DRAFT DOCUMENT FOR COMMENT

THE PENNSYLVANIA BIODIVERSITY CONSERVATION PLAN

SCIENCE FOR BIODIVERSITY CONSERVATION

Science Task Force, Pennsylvania Biodiversity Partnership

Definition: The science supporting biodiversity conservation is the research and analysis, information, and expertise, that provides an understanding of the inventory, systematics, genetics, ecology, and environment of the organisms and biological communities that constitute Pennsylvania's biodiversity.

Background: Successful conservation of biodiversity begins with knowledge and understanding of the resources and issues involved. Such an approach is the framework and springboard on which decisions and actions are based.

Characterization of biodiversity is obtained through endeavors of scientific inquiry and analysis. Science provides inventory and monitoring of the elements of biodiversity; description of those elements; assessments of conservation status; understanding of how biodiversity elements function and interact; and additional knowledge that allows for effective management. Both in concept and operation, biodiversity consists of elements at three levels – species; genetics and populations; and ecological elements ranging from natural communities to landscapes.

Monitoring for all elements and levels is needed in order to keep knowledge and management current. As with inventory, biodiversity monitoring is underway for a few groups of organisms (e.g. Breeding Bird Atlas project), although these efforts and programs are rare. Essentially no monitoring is underway regarding biodiversity resources such as those at the genetic and landscape levels.

Today in Pennsylvania, our knowledge of biodiversity is incomplete at all levels. Where knowledge does exist, it varies in depth and coverage. It is estimated that more than 25,000 species of organisms exist in the state. While the coverage is good for certain groups of living things, it is poor or entirely lacking in other groups. The most basic role of science in the realm of biodiversity management is inventory and distribution. For certain groups of organisms, the state inventory is essentially complete (birds and mammals) and only some gaps remain in distributional information, while for other groups (e.g. certain invertebrates and fungi), basic inventory has not even commenced. Again, inventory of biodiversity is but one service provided by scientists and their programs. Still to mention are needs of information that describe genetics of populations, life histories, ecological roles, and the functions of ecosystems and landscapes. Finally, our knowledge must include details and the answers to specific questions that science needs to address regarding conservation of all elements of biodiversity.

Scientific resources related to biodiversity management exist as data (including curated collections of specimens), literature (published data), electronic databases, active research programs, and a vast set of resources that exist as living experts. Biodiversity resources are both private and public. Private resources are academic and research institutions (universities, natural history museums, etc.) and nonprofit conservation organizations with imbedded science programs. Public resources are largely state and federal agencies with mandates regarding some sort of biodiversity responsibilities (e.g., U.S. Forest Service, U.S. Fish and Wildlife Service, Pennsylvania Game Commission, Pennsylvania Historic and Museum Commission). An enormous challenge for biodiversity science is to ensure communication and coordination among these entities. Another critical challenge is to see that attention is provided for the elements of biodiversity not officially assigned to any particular public agency, or for those elements not receiving much attention. Those elements include the largest and most diverse groups of organisms, such as most invertebrate animals and fungi.

The issue of unequal attention of science relative to all elements of biodiversity is a major consideration. In part, the concept of biodiversity has been popularized. This phenomenon has impacted both public understanding and support for the science necessary to comprehensively treat the subject. The result has been to elevate attention toward biodiversity elements that entertain (river otter, bald eagle, etc.) with limited or no attention elsewhere. This lack of concern for less well-known organisms results in a lack of understanding for all elements and levels of biodiversity and has real implications for both science and management. Ultimately, lack of awareness will influence the success of biodiversity conservation.

Vision: Pennsylvanians will develop a cooperative framework of on-going scientific research and resources that will support biodiversity management by:

1. Establishing an official coordinated program and associated network of private and governmental partners organized to provide science and guidance to biodiversity efforts.
2. Incorporating scientific approaches, both through experimental support and expert advice.
3. Constructing a scientific framework to supply information as a regular and constant facet of biodiversity conservation planning and implementation.
4. Providing information and support at all levels of biodiversity, including genetic, population, taxonomic, ecosystem, and landscape.
5. Identifying, prioritizing, and resolving questions regarding all levels of biodiversity (see #4), including inventory and distribution, monitoring, life histories, ecological function, and landscape processes.
6. Consisting of both basic and applied research.
7. Prioritizing scientific activities based on the needs of biodiversity conservation, such as filling information gaps regarding inventory or potential threats to survival and ecological function.
8. Identifying issues that threaten the health and maintenance of biodiversity.
9. Making available information to understand and predict threats and sources of threats, and how to best address the same.
10. Developing and implementing a status determination and regulatory listing process that is supported by adequate regulatory mechanisms, formalizes the advisory relationship between the Pennsylvania Biological Survey and Pennsylvania's natural resource management agencies, standardizes the status determination and listing protocols used for different groups of organisms, and provides users with clear guidance, such as a written manual of procedure, on how to determine the status of species.
11. Establishing necessary funding support for facilities and personnel.

Issues to be Addressed to Achieve Vision

1. ***Information and research needs should be evaluated and prioritized as a way of assuring scientific review and the implementation of a shared vision*.** The Pennsylvania Biodiversity Conservation Plan includes recommendations relative to needs at many levels, and science will continue to play an active role in both refining statements of need, filling information gaps, and guiding decision-making. Presently, there is no single objective mechanism that reviews needs and options or that steers research and information gathering across the state. The result is some inefficiency, duplication of efforts, and activities that could be misguided in terms of overall biodiversity conservation needs. There are examples in Pennsylvania of either internal or individual agency committees and decision-making routines, e.g. Wild Resource Conservation Program, however, these are presently unguided by a shared biodiversity strategy or agenda, and they are active on just a fraction of the total funding and programs applied to research in the state.

   Biodiversity research and information management in Pennsylvania is presently fragmented and, as such, contains aspects of both redundancy and incompleteness. The present lack of a "system" to guide biodiversity research also means that there are missed opportunities for collaboration and that all, or the most appropriate resources and expertise, are not used or guiding the work. Presently, researchers and conservationists are either independently developing their questions and research topics, or they are often applying for funding with proposals that match grant programs' objectives. These objectives are not necessarily scientifically informed or consistent with more widely held understanding of biodiversity information needs.

   The lack of a statewide strategy for research and information gathering means that both proposal writers and grantors are not advised regarding not only a prioritization of topics and information gaps, but also priorities relative to balancing short-term necessities with long-term essentials. All of the above becomes even more critical in light of the limited resources available to the total sum of biodiversity science initiatives.

Recommendations:

A. Recognize a diverse, independent group with scientific expertise (such as the Pennsylvania Biodiversity Partnership (PBP) Science Task Force and Pennsylvania Biological Survey (PABS)) charged with reviewing and advising on research and information needs.
B. Develop a mutually accepted objective scientific process whereby biodiversity information needs and options are reviewed and prioritized that
   i. Is based on policies to apply the process statewide for multiple stakeholders.
   ii. Is based on standard scientific principles.
   iii. Has outcomes available for use by proposal writers and funding programs.
C. The scientific advisory body and the review process should be guided by the Pennsylvania Biodiversity Conservation Plan, with updates and revisions to the research/information sections of the Plan as needed.
D. Develop a comprehensive and prioritized list of research and information needs that includes both recommendations and options.
E. The process will guide short-term needs for information with a long-term perspective of basic research that continues to generally inform science and conservation.
F. In addition to guiding biodiversity research, guidance and review should also take place regarding proposals to create or compile information, such as appropriate databases. This is a shared task with biodiversity informatics workers.
G. The system established to guide research and information management should be designed in a fashion that will encourage collaboration and an effective use of the best state, regional, and national resources to address objectives.

2. ***Using both detailed ground-based data and statewide remote–sensed imagery, develop a shared consistent classification system that works at a variety of scales.*** Although individual agencies and organizations throughout the state obtain good-quality imagery on a regular basis, there has not been a statewide effort since the GAP project to obtain and classify imagery on Pennsylvania's vegetation. By strategically pooling resources and sharing information, a high-quality statewide dataset could be developed without a significant increase in funding. There are also a number of regional efforts that perhaps could be expanded or adapted. Because much of the ground-verified vegetation data is collected using nonstandard vegetation classification systems, it is difficult or impossible to consistently apply a single classification statewide. This makes the task of assembling an adequate set of ground-verified data points more daunting. There is also very little sharing of vegetation information among organizations and agencies. The Department of Conservation and Natural Resources (DCNR) and Pennsylvania Natural Heritage Program (PNHP) collectively have ground-based vegetation information for over 2.3 million acres in Pennsylvania on state, federal, and private land. This may provide a logical place to start.

Recommendations:

A. Develop a system to gather and, where appropriate, share imagery gathered by agencies and organizations across Pennsylvania.
B. Encourage collaboration and joint planning among agencies and organizations in the acquisition and classification of imagery.
C. Make better use of Pennsylvania Spatial Data Access (PASDA) and other web-based GIS resources for information sharing.
D. Cultivate relationships with regional academic institutions and federal agencies doing work in this area and look for ways to collaborate.
E. Adopt a standard vegetation classification for Pennsylvania (e.g. the Federal Geographic Data Committee's National Vegetation Classification system or PNHP's system).
F. Encourage all state agencies and organizations involved in vegetation classification and mapping to either use this system or provide a cross-walk between their system and the system adopted by the state.
G. Create a mechanism for sharing ground-verified vegetation data.
H. Develop a classification system that treats aquatic ecosystems.

3. ***Taxa and genetic resources.*** A fundamental challenge for any action or investigation pertaining to biodiversity is to be able to consistently and accurately identify the taxa (groups of related organisms) that we are attempting to study, manage, or protect. Because organisms and their attributes change over time by evolutionary processes operating primarily at the level of populations, taxa delimited and classified by evolutionary (phylogenetic) relatedness are most useful for precise communication and for interpreting their population biology and ecology. Everyone recognizes the critical importance of accurately recognizing taxa at the species level because species are the most basic units of genetic and reproductive continuity over time. *Although many species of large or conspicuous organisms in Pennsylvania (vascular plants, vertebrates) are relatively well known, many species of obscure organisms (most invertebrates and fungi) are either not well-delimited, not authoritatively documented in Pennsylvania, or not known at all* (species that are new to science).

   Species are also the taxonomic elements of biodiversity that bear scientific names, and it is by use of those names that we are all able to talk and write in a consistent manner about organisms. Unfortunately, use of the correct scientific name for many species in Pennsylvania is not consistent or confusing, and may lead to miscommunication, incorrect actions, or unnecessary effort and expense. Knowing which name to apply to a species is not something that is easy to determine, and it is important to follow international rules governing the use of those names. For some groups such as birds or mammals, the names are few and widely standardized, and therefore easy to determine. *For many Pennsylvania species, however, finding the correct name to apply is often as difficult as identifying the species to begin with.* Because it is difficult to manage and protect elements of biodiversity that we don't know exist in Pennsylvania or that are difficult to identify, delimit, or name, there is an urgent need to broaden awareness of poorly known species and to prioritize systematic study of those thought to be of special concern for management or conservation.

   Modern systems of biological classification gather species into a hierarchy of related higher taxa (genera, tribes, subfamilies, families, and so on). Because these systems reflect relatedness, they become optimal tools for predicting features of the constituent species that may be unknown or very difficult to observe. Research on phylogenetic relationships is a continuing effort worldwide for all groups of organisms, and this means that classifications are steadily being improved and changing. *A major challenge for making predictions or inferences about species based on classifications is to know which of several alternative classifications might be best*, a choice that can be easily made only by people who are experts in that groups of organisms.

   Species are composed of one to many populations of individuals, and these may be geographically distributed in a variety of ways, from isolated (often restricted to special habitats) to continuous and widespread. Discontinuities in space (and also in time) result in genetic differentiation of populations. Perhaps the most overlooked component of biodiversity is the genetic variation that exists between and within populations of the same species. Spatial and temporal patterns of genetic variation relate directly to the delimitation of species. *Lack of awareness and misunderstanding of such variation and its patterning can complicate recognition of closely related species and prevent assessment of population distinctness that is critical for prioritizing management efforts among populations*. This is especially important for determining the distinctness of populations in Pennsylvania that are disjunct or peripheral to the main species range elsewhere. Similarly, the distinctness of discontinuous Pennsylvania populations of a species can influence reintroductions or priorities for protecting threatened species populations. Ultimately, knowledge of genetic variation within populations allows the geographic origin of individuals to be determined, and this may be critical for both forensic and management purposes.

   Loss or reduction of genetic variation within populations threatens their continued evolutionary success over time (and that of the species they represent). The presence of sufficient genetic variation ultimately determines whether populations can retain their potential for evolutionary change in the absence of intensive management. The maintenance of genetic variation within populations is frequently overlooked as a longer-term objective for population viability. At a larger scale, maintaining species viability requires decreasing the risk that the species will go extinct because its populations are not self-sustaining or fail to interact throughout the species range. Species viability definitely has an abundance (density) component related to short-term ecological factors, but *ultimately the maintenance of sufficient genetic variation to ensure an array of life history strategies essential to long-term persistence and adaptability will determine self-sustainability, therefore species viability*.

Finally, at whatever level from species to populations, taxa validated by systematic research and unique or restricted to Pennsylvania (endemic species, subspecies, or populations; unique variation in Pennsylvania) are first and foremost the responsibility of Pennsylvanians and have high priority for research and validation by Pennsylvania agencies and NGO's.

<u>Recommendations</u>:

A. Sufficient and authoritative information on species delimitation and taxonomic classifications cannot be gathered by one or a few specialists, curators, or database administrators. Rather this information should be acquired from many specialists both inside and outside of Pennsylvania, so that the most current and authoritative information is available. This is not a small or temporary effort for non-vertebrate organisms, and coordination and maintenance is more than can be expected from the usual sources (PABS technical committees, PBP task forces) without funding and staffing. The coordination effort merits state funding and could either be out-sourced to non-government organizations or perhaps handled within a state agency, such as the Office of Conservation Science at DCNR. In either case, the expertise required is partially available through PABS and PBP, but much of it will be scattered elsewhere both inside and outside of Pennsylvania.

B. Use taxonomically-defined technical committees at PABS to review systematic status of species and to assess the relative merit of classifications where the latter are controversial. The active PABS committees are already doing this, but the effort must be expanded to include a far greater number of taxa.

C. Initiate and maintain a statewide on-line resource that is actively expanded, edited, and overseen by multiple systematic specialists (1) to rigorously document the presence of species in Pennsylvania and (2) to provide valid nomenclature and classificatory context in a regularly updated manner. This effort should be coordinated, where possible, through PABS technical committees and PBP task forces and/or through the coordinating office under Recommendation A above. This web-based resource would provide a means for recognizing taxa and variation unique to Pennsylvania, and would emphasize need for research in Pennsylvania that such endemics require. It would contain the most current information available on the presence, classification, and nomenclature of all Pennsylvania organisms, and through linkage to other databases would constitute an authority file sensitive to Pennsylvania species and issues.

D. Develop a statewide on-line resource, concise and regularly updated, to provide basic information on species, including information such as current conservation status, within-species variation in Pennsylvania, occurrence in adjoining states, mapped distribution in Pennsylvania and elsewhere, habitat associations, and identification aids through images or online keys. Some of these functions might be a natural extension of the web-based database in Recommendation C above, or for distributions and habitat information as an extension of the PNHP database or some other maintained part of a statewide biodiversity informatics database.

E. Use the PABS Steering Committee and PBP Task Forces (Biodiversity Informatics, Science, and Stewardship) as a forum to develop an objective process for biennial preparation of (1) a list of needs for systematic research in Pennsylvania (issues of relationship, taxonomic status, and genetic variation within and among populations), (2) alternative solutions to address those needs, and (3) a prioritized list of targeted and explicit research to address those needs and solutions.

F. Establish a manual of standards, best practices, and methods for assessing genetic variation within and among populations for use in forensics, determination of origin, association of life history stages, and assessment of within and between population variation for purposes of conservation genetics. *Practices should include an objective process for determining situations where assessment of genetic variation is warranted* and provide a continuing mechanism for prioritizing needs without compromising comprehensive coverage of taxa, regions, habitats, and/or issues related to genetic variation.

4. ***Inventory and monitoring are needed for all levels of biodiversity, from genetic to landscapes, in both space and time.*** The status of our awareness and our knowledge relative to the different elements of biodiversity varies from level to level and among the taxonomic groups. For different taxonomic groups in Pennsylvania, that knowledge is nowhere complete and ranges from reasonably good (e.g., inventory of birds and some monitoring of birds is underway) to poor (for many invertebrates and fungi limited inventory and no monitoring). Our knowledge about the importance and function of the different levels of biodiversity (genetic / species / natural community / ecosystem-landscape) is a mixture of clear conceptual understanding (genetic) to the undefined (natural communities). While there has been progress in some areas (species definition), little information is available regarding genetic resources. Additionally, beyond baseline inventory, the need and role for long-term monitoring is not well accepted or orchestrated. Funding and the expertise necessary to support all of these efforts are presently limited and unstable. Common, agreed-upon, and effective management practices for the information involved does not exist and does not provide for a common repository or access. In general, these issues are covered in the proceedings of a conference in 1998 hosted by the Pennsylvania Biological Survey and were further summarized in the *Biodiversity in Pennsylvania-Snapshot 2002* (Pennsylvania Biodiversity Partnership).

Recommendations:

A. Identify biodiversity information gaps, for example, the little-studied groups of organisms that don't fall under the jurisdiction of any state agencies (so-called "orphan" taxa) – invertebrates, fungi, and protists – and prioritize those to be addressed through inventory and assessment studies. Distributional gaps should also be treated, such as the geographical areas of the state that have not been inventoried.

B. Develop a system and timeline of inventory and monitoring based on critical species, indicator species and conditions, habitats, locations, and populations (gene pools). Carry out activities at all levels of diversity and do so statewide with links regionally and globally. Such activities should be undertaken in a short timeframe and not spread out over decades.

C. Create a broad repetitive program of monitoring select biodiversity targets as indicators and design more in-depth inventory for specific needs on a regular basis.

D. Design an inventory and monitoring protocol that is consistent across biodiversity groups and compatible with the information system used for data management. Design a system of experts and data capture that provides coordination and quality control, and ultimately is the source of the basic information needed by diverse stakeholders (e.g., checklists of organisms composing the state's biodiversity).

E. Define core habitats, connecting habitats, fragmentation, and other "sink" or vulnerable habitats as part of a priority perspective for assessing the conditions of ecosystems.

F. Use inventory, monitoring, and assessment methods for various genetic, taxa, and ecosystem types that allows for comparable results across different levels and types of biodiversity, and is useful in determining local, statewide, or range-wide conservation status.

G. Ground-truth predictive methods for inventory and monitoring by developing tests to determine usefulness and effectiveness of research approaches.

H. Develop long-term integrated monitoring strategies across biodiversity levels (genetic, taxa, ecosystem) that involve myriad participants operating in one overall peer-reviewed system.

I. Determine the bioindicator species, genomes, and ecosystem (natural community) parameters and qualities related to monitoring that will produce data as feedback for use in long-term tracking and management.

5. ***Successful conservation of Pennsylvania's biodiversity will require an understanding of the ecological function of natural systems at a variety of levels, from populations and communities to landscapes and subcontinental regions.*** Many approaches to biodiversity research and conservation are applied at the level of one or multiple species. An understanding of a species' life history is generally recognized as critical to management and conservation. Life history studies vary in revealing ecological associations of the target species to other organisms, the natural communities present, or the abiotic environment. Generally, natural communities can be roughly classified into types and some types might be rare or endangered, yet no assessments have been made.

Recommendations:

A. Biodiversity research objectives must include an assessment of present ecological knowledge and prioritization of the research needed to fill information gaps.
B. An understanding should be developed regarding the role and function of each species in ecological processes.
C. A better understanding and working model should be constructed of the ecological processes operating at the level of natural communities, watersheds, and landscapes.
D. Research must define and assess the ecological "health" of ecosystems at whatever level is effective, e.g. natural community, watershed, etc.
E. Threats to biodiversity operating at levels of natural community and higher must be identified and described.
F. Ecosystem health assessment tools should be developed which will provide the metrics, indicator species, and indicator conditions necessary for practitioners to manage biodiversity at the level of natural communities, watersheds, landscapes, etc.
G. The conservation status of ecosystems should be assessed at some level (e.g., natural communities) and provided with status assessment much like species (e.g., endangered, threatened, and so on).

6. ***An effective, consistent, and clearly-understood system is needed for determining conservation status and regulatory listing.*** Suggested categories of concern and conservation status (underlined) range from Immediate Concern (e.g. Endangered and Threatened species), through Cautionary Concern (e.g. Near Threatened species) to Biodiversity Concern (e.g. Responsibility species, Focal species, etc.). A combination of science and expert opinion should be used to assign a species to a category of concern commensurate with its risk of becoming extinct in Pennsylvania, or the need for conservation measures to prevent it's being listed as threatened or endangered.

Determination of conservation status and regulatory listing are two different, yet related, activities. Determination of conservation status, or the assessment and categorization of risk, is a process by which scientific experts (in Pennsylvania, typically PABS technical committees) use established procedure (objective science with necessary expert opinions) to evaluate the conservation status (endangered, threatened, etc.) of a species or population, and recommends that the species or population be given special attention for regulatory listing as provided by law.

Based on such independent and scientifically objective status determinations, regulatory listing is the process by which the state agencies that have jurisdiction for groups of organisms (Pennsylvania Game Commission (PGC), Pennsylvania Fish and Boat Commission (PFBC), and DCNR) use regulatory criteria (definitions in rule or code as influenced by policy, cost-benefits, a current protection profile, and other considerations) and established protocol (specifying, among other items, petition documentation requirements and public participation) to classify and list species legally as endangered or threatened.

When supported by other social and biological considerations, such as species recoverability, status determinations and regulatory listings are important tools for informing conservation needs and prioritizing expenditures of funds and manpower. Species at risk of extinction from the state, those classified as endangered or threatened, may need immediate attention. Failure to accurately determine the conservation status of plant and animal species can result in legal challenges of status determinations and regulatory listing decisions, misdirection of scarce conservation resources, and ultimately the loss of species from Pennsylvania.

Passage of the federal Endangered Species Act (ESA) in 1973 signaled the beginning of the Commonwealth's efforts to determine and act on the conservation status of plant and animal species. Lacking the necessary manpower and scientific expertise, the state turned to volunteer scientists and knowledgeable amateurs to help develop and assist in the process of determining conservation status. With assistance from the state jurisdictional agencies, these individuals organized the Pennsylvania Biological Survey (PABS).

Presently, PFBC (responsible for fish, reptiles, amphibians, and aquatic invertebrates), PGC (responsible for birds and mammals) and DCNR (responsible for vascular plants) use different definitions for endangered and threatened species. No agency has codified or formalized a listing process with quantifiable ranking criteria, documentation requirements, directions for handling uncertainty, a species monitoring requirement and timeline for reassessment, or meaningful citizen participation. No law provides for a third category, near threatened, to provide an early warning system of species in danger. There are no codified requirements to designate survival or critical habitat, and recovery plans are not mandated. There are no provisions for voluntary conservation agreements.

PABS is not linked to state agencies in a consistent manner. Since 1980, PABS taxon-specific technical committees and other experts have worked on the status determination process in collaboration with the state agency with jurisdiction for that group of organisms. Species have been assessed by the technical committees using different criteria and ranking procedures. Arbitrary weighting is sometimes applied to ranking variables without adequate explanation. Expert opinion may be substituted for the lack of data or perceived shortcomings in ranking criteria. No comprehensive manual of procedure exists that (1) standardizes definitions, (2) outlines documentation requirements, (3) provides objective criteria for classification of a broad range of taxa according to their risk of state extinction, and (4) provides direction for interpreting and using criteria and handling uncertainty. Without clear guidance, it is difficult to introduce consistency among members of the technical committee, let alone among the different technical committees. Inconsistency and minimal or no transparency can lead to a lack of confidence in the assigned conservation status for species.

Recommendations:

A. Review state endangered species legislation in other states (Florida as is one potential model) for applicability to Pennsylvania.
B. State natural resource management agencies should all incorporate the same standardized listing protocol into their regulatory listing practices.
C. Formalize the relationship between PABS and the state agencies regarding conservation status designation and species management via memoranda of understanding.
D. Standardize the classification system and process used to determine the conservation status for all taxa (the World Conservation Union (IUCN) categories and criteria and Florida's adaptation of these criteria are potential models).
E. Develop additional guidelines and modifiers that help adapt criteria to Pennsylvania circumstances (e.g. the issue of peripherality).
F. Develop a manual of procedures that is applicable to all taxa and can be used by agencies and organizations currently and potentially involved with conservation status determination or regulatory listing.

7. ***Expand the scientific analysis of the threats to biodiversity protection and management that was done for* Biodiversity in Pennsylvania-Snapshot 2002*.*** Threats analysis involves a standardized approach to identifying, naming, defining, and assessing changes in the health of plant and animal populations. Scientists agree that Pennsylvania's biodiversity is in peril for a variety of reasons, some obvious and some subtle. Although threats can be grouped into two major categories, habitat loss/fragmentation and pollution, there are a plethora of often inter-related causes for each of these categories. Threats to animal populations occur at a variety of landscape scales (local versus widespread), over a variety of time periods (some immediate, some long term), a spectrum of severity (low impact versus high impact), and a mix of direct and indirect effects. Direct and indirect threats often act together in space and time until a population finally succumbs under a layer of interrelated threats. For example, *habitat fragmentation* has

limited gene flow among eastern woodrat colonies, perhaps making their populations more vulnerable and less resistant to the effects of *predation* by great-horned owls and intestinal *parasitism* carried by raccoons. Both great-horned owls and raccoons are considered to be habitat generalists and populations of these species have benefited from *habitat fragmentation*. This type of multi-layered, often circular, threat impact often occurs in species at risk in Pennsylvania, regardless of whether the threats come from non-native species (which may include pathogens, parasites, predators and/or competitors), non-point source pollution, changing forest composition, habitat loss, changing land use patterns, urban sprawl, acid precipitation, or global climate change. Each threat to a population results in a cascade of interrelated impacts that a population must adapt to in order to survive.

There is little doubt that human impacts have been largely responsible for a decline in the biodiversity of the Commonwealth, however there is much that we don't know regarding how our actions affect species and ecosystems in Pennsylvania. Waiting for full information before attempting to reverse damaging patterns is not feasible or ecologically responsible. While progress is being made in correcting some threats, such as point-source pollution, others, such as urban sprawl and invasive species, present increasing problems. In a sense, we have tackled the "easy" problems in Pennsylvania, such as point-source pollution and obvious environmental contamination, such as DDT in raptors. What remains is to address the more difficult problems affecting biodiversity - the largely irreversible and interrelated threats that daily impact the plants and animals of Pennsylvania. Because these threats occur across spatial and temporal scales, it is important that conservationists in Pennsylvania work to develop a standardized approach to threats analysis so that remediation actions can be designed for maximum impact.

Recommendations:

A. Uniformly define, name, and describe threats and other related factors affecting animal and plant populations, habitats, and ecosystems at all levels.
B. Provide a system for measuring the magnitude of threats and provide some assessment of the degree of vulnerability and insight regarding issues of recovery.
C. Collect information that documents changes in populations based on human activities.
D. Assess threats across species, targets, habitats, and projects.
E. Provide scientific insight on the sources and details of threats, including advice on adaptive management and predictive decision-making, locally, regionally, and statewide.
F. Establish consistent methods for the spatial mapping of threats for use in developing strategies and planning.
G. Utilize standard threat authority files (cf. IUCN) and compile regular updates to threats issues.

8. ***Ensure high quality scientific research and analysis.*** Science-based decision-making for resource management and stewardship of biodiversity in Pennsylvania requires careful attention to maintaining the highest possible standards for principles and practices that contribute to scientific objectivity and utility. Science begins with observations that must be precise, quantified, documented, verifiable, and, whenever possible, utilize current technology (molecular approaches, image analysis, remote sensing, digital recording, GIS, and many other recent innovations). Verifiability of observations made on organisms, especially accurate taxonomic identification, is best provided by specimens deposited in permanent institutional collections where they should be professionally prepared, curated, studied, and maintained in perpetuity. The need for specimen or sample-based documentation involves more than just preserved organisms and may extend to preserved DNA, secondary chemicals, or associated materials (nests, dung, eggshells, etc.). Biodiversity data that depends on accurate identification of species must be adequately vouchered and large biological specimen collections are increasingly repositories of information on spatial and temporal occurrence of organisms, in addition to providing information on variation between and within species. In recent years, collection of different lineages at the same place and time has allowed specimen-based documentation in collections to provide information on ecological associations, habitats, and natural community composition. Databases including specimen attributes, identification, and collection data (place, date, collector(s), conditions, etc.) are the primary source for most of what we know about the distribution of species in Pennsylvania over time. *Unfortunately, the vast majority of historical*

specimens in collections are not data captured, especially terrestrial insects and other invertebrates, and this shortfall is a major impediment to the precision and accuracy of specimen-derived data and inferences based on those data. Standards for data sharing, biodiversity informatics issues, accurate taxonomic identification and classification, and many other factors contribute to high quality science and are discussed elsewhere.

Careful observation of organisms is just the beginning. Questions generated by studying initial observations may be addressed by either inductive inferential approaches or by formulating falsifiable hypotheses that can be tested using experimental methods. Appropriate use of descriptive statistics to quantify measurements and their variation is essential to high quality descriptive science, including multivariate tools for describing and quantifying community composition, biogeographical patterns, and the attributes of individuals in species or populations. Similarly, the appropriate use of test statistics and other analytical procedures is indispensable to interpreting quantified observations in an experimental context, or providing confidence estimates for inferences based on inductive methods. *The vast array of possible analytical methods and statistical approaches to different biodiversity datasets is mind-boggling, and that complexity increases the likelihood of inappropriate or unjustified usage, or failure to use powerful and effective tools for fear of violating assumptions*. Both of these outcomes decrease the quality of scientific research and the “analytical impediment” to quality research may be as serious as the “taxonomic impediment” involving misidentification and taxonomic uncertainty.

Quality science depends on more than accurate observations and appropriate analysis. *It requires adequate funding and a high integrity procedure for distributing funding that reflects a combination of factors, including goals, urgency, timeliness, practicality, intellectual merit, and indirect benefits accruing from the research other than those addressing the immediate research question.* The key to successful competitive funding for research requires careful analysis and prioritization of research needs followed by high quality external review and processing of proposals and plans. Proposals for basic research benefit most from anonymous peer review, but review of proposals for applied research or of program plans for future research may benefit most from external review by a panel of experts, anonymous or otherwise depending on the circumstances.

<u>Recommendations</u>:

A. Develop a manual or guidelines for “best science practices” with special emphasis on the challenges of research on biodiversity. Funding sources for biodiversity research should be encouraged to provide these guidelines to clarify what is expected for projects they choose to support.
B. Promote the use of appropriate specimen-based documentation for research, including guidelines for best practices including collection, preservation, curation, use, and financial support for vouchering. Requirements of institutional repositories should be explicitly stated, including the need for adequate facilities, procedures, security, technical and taxonomic expertise, and assured access by all concerned persons in the future. Institutional willingness to accept vouchers, and fees for so doing, should be explicitly developed and available from a centralized source on-line.
C. Provide introductory materials and guidelines for appropriate use of new technology for investigating critical biodiversity issues (molecular studies, image analysis, remote sensing, GIS, and many others). For example, a current overview of genetic markers for cost-effective determination of genetic variation in different groups of organisms would be very useful, associated with references or guidelines for best practices in the collection, extraction, amplification, and sequencing of those markers. The same is true for GIS standards, georeferencing, and other information providing spatial context for Pennsylvania issues.
D. Funding sources (agencies, foundations, and others) should be encouraged to establish explicit protocols to ensure high-quality external review of research proposals and program plans. Procedures should include anonymous peer review, panel formation for program review, and other advisory actions. Reporting procedures should not be overlooked, with special emphasis on accountability and quality products and not on volume of paperwork and redundant documentation as is increasingly the case.

E. As part of a general process for identifying scientific research needs and for prioritizing funding (see earlier issues), a special attempt must be made to explicitly require best science practices, especially for applied research with immediate consequences for habitats and species. Examples of required practices might be choice of technologies, survey or monitoring methods, specimen-based documentation, impact assessment methods, data-sharing standards, and use of appropriate statistical methods for data description, exploration, and testing.

F. Foster collaborative research to maximize quality by bringing together expertise in various disciplines to address common problems. All too often investigators are very well equipped to do one part of a research effort (e.g., data collection) but might be much less competent to conduct others (such as data analysis). The need to integrate disciplines through collaboration or partnering on large projects is critical because even in a state as large as Pennsylvania, it will be difficult to find a single organization that has the taxonomic, ecological, conservation, analytical, and technological skills necessary to confront modern complex challenges to biodiversity.

G. High-quality science doesn't just happen; it needs to be carefully planned and constantly defended. Thus it is extremely important that the input of all possible stakeholders be sought and aggressively considered in the process of planning new research initiatives, and that inappropriate or unacceptable scientific practices not be tolerated to save money or to further agendas other than an objective understanding of processes impacting biodiversity.

9. ***Biodiversity information must be as complete and reliable as possible by following appropriate scientific practices*.** The purpose of any science-based endeavor is to produce information that can be trusted by others. Much of the information that is available on the state's biodiversity is scientifically sound, created by experts in taxonomy, ecology, and related disciplines following the best science available. Biodiversity information is all about the known species of animals, plants, fungi, and microorganisms in a defined geographic unit like Pennsylvania. Accurate identification of species opens the door to the rich source of biological and genetic information about that species. Specimen-based information provides the locality, distribution, seasonality, host association, and associated ecological condition.

Biodiversity information is initially based on specimens, which is synthesized at species level. Taxonomic and ecological information about all of the species at a defined geographic unit provides biodiversity information of that unit. Information about species of any specific group of organisms is documented generally for taxonomic purpose at a broad geographic context and thus taxon-specific information is widely scattered throughout the world or by specific region. Biodiversity information for Pennsylvania is incomplete as a large part of the state's biodiversity is still unknown. Information associated with those organisms, particularly those that are important components of ecosystem function, is lacking.

Biodiversity data may be unreliable for a number of reasons, including:

1) Incomplete exploration and documentation of Pennsylvania's biodiversity. Many groups of organisms beyond vertebrates and vascular plants are not well explored and documented. Invertebrates, lower plants, and fungi as well as other microorganisms are little known and described.
2) Biodiversity databases currently available for public use contain inaccurate and often erroneous information. Biodiversity databases built on diverse metadata from different sources often contain taxonomic mistakes, misidentifications, and inaccurate data due to incompetent translations.
3) Specimen-based data often contain generic locality information without much information on the habitat and the collector. It is critically important to have all necessary information on the date, locality (GPS referenced), habitat/association, and collector's name associated with specimens.
4) Scientific names may be incorrect. Taxonomic identifications may be incorrect because the collector lacked sufficient expertise to accurately identify the organism in question. In ecological studies, species identifications may be made based on field observable characters without voucher specimens or when the reliable diagnostic characters are unavailable.

Binomials and names of higher-level taxa occasionally change over time, and reported names may reflect old taxonomies.

5) Biodiversity information is based on metadata in the literature that was collected without vouchers. Biodiversity information must originate from specimens or other voucher materials. Insufficient time or funds may prevent collection of voucher specimens that would otherwise be critical for verification purposes. Ecological parameters such as frequency, dominance, or relative abundance may be based on subjective estimates. Inaccuracies are compounded whenever a second party uncritically receives unverified data, and subsequently passes it along to others in a way that suggests the data are accurate and reliable. Such inaccuracies are especially problematic if individuals charged with making decisions or setting policy unwittingly base their conclusions on faulty data.

<u>Recommendations:</u>

A. Initiate a statewide effort to rapidly explore and document biodiversity information on invertebrates, lower plants, fungi and microorganisms in the shortest time possible.
B. Information scientists and biodiversity database builders should be trained for, and equipped with, sufficient knowledge about the group of organisms involved in the database.
C. Biodiversity inventory and survey must be prepared for labels with relevant information so that each specimen or sample bears necessary information.
D. Specimen-based biodiversity information should ultimately be digitized into searchable databases.
E. Curators of collections and holders of biodiversity data should keep abreast of systematic (taxonomic and nomenclatural) changes, and update specimen identifications/data and other curation issues as appropriate.
F. Individuals collecting ecological data should strive to collect voucher specimens, and seek verification of tentative identifications whenever practical.
G. Individuals and organizations seeking to involve students and amateur naturalists in biodiversity studies should provide sufficient training for those individuals
H. Parties reporting biodiversity data collected by others should attempt to verify the accuracy of the data, and avoid implying levels of precision that do not exist.
I. Care should be taken to ensure that predictions and policies involving biodiversity-related matters are based on accurate and complete information.
J. Reasonable attempts should be made to communicate levels of uncertainty to non-scientists who must use biodiversity data.
K. The following steps should be adopted to enhance and verify the taxonomic and ecological expertise of individuals collecting and disseminating biodiversity data:
    - Strengthen the curriculum in biodiversity studies of colleges and graduate schools so that students are prepared for biodiversity-related careers in systematics, taxonomy, and ecology.
    - Organize and offer technical workshops for collecting, preparation, sorting, and identification of selected group of organisms for parataxonomists and conservation workers.
    - Develop a master naturalist or parataxonomist program to train interested people for biodiversity inventory, assessment, and monitoring.
    - Actively scrutinize the data quality and accuracy of taxonomic names for all ranges of biodiversity information.

10. ***Collections as resources for biodiversity science.*** Biological specimen collections, whether housed in universities, private organizations, or more typically in large museums, are fundamental resources for research on biodiversity. Collections document taxa and their occurrence in space and time. Collections in aggregate document variation and are primary sources for abundant morphological and molecular evidence for species status, condition, and historical change in characteristics and distribution. Collections contain many species and when samples were taken concurrently and syntopically, collections and the databases developed from them are evidence of ecological interactions and co-occurrence of species. Collections may potentially document virtually all biological phenomena that for most species and systems are still unstudied. The larger modern collections have DNA repositories, life history data, documentation of immature stages, and associated information resources (libraries, archives, and databases) that make them truly magnum libraries of biodiversity information. Most important, large collections are associ-

ated with unique expertise in the form of specialists and scientists who work with specimens as preparators, curators, research associates, and conservation collaborators.

Despite these many strengths, collections worldwide suffer from neglect in terms of levels of curation, condition of facilities, and long-term care of information and specimen resources. In almost every case, this is due to the lack of primary infrastructure to maintain scientific activity in these important resources. In Pennsylvania, the vast majority of specimens and data are in the care of private institutions (museums or universities), although increasingly the most frequent use of those collections is not for systematic research, but for investigations and baseline data addressing biodiversity issues and benefiting all Pennsylvanians. As institutional resources are insufficient, or when those institutions will no longer maintain care of collections, they all too easily become orphans and are then lost to even larger institutions remote from Pennsylvania and its problems. In summary, biological specimen collections are more than just a bunch of dead organisms; their specimens, together with the associated information and unique staff expertise, comprise the primary information resource on Pennsylvania biodiversity. As such, their maintenance and goal-directed development are essential to the successful stewardship of Pennsylvania's biodiversity.

Recommendations:

A. In general and whenever possible, specimen-based documentation for Pennsylvania biodiversity should be deposited in institutional collections in Pennsylvania. Specimens deposited elsewhere may have an uncertain future in terms of accessibility or use by Pennsylvanians. At the very least, specimens acquired and deposited with Pennsylvania funding should seek to keep that money in-state.

B. Access to institutional collections and their use over time costs money. Responsible research planning and funding sources should support costs for research use of collections in terms of vouchering fees, use of facilities, and other real expenses.

C. A current list of Pennsylvania collections and related biodiversity resources should be compiled and maintained on-line for easy reference by everyone, and should contain explicit and appropriate fees for vouchering, use of specimens, data, and expertise. This list should explicitly include information on the condition and near-term fate of such collection, i.e., whether they are likely to become orphans and might potentially be lost from the state. All organizations concerned with Pennsylvania biodiversity should be active in retaining collection-based resources within the state. Just as monitoring should be done on all species and habitats to forecast undesirable changes in distribution or abundance, so should collections be regularly monitored to anticipate their utility, exigencies, and financial needs before they become orphans or are lost from the Commonwealth.

D. There is no alternative for obtaining collection-based expertise but to pay for it. Everyone expects to pay their physician for advice and attention that influences their health and ultimately their life; but most people expect that collection-based expertise will be offered for little or nothing, despite the fact that such information also influences their health and ultimately their life. If we didn't pay medical doctors, then we would have a shortage of physicians in short order; but we don't compensate collection-based expertise, so it should surprise nobody that few young people are choosing collection-based research on biodiversity as a career!