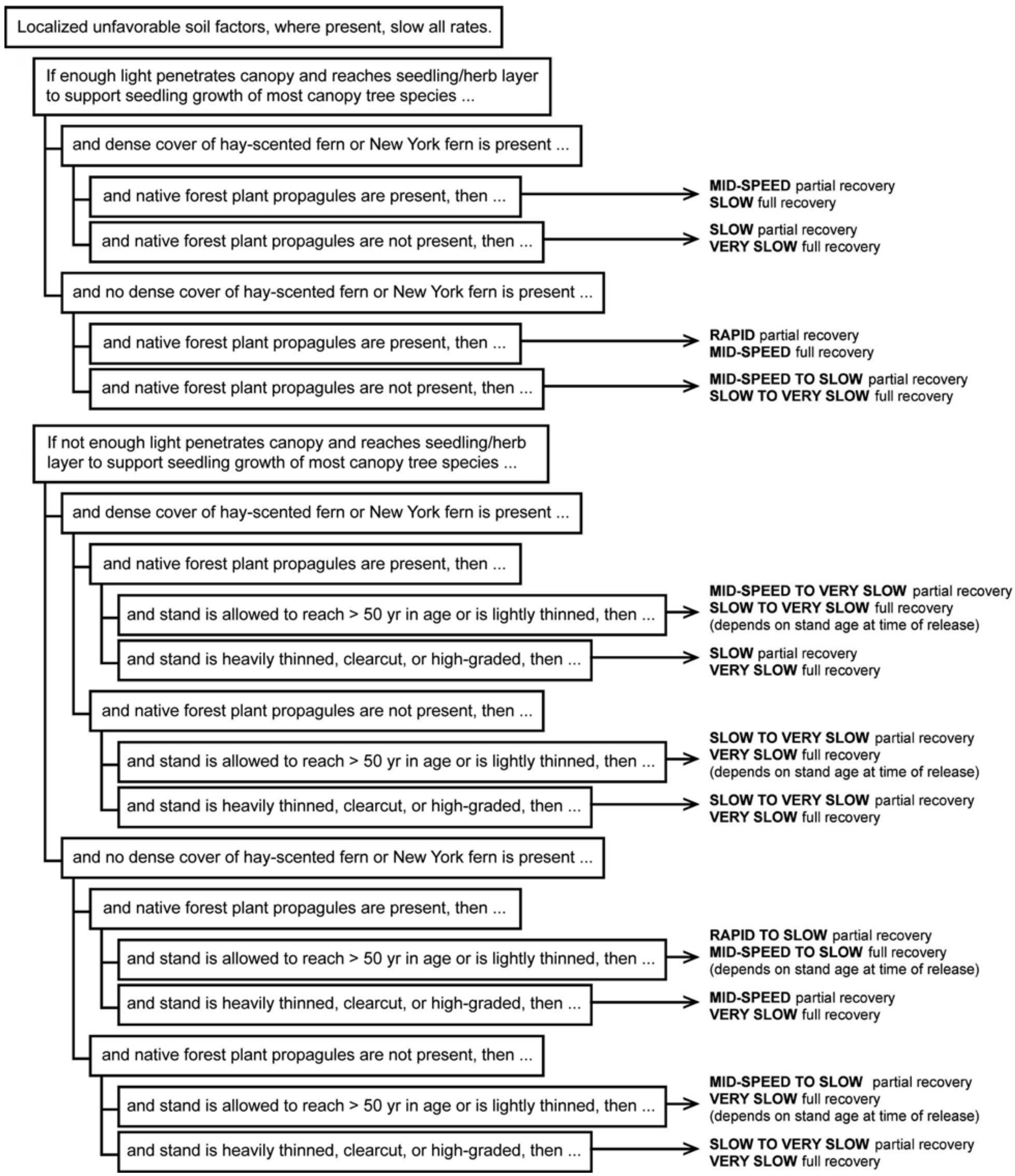


Figure 2. Relationships among major factors affecting rates of recovery of Pennsylvania forests after release from deer overbrowsing

Although this parameterized equation does not go to infinity, as it should, when *D* approaches current values of deer density, a very high value for recovery time, say 150 years, could be considered as tantamount to infinity for A.R.M. purposes.

Equations 3 and 4 provide the framework for a model that could be used as part of an A.R.M. protocol.[5] When a term in the equation for a particular class of species cannot be quantified based on past data, professional judgment needs to be called upon to determine a reasonable initial estimate. Coefficients needed for situations in which there exist no immediately applicable data from past field research could be devised by adjusting coefficients obtained from field data collected in the most similar situations available, using the modifying factors listed in Table 5 and professional judgment.

Under A.R.M., data from subsequent monitoring is used to refine the model coefficients. The only monitoring data that provide useful tests in the short term are from those species with relatively short recovery times or stands with favorable growth conditions such as adequate light at the forest floor. Monitoring of the earliest component of Equation 3, recovery start time, could also provide early tests of models in A.R.M. For example, structural recovery would be recorded as having started as soon as browsing-sensitive plants are found growing amid the fern layer above some threshold density based on data from overbrowsed stands of the same or a similar forest type. For slow-responding species, indicators of progress towards recovery, such as changes in average percent cover or the behavior of surrogates, might prove more useful. Change can be detected earliest by measuring herbaceous and understory plants that recover rapidly, such as *Rubus*, together with a surrogate for herbaceous vegetation in general. One such surrogate is the subset of tree species that can regenerate successfully only if browsing pressure is low enough to also permit recovery of shrub and herbaceous plant diversity (see Chapters 9 and 10 on the use of indicators). Use of this method is predicated on the assumption that seed sources remaining in the canopy are available to initiate fast recovery of this component of the woody flora.

Because each of the lag terms in Equation 3 can be different for individual stands and individual species, depending, for example, on the local availability of refugia and the past history of logging, a great variety of responses to reductions in deer browsing can be expected across the state and even among stands in close proximity to one another. Recovery will be heterogeneous in space and time and across species.

Recovery start time

The first site factor of importance is the amount of light reaching the forest floor. It is influenced by forest type, stand age since the last major, canopy-removing disturbance, stand structure, and the recent history of moderate disturbance. Forest type is important because different species of trees let different amounts of light reach the forest floor.[6] In older stands, mortality of old or injury-weakened trees opens up the canopy, allowing understory plants and tree seedlings to grow and reproduce. In stands thinned by commercial cutting, significant amounts of light reach the forest floor. Natural disturbances such as storms and fires also can open up or even occasionally remove the canopy. Selective browsing by deer on their preferred tree species produces a tight mid-story subcanopy that lets less light through. For example, in northern hardwoods, shade-tolerant striped maple and American beech, which are either less preferred by deer or are resilient to browsing, form a subcanopy layer that further attenuates the small amount of light penetrating the upper canopy. This greatly reduces light availability at the forest floor, effectively shutting down the regeneration of most species. Once a dense mid-story layer of American beech becomes established, it could take considerable time to reverse the pattern. With every year we delay dealing with overbrowsing, more forest acres are converted to this slow-to-recover regime.

Light availability at the forest floor is a crucial predictive factor. In shaded forest stands, recovery of both understory and overstory plants from long-term overbrowsing must await the day when either tree mortality, fire, windstorm, a pest outbreak, or loggers have opened up the canopy. In stands more than about 50 years old, which make up the majority of Pennsylvania forests, the canopy already has gaps that will facilitate recovery. In younger stands, say of age A, it will take around 50 minus A years for normal tree mortality to begin opening up the canopy. Processes other than aging can decrease that lag time. For instance, about 1.3% of the forest can be expected to be opened up by natural disturbance each year,[7] and about 2.5% of the forests in the state can be expected to be cut each year at varying levels of intensity.[8]

If a plant species remains in the understory in a suppressed form, then it will begin to recover as soon as light is available. If not, then additional delay will occur. Similarly, if a plant species persists in refuges protected from deer, such as large boulders or steep slopes, then it can begin to spread to the stand at large after release from overbrowsing as soon as light is available on the forest floor.

Propagule lag time

Condition of the seed supply (or more generally the propagule supply), is a major factor governing the rate of change for individual plant species.[9] For instance, if a tree species remains in the overstory, recovery of that species should be faster.

If a propagule supply is absent due to decades of heavy deer browsing and a lack of local refugia, then propagule lag time will depend on immigration rates. Species dispersed by birds, such as blackberries and raspberries, migrate the fastest. Immigration rates of herbaceous plants dispersed by means other than birds, for example, those dependant on ant or gravity dispersal,[10] are poorly known and may be dominated by unusual events in an area's history that speed up what would otherwise be a very slow process. Many forest herbs migrate slowly, often depending entirely or almost entirely on vegetative spread. Recolonization by such species is expected to be exceedingly slow. Clearly, propagule lag time varies greatly by species.

Some immigration may take place before the recovery start time. Thus, in certain situations immigration might delay recovery only slightly. For species with wind-dispersed seeds, immigration may be facilitated by some of the same events that open the canopy to light, such as storms and high winds. Other canopy-opening events, such as logging, will not carry propagules into an area unless loggers and foresters bring them in deliberately.

Fern penetration lag time

Dense forest-floor cover by hay-scented fern and New York fern often is associated with severe overbrowsing in combination with canopy thinning,[11] and may occur only in the presence of these two factors together.[12] Rhizomatous fern dominance of the forest understory is quite prevalent in some areas of Pennsylvania. Dense cover of these two fern species was found to affect 48% of the stands in a survey taken in the heavily browsed Allegheny National Forest.[13] In the northeastern counties of Pennsylvania, fern dominance was found on approximately 33% of a large sample of non-industrial private lands.[14]

Dense cover of rhizomatous ferns in the forest understory hinders the emergence and establishment of other plant species[15] (see detailed discussion of this issue in Chapters 5 and 7). If deer overbrowsing followed by thinning has driven a forest stand into understory dominance by ferns, recovery times will be longer for nearly all native forest species, in at least some cases a great deal longer.[16]

Competition lag time

The time it takes for a species to reestablish a self-sustaining population depends on how effectively individuals of that species can garner essential resources and preempt them from other plants, given the specific habitat's levels of supply. The lag due to competition depends partly on soil conditions, roughly equivalent to the forestry concept of "site quality." Plants compete less and grow faster in stands with high nutrient availability and adequate (but not excessive) moisture. Other factors being equal, deep, loamy soils[17] high in calcium and magnesium derived from carbonate-containing bedrock (limestone, dolomite, marble) support faster growth than other types of soil for many plant species.

Where moderate light levels are present, such as in thinned stands, *Rubus* and a few other plants (including sweet birch, yellow birch, eastern hemlock, and eastern white pine) can grow through the fern layer, eventually casting enough shade to thin or eliminate it. Later still, when the new tree and shrub growth becomes large enough to begin self-thinning or when the canopy is again thinned by disturbance, enough light can reach the forest floor to support the establishment and growth of species that were not able to grow through the fern layer. Although tree seedlings of some tree species may quickly overtop the ferns, it will still take many more years for the trees to grow tall enough to take their place in the forest canopy.

Variation in climate affects recovery rates, even in an area with as narrow a range in latitude and elevation as Pennsylvania. The frost-free period in parts of Pennsylvania's Piedmont and Atlantic Coastal Plain is more than 30% longer than in McKean County; the length of the growing season varies between these extremes elsewhere in the state,[18] depending on elevation and on distance and direction to Lake Erie and the Atlantic Ocean. A roughly parallel geographic pattern of expected daily radiation (a combination of solar angle and the amount of time when the sun is not behind clouds) most likely magnifies the effect of different growing seasons on plant growth rates, but it may be counterbalanced to some degree by a reverse pattern of annual moisture deficit.[19] The net effect of regional climate on recovery times is likely to favor the fastest recovery rates, if all else were equal, in the southeastern and extreme southwestern counties and produce the slowest recovery rates in the north-central counties.

Average time to recovery

Even though there will be considerable variation in recovery time from stand to stand, we can make some estimates of average time to partial recovery based on the following assumptions: (1) stand age is distributed evenly within size-class categories for which the U.S. Forest Service collects aggregate data,[20] (2) the rate of canopy openings caused by natural disturbance is 1.3% per year, (3) the rate of cutting is 1.25% per year for long-rotation stands (more than 75 years between cuts) and 3% for all others, (4) propagules of some species are still present or immigrate quickly through bird dispersal, and (5) it takes 5 years for fast-growing species like shrubs in the genus *Rubus* to overtop the fern layer, if a fern layer is present. With these assumptions, about 1.6-million acres of timber lands in long rotation and older than 50 years could show partial recovery within 5 years, that is, restoration of a basic understory (e.g., one composed mostly of *Rubus*).[21] For species that require wind dispersal for migration of propagules to replace the local supply destroyed by decades of deer browsing, recovery on long-rotation stands will take longer; the average time for recovery might range from 5 to 80 years, depending on proximity to areas with source propagules.[22] In similar situations, ant- and gravity-dispersed species and those that reproduce vegetatively may take a century or longer to recover without replanting by humans.[23]

Insufficient data are available to estimate partial recovery times for non-industrial private lands that have been partially harvested, either with diameter-limit cuts or thinning. Presumably, the recovery times will be longer than for stands in long rotation because of stronger "legacy effects" from long-term deer overbrowsing (i.e., interfering cover of unpalatable or browsing-resistant species, mainly striped maple, American beech, hay-scented fern, or New York fern). The recovery prospects for stands that have undergone both intense deer browsing and more than two diameter-limit cuts appears particularly bleak.[24] The longer Pennsylvanians wait to reduce deer densities on non-industrial private lands, the more stands will pass into a state that is highly

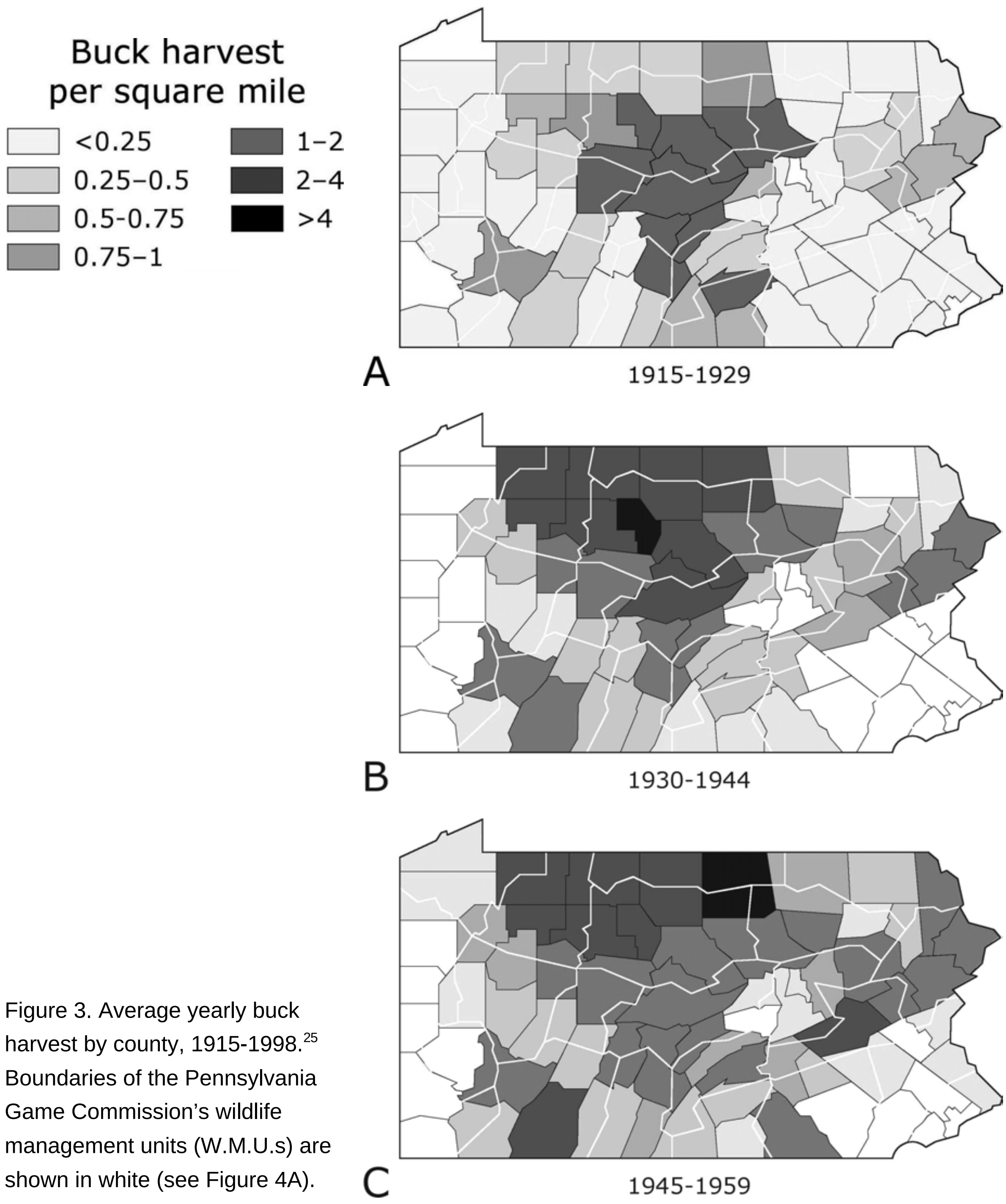


Figure 3. Average yearly buck harvest by county, 1915-1998.[25] Boundaries of the Pennsylvania Game Commission's wildlife management units (W.M.U.s) are shown in white (see Figure 4A).

resistant to recovery, brought about by intense deer pressure and, in many cases, a third diameter-limit cut.

Predicting average times to full structural recovery is a much more difficult exercise than trying to predict times to partial recovery. On non-industrial private lands, the recovery time could exceed the average time between harvests, which may be as low as 27.[26] Consequently, the long-term degree of forest recovery on non-industrial private lands after reduction of deer overbrowsing may have more to do with the quality of future cutting practices than any other factor we have discussed. On lands where trees are not harvested, we assume that full structural recovery will take, on average, at least 50 to 100 years.

D 1960-1974

E 1975-1989

F 1990-1998

Geographical distribution of partial recovery times

It is important to bear in mind that the above figures are intended as ranges and averages. Partial recovery times will vary among forest stands from zero to many decades. Under certain conditions, some changes following release from deer overbrowsing will occur relatively quickly. For instance, where overbrowsing began recently and fern dominance and loss of seed supply are negligible, as in many of the southern-tier counties in Pennsylvania, partial structural recovery should be very rapid in stands where a significant amount of light reaches the forest floor.

Of the four key site factors affecting recovery rates we have identified, three are strongly influenced by deer overbrowsing, namely the amount of light reaching the forest floor, the condition of the seed supply, and the extent to which rhizomatous ferns have taken over. Consequently, the duration of severe deer browsing (see Figure 3, page 122) can serve as an overarching predictor of recovery rate. In parts of the state where deer overbrowsing has gone on for many decades, especially the northern counties, forest recovery is expected to be relatively slow, all other factors being equal. The opposite is expected to be true in the southern counties. Another regional influence is forest type; oak stands, characteristic of most of the southern two-thirds of the state (Figure 4B), tend to let more light reach the forest floor than do northern hardwood and beech-maple forests.[27] Regional variation in the length of the growing season and in expected daily solar radiation roughly parallels the distribution of oak dominance and may reinforce the geographical patterns of both duration of overbrowsing and light transmission through the forest canopy. In addition, nearly all of the areas underlain by carbonate rock, where soils are richest in available calcium and magnesium (and best buffered against acidification by air pollution), are scattered across the southern two-thirds of the state.[28]

The Allegheny High Plateaus region (W.M.U.s 2F, 2G, 3A, and 3B on Figure 4A) has the strongest legacy effects of prolonged high deer densities (Figure 4D, 4E, and 4F). Heavy cover of rhizomatous ferns (Figure 4D) is an important legacy effect but its distribution tells only part of the story. Heavy fern cover typically does not occur where striped maple and American beech saplings already are established and producing dense shade, a frequent occurrence across the northern hardwoods region in the northern one-third of Pennsylvania. Density of shrub cover (Figure 4E) and diversity of shrub species (Figure 4F) may be more reliable than fern cover for comparing the magnitude of legacy effects among different forest types in the state.

Where deer densities are greater than 24 per square mile (Figure 4C), there are assumed to be negative effects on tree regeneration and the higher the deer density, the more severe the effects on regeneration. However, even deer densities below 10 per square mile are likely to limit the full recovery of forest understories.[29] The current very high deer densities (averaging over 40 per square mile) in parts of western Pennsylvania are in the eastern broadleaf–west silvicultural region where the highest regeneration rates are found (Table 3, page 40). This area has the best chance of quick recovery, but only if deer densities are reduced soon. Despite estimates of low overall average deer density in extreme southeastern Pennsylvania (Figure 4C, page 126), dense urban and suburban development and highly fragmented forests there mean that some areas have no deer and small pockets have some of the highest deer numbers found anywhere. Located in the eastern broadleaf–east silvicultural region (Table 3), this part of the state has some of the least-severe legacy effects and should recover quickly after deer density reduction even though regeneration rates are not as high there as in western Pennsylvania.

The good news, in terms of recovery rates, is that there are large areas of forested land in Pennsylvania that should begin to recover relatively quickly after reduction of deer densities (in the lighter-colored areas in Figures 4D through 4F, page 127). The bad news is that the longer we wait to take action on deer, the more this potentially fast-recovering acreage will shrink. Also, there are large areas in the forests of Pennsylvania that will not recover until sufficient time has elapsed for self-thinning, commercial thinning, or natural disturbance to occur. In areas where rhizomatous ferns have become abnormally abundant due to many years of deer overbrowsing combined with tree thinning, it will take even longer for full structural recovery. As a result, there has been interest in exploring ways of speeding up recovery, with the focus so far being on the overstory layer and those trees that have commercial value to the wood products industry.

Speeding up recovery

Historically, measures to speed up recovery following reduction or elimination of deer overbrowsing have been carried out by the wood products industry, targeting the regeneration of commercially valuable tree species following canopy removal by logging. The first and most crucial step has been to reduce deer browsing. Deer browsing pressure has been reduced by cutting large enough tracts to saturate the existing deer population with forage, which grows rapidly after elimination of all overstory shade. With sheer numbers of tree seedlings overwhelming even a dense deer population's food needs, some have the chance to grow to heights beyond the reach of deer. By the time the canopy closes and the amount of alternate forage (shrubs and herbaceous plants) declines, the trees are saplings with leaves above the browse line, able to survive the presence of deer even in high numbers. Although such a technique can work for trees, it will not work for understory plants whose maximum height is near or below the height a deer can reach. Consequently, saturation cutting is not among the methods available to reduce deer browsing pressure when the goal is ecosystem recovery.

Another method of reducing deer browsing pressure other than harvesting the deer themselves is the use of fencing. Successful fencing leads to heterogeneous population densities of deer but at a smaller scale than selective hunting by region. Typically, areas fenced for commercial tree regeneration enclose 10 to 40 acres on state forest lands and the Allegheny National Forest or up to 100 acres on land managed by large wood-products companies, and are maintained for 5 to 10 years before being removed or relocated. Whether fencing is cheaper than hunting or alternative deer removal techniques is an economic question that is not explored in this study. However, if fences were to be repaired indefinitely, as is required to maintain an understory layer, the cost of fencing would be far higher than where the goal is solely to reestablish tree seedlings.

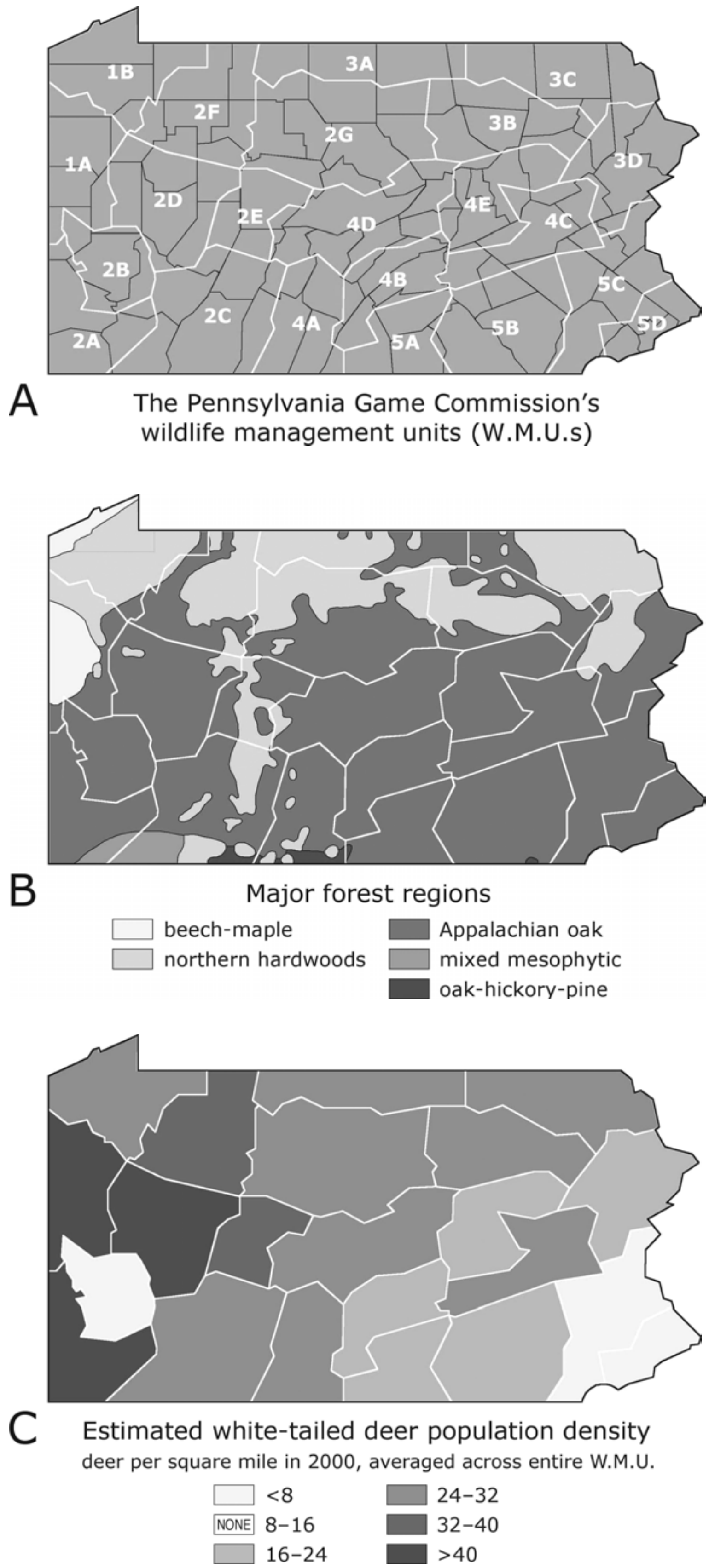
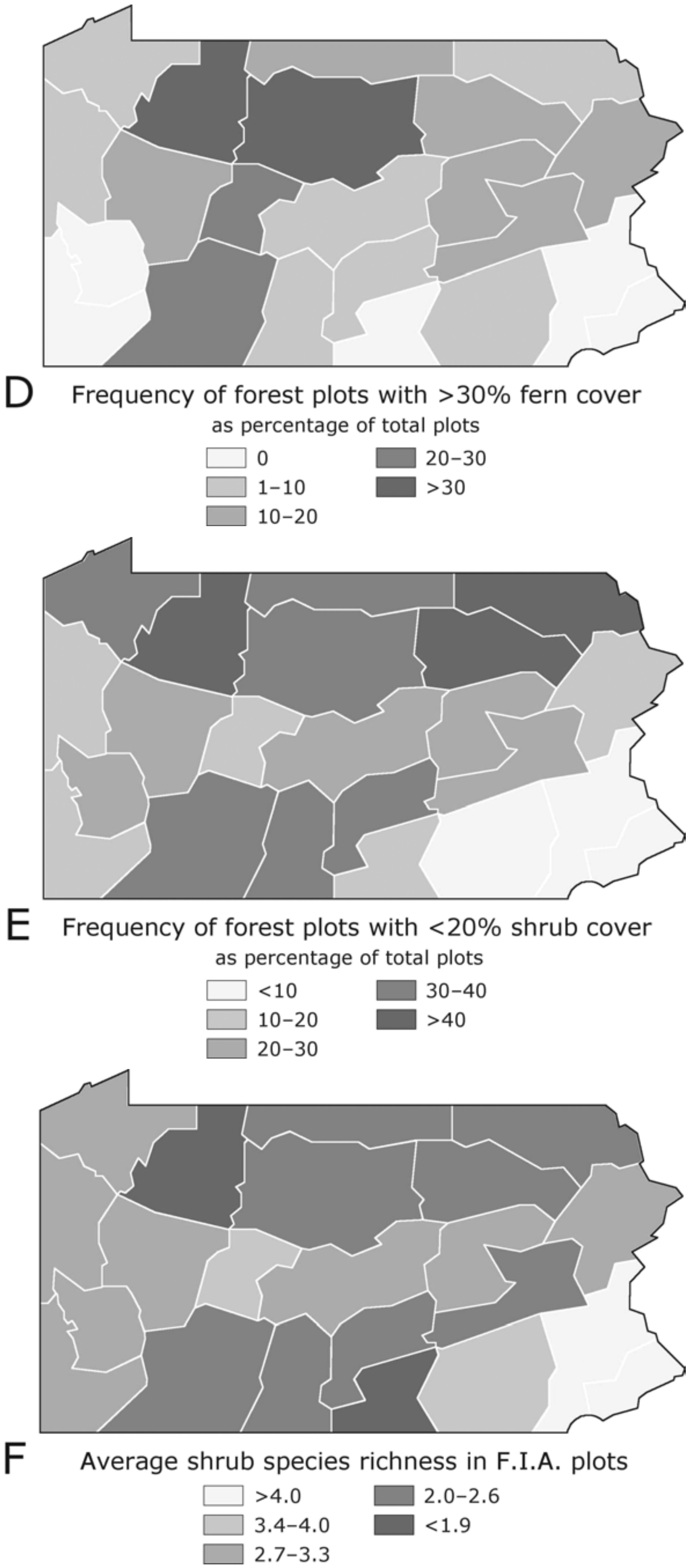


Figure 4. Indicators of factors influencing rates of forest recovery following deer population reduction, by wildlife management unit.[30] Large-scale trends only are depicted; site-specific factors on a local scale can affect individual stands dramatically and in many cases will override the regional trends.



Once deer browsing pressure has been reduced, herbicide is often used in silviculture to remove ferns from fern-dominated forest understories, thereby eliminating the fern-penetration lag time. Measures to remove fern cover with herbicides[31] have been taken on a routine basis by some foresters and landowners since the 1980s.[32] For instance, in the mid-1990s, 4,000 to 5,000 acres per year were sprayed in Pennsylvania to remove ferns and interfering, browsing-tolerant hardwood understories. Virtually all of this practice takes place on public lands and some tracts owned by large wood-products companies. There is little intervention to speed the reduction of understory fern dominance following tree harvesting on private, non-industrial lands. Given the millions of acres in Pennsylvania that have been affected by deer populations, these efforts would need to be vastly expanded following reduction of deer populations if recovery were ever to be accelerated on a large scale. The potential impacts of such a large-scale application of herbicides would also need to be thoroughly explored.[33]

Leaving some trees standing as seed sources also speeds up recovery of tree species. A goal for residual tree cover of 10 square feet of basal area per acre has been recommended for regenerating trees for future harvest.[34] Options for speeding up the recovery of shrubs and herbaceous species through forest management policies need to be explored. In theory, the costs of restoring a diverse understory layer and reversing understory dominance by ferns could be reduced by involving loggers and foresters in dispersing native understory plant seeds. At present, there is no material incentive for landowners, loggers, and foresters to absorb restoration costs. If recourse were to be made to regulations or subsidies, then research should be undertaken to find the best ways of reducing costs. Scientific research is fundamental to speeding recovery and reducing its cost. There is a variety of potential experiments that would increase our understanding of recovery rates for various species following the reduction of deer browsing.[35]

Findings on predicting forest recovery

(1) The length of time that a forest has been subjected to overbrowsing and the extent to which a dense layer of unpalatable vegetation has developed are major variables that will influence the recovery time.

(2) Recovery of forest structure and species diversity will be heterogeneous in space and time and across species. Large areas should begin partial recovery relatively soon after reduction of deer densities; other forest stands will not undergo even partial recovery until sufficient time has elapsed for self-thinning or natural disturbance to occur (unless commercial thinning is undertaken) or for immigration of seeds. Full structural recovery will take decades to a century or more.

(3) A major challenge for the near term is to find rapid and effective measures for detecting partial structural recovery following reduction of deer browsing pressure, so that concerned stakeholders and the general public can have the confidence and patience that will be required to sustain support for continued deer management through the slow process of full structural recovery.

Recommendations on predicting forest recovery

(1) Do not delay action to reduce deer overbrowsing.

(2) Recognize that full forest recovery is a long process, but that partial recovery will be quick in some areas.

(3) Support research on, and development of, indicators of recovery progress.

(4) Focus initial monitoring efforts in those areas where rapid partial recovery is expected to occur.

Endnotes

[1] But see Horsley et al. (2003), which reports the results of 10 years of change with logging and controlled deer densities of 10, 20, 38 and 64 deer per square mile on the Allegheny Plateau in northwestern and north-central Pennsylvania.

[2] Meier et al. 1995

[3] Horsley and Marquis 1983

[4] Some immigration may take place during the recovery start time.

[5] A study nearing completion in the Adirondacks at Huntington Forest shows that absolute densities of deer are not good predictors of impacts of deer on vegetation (Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003). Rather, deer density relative to food supply (absolute density divided by the proportion of forested area in regeneration) appears to be a better statistical predictor. Furthermore, the relationship between deer density and vegetation recovery may not be linear but instead may resemble the curve in Figure 1 of this report (Chapter 5). This work, when completed, may serve as the basis for a better model than Equation 4.

[6] Canham et al. 1994

[7] Lorimer 1977, 1980; Runkle 1982; Frelich and Lorimer 1991

[8] Assuming 400,000 acres are cut each year on private lands (Dr. James C. Finley, Professor of Forest Resources, School of Forest Resources, Pennsylvania State University, personal communication, 2002) and 17,000 per year on state lands (Mark W. Deibler, Chief, Silviculture Section, Bureau of Forestry, Pennsylvania Department of Conservation and Natural Resources, personal communication, 2002)

[9] Matlack 1994; Peterson and Pickett 1995

[10] Meier et al. 1995; Kot et al. 1996

[11] de la Cretaz and Kelty 1999; Horsley et al. 2003

[12] Although the primary disturbance associated with the spread of rhizomatous ferns is the thinning of timber stands, any large disturbance that opens up the canopy (e.g., ice storm, severe windstorm) can also increase the density of a fern understory. However, they are minor in terms of the area affected compared with silvicultural thinning.

[13] Allegheny National Forest 1995

[14] Fredericksen et al. 1998

[15] Horsley 1977, 1993a, 1993b; Horsley and Marquis 1983; George and Bazzaz 1999a, 1999b

[16] Augustine et al. 1998; Stromayer and Warren 1997

[17] Loams are soils that are intermediate in texture, neither predominantly fine- or coarse-textured. They contain moderate amounts of all three size classes of soil particles — sand, silt, and clay.

[18] Cuff et al. 1989

[19] Cuff et al. 1989

[20] The U.S. Forest Service gives for the year 2002 the following proportion of timber by size class: 58% (9.3 million acres), 30% (4.9 million acres), and 11% (1.8 million acres) for sawtimber, poletimber, and saplings, respectively (U.S. Forest Service 2003: Table 3. Area of timberland by forest-type group and stand-size class, Pennsylvania, 2002). For estimation purposes, we take the age of saplings to range from 0 to 20 years; the age of poletimber stands to range from 20 to 65 years, and the age of sawtimber stands to be greater than 65 years.

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[21] These are poletimber stands older than 50 years, which we take to be $\frac{15}{45}$ of the total poletimber stand acreage in Pennsylvania (4.9 million acres) on the assumption that the age distribution of poletimber stands is flat between 20 and 65 years. ($\frac{15}{45} \times 4.9$ million acres = 1.63 million acres. See previous endnote for origin of acreage numbers and assumptions about age distributions in timber classes.) In the absence of high deer pressure, these stands could begin to recover immediately in the absence of a fern layer and at 5 years with a fern layer, under our assumptions.

[22] At one extreme a stand could be relatively close to lands with propagule supplies, so that wind dispersal would not be limiting. In such a case, partial recovery could begin within 5 years. At the other extreme, it might be necessary to wait for a wind disturbance event. In the latter case, we need both a wind disturbance event, with an assumed probability of 1.3% per year and a stand that has passed the 50-year age mark located near enough upwind to contribute wind-dispersed seeds. A numerical integration produces a 79-year average time for this to occur, which is not much longer than the result of a hand calculation computed by neglecting the time for all of the stands to pass the 50-year age mark.

[23] Roberts and Gilliam 2003; Neufield and Young 2003; slow migration and growth rates have been documented for many forest floor herbaceous species (e.g., see Sobey and Barkhouse 1977; Bierzychudek 1982).

[24] After a third diameter-limit cut, the economic potential of most stands has been exhausted. For a very long time the understory will have little prospect of being exposed to sunlight by further logging or by any natural disturbance other than fire. Furthermore, the propagule supply will be gone. Consequently, there is little likelihood of canopy replacement by a new crop of merchantable tree species. Only fire, which is relatively rare, is a likely source of renewal, although the lack of a propagule supply would make even postfire recovery a very slow process.

[25] Data depicted on Figure 3 maps were provided by Dr. Duane R. Diefenbach and Justin Vreeland, Cooperative Fish and Wildlife Research Unit, Pennsylvania State University.

[26] Estimating the average time between harvests on Pennsylvania's non-industrial private lands from available data is a challenge. We base our estimate on the U.S. Forest Service's Forest Inventory and Analysis (F.I.A.) statistics for 1989 (U.S. Forest Service 1993). To get the number of acres cut per year, we make two estimates using different sets of data. First, we rely on an F.I.A. estimate that 30% of the Pennsylvania timber base of 15.9 million acres was cut to some degree from 1978 through 1989 (Dr. William H. McWilliams, U.S. Forest Service, Forest Inventory and Analysis, personal communication, 2004). Dividing 30% by 11 years yields an estimate of 2.72%, or 430,000 acres, per year. If these cuts were spread uniformly over the 15.9 million acres, the average time between cuts would be 37 years, which we round to 40. However, the average turnaround time on non-industrial private lands is lower, because considerable timberland in Pennsylvania is in long rotation (in excess of 75 years between cuts). In fact, based on the acreage in sapling and poletimber size classes (8.2 million acres), it appears that about half of all timberlands were in long rotation in 1989. Assuming that 50% of the land is in 75-year rotation or longer (using an average of 80 years), the average time between cuts on the remaining land must be 27 years, if the 40-year estimate of the average for the entire timber base is accepted. Our second estimate is derived by using production statistics in board-feet per year to obtain the average number of acres cut per year, by dividing the number of board feet removed per year by the average number of board feet removed per acre (Dr. James C. Finley, School of Forest Resources, Pennsylvania State University, personal communication, 2004). Using 1989

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F.I.A. data (U.S. Forest Service 1993), we estimate total timberland harvested during the year at 220,000 acres. Assuming, again, that 50% of the timber land base is in an 80-year rotation, we find from this second method of estimation that the average time between cuts on the remaining land will be the same as on the long rotation, 80 years. Given the disparity in the estimates (27 vs. 80 years), the only conclusion we can draw from the available data is that the average time between cuts on non-industrial private land *may* be as low as 27 years.

[27] Dr. Patrick H. Brose, Research Silviculturist, Northeastern Research Station, U.S. Forest Service, Irvine, Pennsylvania, personal communication, 2004

[28] Cuff et al. 1989

[29] deCalesta and Stout 1997

[30] Sources: Figure 4B, Küchler 1964; Figure 4C, data provided by Dr. Marrett D. Grund and Chris Rosenberry, Pennsylvania Game Commission; Figures 4D through 4F, data provided by Dr. William H. McWilliams, Forest Inventory and Analysis, U.S. Forest Service

[31] At $122 per acre treated with herbicide, fully treating a million acres would be very expensive. For comparison, the annual budget of the Pennsylvania Game Commission is ~ $60 million. The cost of herbicides is not usually economically justifiable in non-industrial private forestry, so it is not reasonable to expect private landowners to cover these costs routinely.

[32] There presently are three Pennsylvania contractors who spray herbicide. The Allegheny National Forest, Pennsylvania Bureau of Forestry, and Pennsylvania Game Commission conduct fencing and herbicide operations themselves or use contracting firms. Development of the herbicide guidelines using glyphosate (Accord) and sulfometuron methyl (Oust) that now are in wide use in Pennsylvania began in 1976; use of these prescriptions increased dramatically in the 1980s and 1990s.

[33] Research has been underway for 9 years by the U.S. Forest Service Northeastern Research Station in northwestern Pennsylvania to assess the effects on understory structure and diversity of large-scale herbicide application to accelerate tree regeneration after deer density reduction and canopy removal. Publication of the results is awaiting completion of the first 10 years of data collection.

[34] Horsley et al. 1994

[35] Robinson and Handel 2000

Part III. Indicators of Progress Towards Forest Recovery

Chapter 9. Indicators of Forest Recovery Useful for Ecosystem Management

Chapter 10. Methods of Estimating Abundance of White-tailed Deer

Chapter 9. Indicators of Forest Recovery Useful for Ecosystem Management

Measurable indicators are the basic tools required for monitoring the success of any program to recover forest structure, diversity, and ecological processes. Their use is a requirement in adaptive resource management to compare model predictions with results in the field. It is impossible to measure directly the changes in every component of the structure and diversity of a forest ecosystem. Indicators are selected that can serve as surrogates for key species and processes that are too costly or difficult to measure. The challenge is to pick those few components whose changes most fully reflect the processes, functions, and diversity trends of the entire ecosystem.[1] The effectiveness of chosen indicators can and should be tested in subsequent research to see if they indeed predict improvement across a broad range of species, structural components, and processes.

One key consideration in designing the monitoring component of an A.R.M. program is cost. In the abstract, according to wildlife ecologist William F. Porter, "many stakeholders are most comfortable with a complete census of indicator species, increasingly uncomfortable with estimates when confidence intervals enter the discussion, and suspicious when presented with indices. However, when they are confronted with the economic realities of getting the data, their comfort begins to change."[2] For example, accurately estimating deer populations over a relatively modest area in just one year can cost millions of dollars (see Chapter 10). A.R.M. planners should get a feeling early in the planning process for where to strike the balance between monitoring cost and level of monitoring precision by obtaining realistic cost estimates for a range of monitoring strategies.

Indicators are needed to gauge forest recovery, deer browsing pressure, and soil chemistry, including acidity and buffering capacity. Forest ecosystems include many organisms in addition to herbaceous plants, shrubs, understory trees, and canopy trees that are of great interest and have strong relevance to forest recovery. Some have been used as indicators of ecosystem restoration, for example, the diversity and abundance of bird species that use the subcanopy and shrub layers.[3] However, we focus in this report on species that deer affect most directly, namely those that they eat. We assume that birds and other vertebrates, insects and other invertebrates, fungi, and soil microorganisms will also benefit from the recovery of vegetation.[4]

A key quality of indicators is how rapidly they respond to the application of a management practice. The density of the shrub layer, for example, has been shown to be useful for detecting progress in restoring forest structure within 5 years after a significant reduction in deer density, at least where seeds or live root systems are present and shade is not too dense. Results from a study carried out at the U.S. Forest Service's Northeastern Research Station at Irvine, Pennsylvania,[5] indicate that tree seedlings and certain herbaceous species can serve in documenting change within 10 years after deer density reduction.

At the start of any program to manage deer from an ecosystem perspective, it would be wise to monitor a fairly broad spectrum of indicators and hone it down to a smaller, more cost-effective set in later years as data are analyzed and less-effective measures are identified and dropped. In this way, costs of the overall program can be reduced over time.Indicators of forest structure, such as extent of herbaceous cover and tree regeneration, are essential for measuring progress in ecosystem management, but it is also useful to have some direct measures of deer impact, for example, percentage of browsed twigs of non-preferred species, as consistency checks. Indicators of soil chemistry may be helpful in explaining variation in recovery rates by stand. It is also useful to monitor indicators of deer density to be sure that desired population changes have actually been achieved (see next chapter).

Certain tree species as rapid-response surrogates for all forest plants

Direct sampling of the most vulnerable components — shrubs and understory plants — is problematic in the short term, because recovery in forests that have been severely overbrowsed will likely take many years. Given this problem, Forum members have looked at supplementing direct measures of herbaceous and understory plants that recover rapidly, such as *Rubus* species, with a more rapidly responding surrogate for herbaceous vegetation. The surrogate is a subset of the tree species, namely, those that can regenerate successfully only if browsing pressure is low enough also to permit recovery of shrub and herbaceous plant diversity. The assumption is that seed sources remaining in the canopy are available to initiate recovery of this component of the woody flora quickly, even where the reappearance of most shrubs and herbaceous species will take longer because of the deer-induced decline of local seed sources. Whether deer management policies that enhance the regeneration of the suite of indicator trees will actually enhance the regeneration of understory plants will need to be tested in the years ahead.

In the well-studied northern hardwood forests of northwestern Pennsylvania, many of the trees regenerate at less than 20 deer per square mile; herbaceous vegetation however, needs densities of less than 10 deer per square mile and full recovery of herbaceous and shrub species diversity may require even lower deer densities. As deer density is reduced, seedlings of black cherry (one of the species least preferred by deer) return first, then sweet birch or yellow birch. followed by eastern hemlock, red maple, white ash, and yellow-poplar (species highly preferred by deer). The latter species are useful as indicators of progress toward recovery. Because of regional variation in tree species composition, it will be necessary to tailor the suite of indicator species by region (see Table 4, pages 53-58).

Data collection would focus on the height and density by species of tree seedlings in scattered sample plots within each of a series of study areas across the state. Typically, tree seedlings of species that deer prefer fail to grow over 1 foot tall if subjected to heavy browsing in uncut or partially cut stands.

Not all forest stands are suited for measurements of indicator-tree regeneration. Stands must be selected where light at the forest floor is sufficient to support the relatively rapid growth of seedlings, which generally excludes stands where the most recent cutting was less than 50 years ago unless they are thinned at around the time when management to reduce deer density is begun. Clearcut stands do not qualify because the flush of new growth can temporarily provide enough forage to satiate even a very dense deer population, delaying the detection of differences in tree seedling survival between clearcut sites where the deer population is reduced and comparison clearcuts where deer management is left unchanged. One possibility for measuring rapid vegetation response to deer herd manipulation may be intact stands more than 50 years old with scattered openings in the canopy due to the death of mature trees. The main advantage of such sites is that it is easy to characterize the forest canopy composition in an intact stand, thereby establishing a baseline against which species' rates of seedling survival can be compared. The disadvantage is that indicators will respond slowly and only in patches, due to the localized availability of light. Indicators are likely to respond faster in stands that have had a partial overstory removal in the past 5 years or so, where light is likely to be more uniformly available at ground level. Furthermore, germination from the seed bank is often accelerated by soil disturbance associated with canopy thinning and potential sites should be easy to identify using aerial photographs or records of recent timber sales. However, in recently thinned stands a much more laborious analysis of the cut stumps would be necessary to establish the baseline forest canopy composition for comparison.

Combined sets of indicators for northern hardwood forest regeneration

In recommending indicators of forest recovery, we focus on the northern hardwood forests across Pennsylvania's northern tier because that is the forest region where the most extensive, directly pertinent research has been done, in large part by scientists at the U.S. Forest Service's Northeastern Research Station in Irvine, Pennsylvania. Some, but not all, of these indicators will be useful in other forest types. Developing state-of-the-art sets of indicators for the remainder of the state will require a comprehensive review of past and ongoing research in Pennsylvania and nearby states on oak-mixed hardwood forests and other forest types. Based on a review of data by staff at the Northeastern Research Station in areas treated with different, controlled deer densities, one might expect to detect significant effects on the recommended indicators (see next page) within 3 to 5 years in thinned stands and 5 to 10 years in intact stands more than 50 years old. These estimates are based on the assumptions that (1) deer density is reduced to about 20 per square mile or lower, (2) stands are in a matrix of managed forest, (3) and there is no agricultural land in the surrounding landscape.

Recommended forest recovery indicators for northern hardwood forests in Pennsylvania are:

(1) Number of stems more than 1 foot tall, categorized by size classs, of tree species most preferred by deer (e.g., red maple, white ash, yellow-poplar, cucumbertree, oaks, eastern hemlock; see Table 4, pages 53-58).

(2) Species richness of tree seedlings and saplings between 1 foot tall and browse height (5 feet) per unit of area.

(3) Equitability or evenness among species of tree seedlings and saplings between 1 and 5 feet tall per unit of area (a common measure of this component of diversity is Simpson's index, the probability of any two individuals drawn at random belonging to different species).

The first three recommended indicators are measurements of tree seedling size and diversity. They are a short-term surrogate for total vascular species composition. It is likely that restoration of herbaceous species diversity will take much longer due to lack of propagules in many areas.

(4) Percent ground cover of *Rubus* (increased cover by *Rubus* is an early indicator of low deer impact where shade at the forest floor is not too dense).[6]

(5) Ratio of *Rubus* to hay-scented and New York ferns.

The *Rubus*-to-fern-cover ratio can serve as a short-term surrogate for the development of full-blown shrub and understory layers (partial structural restoration) which will take much longer.

(6) Ratio of cover of seedlings of deer-preferred trees (e.g., oaks, eastern hemlock, red maple, white ash, and yellow-poplar) to cover of seedlings of less-preferred trees (e.g., black cherry, sweet birch, yellow birch)

(7) Trillium height[7]

(8) Percent of Canada mayflower with flowers or seeds[8]

(9) Percent of American beech stems that are browsed, categorized by browsing severity (American beech is very widely distributed in Pennsylvania and resistant to browsing)

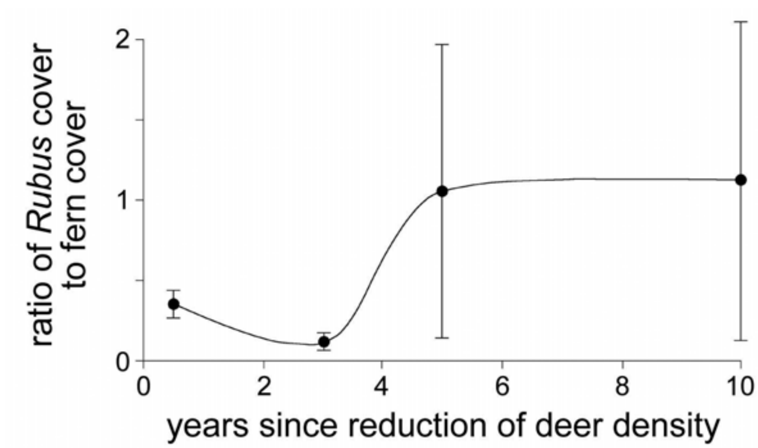
(10) Height of the tallest stem of each preferred species and of the tallest stem of all species combined

Other plants with potential for indicator status that might be considered at some point, either in northern hardwood forests or in other forest types, include wild sarsaparilla[9], sweet-cicely, jack-in-the-pulpit, white baneberry,[10] and Indian cucumber-root.[11] Species considered by various researchers but not recommended for use in Pennsylvania (see endnotes for reasons) include bluebead lily and white wood-lily[12], American yew[13], wood nettle[14], turtlehead, white wood aster, zigzag aster, and jewelweed[15], and eastern hemlock.[16]

For the recommended indicators to be useful in A.R.M., it is necessary to make predictions, based on previously collected data, of their change in response to managed reductions in deer density. For instance, in northern hardwood forests, indicator data (or a composite function of the data) obtained by researchers at the Northeastern Research Station could be graphed as a function of time after deer density reduction, allowing predictions of when the changes would be detectable.

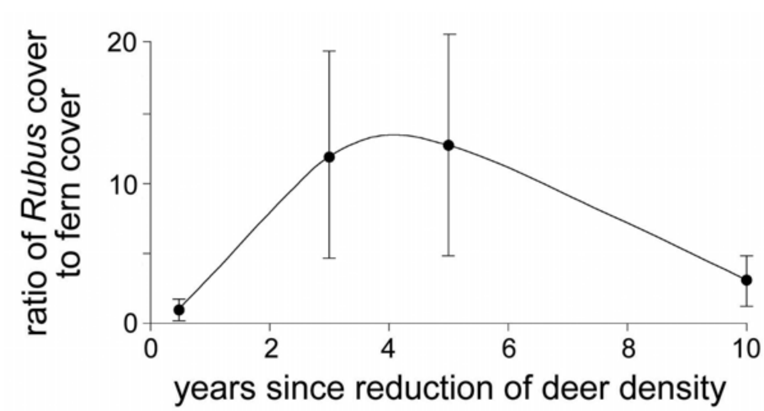
Here we show examples (Figures 5 and 6) based on the ratio of *Rubus* cover to hay-scented and New York fern cover, calculated from data collected in four northern hardwood forest stands in northwestern Pennsylvania.[18] The data were collected after deer density was reduced to approximately 20 deer per square mile from an initial level thought to be about 40 deer per square mile.

Figure 5. Average ratio of *Rubus* cover to hay-scented and New York fern cover in uncut stands over 50 years old, following abrupt reduction of deer density from 40 to 20 deer per square mile (data are from northwestern Pennsylvania;[17] error bars are ± 1 standard error of the mean).



In uncut stands over 50 years old (Figure 5, above), the ratio increased dramatically by 5 years after deer density reduction. However, the error bars are large in this four-stand average. It would be necessary to take measurements in approximately 64 stands to be confident of finding an effect with reasonable statistical significance.[20]

Figure 6. Average ratio of *Rubus* cover to hay-scented and New York fern cover in recently thinned stands following abrupt reduction of deer density from 40 to 20 deer per square mile (data are from northwestern Pennsylvania;[19] error bars are ± 1 standard error of the mean).



In stands thinned at the same time that the deer population was reduced (Figure 6), the ratio rose dramatically within 3 years. By 10 years, as the stand closed up around the thinned areas, the ratio dropped. Even then, however, the ratio was much higher than it was at the time of deer density reduction. The 10-year ratio in these thinned stands is similar to the ratio at 10 years for the uncut stands (Figure 5). However here again, due the large error bars, to be confident of finding an effect as part of an A.R.M. program, the number of stands would need to be increased to around 64.

Based on the graphical analysis (Figures 5 and 6), it would be reasonable to predict a delay of 3 to 5 years before meaningful feedback could be provided from field measurements following a successful reduction in deer density. In practice, changes in deer densities as part of an A.R.M. process will not be abrupt. An increase in antlerless deer harvest permits will not have its full impact until several years after its introduction. Therefore, an additional delay, say 2 years, would be needed, bringing the total time to 5 to 7 years before the initial weights chosen for A.R.M. could be modified for the first time. Thereafter, corrections could be made as often as monitoring measurements were taken.

The data from the Northeastern Research Station represent a 50% reduction in deer density. Presumably, it would take longer to detect changes in the *Rubus*-to-fern cover ratio following lesser reductions in deer density.

Forum members were not able to obtain data that could be used to test the potential utility of the other indicators listed in the set recommended earlier in this chapter to begin A.R.M. in northern hardwood forests. However, data on some of these indicators are now being collected as part of ongoing work at the Northeastern Research Station and will be available in the future. Using results from this and other ongoing research, analysts and A.R.M. program planners will be able to find combinations of indicators that perform far better than any single indicator, including the *Rubus*-to-fern-cover ratio, in terms of the time necessary to detect a change or in the number of stands that will need to be sampled. Once an adaptive research management program is underway, data collected as part of the A.R.M. protocols will be invaluable in improving the choice of indicators used to provide feedback to managers.

Indicators of soil acidity and other soil chemical properties

Chemical element content of leaf tissue and wood from key indicator species such as shrubs in the genus *Rubus* can be tested to determine nutritional status as affected by interactions among natural soil fertility, atmospheric deposition, and deer management. Foliar tissue collected late in the growing season or recently formed xylem tissue collected in the dormant season from woody species can be used for analysis. Molar ratios of calcium (Ca) or magnesium (Mg) to manganese (Mn) or aluminum (Al) in plant tissue have been found to be useful for monitoring differences in soil fertility among regions and changes in soil fertility over time in a given region.[21] Lower ratios of Ca:Mn, Mg:Mn, Ca:Al, and Mg:Al signify increased stress on plants' growth due to poorer soil fertility relative to areas with higher ratios. Decreases in these ratios over time in a given region suggest changes due to atmospheric deposition, whereas increases in these ratios in a region could indicate positive effects of deer management. Soil fertility should be documented within the various deer management treatments and regions over time. A simple Al stress test is recommended, such as the one performed routinely on soil samples by the Pennsylvania State Analytical Services Laboratory using the strontium chloride extraction method, which approximates mineral nutrient concentrations available to plants. Molar ratios of Ca:Al in soil have been used to indicate stress on plant growth. According to one recent study, "there is a 50:50 risk of adverse impacts on tree growth or nutrition when the soil solution Ca:Al ratio is as low as 1.0, a 75% risk when the soil solution ratio is as low as 0.5 and a nearly 100% risk when the soil solution Ca:Al molar ratio is as low as 0.2."[22]

Tolerances of various plant species such as *Rubus* spp. to soil chemical conditions are major variables to be considered in the design of an A.R.M. program. Plant response to deer management may be rapid in areas with soil chemical conditions favorable to an indicator species' growth but non-existent in areas with unfavorable soil conditions. Little information is available about the responses of many indicator plant species to a range of soil conditions. At a minimum, monitoring of soil fertility indicators is needed to help interpret results.[23] Certain types of results would suggest the need for further experiments to disentangle the effects of soil nutrients from deer impacts.

Findings on indicators

(1) Reasonable indicators of forest recovery for use in ecosystem management and deer A.R.M. include the frequency of occurrence, density, and condition (e.g., height, severity of browsing) of representative plant species, both herbaceous and woody. A candidate set is recommended in this report. Expected response times after substantial reduction of high deer densities range from 3 to 10 years. Indicators of soil quality, such as soil acidity, are included to assist in understanding variations in forest recovery rates. Over time, the most cost-effective set of indicators can be identified as an outcome of the A.R.M. process, discussed in Chapter 12.

(2) Indicators include measurements of tree seedling size, abundance, and species diversity, which are short-term surrogates for recovery of the entire vascular plant species community. It is likely that restoration of herbaceous species diversity (full structural recovery) will take much longer due to lack of propagules in many areas. The *Rubus*-to-fern-cover ratio can

serve as a short-term surrogate for the development of full-blown shrub and understory layers (partial structural recovery) which will take somewhat longer.

(3) Although many of the indicators identified for northern hardwoods will apply to other forest types in Pennsylvania, complete sets of indicators need to be developed for the other forest types. This could be done by an ad hoc scientific advisory committee established by agencies in Pennsylvania responsible for public forestlands.

(4) With input from stakeholders and scientists, agencies should adopt short-term goals and, where a consensus exists, long-term goals on the target values for measurable indicators of forest ecosystem recovery. Where a scientific consensus does not exist on long-term ecosystem recovery goals, a group of scientists should be convened to develop such a consensus.

Endnotes

[1] Keddy and Drummond 1996; Lindenmayer et al. 2000

[2] Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003

[3] McShea and Rappole 2000; deCalesta 1994

[4] This assumption needs to be tested periodically.

[5] Horsley et al. 2003

[6] In thinned stands, a strong, highly statistically significant relationship has been found in northwestern Pennsylvania between percent ground cover by *Rubus* and deer density (Horsley et al. 2003). The effect was detected in as little as 3 years at one of three study sites (Fools Creek, Warren County). The same phenomenon was seen in uncut stands, but there *Rubus* growth took 10 years for the effect to be large enough to be detected.

[7] The height of large white trillium plants has proved useful as an indicator of browsing intensity in Illinois (Anderson 1994) and Minnesota (Augustine and Frelich 1998). Large white trillium might be a useful indicator in the westernmost quarter of Pennsylvania, the only part of the state in which this species was ever common and abundant (Rhoads and Klein 1993). However, it is possible that only in the extreme southwestern counties does large white trillium remain common enough to be useful. Purple trillium and painted trillium are somewhat more abundant and widespread. Recent research by Susan Stout and colleagues at the Forestry Sciences Laboratory in northwestern Pennsylvania has shown that the height of purple trillium or painted trillium is a useful indicator of deer impact in the northwestern counties (Dr. Susan L. Stout, Silviculturist/Research Project Leader, Forestry Sciences Laboratory, U.S. Forest Service, and Chad D. Kirschbaum, Sand County Foundation, personal communication, 2003). Augustine and deCalesta (2003) suggested that a sensitive indicator of browse intensity can be constructed by observing flowering rate, mean stem height, size class distribution, and browsing rate of *Trillium* plants.

[8] Canada mayflower was suggested as an indicator by Balgooyen and Waller (1995). Research conducted in northwestern Pennsylvania by Rooney (1997) documented larger leaves and greater frequency of flowering shoots in populations growing on large boulders out of the reach of deer compared with those on small boulders that deer could reach. Based on Rooney's work, recently initiated research by the U.S. Forest Service at Irvine,

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Pennsylvania, is using leaf size and flowering frequency of Canada mayflower as an indicator in a quality deer hunting demonstration area study. Canada mayflower is common and abundant in moist forests throughout the state (Rhoads and Klein 1993). It remains visible throughout the growing season. Plants that will flower or have flowered in the current season are readily distinguishable.

[9] Wild sarsaparilla is another species that Balgooyen and Waller (1995) considered to be a potentially useful indicator. It is a plant of widespread occurrence in Pennsylvania, especially in dryish, acidic, upland forests (Rhoads and Klein 1993). Many populations appear to have few if any flowering/fruiting stems, but it is not known if that can reliably be correlated with intensity of deer browsing.

[10] Webster and Parker (2000) evaluated the potential of sweet-cicely, jack-in-the-pulpit and white baneberry to serve as indicators of browsing intensity. They found a correlation between stem height of all three species with herbaceous species cover adjusted to discount the invasive weed garlic mustard and native species observed to increase in heavily browsed areas (wild ginger and mayapple). They concluded that the mean height of mature plants of sweet-cicely, jack-in-the-pulpit, and white baneberry is significantly reduced in deer impacted areas and that flowering is reduced in white baneberry and jack-in-the-pulpit. They suggested that a single indicator is inadequate because of uneven abundance. All three species examined in this study are widespread in Pennsylvania; jack-in-the-pulpit is the most abundant. There is some doubt that mayapple commonly increases in heavily browsed areas; this is certainly not true in the Wissahickon section of Fairmount Park in Philadelphia. In the Wissahickon forest, mayapple stands are almost gone from the most heavily browsed area; all that remains in some sites are a few juvenile shoots that are barely hanging on (A. F. Rhoads, personal observation). The impact of grazing on the leaves of jack-in-the-pulpit was discussed by Ruhren and Handel (2000), who found lower than expected flower and fruit production among affected plants in a study of browsed forests in New Jersey. One reviewer of an earlier draft of this chapter had an alternate view of the usefulness of some of the proposed indicators, stating: “Based on my data, I disagree with, or would suggest amendments or alternatives to, several of the measures proposed as indicators in Chapter 9. Of course, I understand that the report’s list of possible indicators is only a first stab at some likely ones. The A.R.M. team that eventually oversees the application of A.R.M. will obviously have to do their own initial evaluation, and propose assays that seem reasonable within the model’s framework” (Dr. Daniel Townsend, Associate Professor of Ecology, Department of Biology, University of Scranton, personal communication, 2003). We encourage participation by this reviewer and others who have conducted pertinent research in Pennsylvania forests in subsequent evaluations of indicators.

[11] Indian cucumber-root is visible all summer. Blooming plants form a second tier of whorled leaves. Flowering and the formation of the upper whorl appear to be suppressed in heavily browsed areas.

[12] Bluebead lily has been suggested as a browsing-intensity indicator in Wisconsin (Balgooyen and Waller 1995). In Pennsylvania it was historically found in northern counties and at high elevations along the Allegheny Front (Rhoads and Klein 1993). It is much more limited in abundance today, and may have already become too depleted to be a sensitive indicator. It is rarely found blooming. More often just leaves are present and those tend to be at scattered sites. The closely related white wood-lily was once abundant in the western third of Pennsylvania but is now greatly diminished, especially in the northwest.

[13] American yew has been identified as a species that is preferentially browsed (Allison 1990a, 1990b, 1992) and suggested as an indicator (Balgooyen and Waller 1995). It was widespread in Pennsylvania at one time (Rhoads

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and Klein 1993), but has become so depleted as to be of little use as an indicator today. It persists mainly on steep slopes and cliffs out of reach of deer.

[14] Wood nettle, whose potential value as a browsing-intensity indicator was discussed by Augustine et al. (1998), occurs throughout the state, primarily in low, moist forests and floodplain areas (Rhoads and Klein 1993). It may be too narrowly habitat-restricted to be generally useful as an indicator of browse severity.

[15] Williams et al. (2000) concluded that although turtlehead was frequently browsed, stem height could not reliably be correlated with deer density. Although it occurs throughout the state, turtlehead is limited to riparian and wetland areas (Rhoads and Klein 1993). Williams et al. (2000) suggested that an assemblage of herbaceous species might be more reliable than a single indicator and mention white wood aster, zigzag aster and jewelweed as possibilities. Bluestem goldenrod and silverrod have also been suggested for this purpose (Dr. Daniel Townsend, Associate Professor of Ecology, Department of Biology, University of Scranton, personal communication, 2003). White wood aster, bluestem goldenrod, and silverrod are common and abundant forest plants throughout Pennsylvania, and jewelweed and zigzag aster are common to abundant in wetlands (Rhoads and Klein 1993).

[16] Several researchers have suggested that seedlings of eastern hemlock could serve as an indicator of deer browsing intensity. However, many factors have been shown to affect the establishment and successful growth of hemlock seedlings (Long et al. 1998; Mladendorff and Stearns 1993), making it doubtful that their abundance or condition could reliably be used to infer browsing intensity alone.

[17] S. B. Horsley, unpublished data; see Horsley et al. (2003) for methods.

[18] S. B. Horsley, unpublished data; see Horsley et al. (2003) for methods.

[19] S. B. Horsley, unpublished data; see Horsley et al. (2003) for methods.

[20] Based on $\alpha = 0.1$ and $\beta = 0.2$, i.e., with a 90% chance of correctly accepting the null hypothesis if it is true and an 80% chance of correctly rejecting the null hypothesis if it is false would probably be adequate.

[21] Dr. David R. DeWalle, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, personal communication, 2003

[22] Cronan and Grigal 1995

[23] Dr. David R. DeWalle, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, personal communication, 2003

Chapter 10. Methods of Estimating Abundance of White-tailed Deer

It is difficult to observe deer and estimate abundance using simple counts; nevertheless there have been many methods developed to estimate the abundance of white-tailed deer because they are an economically important species. Methods that provide accurate and precise population estimates usually are expensive. Traditionally, wildlife managers have used estimates or indices of deer abundance to recommend harvest quotas to meet management goals based on deer densities.[1] This approach to deer management does not necessarily explicitly acknowledge the uncertainty (levels of bias and precision) of these population estimates, and public disagreement over deer numbers often leads to confusion for decision makers. Aldo Leopold and colleagues noted, "A common error is to try to appraise [deer numbers] by census, rather than by browse conditions. The public can dispute endlessly about censuses, but it cannot dispute dead browse plants."[2]

In this report we investigate the use of plant indicators for monitoring forest ecosystem conditions and the effect of deer (see Chapters 9 and 11) within an adaptive resource management paradigm. However, to do this one still needs to monitor deer abundance to make certain that management actions intended to reduce (or increase) deer populations actually do so. Because A.R.M. incorporates uncertainty of data inputs into the process, a measure of deer abundance statewide or in large regions within the state could be quite crude and still be useful, for example, an index of deer abundance such as road-kill counts. However, if the importance of deer browsing impacts on forest conditions is to be studied at a more experimental scale (see Chapter 12) then more accurate and precise (and expensive) deer population estimates will be required.

Survey methods can be classified into two general types: indirect methods based on monitoring deer signs (e.g., tracks or harvest numbers) and direct methods that require capturing or observing deer. This chapter describes the various methods that have been developed by wildlife biologists to estimate population abundance or to monitor changes in abundance over time.

Indirect Methods

Most of the indirect methods do not provide estimates of absolute abundance, but are intended to provide an index of relative abundance that can be used to detect relative changes over time. For example, counts of the abundance of deer trails,[3] tracks,[4] deer sightings per kilometer walked on foot,[5] intensity of browsing,[6] abundance of fecal pellet groups,[7] and number of deer killed along roads[8] have all been used as indices of abundance. Hunter harvest data have been used as an index of abundance (e.g., density of buck harvest) as well as to obtain population estimates.[9] All of the index methods assume that potential sources of variability in the index (e.g., deer defecation rates, hunter effort, or movement by deer across the landscape) are constant over time so that even though the method does not provide a measure of absolute abundance, the changes in the index over time reflect changes in population size alone.

In addition to providing an index of abundance, pellet group counts have been used to obtain estimates of absolute (actual) abundance[10] by relying on certain assumptions about deer defecation rates. Although specific field methods used to collect pellet group data vary widely, the following general equation is used to estimate deer density:[11]

$$\textit{deer density} = \frac{G}{R \times Y} \qquad \text{Eq. 5}$$

where G is the density of pellet groups on the study area, R is the defecation rate of an individual deer (pellet groups per deer per day), and Y is the number of days deer have been defecating. A typical method would be to visit a sample of circular plots across the study area and eradicate all existing pellet groups on the plot, then return to those plots Y days later and count the newly deposited pellet groups. By assuming a defecation rate, deer density can be estimated using Equation 5 and abundance can be estimated by multiplying by the size of the study area. The assumptions of this method are that a random sample of plots has been selected, the defecation rate (R) is constant among deer and surveys, and pellet groups are counted accurately on the plots.

There is some value in discussing how the pellet group technique has been used in Pennsylvania, because it has generally been applied somewhat differently from this description.[12] First, the number of days (Y) has been taken to be the number of days since leaf drop. This removes the labor requirement of first eliminating all existing pellet groups on plots, but imposes the assumption that all pellet groups deposited prior to leaf fall have been covered by leaves and that this event occurs on a specific date. Second, pellet groups are typically counted along 6-foot wide transects that are approximately 5,000 feet long; however, current recommendations are to count pellets on 4-foot radius plots located every 100 feet along the transect, and to survey more transects of shorter length.

In applying the pellet group counting method, including modifications of the technique,[13] several factors must be considered to minimize variability and bias in the resulting density estimates: (1) observer skill and fatigue in detecting pellet groups, (2) choice of plot shape, (3) habitat (vegetation) influences on detection of pellet groups, (4) decay rate of pellet groups, and (5) an appropriate sampling design. A study design and data analysis that take into account many of the potential problems with typical pellet group surveys have been described and implemented by a group of researchers in Scotland.[14] They used distance sampling[15] to account for differential detection among habitats, included decay rates of pellet groups, and used a statistically based sampling design. However, even these methods require a number of suspect assumptions, including a constant defecation rate and no variation in decay rates among habitat types. Research on defecation rates indicates that they vary among seasons (presumably because of dietary changes) and age-sex classes[16] and decomposition rates differ according to habitat type.[17]

Indices or estimates of abundance based on hunter harvest data have been commonly used by state agencies because harvest data are readily available. A review of nine general types of methods of estimating abundance using harvest data,[18] including multiple methods within each type, concluded that index-removal, change-in-ratio, and life table analysis methods were least satisfactory because critical assumptions could not be met. Harvest age structure and harvest sex ratio methods were better but did not provide precise population estimates. Population reconstruction methods were sensitive to varying harvest rates but could only provide historical population estimates. Some of the models based on a catch-per-unit-effort (C.P.U.E.) approach were best at closely monitoring trends in abundance. The Lang-Wood and Fraser methods were not as effective as the C.P.U.E. models, but the reviewers suggested they could serve as supplemental methods of analyzing harvest data.[19]

C.P.U.E. techniques can be used if hunter harvest and capture effort are recorded (e.g., hunter-days or trap-nights) and these data are collected over t time intervals (usually days or weeks). The simplest form of a C.P.U.E. model assumes the following relationship between harvest (catch), effort, and population size:

$$\frac{harvest}{effort} = kN \qquad \text{Eq. 6}$$

where the t data points are used to estimate N at $t = 0$ (i.e., the population size prior to any removals). The key assumptions of this technique are that the population is closed during the time interval under study (no immigration, emigration, births, or deaths) except for the known removals and that all individuals are equally susceptible to harvest. More complicated models that relax the assumption of closure or equal harvest probability have been developed.[20] One research group who applied the C.P.U.E. technique to deer at Chesapeake Farms, Maryland, found that the population density estimates were, on average, 14% below direct estimates of abundance, but that the method accurately described relative changes in the population.[21]

Direct methods

Methods of monitoring deer populations in which animals are counted in some manner may or may not attempt to adjust for the fact that the probability of detection is less than 100%. If the probability of detection is assumed to be 100%, the counts can be treated as an estimate of absolute abundance; otherwise, the counts are treated as an index of relative abundance. In all the methods discussed hereafter, if the method does not directly incorporate an estimate of detection probability, counts can be adjusted for a probability of detection less than 100% by marking a subset of deer and using them to estimate the probability of detection experimentally.

Drive counts

In fenced areas, researchers have used drives to count deer. Drives involve a line of people traversing the study area and counting all deer observed on the area. Problems found with this technique include (1) double-counting by observers, (2) deer gone undetected in thick vegetation, (3) gaps in the observer drive line where deer escaped undetected, and (4) differences in the behavior of deer among years because of weather conditions and other unknown causes.[22] Even if the protocols used to conduct the count are standardized as much as possible, the estimates are unlikely to have a constant bias, and will simply provide a minimum number of animals on the study area.

Spotlight counts

Spotlight counts have been used to census deer[23] because the species is more active at dusk and can be seen in greater numbers at this time of day. The primary problem is that spotlight counts typically are conducted along roads and do not survey areas inaccessible by vehicles. Spotlight surveys have a probability of detection less than 100% because of the areas not surveyed and because not all animals are visible behind obstructing vegetation.

Aerial surveys

Aerial surveys provide the ability to cover large areas quickly and easily, although the hiring of pilots and rental of aircraft can be expensive. Moreover, to obtain accurate and precise population estimates the probability of detection must be estimated and incorporated into the estimator of abundance. A 1987 review of various estimators applicable to aerial surveys summarized methods of estimating abundance[24] by (1) correcting aerial counts with a subset of areas where both aerial and ground counts are conducted, (2) using observations from independent observers of the same area with Lincoln-Petersen or Zippin estimators, (3) having a marked (e.g., radio-collared) subpopulation of animals to estimate detection probability,[25] (4) multiple counts (e.g., bounded count estimator[26]), (5) distance sampling, and (6) sightability modeling.

Theoretical development and application of distance sampling in aerial surveys has been greatly expanded since the 1987 review; the methods were reviewed in detail in 2001 by another research group.[27] Line transect distance sampling assumes that all objects on the transect line are detected, but in reality detection probability may decline away from the transect line. By modeling this decline as a mathematical function, a detection probability can be estimated for any distance an object is located from the transect line. The difficulty with applying distance sampling for deer via aerial surveys is that the assumption that all objects on the transect line are detected is likely to be violated.[28]

Sightability estimators model the probability of detection as a function of animal and background environmental characteristics (e.g., group size, vegetation cover, behavior of the animal).[29] This model is developed from data collected by marking animals, conducting aerial surveys, and then recording the characteristics of each animal and whether it was observed or not. The method is appealing because once a sightability model is developed, additional animals do not have to be marked, which greatly reduces the cost of the technique. However, in a study of elk in Pennsylvania the population estimates were found to be too variable for use as a management tool.[30]

Thermal imagery

The primary problem with using aerial surveys for white-tailed deer in Pennsylvania is the visual obstruction by vegetation. Wildlife agencies in the western United States rely primarily on aerial surveys to estimate abundance of big game species,[31] but visual obstruction in sagebrush and other open habitats is a far less significant problem than in the forested habitats of Pennsylvania. Moreover, snow cover is not consistent in Pennsylvania, and snow enhances visibility of animals for aerial surveys.[32] One technological solution to the visibility problems associated with aerial surveys of deer is the use of thermal imagery. Researchers in Florida reported that standard aerial survey methods counted only 58% of the number of deer counted using thermal imagery;[33] however, whether the thermal imagery detected all deer is unknown. Detection probabilities of 72 to 87% were reported using a helicopter to survey white-tailed deer in forested habitat in Missouri with snow cover,[34] which suggests that thermal imagery may have greater detection rates than other aerial survey methods.

Mark-recapture

Mark-recapture methods involve individually marking deer and comparing the proportion of marked deer recovered in the harvest with the total harvest. The estimator is the same as that used in aerial surveys described above.[35] This method is expensive because a large number of deer need to be marked — at least 45% of the deer if the population is small (less than 200 animals). In addition, the method is based on the assumption that marks are never lost and that deer do not emigrate from the study area. The mark-recapture method has been shown to overestimate deer population size because of unknown mortality of marked deer and emigration from study areas.[36] Accurate monitoring of mortality and emigration requires the use of radio-collars in place of marks. Another problem with this method is that every deer is assumed to have the same probability of being harvested, which is unlikely to be true. Harvest rates are likely to differ between sexes because of harvest regulations (limited antlerless permits) and hunter preferences, and among deer of different ages (e.g., lower harvest rates of older age-classes).

Camera surveys

Infrared emission-triggered cameras have been used to collect sighting-resighting data to estimate the population size of white-tailed deer,[37] in some cases using the Lincoln-Petersen estimator with photographic "recaptures" of previously radio-collared deer.[38] Camera surveys have also been used to derive minimum deer population estimates using the ratio of spike-to-branch-antlered bucks, the fawn-to-doe ratio, and the number of unique branch-antlered bucks photographed.[39] However, unless the study area is saturated with cameras, the capture probabilities among deer will be heterogeneous and population estimates will be biased low. A 1997 estimate of the cost of a 140-day survey, at one camera per 160 acres, was 52 cents per acre per year with the cost of equipment amortized over 5 years.[40]

Change-in-ratio

The change-in-ratio technique, when used for deer, requires surveys of the ratio of antlered to antlerless deer prior to and following a hunting season, as well as the number of deer harvested.[41] Although the data are relatively simple to collect, the assumption that antlered and antlerless deer are seen with the same probability is likely to be violated;[42] however, if only one type of animal (e.g., only antlered deer) is removed during the hunt, the population estimate for that type is unbiased.[43] An evaluation of the method at Chesapeake Farms, Maryland, in relatively open habitat showed that sample sizes to obtain adequate precision of population estimates could be achieved.[44] The observation rate there was 196 deer per 100 miles of survey route. A drawback is that if a deer population is managed near a 1:1 antlered-to-antlerless ratio then the change-in-ratio estimator will not work because the change in ratio will be near zero.

Findings on methods of estimating abundance of white-tailed deer

(1) Within A.R.M., confirmation of changes in deer abundance following management actions will be necessary to ascertain that management actions intended to decrease (or increase) deer populations actually do so.

(2) Precise and accurate estimates of deer abundance are expensive. For large areas (e.g., the Pennsylvania Game Commission's 21 wildlife management units covering all of

Pennsylvania; see Figure 4A), relatively crude but easy-to-measure indices of abundance may have to be used.

(3) If deer populations are manipulated on a small area (e.g., several square miles) to learn more about the effect of deer browsing on forest conditions in an experimental context, more accurate and precise population estimates will be required.

Recommendations on methods of estimating abundance of white-tailed deer

(1) The Pennsylvania Game Commission currently obtains accurate estimates of deer harvest, by wildlife management unit, to estimate the deer population prior to the hunting season; this method of population estimation would likely be sufficient for A.R.M. applied on a statewide basis.

(2) Experimental areas where deer populations are intentionally manipulated to provide a more direct test of competing models under A.R.M. will require more expensive methods of population estimation. Because the best method depends upon the characteristics of the study area, specific recommendations are not possible within the scope of this report.

Endnotes

[1] E.g., Kubisiak et al. 2001
[2] Leopold et al. 1947: p. 175
[3] McCaffery 1976
[4] Yanosky and Mercolli 1994
[5] Vincent et al. 1991
[6] Morellet et al. 2001
[7] Neff 1968
[8] McCaffery 1973
[9] Roseberry and Woolf 1991
[10] Neff 1968
[11] Neff 1968
[12] deCalesta 1991
[13] deCalesta 1991
[14] Marques et al. 2001
[15] Buckland et al. 2001
[16] Rogers 1987
[17] Dr. Duane R. Diefenbach, Assistant Unit Leader, Pennsylvania Cooperative Fish and Wildlife Research Unit, Pennsylvania State University, unpublished data
[18] Roseberry and Woolf 1991
[19] Roseberry and Woolf 1991
[20] DuPont 1983; Laake 1992
[21] Lancia et al. 1996

Endnotes

[22] McCullough 2001

[23] Rakestraw et al. 1998

[24] Pollock and Kendall 1987

[25] Bartmann et al. 1987

[26] Robson and Whitlock 1964

[27] Buckland et al. 2001

[28] Quang and Lanctot 1991

[29] Samuel and Garton 1994

[30] Cogan and Diefenbach 1998

[31] Rabe et al. 2002

[32] Samuel et al. 1987; Beringer et al. 1998

[33] Havens and Sharp 1998

[34] Beringer et al. 1998

[35] Pollock and Kendall 1987

[36] Kubisiak et al. 2001

[37] Garner et al. 1995

[38] Jacobson et al. 1997

[39] Jacobson et al. 1997

[40] Jacobson et al. 1997

[41] Conner et al. 1986

[42] McCullough 2001

[43] Seber 1982: p. 359

[44] Conner et al. 1986

Part IV. Details of How Deer Might be Managed in Pennsylvania from an Ecosystem Perspective

Chapter 11. Management of White-tailed Deer Populations

Chapter 12. How Deer Might be Managed in Pennsylvania from an Ecosystem Perspective Using Adaptive Resource Management

Chapter 11. Management of White-tailed Deer Populations

Regulating deer densities in forested regions is a crucial tool for managing deer from an ecosystem perspective. However, it is only feasible for managers to affect deer populations directly in large forest tracts by changing just one of the four components of the classical population equation:[1]

$$N_{t+1} = N_t + \textit{births} - \textit{deaths} + \textit{immigrants} - \textit{emigrants} \qquad \text{Eq. 7}$$

namely deaths, by regulating hunting rates. Nonetheless, the ways that management actions can affect deer densities are complex. Hunting rates can be regulated separately for bucks and does and for different age classes and manipulating habitat and predators can affect deer populations indirectly. In an ecosystem-based model of the effect of various white-tailed deer management schemes developed for the Huntingdon Forest in New York's Adirondack Mountains,[2] the included variables were winter severity, population density, fawn survival, predation, illegal hunting, area inhabited, habitat quality, deer reproduction, deer recruitment, hunting, and roadkill. Preliminary model predictions indicate that reaching and maintaining population levels of 10 to 20 deer per square mile at that site will require simultaneous manipulation of five control parameters: the harvest rates of adult males, yearling males, and females, manipulation of habitat quality, and predation.

Ecology of deer and their role in ecosystems

White-tailed deer are herbivores that primarily feed on woody browse during the winter, leafy browse and herbaceous plants during spring and summer, and mast (primarily acorns) and agricultural crops when available. Deer are selective, preferring some plant species over others, but they are considered to be dietary generalists because they consume a wide range of plant species as availability changes among seasons, years, and habitats.

Deer are highly adaptive and thrive in urban, agricultural, and forested ecosystems throughout the country.[3] Climate, habitat type, and quality and quantity of habitat determine the ecological carrying capacity, or number of deer a particular area can support without substantially altering the vegetation[4] (see box on page 16). The size of a deer population in relation to a habitat's carrying capacity has a strong influence on the impacts deer have on the ecosystem. As deer numbers approach or exceed the carrying capacity, preferred foods become less abundant per capita and deer begin to eat less-preferred plants. Plant diversity decreases as preferred plants become less abundant. Consequently, the impacts deer have on ecosystems are dramatically increased when deer numbers approach or exceed the carrying capacity.

Carrying capacities vary across space and time because food and cover resources are more abundant in some areas than in others and in some years and seasons. Thus, a population of 40 deer per square mile in a heavily forested region where there is a low carrying capacity for deer will have greater impacts on the ecosystem than the same deer density in a woodlot surrounded by agricultural fields where the carrying capacity for deer is higher. The extent to which agricultural crops buffer the impacts deer have on the ecosystem has not been studied extensively;[5] however, it is reasonable to assume that the presence of cropland buffers deer impacts on nearby forests, because crops are preferred foods and comprise much of the diet of deer when available.[6]

Furthermore, deer populations and carrying capacities vary according to the scale of observation. Work conducted from 1958 to 2003 on the Huntington Forest in the New York's Adirondack Mountains showed a spatially variable response of tree regeneration to reductions in deer population density.[7] Telemetry studies involving more than 600 radio-tagged deer have shown that deer are patchy in distribution, with some areas of around 500 acres experiencing about 40 deer per square mile even though the estimated overall density in the region is less than 10 deer per square mile.[8] Conventional wisdom has held that, when deer density is reduced locally, deer fill in quickly, equalizing the density across the broader area. Recent evidence refutes this assumption. At Huntington Forest, removal of a matrilineal group resulted in a significantly lower deer density than that of surrounding areas for 5 years.[9] (In practice, seasonal fidelity of deer to home ranges renders knowledge of familial relationships unnecessary.) Recent studies have shown this phenomenon in a range of environments from wildlands to suburbs.[10] Importantly, such studies show that it is possible to manage deer populations at scales of 1,000 to 10,000 acres, and perhaps at the stand level (10 to 100 acres), by focusing removal on smaller groups of deer. Thus, it is reasonable to suppose that our proposed reductions of deer densities in 10-square-mile (6,400-acre) treatment areas as part of A.R.M. (see Chapter 12) will not be undermined by rapid immigration.

Historical assumptions about deer population dynamics at landscape and regional scales have come under review in recent years.[11] For example, New York's Adirondack region has been generally treated by wildlife managers as a single entity but the deer population appears actually to be about five subpopulations, each responding differently to management and natural environmental pressures.[12] Until shown otherwise, it should be assumed that the same is likely to be true across Pennsylvania, probably to an even greater degree because of the state's much larger size, regional variation in environmental factors, and uneven distributions of agricultural, urban, and suburban land uses. Moreover, hunting effort is not spread uniformly across the forest landscape, among forested areas within counties, or among regions within the state. For example, hunters tend to cluster near roads and on public lands. It is crucial that future research and A.R.M. programs, including the theories on which they are based, should be designed and formulated with explicit attention to differing expectations at different spatial and time scales.

Ecologists sometimes refer to deer as a "*K*-selected" species, which means they are large, mature slowly, have low reproductive rates, and are long-lived relative to most other animal species.[13] Such species tend to have density-dependent mechanisms that stabilize their population numbers near carrying capacity. Preferred foods become less available for each deer as deer numbers approach carrying capacity, which adversely affects their physical condition. Reduced physical condition results in lower body weights, reproductive rates, and fawn survival, which in turn result in reduced population growth rates.[14]

Population ecology of white-tailed deer

Managing white-tailed deer herds and understanding the population ecology of deer — how deer herds respond to environmental conditions — is more complex than many people believe. It often is believed that more deer can be harvested if there are more deer in the population. In fact, the management of game animals for a long time was based on this concept, known as the "annual surplus" theory.[15] However, research over the past several decades has improved our understanding of how population ecology relates to deer harvest management. Scientific studies examining productivity and mortality rates in deer populations have determined that maximum numerical harvests occur when deer populations are intermediate in size; the number of deer available to harvest begins to decline as habitat conditions deteriorate due to too many deer eating a diminishing amount of food.[16] Therefore, the annual surplus theory is correctly applied only when deer densities are very low and all deer in the population are in good health. In order to explain why this is so, it is necessary to set the stage with some additional background on population ecology.

Population growth rates

Deer population growth rates can increase exponentially under optimum conditions, where there is no shortage of food, cover, or space and diseases or predators are not affecting the population. In this situation, the birth rate is maximized and the death rate is at a minimum, which allows the population to grow at the fastest rate possible. The general model explaining this relationship, called the exponential model, is:

$$\textit{annual change in number of deer} = r \times N \qquad \text{Eq. 8}$$

where r is the maximum annual reproductive rate and N is the number of deer in the population. This model suggests that 10 female deer with a typical maximum birth rate of 1.9 fawns[17] and a 50:50 sex ratio at birth can grow to 4,076 deer in 10 years (Figure 7, on next page).

Although deer herds can grow very rapidly,[18] it is obvious that the assumptions of the exponential model cannot be met in the real world because food, cover, and space are finite. The population will not grow exponentially if: (1) the amount of food resources does not meet the demand by the deer population, (2) there is not adequate cover for all of the deer, (3) predators increase in number as a response to a larger deer herd, or (4) disease increases mortality rates as a result of high deer densities. Previous studies have shown limited nutritional availability,[19] inadequate habitat,[20] predators,[21] and disease[22] reducing deer populations. These factors may affect a population by decreasing the reproductive rate or increasing the mortality rate so that the population does not grow indefinitely. The general model explaining this relationship is referred to as the logistic model and is described by:

$$\text{annual change in number of deer} = \frac{dN}{dt} = r \times N \times \frac{K - N}{N} \qquad \text{Eq. 9}$$

where r is the maximum annual reproductive rate, N is the current number of deer, and K is the maximum number of deer the area can support (i.e., carrying capacity). This more realistic model suggests that the deer population will grow exponentially as long as the number of deer is below 50% of carrying capacity. This point often is referred to as the inflection point; it is where the annual population growth rate (the slope of the curve) reaches a maximum (Figure 8).

Using the logistic model with the same reproductive rates used in the exponential model, but assuming a particular area has a carrying capacity of 4,076 deer, it takes a deer herd 15 years to reach the same number of deer modeled by the exponential equation in 10 years. This is due to the relationship between high deer numbers and the number of deer the environment can support

Figure 7. Deer population sizes derived from the exponential growth model

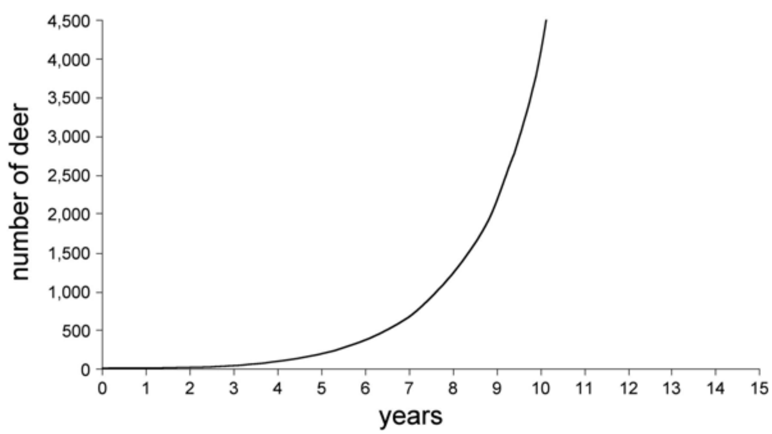
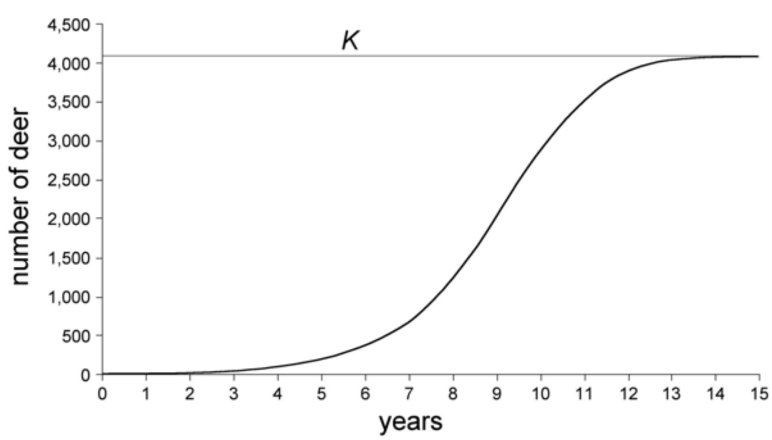


Figure 8. Deer herd sizes modeled by the logistic model. *K* (carrying capacity) was assumed to be 4,076 for comparison to the exponential model in Figure 7.



(Figure 8).[23] Because the population growth rate depends on the density of the deer population itself, the pattern of population change described by the logistic model is said to be a *density-dependent* process.

Sustained harvest yield theory

The logistic model is part of the foundation of deer harvest management. A deer population will grow to *K* (carrying capacity) if it is not hunted and density-*independent* sources of high mortality (e.g., severe winter weather) are not continuously affecting the population. Along the periphery of a species' range, density-independent factors may control population numbers rather than density-dependent factors.[24] However, the white-tailed deer's range extends well to the north of Pennsylvania suggesting that (1) density-dependent factors should control deer numbers most of the time (infrequent exceptions may occur during unusually severe winters, but even then only in a fraction of the state's area) and (2) the logistic model is useful for describing population growth rates as well as population responses to various harvest management options.

The number of deer born each year that survive to the following year (recruitment) in relation to the number of adults that survive determines whether the population increases or decreases. The deer population will increase if the number of fawns recruited into the population exceeds the number of adults that die. Conversely, the population will decrease if the number of adults that die exceeds the number of fawns recruited in a given year. The population will be stable if recruitment and mortality are identical. Consequently, the effect of the number of deer harvested on the total population depends exclusively on the number of deer recruited each year. If more deer are harvested than recruited, the population will decline and if more deer are recruited than harvested, the population will grow. Again assuming a population with the same birth and death rates as described above in the logistic model example, a sustained harvest rate of 400 deer per year can be taken when there are either about 500 or about 3,400 deer (Figure 9, on next page). This occurs because the low-density deer population has a high recruitment rate but the high-density deer population has a low recruitment rate. Thus, the total number (but not the rate per adult female) of fawns recruited is similar in both scenarios as are the numerical harvests.

Management tools can be applied to increase future annual harvests, but they differ between the two scenarios. For the smaller herd, future annual harvests can be increased by under-harvesting the herd for 1 year or more, allowing more does (*N*) to survive and produce fawns at the maximum reproductive rate. For the larger herd, annual harvests can be increased by decreasing the population, making more resources available for each doe and thereby increasing the per capita recruitment rate. The maximum sustained yield (M.S.Y.) occurs experimentally at about 56% of *K*, which is essentially the same as the inflection point on the population growth curve produced by the logistic equation.[25]

The general principles of sustained harvest yield theory are: (1) hunted populations cannot be maintained at *K* (carrying capacity); (2) sustained yield (S.Y.) is achieved when numerical harvests are equal to the number of animals recruited into the population; (3) the same S.Y. occurs at two population densities — a low population density with high recruitment and harvest rates and a high population density with low recruitment and harvest rates; (4) the deer population will be driven to extinction if the population is on the left arm of the curve (Figure 9) and harvest continually exceeds recruitment; (5) if the population is on the right arm of the curve and harvest exceeds recruitment (but is less than M.S.Y.), the deer population will decline to the balance point (where harvest = recruitment) on the right arm of the curve, whereas if the harvest is less than recruitment, the population will increase to the balance point on the right arm of the curve.[26]

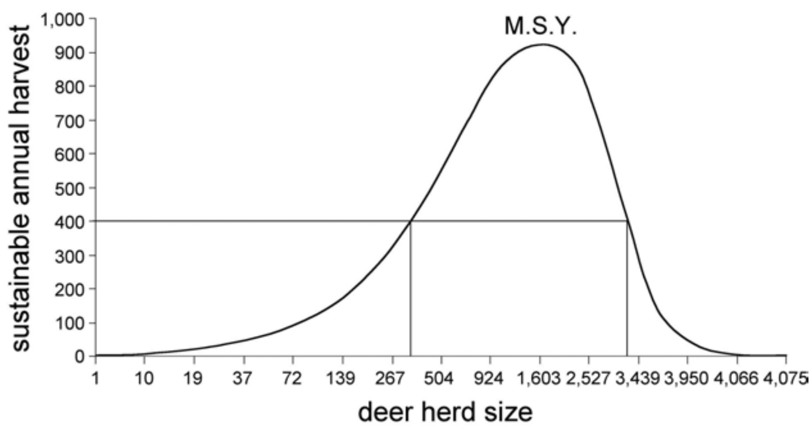


Figure 9. Number of deer available to harvest (sustained yield), based on the number of deer recruited at each population size calculated in Figure 8. In this example, approximately 400 deer can be sustainably harvested when there are either 500 or 3,400 deer, and maximum sustained yield (M.S.Y.) occurs at about 2,000 deer.

Thus, even though deer densities will decrease in Pennsylvania as a result of managing deer from an ecosystem perspective, numerical harvests should be expected to increase for many areas in Pennsylvania that have deer numbers presently exceeding the level that would produce M.S.Y. because recruitment rates will be stimulated as the habitat recovers. There may be fewer deer seen by hunters, but sustainable harvest rates will be increased wherever recruitment rates increase. Assuming that there are sufficient numbers of hunters or levels of effort per hunter, this translates into higher numerical harvests for both antlerless deer and adult bucks in those areas.[27]

Immunocontraception as an alternative to hunting

Perhaps the most often cited possible alternative to hunting for reducing deer populations is lowering the birth rate using contraception. Although the technology for inducing contraception in wild large-mammal populations is advancing, no technique has been developed that is effective in any but small, isolated populations and all methods developed to date are extremely expensive.

Immunocontraception using porcine zona pellucida protein (PZP) has been successfully used to control ungulate populations in zoos and other captive herds. However, to be most effective, repeated injections of each treated animal have been necessary.[28] The difficulty of successfully administering the vaccine to free-ranging animals has been barrier to the wider use of this technique.

Several recent research papers address efforts to utilize PZP to control free-ranging deer in suburban settings. One study in Connecticut indicated that treatment of about 70% of a free-ranging suburban white-tailed deer population is possible.[29] However, the cost to treat 30 deer for 2 years was estimated at $33,833 ($1,128 per deer). Another study of the potential for controlling free-ranging deer with PZP was conducted in a 17-square-mile suburban community in New York State with about 400 deer.[30] The authors concluded that immunocontraception has the potential for holding suburban deer populations at 30 to 70% of ecological carrying capacity, but is likely to be effective only in localized populations where the number of females to be treated is less than 200.

We were unable to locate any published research that addressed the potential for using PZP to control deer in large forested tracts. However, the Humane Society of the United States reports that a one-shot form of PZP known as SpayVac™ produced by ImmunoVaccine Technologies, Halifax, Nova Scotia, has demonstrated long-term effectiveness.[31] It is not clear to what extent this new product will overcome the obstacles and costs cited above. It would be difficult and is likely to be prohibitively expensive to administer even a single shot to enough female deer to effectively limit reproduction over large areas.

Findings on deer population management

(1) It often is believed that more deer can be harvested if there are more deer in the population. However, scientific studies examining productivity and mortality rates in deer populations have determined that maximum numerical harvests occur when deer populations are intermediate in size. The number of deer available to harvest begins to decline as habitat conditions deteriorate due to too many deer eating a diminishing amount of food.

(2) Even though deer densities will decrease statewide as a result of managing deer from an ecosystem perspective, numerical harvests should increase in many areas where deer

numbers presently exceed levels that would produce the maximum sustained yield, because recruitment rates will be stimulated as the habitat recovers. Hunters may see fewer deer but sustainable harvest rates will increase wherever recruitment rates increase. Assuming sufficient hunter numbers and levels of effort per hunter, this translates into higher numerical harvests for both antlerless deer and adult bucks in those areas.

(3) Contraception is often mentioned as a possible alternative to hunting for reducing deer populations. Although the technology for inducing contraception in wild large-mammal populations is advancing, no technique has been developed to date that is effective except in small populations isolated in suburban forest fragments, and all methods so far are extremely expensive.

Endnotes

[1] Where *t* is a point in time and the numbers of births, deaths, immigrants, and emigrants are those that occur during the interval from *t* to *t* + 1.

[2] Sage et al. 2003a

[3] Nixon et al. 1991; Van Deelan et al. 1997; Grund et al. 2002

[4] McCullough 1979

[5] But see Taylor 1984; Underwood and Porter 1997; Augustine and Jordan 1998.

[6] Nixon et al. 1970

[7] Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003; see also Didier and Porter 2003.

[8] Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003

[9] Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003; see also McNulty et al. 1997.

[10] Porter et al. 2004

[11] Porter et al. 1991; Mathews and Porter 1993

[12] Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003

[13] Fowler 1981

[14] Woolf and Harder 1979; Severinghaus and Moen 1983; Nielsen et al. 1997

[15] Caughley 1976

[16] McCullough 1979; White and Bartmann 1997

[17] Downing and Guynn 1985

[18] E.g., McCullough 1979

[19] McCullough 1979

Endnotes

[20] DePerno et al. 2000

[21] Mech and Nelson 2000

[22] Gross and Miller 2001

[23] Previous studies have demonstrated that *K*-selected species do not exactly conform to the logistic model (Fowler 1981), but the deviation is insignificant for our purposes. The inflection point for deer is reached at 56% of carrying capacity (McCullough 1987), which is quite close to the 50% predicted by the logistic model.

[24] Krebs 1978

[25] McCullough 1987

[26] McCullough 1984

[27] McCullough et al. 1990; McCullough 2001

[28] Turner et al. 1996

[29] Walter et al. 2002

[30] Rudolph et al. 2000

[31] Humane Society of the United States 2003

Chapter 12. How Deer Might be Managed in Pennsylvania from an Ecosystem Perspective Using Adaptive Resource Management

There is sufficient evidence to justify significant reductions in deer densities in large areas of forestland in Pennsylvania. The Pennsylvania Game Commission has issued increased numbers of antlerless deer harvest permits in the last few years, which should lead to some reductions. Powerful advantages would accrue if the issuance of permits were tied to an adaptive resource management protocol, with field monitoring providing feedback in the decision loop. In the case of managing deer to promote forest recovery, however, the self-correction feature of A.R.M. will not begin immediately. Because of lags in achieving deer density reductions and in detecting forest improvement, there will be a delay of 5 or more years before meaningful feedback can be applied to improve management decisions. Forum members believe that current knowledge of deer impacts is sufficient to commit to an initial set of weights for use in an A.R.M. program. The self-correction process, one of the greatest strengths of the A.R.M. approach, would not begin until measurable changes in indicators are achieved, expected in 5 or perhaps as many as 10 years after the start of the program.

The simplest statewide A.R.M. protocol would combine forest-structure monitoring with the issuance of permits. Possibly, the U.S. Forest Service's Forest Inventory Analysis (F.I.A.) could be adapted to provide the necessary data. A formula would then be devised for adjusting antlerless deer harvest permits based on the success of different models in predicting the impacts of deer density reduction, as discussed in Chapter 9. Because there is a nearly universal scientific consensus that high deer densities are causing the damage to forest structure, agencies should give this view a very high weight in initial decisions on deer harvest permits, other deer control actions, and other ecosystem management policies. An appropriate initial weighting would be 90% assigned to the consensus view that white-tailed deer are harming forest structure and a 10% weight assigned to theories that white-tailed deer are relatively unimportant.

A more scientifically sophisticated approach than applying a single set of management actions statewide would be to divide the forest areas known to be damaged into two sets of large "treatment" and "comparison" areas, one set where measures would be taken to reduce deer densities dramatically and the other, where hunters would operate as usual. The two sets of areas would serve as replicated treatment and control plots, enabling sound, scientifically valid conclusions about the effectiveness of management actions in promoting forest recovery.

However, Forum members realize that reducing deer densities across the state dramatically rather than incrementally, no matter how well justified, might be very difficult in the short term because of limitations in the number of additional permits that the state's hunters could absorb. And even if hunter numbers were not a limitation, it might be difficult to reach a political consensus on dramatic reductions in light of high-profile theories that challenge the importance of deer in the decline of forest structure and diversity in the first place. Therefore, the Deer Management Forum proposes a two-tiered A.R.M. program. The first tier, already described in general terms (Chapter 2), would apply to the state as a whole. The second tier would apply A.R.M. at a smaller scale, to multiple, 10-square-mile forest treatment areas and comparison areas (untreated experimental "controls") in all of the major forest regions of the state, but with a wider range of management treatments (reductions in deer densities), as well as a wider range of tests of alternative theories. Lessons would be learned faster with such smaller-scale manipulations.

For instance, if the consensus view should somehow turn out to be incorrect, it will become obvious as data are collected while monitoring these 10-square-mile areas. Theories about the effects of soil acidity, how to speed up recovery, and optimal deer densities could be tested in this manner as well. We recommend this two-tiered approach to the application of A.R.M. so that changes in management can be implemented immediately at the state level based on the best current knowledge, while uncertainty is reduced as the models are subjected to rigorous tests in a spatially replicated, scientifically valid fashion. The results of the model predictions on the 10-square-mile areas would be used, along with the results of the statewide monitoring program, to weight management decisions applied to the entire state each year.

There exist a number of research protocols that could be chosen for both A.R.M. tiers. In this chapter, we present an illustrative example, with the second tier restricted to state lands. We do not propose to include federal lands in the example because of the complex procedures necessary to gain approval for treatments on federal lands.

Steps that would be needed to develop an A.R.M. program both statewide and in the smaller test areas are listed in Table 6. We envision any actual research protocol to be chosen by Pennsylvania Department of Conservation and Natural Resources (D.C.N.R.) and Pennsylvania Game Commission (P.G.C.) staff with the advice of a broad-based, ad hoc research advisory committee. In addition we suggest that a public advisory committee, also ad hoc, should be formed to represent public constituencies. The public advisory committee would be kept informed of ongoing scientific progress and provide feedback to the agencies and research advisory committee to help ensure that choices are made that will be supported by stakeholders and the general public. From this point on, we refer to the designated D.C.N.R. and P.G.C. staff together with the ad hoc advisory committees as the "A.R.M. team," recognizing that final decision authority always rests with the agencies.

The A.R.M. team would request researchers to propose theories relating deer densities and other factors to regeneration of woody and herbaceous vegetation. Estimates would also be needed of changes required in deer harvest permit allocations to reach a detectable level of

Table 6. Steps that might be taken to develop a protocol for managing deer using adaptive resource management in multiple, 10-square-mile forest treatment and comparison areas

step	comment
Formation of an ad hoc research advisory committee	To be chosen by D.C.N.R. and P.G.C.
Formation of an ad hoc public advisory committee	To be kept informed of scientific progress and provide feedback to D.C.N.R., P.G.C., and the research advisory committee.
First cut at research protocol	The A.R.M. team would choose (1) the number, size, and location of forest areas to be treated, (2) the range of target deer densities, the control techniques to be tested, and the deer monitoring methods (3) the alternative treatments to be included, such as seeding, liming, or fencing, (4) the sets of plant indicators and the frequency of measurements.
Baseline (pre-treatment) measurement of indicators in A.R.M. areas (year 0)	Permission to monitor plots in the treated areas would need to be obtained. If drought, late spring freeze, or other unusual weather were to give anomalous measurements in year 0, a second baseline data set would be collected in the following year.
Providing guidance to theorists; attempting to reach consensus on data to be collected	Workshops would be held to explain the A.R.M. process to persons who might propose theories to test, including the necessity to accompany any theory with an estimate of the expected rate of error. Workshops would also be held to provide guidance to agency staff on what data should be collected as part of the A.R.M. process.
Garnering public views on initial weights to be assigned to theories	A meeting would be held to provide guidance to agency staff on the initial weights to be assigned to proposed theories.
Initial weighting of theories	Agency staff, advised by the scientific advisory committee and public input, would assign percentage weights to the various theories.

(Table continued on next page.)

step	comment
Deciding on and applying a range of deer control methods to test in 10-square-mile areas or regions including them (first tier)	In the early years of the program, a range of innovative control options would be tried, such as varying permit allocations, permit price, and the number and duration of hunting seasons.
Monitoring the success of deer control methods in changing the number of deer taken per year in the control regions (years 2 and 3) and, if necessary, adjusting the methods used	Monitoring would compare the number of tags paid for or granted to hunters and the number of deer taken per tag.
Monitoring the success of deer removals in changing deer density and, if resulting declines are inconsistent with the desired target range, adjusting control strategies accordingly (years 2 and 3)	Methods of estimating deer abundance would be applied to see whether target ranges for deer density have been reached
Ongoing measurement of indicators and evaluation of success of theories (years 5, 8, 11, and thereafter)	The criteria for success in improving forest structure are statistically significant improvements in indicators of forest structure.
Conducting research to develop a combination of indicators that responds faster than the ratio of *Rubus* to hay-scented and New York fern cover	Forum members believe that a suite of indicators and indicator ratios can be determined that will respond quickly to changes in deer density, thereby decreasing the lag time before feedback can be applied to annual management decisions.
Reweighting and allowing for theory modification (year 5 and each year afterward)	Relative model weights would be adjusted and model proponents would adjust their models, if the data indicate that they need improvement.
Benefiting from lessons learned	Management actions, such as permit issuance rates, would be adjusted to favor the best-performing models.
Evaluation of A.R.M. program	Participating agencies would schedule program performance evaluation at regular intervals.

improvement. P.G.C. biologists would provide assistance in this regard. Workshops would be held to explain the A.R.M. process. Only theories that are quantitative, or theories that the A.R.M. team can make quantitative predictions from, could be considered. To qualify for consideration a theory also would have to include an estimated rate of uncertainty.[1]

After submission of the models for consideration, the agency staff portion of the A.R.M. team would use its best judgment, informed by advice of the scientific advisory committee, to assign initial percentage weights to the various theories. These weights would be used, along with considerations of public safety, to pick the initial range of treatments to be applied to the A.R.M. areas. In subsequent years, as data come in from measuring indicators, standard A.R.M. procedure would be used to update the original weights based on the success of each theory and to update treatment ranges and indicator choices. Over the years, these updated weights could be used by agencies to adjust their management practices on lands outside the A.R.M. areas. Private landowners could also benefit if they chose to adopt the updated management practices for their region of the state.

An illustrative example of A.R.M. was given in Chapter 2, showing the use of probability theory to update the model weights. In that case, only two models were considered. However, many more could be included. In fact, given the uncertainties in predicting forest recovery rates, it would be wise to consider a series of submodels for each basic model. Each submodel would use a different value of an uncertain parameter. For example, consider a model developed to predict the relationship between permit allocations and a detectable increase in a fast-response, composite indicator of forest recovery.[2] Submodels might be chosen with two values for permit allocations below and two above the basic model. Including the basic model, there would be a total of five submodels. The initial weight assigned to the basic model would be divided among the five submodels and updated based on future monitoring data. As a result, not only would monitoring data be used to choose between different theoretical models of forest dynamics, but the data would also be used to pick out the best deer harvest permit allocation to use in conjunction with the model. Data from the more experimental, second-tier A.R.M. areas would have the greatest power to pick out the best submodels, because a wide range of deer densities could be achieved.

As an illustration, we have estimated the percentage increase in permit allocations and number of hunting days that might be required for the forest-recovery indicator example given in Chapter 9, the ratio of *Rubus* cover to hay-scented and New York fern cover (Table 7). These estimates are illustrative only and would need to be refined by the A.R.M. team.

The A.R.M. team would determine the nature of the treatment and comparison areas, choosing (1) the number, size, and location of forest areas across the state under agency management to be treated, (2) the range of target deer densities and harvest permit allocations,

(3) the range of deer control techniques to be tested, (4) the target range for any alternate treatments chosen, such as seeding, liming, or fencing, (5) the indicator sets to be used, and (6) the frequency and timing of indicator measurements.

An example of a second-tier A.R.M. protocol

The A.R.M. team chooses 20 forest treatment and comparison areas, each 10 square miles in size (the size of squares with 3.16-mile sides or 3.57-mile diameter circles), spread across the

Table 7. Examples of quantitative goals for adaptive management to improve forest conditions, as measured by the ratio of *Rubus* cover to hay-scented and New York fern cover in sites with moderate light levels at the forest floor

item	quantity
Deer density reduction target needed to detect change in 3 years after target is reached	From 35 to 20 deer per square mile[a]
Deer management actions that might be sufficient to achieve the 20 deer per square mile over a 3-year period in a 10-square-mile forest tract	75% increase in antlerless permits and a 33% increase in the number of hunting days[b]
Other values that might be tested in A.R.M. as submodels	5, 10, 15 deer per square mile

[a] Based on a fit to data in Chapter 9 with an 80% chance of seeing an effect at the 95% confidence level.

[b] Assuming these actions will produce a harvest of 100 deer out of a population of 400 located within a 10-square-mile forest tract.

state to be treated to reduce deer density. Five are comparison areas with no change in hunting rules or deer management methods, five treatment areas are reduced to 20 deer per square mile, five to 13 deer per square mile, and five to 7 deer per square mile. The A.R.M. team identifies a suite of control methods designed to reach these targets. Nearest neighbor blocks receive different treatments so that as much as possible models may be tested for a range of deer densities within each forest type.[3] Modelers participating in the A.R.M. exercise take into account likely variations due to the passage of time and differences among locations.

The 10-square-mile size of each treatment and comparison area is a compromise, small enough to make reducing deer density practical in a relatively short time and large enough that immigration would not quickly fill the void.[4] Treatment/comparison areas are embedded in larger contiguous forest areas to avoid edge effects and influences of adjoining land usesThe perimeter of each treatment and comparison area is at least 1 mile from the edge of any nonforested area of significant size, including clearcuts less than 5 years old of 25 acres or larger and cultivated areas of 10 acres or larger, and deer harvest treatments are applied to a 1-mile-wide buffer zone surrounding each treatment area as well as to the treatment area itself.

Wherever possible, treatment and comparison areas are situated where monitoring deer populations is relatively easy and the human population is receptive to the changes in deer density needed for the 10-square-mile treatment areas. Ideally, treatment and comparison areas are distributed evenly between the two major forest regions in the state: northern hardwoods in much of the northern one-third of the state, extending southward at high elevations, and oak-mixed hardwood forests in much of the southern two-thirds.

In each treatment and comparison area, four randomly located forest stands are sampled in an effort to average out the spatial variability across the 10-square-mile area in a host of factors, including deer density, that may affect indicator responses.[5] First, a sequence of random locations is assigned within each treatment or control area; the first four that prove to meet a set of previously developed criteria when examined on the ground are chosen as the forest stands where forest recovery indicator data are collected. To be included in the sampling array, a forest monitoring stand must possess characteristics for which at least one competing model predicts a change detectable in 3 to 5 years of treatment.[6] Data are collected only where (1) adequate sunlight is available at the forest floor to support substantial new growth (shelterwood cuts, thinnings, or areas where natural disturbance has thinned the canopy) and (2) a strong "legacy effect" of long-term deer overbrowsing is absent (i.e., areas without an interfering cover of unpalatable or browsing-resistant species, mainly striped maple, American beech, hay-scented fern, or New York fern). The selection criteria will assure that changes in indicators, if they occur, may be detected within a reasonably short period of years.[7] Within each forest stand, 18 subplots are randomly located for sampling.

In the example, the data consist of measurements of *Rubus* cover and hay-scented and New York fern cover, for computation of the *Rubus*:fern cover ratio, and a set of additional indicators chosen from the list provided in Chapter 9 or otherwise selected by the A.R.M. team. The indicators chosen are those expected to respond rapidly, even within 1 year, to the complete exclosure of deer, but whose response rate is not known when deer densities are reduced to levels above zero. Average costs of vegetation monitoring alone over 5 years are estimated to be $42,000 per year (Table 8). Also included in the program is a measurement of soil acidity in the first year, which is used to test predictions about the effects of soil acidity on response rates. The estimated cost averaged over 5 years, including the acid rain component but with deer monitoring costs excluded, is $50,500 per year. Agency commitment to the forest monitoring part of the A.R.M. program is estimated to be 2 person-months per year in each of the two agencies, P.G.C. and D.C.N.R.

The cost of the statewide first-tier A.R.M. program, which would include stands beyond the 80 targeted for monitoring in the second-tier program, is estimated to be considerably less, because measurements would be taken half as frequently. The statewide program, averaged over the first 5 years, would add only an estimated $12,000 to the total cost per year. Thus, the grand total for forest monitoring over the first 5 years in both tiers of the proposed A.R.M. program is an estimated $62,500 per year (Table 8).

Table 8. Forest monitoring cost estimates for the second tier (experimental component) of the adaptive research management protocol

item	quantity
Number of treatment and comparison areas and forest stands in which monitoring would be conducted each year	20 treatment/comparison areas 80 forest stands (4 per area) 1,440 subplots (18 per stand)
Cost to locate and classify treatment and comparison areas and, within them, forest monitoring stands (a first-year cost)	$36,000[a]
Cost to measure indicators for a single year in one forest monitoring stand	$500[b]
Cost to monitor all 80 forest monitoring stands (needed every third year; more often if unusual weather results in anomalous measurements in one or more years[c])	$40,000
Supervisory costs and data-analysis costs in year data are collected	$6,000
Total cost of vegetation monitoring alone averaged over first 5 years	$42,000 per year
Agency staff commitment per year	2 person-months in P.G.C. 2 person-months in D.C.N.R.
Cost in first year to measure soil acidity in 80 forest monitoring stands	$43,000[d]
Total cost of monitoring program, including acid rain component, averaged over first 5 years	$50,500 per year

[a]Assumes supervisor can identify and classify two acceptable forest monitoring stands per day, hourly rate of $50 per hour, overhead rate as 100% of wages, extra travel expenses of $100 per day. Marking the 18 subplots within a forest monitoring stand is assumed to require two technicians for two hours per stand.

[b] Assumes two field workers paid $20 per hour who together can cover three forest monitoring stands per day, overhead rate as 100% of wages, extra travel expenses of $100 per day.

[c] Drought, late spring freeze, or other unusual weather in the first year is assumed to give anomalous measurements requiring remeasurement in the following year 33% of the time.[d] Assumes sample collection will add no more than 45 minutes per forest monitoring stand, equipment costs are $5,000, laboratory analysis costs are $25 per sample. If acidity monitoring equipment must be left and picked up later, two visits are required. The cost of a second visit, which we assume is necessary, increases the total cost from $27,000 to $43,000.

To keep costs to a minimum, the monitoring program is designed to discriminate between models only at the scale of the entire state, not at the scale of regions within the state. However, every effort should be made to distribute treatment areas among regions to maximize the likelihood of extracting information that will be statistically valid at the regional level. With only a few of the 10-square-mile areas in each specific combination of forest type, local climate, terrain, deer population history, and other factors that vary among regions, analysts will not always be able to say with confidence that a particular model is best in an individual region, nor will it always be possible to assign model weights that vary with region. Still, previous studies of the effects on vegetation of manipulating deer numbers give good reason to be confident that, with careful placement of treatment areas, useful information pertaining to particular regions should be obtainable, especially where recovery is found to be relatively rapid. Deer density has been found to be such a strong factor that its effects have shown clearly (and statistically significantly) through the “noise” of variation in many other site and environmental factors.[8]

It would be considerably more expensive to design the monitoring program specifically to account for regional variations. However, agencies or institutions responsible for forest research may well become interested in building on the A.R.M. program and may support their own research within the monitoring blocks, gathering data from additional stands that could benefit the A.R.M. program. Such synergism would be encouraged if the research opportunities available as add-ons to the A.R.M. program were publicized among the research community.

Additional monitoring stands beyond the 80 funded under the A.R.M. program could be used to test models of forest dynamics that would be useful in deer management, even though their main function might be to advance pure research or address non-deer management problems. With the addition of extra treatment and comparison areas beyond the 20 in the A.R.M. proposal, model performance might be testable in regions within the state, which would be of great interest to regional stakeholders.

The illustrative program presented here assumes that one model will work for all regions in the state that contain treatment and comparison areas. If, on the other hand, different models had to be used for, say, northern hardwood forests and oak-mixed hardwood forests, then there would probably not be sufficient monitoring stands in our example to test separate models for each of the two forest types. If it is determined to be a priority to focus initially on one forest type, the A.R.M. program might begin by putting all 20 treatment and comparison areas in that forest type to keep the total cost down while the program is proving its usefulness.

The cost of deer monitoring, which is necessary to determine if deer numbers have indeed been reduced to target levels, is not low. Even kept to a minimum level, our rough estimates of deer monitoring costs turn out to be comparable to the costs of monitoring vegetation response to deer reductions. For purposes of cost estimation, we assume that both hunter surveys and deer pellet counts are used to assess success at reaching the target deer densities set in the A.R.M. program. Hunters with licenses to hunt in a 10-square-mile A.R.M. tract are surveyed by telephone after the deer season. Data from this survey indicate hunter effort. In addition, the number of deer taken per hunter day is a relative measure, albeit indirect, of deer populations, because success per hunter day should decline as deer populations decline. To assess the reliability of information gained from hunter surveys, results from 5 of the 20 ten-square-mile tracts are compared with deer pellet counts. The approximate cost of the proposed deer monitoring would be $43,000 per year, averaged over the first 5 years (Table 9). Estimating the costs of monitoring deer populations is difficult and our rough estimates would need to be refined as part of A.R.M. implementation.

Combining the $43,000 per year estimated for deer monitoring with the $62,500 per year estimated for vegetation response monitoring gives a total of approximately $105,500 per year. Thus, we expect the cost of the A.R.M. program to be about $100,000 per year in outside expeditures, with a total agency staff commitment of 7 person-months per year. Although not insignificant, such a cost is small compared to P.G.C.'s total budget, which is in excess of $60 million per year.

In our example, four theories are proposed for testing:

No-impact theory — Prediction: There will be no change in indicators from year to year from current trends, regardless of treatment. Estimated rate of error is the average year-to-year fluctuation around the current trend.

Deer-dominance theory — Predictions: (1) Indicators will improve in areas where deer populations are reduced. (2) Response times for recovery of forest structure will be faster in areas of the state where deer densities have historically been in excess of 20 per square mile for less than 10 years, based on the likelihood that forest-floor plant propagules still exist in those areas. (3) Response times will be faster in areas where light reaches the forest floor, e.g., in recently cut forest stands or in stands over 50 years old in which self-thinning has taken place. Furthermore, change is expected to be slow where dense understories of hay-scented fern, New York fern, American beech, or striped maple already are well established (legacy effect). Estimated rates of error for these predictions are provided by advocates of the deer-dominance theory. In areas where deer have been densely populated for more than a decade, seeds of indicator species are applied in randomly selected areas within each treatment and comparison

Table 9. Deer monitoring cost estimates for second tier (experimental component) of the adaptive research management protocol

item	quantity
Number of forest stands in which deer monitoring would be conducted	80 forest stands
Number of stands per 10-square-mile tract	4[a]
Cost of post-season phone surveys for hunters with special-area licenses (to obtain hunter effort and success per hunter day)	$32,500 per year [b]
Cost of pellet counts in five of the 10-square-mile treatment and comparison areasas a check on inferences from phone survey (includes 15 of 80 stands)	$53,000 per year [c]
Total cost of program averaged over first 5 years	$43,000 per year [d]
Agency staff commitment per year	3 person-months in P.G.C.

[a] Stands are assumed to be less than 200 acres in size. It is also assumed that all four stands for a forest district can be located in the same 10-square-mile (6,400-acre) treatment/comparison area.

[b] Assumes $3.50 per survey, 300 hunters per 10-square-mile treatment/comparison area, and 20 treatment/comparison areas. Survey development and data analysis are assumed to require 200 hours at an hourly rate of $50, which includes a 100% overhead charge.

[c] Assumes pellets can be counted at the rate of 0.5 to 1.5 square miles per person per day, an hourly cost plus overhead of $25 per hour, 100 hours of supervisory time per tract at a cost plus overhead rate of $50 per hour, and travel and equipment costs of $3,100 per treatment/comparison area.

[d] Assumes measurements are made every year for the first 3 years and every 2 years thereafter.

area to test the hypothesis that loss of propagules slows recovery of forest structure. In areas where little light is reaching the forest floor, the tree canopy is thinned in randomly selected areas within each treatment area to test quantitative predictions of the degree to which recovery of forest structure will be speeded up by allowing light to reach the forest floor.

Acid rain-dominance theory — Predictions: (1) Indicators will not differ between areas with different deer density reduction treatments. (2) Plant indicators will improve where some optimal amount of lime is applied. (3) Regeneration will be better in valleys underlain by limestone than ridges of sandstone or other non-calcareous rock, because soils weathered from calcareous rock have greater buffering capacity (valleys also generally have more mesic soil moisture regimes and ridges are more xeric — a potentially confounding factor). Proponents of the theory provide estimated error rates. In the 10-square-mile areas with high initial deer populations, lime treatments are applied in randomly selected portions of each treatment and comparison area to test quantitative predictions of the acid rain-dominance theory. Values for the amount of lime to be used in treatments are chosen by the proponents of the theory.

Deer and soil acidity interaction theory — Prediction: Recovery response times of forest structure following deer reductions will be faster in areas with non-acidic soils. Estimated rates of error are determined by agreement between proponents of the two parent theories.

The quantitative predictions of each theory are modified by consideration of regional factors such as historic duration of deer overbrowsing and soil characteristics.

The A.R.M. team decides on the methods of deer control to be used and tested. Based on analysis of controlled studies of vegetation response due to changes in deer densities, Forum members have estimated that a 50% reduction in deer density would be needed to make detection of a vegetation response possible in 3 to 5 years. Achieving such large reductions (e.g., from 40 to 20 deer per square mile) will take time, further delaying the acquisition of useful feedback after the program's start. It is also not clear that there will be sufficient hunters in the 10-square-mile A.R.M. areas to make use of the required two- to three-fold increase in harvest permit allocations.

A major task of the team is to devise control measures to achieve the desired target levels while maximizing hunter satisfaction to the greatest possible extent. A number of innovative methods should be explored, including the use of baiting and spotlighting. Also, hunters could be offered a free permit to take an antlerless deer, with the permit replaced at no cost every time a hunter turns in a used tag. The effectiveness of such methods in stimulating hunters to take and use additional permits could be tested in an A.R.M. weighting process. Feedback in this part of the A.R.M. program would be rapid.

As the next step in the A.R.M. process, baseline monitoring of forest recovery indicators in all treatment and comparison areas is completed. Next, the chosen deer density reduction treatments are applied and their effectiveness checked, using methods of population estimation. Once deer control methods achieve the desired target densities, monitoring of forest recovery indicators resume. Deer control treatments continue, with adjustments as needed based on continued population monitoring to maintain the target densities. Success in improving forest structure, as opposed to success in testing theories, is obtained when statistically significant improvements in indicators of forest structure are found.

As field data are analyzed, the relative weights assigned to each theory are reweighted by agency staff using probability theory.[9] Field data may spur some proponents to modify their theories. In such cases, to be fair no modified theory could be reweighted until a subsequent year's data had been collected. As the various weights of the tested theories go up or down over the years, land managers across the state interested in ecosystem management could adjust their practices accordingly. At regular intervals, the A.R.M. program would be evaluated by the participating agencies.

We recognize that, in focusing on the programmatic details of an A.R.M. proposal, we have glossed over the vital social science aspects. Specialized expertise will need to be tapped to develop effective ways of getting the cooperation of stakeholders, local communities, and local governments in supporting the establishment of the second-tier A.R.M. treatment and comparison areas and the special hunting efforts that will be required in them.[10] In this regard, the advice of the proposed ad hoc A.R.M. public advisory committee will be extremely important. Consultation with experts in the human dimensions of wildlife management may also be required.

Findings on how A.R.M. might work in Pennsylvania

(1) There is already sufficient evidence to justify significant reductions in deer densities in large areas of forestland in Pennsylvania, and applying A.R.M. to the state as a whole.

(2) Reducing deer densities across the state dramatically rather than incrementally, no matter how well justified, might be very difficult, particularly in light of theories that challenge the importance of deer in the decline of forest structure and diversity in the first place.

(3) Practical applications of A.R.M. to deer require agency staff commitments for multiple years. Financial support is also necessary, but the advantages of a science-based methodology that is designed to deal with uncertainty and controversy would be a compensation.

(4) The initial commitments involved in preparing A.R.M. alternatives could be made within existing budget authorizations, provided agencies are willing to assign staff to the process. However, because of the great damage that has already been done to the structure of forests and because of the depletion of the seed supply in many parts of the state, a long-term commitment to the A.R.M. process is needed.

(5) The sooner effective treatments are implemented, the sooner further deterioration will be prevented, saving larger areas of forested land in Pennsylvania from slipping below the threshold for fast recovery.

Recommendations on how A.R.M. might work in Pennsylvania

(1) Forum members propose a two-tiered A.R.M. program. The first tier would apply to the state as a whole. Its initial treatments would take into account factors that go beyond ecosystem management, for example, budgetary constraints and local traditions. The second tier would apply A.R.M. at a smaller scale, to multiple 10-square-mile forest treatment and comparison areas in all of the major forest regions of the state. In contrast to the first tier, treatments on these forest recovery-monitoring tracts would include a range of deer densities, as well as tests of alternative theories on causes of forest degradation and recovery. The focus would be exclusively on ecosystem management. Lessons learned from these smaller-scale manipulations could be applied to forested areas across the state as a whole in subsequent years.

(2) State land-managing agencies should begin the process of developing a set of alternative A.R.M. proposals. Once agency staff has developed a suitable set of options, they should seek authorization approval.

(3) As a fast-track planning tool, D.C.N.R. and P.G.C. should manage significant portions of lands under their jurisdiction using a formal adaptive resource management paradigm. At the start, these could be the multiple 10-square-mile areas around the state recommended in the proposed A.R.M. program's second tier to be subjected to varying levels of deer population control.

(4) An ad hoc, external scientific advisory committee should be established to assist the agencies in the choice of test areas, the size of buffer areas that might be needed, and indicator measurement protocols. An ad hoc citizens advisory committee also should be formed to help in developing consensus on the A.R.M. process.

Endnotes

[1] The greater the rate of error proposed by a theory's proponent, the less likely the theory is to be conclusively refuted, but at the same time it will be less likely to prove influential in future management decisions.

[2] Such predictions could be extracted from the consensus theory of forest damage as follows. Consider one fast-response indicator, the ratio of *Rubus* to hay-scented and New York fern cover. Graphs of the change of this ratio over time have been calculated from field data already collected in northern hardwood stands across a broad range of deer densities by U.S. Forest Service researchers at the Northeastern Research Station, Irvine, Pennsylvania, following reductions in deer density. They would allow an estimate to be made of the time it takes to achieve a

Endnotes

statistically significant increase in the indicator ratio in northern hardwoods, assuming various sample sizes, for reductions from 40 or more deer per square mile to a series of lower target densities. Next, it would be necessary for experts on deer population biology to estimate the changes in deer harvest permit allocations needed to bring deer density down to those target densities

[3] I.e., fulfilling the "interspersion of treatments" rule for most effectively achieving true experimental replication (Hurlbert 1984)

[4] Aycrigg and Porter 1997

[5] *N* = 5 experimental replicates in our design. The four forest monitoring stands within each of the 20 A.R.M. forest monitoring areas are subsamples intended to account for spatial variability, and can in no sense be considered as replicates. Prior to statistical analysis, data are averaged across the four stands to yield a single value for each measured indicator in each forest monitoring area. The predictions by modelers for each indicator would also be averaged across the four stands before they are statistically compared with the measured averages.

[6] Prior to stand identification, modelers provide a list of generic stand characteristics that will allow the identifying team to (roughly) rank a stand's suitability for inclusion in the monitoring program. Modelers set threshold criteria for determining when, according to their model, a stand should show a detectable change in 3 to 5 years. If no stand qualifies after examinaton of several stands, the field team relaxes the threshold criteria for each model. In Pennsylvania, there are only two models in contention, the deer-damage model and the acid-rain model. If the number of models exceeds two, then the site-selection criteria for each would need to be made stricter (at least two models must predict a detectable change in indicators before a stand is accepted).

[7] The A.R.M. approach generally assumes that at least one model is a reasonable predictor of the system dynamics (Johnson et al. 2002).

[8] E.g., Horsley et al. 2003

[9] It should be noted that the weightings would represent a true probability-based assignment only if the standard deviations assigned by the modelers represent true standard deviations, but in practice this may well not be the case. Thus it is more correct to say that agency staff will be using a "scoring function" to assign weights, one that is based on a probabilitistic framework with uncertain parameters. If no model should perform reasonably well with the values assigned for standard deviations, then the A.R.M. team would have to make adjustments to avoid computing meaningless model weights. For instance, as an alternative, the A.R.M. team could increase all of the models' assigned standard deviations to be equal to the average differences between the predictions and the measured quantities. In effect, this would force a model's weight for an individual indicator to vary inversely with the average deviation of its predictions from the measurements. For simplicity, the agency staff might pick this scoring approach from the start. It would obviate the need for modelers to assign a standard deviation to their predictions. However, we do not necessarily recommend such a step, because the discipline of having to assign a model error can be sobering for a modeler and lead to more careful model development.

[10] Schaeffer 2001

Part V. Deer Management Policy and Institutional Structures Necessary for Carrying Out Deer Management from an Ecosystem Perspective

Chapter 13. Deer Management Policy and Administration in Pennsylvania

In this chapter, which is more Pennsylvania-specific than most of the earlier chapters, we explore who has authority to regulate deer numbers, who is ultimately responsible for deer policy in the state, and the recent history of deer management in Pennsylvania.

Introduction

There is a broad consensus that deer densities in Pennsylvania are too high from the forest ecosystem perspective, a position accepted by some members of the Pennsylvania Game Commission (P.G.C.) staff,[1] at times by P.G.C. commissioners themselves,[2] and by much of the public at large.[3] A statewide survey of randomly selected Pennsylvania households conducted in December 2003[4] indicates that 74% of respondents are at least somewhat familiar with P.G.C. and 64% are aware of Pennsylvania's deer program. Approximately 19% of respondents indicated that they hunt and 81% supported or did not disapprove of hunting. This level of support for hunting agrees with a 1996[5] survey conducted by Responsive Management (Harrisonburg, Virginia) on behalf of P.G.C. in which 84% of Pennsylvania respondents supported or did not disapprove of hunting activities. When asked to rate their level of agreement with potential goals on a 10-point scale (with 10 signifying complete agreement with the goal),[6] respondents' top-ranked goals were "manage deer herd numbers to promote healthy and sustainable forests" (average score 7.5) followed by "manage deer herd numbers making minimum conflicts with humans" (6.4). In the same survey, "manage deer herd numbers making hunting activities the priority" was ranked as lowest in priority (5.9). Predictably, hunters and anglers placed higher importance (7.1) on promoting hunting activities than respondents who did not hunt or fish, but they also gave a higher rank to promoting forest health and sustainability (7.8).

P.G.C. over the years has set goals to reduce deer densities and implemented programs to achieve those ends (e.g., "bonus tags"). However, recently the agency has apparently abandoned the idea of being bound by the goals that it had established and announced in public documents (which we discuss later in this chapter). As a result, deer densities are now 40% to 120% higher than the goals set in 1979,[7] when target numbers were set for geographical units "at the maximum number of deer that the forest can support over winter without adversely affecting tree regeneration."[8] This departure of actual deer numbers from science-based goals has occurred while P.G.C. policy decisions have deviated sharply from the recommendations of staff biologists.[9]

We discuss in this chapter two distinct types of target numbers for deer densities (see box on next page for a description of how deer densities are estimated). The first type of target is based

Estimating deer densities

Numerical harvests and the sex and age composition of the harvest are the primary sets of data used in population models or formulas to estimate deer densities in Pennsylvania.[11]

Model estimates are supported by independently derived field indicators,[12] including deer-vehicle collisions, estimated at 80,000 to 100,000 per year in Pennsylvania,[13] and agricultural damages for the average farmer exceeding $9,000 per year.[14]

on the sustainability of the deer herd and commercial timber trees; an example is the set of numbers prescribed in 1979 for individual deer management units,[10] which are not based on wider ecological concerns such as those that would be addressed by the A.R.M. program presented in earlier chapters. We refer to these as the "1979 deer-density targets." These historical targets have never been met in practice, and in fact the trend has been opposite to the direction desired, with deer numbers increasing rather than falling. However, the 1979 targets do represent a near consensus, notwithstanding the difficulty that was experienced in reaching agreement on them. In our view, deer densities should be reduced to the 1979 targets even though they are not ecosystem-based and irrespective of any decision to manage deer from an ecosystem perspective. If P.G.C. cannot achieve the consensus targets, then there is little hope of implementing a system of managing deer from an ecosystem perspective.

The second set of deer-density targets — discussed implicitly in earlier chapters — are hypothetical; they are to be based on ecosystem considerations that take into account the restoration and preservation of forest structure and function. Should P.G.C. adopt such an ecosystem approach, these targets might be estimated at the start of an A.R.M. process and updated based on subsequent experience as described in earlier chapters. Thus, there are two distinct, but related, questions that are posed in this chapter and addressed in Chapter 14: (1) What needs to be done to help P.G.C. meet the 1979 targets, which were based on considerations of deer health and tree regeneration? (2) What would need to be done if P.G.C. wanted to move toward managing deer from an ecosystem perspective?

The obstacles to meeting deer-density targets appear to be sociopolitical. A majority of sportsmen have never fully understood the relationship between deer population and habitat condition,[15] despite education efforts initiated in the 1950s[16] and intensified in recent years.[17] Even though recommendations for deer management (e.g., seasons and bag limits) presented to administrators by P.G.C. staff members have been science-based and formulated with respect to established policy, management decisions have deviated from both scientific recommendations and established policy.[18]

The inability of P.G.C. and Pennsylvania's leaders to reduce deer densities, despite repeated attempts to do so, dates from well before 1979. Within 20 years after the agency was created, deer densities in north-central Pennsylvania were above what agency biologists considered acceptable given habitat conditions.[19] Articles in *Pennsylvania Game News* over the past 70 years have pointed out the problem of high deer densities and resulting habitat degradation.[20] It is clear that, in Pennsylvania, we have been unable to take control of the deer population for the last 70 years.

Over the past few years, P.G.C. has implemented a highly successful education campaign among hunters that, along with demographic shifts, has helped produce the change in hunter attitudes revealed in survey data (which we review later in this chapter). Measures enacted in recent years by P.G.C. appear to have brought about a plateau in deer numbers, which previously had always been rising, and staff biologists projected a 5% decline in most wildlife management units (W.M.U.s) in 2004.[21] These measures include increased antlerless deer harvest permits, a concurrent buck and doe season, an October hunting season for seniors and juniors, and the Deer Management Assistance Program (DMAP), a program to increase the number of tags allocated on specific land units at the owner's request (see Table 10 on next page for additional details).

These measures, taken at a time when there is a critical need for scientific leadership and a strong focus on wildlife management, do not represent fundamental changes in a structure that functions largely as a law enforcement agency (a crucial point discussed later in this chapter). However, the fact that relevant action has been taken at all indicates that deer management in Pennsylvania is at a historic transition point. These recent developments either could blossom into a shift to managing deer from an ecosystem perspective taking into account a range of stakeholder views, or they could be rescinded, with the agency falling back into a business-as-usual mode, letting concerns about hunters' reactions to change lead to management paralysis and the continuation of high, forest-damaging densities of deer.

The challenge for P.G.C. and the oversight levels of government — the General Assembly and the Governor's office — is to manage the perceived conflict between those hunters who want to continue seeing as many deer as are now in the woods and other stakeholders who have an interest in lower deer densities. Another issue P.G.C. has to deal with while lowering deer densities is the inherent fiscal quandary associated with any reduction in hunter satisfaction. Deer management in Pennsylvania has focused on deer numbers, deer condition, and hunter satisfaction rather than on broader ecological goals. P.G.C.'s organization is similar to that of a recreation commission designed to address the recreational needs, desires, and wants of its service base, consisting of deer hunters. The agency is administered by hunters, staffed by hunters, and funded by hunters, and views its mission as protecting the interests and traditions of hunters. Nearly 95% of those hunters hunt deer as their primary game species. Nearly 95% of P.G.C.'s funding comes from hunting license sales, taxes on hunting equipment, and timber sales on lands purchased with hunter dollars. Any program changes that might reduce deer hunter satisfaction and participation threatens the organization's funding base. The end result is that one of the prime considerations in reaching deer management decisions is how a decision may affect recreational user fees.

One option is to use techniques of negotiated conflict resolution to manage potential conflicts that may arise, once deer numbers begin to come down. Ultimately, however, if such techniques are not successful, government leaders are going to have to make some tough choices, recognizing that the forests of Pennsylvania belong to a broad constituency and that hunters unsympathetic to ecosystem management represent only 11% of Pennsylvania hunters.[22]

Table 10. Changes in Pennsylvania's deer management program most pertinent to the ability to achieve density goals.[23]

1957	Antlerless seasons offered annually
1979	Deer density goals established based on forage availability
1987	Bonus and surplus licenses
1990	Deer-damage farm program
1992	Archers added to the antlerless allocation system
1993	Archery seasons extended two weeks in the fall
1994	Community/urban deer program
1995	Agricultural depredation permit program
1997	Bonus licenses eliminated
1998	Formed the Deer Management Work Group
1999	Accepted recommendations of the Work Group
	Established new Deer Management Section, headed by Dr. Gary Alt
	Conducted a series of public open houses on deer management
2000	Implemented concurrent buck/doe season for youth and senior hunters
	Approved three-day October muzzleloader antlerless season
	Opened antlerless season on the last day of buck season
	Initiated conception and survival studies of fawns
2001	Implemented two-week concurrent buck/doe season
	Implemented one-week October muzzleloader antlerless season
	Implemented three-day October antlerless hunt for youth and senior hunters
	Completed antler measurement and fawn survival studies

	Cooperated with a study of hunter movements on public lands
2002	Produced educational video and distributed over 30,000 free copies
	Adopted higher minimum antler-size restrictions
	Increased antlerless deer harvest license allocations to one million tags
	Began buck survival, harvest rate, and dispersal research
	Conducted stakeholder session on goals and objectives
	Proposed new deer management units
	Proposed Deer Management Assistance Program
2003	Implemented a limited Deer Management Assistance Program (DMAP) for landowners enrolled in P.G.C. public access programs
	Changed geographical units for administration and planning to 21 ecologically based wildlife management units
	Continued buck field research
2004	DMAP expanded to include most private lands in Pennsylvania
	Crossbow use expanded, particularly in urban W.M.U.s

Currently, the foundation of P.G.C.'s Bureau of Wildlife Management rests on a species-specific management approach, rather than one that focuses on managing habitats or ecosystems. Adopting a program of managing deer from an ecosystem perspective is an alternative that would provide both advantages and challenges for P.G.C. Ecosystem considerations would likely lead to recommendations that deer densities in some parts of the state should be reduced below 1979-target levels — targets that have never come close to being reached. Reaction among some hunters would be quite negative even if other hunters were part of the stakeholder process for working out the details. On the positive side for P.G.C., adoption of a policy of managing deer from an ecosystem perspective would make a reality of the senior staff's vision of being a "leader in conservation." [24] Such a policy would also provide a new set of arguments for encouraging landowners to allow hunter access, perhaps helping to slow the increasing tendency of landowners to post their lands, which has been a growing concern for hunters and P.G.C.

A program of A.R.M. could fill major gaps in the efforts of P.G.C. staff members to bring deer densities more in line with biological (deer health and condition) and ecosystem targets. A.R.M. could be especially helpful in resolving the argument about the relevance of acid rain in causing forest damage, which some in P.G.C. believe is a major obstacle to hunter acceptance of the need to reduce deer densities. It could help in setting targets for deer density based on ecosystem biology. A.R.M. could also help to resolve differences that may arise in future stakeholder dialogues and negotiations. This report itself could provide part of the background material used by stakeholders. However, it would be wholly inappropriate to let a program of A.R.M. or stakeholder negotiations end up delaying efforts now planned or in progess that have already been scientifically justified.

Despite the signs of change that we have mentioned, there are sociopolitical and bureaucratic obstacles in the way of P.G.C. moving significantly away from single-species management to a policy grounded in ecosystem considerations. Senior P.G.C. staff members argue that they have done all that is possible in the current political climate. While we find there are many more measures that the P.G.C. staff could and should implement (discussed in Chapter 14), we do not minimize the sociopolitical constraints under which P.G.C. staff members must operate. Nor do we doubt that it took leadership to implement the recent staff-initiated changes to hunting seasons, permit allocations, and the fledgling Deer Management Assistance Program. The obstacles are so great that it is not even clear that these measures will last. No one to whom we have talked is optimistic, given the current management structure and commissioner appointment system, that the measures that have brought deer populations to a plateau will survive the counter-pressures that are likely to build when deer numbers start to come down.

Therefore it is not likely that P.G.C. on its own, without persistent pressure and support from the Governor’s office and the General Assembly, can finalize the shift from a law-enforcement agency to a resource conservation agency — a long overdue change that has shown signs of beginning under the current leadership. It would be naïve, in light of the long history of failure to bring deer numbers under control, to think that such changes can be made without major reallocation of agency resources to the biology section and without staff retraining. It would be equally naïve to believe that necessary changes can be made without a majority of the P.G.C. commissioners viewing their constituency as all of the citizens of Pennsylvania and without the appointment of commissioners who feel a strong responsibility for protecting Pennsylvania’s forests.

Management of deer from an ecosystem perspective cannot become policy without cooperation between government leaders, external stakeholders, and P.G.C. commission and staff. The need for change is so great and the obstacles so formidable that radical options need to be on the table. Guidance should be sought from the experiences of other states. Likely “counterrevolutionary” reactions need to be anticipated and effective responses considered. Totally new approaches need to be explored, including those that may come out of facilitated negotiations among hunters, forest conservationists, and other stakeholders.

In order for this document to contribute to finding ways of overcoming past stumbling blocks, it is necessary to explore in depth the possible causes for the failure to control deer densities and potential solutions. To this end, in the sections that follow we present background information on the regulatory structure in Pennsylvania, the regulatory authority under which deer are managed, and the past and present policies established by P.G.C. to manage deer. We also discuss the successes and failures of efforts by P.G.C. both to control deer numbers and to move away from single-species management. We analyze the key lessons from past reviews of P.G.C. that have identified structural problems with deer management in Pennsylvania.[25] We also explore the extent to which P.G.C. has responded to, and corrected, problems identified in past reviews. Finally, we explore changes to decision making, legislation, staffing, and regulation that might assist P.G.C. in moving away from single-species management towards implementing ecosystem-based management of deer.

Background information on regulatory structure and authority

Regulatory structure in Pennsylvania

Unlike any other state, Pennsylvania's management of wild animal species (by statute, including all vertebrate and aquatic invertebrate species) is divided between two agencies, the Pennsylvania Game Commission (P.G.C.) and the Pennsylvania Fish and Boat Commission (P.F.B.C.), with neither agency having direct-line reporting to the Governor or a cabinet-level secretary.[26] Wildlife management rules and regulations for animal species are approved by P.G.C.'s Board of Commissioners, members of which are appointed by the Governor with approval by two-thirds of the state Senate required for confirmation. The commissioners, not the staff, set seasons, bag limits, and antlerless deer harvest permit allocations. The Governor can replace commissioners. There are no eligibility qualifications specifically regarding education or experience in natural resource management to be a commissioner. Without such backgrounds represented among the majority of commissioners, it may be difficult for the Board to interact productively with staff biologists and to communicate to the public at large about the need for, and scientific basis of, ecosystem considerations for deer management.

The management of state parks and state forests is the responsibility of the cabinet-level secretary of the Department of Conservation and Natural Resources (D.C.N.R.) appointed by the Governor. No state agency has jurisdictional responsibility for terrestrial invertebrates , and the Pennsylvania database on the status and known locations of endangered and threatened species is housed within D.C.N.R., an agency with no regulatory authority over wildlife. The Wild Resource Conservation Fund, a state government entity created to fund wildlife education, research, and protection efforts, with an emphasis on endangered and threatened species, is separate from P.G.C. and P.F.B.C. and is housed within D.C.N.R.

P.G.C. and P.F.B.C. are self-supporting through hunting and fishing license sales and other self-generated revenue; they do not receive any funding from state tax revenues. The Wild

Resource Conservation Fund is funded from D.C.N.R. Growing Greener appropriations, vehicle license plate sales, and a voluntary income tax contribution. D.C.N.R. is funded by legislative appropriations from the general fund, fees, royalties, and lease payments.

How does this situation compare to other states? There are two basic types of fish and wildlife agencies in the United States: independent agencies, which would be similar to a combined P.G.C. and P.F.B.C, and fish and wildlife departments that are part of a broader natural resource agency, similar to a bureau within D.C.N.R.[27] A recent review of independent state wildlife agencies indicated that the chief administrator typically reports to a commission or board instead of the governor.[28] While there is a broad assumption that they are independent, in practice these agencies have strong policy and funding linkages to the governors and legislatures of their respective states.

P.G.C. is independent only in that the Board of Commissioners sets seasons and bag limits without approval from the General Assembly or the Governor. In Pennsylvania, the Governor approves the annual P.G.C. budget, often imposing limits on the staff complement and spending. Also, the Pennsylvania Commonwealth Court recently ruled that the Governor has authority to remove commissioners from the P.G.C. board.[29] In 10 of 24 states with an independent wildlife agency, the governor or legislature prepares the agency's budget and 13 independent agencies receive annual or biennial appropriations from their state's legislature.

As in other states, politics can influence wildlife management policy in Pennsylvania. The General Assembly and Governor must authorize increases in hunter license fees, which are the primary source of funding for P.G.C. In addition, the Legislative Budget and Finance Committee (L.B.F.C.), consisting of members from the House and Senate, is charged with periodic performance audits of P.G.C. The L.B.F.C. audits consist of reviewing revenues, expenses, and financial condition and assessing how well P.G.C. is performing in accordance with its strategic plan.

Regulatory authority to manage deer

Although there are myriad government agencies and non-governmental organizations interested in wildlife management issues, state governments are ultimately responsible for regulating the harvest of game animals and the protection of wildlife.[30] The federal government can establish authority over state governments through the commerce, treaty, or property clauses of the U.S. Constitution,[31] but state governments are responsible for setting and implementing policy for the taking and protection of wildlife in nearly all situations.[32]

The context for managing wildlife in Pennsylvania is defined by the state constitution and by P.G.C.'s enabling legislation. Pennsylvania's constitution states:

The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people.[33]

It is the responsibility of the executive branch, ultimately the Governor, to ensure that the state constitution is upheld and that the commonly held resources are conserved and maintained now and for future generations.

The Game and Wildlife Code (Pennsylvania Consolidated Statutes, Title 34) is the enabling legislation for P.G.C. Section 103 states:

(a) General rule. — The ownership, jurisdiction over and control of game or wildlife is vested in the Commission as an independent agency of the Commonwealth in its sovereign capacity to be controlled, regulated and disposed of in accordance with this title.

(b) Method of management. — The Commission shall utilize hunting and trapping as methods of effecting necessary management of game, furbearer and wildlife populations.

The enabling legislation provides the foundation for the policies established by P.G.C. for managing and conserving wildlife. We note that the legislature does not give guidance to P.G.C. on two of the major issues, namely conflicts between humans and wildlife and damage to forests, that have arisen since deer populations rebounded early in the twentieth century. It would be useful for the legislature to modify the enabling legislation to specifically expand P.G.C.'s responsibilities to include resolving wildlife-human conflicts and helping D.C.N.R. and other landowners to protect forest vegetation.

Deer management policy established by P.G.C.

In this report, *policy* refers to a course of action adopted by an organization, either in writing or by public verbal affirmation, as distinguished from the administration or implementation of policy. The distinction is important because it is possible for a policy to be developed but fail to be implemented. For the purposes of this report, policy includes all mission statements, goals, rules, regulations, statutes, and laws that affect the conservation of wildlife and other natural resources in Pennsylvania. Laws are developed through the legislative branch of government (e.g., no Sunday hunting in Pennsylvania), whereas rules and regulations are developed by agencies, commissions, boards, or other regulatory groups in the executive branches of state government (e.g., seasons and bag limits).

In this section we focus on agency policy. Statements about policy that are meant to guide the adoption of rules and regulations at P.G.C. appear in various documents, which are updated or rescinded from time to time. Such documents include explicit policies or policy manuals adopted by the Board of Commissioners. There are also statements of management policy that appear as part of strategic plans and species population management plans.

In 1976, P.G.C. established a deer management policy (see Appendix F, page 339) that remained on the books until June 2003 when a new policy manual was adopted by the Board of Commissions as a routine matter, not needing a vote at a public meeting.[34] The new document is missing language present in the earlier policy that pledged P.G.C. explicitly to manage deer in a way that is compatible with other land uses. It is also missing (appropriately) language that committed P.G.C. to a method of management, maximum sustainable harvest, that is no longer considered scientifically valid or appropriate. In 1976, "Policy 5101 — Deer Management" stated:

- *The Commission recognizes that deer belong to all citizens of the Commonwealth and that recreational hunting is a privilege, not a right.*
- *The Commission recognizes that recreational hunting is the major use of deer. Consistent with its responsibilities to the resource and the people, the Commission will endeavor to manage deer on the basis of:*
    - *(a) compatibility with other land uses,*
    - *(b) maximum overall recreational opportunity,*
    - *(c) maximum sustained harvest and,*
    - *(d) maximum aesthetic appeal.*
- *The Commission recognizes that responsible deer management must be based on sound information obtained through continuous research and inventory.*
- *The Commission recognizes that an informed public is an enlightened public; therefore, it will continue to pursue its educational efforts concerning deer and deer management.*

The idea of managing deer for maximum sustained yield (M.S.Y.) is typical of deer management thinking in the mid-1970s when the older P.G.C. policy was enacted. We note that deer management based on M.S.Y. is actually inconsistent with managing deer in "compatibility with other land uses," which is the first item on the above list. In fact, the deer population density compatible with many land uses in Pennsylvania is much lower than that of a population managed for maximum harvest and hunting opportunity[35] (see Chapter 11).

In the mid- to late 1970s, scientists recognized that maximum sustained harvest was a management objective that could not be implemented in practice.[36] The concept of maximum sustained yield starts from a simplifying assumption that a habitat has a limited, relatively stable carrying capacity for each animal population, and applies basic principles of population biology to conclude that population numbers maintained at about one-half M.S.Y. will provide the greatest number of animals available for annual harvest. Although the part of the theory that deals with population dynamics has a solid quantitative foundation that has been well studied[37] (see Chapter 11), M.S.Y. has not proven to be applicable to real-world situations because a habitat's carrying capacity for a population cannot be measured and is rarely, if ever, stable. For instance, when deer or other herbivores increase in abundance their effect on the habitat (e.g., increased browsing of vegetation) can change its carrying capacity (see box on page 16). There are many examples where attempts to manage populations at M.S.Y. have not succeeded.[38]

The new policy manual approved by the Board of Commissioners in 2003 gives no guidance on the paradigm that should replace maximum sustained harvest. Forum members believe that in Pennsylvania managing deer from an ecosystem perspective should replace maximizing sustained yield, because there is scientific consensus that M.S.Y. management has allowed deer to have significant negative impacts on Pennsylvania's natural resources.

The M.S.Y. approach adopted by P.G.C. in 1976 is similar to an agricultural paradigm that strives to produce the maximum annual surplus, in this case deer for hunters to harvest.[39] Deer density goals were derived from studies that estimated how many deer the forest could support during the winter without overbrowsing important commercial tree species.[40] There was no ecological foundation identified in this policy that considered other wildlife species, habitats, or biodiversity even though many studies have demonstrated the adverse effects deer can have on forest structure, species diversity of other animals and of plants, and ecological processes[41] (see Chapter 5).

Because the new policy manual is devoid of guidance on how to manage wildlife, we must turn to staff documents to get an idea of current management ideas within the agency, in particular to strategic plans and deer population management plans.

The most recent strategic management plan (2003-2008)[42] has the following mission statement:

To manage all wild birds, mammals and their habitats for current and future generations.

In this statement, there is an implicit recognition of the importance of diversity of wildlife and their habitats; also the need to protect and conserve them. The inclusion of "habitats" as targets of management action appears to be a nod to the idea that single-species management plans are too limiting. This statement replaces a longer statement in the previous strategic plan, adopted in 1998, which explicitly mentioned protecting and conserving the diversity of wildlife and their habitats:[43]

As the agency charged as steward of the Commonwealth's wild birds and wild mammals for the benefit of present and future generations, the Pennsylvania Game Commission will:

- *Protect, conserve and manage the diversity of wildlife and their habitats,*
- *Provide wildlife related education, services and recreational opportunities for both consumptive and non-consumptive uses of wildlife, and*
- *Maintain and promote Pennsylvania's hunting and trapping heritage.*

A major strength of the 1998 strategic plan was the establishment of an objective to reduce and maintain deer population densities to within 20% of the management unit goal approved by the Commission in the late 1970s.[44] Unfortunately, as discussed earlier, this policy was not implemented; in fact, the statewide deer herd has increased by more than 20% since 1998.[45] The current strategic plan (2003-2008) only mentions deer in relation to diseases and improving the deer and elk fencing program.[46] P.G.C.'s current deer population management plan, which is a subdocument of the strategic plan, does not contain any numerical targets either.[47] So, even though deer numbers have increased above levels long considered to be too high, there is no deer density target in the new strategic plan to which P.G.C. can be held accountable.

It is not that P.G.C. has said that past targets were scientifically wrong. In fact, the current population management plan states that "there are approximately twice the number of deer in Pennsylvania than can be supported during the winter without overbrowsing forested habitats." It appears that the omission of numerical goals is a result of political considerations, not scientific ones. A recent review of deer management concluded that P.G.C.'s inability to achieve deer density goals was because of sociopolitical factors rather than a lack of scientific knowledge.[48]

Thus, based on explicit policy guidance in public documents alone, the situation today is alarming. Currently P.G.C. is no longer explicitly committed to reducing deer numbers, despite the 20% increase over levels that were already too high in 1998 when they ranged from approximately 50% to 100% over targets set in 1979.[49] The main strategic planning document of P.G.C., developed by senior staff members, does not acknowledge that high wildlife populations can be a problem for ecosystems nor concede that the agency has failed to bring the deer population in line with past targets.[50] When senior staff members focus only on successes and fail to publicly acknowledge past problems, the agency risks losing credibility with its staff, the public, and its stakeholders. In contrast, the deer population management plan[51] and the P.G.C. web site do discuss the negative impact of deer on forest vegetation. This divergence in acknowledgment of deer problems sends a mixed message about the need for ecosystem considerations in managing deer, possibly because of an ongoing debate within the staff and Board of Commissioners about the future of the agency. It appears that P.G.C. is in the midst of establishing a new paradigm for managing deer and ambiguities and omissions in the planning documents still need to be reworked.

Removing explicit deer density targets from strategic plans is not the answer to an inability to meet previously established targets. Doing so only serves to mask the urgency of the situation and deflate the pressure to take significant action. It hides from frank consideration a historical failure to protect habitats and silvicultural resources — a nonachievement so long-running and consistent that it suggests a compelling need for creative changes to the regulatory system. We hope that the strategic planning document will be revised to endorse specific numerical targets and to mention the goal of moving towards consideration of ecosystem factors. However, we strongly recommend that P.G.C. first bring deer densities in line with its own goals established in 1979[52] and then refine the management model to embrace ecosystem management concepts.

A key source of information about how the agency currently proposes to manage deer is its "Population management plan for white-tailed deer in Pennsylvania (2003-2007)."[53] P.G.C. developed this new plan with input from stakeholders, which represents a first step in moving beyond single-species management. Stakeholders involved in providing recommendations and prioritizing goals and objectives for the deer population management plan suggested that P.G.C.'s number-one goal should be "to improve the health and sustainability of the ecosystem." This recommendation from the stakeholder group agrees with findings from a statewide survey of randomly selected Pennsylvania households conducted in December 2003.[54] Respondents' top-ranked goals were "manage deer herd numbers to promote healthy and sustainable forests" followed by "manage deer herd numbers for minimum conflicts with humans." In the same survey, "manage deer herd numbers making hunting activities the priority" was ranked as lowest in priority on average across all respondents. Hunters and anglers placed more importance on promoting hunting activities than respondents who did not hunt or fish, but they also ranked their top priority, promoting healthy and sustainable forests, higher than did the general population. It is noteworthy that P.G.C. reprioritized the goals in the deer population management plan, placing managing deer to promote ecosystem health at the bottom of the list.

The deer population management plan stated:

> *Deer affect and impact people in countless ways, both positively and negatively. This is the fundamental dilemma that overshadows a majority of Pennsylvania's deer management decisions. Our goal is to do what's best for the resource and the Pennsylvanians who seek them, unintentionally interact with them, or suffer damage from them. The need to balance these important considerations is the primary reason for developing a deer management plan.*[55]

There is no explicit recognition in this statement of the value of other species and P.G.C.'s responsibility for them, but because there are stakeholders with an interest in biological diversity, there is implicit recognition, at least, of the need to consider the impacts of deer on ecosystems in any balancing exercise.

Under P.G.C.'s Deer Management Assistance Program (DMAP), which gives landowners extra permits, the balancing could be done by the individual landowner. In fact, one of the 2003-2007 objectives in the population management plan is to "revise the Deer Management Assistance Program … to allow all landowners to achieve their land-use objectives." Turning over more decision-making authority to landowners concerning deer densities on private property is a major recent shift in P.G.C. policy. The purpose of DMAP is to provide landowners with the potential to keep deer populations in balance with their land-use goals. The concept was endorsed by the Deer Management Work Group, which called for deer management based on landowner goals and values, as well as P.G.C.'s Deer Stakeholder Group, which stated that P.G.C. should "provide public and private landowners with the deer management tools they need to achieve their land use objectives."[56]

DMAP would not affect lands where landowners do not wish to take on the admistrative burdens of DMAP or where landowners allow hunting to take place under P.G.C.'s default regulations but are uninterested in DMAP. Furthermore, research has shown that the majority of hunters do not hunt beyond about one-third mile from a road,[57] which means that roadless areas are also out of DMAP's reach. P.G.C. staff members are exploring a new option to deal with non-DMAP lands, namely, taking guidance from a citizen task force in setting deer population goals in each management unit.[58] If adopted, this approach might turn out to be P.G.C.'s alternative to the agency setting target goals on its own as it did in 1979 and 1998. However, it is not clear at this point whether a broad and balanced set of stakeholders could be found for every W.M.U. or how P.G.C. would deal with local community values and goals as they relate to state and federal public lands. The only other management principle we could identify in the 2003-2007 deer population management plan involves the role of hunting and P.G.C.'s willingness to go beyond regular hunting seasons to manage deer herds:

> *We will continue to use hunting as the principal method for controlling deer numbers and deer impacts in the Commonwealth.* (p. 21)
>
> *At times, when regular hunting seasons prove insufficient or ineffective in adequately managing deer herd numbers, special laws, regulations and programs will be used to facilitate the taking of additional deer.* (p. 22)

At the end of the document, three goals and a number of objectives related to the goals for the 2003-2007 period are listed, two of which we have already discussed. Several are consistent with recommendations in our report. In fact, information presented in this report (e.g., on indicators and A.R.M.) should be helpful to P.G.C. in reaching some of the stated objectives. In the following paragraphs we list the three goals with our comments.

GOAL 1: MANAGE FOR A HEALTHY DEER HERD

Objective 1.1: Identify a suite of population condition indices that will evaluate the health of deer populations and monitor trends in indices in each Wildlife Management Unit through 2007.

Objective 1.2: Implement management programs to control disease risks and surveillance programs to detect diseases that potentially could threaten the health of statewide deer populations, humans, or livestock in Pennsylvania and implement strategies to minimize disease transmission by 2004.

Goal 1 reinforces the concern that the focus of the P.G.C. deer management program may continue to reflect a single-species management approach based on a "density-dependent theory" (see Chapter 11), which uses deer health as a reflection of ecosystem condition rather than more direct measures of deer impact.

GOAL 2: REDUCE DEER-HUMAN CONFLICTS

Objective 2.1: Develop seasons, bag limits, and hunting methods that enable landowners to achieve their deer management and/or land-use objectives through 2007.

Objective 2.2: Provide direct technical assistance for administering deer management programs to interested landowners by 2003.

Objective 2.3: Evaluate the feasibility by June 30, 2004 and, if deemed feasible, implement a citizen task force (CTF) approach to setting deer population goals in each management unit.

The first objective could play a major role in bringing deer numbers down on millions of acres within the state where such reductions are desired by landowners. DMAP is one component of implementing this objective.

Regarding the third objective, the failure to commit to targets for reduction of statewide deer densities is an indication that citizen task forces, even if found to be feasible and implemented, would not result in a change from the status quo. Ultimately, the Commissioners have to sign off on any final deer density targets. Will they do so if a citizen task force comes forward with recommendations that numbers of deer be reduced? P.G.C. did not accept the recommendation from the Deer Management Plan stakeholder group to make managing deer to promote healthy forests a high priority. Will the P.G.C. staff spend another 20 years trying to perform a balancing act in each W.M.U. between biological and sociopolitical factors, only to throw up its hands in frustration yet again? If the past is any guide to the future, this is a likely scenario. Even if P.G.C. were to shift to a policy of gathering guidance on setting deer density targets from citizen task forces, there should be target levels proposed for each W.M.U. that would give each task force a starting point. However, at this point there are no such citizen task forces and it is unknown whether they ever will exist, let alone produce useful input to P.G.C. Therefore, P.G.C. should set target levels now, without waiting for the formation of citizen task forces; targets could be modified later based on public input.

GOAL 3: MANAGE DEER TO MAINTAIN, AND WHERE APPROPRIATE, RESTORE THE HEALTH OF THE ECOSYSTEM

Objective 3.1. Identify a suite of plant and animal species to serve as feedback loops for evaluating the impact white-tailed deer have on wildlife communities and establish achievable goals for the suite of species for each Wildlife Management Unit by 2007.

Objective 3.2. Inform and educate all interested Pennsylvanian's about deer management issues, the role deer have in Pennsylvania ecosystems, and the importance of regulated hunting in managing deer herds throughout the Commonwealth.

Although the first objective has similarities to recommendations in our report about indicators, there are major differences. We do not think there is a need to evaluate the impact white-tailed deer have on wildlife again from scratch. As the discussion in this report makes clear, there already is an overwhelming amount of evidence that white-tailed deer adversely affect forest communities in many ways and, in some cases, severely. This objective could lead to P.G.C. trying to re-invent the wheel, potentially resulting in decades of lost time. It is our view that indicator suites are useful for resolving disputes over management policies in an adaptive resource management program. As written, the objective does not indicate that management steps will be taken, based on existing knowledge, in an adaptive framework. That may have been implied in the objective by the use of the phrase "feedback loop," but it should be made explicit.

We also note that it is very difficult to assign goals for a suite of species (see Chapter 9). We have concluded that the best one can do at this time in most cases is specify the direction of the change that is desired, leaving the actual target level to subsequent study groups.

We are also concerned that the failure to reduce deer densities in the past makes it hard to believe that Goal 3 can be achieved without major changes to the ways deer are managed and decisions are made about deer, including changes in the viewpoints of the majority of commissioners. If implemented, the Goal 3 objectives, even though they are important first steps, will not by themselves protect a single area. We also question whether P.G.C. has the in-house expertise at this time to make progress on this goal, with or without the use of consultants; progress may hinge on the agency expanding its skill mix by adding to its professional staff.

Although there is no explicit statement of the policy foundation on which the three goals are grounded, the language makes clear that the underlying policy commits the agency to deal with the issues that affect stakeholders, including non-hunters. As has already been mentioned, it may be useful for the legislature to modify the relevant enabling legislation, expanding P.G.C.'s responsibility to include resolving wildlife-human conflicts and controlling deer damage to trees, other vegetation, and biodiversity. Without such a legislative mandate, it may be difficult to keep many of these goals operational. Although it is not explicitly stated in policy documents, based on our discussions with staff members and commissioners it appears that increasing the buck/antlerless deer ratio from its present low point appears to be the crux of P.G.C. efforts to bring deer densities in line with deer health and condition goals. Increasing the buck/antlerless deer ratio draws strong support in surveys of hunters,[59] although whether new regulations result in a sufficient increase in the deer harvest to reduce deer densities and whether the willingness of hunters to trade an increased proportion of antlered deer for fewer deer overall is not known.

Of all the new measures initiated in recent years by P.G.C. the most intricate is DMAP, which shifts some responsibilities away from P.G.C. for choosing deer densities, transferring it to landowners who can apply for additional permits for use solely on their properties. If it were to work effectively, DMAP might allow P.G.C. to satisfy those landowners clamoring for reduced deer densities on their properties while freeing the P.G.C. commissioners every year from the unpleasant task of deciding on permit numbers. Several obstacles stand in the way, however. First, most of Pennsylvania's land is privately owned and the vast majority of landowners do not understand the ecological impacts of overabundant deer. Thus, most of Pennsylvania's land will not benefit from any science-based application of DMAP. Further, the current program is administratively complex. Even if improved, it is unlikely that anyone but large landowners will accept the administrative burdens and make use of it, leaving most of the state unaffected. DMAP will not eliminate the need to set seasons, bag limits and antlerless allocations. Few hunters are criticizing DMAP on private land but some sportsmen's groups oppose it on state lands. Political pressure to keep deer numbers high on state lands will not disappear under DMAP.

There are other more subtle concerns about DMAP. The existence of the program may ease pressure on the commissioners for more far-reaching and effective reforms. Even on the small proportion of the state's lands where DMAP is expected to be used, additional deer removals are likely to serve primarily to replace existing fencing on timberlands, reducing costs to the landowners but producing little net benefit to the overall state of the forests across Pennsylvania. DMAP is to some extent a policy of transferring decision-making responsibility from P.G.C. to landowners. The only way that the program will support ecosystem management is if P.G.C. develops a science-based ecosystem management program and provides advice to DMAP landowners on achieving and sustaining deer densities that are compatible with conserving forest structure, diversity of animal and plant species, ecological processes, and ecosystem function.

How P.G.C. deer management policy affects management of other natural resources: an example

D.C.N.R. is responsible for managing 2.1 million acres of state forests and 250,000 acres of state parks. In managing these lands, the agency is responsible for sustaining the species diversity of native flora and fauna and the integrity of ecological communities and processes. To help assure that management deliberations consistently take place within an ecosystem perspective, D.C.N.R. has established the Office of Conservation Science and the Ecosystem Management Advisory Committee to provide guidance to managers and planners within the department. This may signify a significant early step by D.C.N.R. toward ecosystem management, although it is too soon to evaluate its overall effectiveness.

In 1998, D.C.N.R.'s state forest system was evaluated by Scientific Certification Systems, an international certifier of sustainable forest management operations accredited by the Forest Stewardship Council. The resulting report noted that "B.O.F.'s [Bureau of Forestry's] silvicultural systems are dominated and severely limited by the challenges of overabundant deer" and that "the Bureau's operations are so focused on the immediate challenges of overabundant deer that they have failed to adequately address other potential long-term threats to forest health."[60] Again we note that the deer population in Pennsylvania has increased by more than 20% since 1998, when this report was released.

D.C.N.R. received Forest Stewardship Council certification in 1998, but with conditions to be met before becoming recertified in 2003. One condition was that:

> *Steady and continuous progress will be made by the Commonwealth of Pennsylvania to develop and implement a deer management program that shifts from the current nutritional carrying capacity paradigm to one of diversity carrying capacity. This shift will view deer herbivory as a natural process to be managed within the parameters of sustainable forest management, biodiversity conservation, and forest economics.*[61]

In managing the state forest system D.C.N.R. faces a dilemma. A separate, independent agency (P.G.C.) has jurisdiction over one natural resource (deer) that has powerful repercussions for the management of other natural resources (forest communities and plant species) under D.C.N.R.'s authority. The Forest Certification Report acknowledged this situation: "The Evaluation Team … is cognizant that the Bureau has no regulatory authority over the deer resource on its own lands and is dependent upon the Pennsylvania Game Commission for management decisions that balance deer numbers with forest health issues."[62] Deer-browsing effects in the state forests today are even more severe than they were six years ago when the Scientific Certification Systems report was released.

D.C.N.R.'s state forest system was reevaluated by Scientific Certification Systems in 2004. The resulting report states that "[b]rowsing and grazing by an overabundant deer herd has resulted in reduced diversity (current and future) of herbaceous, shrub, and tree species seedlings that will result in reduced species composition and abundance of the next and succeeding floral communities. The current ubiquitous understory of hay-scented fern on the majority of the State forests bears testimony to this reality."[63] The report concludes:

> *It is doubtful that the political situation (influence of the majority of hunters, and majority of Commissioners on the Board of the P.G.C. against reductions of deer density) will change sufficiently in the future to assure that deer density will ever be reduced to ecologically sustainable levels within District [state] Forests if the mechanism for this reduction is deer harvest regulations as currently promulgated by the P.G.C. Therefore, impact by an overabundant deer herd will continue to decimate diversity and sustainability of flora and fauna on District Forestlands in spite of planning efforts by the B.O.F. unless regulations allowing more liberal harvest of antlerless deer on District Forestlands are provided to the B.O.F. Scenarios that would allow this to happen include: (1) enhancement of DMAP regulations, designed by independent, third-party scientists and natural resource managers, that allow more liberal harvest of antlerless deer on District Forestlands, and are granted to the B.O.F. on a continuing and contingency basis by the P.G.C. Commissioners; (2) legislative fiat, whereby administration and control of deer hunting regulations on District Forests are transferred from the P.G.C. to the B.O.F., or to its parent agency, the Pennsylvania Department of Conservation of Natural Resources (D.C.N.R.); or, (3) P.G.C. is merged with the D.C.N.R. in a combined natural resource agency and control of hunting regulations is overseen by a more balanced representation of natural resource interests, instead of the current situation where regulations are subject to the pressures exerted by the P.G.C.'s only paying constituents, hunters. It is understood that there will be a certain lag time between reduction in deer density and improvement in recovery of understory structure and diversity.*[64]

The objectives expressed in the 2003-2007 population management plan with respect to DMAP are consistent with the first scenario, redesign of DMAP regulations by independent scientists and natural resource managers to allow sufficient harvest of antlerless deer on state forest lands to achieve and sustain desired deer population levels. Some revisions to DMAP have already been made, which P.G.C. staff members believe are sufficient to solve D.C.N.R.'s problems. For instance, allowable permits per contiguous tract of land in a single ownership have been increased. However, the new change does not allow D.C.N.R. to concentrate hunting effort on the specific areas where it is most needed by moving its most effective hunters from area to area to take multiple deer. The Scientific Certification Systems report concludes that the current DMAP structure likely will result in little to no net decrease in deer density or impact within state forests. For DMAP to have a chance at bringing about a meaningful reduction of deer density and impact in state forests, according to the report, three things must happen: (1) the convoluted process by which hunters apply for and receive licenses to harvest antlerless deer within DMAP units must be streamlined, as it is for example in New York;[65] (2) hunters must be able to apply for and receive multiple licenses for individual DMAP units (current Pennsylvania regulations permit only one license per hunter; other programs such as New York's allow more than one); and (3) hunters must somehow gain access to areas remote from roads.[66] Failing any one of these conditions will likely result in failure of DMAP to reduce deer density and impact sufficiently to protect biodiversity and forest regeneration on state forest lands.

As we have stated several times, despite the numerous changes made in deer management over the years, the statewide deer population is now over 20% larger than in 1998,[67] which even then was far too high from the perspective of deer health and condition, let alone ecosystem considerations. What are the roots of this 70-yearlong failure to control deer numbers? As part of our effort to explore this question, we turn to outside reviews of P.G.C.

Lessons to be learned from external reviews of P.G.C.

The Legislative Budget and Finance Committee audits the P.G.C. budget every three years. The audit focuses on the agency's progress in achieving goals as well as reviewing the budget and finances. The 2000 audit reported that P.G.C. had not made a systematic and concerted effort to implement its 1998 strategic plan, and that the plan itself had "numerous deficiencies."[68] In another review issued in February 2003, L.B.F.C. noted that "strategic planning is not yet a significant factor in guiding Game Commission operations, programming, and fiscal decision making."[69] The report also noted that one of the plan's objectives called for providing seasons and bag limits that provide "socially desirable recreational opportunities, but are commensurate with sustainable wild game populations," but that there were no measures in place to gauge attainment of this objective.

Another objective stated in P.G.C.'s 1998 strategic plan was to maintain deer population densities within 20% of the management unit goal established by the Game Commission in the late 1970s. L.B.F.C. found that over 77% of the management units (52 of 67 counties) had deer densities more than 20% above the population goal, and 21% (14 of 67 counties) had deer densities exceeding 200% of their goal. In addition, the report indicated that the hunting season framework and harvest regulations were in direct conflict with the population goals established in P.G.C.'s strategic plan.

Since all of the documents that the L.B.F.C. cited as evidence that P.G.C. was not meeting its goals have been rescinded, a cynic might conclude that P.G.C. is dealing with its inability to make progress by backing away from its previous commitments. The 2003-2007 population management plan is the only document left with explicit and measurable goals on which the agency's performance can be judged in future audits. A more positive view is that the 2003-2007 population management plan has replaced unattainable objectives with those that have a better chance of being reached. In our view, the previous deer density targets should have been kept until a replacement was in place and used as a starting point for future discussions, say, among the proposed citizen advisory task forces if they are one day implemented.

Furthermore, the previous deer-density objectives have been unrealized, it seems, because the P.G.C. commissioners have not been willing to do any "balancing" of non-hunter needs. Is it plausible that citizen advisory task forces will make the commissioners significantly more inclined to make decisions likely to be unpopular with the segment of the hunting community who thinks there are not enough deer on the landscape? Another problem P.G.C. will have to deal with is local community values and goals as they relate to state and federal public lands. We are skeptical that commissioners will break with past performance and heed other public-land stakeholders over those hunters who believe that public lands should be managed to maximize the production of deer hunting opportunities. At the next two legislative audits, the L.B.F.C. may well find the agency failing to make progress on its 2003-2007 population management plan. Will that plan then be scrapped and another put in its place, rather than support the measures that outside reviewers and others have advocated (discussed later in this section) such as a transition from a law-enforcement agency to a natural resource conservation agency and the allocation of some places on the Board of Commissioners to those representing broader constituencies?

The preponderance of scientific evidence argues that the forests of Pennsylvania are in a seriously degraded ecological condition as a result of high deer densities (see Chapter 5). Yet P.G.C. continues to restrain the potential of hunters to solve the problem, treating deer as a fragile resource that is easily overharvested. At a time when managers on the ground question whether hunters can kill sufficient deer to control deer populations and the negative impacts of high deer densities,[70] P.G.C. continues to restrict harvest numbers, maintain the shortest season lengths among all of the Northeastern states,[71] and hold on to equitable-distribution and public-access approaches long abandoned by other states. The fact that Pennsylvania's wildlife management agency holds a position that diverges widely from its counterparts in other states within the core range of white-tailed deer[72] raises a question as to whether the differences are based on a lack of information or on differing values.

One set of values leads to the conclusion that the greatest overall benefit to the widest range of stakeholders would be served by allowing hunters, through increased deer harvests, to restore forest structure, diversity, ecological processes, and ecosystem function to a state similar to the conditions that prevailed in the relatively recent past, while also reducing deer vehicle collisions, agricultural damage, and other deer-human conflicts. Another value is that the current level of deer impact is acceptable, a fair price for facilitating hunter satisfaction and participation.

In 1998, with a goal of improving the agency's effectiveness and efficiency, P.G.C. contracted with the Management Assistance Team (MAT) of the U.S. Department of the Interior, Fish and Wildlife Service to conduct a comprehensive review of the agency. MAT reviewed P.G.C.'s structure, personnel, culture, and programs and provided its client with a set of recommendations.[73] To its credit, in the face of a report that was highly critical, P.G.C. issued a press release, stating:

> *The report is not meant to be complimentary of the Game Commission. We requested the MAT review to point out our weaknesses and to provide recommendations on how we may improve in those areas and thereby improve the Commission's overall effectiveness.*[74]

Members of the P.G.C. staff maintain that since the report was released the agency has responded to the critiques of the MAT review that they believe were valid. The report listed eight systemic management and operational deficiencies and gave detailed plans for remediation.[75] One fundamental problem identified in the report was the dichotomous culture within the agency, described as "law enforcement and everyone else." The domination of law enforcement personnel has created a unique culture in the organization resulting in a state government wildlife agency that has a "committed workforce" and "has maintained a strong enforcement orientation, but has not achieved concurrently strong orientation for professional wildlife biology." The report summarized the dichotomy issue within the agency by posing the question "Is the P.G.C. a wildlife management agency that uses law enforcement as a tool, or a law enforcement agency that does some wildlife management?"

The MAT review of the P.G.C. budget, current staffing, job descriptions, and job requirements supports the conclusion that the agency is more poised to function as a law enforcement agency than as a science-based natural resource management organization. Its organizational structure isolates the limited number of wildlife biologists the agency employs by having them work out of their homes (18 of 21 biologists on staff),[76] while the regional and Harrisburg offices are staffed mainly by law enforcement-trained personnel. At present there are no wildlife biologists working out of any of the six regional offices, although plans are moving forward to fill such positions in each of the six regions. The isolation inherent in the current arrangement challenges P.G.C.'s biologists to maintain professional contacts or keep up with the current scientific literature (P.G.C. does not purchase scientific journals or provide funding for their employees to obtain them).

Most state wildlife agencies focused more on science-based natural resource management rather than law enforcement after the Pittman-Robertson Act passed in 1937.[77] The federal monies generated by the Pittman-Robertson program provided wildlife agencies with the necessary funds to hire professional biologists to carry out broader responsibilities. The influx of professional biologists allowed most wildlife agencies throughout the United States to make the transition from law enforcement agencies designed to protect game animals to wildlife management agencies designed to preserve, protect, and enhance natural resources.[78] The Pittman-Robertson program is used extensively by state agencies to improve wildlife management practices through applied research. Pennsylvania and Minnesota were the only two states that did not use Pittman-Robertson monies to fund wildlife research projects in 1997.[79] In that same year, there were 1.86 staff members employed as wildlife biologists and technicians for every conservation officer employed by the Minnesota Department of Natural Resources. This contrasts with 0.15 wildlife biologists and technicians for every conservation officer employed by P.G.C.[80] Presumably, the Minnesota Department of Natural Resources used their Pittman-Robertson monies toward funding wildlife biologists and field technicians performing duties other than research.

With resources historically directed mainly at law enforcement, P.G.C. is struggling with making the transition from a law enforcement agency to a natural resource agency — a transition that most state agencies made many years ago. It is not clear that the transition can be made without continued and increased outside pressure.

There is strong evidence of public support for a broader approach to species management. The 2003 public survey[81] showed that 71% of the respondents agree that a greater proportion of resource agency budgets should go toward non-game wildlife and threatened and endangered species (11% disagreed). Sportsmen support this concept also, with 70% of hunter and anglers agreeing and 11% disagreeing.

If ecosystem management is to be implemented successfully, P.G.C. must become more focused on natural resource conservation issues and shift away from dominance by law enforcement. P.G.C. staff members have told us that they think they can do both, that is, be an effective natural resource conservation agency while maintaining the dominance of law enforcement without having to make major reallocation of resources, including shifts in hiring practices and staff retraining in forest ecology and wildlife biology. While we admire the “can do” attitude of the staff, the lack of success in bringing deer numbers down, coupled with the lack of a coherent plan to do more than “improve trends,” makes us very skeptical. Until evidence of success is demonstrated under the current system, groups like ours and outside evaluation committees will call for change at P.G.C., including a major increase in the number of internal personnel supporting ecosystem management.

Certainly, the existing P.G.C. staff is well-qualified to protect the deer resource; they have a solid track record in this regard. Agency staff members are accomplished experts in deer biology and they run an effective law enforcement agency. It is in the conservation of non-deer species, including forest vegetation, where the agency needs to bolster its capabilities and focus. Given the historical failure of P.G.C. to bring down deer densities that have climbed over time, we think the burden is on P.G.C. to prove to outside observers that they can do the job without major staff reorganization. Until such time, it should be presumed that the dilution of resource management resources in the agency by the emphasis on law enforcement is a contributing cause of the agency's inability to bring deer density down and a reason to be pessimistic that any new initiatives will reverse the trend.

The counterargument is that the problem is not with how agency staff is allocated, but with commissioners who cannot sign off on measures brought before it because of political pressures. However, until staff training and job responsibilities are focused on hunter and public education, especially about deer impacts and opportunities for change through adjustment of buck/antlerless deer harvest ratios, outside observers are going to criticize the agency for its predominantly law-enforcement culture.

The MAT report highlighted other problems that existed at the time, stating that "the current commissioners lack credibility with the public and with the P.G.C. employees," and warned, "this is an area clearly identified as extremely serious for the P.G.C." The only rule about who may become a member of the Board of Commissioners is that commissioners are appointed by the Governor and need approval by two-thirds of the Senate. There are no qualifications or specific requirements regarding natural resource management education or experience. The MAT report indicated that the commissioners "are problematic to P.G.C. effectiveness" and stated:

> *Commissioners would profit from training in governance, meeting process and facilitation skills, clear decision-making processes, public relations, diversity awareness, and conflict management. However, while such training would be effective, it would not be sufficient. All P.G.C. commissioners need to fully commit to any reinventing process and back such commitment with actions.*[82]

Since the 1998 MAT report, the makeup of the Board of Commissioners has changed with turnover in several positions. Some commissioners have participated in stakeholder discussions, which is an excellent way to get ideas on how to move away from single-species management. Nevertheless, P.G.C. commissioners are all still selected to represent sportsmen and hunting and trapping groups, which make up less than 8% of the population in the state.[83] As long as the chief policy makers represent only sportsmen and not all of the people of Pennsylvania, are not required to have natural resource management expertise, and can routinely overrule the scientific recommendations of staff biologists, ecosystem management stands little chance of success. We do not mean to imply that the current set of commissioners as a group does not want to see progress. The problem is the message that is sent when all commissioners are selected to represent a small set of stakeholders. Only when the Board of Commissioners is required to include members selected to represent a broader range of stakeholders (which does not bar them from also being hunters), will the Governor and the General Assembly make it clear to everyone that P.G.C. has responsibilities beyond hunters and trappers.

The MAT report was completed in 1999. The annual benchmarking reports issued thereafter by MAT were critical of P.G.C. for addressing only the minor problems identified in the original report, while acknowledging that "it is not uncommon for organizational changes such as these to require from three to five years to implement fully."[84] The 2001 benchmarking report, issued by MAT in April, 2002,[85] reported that there had been numerous improvements since 1999. However, the report stated that P.G.C. still remained focused on addressing only the minor issues while ignoring the more substantial problems identified in the initial report, including the dichotomous culture issue. The benchmarking report stated that overall P.G.C. "is in a much better position today than it was two years ago to make substantive, enduring change for improvement."

In its 2003 audit report, L.B.F.C. noted that "despite noteworthy changes having been made, several key core areas identified by the MAT team are still in need of improvement." The report recommended that "P.G.C. should continue to implement the recommendations from the 1999 Management Assistance Team reports with particular emphasis on addressing the 'core areas' of agency operations identified by the benchmarking review as still needing improvement."[86]

In a letter of response that L.B.F.C. included in the 2003 report, P.G.C. Executive Director Vern Ross stated, "As for those recommendations directed at key 'core areas,' I want to assure the members that I am committed to moving forward on several of those items." In the same letter he wrote that "not all MAT recommendations will be implemented as written, and some may never be implemented."

One of the core-area recommendations was that positions such as regional director and land manager should be open to all qualified applicants. L.B.F.C. noted that in 2003 these positions still required graduation from the Ross Leffler School of Conservation, P.G.C.'s law-enforcement training facility. In January 2003, P.G.C. informed L.B.F.C. that rather than remove this requirement, they were considering establishment of a course that would allow all interested parties to attend the Ross Leffler School for a short program that will "prepare them to move into supervisory roles."[87] Since that time, however, five of the six regional directors have retired and all were replaced by Ross Leffler School graduates. Apparently, no one other than Ross Leffler

School graduates applied,[88] which suggests the need for some active recruiting as well as making good on the promise to develop a Ross Leffler School short course.

Although the major concern of the MAT report about the dichotomous culture has not been addressed, there have been significant changes made by the agency's leadership. Those changes have not yet led to any declines in total deer numbers, although statewide population estimates have been essentially flat for three years. One of the most significant changes has been the establishment of a dialogue with stakeholders. Some commissioners have participated in these sessions. Other changes, mentioned earlier in this chapter, include improved outreach to hunters on conservation issues, especially with the hiring of Dr. Gary Alt as chief biologist and hunter communicator for the deer management program, in the position of Supervisor of the Deer Management Section.

Many agency staff members and some of the commissioners appear committed to a philosophy of reducing deer numbers through increased doe harvests. Staff members have recommended and the commissioners have accepted increased numbers of antlerless deer harvest permits. The Deer Management Assistance Program for landowners has been introduced and modified in the face of critiques. If the latest population management plan survives, the agency will be able to say that it has undergone a shift in management philosophy and has developed a practical plan, focused on landowners and stakeholders, that may be able to break through some of the political roadblocks. However, until these ideas are internalized throughout the agency, the weaknesses in the plan corrected, and internal resources brought to bear on carrying out the difficult objectives set out in the 2003-2007 plan, we do not see how the plan can succeed, let alone survive for very long in the face of the inevitable partisan criticism that it will engender if it starts to make a difference.

Another recent report regarding natural resource management agencies titled "Recommendations to the Rendell Administration on Environmental and Natural Resources Priorities"[89] was written and distributed in July 2003 by Robert McKinstry, Maurice K. Goddard Professor of Forestry and Environmental Resources Conservation at Pennsylvania State University. The report stated:

> *The deficits in appropriate training and allocation of resources to wildlife management, as opposed to law enforcement, and the focus on the concerns of one narrow interest group have, in the past, produced significant problems in deer management, one of the most critical functions of P.G.C.*

Advice to D.C.N.R. on agency cooperation has been given by its Conservation and Natural Resources Advisory Council. This group reviewed D.C.N.R.'s forest management plan in 2003 and had several recommendations for deer management in Pennsylvania:

(1) D.C.N.R. should continue to work with P.G.C. to promote effective and strategic management of the deer herd and to reduce their numbers in order to promote forest regeneration.

(2) D.C.N.R. should support P.G.C.'s Deer Management Assistance Program but should advocate for expansion of the program's availability to private landowners and simplification of the application process in order to promote landowner participation in the program.

(3) D.C.N.R. should advocate and support educational outreach concerning forest regeneration issues as they relate to Pennsylvania's deer population.

(4) The Secretary should request the Governor's office to convene an interdepartmental Deer Management Task Force consisting of leadership at the secretary level from, at a minimum, D.C.N.R., Department of Environmental Protection, Department of Agriculture, and P.G.C., in order to address deer population and deer-related impact issues.

(5) If P.G.C. programs do not effectively reduce deer populations, then D.C.N.R and other landowners should consider necessary legal and legislative action to protect the resources.[90]

A few of these recommendations have been addressed. For instance, P.G.C. staff members believe that, with their latest revisions to DMAP, they have given D.C.N.R. everything it needs to meet its deer management goals. (However, as noted elsewhere, the new change does not allow D.C.N.R. to target specific problem areas by requiring hunters with DMAP permits to move from area to area to take multiple deer.) Consistent with the third recommendation of the Conservation and Natural Resources Advisory Council, P.G.C. staff members expressed surprise that D.C.N.R. has not publicly stated that there are too many deer on state lands. D.C.N.R. has subsequently begun to be more public on this issue.[91]

Summary of contributing causes to the current high populations of white-tailed deer

There appear to be multiple, interacting causes for the failure to control deer numbers and for the widespread pessimism that exists concerning the prospects for long-term improvement under the current management system:

(1) P.G.C. commissioners are currently selected to represent a narrow range of constituencies (sportsmen and hunting and trapping groups), rather than the full set of stakeholders affected by deer populations. Concerned about perceived hunter reaction, the Board of Commissioners has routinely overruled the scientific recommendations of staff biologists.

(2) There is an unusual three-way resource management structure in Pennsylvania with responsibility given by the legislature to P.G.C. for mammals and birds, to P.F.B.C. for aquatic animals, and to D.C.N.R. for forests. This situation tends to reinforce single-species management at P.G.C.

(3) State agencies that are responsible for, affect, or have a stake in the management of natural resources in Pennsylvania are not collaborating to ensure that policies by one agency do not adversely affect another's ability to carry out its mission.

(4) Although the P.G.C. staff is strong in the areas of deer biology and in implementing and enforcing regulations to make hunting safe, the staff is very thin in the field of general ecology. External reviews have found that P.G.C. operates primarily as a law enforcement agency. This situation continues to this day as far as we can tell, with the changes that have been made in response to outside critiques failing to solve the identified problems.

(5) The source of funding for P.G.C. serves to perpetuate the idea that P.G.C. is a bastion unto itself, with responsibilities only to hunters.

(6) Even though a few conservation organizations in Pennsylvania have been voicing concern for many years, until recently most such organizations did not make overbrowsing of forest vegetation by deer a priority. As a result, the conservation voice was muted in debates over deer numbers.

(7) Until recently, there has been a widespread belief in and out of government that because hunters paid license fees and were supposedly the only stakeholder strongly interested in deer, they should have dominant influence over deer management. The appearance in the public arena of more and more stakeholders concerned about deer-human conflicts is helping to change that view.

(8) Disputes over causes of forest damage (e.g., acid rain vs. deer overbrowsing) have slowed the adoption of measures that would bring deer numbers down.

Issues that must be addressed by any proposal that relies on recreational hunting to manage deer populations

Anyone making proposals to rely on recreational hunting to manage deer must consider P.G.C.'s current revenue sources, trends in license sales, and factors that may influence hunter participation.

Revenues and decline in hunter numbers

Like all of the other states, Pennsylvania uses recreational hunting as the primary means of manipulating deer population size[92] and harvesting females is the sole basis for affecting deer population growth rates.[93] Therefore, the number of antlerless deer harvest permits required to increase, stabilize, or decrease the deer herd can be calculated based on the estimated population size relative to the population goal and the assumed efficiency of hunters in shooting deer (deer harvested per permit issued). However, such a calculation assumes there are enough hunters wanting to purchase the permits. Although Pennsylvania deer populations have increased dramatically over the past 20 years, the number of licensed hunters has continued to decline (Figure 10). From 1955 through 2001, the growth in hunter numbers throughout the United States lagged behind the rate of population growth, resulting in a net 23% decline in hunters as a percentage of the total population.[94] Forecasts based on trends in license sales, the aging hunter population, and declining rates of new-hunter recruitment strongly suggest that the number of hunters in Pennsylvania and adjacent states is likely to continue falling.[95] The preferred method to reduce deer population size, and one of the most cost-effective and efficient, is recreational hunting,[96] so factors that influence hunter participation are a major concern. The decline in hunter numbers affects P.G.C. not only because it relies on hunters to regulate deer populations but also because hunter license fees are the primary source of revenue for the agency.

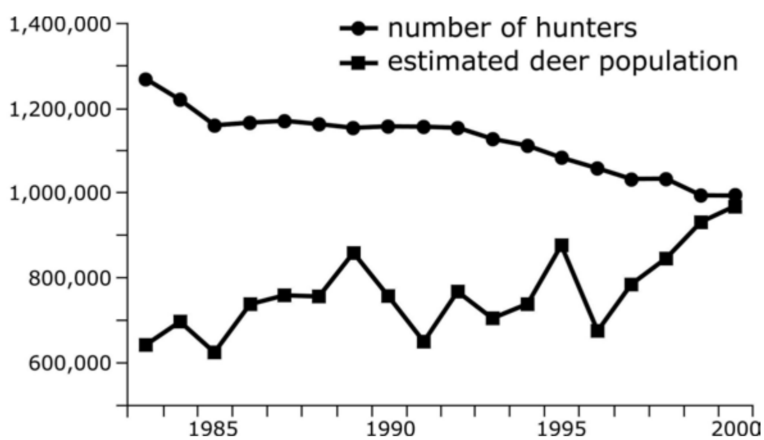


Figure 10. Number of Pennsylvania hunting licenses purchased and statewide post-hunt deer population estimates based on a sex-age-kill model, 1983-2000.[97] In this graph, “number of hunters” is the total number of hunting licenses of all types issued by P.G.C. (Figure 11C, page 213, shows the 20-year trend in sales of resident adult hunting licenses, the principal source of revenue for P.G.C.).

Seasons and bag limits

The continuing decline in hunter numbers suggests that seasons and bag limits will likely need to be very liberal in future years to provide hunters ample opportunity to harvest multiple deer. For example, if there were only 387,000 Pennsylvania deer hunters in 2030 (a linear projection from recent trends), each hunter would need to harvest 1.3 antlerless deer on average if a harvest of 500,000 does was required to stabilize population growth, which was the case in 2002.[98] A recent study conducted of Pennsylvania hunters indicated that participants, on average, are willing to harvest only 1.7 deer.[99] At first glance, this looks sufficient to stabilize population growth. However, not all hunters are successful and most hunters prefer to harvest at least one buck, which has a negligible effect on the population growth rate. In 2002, P.G.C. issued more than 1,000,000 antlerless deer harvest permits but less than 400,000 antlerless deer were harvested. It is not known how many hunters purchased these permits but the harvest rate of less than 0.4 deer per license strongly suggests that hunters are falling short of the success rate required in our 2030 scenario merely to keep the population stable.

P.G.C. should manage this problem proactively, because a future deer herd comparable in size to the present-day deer population will probably not be manageable with recreational hunting if the current relationship between hunter numbers and necessary harvests continues. One way to be proactive is to use the current crop of hunters to reduce the deer herd to a level that would be feasible for future hunters, even though reduced in numbers, to keep under control. Such a management strategy would be based on the development of a methodology to estimate future trends in hunter numbers.

The trend of declining hunter numbers is likely to result in increasing pressure to supplement recreational hunting with additional means of controlling deer. Immunocontraception almost certainly will remain impractical for many years to come except perhaps in very small areas with extraordinarily large budgets (see page 161). The use of sharpshooters or permanent fences is also cost-prohibitive except in very small areas where special circumstances justify the expense. Increasing attention is being paid by scientists[100] and others to large-predator reintroduction, although in a state with as large a human population as Pennsylvania's, only a fraction of the area, if any, may be remote enough for large predators to sustain numbers capable of affecting deer populations. However, it is premature to focus on alternatives to recreational hunting until hunters are given adequate tools to control deer numbers.

Non-license revenues

In response to revenue concerns, it appears that P.G.C. has increased its timber harvest operations to compensate for the loss in hunter license sales over the past 20 years (Figure 11). If revenue needs by the agency follow the historical trend (Figure 11A), P.G.C. would need to increase its timber operations substantially. The McKinstry report indicates that P.G.C. has no forest inventory data and no forest management plans,[101] therefore, it cannot be determined whether the current timber harvesting levels or projected future harvest levels are sustainable or attainable. If the projected loss in license sales were to continue and P.G.C. were to choose not to increase timber harvests, the only alternative under current law would be to increase the cost of

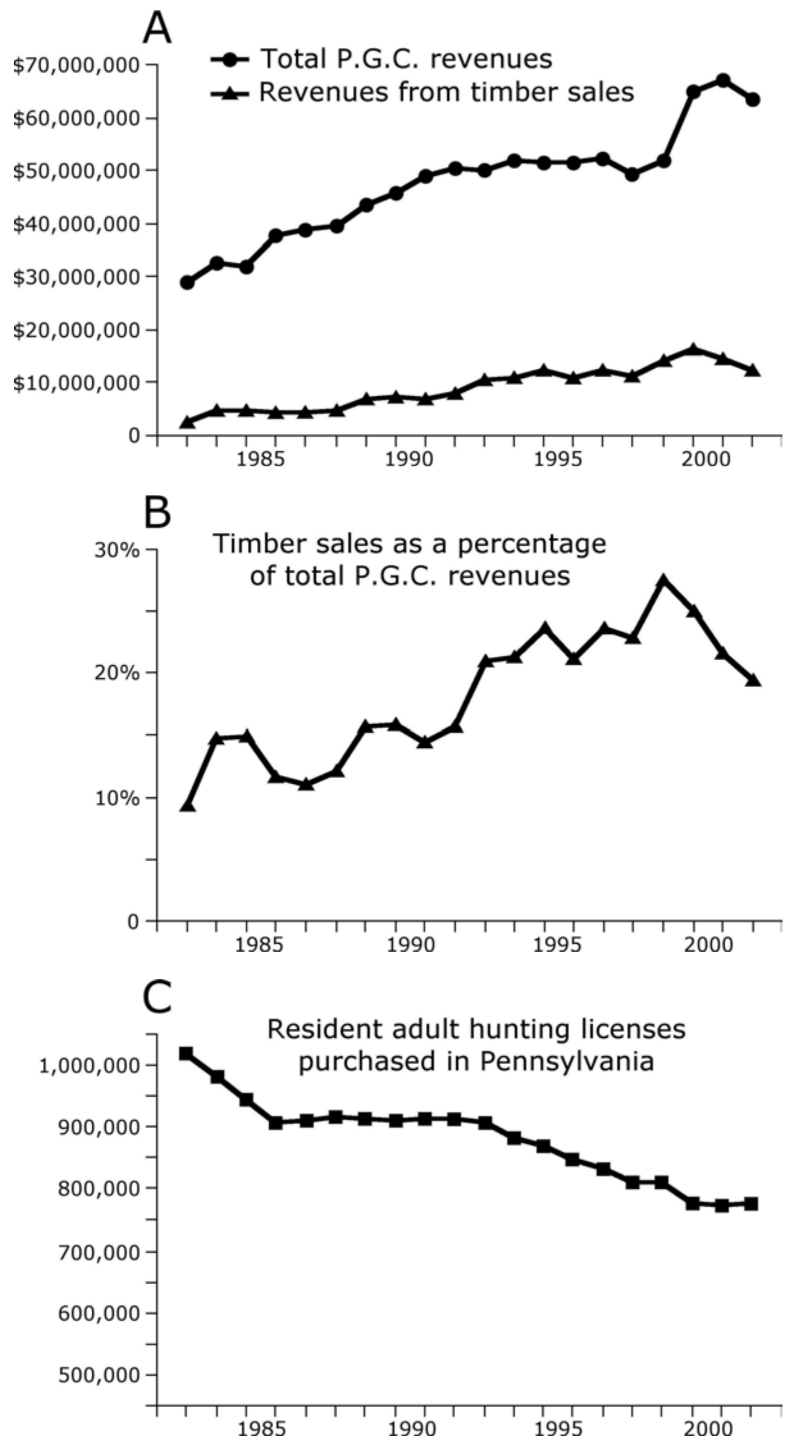


Figure 11. Twenty-year trends in Pennsylvania Game Commission revenues (A, B) and resident adult hunting license sales (C). Data from P.G.C. annual reports,[102] fiscal years 1982-1983 through 2001-2002.

individual hunting licenses. Assuming hunters were to fund the remaining part of the budget (excluding timber sales), each hunter would need to pay considerably more in the next 10 years for licenses.

In its 2003 performance audit of P.G.C., L.B.F.C. looked into the funding issue, concluding that "while further license increases may provide temporary relief, other revenue enhancements and alternative revenue sources need to be identified."[103] The report noted that the resident hunting population has declined by 15% in the past 10 year, and predicted that this trend will be compounded as the licensee base grows older. According to L.B.F.C., P.G.C. has acknowledged that wildlife agencies forced to rely on license sales with no general fund monies will increasingly experience serious financial difficulties and, accordingly, has considered several alternative funding sources.[104] For instance, in its current strategic plan, P.G.C. proposes seeking revenues from the Commonwealth's general fund.

The 2003 public survey shows support for a broader funding structure.[105] When asked about supplementing agency budgets with existing public funds to increase the proportion used for non-game species management, 58% agreed and 23% were opposed. Hunters and anglers agreed 60% to 25%. This support declined when the question tied funding to a new dedicated tax. The survey shows that the public, including sportsmen, will support a change in agency funding in order to broaden the scope beyond single-species management.

Given declining revenues from license sales, and until such alternative revenue sources are enacted, there will remain a potential for timber harvesting and mineral extraction on game lands to be driven by the need for revenues despite adverse affects on the integrity of the affected ecosystems. We note that P.G.C. did not put any game lands into DMAP this year even though exclosures on game lands, particularly in north-central Pennsylvania, demonstrate that many are overbrowsed.

In this chapter, we reviewed some of the problems identified by other agencies and by external reviewers and we highlighted issues that need to be considered in developing solutions. In the next chapter, we propose measures that we believe will contribute to improvement.

Findings on deer management policy and administration in Pennsylvania

(1) With the exception of a vocal minority of hunters, there is a broad consensus that deer densities in Pennsylvania are too high from an ecosystem perspective. In a 2003 survey of Pennsylvanians, the general public ranked managing deer to promote healthy and sustainable forests highest among potential goals (average 7.5 of 10) and hunters and anglers ranked it even higher (7.8 of 10). Pennsylvania hunters and anglers ranked managing deer to promote healthy and sustainable forests higher than managing deer to promote hunting opportunities (7.8 vs. 7.1 of 10). The stakeholder group P.G.C. convened to recommend goals and objectives for its statewide deer management plan also ranked managing deer to promote healthy forests and ecosystems as its top goal.

(2) In a reevaluation of D.C.N.R.'s state forest system in 2004, Scientific Certification Systems predicted that overabundant deer will continue to decimate the flora and fauna in Pennsylvania's state forests without:

- (a) enhanced DMAP regulations that allow more liberal harvest of antlerless deer on state forest lands and are granted to the D.C.N.R. Bureau of Forestry on a continuing and contingency basis by the P.G.C. commissioners; or
- (b) legislative fiat, whereby administration and control of deer hunting regulations on District Forests are transferred from P.G.C. to D.C.N.R.; or
- (c) merger of P.G.C. with D.C.N.R. in a combined natural resource agency resulting in oversight of hunting regulations by a more balanced representation of natural resource

interests. Note: both agencies are on record in opposition to such a merger and there appears to be no real political will to pursue it at this time.

(3) The P.G.C. commissioners, in response to proposals by staff to bring the deer herd more in line with its habitat and to protect commercially valuable trees, set targets for lower deer densities in Pennsylvania in 1979; however, those goals have never been met. In a renewed effort to reduce deer population levels, numerous changes were made in the deer management program from 1998 through 2003. However, the deer herd has not decreased and has, in fact, increased more than 20% since 1998.

(4) With the reorganization in 1999 of the Wildlife Management Bureau (with Dr. Gary Alt named chief of the newly formed Deer Management Section) and the support of agency policy makers, P.G.C. is poised to pursue a more aggressive deer management program that, in theory, can effectively reduce deer densities in many parts of Pennsylvania. Its success depends critically on whether the changes are formalized in a way that enables them to last through the turnover of personnel on the staff and Board of Commissioners.

(5) Although the P.G.C. staff is strong in the areas of deer biology and in implementing and enforcing regulations to make hunting safe, the current staff has limited expertise in the field of general ecology. External reviews have found that P.G.C. operates primarily as a law enforcement agency, with its limited number of biologists isolated and, with few exceptions, not engaged in the core functions of the agency. With resources historically directed mainly at law enforcement, P.G.C. is struggling with making the transition from a law enforcement agency to a natural resource agency — a transition that most state agencies made many years ago.

(6) P.G.C. senior staff members argue that they have done all that is possible to manage deer under the current sociopolitical environment. While we find there are many more measures that the P.G.C. staff could and should implement, we do not minimize the sociopolitical constraints under which P.G.C. staff members must operate. Nor do we doubt that it took substantial effort to implement the staff-initiated changes on hunting seasons, permit allocations, and the fledgling Deer Management Assistance Program that have been made in recent years.

(7) P.G.C. gives mixed messages about the need for ecosystem considerations. This reflects a mix of *internal* stakeholders with differing views and is evidence of an ongoing debate within the staff and Board of Commissioners about the future of the agency. For instance, P.G.C.'s web site discusses forest damage caused by high deer populations, as does the current deer population management plan. However, P.G.C.'s main strategic planning document, developed by senior staff members, does not acknowledge that high wildlife

populations can be a problem for ecosystems nor does it concede that the agency has failed to bring the deer population in line with past targets.

(8) Adopting a program of managing deer from an ecosystem perspective would provide both advantages and challenges for P.G.C. Ecosystem considerations would lead to the conclusion that deer densities in some parts of the state should be reduced below levels that would be set solely by considerations of deer health and condition. This would require targets even lower than those P.G.C. has been unable to reach in the past. The reaction of some hunters to lower densities may be negative but the 2003 survey results indicate that the majority of hunters would support the goal of managing deer to promote healthy and sustainable forests.

(9) There is an unusual three-way resource management structure in Pennsylvania with responsibility given by the legislature to P.G.C. for mammals and birds, to P.F.B.C. for aquatic animals, and to D.C.N.R. for forests. This situation tends to reinforce single-species management at P.G.C.

(10) State agencies that are responsible for, affect, or have a stake in the management of natural resources in Pennsylvania are not collaborating to ensure that policies by one agency do not adversely affect another's ability to carry out its mission. For instance, at present D.C.N.R. cannot fully implement ecosystem management on its lands because it does not have the necessary authority to manage deer populations in state forests and state parks, even with the latest version of P.G.C.'s Deer Management Assistance Program. As a result, deer populations continue to adversely affect forest ecosystems on state lands. Based on conditions placed on Forest Stewardship Council certification, this could present challenges to continued recertification of D.C.N.R. land. High deer densities also acutely affect the domains of responsibility of the Departments of Agriculture and Transportation.

(11) P.G.C.'s mandate, "To manage all wild birds, mammals and their habitats for current and future generations," is consistent with the goal of managing deer from an ecosystem perspective, but is not adequately reflected in the agency's current policies or skill mix. Neither is the mission fulfilled in practice due to P.G.C.s' primary focus on single-species management.

(12) Wildlife management rules and regulations for animal species are set by P.G.C.'s Board of Commissioners, members of which are appointed by the Governor with approval by two-thirds of the state Senate required for confirmation. The commissioners, not the staff, set seasons, bag limits and antlerless deer harvest permit allocations. The Governor can replace commissioners. There are no eligibility qualifications specifically regarding education or experience in natural resource management to be a commissioner.

(13) Commissioners are currently selected to represent sportsmen and hunting and trapping groups without representation of other constituencies affected by deer populations.

(14) There is sufficient authority under the state constitution for P.G.C. to introduce management of deer from an ecosystem perspective. However, neither P.G.C.'s enabling legislation nor the staff-written mission statement explicitly charges the agency with resolving wildlife-human conflicts and protecting forest ecosystems from artificially high densities of wildlife.

(15) The management of deer is a service provided to all citizens of Pennsylvania, yet P.G.C. is currently funded primarily by license dollars and timber-harvest revenues from state game lands. Neither source is predicted to be sustainable in the long term. A more stable and equitable funding base is required if deer management is to meet broader conservation goals.

(16) Although the chief executive of Pennsylvania's wildlife agency does not report directly to the Governor, the administrative and legislative branches of state government have direct and indirect influence over the management of deer and other wildlife.

(17) The goal of keeping deer densities within 20% of targets set for W.M.U.s by past Boards of Commissioners has been rescinded with publication of the latest set of strategic planning documents. The staff-approved deer population management plan calls only for "improvement" in indicators of deer impact, rather than specific targets.

(18) The total number of deer in Pennsylvania, after decades of growth, appears to have reached a plateau at around 1.6 million deer in the fall population. Staff biologists projected a 5% decline in most wildlife management units in 2004. The seasonal framework and hunting regulations adopted over the past 5 years made this projected decline possible. So far these measures have not resulted in any observable decrease in deer densities, but some P.G.C. senior staff members expect that their effect will soon become evident. However, no one outside P.G.C. with whom we have talked is optimistic, given the current management structure and commissioner appointment system, that such measures will survive the sociopolitical counter-pressures that will build if deer numbers should start to come down.

(19) No target density or A.R.M. protocol has been established to guide management decisions over the long term. The current deer management goal is to adjust seasons, bag limits, and antlerless deer harvest license allocations to improve trends in deer density and other indicators such as body weights, percent yearling males in the buck harvest, pregnancy rate in females, multiple fetus rate in females, and fawn/doe harvest ratios.

(20) Of all the new measures initiated in recent years by P.G.C., the most intricate is DMAP, which shifts some responsibilities away from P.G.C. for choosing deer densities, transferring it to landowners who can apply for additional permits for use solely on their properties. If it were to work effectively, DMAP might allow P.G.C. to satisfy those landowners clamoring for reduced deer densities on their properties while freeing the P.G.C. commissioners from the unpleasant yearly task of deciding on permit numbers. However,

most of Pennsylvania's land is privately owned and the vast majority of landowners do not understand the ecological impacts of deer overbrowsing. Thus, most of Pennsylvania's land will not benefit from any science-based application of DMAP.

(21) Without forest inventory data and forest management plans, it cannot be determined whether the current timber harvesting levels or projected future harvest levels on state game lands are sustainable or attainable. Given declining revenues from hunting license sales, there is a potential for timber harvesting and mineral extraction on game lands to be driven by the need for revenues despite adverse affects on the integrity of the affected ecosystems.

(22) Declining hunter numbers have led some scientists to conclude that hunters eventually will be unable to keep the deer herd under control and that other methods will be needed. Until hunters are given adequate tools, however, it would be premature to conclude that recreational hunting cannot do the job.

(23) A program of A.R.M. could fill major gaps in the efforts of P.G.C. staff members to bring deer densities more in line with deer health and ecosystem targets. A.R.M. could be especially helpful in resolving the argument about the relevance of acid rain to forest damage, a controversy that some P.G.C. staff members believe is a major obstacle to hunter acceptance of the need to reduce deer densities.

Recommendations on deer management policy and administration

Recommendations to the Pennsylvania Game Commission

(1) Members of the staff should recommend and the commissioners approve goals that go beyond those in the population management plan that call for "improving indicators." Members of the staff and commissioners should establish intermediate, quantitative deer-density goals, such as those that were dropped from the strategic plan in 2003 — targets that were based on deer health and condition and the protection of commercial timberlands. If the measures enacted in recent years, such as the October hunting season, do not produce a detectable and significant change in deer densities over the next year, staff members should recommend and the commissioners should take action on adopting seasons, bag limits, and numbers of antlerless deer harvest licenses that will achieve the targets.

(2) P.G.C. should ensure sustainability of forests on state game lands by developing and implementing an ecologically based forest inventory and forest management plan. When necessary, sections of state game lands should be entered into DMAP.

(3) P.G.C. should formalize the recent organizational changes that have enabled its Wildlife Management Bureau to pursue a more aggressive deer management program, to insure that

crucial structures will remain intact as key players come and go with routine personnel turnover.

(4) P.G.C. should adopt a revised mission statement that reflects its responsibility to a broad range of stakeholders. Staff members and commissioners must make it clear in the drafting of the mission statement, as well as in regular communications at meetings, that their prime responsibility is to the citizens of Pennsylvania rather than to any particular stakeholder group. Resolving wildlife-human conflicts should be stated as one of P.G.C.'s major responsibilities. Protecting Pennsylvania's forests should be acknowledged as another responsibility.

Recommendations to the Governor, the Governor's Advisory Council on Hunting, Fishing and Conservation, the Department of Conservation and Natural Resources, and the General Assembly

(1) The Governor and the General Assembly, in collaboration with P.G.C., should identify a funding base that is more stable and equitable than funding derived exclusively from license dollars and timber sales on game lands, in order to facilitate the shift from single-species management to ecosystem management.

(2) The General Assembly should modify P.G.C.'s enabling legislation to make it unambiguously clear that part of the agency's mission is to resolve wildlife-human conflicts and protect forest ecosystems. The enabling legislation should say that commissioners should be chosen to represent all Pennsylvanians.

(3) All efforts should be made to forge, through negotiation with stakeholders, a mutually acceptable approach to balancing the number of deer in the forest. However, if an impasse arises and progress appears unlikely, the various levels of government will have to step in and make sure that ecosystem-based management of deer is not lost in attempts to balance biological and sociopolitical factors when decisions are made in connection with seasons, bag limits, and antlerless deer harvest licenses.

(4) P.G.C., in conjunction with D.C.N.R. and with assistance from the Governor, should address the conditions that must be met to maintain continued certification of the state forest system, particularly regarding the adverse effects of deer. D.C.N.R. should continue to expand its use of a broad range of tools to reduce the deer herd on state forest and state park lands including DMAP, special hunts, and others that may become available as regulations are amended or refined.

(5) DMAP should be thought of as an add-on to an overall program to meet these goals, not a substitute, particularly because DMAP does not realistically apply to all Pennsylvania lands. At the same time a program of adaptive resource management, such as is described in this report, should be designed and implemented to further adjust deer-density targets based on

overall ecosystem concerns. The aim should be to provide all property owners whose goals include restoring forest structure, diversity, ecological processes, and ecosystem function the ability to manage deer in ways that will enable them to achieve those goals. It is vital that both be undertaken concurrently; planning and developing an A.R.M. program must not become an excuse for further postponing action to meet longstanding deer density goals.

Endnotes

[1] Diefenbach and Palmer 1997; Pennsylvania Game Commission 2003b

[2] R. S. Palone, in Audubon Pennsylvania 2004a, 2004b

[3] There is a vocal, but minority (Reed Haldy McIntosh & Associates 2003) subgroup of hunters who believe and actively promote the idea that deer numbers are overestimated and that the deer herd in Pennsylvania is threatened, particularly by antlerless licenses. They also maintain that acid rain is the cause of the damage on state lands. They do apparently concede that deer may be contributing to damage on private lands (www.usp.cc, accessed 2004-10-13).

[4] Reed Haldy McIntosh & Associates 2003

[5] Responsive Management 1996

[6] Reed Haldy McIntosh & Associates 2003

[7] Legislative Budget and Finance Committee 2000

[8] DuBrock 1999

[9] Diefenbach and Palmer 1997

[10] DuBrock 1999

[11] Diefenbach et al. 1997

[12] Wallingford 2000

[13] Pennsylvania Game Commission 2003a

[14] Michael Pechart, Director of Local Government Programs, Farm Bureau, Pennsylvania Department of Agriculture, personal communication, 2003

[15] Diefenbach et al. 1997; Diefenbach and Palmer 1997

[16] Wingard 1964

[17] Anonymous 2001b

[18] Diefenbach and Palmer 1997

[19] Kosack 1995

[20] E.g., Luttringer 1931; Phillips 1940; Latham 1950; Dzemyan 1994

[21] Dr. Gary L. Alt, Supervisor, Deer Management Section, Bureau of Wildlife Management, Pennsylvania Game Commission, personal communication, 2004

[22] Responsive Management 2001: p. 9

[23] DuBrock 1999; Pennsylvania Game Commission 2004

Endnotes

[24] Pennsylvania Game Commission 2003b

[25] Inclusion of material critical of P.G.C. in this chapter was deemed controversial by some readers of draft versions of this report.

[26] Wildlife Management Institute 1997: Fig. X1

[27] Bolen and Robinson 2003

[28] 19 of 24 states; Wildlife Management Institute 1997

[29] Colins 2002

[30] Matthews 1986

[31] E.g., Migratory Bird Treaty Act (1918), Endangered Species Act (1973), Lacy Act (1905); Matthews 1986

[32] E.g., the Pennsylvania Digest of Hunting and Trapping Regulations is issued by P.G.C.

[33] Pennsylvania Constitution, Article 1, Section 27

[34] Pennsylvania Game Commission 2003d; C. W. DuBrock, Wildlife Management Director, Pennsylvania Game Commission, personal communication, 2004

[35] Roseberry and Woolf 1991

[36] Larkin 1977; Holt and Talbot 1978

[37] E.g., Caughley 1977

[38] Caughley 1985

[39] Dasmann 1981

[40] More recent studies of this type include Drake et al. 1985; Drake and Palmer 1986, 1991; Tzilkowski et al. 1994

[41] E.g., Curtis and Rushmore 1958; Beals et al. 1960; Anderson and Loucks 1979; Euller and Lloyd 1980; Frelich and Lorimer 1985; Tilghman 1989; Anderson and Katz 1993; Anderson 1994; deCalesta 1994; Horsley et al. 2003

[42] Pennsylvania Game Commission 2003b

[43] Pennsylvania Game Commission 1998b

[44] Pennsylvania Game Commission 1998b

[45] M. Grund, unpublished data, 2003

[46] Pennsylvania Game Commission 2003b

[47] Pennsylvania Game Commission 2003e

[48] Diefenbach and Palmer 1997

[49] Legislative Budget and Finance Committee 2000

[50] Pennsylvania Game Commission 2003b

[51] Pennsylvania Game Commission 2003e

[52] DuBrock 1999

[53] Pennsylvania Game Commission 2003e

Endnotes

[54] Reed Haldy McIntosh & Associates 2003

[55] Pennsylvania Game Commission 2003e

[56] Pennsylvania Game Commission 2002a

[57] Diefenbach et al. 2005

[58] Pennsylvania Game Commission 2003e: Goal 2, p. 43

[59] Responsive Management 2001

[60] Shissler et al. 1998

[61] Shissler et al. 1998

[62] Shissler et al. 1998

[63] Wager et al. 2003

[64] Wager et al. 2003

[65] M. Grund, in Wager et al. 2003

[66] We note that this doesn't mean we need more roads. Rather, regulations need to be developed that provide incentives for hunters to be willing to walk farther from roads, for instance, special seasons in October, January, or February when the only places where hunters can legally harvest deer in Pennsylvania are in these remote areas. A working definition of "remote" is more than 0.3 mile from any road; recent research (Diefenbach et al. 2005) indicates that the majority of deer hunters in the state do not hunt beyond this zone.

[67] M. Grund, unpublished data, 2003

[68] Legislative Budget and Finance Committee 2000

[69] Legislative Budget and Finance Committee 2003a

[70] Brown et al. 2000

[71] M. Grund, unpublished data, 2003

[72] M. Grund, unpublished data, 2003

[73] Angus Guynn and Guynn 1999

[74] Pennsylvania Game Commission 1999

[75] Angus Guynn and Guynn 1999

[76] Robert C. Boyd, Assistant Bureau Director and Research Division Chief, Pennsylvania Game Commission, personal communication, 2004

[77] Angus Guynn and Guynn 1999

[78] Angus Guynn and Guynn 1999

[79] Wildlife Management Institute 1997

[80] Wildlife Management Institute 1997

[81] Reed Haldy McIntosh & Associates 2003

[82] Angus Guynn and Guynn 1999

Endnotes

[83] Wildlife Management Institute 1997

[84] Angus Guynn and Guynn 2002

[85] Angus Guynn and Guynn 2002

[86] Legislative Budget and Finance Committee 2003a

[87] Legislative Budget and Finance Committee 2003a

[88] C. W. DuBrock, Wildlife Management Director, Pennsylvania Game Commission, personal communication, 2004

[89] McKinstry 2003

[90] Conservation and Natural Resources Advisory Council 2003

[91] DiBerardinis 2004

[92] Woolf and Roseberry 1998

[93] Caughley 1977; McCullough 1979

[94] U.S. Fish and Wildlife Service and U.S. Census Bureau 2002

[95] Brown et al. 2000; Enck et al. 2000; Riley et al. 2003

[96] Pennsylvania Consolidated Statutes 1996; Woolf and Roseberry 1998. However, if adequate tools are not provided to hunters or hunter numbers fall too far, it would be necessary to implement more expensive measures to regulate deer herds.

[97] Pennsylvania Game Commission 2002a

[98] M. Grund, unpublished data, 2003

[99] Enck and Brown 2001

[100] Soulé and Terborgh 1999; Miller et al. 2001

[101] McKinstry 2003: page 16

[102] Anonymous 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001a, 2002, 2003

[103] Legislative Budget and Finance Committee 2003a

[104] Legislative Budget and Finance Committee 2003a

[105] Reed Haldy McIntosh & Associates 2003

Chapter 14. Toward Management Solutions

Having discussed some of the problems identified by external reviewers and others as well as issues that must be considered in developing solutions, we turn now to various proposals for improvement. The recommendations at the end of this chapter are supported by findings in both Chapter 13 and Chapter 14.

Proposal for changes to the appointment process for P.G.C. commissioners

Members of the Board of Commissioners are currently selected to represent a narrow range of constituencies (sportsmen and hunting and trapping groups) rather than the full set of stakeholders affected by deer populations. The commissioners routinely overrule the scientific recommendations of staff biologists. This narrow focus on sportsmen makes it difficult to replace single-species management with the broader approach of ecosystem management. Of all the obstacles facing ecosystem management, this may be the simplest to address, because the Governor appoints commissioners (subject to confirmation by a two-thirds vote of the Senate).

The Governor's Advisory Council on Hunting, Fishing and Conservation plays a significant role in the commissioner appointment process. If the council were to recommend candidates to the Governor who strongly support managing deer from an ecosystem perspective, who have training or experience in natural resource management, and who see their responsibilities to the entire citizenry of Pennsylvania, not just hunters and trappers, then the prospects for P.G.C. ultimately deciding to adopt a program of managing deer from an ecosystem perspective would be vastly improved. The latest council includes members who are sympathetic to ecosystem management. However, it is not clear that there are sufficient votes on the council to limit candidate recommendations to those who strongly support managing deer from an ecosystem perspective. If not, then the Governor would need to send back the recommendations, giving explicit guidance on the type of candidates desired.

Proposals for structural change

A proposal to investigate combining P.G.C. and the Pennsylvania Fish and Boat Commission (P.F.B.C.), introduced as Pennsylvania House Resolution 15 by Representative Bruce Smith, Chairman of the House Game and Fisheries Committee, was adopted by the full House of Representatives in February 2003. The committee heard testimony from a variety of organizations and individuals at five public hearings. The resolution was amended to "explore a broad range of options" to structure Pennsylvania's wildlife agencies. The amendment directed L.B.F.C. to update its 1989 report on merging the agencies.

L.B.F.C.'s updated report, released in November 2003, stopped short of directly recommending merged agencies but proposed a structure for a combined "Fish and Wildlife Commission" and showed related cost savings of $5 million annually.[1] The report stated that, in addition to streamlining by eliminating redundant positions, a merger "would also provide a better balance between the Commission's law enforcement functions and wildlife conservation functions, and would better position the combined Commission to request general fund or other state funding to meet its infrastructure needs."[2] As a step toward ecosystem-based management, the report called for "creation of a new Bureau of Non-Game Species to address the perceived lack of focus on biodiversity and non-game species."

Additionally, Representative Ed Staback introduced House Resolution 222, which directed the Joint State Government Commission to study the feasibility of transferring the law-enforcement functions of P.G.C. and P.F.B.C. to a new Bureau of Law Enforcement within D.C.N.R. The House amended H.R. 222 in June 2003 to add "or other Department." The resulting report stated that "[c]onsolidating the conservation law enforcement personnel and functions currently performed by the P.G.C., the P.F.B.C., and D.C.N.R. into a single conservation law enforcement unit is feasible." However, the first-year costs to operate such a bureau were estimated at $33.8 million, about $5.8 million more than under the existing structure. All three agencies are on record in opposition to such a merger and there appears to be no real political will to pursue it at this time.

In 2003, the McKinstry report recommended reorganizing "… D.C.N.R., Fish and Boat Commission, and P.G.C. to increase integration of land, water and biological resource management while assuring independence of voices."[3] The report discussed staffing, coordination, allocation of resources, and other issues relating to the current governmental structure and recommended a broad legislative and public process to examine a potential merger of the resource agencies.

When D.C.N.R. underwent forest recertification in 2003, one of the potential remedies ("scenarios") suggested in the recertification report to overbrowsing by abundant deer was: "P.G.C. is merged with the D.C.N.R. in a combined natural resource agency and control of hunting regulations is overseen by a more balanced representation of natural resource interests, instead of the current situation where regulations are subject to the pressures exerted by the P.G.C.'s only paying constituency, hunters."[4] The U.S. Fish and Wildlife Service's Management Assistance Team had come to a similar conclusion in their 1998 study of P.G.C., commissioned by the agency itself.[5]

There is a perception by some Pennsylvania residents that maintaining separation between the state agencies managing Pennsylvania's natural resources is strongly supported by the public at large. However, the statewide survey of randomly selected Pennsylvania households conducted in December 2003 indicated that 75% of respondents were in favor of combining P.G.C., P.F.B.C., and D.C.N.R. into a single agency provided that the single agency would result in a more efficient or cost-effective system for managing natural resources; 14% of the respondents were opposed to the idea and only 9% of the respondents had no opinion. Later in the same survey respondents were asked whether they were in favor or opposed to merging the natural resource agencies even if there was no impact on the efficiency or cost-effectiveness of managing natural resources in Pennsylvania; 64% of the respondents were either in favor of or had no opinion and 33% were opposed. Interestingly, hunters and anglers responded to this question at approximately the same rate (37% opposed) as the overall set of respondents.

The prospects for structural change are highly uncertain. In the current political climate, reorganization at the scale described by the House of Representatives, L.B.F.C., the McKinstry report, and others would require an enormous expenditure of political capital by a Governor and members of the General Assembly.

Proposal for better coordination between agencies through the Natural Resources Workgroup

Implementation of ecosystem-based management of deer will require substantial cooperation and communication among state agencies, most notably between D.C.N.R. and P.G.C. Although ecosystem management has been embraced in concept by D.C.N.R., we are unaware of any consideration for its implementation within P.G.C. other than indirect references in the 2003-2007 deer population management plan, the future of which is uncertain.

The relationship between D.C.N.R. and P.G.C. changes regularly and can be hard to track. For instance, early in 2004, the Secretary of D.C.N.R., Michael DiBerardinis, directed that D.C.N.R. grant funds not be used to help acquire game lands.[6] This step apparently arose out of frustration on the part of the D.C.N.R. Secretary with the Game Commission's lack of action on D.C.N.R.'s recommendations to reduce the deer herd. Because D.C.N.R. lacks direct jurisdictional control of the deer on its own land, this move was intended to emphasize the depth of the agency's concern over P.G.C.'s failure to act on its recommendations.

On the other hand, in April 2004, D.C.N.R.'s Policy Director testified that D.C.N.R. was against the merger of P.G.C. and the Fish and Boat Commission into D.C.N.R., and that it was the Department's intention to pursue a collaborative approach to the management of wildlife and habitat.[7] At the same time, D.C.N.R. emerged as a strong supporter of funding for both the Fish and Boat Commission and the Game Commission in the Governor's Growing Greener package and for the provision of the funds without a 50% match requirement.

The Secretary then began a direct discussion with the President of the Board of Commissioners in an effort to move forward on providing more tools for the agency to meet its goals in sustainable forest management.[8] Secretary DeBerardinis testified at the October meeting of the P.G.C. Board of Commissioners and announced that as a show of good faith in beginning serious discussions with the commissioners, he would lift the moratorium to buy lands for addition to the state game land system.[9] He asked the Game Commission to extend the seasons and expand the tools to allow a greater reduction of the deer herd and to institute more flexibility and simplify the process for private forest landowners seeking to use DMAP. It will be interesting to see if these negotiations, which we encourage, bear fruit on the ground.

One possible vehicle for improving communication between P.G.C. and D.C.N.R., as well as other agencies, is greater use and expansion of the Natural Resources Workgroup. This interagency panel, formed in 1996, was organized to improve communication among various government entities. It is currently composed of representatives from D.C.N.R., P.G.C., P.F.B.C., the Conservation and Natural Resources Advisory Council (citizens' advisory group to D.C.N.R.), and the Governor's Sportsmen's Advisor. An initial task was to develop a vision statement regarding biodiversity. The statement, adopted by the agencies in 1998, declared:

> *Biodiversity is the variety of species, their genetic make-up, and the natural communities in which they occur. Biodiversity is important to sustain healthy ecological systems, to provide resources for recreational opportunities and other beneficial uses, and to assure the long-term welfare of ourselves and future generations. The three resource agencies will work together to promote the conservation of Pennsylvania's biological diversity in the management of lands and waters through programs and services we provide to the public.*[10]

A series of meetings held by the Natural Resources Workgroup has provided the agencies opportunities to share information and work together more closely. One significant project undertaken by this group was the development of a status report on the condition of habitat for all wildlife in Pennsylvania, "Wildlife Habitat in Pennsylvania: Past, Present and Future."[11] This comprehensive report recognized the adverse effects of high deer density as a critical factor in the decline of habitat for many species of wildlife.

In late 2002, the Conservation and Natural Resources Advisory Council issued a transition report to the incoming Governor.[12] One of the recommendations was to identify and evaluate areas of conflict, inconsistency, and duplication within and among natural resource agencies and work toward their resolution. The Council recommended that D.C.N.R. continue to work with P.G.C. to implement science-based management of the state's deer herd.

The Natural Resources Workgroup could address additional issues and conflicts by expanding its membership to include other state agencies that affect, or are affected by, natural resource management either directly or indirectly. For example, deer management acutely affects the domains of responsibility of the Departments of Agriculture and Transportation. Other agencies with a stake in natural resource management include the Departments of Education, Environmental Protection, and Health.

Proposal to focus on hunter education and dialogue

Hunting is the obvious first choice for practical landscape- and regional-scale deer management but declining hunter numbers have led some scientists to conclude that even hunters will not be able to bring the deer herd under control and that other methods will be needed.[13] However, hunters and landowners have not been given the tools and opportunities that would allow them to meet ecosystem management targets. It is therefore premature to abandon recreational hunting as the primary tool for managing deer from an ecosystem perspective. For hunting to be effective, policies must encourage hunter participation and satisfaction. If an ecosystem approach to deer management is to be achieved, declining hunter numbers make it urgent that we balance deer numbers with habitat conditions now and build lasting bridges between wildlife managers and landowners. Landowners ultimately make the decisions that determine whether hunting can be an effective tool for managing deer in broad landscapes. It is imperative that Pennsylvania's wildlife agency develop policies and programs to match members of the public who own the land with members of the public who desire to hunt (see box on next page).

In the past, conventional wisdom was that hunters would never accept adding ecosystem concerns to deer management and that hunters were the major obstacles to bringing deer numbers in line with biologically based deer targets. For example, it was widely believed that hunters would not support the 1998 modifications to the framework of Pennsylvania's traditional deer hunting season. This belief had some validity, at least initially. Consider, for instance, the early response among hunters to P.G.C.'s proposal for a concurrent buck and doe season. In a survey conducted prior to efforts by agency staff members to educate the public about the proposal, 50% of hunters opposed it and 43% supported it.[14] The head of P.G.C.'s Deer Management Section, Dr. Gary Alt, launched an education campaign in January 2001 to explain the reasons why a concurrent buck and doe season was necessary. Dr. Alt gained support among hunters during public meetings as well as the support of P.G.C. commissioners. The commissioners adopted the two-week concurrent buck and doe season in April 2001, a clear sign that hunter opinion had shifted as a result of a solid education effort.

Although some polling data support the idea that hunters react first with opposition to proposals to control the deer herd, this is not always the case. For example, members of the P.G.C. staff assumed there was little support among hunters to raise the minimum antler-size regulations and that a massive education campaign would again be necessary before its proposed implementation in 2002. Dr. Alt conducted 70 public meetings in January through April 2002 to

Linking hunters and landowners

P.G.C. must attempt to match the general population, who are the owners of public and private land, with those who hunt in a way that is beneficial to both and mutually agreeable. This is likely to depend on the willingness of P.G.C. to:

- enforce trespass laws on private land
- surrender the traditional value of equitable distribution (the concept that all hunters should harvest an equal number of animals)
- adopt more liberal season and bag limits that would allow hunters to be effective in resolving landowners' problems with deer overbrowsing

explain the rationale behind the proposed new regulations to Pennsylvania deer hunters. However, a survey conducted by Pennsylvania State University in December 2001, prior to the education campaign but not reported until afterward, estimated that only 36% of hunters were opposed to the change.[15] Today there is widespread support among Pennsylvania deer hunters to hold concurrent buck and doe seasons and there seems to be overwhelming support for the new, larger antler-size restriction.[16] Surveys of hunters reveal very high support for "managing game populations to promote healthy habitats for all species."[17] In fact, the statewide survey of randomly selected Pennsylvania households conducted in December 2003 indicated that hunters rank forest health and sustainability higher than hunting activities as rationales for managing deer population densities. When asked to rate agreement with potential goals on a 10-point scale (10 signifying complete agreement with the goal), hunters rated managing deer herd numbers to promote healthy and sustainable forests the top priority (average score 7.8) followed by management to promote hunting activities (7.1).[18]

The perception that hunters are not willing to tolerate changes to the deer program is incorrect. There is, therefore, considerable political freedom for P.G.C. to implement a policy of managing deer in Pennsylvania from an ecosystem perspective. Whether the commissioners under the current agency structure could maintain such a policy, if implemented, in the face of declining deer numbers is another question. In this regard, continued efforts on hunter education and dialogue seem essential, perhaps with expanded multi-stakeholder communication and introduction of programs on negotiated conflict resolution.

Proposal to focus on stakeholders

P.G.C. has begun to experiment with stakeholder consultation. For instance, a draft deer management plan released by P.G.C. in 2002 included many elements that could be used to manage deer from an ecosystem perspective.[19] The draft plan included input from a workshop of stakeholders selected by P.G.C. to represent a broad spectrum of the public on deer management (see Chapter 16). These stakeholders, like both hunters and non-hunters in the 2003 statewide survey,[20] ranked ecosystem management as the highest priority. However, in its final version of the plan P.G.C. subsequently put ecosystem-based management of deer at the bottom of the list.[21] Nevertheless, consultation with a broad range of stakeholders is one way to move away from single-species management. Creative interaction among stakeholders can lead to identification of "least painful" and "win-win" solutions to deer-human conflicts. There is a large body of literature dealing with negotiated conflict management and resolution that could be brought to bear on stakeholder consultation. Professional facilitators could be especially helpful; they could be drawn from the many organizations that have experience in this field.

Proposal for augmentation of P.G.C. staff expertise

Implementing ecosystem-based management and moving beyond the traditional species-specific approach to wildlife management will require access to a broader range of expertise than is now present within the P.G.C. staff. Tasks required for successful ecosystem management will include inventory and monitoring of plant and indicator invertebrate populations, forest restoration experimental design, analyzing and interpreting ecosystem research data, managing field research staff, interacting with private and public landowners, and publishing research results in peer-reviewed scientific journals.

Of 705 salaried positions filled at P.G.C. (of 732 authorized),[22] only 19 (less than 3%) are currently filled by staff members employed as wildlife biologists, who are required to have post-graduate degrees in wildlife-related disciplines.[23] Pennsylvania has one of the fewest in number and lowest percentages of staff members employed as biologists among all of the states' natural resource agencies.[24] For example, the number of staff members employed as biologists by agencies in New York, Indiana, Montana, Virginia, West Virginia, and Florida in a recent survey ranged from 47 (West Virginia) to 566 (Florida), representing 16 to 43% of agency personnel.[25]

The staff of the Allegheny National Forest, which manages 500,000 acres in Pennsylvania compared to P.G.C.'s 1,400,000 acres, includes foresters, silviculturists, wildlife biologists, a botanist, a hydrologist, a soil scientist, a fisheries scientist, a geologist, an archeologist, a forest ecologist, and a fire ecologist.[26] The biologists currently on P.G.C.'s staff are specialists in administration (two biologists), Allegheny wood rat, American woodcock, bats (two), black bear, biometrics, bobcat (two), white-tailed deer (four), elk, fisher, furbearers, grassland birds, ring-necked pheasant (several), protected birds, river otter, ruffed grouse, small game, waterfowl (three), wild turkey, and wildlife grant proposals (these sum to more than the total number of biologists because some staff members have multiple specialties).[27] At present there are no wildlife biologists working out of any of the regional offices; however, plans are moving forward to fill such positions in each of the six regions. P.G.C. has no forest ecologists, community ecologists, soil scientists, aquatic ecologists, or botanists.

To its credit, P.G.C. has taken advantage of outside funding sources such as the Wild Resource Conservation Fund and the federal Conservation Reserve Enhancement Program to pursue efforts that benefit non-game species. For example, under the federal Landowner Incentive Program, biologist positions have been established in each region to assist landowners with plans to conserve species of special concern. These Wildlife Diversity Biologists will provide technical assistance and help develop habitat management plans related to landowner objectives. The positions are funded by annual federal appropriations, and are full time but "limited term," meaning the positions would disappear if funding were discontinued.

One note of caution: Even if its small staff of wildlife biologists were to be augmented with new staff positions, outside consultants, or both, the sum of recent external reviews strongly suggests that P.G.C. — with its present culture weighted heavily toward law enforcement and its constituency overwhelmingly dominated by sportsmen — may not currently have the will to implement A.R.M. or introduce ecosystem management principles into deer management.

Proposal for D.C.N.R. to be more publicly visible on the deer issue

Although D.C.N.R. has been very active in making the case within government that deer numbers are too high on state forests, it has not been equally active among hunters and the general public in calling for reduced deer densities on state forests. In fact, nothing appears on the D.C.N.R. web site (as of January 2005) indicating that there are too many deer on state-owned lands. This contrasts with the P.G.C. web site, where the argument is made in many places that deer numbers are too high.

D.C.N.R. has an effective Forest Stewardship Program in which staff members work with various forest landowner groups. The program focuses on the impact of overabundant deer and options for landowners to use DMAP. However, this program has not been publicized beyond personal contacts.

Proposal to increase hunter access to land

Hunter distribution and access to land is another major concern if hunting is to remain a deer-management tool.[28] Hunting will fail to be a regulating force on deer populations if the harvest of antlerless deer does not occur where it is needed, even if hunter numbers were to remain constant or increase. Land ownership continues to be divided into ever-smaller parcels, which creates a landscape where, either because of safety concerns or landowner preferences, the proportion of land that is hunted is declining. Because 74% of Pennsylvania's forestland is privately owned, any plan to conserve the diversity of wildlife and habitats must take landowner values and goals into consideration.

A survey of Pennsylvania private landowners, conducted in 2002 by Pennsylvania State University researchers, was presented at the January 2003, meeting of the P.G.C. Board of Commissioners.[29] Several key findings from the survey included:

- Almost 70% of properties in Pennsylvania were posted. However, hunting by the landowners, their friends, or other assignees occurred on 75% of posted land; 18.5% of properties are posted and entirely closed to hunting.
- Property owners had a tendency to allow friends, family, and neighbors, but not strangers, to hunt on their land.
- Property owners who purchased their properties more recently were more likely to post their land, suggesting that the trend of increasing posting is not likely to reverse.
- External factors such as regulation changes or incentives were unlikely to influence landowners' decisions to post their properties.

Given these trends, there is the possibility that a program of managing deer from an ecosystem perspective — one that emphasized the ecological value of hunting deer in Pennsylvania — might induce some reluctant landowners to allow hunting, particularly those with an environmental and conservation sensibility.

One model for increasing hunter access to private property already exists in Pennsylvania, the "red tag" program developed for agricultural lands. It allows farmers to receive extra antlerless deer harvest permits as in DMAP, but at no cost. One permit is issued for each 5 acres of cultivated ground. Farmers distribute the permits as they wish. Hunters may approach farmers to request red tag hunting privileges. If crop losses are still a problem after a farmer's allocation for the year is exhausted, P.G.C. will issue more permits on request. Under this program, deer are taken from 1 February through 28 September, not during the regular seasons; most are harvested in late winter and spring. Appropriate modifications would be required to adapt the program to ecosystem management of deer, for instance, restrictions on hunting seasons for small properties.

Findings on making progress toward solutions

(1) The prevailing wisdom about what the public will support is not always right. For example, there is a perception by some Pennsylvania residents that maintaining the separation between the state agencies managing Pennsylvania's natural resources is strongly supported by the general public. However, the statewide survey of randomly selected Pennsylvania households conducted in December 2003 indicated that 75% of respondents were in favor of combining P.G.C., P.F.B.C., and D.C.N.R. into a single agency provided that the single agency would result in a more efficient or cost-effective system for managing natural resources. Nonetheless the three agencies are on record in opposition to such a merger and, in any case,

achieving a change of this magnitude would require an improbably large expenditure of political capital.

(2) The perception that hunters are unwilling to tolerate changes to the deer program is incorrect. When the reasons for management changes are explained effectively to hunters there is considerable political latitude for P.G.C. to implement a policy of managing deer from an ecosystem perspective.

(3) P.G.C. has begun to experiment with stakeholder consultation but has not formalized stakeholder input into its planning processes.

(4) The Governor's Advisory Council on Hunting, Fishing and Conservation plays a significant role in the commissioner appointment process. Council members who are sympathetic to ecosystem management could improve the likelihood of its adoption by P.G.C. by recommending candidates who strongly support managing deer from an ecosystem perspective, have training or experience in natural resource management, and shoulder responsibility to the entire citizenry of Pennsylvania, not just hunters and trappers.

(5) D.C.N.R. has become more involved in the deer issue recently, announcing its intention to collaborate more closely with P.G.C. in the management of wildlife and habitat on state park and state forest lands, but it has not been active in outreach to hunters and the general public.

Recommendations on making progress toward solutions

Findings in Chapter 13 and in this chapter support the following recommendations.

Recommendations to the Pennsylvania Game Commission

(1) P.G.C. should formally review its staffing capabilities and in-house training. The management of wildlife in Pennsylvania from an ecosystem perspective requires P.G.C. and perhaps other natural resource agencies to employ more wildlife biologists, ecologists, and other scientifically trained staff members in key positions within central and regional office structures. P.G.C. should also improve training of all staff members on ecosystem issues. To facilitate effective dialogue with hunters, P.G.C. should bring into core positions more people with both strong biological backgrounds and good communication skills. Employment of staff members with backgrounds in disciplines such as resource economics, ecological economics, and sociology should also be considered.

(2) To move away from single-species management, P.G.C. should continue to involve a broad range of stakeholders in discussions with an emphasis on the exploration of desirable deer densities. P.G.C. should hire persons trained in techniques of negotiated conflict resolution and make use of experienced facilitators in its stakeholder work.

Recommendations to the Governor, the Governor's Advisory Council on Hunting, Fishing and Conservation, the Department of Conservation and Natural Resources, and the General Assembly

(1) To identify the most effective way for P.G.C. to achieve its mission, the commissioner system should be reviewed by the Governor and the General Assembly. If the system is retained, it should be changed to ensure that the commissioners represent all the citizens of Pennsylvania, not just those who hunt.

(2) The Governor's Advisory Council on Hunting, Fishing and Conservation should recommend candidates for P.G.C.'s Board of Commissioners who have a strong commitment to ecosystem management. If the council is not able to do so, the Governor needs to fill council vacancies with more supportive members and must be prepared to look beyond the recommendations of the council in the near term for commissioner candidates.

(3) The Governor and the General Assembly should regularly declare their full support for ecosystem-based management and take appropriate action. The Governor, for instance, should appoint persons to P.G.C.'s Board of Commissioners who are sympathetic to such a view and have basic training or expertise in natural resource or ecosystem management.

(4) Until such time as P.G.C. can successfully bring deer densities down to previously approved targets and be well on its way to implementing ecosystem management, an annual review of P.G.C.'s mission, organization, skill mix, policies, funding adequacy, funding sources, and priorities, along with the sociopolitical obstacles it faces, should be conducted by an independent entity appointed by the Governor and the General Assembly. These reviews would build on past reports by the Management Assistance Team, Legislative Budget and Finance Committee, and others, together with input from P.G.C. staff members on recent changes and difficulties. The review process could help all parties understand why P.G.C. has not been able to bring deer numbers under control and help build consensus on how the agency can reach its previously approved goals. Without consensus among members of the General Assembly and the Governor, it will be very difficult to overcome the sociopolitical obstacles that P.G.C. staff members believe are holding them back. Appropriate recommendations should accompany the findings of the annual review.

(5) The Natural Resources Workgroup should be expanded to include other state agencies and departments with major concerns about the effects of high deer densities on the environment and human health and safety, for example, the Departments of Agriculture, Education, Environmental Protection, Health, and Transportation. The Workgroup should compile a list of conflicts among agency policies and bring them to the attention of the Governor, along with recommendations for resolution.

(6) D.C.N.R. should launch a far-reaching education and outreach program to inform the general public about the impacts of current deer population levels on ecosystems and biodiversity and to train hunters and the general public on how to recognize habitat indicators of deer overbrowsing. In addition, D.C.N.R. should increase access to D.C.N.R. lands and more thoroughly advertise the availability of its lands for hunters.

(7) P.G.C. should expand policies well beyond the limited measures currently proposed for DMAP to allow landowners to manage deer to meet their land-management objectives, including those landowners who wish to preserve biological diversity and restore full and healthy ecosystem function. The red tag program developed for agricultural lands provides a possible model, albeit with appropriate modifications such as restrictions on hunting seasons for small properties. If legislative changes are needed to enable such a program to be effective, P.G.C. should request the necessary modifications and the legislature should enact them.

Endnotes

[1] Legislative Budget and Finance Committee 2003b

[2] Legislative Budget and Finance Committee 2003b; P.G.C. expressed disagreement with many of the findings of this report (Pennsylvania Game Commission 2003a)

[3] McKinstry 2003

[4] Wager et al. 2003

[5] Angus Guynn and Guynn 2002

[6] DiBerardinis 2004

[7] Carlson 2004

[8] DiBerardinis 2004

[9] DiBerardinis 2004

[10] Pennsylvania Game Commission 1998a

[11] Goodrich et al. 2002

[12] Conservation and Natural Resources Advisory Council 2002

[13] Riley et al. 2003; Giles and Findlay 2004

[14] Enck and Brown 2001

[15] Luloff et al. 2002

[16] Dr. Gary L. Alt, Supervisor, Deer Management Section, Bureau of Wildlife Management, Pennsylvania Game Commission, personal communication, 2003

[17] Responsive Management 2001

[18] Reed Haldy McIntosh & Associates 2003

Endnotes

[19] Pennsylvania Game Commission 2002a

[20] Reed Haldy McIntosh & Associates 2003

[21] Pennsylvania Game Commission 2003e

[22] Legislative Budget and Finance Committee 2003b

[23] Pennsylvania Game Commission 2003c; Robert C. Boyd, Assistant Bureau Director and Research Division Chief, Pennsylvania Game Commission, personal communication, 2004

[24] Angus Guynn and Guynn 1999: page 50; some members of the P.G.C. law-enforcement staff have undergraduate training in biology and related fields.

[25] Angus Guynn and Guynn 1999: page 50

[26] Brad Nelson, Wildlife Biologist, Allegheny National Forest, personal communication, 2003

[27] Pennsylvania Game Commission 2003c; Robert C. Boyd, Assistant Bureau Director and Research Division Chief, Pennsylvania Game Commission, personal communication, 2004

[28] Brown et al. 2000

[29] Steele et al. 2003

Chapter 15. Hunter Satisfaction and Adaptive Resource Management

Managing deer under an A.R.M. paradigm will require adjusting deer density levels with the help of recreational hunters. Yet, hunters are the major constituency that may experience a decline in satisfaction resulting from management of deer populations from an ecosystem perspective: there will be fewer deer to see in the woods and studies have shown hunters derive satisfaction from seeing many deer as well as harvesting a deer.[1] However, hunters benefit from managing deer under an ecosystem management paradigm because (1) with reduced deer densities there should be more food resources available per deer, which should result in larger body sizes and larger antlers, (2) due to the fact that current deer populations are likely greater than M.S.Y. (Chapter 11) throughout much of the state, hunters will be able to harvest more deer even though populations are reduced, and (3) hunters should be perceived more favorably by society because of their instrumental role in ecosystem management. Hunters should be acknowledged as our first line of defense in regulating deer numbers.

The greatest changes to hunting that will result when deer are managed from an ecosystem perspective involve shifting the focus from recreational buck hunting to antlerless deer hunting as a population regulation tool. This paradigm shift is necessary to reduce deer populations, which, in turn, is necessary if we are to restore forest habitats as well as demonstrate that hunting not only provides recreation but also serves the needs of society. That does not mean, however, that hunters must sacrifice their personal enjoyment of hunting in general, and buck hunting in particular. For example, managing deer under A.R.M. does not preclude the use of antler restriction regulations such as those that have recently been enacted in Pennsylvania to increase the average antler size of bucks. In addition, if antlerless harvests are to increase it will require a greater diversity of hunting opportunities be available to hunters. This, in turn, will likely result in improved quality of the hunting experience as well as greater flexibility in when hunters may pursue deer.

Also, the increased hunting opportunities required to attain greater harvest rates could be used to strengthen the hunting tradition in Pennsylvania: (1) More hunting opportunities should allow hunters to further develop their skills and greater proficiency should enhance enjoyment from hunting. (2) Additional antlerless permits could be used to improve recruitment and retention rates of youth hunters. (3) Greater opportunities to harvest an antlerless deer should allow hunters to be more selective when buck hunting because they will have other opportunities to harvest a deer for venison. (4) Reduced deer populations with a greater buck:doe ratio should provide more exciting hunting experiences because there should be larger-sized deer, a more intensive rut, and higher reproductive rates.

If A.R.M. is to be effective, not only must decision makers embrace it, but hunters must understand the objectives and benefits of A.R.M. even if they will not be involved in the details of evaluating models and setting harvest quotas. Therefore, an A.R.M. program must be carefully designed with flexibility to adapt to changes in hunters over time. Also, the program must have a wide range of management options available to landowners and hunters to achieve desired deer harvests. Those opposed to hunting may be distressed by the methods needed to control deer populations. However, farmers, forest-products companies, environmentalists, owners of land harmed by deer browsing, motorists, and society as a whole would benefit from a reduction in deer densities carried out as part of ecosystem management. In some parts of the state, conventional recreational hunting may be insufficient to reduce deer densities as much as is needed. In such areas, it may be necessary to provide incentives to recreational hunters to remove excess deer. Innovative programs, such as those that deliver venison to organizations that provide meals, should be given due consideration.

Findings on hunter satisfaction

(1) Hunters are critical to the success of deer population management because hunting is currently the only feasible method of regulating deer populations on a large scale.

(2) Hunters are a major constituency that risks a decline in satisfaction from management of deer populations from an ecosystem perspective. However, hunters do stand to gain from A.R.M.

(3) Under A.R.M., hunters should benefit from more opportunities to harvest deer and greater flexibility in when they can hunt resulting from more seasons, longer seasons, and higher bag limits.

(4) Hunters should be perceived more favorably by society because under A.R.M. they will have a key role in protecting the environment.

(5) Those opposed to hunting may be distressed at the methods needed to control deer populations. However, farmers, forest-products companies, environmentalists, owners of land harmed by deer browsing, motorists, and society as a whole would benefit from a reduction in deer densities carried out as part of ecosystem management.

Recommendations on hunter satisfaction

(1) The Pennsylvania Game Commission (P.G.C.) should launch an aggressive campaign to educate and inform hunters about the objectives of A.R.M. and its benefits to them, including increased hunting opportunities and ways in which it may strengthen the hunting tradition.

(2) P.G.C. should experiment with programs to increase hunter success, satisfaction, recruitment, and retention, possibly within the framework of A.R.M. itself. For example, if two different

methods of harvesting deer are equally effective but may result in different levels of hunter satisfaction, hunter satisfaction can be included as a constraint under A.R.M.

(3) P.G.C. should actively promote deer as a high-quality food, and teach (or re-teach) hunters the skills required to process, preserve, and prepare venison for the home table, maximizing its appeal and nutritional benefits.

Endnote

[1] Applegate 1973; Langenan 1979

Chapter 16. Stakeholder Participation in Deer Management Policy Development

Many external stakeholder groups have invested considerable effort over the past 30 or more years to move deer management in Pennsylvania towards a more scientific or ecologically sensitive mode of operation. These efforts have included research and demonstration projects, educational programs, written and oral testimony, and input to the Pennsylvania Game Commission (P.G.C.).

The list of involved stakeholder groups includes, but is not limited to:

Audubon Pennsylvania

Deer/Forest/Farms Committee (Society of American Foresters and the Pennsylvania Farm Bureau)

Pennsylvania Biological Survey

Pennsylvania D.C.N.R., Bureau of Forestry

Pennsylvania Deer Association

Pennsylvania Farm Bureau

Pennsylvania Forestry Association

Pennsylvania Federation of Sportsmen's Clubs

Pennsylvania Habitat Alliance

Pennsylvania Organization for Watersheds and Rivers

Pennsylvania Society for Ornithology

Pennsylvania Vegetable Growers Association

Pennsylvania Wildlife Society

Quality Deer Management Association

Sand County Foundation

The Nature Conservancy

United Bowhunters of Pennsylvania

Western Pennsylvania Conservancy

In addition to involvement by individual organizations, there have been several coordinated efforts by coalitions of groups, some of which were convened by government agencies:

Deer Management Working Group. P.G.C. convened this group of stakeholders in September, 1998, to provide a forum for discussion about management of deer. Facilitated by the Wildlife Management Institute, the groups represented included D.C.N.R., the Governor's Sportsmen's Advisor, Pennsylvania Department. of Agriculture, Pennsylvania Forestry Association, Pennsylvania Federation of Sportsmen's Clubs, Unified Sportsmen, Ruffed Grouse Society, Safari Club, Quality Deer Management Association, Audubon, Pennsylvania Farm

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Bureau, Pennsylvania Hardwood Association, Allegheny National Forest, Western Pennsylvania Conservancy, Vegetable Growers Association, Association of Conservation Districts, Penn State University, Pennsylvania Sportsman magazine, and others. The working group met over a 2-year period and presented its findings and recommendations at meetings of P.G.C.'s Board of Commissioners in January, 1999, and January, 2000. The group presented eight findings and six recommendations, plus a proposal for large landowner permits.[1] Fundamental to this group's recommendations were the principles that management of deer should be based on landowner values and that quality of habitat should be the primary driver of such management.

Conference on Deer Impacts. In September, 1999, a group of organizations including Audubon Pennsylvania, the Pennsylvania Chapter of the Sierra Club, the Western Pennsylvania Watershed Protection Program, the Western Pennsylvania Conservancy, and the University of Pittsburgh convened a conference on the impacts of deer. This conference brought together a series of presenters representing a variety of deer management stakeholders, including government agencies and non-governmental organizations, farming and timber industries, sportsmen and academics. The resulting proceedings (*The Impacts of Deer on the Biodiversity and Economy of the State of Pennsylvania*) are available on the Audubon web site.[2]

Pennsylvania Biodiversity Partnership. In March, 2000, the Pennsylvania Biodiversity Partnership was launched "to conserve biodiversity statewide by promoting communication and cooperation among a broad spectrum of stakeholders." This public-private partnership was formed in response to the *Report of the Pennsylvania 21st Century Environment Commission*,[3] which recommended the creation of a broad-based partnership focused on biodiversity conservation issues in Pennsylvania. Members include conservation and environmental organizations, government agencies, businesses, industries, scientists, academic institutions, and individuals. The Partnership is governed by a board of directors that acts on recommendations from seven task forces (Bioinformatics, Education, Funding, Policy, Public Relations, Science, and Stewardship).

One of the first actions by the Partnership was to send a letter to P.G.C. Executive Director Vern Ross about the deer issue, stating:

> *The impacts of white-tailed deer must be addressed as a critical component of any comprehensive strategy for biodiversity conservation in Pennsylvania. We view deer as a keystone species that, if not managed appropriately, will:*
>
> - *significantly reduce or eliminate natural forest regeneration;*
> - *dramatically alter forest structure and composition;*
> - *negatively affect other wildlife and plants, including songbirds and wildflowers*
> - *threaten forest sustainability.*

The Partnership encouraged the Commission to "fully support the efforts of its staff biologists and to give favorable consideration to their recommendations for bringing Pennsylvania's deer herd into proper balance." The primary project of the Partnership is a Pennsylvania biodiversity conservation plan. The initial phase, completed in 2002, is a literature-based report that describes the present status of Pennsylvania's biodiversity, including wildlife and their habitats, laws, policies, funding mechanisms, and educational resources relevant to biodiversity. The report, released in December, 2002,[4] states:

Deer represent a major threat to biodiversity because of their present over-abundance in many areas of the state. ... Their increasing numbers and broad dietary preferences have reduced forest understory plants and retarded forest regeneration. ... In areas of high deer density, hay-scented fern dominates the forest floor vegetation, forming a nearly impenetrable layer that chokes out other herbs as well as young shrubs and tree seedlings ... [deer] therefore are changing the composition of Pennsylvania's forests.[5]

Deer Management Stakeholder Meeting. In July, 2002, P.G.C. convened another group of stakeholders to provide input to a new deer management plan that was under development. The group developed the following vision statement for deer management:

We will manage deer to restore and provide healthy and sustainable ecosystems with a healthy, viewable, huntable deer herd throughout the Commonwealth for the benefit of our citizens and natural resources compatible with other species and land uses.

The group also developed six goals, with associated objectives, to drive the deer management plan.[6] The goals, as prioritized by the group, are as follows:

(1) To improve the health and sustainability of the ecosystem
(2) To provide public and private landowners with the deer management tools they need to achieve their land use objectives
(3) To improve and maintain a healthy deer herd
(4) To increase recreational opportunities involving deer
(5) To increase citizen understanding of healthy ecosystems and healthy deer herds
(6) To reduce human-deer conflicts

Second Deer Conference — "The Challenge of Overabundant Deer in Pennsylvania: a Call for Partnerships." In January, 2004, over 80 organizations representing a wide range of interests came together to cosponsor a conference to review the status of deer management and seek ways to work together for further progress. Nearly 500 people attended, hearing presentations by a member of the Board of Game Commissioners, the secretaries of D.C.N.R. and the Department of Agriculture, deputy secretary of the Department of Transportation, co-directors of P.G.C.'s Deer Management Section, regional director of the Quality Deer Management Association, and other leaders in deer management from across the state. Breakout sessions provided an opportunity for attendees to present input regarding deer management in big-woods, urban/suburban and rural mosaic settings, and partnership opportunities among government agencies and private, for-profit and nonprofit concerns. A summary of the conference was presented to the Board of Game Commissioners at its January, 2004, meeting.

Findings on deer management stakeholders

(1) There has been significant increase in efforts by citizens and organizations in Pennsylvania with a stake in deer management to influence management planning in recent years.

(2) Citizens and organizations in Pennsylvania with a stake in deer management have overwhelmingly urged P.G.C. to adopt an ecosystem management approach.

Recommendation on deer management stakeholders

P.G.C. should continue to use and improve upon the stakeholder outreach process to gather input on managing deer from an ecosystem perspective and to assist in performing some of the critical tasks of ecosystem-based adaptive management, including inventory, monitoring, and research.

Endnotes

[1] Williamson 2000

[2] Gibbon 2000

[3] Pennsylvania 21st Century Environment Commission 1998

[4] Thompson 2002

[5] Thompson 2002

[6] Pennsylvania Game Commission 2002a

Chapter 17. Planning for the Long Term

Based on the preponderance of scientific evidence that has been collected in Pennsylvania to date, the Deer Management Forum has concluded that it can anticipate the broad outcome, at least, of an A.R.M. program. The probability is high that the results of A.R.M. will demonstrate that recovery of forest structure, diversity, ecological processes, and ecosystem function requires significant deer-density reductions. After such reductions, time alone will be enough to allow recovery to occur in most of the state's forestlands. For areas where accelerated recovery is desired to enhance commercial tree species, we do not yet have enough information to anticipate the mix of herbiciding, liming, seeding, and fencing that will be appropriate in various parts of the state to speed up recovery. Neither can we anticipate the actual deer-density numbers that will be needed for ecosystem recovery in all forests in the state. Whatever level of deer density reduction may be necessary, achieving such reductions will be difficult and will require hard work at building a new consensus on forests in Pennsylvania.

To this end, it is desirable to begin a consensus-building process that attempts to minimize the "pain" to parties who might feel negatively affected by significant reduction in deer densities. One possibility would be to adjust the pace of change by region or by smaller, multi-county units based on research and stakeholder concerns. No doubt there are other and better compromise proposals waiting to be discovered, if the affected parties can be induced to deal with each other. A consensus process can be convened by stakeholders themselves or by government leaders with the power to take action on their own, such as the Governor or agency heads.

Finding on long-term planning

Successfully applying lessons learned from a small-scale A.R.M. process to all of the degraded, unproductive, and diversity-stripped forests in Pennsylvania will require a significant degree of consensus among stakeholders.

Recommendation on long-term planning

Possibilities for convening groups of stakeholders to build consensus on how to address the deer problem statewide need to be explored.

Major Findings and Recommendations

Major findings regarding science and management of forests and wildlife

(1) Pennsylvania's forested ecosystems have been severely altered. Virtually all of the published literature on forest damage in Pennsylvania suggests a major role for high densities of white-tailed deer.

(2) In the areas that have been affected the longest by high deer densities, the diversity of canopy tree species has decreased. Even in some areas that have sustained high deer densities for just a few decades or less, understory tree and shrub layers have been diminished in species diversity, height, and density or completely eliminated, and the formerly diverse ground layer has been reduced to ferns and a few other species that are either not preferred by deer or resilient to repeated browsing.

(3) As a result of the elimination of large predators in the 1700s and 1800s, humans are the only species still present in Pennsylvania capable of maintaining the population density of white-tailed deer in balance with its habitat. Active intervention by humans to keep deer populations below levels that severely alter the composition and diversity of forests will have to be sustained forever, assuming that it is impractical to restore the full complement of predators across the entire range of white-tailed deer in the state. Hunters are critical to the success of deer population management because hunting is currently the only feasible method of regulating deer populations on a large scale.

(4) Adaptive resource management (A.R.M.) is a science-based methodology that is well suited to managing deer from an ecosystem perspective while accommodating disagreements over models of forest dynamics or causes of forest alteration. The A.R.M. approach provides for testing competing scientific models or hypotheses about how forests and wildlife populations function while, at the same time, providing a framework for regular management decisions to be made and implemented based on the best available information.

(5) Two major challenges exist in implementing A.R.M. for deer in Pennsylvania. First, management objectives must be determined in the political arena before A.R.M. can proceed. Second, recovery of the structure, diversity, and function of forest ecosystems may take years or decades. Evaluating progress over a multi-year time frame presents difficulties when deer harvest goals need to be set annually.

(6) The initial commitments involved in preparing A.R.M. alternatives could be made within existing budget authorizations, provided agencies are willing to assign staff to the process. However, because of the great damage that has already been done to the structure of forests

and the depletion of the seed supply in many parts of the state, a long-term commitment to the A.R.M. process is needed.

(7) The sooner effective treatments are implemented, the sooner further deterioration will be prevented, saving larger areas of forested land in Pennsylvania from slipping below the threshold for fast recovery.

Major findings regarding policy and administration

(1) The goal of bringing back the understory vegetation and ensuring the continuation of a self-renewing and diverse forest overstory into the future is not a scientific choice but, instead, a values choice.

(2) With the exception of a vocal minority of hunters, there is a broad consensus that deer densities in Pennsylvania are too high from an ecosystem perspective. In a 2003 survey of Pennsylvanians, the general public ranked managing deer to promote healthy and sustainable forests highest among potential goals (average 7.5 of 10, with 10 meaning complete agreement) and hunters and anglers ranked it even higher (7.8 of 10). Pennsylvania hunters and anglers ranked managing deer to promote healthy and sustainable forests higher than managing deer to promote hunting opportunities (7.8 vs. 7.1 of 10). The stakeholder group P.G.C. convened to recommend goals and objectives for its statewide deer management plan also ranked managing deer to promote healthy forests and ecosystems as its top goal.

(3) P.G.C.'s Deer Management Assistance Program (DMAP) provides for increasing the number of deer harvest permits allocated on specific land units at the owner's request. It is intended as a tool for landowners to manage deer on their own property in line with their values.

(4) In a reevaluation of D.C.N.R.'s state forest system in 2004, Scientific Certification Systems predicted that overabundant deer will continue to decimate the flora and fauna in Pennsylvania's state forests without:

   (a) enhanced DMAP regulations that allow more liberal harvest of antlerless deer on state forest lands and are granted to the D.C.N.R. Bureau of Forestry on a continuing and contingency basis by the P.G.C. commissioners; or

   (b) legislative fiat, whereby administration and control of deer hunting regulations on District Forests are transferred from P.G.C. to D.C.N.R.; or

   (c) merger of P.G.C. with D.C.N.R. in a combined natural resource agency resulting in oversight of hunting regulations by a more balanced representation of natural resource interests. Note: both agencies are on record in opposition to such a merger and there appears to be no real political will to pursue it at this time.

(5) The P.G.C. commissioners, in response to proposals by staff to bring the deer herd more in line with its habitat and to protect commercially valuable trees, set targets for lower deer

densities in Pennsylvania in 1979; however, those goals have never been met. In a renewed effort to reduce deer population levels, numerous changes were made in the deer management program from 1998 through 2003. However, the deer herd continued to increase and remains today at 20% above the 1998 level.

(6) Adopting a program of managing deer from an ecosystem perspective would provide both advantages and challenges for P.G.C. Ecosystem considerations would lead to the conclusion that deer densities in some parts of the state should be reduced below levels that would be set solely by considerations of deer health and condition. This would require targets even lower than those P.G.C. has been unable to reach in the past. The reaction of some hunters to lower densities may be negative but the 2003 survey results indicate that the majority of hunters would support the goal of managing deer to promote healthy and sustainable forests.

(7) With the reorganization in 1999 of the Wildlife Management Bureau (with Dr. Gary Alt named chief of the newly formed Deer Management Section) and the support of agency policy makers, P.G.C. is poised to pursue a more aggressive deer management program that, in theory, can effectively reduce deer densities in many parts of Pennsylvania. Its success depends critically on whether the changes are formalized in a way that enables them to last through the turnover of personnel on the staff and Board of Commissioners.

(8) P.G.C. senior staff members argue that they have done all that is possible to manage deer under the current sociopolitical environment. While we find there are many more measures that the P.G.C. staff could and should implement, we do not minimize the sociopolitical constraints under which P.G.C. staff members must operate.

(9) The management of deer is a service provided to all citizens of Pennsylvania, yet P.G.C. is currently funded primarily by license dollars and timber-harvest revenues from game lands. Neither source is predicted to be sustainable in the long term. In the results of a 2003 survey of Pennsylvania residents, 71% of the respondents agreed that a greater proportion of resource agency budgets should go toward non-game wildlife and threatened and endangered species (11% disagreed). Sportsmen supported this concept also, with 70% of hunters and anglers agreeing and 11% disagreeing. A more stable and equitable funding base is required if P.G.C. is to meet broader conservation goals.

(10) Of all the new measures initiated in recent years by P.G.C., the most intricate is DMAP, which shifts some responsibilities away from P.G.C. for choosing deer densities, transferring it to landowners who can apply for additional permits for use solely on their properties. However, most of Pennsylvania's land is privately owned and the vast majority of landowners do not understand the ecological impacts of deer overbrowsing. Thus, most of Pennsylvania's land will not benefit from any science-based application of DMAP.

(11) P.G.C. gives mixed messages about the need for ecosystem considerations. This reflects a mix of *internal* stakeholders with differing views and is evidence of an ongoing debate within the staff and Board of Commissioners about the future of the agency. For instance, P.G.C.'s web site discusses forest damage caused by high deer populations, as does the current deer population management plan. However, P.G.C.'s main strategic planning document, developed by senior staff members, does not acknowledge that high wildlife populations can be a problem for ecosystems nor does it concede that the agency has failed to bring the deer population in line with past targets.

(12) Although the P.G.C. staff is strong in the areas of deer biology and in implementing and enforcing regulations to make hunting safe, the current staff has limited expertise in the field of general ecology. External reviews have found that P.G.C. operates primarily as a law enforcement agency, with its limited number of biologists isolated and, with few exceptions, not engaged in the core functions of the agency. With resources historically directed mainly at law enforcement, P.G.C. is struggling with making the transition from a law enforcement agency to a natural resource agency — a transition that most state agencies made many years ago.

(13) There is an unusual three-way resource management structure in Pennsylvania with responsibility given by the legislature to P.G.C. for mammals and birds, to the Pennsylvania Fish and Boat Commission (P.F.B.C.) for aquatic animals, and to D.C.N.R. for forests. This situation tends to reinforce single-species management at P.G.C.

(14) State agencies that are responsible for, affect, or have a stake in the management of natural resources in Pennsylvania are not collaborating to ensure that policies by one agency do not adversely affect another's ability to carry out its mission. For instance, at present D.C.N.R. cannot fully implement ecosystem management on its lands because it does not have the necessary authority to manage deer populations in state forests and state parks.

(15) The prevailing wisdom about what the public will support is not always right. For example, there is a perception by some Pennsylvania residents that maintaining the separation between the state agencies managing Pennsylvania's natural resources is strongly supported by the general public. However, the statewide survey of randomly selected Pennsylvania households conducted in December 2003 indicated that 75% of respondents were in favor of combining P.G.C., P.F.B.C., and D.C.N.R. into a single agency provided that the single agency would result in a more efficient or cost-effective system for managing natural resources. Nonetheless the three agencies are on record in opposition to such a merger and, in any case, achieving a change of this magnitude would require an improbably large expenditure of political capital.

Major recommendations regarding science and management of forests and wildlife

(1) Until proven otherwise, policy makers should assume that the consensus view on the impacts of the current high densities of white-tailed deer on forest ecosystems is correct.

(2) Deer management should focus on managing the ecosystems of which deer are a part. Deer densities in Pennsylvania's major forested areas should be brought down to levels that will allow the restoration of full forest structure, diversity, ecological processes, and ecosystem function.

(3) Adaptive resource management (A.R.M.) should be chosen as the framework for implementing management of deer from an ecosystem perspective. The science-based approach of A.R.M. will allow agencies to begin applying remedies based on the best available information while updating their operational theories as new data become available.

(4) Forum members propose a two-tiered A.R.M. program. The first tier would apply to the state as a whole. Its initial treatments would take into account factors that go beyond ecosystem management, for example, budgetary constraints and local traditions. The second tier would apply A.R.M. at a smaller scale, to multiple 10-square-mile forest treatment and comparison areas in all of the major forest regions of the state. In contrast to the first tier, treatments on these forest recovery-monitoring tracts would include a range of deer densities, as well as tests of alternative theories on causes of forest degradation and recovery. The focus would be exclusively on ecosystem management. Lessons learned from these smaller-scale manipulations could be applied to forested areas across the state as a whole in subsequent years.

Major recommendations regarding policy and administration

(1) The Governor and the General Assembly, in collaboration with P.G.C., should identify a funding base that is more stable and equitable than funding derived exclusively from sources such as license dollars and timber sales on game lands, in order to facilitate the shift from single-species management to ecosystem management.

(2) To identify the most effective way for P.G.C. to achieve its mission, the commissioner system should be reviewed by the Governor and the General Assembly. If the system is retained, it should be changed to ensure that the commissioners represent all the citizens of Pennsylvania, not just those who hunt. Although the Governor now has the power to do this through the appointment process, the General Assembly also should give its approval to broad representation on the Board of Commissioners.

(3) The General Assembly should modify P.G.C.'s enabling legislation to make it unambiguously clear that part of the agency's mission is to resolve wildlife-human conflicts and protect forest ecosystems.
(4) P.G.C. should formally review its staffing capabilities and in-house training. The management of wildlife in Pennsylvania from an ecosystem perspective requires P.G.C. and perhaps other natural resource agencies to employ more wildlife biologists, ecologists, and other scientifically trained staff members in key positions within central and regional office structures. P.G.C. should also improve training of all staff members on ecosystem issues. To facilitate effective dialogue with hunters, P.G.C. should bring into core positions more people with both strong biological backgrounds and good communication skills.
(5) Until such time as P.G.C. can successfully bring deer densities down to previously approved targets and be well on its way to implementing ecosystem management, an annual review of P.G.C.'s mission, organization, skill mix, policies, funding adequacy, funding sources, and priorities, along with the sociopolitical obstacles it faces, should be conducted by an independent entity appointed by the Governor and the General Assembly. These reviews would build on past reports by the Management Assistance Team, Legislative Budget and Finance Committee, and others, together with input from P.G.C. staff members on recent changes and difficulties.
(6) Public agencies need to lead by example in managing forestlands. P.G.C., in conjunction with D.C.N.R. and with assistance from the Governor, should address the conditions that must be met to maintain continued certification of the state forest system, particularly regarding the adverse effects of deer. In addition, P.G.C. should ensure sustainability of forests on state game lands by developing and implementing an ecologically based forest inventory and forest management plan. When necessary, sections of state game lands should be entered into DMAP.

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Appendices

Appendix A. Biographies of Members of the Deer Management Forum

Appendix B. Presentations to the Forum

Appendix C. Forum Field Trips

Appendix D. Responses to Review Comments

Appendix E. Names of Plants, Animals, and Other Organisms Mentioned in the Report

Appendix A. Biographies of members of the Deer Management Forum

Merlin Benner

Merlin Benner is the Wildlife Biologist for the Pennsylvania Department of Conservation and Natural Resources' Bureau of Forestry, and has served in that role for the past 11 years. His responsibilities to D.C.N.R. include advising the agency on wildlife issues related to the management of the state forest system. Deer impact has been a major component of his duties.

Mr. Benner received his B.S. in Wildlife Science from Unity College in Maine, and his M.S. in Wildlife Biology from Tennessee Technological University. In the interim, he worked as Wildlife Technician at the Savannah River Ecology Laboratory of the University of Georgia.

Mr. Benner serves on a number of statewide committees concerned with the conservation of wild resources in the Commonwealth. He also serves as a director on the board of the Pennsylvania Institute for Conservation Education.

Jan Beyea, Ph.D. (Facilitator and contributor)

Jan Beyea is a regular member of panels and boards of the National Research Council of the National Academy of Sciences, and is thus familiar with the production of policy reports based on science. He is an advisor to the Division of Engineering and Physical Sciences of the National Research Council. Over the years, Dr. Beyea has researched, written, or testified on virtually every environmental issue. He is the author of over 100 articles and reports that span a diverse range of topics, including risk assessment, wildlife ecology, human epidemiology, and science/law issues. He was a co-founder of the Audubon-P. & G. research partnership on wildlife impacts of forest harvest options in northeastern Pennsylvania and is a co-author of the five resulting publications, including "Adequacy of natural hardwood regeneration on forestlands in northeastern Pennsylvania" (1998, *Northern Journal of Applied Forestry* **15**), which deals with deer impacts.

Dr. Beyea spent 15 years at the National Audubon Society as Senior Scientist, and ultimately as Chief Scientist and Vice President. Currently, he is Senior Scientist at Consulting in the Public Interest, Lambertville, New Jersey, providing scientific assistance to not-for-profits, universities, government, and injured plaintiffs.

Cindy Adams Dunn

Cindy Dunn is a former Executive Director of Audubon Pennsylvania, which has 28,000 members and 24 local chapters. Her work there was to facilitate the goals of Audubon in Pennsylvania, including the protection of 79 Important Bird Areas and the establishment of a network of Audubon Centers and education endeavors. Audubon's primary policy work includes conservation funding and forest habitat.

In 2003 Ms. Dunn was appointed Director of the Office of Education, Communications and Partnerships at the Pennsylvania Department of Conservation and Natural Resources to oversee all communications, community relations activities, and education development. Prior to her position at Audubon, she worked for 10 years as the Pennsylvania Director of the Alliance for the Chesapeake Bay. She has also worked as Air Quality Specialist for the Department of Environmental Resources and Environmental Educator for the Chesapeake Bay Foundation.

Ms. Dunn served as a member of the Governor's 21st Century Environment Commission and the Natural Diversity Task Force and was Chair of the Community Watershed Task Force of the Chesapeake Bay Program. She serves on the boards of 10,000 Friends of Pennsylvania, Pennsylvania Organization for Watersheds and Rivers, Pennsylvania Environmental Council, and the Biodiversity Partnership. She was awarded Conservationist of the Year by the Pennsylvania Federation of Sportsmen's Clubs and the Pennsylvania Wildlife Federation.

Ms. Dunn holds an M.S. in Biology from Shippensburg University.

Mary Ann Fajvan, Ph.D.

Mary Ann Fajvan received a B.S. in Forest Management from Rutgers University, an M.F.S. degree from the Yale School of Forestry and Environmental Studies, and a Ph.D from the University of Maine. Both of her graduate degrees are in the areas of quantitative silviculture and forest stand dynamics. She was an instructor in forest resources extension at Penn State University and served for over 11 years as Associate Professor in the Division of Forestry at West Virginia University, teaching and conducting research in silviculture and forest stand dynamics. She is currently Research Silviculturist at the U.S. Forest Service, Northeastern Research Station, Morgantown, West Virginia.

Dr. Fajvan's research focuses on forest response to natural and human disturbance. She has examined the effects of gypsy moth defoliation on forest structure and development and the effects of harvesting practices on forest dynamics. She also has several long-term studies in place examining the effects of shelterwood harvests, prescribed fire, and diameter-limit harvesting on residual stand development and regeneration. She coordinated the West Virginia survey associated with a study assessing harvesting practices that was conducted simultaneously in Pennsylvania and New York.

Dr. Fajvan serves as an Associate Editor for the *Northern Journal of Applied Forestry*. In January, 2001, she received a Charles Bullard Fellowship in Forest Research from Harvard University and spent 6 months conducting research on forest disturbance with scientists at the Harvard Forest.

Ronald R. Freed

Ron Freed is a former Policy Analyst for Audubon Pennsylvania. He is the founder and former chairman of the Pennsylvania Habitat Alliance, a coalition of conservation, sportsmen and land trust organizations. Mr. Freed's extensive list of volunteer experience includes past Chairman of the Board of the Pennsylvania Wildlife Federation, former Pennsylvania affiliate representative to the National Wildlife Federation, and various positions within the Pennsylvania Federation of Sportsmen's Clubs. He currently serves on the Pennsylvania Biodiversity Partnership Policy Task Force and the Ralph Abele Conservation Scholarship Fund Board. Mr. Freed has also served on several special groups, including the Wildlife Management Institute and Pennsylvania Game Commission's Deer Management Working Group, the Forest Stewardship Committee, and the D.C.N.R. Habitat Advisory Committee. He retired after 30 years with Sprint, where he was the Director of Information and Administrative Services. He holds a B.S. in Education from Shippensburg University.

Marrett Grund, Ph.D.

Marrett Grund is the Deer Project Leader for the Minnesota Department of Natural Resources' Farmland Wildlife Research and Populations Group. He received a B.S. in ecology from Minnesota State University, an M.S. in fisheries and wildlife from the University of Missouri, and a Ph.D. in zoology (wildlife ecology) from Southern Illinois University. He was employed as a Wildlife Biologist for the Pennsylvania Game Commission from 2001 to 2004 and supervised the Deer Research and Management Section during his last year of service.

Dr. Grund's research focuses on deer population ecology and modeling and game harvest theory and management. He has studied white-tailed deer in urban, agricultural, and forested landscapes since 1992. His doctoral dissertation research focused on deer population modeling and estimation at the broad landscape level. Currently, his research includes validating population modeling estimates using distance sampling and aerial surveys and evaluating biological, ecological, social, political, and fiscal impacts of alternative deer management strategies in Minnesota.

Stephen B. Horsley, Ph.D.

Steve Horsley received a B.S. in Forestry from Penn State University, an M.S. in Forest Ecology from the Department of Forestry and Wildlife Management at the University of Massachusetts, and a Ph.D. in Plant Physiology from the Department of Forestry and Wildlife Management at the University of Massachusetts. Since 1972, Dr. Horsley has worked as Plant Physiologist at the U.S. Forest Service Northeastern Research Station. He has been located at the Northeastern Research Station in Irvine, Pennsylvania, since 1973.

During his career, Dr. Horsley has worked extensively on problems of forest regeneration, including plant-plant and herbivore-plant interference relationships and methods of vegetation management. Recently he and his collaborators have studied the factors contributing to sugar maple decline in Pennsylvania.

Dr. Horsley serves as an Associate Editor of the *Canadian Journal of Forest Research* and previously was an Associate Editor of *Forest Science*. He has served as national chairman of the Society of American Foresters Physiology Working Group and chairman of Division 2.08 of the International Union of Forestry Research Organizations. He is Adjunct Professor in the School of Forest Resources at Penn State University and Adjunct Professor at the State University of New York, College of Environmental Science and Forestry.

Roger Earl Latham, Ph.D. (Editor and contributor)

Roger Latham's career as an ecologist, conservation biologist, and environmental planner spans 31 years. His basic research is on plant diversity patterns, from micro- to global scales. He does applied research and planning as a consultant for The Nature Conservancy, Natural Lands Trust, National Park Service, and other organizations and agencies involved in wildland management.

Since earning his B.A. in biology at Swarthmore College and his Ph.D. in biology at the University of Pennsylvania, he has also served as Director of Science and Stewardship and Stewardship Ecologist for The Nature Conservancy in Pennsylvania; post-doctoral researcher in fire ecology and forest biogeochemistry at the Department of Geology, University of Pennsylvania; and Assistant Professor in the Department of Biology at Swarthmore College.

His work has been published in top ecological journals, including *Ecology*, *American Naturalist*, *Oikos*, *Quarterly Review of Biology*, *Biodiversity and Conservation, Landscape Ecology, Forest Ecology and Management*, and *Canadian Journal of Forest Research*. His scientific publications also include chapters in peer-reviewed books and proceedings: *Species Diversity in Ecological Communities: Historical and Geographical Perspectives* (R. E. Ricklefs and D. Schluter, 1993, U. of Chicago Press); *Global Biodiversity Assessment* (V. H. Heywood, 1995, Cambridge U. Press/U.N. Environmental Programme); and *Shrublands and Early-successional Forests: Critical Habitats Dependent on Disturbance in the Northeastern United States* (J. A. Litvaitis et al., 2003, Elsevier). He currently serves as Editor of *Bartonia*, the journal of the Philadelphia Botanical Club, and is working on a book about the vegetation of Pennsylvania and how earth history, geology, climate, hydrology, soil processes, fire, and human influences have shaped it.

Ann Fowler Rhoads, Ph.D.

Ann Rhoads received her Ph.D. from Rutgers, The State University of New Jersey. She has been a member of the staff of the Morris Arboretum of the University of Pennsylvania for 25 years where her present title is Senior Botanist. She is also Adjunct Professor of Biology at the University of Pennsylvania and a research associate in the Botany Department at the Academy of Natural Sciences of Philadelphia.

Her work has included the establishment of the Pennsylvania Flora Database, which contains records of the more than 3,300 different kinds of plants that grow in Pennsylvania. She also works on documenting the status of endangered, threatened, and rare plants for the Pennsylvania Natural Heritage Program. In 1999, Dr. Rhoads completed *Natural Areas Inventory of Bucks County, Pennsylvania*, in conjunction with the county open space initiative. Current projects include an inventory of state park natural areas for the Pennsylvania Bureau of State Parks and an inventory of aquatic plants of glacial lakes in northeastern Pennsylvania.

Dr. Rhoads was principal author of two recent books published by the University of Pennsylvania Press. *Trees of Pennsylvania, a Complete Reference Guide* (2004) includes drawings and color photographs, descriptions, keys, range maps, and information on uses by wildlife and humans, historical significance, and habitat relations of the state's native and naturalized tree species. *The Plants of Pennsylvania, an Illustrated Manual* (2000) contains keys, descriptions and over 2,500 illustrations of all the plants known to grow in the state. In 1993 the American Philosophical Society published her previous book, *The Vascular Flora of Pennsylvania: Annotated Checklist and Atlas*.

She serves on the Ecosystem Management Advisory Committee to the Pennsylvania Bureau of Forestry, is past President of the Pennsylvania Biological Survey, and was a member of the founding committee and, later, the Executive Board of the Pennsylvania Biodiversity Partnership.

Bryon P. Shissler

Bryon Shissler is a Certified Wildlife Biologist and the President of Natural Resource Consultants, Inc., a firm that provides a broad range of ecological services including assisting communities, park systems, and private landowners with the assessment and management of localized deer problems. Currently, Mr. Shissler is serving as a consultant to Audubon Pennsylvania on deer and forest ecology issues with a focus on assisting the Pennsylvania Game Commission and Department of Conservation and Natural Resources in the design and implementation of an ecosystem-based deer management program for the state of Pennsylvania. Other clients have included Scientific Certification Systems, which contracts with N.R.C., Inc. to provide third-party forest management evaluations under the International Forest Stewardship

Council's Principles and Criteria guidelines to municipalities, international corporations, utility companies, and private landowners with long-term conservation goals.

Mr. Shissler has published over 85 juried and popular articles on forest ecology, natural history, and natural resources management, served as a columnist for *Pennsylvania Wildlife* and as Conservation Editor for the *Pennsylvania Sportsmen Magazine*. He conducts public meetings as a consultant to municipalities on controversial issues such as deer management, goose control, and land-use issues and has served on such groups as the Lancaster County Growth Management Task Force, State Forest Stewardship Committee, D.C.N.R. Ecosystem Management Advisory Committee, Governor's Sportsmen Advisory Council, Wildlife Management Institute, the Pennsylvania Game Commission's Deer Management Working Group, and the Forest Stewardship Council, Certification Working Group, Central Appalachian Region.

Mr. Shissler received a B.S. in Biology from Penn State University and an M.S. in Wildlife Management from West Virginia University.

Appendix B. Forum presentations and interviews

Presentations

"Informed decision making: adaptive resource management," Dr. William L. Kendall, Research Biometrician, Patuxent Wildlife Research Center, U.S. Geological Survey, Laurel, Maryland

"Adaptive management of invasive exotic plants in Philadelphia's Fairmont Park system," Dr. James N. McNair, Head, Quantitative Population Biology Section, Patrick Center for Environmental Research, Academy of Natural Sciences of Philadelphia

"Plant indicators of deer browsing intensity," Dr. Roger C. Anderson, Professor of Ecology, Department of Biology, Illinois State University, Normal

"Deer management in the Southeast — recent changes in regulations and population/harvest responses," Dr. Karl V. Miller, Associate Professor, Warnell School of Forest Resources, University of Georgia, Athens

"Some thoughts on monitoring and managing deer herds," John L. Roseberry, Senior Scientist (Emeritus), Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale

"Regional bioconservation," Dr. Michael Soulé, Research Professor (Emeritus), Environmental Studies Department, University of California, Santa Cruz

"Human dimensions of deer management," Dr. Jody W. Enck, Research Associate, Department of Natural Resources, Cornell University, Ithaca, New York

"Deer hunting and deer hunters: what we have and what hunters want," Dr. Harry Zinn, Assistant Professor, School of Hotel, Restaurant and Recreation Management Program, Pennsylvania State University, University Park

"Ecosystem management," Dr. Malcolm L. Hunter, Jr., Professor, Department of Wildlife Ecology, University of Maine, Orono

Interviews

Subject: forest succession; Dr. Walter P. Carson, Associate Professor, Department of Biological Sciences, University of Pittsburgh

Subject: importance of soil acidity for growth of vegetation; Dr. David R. DeWalle, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, University Park

Subject: acid rain impacts on vegetation; Dr. William E. Sharpe, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, University Park

Appendix C. Forum field trips

Recent clearcut and deer exclosures on State Game Land 211, Dauphin County, Pennsylvania (15 May 2002)

J. Hassinger, S. B. Horsley, and R. E. Latham visited a recent clearcut in State Game Land 211 surrounded by a large area of dense oak-mixed hardwood forest. Regeneration consisted of small oak seedlings almost entirely overtopped by tall seedlings of non-oak species. The stop illustrated that even when some oak seedlings become established, they typically are outgrown by competitors that emphasize height growth in early life rather than below-ground root growth as oaks do. Oaks were judged unlikely to become a major component of the future stand.

Nearly all Forum members, together with guest speaker Dr. Michael Soulé, visited six deer exclosures in a 12-acre Bureau of Forestry forest management demonstration site in State Game Land 21. The small size and number of exclosures, the lack of an experimental design, and the availability of alternative forage made it difficult to draw any conclusions about deer impacts on the forest. The exclosures were more of a demonstration of the impacts of different forest cutting intensities on successional trajectories than a demonstration of the impacts of deer. Forum members decided to schedule additional field trips to look at sites where controlled experiments have been set up specifically to look at deer impacts on forests, particularly in non-residential areas.

Impacts of deer on regeneration in Allegheny Plateau forests, Warren, McKean, and Jefferson Counties, Pennsylvania (9 and 10 July 2002)

All Forum members made a 2-day trip to view the impacts of deer on regeneration of northern (and Allegheny) hardwoods and oaks in northwestern Pennsylvania. The first stop, on private land, featured a comparison of adjacent fenced and unfenced stands 3 years after the final overstory removal cut of a shelterwood harvest sequence in an oak-northern hardwood stand. The unfenced stand showed heavy browsing on seedlings of red maple, black cherry, sweet birch, *Rubus*, and American beech not protected by slash. Protected from browsing amid slash piles, seedlings were growing well. Between slash piles there were fern-covered “eat-outs” with few or no seedlings. The adjacent fenced stand had dense, tall seedlings of red maple, black cherry, sweet birch, and oaks.

The second stop was at the Hearts Content Natural Area in the Allegheny National Forest. Forum members saw regeneration of eastern hemlock, eastern white pine, and hobblebush, which occurred following a reduced impact of deer in the late 1980s and early 1990s resulting from a deer density decrease and a simultaneous increase in forage availability in the area. This was the first cohort of these species to appear in the Hearts Content area since the 1920s. Two small fenced exclosures placed in the area in the late 1980s also showed regeneration of sweet birch, eastern hemlock, red maple, devil's-walkingstick, cucumbertree, and *Rubus* inside the fences. Most of these browse-sensitive species were not regenerating outside the fences.

The third stop was at the oak management strategies research site maintained by the U.S. Forest Service's Northeastern Research Station in the Allegheny National Forest. Forum members viewed a comparison of fenced (since 1989) versus unfenced areas in an oak stand managed by single-tree selection. The unfenced stand had many new germinants of northern red oak that resulted from the 2001 bumper seed crop. These seedlings were too small and their root systems not yet sufficiently developed for them to be considered as established. There is little other regeneration. The fenced stand had many large well-established northern red oak seedlings from two previous cohorts as well as large seedlings of sweet birch and other species.

The fourth stop was in an unfenced Allegheny hardwood stand in the Allegheny National Forest, clearcut in 1982 when deer density was 40 to 60 deer per square mile and there was little forage in the vicinity. The stand also had been treated with nitrogen and phosphorus fertilizer to force seedlings to grow their leaf canopies out of reach of deer quickly. The trees, now about 25 years old, were nearly all black cherry, a species not preferred by deer. A second, adjacent stand was a mixture of black cherry and sweet birch. This stand resulted from a 1997 clearcut together with the lower deer impact level prevailing at that time (30 to 40 deer per square mile with more alternative forage from other cuts in the vicinity). Many other species that are more highly preferred by deer than black cherry and sweet birch were not present. These species require lower levels of deer impact to regenerate.

The fifth stop was a thinned northern hardwood stand in the Allegheny National Forest with a moderately dense fern understory and heavy deer browsing on seedlings. The overstory appeared not to be an impediment to seedling development. It was projected that seedlings probably could grow into larger size classes if deer impact were to be reduced to a low level, but if it remains high ferns will close in and most of the species of seedlings present will not be able to grow through their dense shade.

The sixth stop was a fenced northern hardwood stand in the Allegheny National Forest where the final overstory removal cut had been made recently. Inside the fence many species of trees and *Rubus* were regenerating. Outside the fence regeneration was not occurring.

The next day Forum members journeyed to the Pennsylvania Department of Conservation and Natural Resources' Clear Creek State Forest to view the regeneration of oaks. Stops were made in three stands. The first was an oak stand that originated after a fire in 1905 and has not been cut. There were many new oak germinants from the 2001 seed crop, but these did not have deep roots and there were no older oak seedlings. At the second stand, members were able to compare unfenced and fenced areas 4 years after a shelterwood cut. The unfenced area was heavily covered with hay-scented fern and there was little regeneration of any species. The fenced area had many large oak seedlings, *Rubus*, and established seedlings of about a dozen other hardwood species. Oaks generally were overtopped by the other hardwood species. The nearby third stand had been similar to the second stand prior to the use of a prescription burn to remove fire-sensitive non-oak species that compete with oak. During the visit, 2 years after the burn, there were many large, well-established oak seedlings that were growing well.

Appendix D: Responses to review comments

The draft version of this report or portions of it were reviewed by the respected scientists and wildlife management specialists listed below. We are very grateful for their generous contribution of time and expertise. Naturally, we were pleased by the complimentary language,[1] but we were also grateful to reviewers for pointing out problems and shortcomings in the draft report, which enabled us to improve the final product.

Kip Adams
Director
Northeast Regional Office, Quality Deer Management Association
Hanover, Pennsylvania 17331

Dr. David R. DeWalle
Professor of Forest Hydrology
School of Forest Resources, Pennsylvania State University
University Park, Pennsylvania 16802

Dr. Malcolm Hunter. Jr.
Professor of Conservation Biology
Department of Wildlife Ecology, University of Maine
Orono, Maine 04469

Dr. William J. McShea
Research Scientist
Conservation and Research Center, Smithsonian Institution
Front Royal, Viriginia 22630

Ben Moyer
Editor, *Pennsylvania Sportsman* magazine; Outdoor Writer, Pittsburgh *Post-Gazette*
Farmington, Pennsylvania 15437

Dr. William F. Porter
Professor of Wildlife Ecology; Director, Adirondack Ecological Center; Director, Roosevelt Wild Life Station
Department of Environmental and Forest Biology
State University of New York
Syracuse, New York 13210

Dr. Timothy D. Schaeffer
Central Pennsylvania Regional Director
Pennsylvania Environmental Council
Harrisburg, Pennsylvania 17101

Dr. Susan L. Stout
Silviculturist; Research Project Leader
Forestry Sciences Laboratory, U.S. Forest Service
Irvine, Pennsylvania 16329-0267

Dr. Daniel Townsend
Associate Professor of Ecology
Department of Biology, University of Scranton
Scranton, Pennsylvania 18510-4625

Dr. Robert J. Warren
President of the Wildlife Society
Professor of Wildlife Ecology and Management
School of Forest Resources, University of Georgia
Athens,Georgia30602-2152

The draft letter to the reviewers stated:

First and foremost, we are interested in the accuracy of the findings presented in each chapter you choose to review. Next, we would like your opinion as to whether or not the recommendations follow from the findings.

In addition to the findings and recommendations, there are interpretations of the scientific literature made throughout the report. You may well have comments on them.

We were able to incorporate the vast majority of suggestions made by the reviewers and to address shortcomings that they identified, either by modifying the content of the report, providing additional references, or explaining our intent and meaning more clearly. We made changes or clarifications in over 180 places in the draft report that were directly attributable to reviewer comments. However, the reviewers have not seen our responses, nor were they ever asked to endorse our recommendations.

Perhaps the most serious criticism rendered by a reviewer was the statement that in the draft report we had not separated values sufficiently from science. We thought we had done so in the original, but have made the distinction clearer in the final version. We have removed terms that might be construed as value-laden. We have explicitly stated that the goals of ecosystem management, such as the preservation of biodiversity, are value choices.

Certain suggestions made by the reviewers went beyond the scope of the report:

(1) We were urged to consider issues of landscape scale in the interaction of deer with vegetation. This is an important topic but it is still evolving in the scientific literature and would have required extensive discussion for us to do justice to it. Nevertheless, we have included some relevant material about landscape-scale issues in Chapter 11.

(2) One reviewer wanted us to flesh out our brief mention of cultural carrying capacity. We added a small amount of pertinent text, but time limitations made it impractical for us to comply more fully with this suggestion.

(3) It was suggested that the report "should, in fact, be of two parts, one directed at the policy makers and general public (a third audience that includes such diverse groups as hunters, private landowners and animal rights advocates), and the second a technical section that will satisfy those who require a more rigorous exposition." This comment came in too late to allow the major revisions that adoption of the recommendation would have entailed. Forum members are aware of the dichotomy of style in the report. Future documents based on this report could make the material more accessible to nonprofessional audiences. Furthermore, our report is scientifically general; future efforts will be required to work out all the details of our recommendations.

(4) One reviewer commented: "Hunting is a great tool that should be the primary tool, but hunters will never substitute for real predators. There are two components to deer foraging:

numerical and functional. Hunters can reduce the numerical abundance of deer but they will not be nearly as effective as predators in shifting their behavior to avoid areas and reduce foraging times. I would hope somewhere in the vast state could support a predator population." Although Forum members are sympathetic to the idea of supporting a large-predator population somewhere in Pennsylvania, it does not seem likely that it would have much of an impact on deer density statewide, given the limited potential size and range of a large-predator population in a state with 12 million human residents and nearly one-third of its land area in farms, suburbs, and other prime deer habitat where large predators may never be welcome. Nevertheless, we did add a small amount of text and supporting citations indicating that, although hunters can reduce the numerical abundance of deer, they are much less effective than predators in shifting deer behavior to avoid large portions of remote areas and reduce foraging time.

(5) One reviewer thought there could be more attention to the local government decisions that are driving fragmentation. This is certainly an important issue, but dealing with the fragmentation of Pennsylvania's forests is beyond the scope of the report, as we now explicitly note in the section on limitations in the Introduction.

(6) This same reviewer felt that we did not go deeply enough into the possible resistance that might emerge to an A.R.M. approach. Our report is merely the beginning of a process and we had to choose an endpoint for this piece. Our charge was to lay out a vision of how managing deer from an ecosystem perspective could be achieved. It is beyond the scope of the report to go deeply into the issue of potential resistance, although, clearly, stakeholders and advisory groups will have to come on board for the program to be implemented.

(7) One reviewer questioned our reliance on plant indicators as a surrogate for animal species: "Most of the literature I have read says bioindicators rarely indicate much beyond that species. If you are interested in migratory birds then migratory birds should be measured." Certainly, in the long run data should be collected on the diversity of a range of organisms to verify that we are achieving the desired goals, but Forum members see no way to avoid the use of a relatively narrow set of surrogates in the short-term. Because animals are dependent on suitable habitat, we assume in the report that plants (including trees), which provide the basis for forested habitats, can be used as a surrogate measure for the recovery of the entire community (including animals and other organisms that are not plants). A further assumption, subject to ongoing verification, is that a suite of carefully chosen plant indicators will be sufficient as a surrogate for the plant community as a whole. Parenthetically, recovery of indicator species' populations alone would be a major victory for biodiversity and ecosystem management.

Some suggestions we leave to future committees that must take up where this report leaves off, if our recommendations are followed:

(1) A number of comments were made about improving the indicators to be used in A.R.M. For instance, it was suggested that indicators should be chosen that are relevant to stakeholders and that they need to be adapted to different regions of the state. One reviewer wanted a discussion of the variability of indicators and the precision possible in measuring them. We leave these tasks to those who follow us. In particular, future committees will need to choose a method of estimating deer density and assessing measurement variance within the 10-square-mile A.R.M. treatment and comparison areas.

(2) We leave a more detailed explanation of how A.R.M. would be applied to a future committee.

(3) We also leave to a future committee an exploration of how variability among forest stands across Pennsylvania can be incorporated into the model's application to deer management.

(4) One reviewer has this to say about measurements of deer densities: "Chapter 10 — Good review. I think that you could draw an additional conclusion, specifically regarding whether or not you believe that population estimates that are used as indices (as opposed to those intended to produce absolute population estimates) of change will be adequate for your study areas. I really think that you're copping out by not suggesting at least a narrowed range of population estimators, though." Perhaps we are indeed evading an important issue, but we had no choice because of time constraints. We leave this task to a subsequent committee.

(5) We also leave to a future committee the task of identifying and publishing a list of potential recovery research projects related to A.R.M. for deer but unlikely to be funded within our proposed A.R.M. program. In that way, researchers interested in conducting those studies could cite that list when applying for research grants.

In a small number of cases, reviewers were split on their recommendations. In such cases, we usually kept our original approach, while modifying the language in the report to acknowledge or accommodate as much as possible the criticisms or suggestions that we did not accept. For example, two reviewers thought it would be better to drop the chapter that included criticisms of the Pennsylvania Game Commission (P.G.C.). Other reviewers thought it was essential to include such criticism, which is the approach adopted by Forum members for the reasons stated in the Preface.

If a few cases, Forum members did not agree with a reviewer on an issue and did not modify the report to accommodate the criticism. However, in almost all such cases, we noted in the text, endnotes, or this appendix that there exist different points of view on the subject, often including language taken directly from the reviewer. The topics where we disagreed with reviewers (other than purely editorial suggestions) included:

(1) Advocacy by several reviewers, or suggestion that we discuss the feasibility, of using other means of restoring balance between deer and habitat than recreational hunting. Although we did add (in Chapter 11) a discussion of immunocontraception and its lack of usefulness at the current state of technology in the large forest tracts that are the subject of the report, we did not include discussion of other methods except in passing mention. We left the task of devising alternate methods to the professionals at P.G.C., should expanded recreational hunting prove inadequate. Forum members concluded that it is premature to give up on recreational hunting until and unless additional or extended hunting seasons, increased bag limits, and other tools are put in place and shown to be inadequate.

(2) One reviewer suggested that high deer populations and corresponding damage to vegetation could be part of normal fluctuations over hundreds or thousands of years. Although this is theoretically possible, large-scale human intervention in forest processes in the form of hunting, forestry, adjacent agriculture, eradication of large predators, road building, air pollution, greenhouse-gas induced climate change, and other practices make the effects of non-anthropogenic processes on the current high deer densities ambiguous at best. Forum members maintain that continuous active management is now necessary to preserve the values that we and other stakeholders support, such as the preservation of biodiversity. White-tailed deer have reduced populations of certain species dramatically. If we want those species to be sustained, the simplest approach, and the only one we have evidence will work, is reduction of deer populations. To build in ongoing future checks on whether our analysis is correct, we embed our recommendations in an adaptive resource management framework.

(3) It was suggested that indicators need to clearly represent broader ecosystem processes. Although this is a desirable ideal to bear in mind, Forum members do not know how to guarantee that such indicators can be identified unambiguously; nor do we think a subsequent committee will necessarily be able to guarantee their inclusion. In the report, we recommend that a range of indicators be measured concurrently on the assumption that a breadth of indicators will reflect a combination of ecosystem processes, including those that are most critical for sustaining the indicator species' establishment, growth, and reproduction. No doubt, the individual indicators chosen to comprise the suite of indicators to be employed can be optimized to increase the probability that broader ecosystem processes are represented; we pass such advice on to succeeding committees.

(4) One reviewer thought that "Chapter 4 seems an afterthought and an unnecessary splitting of focus — why not incorporate its content into the historical overview of Chapter 3?" Forum members felt that the material in Chapter 4 has a significantly different focus from (and is perhaps somewhat more speculative than) the material in Chapter 3 and warrants a clean separation.

(5) One reviewer felt that statements in the report might lead readers to think that by reducing deer populations, one might be able to decrease tick abundance and reduce the risk of Lyme disease. Although we clarified the wording to respond to this reviewer using some of his language, Forum members concluded after a more detailed reexamination of the literature that Lyme disease almost certainly does increase as deer populations increase, although there is some ambiguity in study results. Expanded discussion on this topic was included in an endnote.

(6) One reviewer suggested that we should be more consistent in the list of 116 native "tree" species (Table 4), which, he pointed out, includes canopy/subcanopy trees as well as several shrubs. "If the intent is to include 'tree species with commercial value' then get rid of the shrubs (or small trees that cannot be considered to have commercial value). If your intent is to indicate both commercial value and what is known about browsing preferences, then include all reasonably common small tree/shrub species, including such species as witch-hazel, maple-leaved viburnum, elderberries (both species), mountain-laurel, and rosebay rhododendron." The table reproduces the 116 native tree species listed in the Flora of Pennsylvania Database (exclusive of subspecies, varieties and hybrids); of these, 13 are cross-listed as shrub species. We wanted to keep the focus of the table on trees. In the final report, a clarifying sentence was added to the table for purposes of consistency to indicate that the list includes 13 species that can have either a tree or shrub growth form. The remainder of the table was kept unchanged. The database lists 179 native shrub and 22 native woody vine species (exclusive of subspecies, varieties and hybrids). Thus, a combined list of native woody plants would have 304 species. Were we to have included all 304 species, "browsing preference" would be blank for most of them. Furthermore, had we picked species to list based on criteria such as "reasonably common," we would be departing from our biodiversity focus. Also, it is our assumption that the more common species would not be chosen as potential indicators for testing predictions of deer impact in an A.R.M. program. We agree with the reviewer that, at a later date, it would be useful to prepare a separate table for native shrub and woody vine species and see to what degree published research and expert opinion can be used to evaluate their relative browsing preference ranks.

(7) One reviewer suggested that the A.R.M. program try to account for the multi-factor nature of the potential causes of recent changes in forest vegetation. Although we have included soil acidity in the proposed A.R.M. program, we have not included experiments with other non-deer potential impact factors. Barring controversy over the appropriate model to use in predicting vegetation impact, the multi-factor experimental approach suggested by the reviewer seems to cross the line between basic research and A.R.M. True, there is a possibility, however small, that all of the models picked for an A.R.M. program will be wrong or the chosen measurements insufficiently broad to allow model correction. In light of this possibility, it would probably be wise to request additional funding from agencies or foundations supporting forest research, so

that supplementary multi-factor experiments could be included as add-ons to the A.R.M. program. Research agencies might find it very efficient to piggy back onto an A.R.M. program.

(8) Forum members did not agree with a suggestion to avoid the term model to refer to competing quantitative predictions of forest recovery. A definition of model has been added to the text. Theory is a more widely understood word than model, but theory as used by scientists usually implies a well established body of work with more general applicability than the much more specific predictions that may be made for forest recovery in particular areas of the landscape.

Endnote

[1] Complimentary comments from reviewers included the following:

"I will start by complimenting the authors on the wealth of information contained in the report. It is a good reference source for a range of ecosystem topics."

"First and foremost, I want to congratulate all of you on this wonderful document. I know how incredibly hard you worked to produce this, and that work is richly and sometimes eloquently reflected on each page of this document. It is quite unusual in both its breadth and depth, its degree of interdisciplinarity, its readability (no, it's not casual reading, but interested parties from nearly any discipline or interested lay people will gain a great reward for the effort that they put into perusing this volume, and it is accessible to the willing from across that range), and its specific adaptive resource management framework."

"The report of the Deer Management Forum is a fascinating and superb effort to capture deer management in a comprehensive context. The report is an impressive document written by a group of biologists who have rich experience with the issues of deer in eastern forest ecosystems. The adaptive management approach provides the framework for a managing both deer and forests in manner that can build consensus for multiple objectives and incorporate the best scientific knowledge. The synthesis of existing knowledge presented here makes this a valuable document to many readers beyond the intended audience."

"First, I would like to say it was a great read. The task force is to be congratulated on pulling together an amazing amount of information. I have tried to write several chapters like the ones in this plan and I know how scattered the information is. Excellent job."

"I have just spent the last couple hours reading your draft report and I wish to commend you all on a job very well done. I came away from my visit with the [Deer Management] Forum feeling overwhelmed with the complexity of the task before you but somehow you seem to have got your arms around it and come up with a credible way forward. Congratulations!"

"In general, I think that this is an excellent publication. I was particularly impressed by the logical, organized presentation of information in the book. I also think that the sections at the end of each chapter on 'Findings' and 'Recommendations' will greatly improve the utility of the publication."

Appendix E. Names of plants, animals, and other organisms mentioned in the report

Nomenclature for plants follows Rhoads and Block (2000); for other organisms, various current sources were consulted including the Integrated Taxonomic Information System (www.itis.usda.gov) and the National Center for Biotechnology Information taxonomy database (www.ncbi.nlm.nih.gov/Taxonomy/tax.html).

Trees

ailanthus* (tree-of-heaven)	*Ailanthus altissima* (Mill.) Swingle*
Allegheny chinkapin	*Castanea pumila* Mill.
Allegheny plum	*Prunus alleghaniensis* Porter
Allegheny serviceberry	*Amelanchier laevis* Wieg.
alternate-leaved dogwood	*Cornus alternifolia* L.f.
American basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
American chestnut	*Castanea dentata* (Marshall) Borkh.
American elm	*Ulmus americana* L.
American holly	*Ilex opaca* Aiton
American hornbeam (blue-beech, musclewood)	*Carpinus caroliniana* Walter
American mountain-ash	*Sorbus americana* Marshall
American plum	*Prunus americana* Marshall
American sycamore	*Platanus occidentalis* L.
Atlantic white-cedar	*Chamaecyparis thyoides* (L.) Britton, Stearns & Poggenb.
balsam fir	*Abies balsamea* (L.) Mill.
balsam poplar	*Populus balsamifera* L.
bigtooth aspen	*Populus grandidentata* Michx.
Biltmore hawthorn	*Crataegus intricata* Lange
bitternut hickory	*Carya cordiformis* (Wangenh.) K.Koch

* Introduced or escaped and naturalized in Pennsylvania

Trees

black ash	*Fraxinus nigra* Marshall
black cherry	*Prunus serotina* Ehrh.
black locust	*Robinia pseudoacacia* L.
black maple	*Acer nigrum* Michx.f.
black oak	*Quercus velutina* Lam.
black spruce	*Picea mariana* (Mill.) Britton, Stearns & Poggenb.
black walnut	*Juglans nigra* L.
black willow	*Salix nigra* Marshall
blackgum (black tupelo)	*Nyssa sylvatica* Marshall
blackhaw	*Viburnum prunifolium* L.
blackjack oak	*Quercus marilandica* Münchh.
boxelder	*Acer negundo* L.
Brainerd hawthorn	*Crataegus brainerdii* Sarg.
broadleaf hawthorn	*Crataegus dilatata* Sarg.
bur oak	*Quercus macrocarpa* Michx.
butternut	*Juglans cinerea* L.
chestnut oak	*Quercus montana* Willd. (= *Q. prinus* L.)
Chickasaw plum	*Prunus angustifolia* Marshall
chinkapin oak (yellow oak)	*Quercus muhlenbergii* Engelm.
coastal plain willow	*Salix caroliniana* Michx.
cockspur hawthorn	*Crataegus crus-galli* L.
common chokecherry	*Prunus virginiana* L.
common persimmon	*Diospyros virginiana* L.
cucumbertree (cucumber magnolia)	*Magnolia acuminata* (L.) L.
devils-walkingstick	*Aralia spinosa* L.
dotted hawthorn	*Crataegus punctata* Jacq.
downy hawthorn	*Crataegus mollis* (Torr. & A.Gray) Scheele

Trees

downy serviceberry (juneberry, shadbush)	*Amelanchier arborea* (Michx.f.) Fern.
eastern cottonwood	*Populus deltoides* Marsh.
eastern hemlock	*Tsuga canadensis*
eastern hophornbeam	*Ostrya virginiana* (Mill.) K.Koch
eastern redbud	*Cercis canadensis* L.
eastern redcedar	*Juniperus virginiana* L.
eastern white pine	*Pinus strobus* L.
fanleaf hawthorn	*Crataegus flabellata* (Spach) G.Kirchn.
fireberry hawthorn	*Crataegus rotundifolia* Moench (= *C. chrysocarpa* Ashe)
fleshy hawthorn	*Crataegus succulenta* Schrad. ex Link
flowering dogwood	*Cornus florida* L.
fringetree	*Chionanthus virginicus* L.
frosted hawthorn	*Crataegus pruinosa* (H.L.Wendl.) K.Koch
Georgia hackberry (dwarf hackberry)	*Celtis tenuifolia* Nutt.
gray birch	*Betula populifolia* Marshall
green ash (red ash)	*Fraxinus pennsylvanica* Marshall
hackberry	*Celtis occidentalis* L.
honeylocust	*Gleditsia triacanthos* L.
Japanese larch*	*Larix kaempferi* (Lamb.) Carr.*
Kentucky coffeetree	*Gymnocladus dioicus* (L.) K.Koch
mockernut hickory	*Carya tomentosa* (Lam. ex Poir.) Nutt.
northern red oak	*Quercus rubra* L. (= *Q. borealis* Michx.)
oaks	*Quercus* spp.
Ohio buckeye	*Aesculus glabra* Willd.
paper birch	*Betula papyrifera* Marshall
pawpaw	*Asimina triloba* (L.) Dunal
peachleaf willow	*Salix amygdaloides* Andersson

* Introduced or escaped and naturalized in Pennsylvania

Trees

pear hawthorn	*Crataegus calpodendron* (Ehrh.) Medik.
pignut hickory	*Carya glabra* (Mill.) Sweet
pin cherry	*Prunus pensylvanica* L.f.
pin oak	*Quercus palustris* Münchh.
pitch pine	*Pinus rigida* Mill.
poison-sumac	*Toxicodendron vernix* (L.) Kuntze
post oak	*Quercus stellata* Wangenh.
pumpkin ash	*Fraxinus profunda* (Bush) Bush
quaking aspen	*Populus tremuloides* Michx.
red maple	*Acer rubrum* L.
red mulberry	*Morus rubra* L.
red pine	*Pinus resinosa* Aiton
red spruce	*Picea rubens* Sarg.
redbud	*Cercis canadensis* L.
river birch	*Betula nigra* L.
sassafras	*Sassafras albidum* (Nutt.) Nees
scarlet hawthorn	*Crataegus coccinea* L. (= *C. pedicellata* Sarg.)
scarlet oak	*Quercus coccinea* Münchh.
shagbark hickory	*Carya ovata* (Mill.) K.Koch
shellbark hickory	*Carya laciniosa* (F.Michx.) Loudon
shingle oak	*Quercus imbricaria* Michx.
shortleaf pine	*Pinus echinata* Mill.
showy mountain-ash	*Sorbus decora* (Sarg.) Schneid.
Shumard oak	*Quercus shumardii* Buckley
silver maple	*Acer saccharinum* L.
slippery elm	*Ulmus rubra* Muhl.
sourwood	*Oxydendrum arboreum* (L.) DC.
southern red oak	*Quercus falcata* Michx.

Trees

striped maple (moosewood)	*Acer pensylvanicum* L.
sugar maple	*Acer saccharum* Marshall
swamp white oak	*Quercus bicolor* Willd.
sweet birch (black birch)	*Betula lenta* L.
sweet crab apple	*Malus coronaria* (L.) Mill.
sweet pignut hickory (red hickory)	*Carya ovalis* (Wang.) Sarg.
sweetbay (sweetbay magnolia)	*Magnolia virginiana* L.
sweetgum	*Liquidambar styraciflua* L.
Table-Mountain pine	*Pinus pungens* Lamb.
tamarack	*Larix laricina* (DuRoi) K.Koch
tuliptree (yellow-poplar)	*Liriodendron tulipifera* L.
umbrella magnolia	*Magnolia tripetala* (L.) L.
Virginia pine (scrub pine)	*Pinus virginiana* Mill.
white ash	*Fraxinus americana* L.
white oak	*Quercus alba* L.
willow oak	*Quercus phellos* L.
yellow birch	*Betula alleghaniensis* Britton
yellow buckeye	*Aesculus flava* Sol. (= *A. octandra* Marsh)
yellow oak (chinkapin oak)	*Quercus muhlenbergii* Engelm. (= *Q. muehlenbergii*)
yellow-poplar (tuliptree)	*Liriodendron tulipifera* L.

Shrubs, vines, and herbaceous plants

American hazelnut	*Corylus americana* Walter
American yew	*Taxus canadensis*(L.) Carr.
arrow-leaved tearthumb	*Polygonum sagittatum* L.

Shrubs, vines, and herbaceous plants

asters	*Doellingeria* spp., *Eurybia* spp., *Oclemena* spp., *Sericocarpus* spp., *Symphyotrichum* spp. (= *Aster* spp.)
barren chickweed	*Cerastium velutinum* Raf. (= *C. arvense* L. var. *villosum* (Muhl.) Hollick & Britt. and var. *villosissimum* Pennell)
beaked hazelnut	*Corylus cornuta* Marshall
bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
bellwort	*Uvularia perfoliata* L or *U. sessilifolia* L.
big bluestem	*Andropogon gerardii* Vitman
bird's-foot violet	*Viola pedata* L.
bishop's-cap	*Mitella diphylla* L.
blackberries	*Rubus allegheniensis* Porter (common blackberry), *R. canadensis* L. (smooth blackberry), *R. pensilvanicus* Poir. (blackberry)
black huckleberry	*Gaylussacia baccata* (Wang.) K.Koch
black snakeroot	*Cimicifuga racemosa* (L.) Nutt.
bladdernut	*Staphylea trifolia* L.
bloodroot	*Sanguinaria canadensis* L.
blue cohosh	*Caulophyllum thalictroides* (L.) Michx.
blue lupine	*Lupinus perennis* L.
bluebead lily	*Clintonia borealis* (Aiton) Raf.
blue-eyed-Mary	*Collinsia verna* Nutt.
bluestem goldenrod	*Solidago caesia* L.
bog-laurel	*Kalmia polifolia* Wangenh.
bog-rosemary	*Andromeda polifolia* L.
bracken fern	*Pteridium aquilinum* (L.) Kuhn
brambles	*Rubus* spp. (see blackberries, raspberries, dewberries)
burning-bush*	*Euonymus alatus* (Thunb.) Siebold*
bush-honeysuckle	*Diervilla lonicera* Mill.
Canada mayflower	*Maianthemum canadensis* Desf.
cinnamon fern	*Osmunda cinnamomea* L.

* Introduced or escaped and naturalized in Pennsylvania

Shrubs, vines, and herbaceous plants	
clearweed	*Pilea pumila* (L.) A.Gray
climbing fern	*Lygodium palmatum* (Bernh.) Swartz
coast violet	*Viola brittoniana* Pollard
common blackberry	*Rubus allegheniensis* Porter
cranefly orchid	*Tipularia discolor* (Pursh) Nutt.
declined trillium	*Trillium flexipes* Raf.
dewberries	*Rubus enslenii* Tratt. (southern dewberry), *R. flagellaris* Willd. (northern dewberry), *R. hispidus* L. (swamp dewberry), *R. recurvicaulis* Blanch. (dewberry)
dragon's-mouth	*Arethusa bulbosa* L.
Dutchman's-breeches	*Dicentra cucullaria* (L.) Bernh.
dwarf chinkapin oak (dwarf chestnut oak)	*Quercus prinoides* Willd.
dwarf cornel (bunchberry)	*Cornus canadensis* L.
dwarf ginseng	*Panax trifolius* L.
dwarf larkspur (wild delphinium)	*Delphinium tricorne* Michx.
dwarf sand cherry	*Prunus pumila* L. var. *pumila*
false-gromwell	*Onosmodium molle* Michx.
Solomon's-plume	*Smilacina racemosa* (L.) Desf.
fly-honeysuckle	*Lonicera canadensis* Marshall
foamflower	*Tiarella cordifolia* L.
fragrant sumac	*Rhus aromatica* Aiton
Fraser's sedge	*Cymophyllus fraserianus* (Ker Gawl.) Kartesz & Ghandi
frost grape	*Vitis riparia* Michx.
garlic mustard*	*Alliaria petiolata* (M.Bieb) Cavara & Grande*
giant knotweed*	*Polygonum sachalinense* F.W.Schmidt ex Maxim*
glade spurge	*Euphorbia purpurea* (Raf.) Fernald
golden puccoon	*Lithospermum caroliniense* (J.F.Gmel.) MacMill.

* Introduced or escaped and naturalized in Pennsylvania

Shrubs, vines, and herbaceous plants	
goldenclub	*Orontium aquaticum* L.
grasses	Poaceae
grass-pink	*Calopogon tuberosus* (L.) Britton, Stearns & Poggenb.
great nettle (stinging nettle)	*Urtica dioica* L.
greenbrier	*Smilax rotundifolia* L.
halberd-leaved tearthumb	*Polugonum arifolium* L.
hay-scented fern	*Dennstaedtia punctilobula* (Michx.) T.Moore
hepatica	*Hepatica nobilis* Mill.
highbush blueberry	*Vaccinium corymbosum* L.
hoary puccoon	*Lithospermum canescens* (Michx.) Lehm.
hobblebush (witch-hobble)	*Viburnum lantanoides* Michx. (= *V. alnifolium* Marshall)
honeysuckles* (species that are introduced and invasive in Pennsylvania)	*Lonicera bella* Zabel,* *L. japonica* Thunb.,* *L. maackii* (Rupr.) Maxim.,* *L. morrowii* A.Gray,* *L. tatarica* L.*
Indian cucumber-root	*Medeola virginiana* L.
Indian grass	*Sorghastrum nutans* (L.) Nash
jack-in-the-pulpit	*Arisaema triphyllum* (L.) Schott
Japanese barberry*	*Berberis thunbergii* DC.*
Japanese honeysuckle*	*Lonicera japonica* Thunb.*
Japanese knotweed*	*Polygonum cuspidatum* Siebold & Zucc.*
Japanese stilt grass*	*Microstegium vimineum* (Trin.) A.Camus*
jumpseed	*Polygonum virginianum* L.
Labrador-tea	*Ledum groenlandicum* Oeder
large round-leaved orchid	*Platanthera orbiculata* (Pursh) Lindl.
large white trillium	*Trillium grandiflorum* (Michx.) Salisb.
leafy white orchid	*Platanthera dilatata* (Pursh) Lindl. ex Beck
lesser celandine*	*Ranunculus ficaria* L.*
little bluestem	*Schizachyrium scoparium* (Michx.) Nash

* Introduced or escaped and naturalized in Pennsylvania

Shrubs, vines, and herbaceous plants	
lowbush blueberry (late low blueberry)	*Vaccinium pallidum* Aiton
maple-leaf viburnum	*Viburnum acerifolium* L.
marginal wood fern	*Dryopteris marginalis* (L.) A.Gray
Maryland meadow-beauty	*Rhexia mariana* L.
mayapple	*Podophyllum peltatum* L.
Morrow's honeysuckle*	*Lonicera morrowii* A.Gray*
moss-pink	*Phlox subulata* L.
mountain maple	*Acer spicatum* Lam.
mountain winterberry (mountain holly)	*Ilex montana* (Torr. & A.Gray) A.Gray
mountain-laurel	*Kalmia latifolia* L.
multiflora rose*	*Rosa multiflora* Thunb. ex Murray*
New York aster	*Symphyotrichum novi-belgii* (L.) Nesom (= *Aster novi-belgii* L.)
New York fern	*Thelypteris noveboracensis* (L.) Nieuwl.
nodding trillium	*Trillium cernuum* L.
northern arrowwood	*Viburnum recognitum* Fernald
painted trillium	*Trillium undulatum* Willd.
pale jewelweed (yellow touch-me-not)	*Impatiens pallida* Nutt.
Pennsylvania sedge	*Carex pensylvanica* Lam.
perfoliate-leaved bellwort	*Uvularia perfoliata* L.
pilewort (fireweed)	*Erechtites hieracifolia* (L.) Raf. ex DC.
pink lady's-slipper	*Cypripedium acaule* Aiton
pinxter-flower azalea	*Rhododendron periclymenoides* (Michx.) Shinners (= *R. nudiflorum* [L.] Torr.)
pipsissewa (striped wintergreen)	*Chimaphila maculata* (L.) Pursh
pitch pine	*Pinus rigida* Mill.

* Introduced or escaped and naturalized in Pennsylvania

Shrubs, vines, and herbaceous plants

pitcher plant	*Sarracenia purpurea* L.
poison-ivy	*Toxicodendron radicans* (L.) Kuntze
prairie dropseed	*Sporobolus heterolepis* (A.Gray) A.Gray
privets*	*Ligustrum obtusifolium* Sieb & Zucc.,* *L. ovalifolium* Hassk.,* *L. vulgare* L.*
purple trillium (wakerobin)	*Trillium erectum* L.
raspberries	*Rubus idaeus* L. (red raspberry), *R. occidentalis* L. (black raspberry), *R. odoratus* L. (purple-flowering raspberry), *R. pubescens* Raf. (dwarf raspberry)
rattlesnake fern	*Botrichium virginianum* (L.) Sw.
red-berried elder	*Sambucus racemosa* L.
rhodora	*Rhododendron canadense* (L.) Torr.
rose mandarin	*Streptopus roseus* Michx.
rose pogonia	*Pogonia ophioglossoides* (L.) Ker Gawl.
rosebay rhododendron	*Rhododendron maximum* L.
round-leaved sundew	*Drosera rotundifolia* L.
Rubus spp.	(see blackberries, raspberries, dewberries)
Russian-olive*	*Elaeagnus angustifolia* L.*
sagebrush‡	*Artemisia* spp.‡
scrub oak (bear oak)	*Quercus ilicifolia* Wangenh.
sedges	*Carex* spp.
sensitive fern	*Onoclea sensibilis* L.
serpentine aster	*Symphyotrichum depauperatum* (Fern.) Nesom (= *Aster depauperatus* (Porter) Fern.)
sessile-leaved bellwort	*Uvularia sessilifolia* L.
shale-barren ragwort	*Senecio antennariifolius* Britton (= *Packera antennariifolia* [Britton] W.A.Weber & A.Love)
sharp-lobed hepatica	*Hepatica nobilis* var. *acutiloba*
sheep-laurel	*Kalmia angustifolia* L.

* Introduced or escaped and naturalized in Pennsylvania
‡ Not present in the wild in Pennsylvania

Shrubs, vines, and herbaceous plants	
shining clubmoss	*Huperzia lucidula* (Michx.) Trevis. (= *Lycopodium lucidulum* Michx.)
showy lady's-slipper	*Cypripedium reginae* Walt.
showy orchis	*Galearis spectabilis* (L.) Raf.
side-oats gramma	*Bouteloua curtipendula* (Michx.) Torr.
silky dogwood	*Cornus amomum* Mill.
silverrod	*Solidago bicolor* L.
skunk-cabbage	*Symplocarpus foetidus* (L.) Salisb. ex Nutt.
smooth alder	*Alnus serrulata* (Drand. ex Aiton) Willd.
solomon's-seal	*Polygonatum biflorum* (Walter) Elliot
southern arrowwood	*Viburnum dentatum* L.
speckled alder	*Alnus incana* (L.) Moench
spicebush	*Lindera benzoin* (L.) Blume
spotted jewelweed (orange touch-me-not)	*Impatiens capensis* Meerb.
spring-beauty	*Claytonia virginica* L.
squirrel-corn	*Dicentra canadensis* (Goldie) Walp.
starflower	*Trientalis borealis* Raf.
swamp azalea	*Rhododendron viscosum* (L.) Torr.
swamp dog-hobble	*Leucothoe racemosa* (L.) A.Gray
sweet-cicely	*Osmorhiza claytonii* (Michx.) C.B.Clarke
sweet low blueberry (early low blueberry)	*Vaccinium angustifolium* Aiton
sweet pepperbush	*Clethra alnifolia* L.
sweetgale	*Myrica gale* L.
Tatarian honeysuckle* (Tartarian honeysuckle*)	*Lonicera tatarica* L.*
teaberry (checkerberry wintergreen	*Gaultheria procumbens* L.

* Introduced or escaped and naturalized in Pennsylvania

Shrubs, vines, and herbaceous plants	
toadshade	*Trillium sessile* L.
trailing-arbutus	*Epigaea repens* L.
turk's-cap lily	*Lilium superbum* L.
turtlehead	*Chelone glabra* L.
twinleaf	*Jeffersonia diphylla* (L.) Pers.
variable sedge	*Carex polymorpha* Muhl.
violets	*Viola* spp.
Virginia bluebell	*Mertensia virginica* (L.) Pers. ex Link
white fringed orchid	*Platanthera blephariglottis* (Willd.) Lindl.
white monk's-hood	*Aconitum reclinatum* A.Gray
white snakeroot	*Eupatorium rugosum* Houtt.
white wood aster	*Eurybia divaricata* (L.) Nesom (= *Aster divaricatus* L.)
white wood lily	*Clintonia umbellulata* (Michx.) Morong
whorled loosestrife	*Lysimachia quadrifolia* L.
wild blue phlox	*Phlox divaricata* L.
wild currants	*Ribes* spp.
wild hydrangea	*Hydrangea arborescens* L.
wild leek	*Allium tricoccum* Aiton
wild sarsaparilla	*Aralia nudicaulis* L.
wild strawberry	*Fragaria virginiana* Mill.
wild-ginger	*Asarum canadense* L.
winterberry	*Ilex verticillata* (L.) A.Gray
witch-hazel	*Hamamelis virginiana* L.
wood anemone	*Anemone quinquefolia* L.
wood ferns	*Dryopteris* spp.
wood geranium	*Geranium maculatum* L.
wood nettle	*Laportea canadensis* (L.) Wedd.
yellow fringed-orchid	*Platanthera ciliaris* (L.) Lindl.

Shrubs, vines, and herbaceous plants

yellow trout-lily	*Erythronium americanum* Ker. Gawl
zigzag aster	*Symphyotrichum prenanthoides* (Muhl. ex Willd.) Nesom (= *Aster prenanthoides* Muhl. ex Willd.)

Animals

acorn moth	*Valentina glandulella* (Riley)
acorn weevils	*Curculio* spp. and *Conotrachelus* spp.
American cheetah†	*Acinonyx trumani* Orr†
American robin	*Turdus migratorius* L.
Armbruster's wolf†	*Canis armbrusteri* Gidley†
beech scale*	*Cryptococcus fagisuga* Lindinger*
black bear	*Ursus americanus* Pallas
black-and-white warbler	*Mniotilta varia* (L.)
blue jay	*Cyanocitta cristata* (L.)
bobcat	*Lynx rufus* (Schreber)
brown bear† (grizzly bear)	*Ursus arctos* L.†
cherry scallopshell moth*	*Hydria prunivorata* Ferguson*
chipmunk	*Tamias striatus* (L.)
chipping sparrow	*Spizella passerina* (Bechstein)
deer mouse	*Peromyscus maniculatus* (Wagner)
deer tick (black-legged tick)	*Ixodes scapularis* Say (= *I. dammini* Spielman, Clifford, Piesman & Corwin)
dire wolf†	*Canis dirus* Leidy†
eastern cougar†	*Puma concolor* L. *couguar* Kerr† (= *Felis c.* L. *c.* Kerr)
eastern phoebe	*Sayornis phoebe* (Latham)
eastern tent caterpillar (moth)	*Malacosoma americanum* (F.)
eastern towhee	*Pipilo erythrophthalmus* (L.)

* Introduced or escaped and naturalized in Pennsylvania
† Extirpated in Pennsylvania or extinct

Animals

eastern wood-pewee	*Contopus virens* (L.)
elk (eastern elk†, Rocky Mountain elk*)	*Cervus elephas* L. *canadensis* Erxleben† (eastern elk†); *Cervus elephas* L. *nelsoni* Bailey* (Rocky Mountain elk*)
elm spanworm (moth)	*Ennomos subsignaria* (Hübner)
fallow deer‡	*Dama dama* (L.)‡
filbertworm	*Melissopus latiferreanus* (Walsingham) (= *Cydia latiferreana* [Walsingham])
forest tent caterpillar (moth)	*Malacosoma disstria* Hübner
giant short-faced bear†	*Arctodus simus* Cope†
gray squirrel	*Sciurus carolinensis* Gmelin
gray wolf†	*Canis lupus* L.†
grizzly bear† (brown bear)	*Ursus arctos* L.†
gypsy moth*	*Lymantria dispar* (L.)* (= *Porthetria dispar* L.*)
hemlock woolly adelgid* (aphid)	*Adelges tsugae* Annand*
hooded warbler	*Wilsonia citrina* (Boddaert)
human	*Homo sapiens* L.
indigo bunting	*Passerina cyanea* (L.)
jaguar†	*Panthera onca* L.†
Karner blue butterfly†	*Lycaeides melissa samuelis* Nabokov†
least flycatcher	*Empidonax minimus* (Baird & Baird)
lesser short-faced bear†	*Arctodus pristinus* Leidy†
mountain lion†	*Puma concolor* L. *couguar* Kerr† (= *Felis c.* L. *c.* Kerr)
ovenbird	*Seiurus aurocapillus* (L.)
pear thrips*	*Taeniothrips inconsequens* (Uzel)*
pip gall wasp	*Callirhytis operator* (OS)
redback salamander	*Plethodon cinereus* (Green)

* Introduced or escaped and naturalized in Pennsylvania
† Extirpated in Pennsylvania or extinct
‡ Not present in the wild in Pennsylvania

Animals

red deer‡	*Cervus elaphus* elaphus L.‡
ring-necked pheasant*	*Phasianus colchicus* L.*
stony gall wasp	*Callirhytis fructuosa* Weld
Studer's cheetah†	*Acinonyx studeri* Savage†
white-footed mouse	*Peromyscus leucopus* (Rafinesque)
white-tailed deer	*Odocoileus virginianus* (Zimmermann)
wild turkey	*Meleagris gallopavo* L.
wolf coyote†	*Canis priscolatrans* Cope†
yellow-billed cuckoo	*Coccyzus americanus* (L.)

Fungi

beech bark disease*	*Nectria coccinea* Desm. var. *faginata* Lohman, A.M.Watson & Ayres* and *Nectria galligena* Bres.
cherry leaf-spot fungus* (cherry shot hole fungus*)	*Blumeriella jaapii* (Rehm) Axe.*
chestnut blight*	*Cryphonectria parasitica* (Murrill) Barr.*
dogwood anthracnose*	*Discula destructiva* Redlin*
Dutch elm disease*	*Ophiostoma ulmi* (Buisman) Nannf.*
maple anthracnose*	*Discula campestris* (Pass.) Arx*
sudden oak death fungus*	*Phytophthora ramorum* Werres & A.W.A.M. de Cock*

Bacteria

Lyme disease spirochete*	*Borrelia burgdorferi* R.C. Johnson, G.P. Schmid, F.W. Hyde, A.G. Steigerwaldt, D.J. Brenner*

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† Extirpated in Pennsylvania or extinct
‡ Not present in the wild in Pennsylvania

Appendix F: The Pennsylvania Game Commission's 1976 deer management policy

5000 BUREAU OF GAME MANAGEMENT

5100 -- POLICIES

5101 -- Deer Management

Under Game Commission stewardship since just before the turn of the century, Pennsylvania's whitetail deer population has been brought from near-extinction in the early 1900's to today's era of abundance. Whitetails are now found in all sixty-seven counties of the State, and they annually provide over four million man-days of recreation for approximately one and one quarter million hunters. Moreover, the resource provides countless hours of outdoor recreation in such non-consumptive uses and wildlife photography and nature appreciation.

In formulating and implementing deer management programs, the Commission must consider not only the overall goal of perpetuating the whitetail for this and future generations, but also the broad spectrum of needs and desires of an increasing human population.

DEER POLICY STATEMENT

The Commission recognizes that deer belong to all citizens of the Commonwealth and that recreational hunting is a privilege, not a right.

The Commission recognizes its legislative mandate to manage deer on a sustained yield basis for the benefit of the resource and the consumptive as well as the non-consumptive user.

The Commission recognizes that recreational hunting is the major use of deer. Consistent with its responsibilities to the resource and the people, the Commission will endeavor to manage deer on the basis of: (a) compatibility with other land uses, (b) maximum overall recreational opportunity, (c) maximum sustained harvest and, (d) maximum esthetic appeal.

The Commission recognizes that responsible deer management must be based on sound information obtained through continuous research and inventory.

The Commission recognizes that an informed public is an enlightened public; therefore, it will continue to pursue its educational efforts concerning deer and deer management.

POLICY IMPLEMENTATION

Management techniques may include, but are not limited to, regulatory control of hunting and/or harvest by time, space, sex and/or age characteristics of animals, type of sporting arm and number of hunters. Management programs using these techniques must be sufficiently flexible to meet ever changing conditions and priorities.

In recognition of the singular importance of food and cover to deer and other wildlife species, the Commission will continue its active habitat development and maintenance activities on State Game Lands and other lands under its control. Where feasible, industry and the private sector will be encouraged to manage their lands in a similar manner.

Situations may arise necessitating the removal of deer or reduction of deer numbers in response to unique problems. In these cases control will be exerted only after an investigation by Commission personnel reveals a valid need exists. When control by the agency is justified, it will be accomplished as expeditiously and humanely as possible. In all but exceptional cases, control will be effected by sport hunting.

The Commission adopted the foregoing deer management policy Oct. 22, 1976 replacing the one approved in April 1960.