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Declining amphibian populations – a global phenomenon ?* Findings and recommendations**

Amphibian populations are in decline in many parts of the world – in some cases and in some areas to the point of extinction. Much of the decline is attributable to obvious habitat destruction or modification. However, the decline of populations even in protected areas indicates that more subtle effects are involved. Where data are available, anthropogenic factors, such as acid precipitation, pesticide release, agricultural practices, land-use changes, and introductions of exotic species have been important in bringing about these population changes. Although other organisms certainly are affected by the same factors, amphibians are particularly sensitive bioindicators because of their permeable skins, biphasic life history, pattern of embryonic development, aspects of their population biology, and the complexity of their interactions in communities and ecosystems. Several study programs should be initiated, including carefully planned and integrated long-term studies of populations and key communities, analyses of bibliographic and museum data, and resurveys of previously studied populations. In the immediate future, the findings of the workshop should be disseminated widely and the desirability of a conference to deal with issues such as the use of amphibians in biomonitoring, analyses of factors involved in declines, and future directions in integrated approaches to the world-wide crisis in loss of biodiversity should be explored. Careful evaluation should be given to proposals for new public (such as a National Institute for the Environment) or private organizations that would give attention to taxon-centered as well as more global monitoring and study programs in the area of biodiversity.

* This is the title of a workshop, sponsored by the Board on Biology of the National Research Council of the U.S.A., which was held at the Arnold and Mabel Beckman Center (Irvine, California, U.S.A.) on 19-20 February 1990.

** The conclusions, opinions, and recommendations contained in this article are those of the workshop participants and do not necessarily reflect the views of the National Research Council or the National Academy of Sciences of the U.S.A.

INTRODUCTION

The workshop was organized because of an increasing awareness among biologists around the world that many populations and species of amphibians (frogs, order Anura; salamanders, order Caudata; caecilians, order Gymnophiona) have experienced declines and extinctions, even in protected natural areas. Internal funding from the National Research Council was obtained in November 1989 by the Board on Biology, and a workshop was organized by David B. WAKE and Harold MOROWITZ, members of the Board on Biology, and by the staff of the Board. The workshop included presenters of information and discussants representing an array of disciplines (see Appendix).

FINDINGS

The workshop addressed the proposition that " worldwide, amphibian populations are in decline. " To a degree, this is true, but the statement is not universally applicable to all taxa in all locations, nor is there evidence of a single planetary causal factor. Drastic habitat modification by humans is a major cause of decline in amphibian populations, but other human activities are also important. However, the decline and extinction of some amphibian populations in seemingly pristine areas cannot be directly tied to human activities.

I. DATA-BASED CONCLUSIONS

A. Many montane species of western North America are in decline, even in protected preserves and undisturbed areas where habitat alteration is not apparent. Montane areas in other regions of the New World also have declining amphibian populations (e.g., Middle America, Atlantic Coastal forest of Brazil). Frogs from some low elevation sites in different parts of the world are declining or have disappeared. Many declines first became evident in the period between 1978 and 1982, although some occurred earlier.

B. Populations of several species in different areas (northwestern United States, southern and eastern Canada, and eastern Australia) have experienced severe declines at many sites, but data are fragmentary.

C. Populations in some regions, such as the southeastern United States, show little evidence of general declines, apart from that clearly attributable to habitat destruction.

D. In some habitats, declining and stable species co-occur; for example, populations of the Wood Frog, *Rana sylvatica*, appear to be stable in the Rocky Mountains, but populations of the Leopard Frog, *Rana pipiens*, in the same area are declining. Accordingly, there is species-specificity in the response to factors causing declines.

(1) Reasons for species specificity may be attributable in part to differences in physiological (e.g., tolerance to low pH), behavioral, ecological (e.g., short developmental period), or other properties.

(2) Declining and stable species sometimes are related phylogenetically, such as being members of the same genus.

(3) Certain species are experiencing difficulty over broad regions, yet appear to be doing well in other locations.

E. No evidence was presented for declines of populations living at low elevations in equatorial regions (between 10 degrees N and S latitude), except in areas of severe habitat destruction (e.g., timber harvest, agricultural practices such as grazing and irrigation, desertification). Information from long-term studies is available only for Borneo and Panama.

F. Where declines and extinctions are documented, we generally do not know which stages of the life cycle are most affected. No specific pathologic conditions thus far have been identified to suggest a unifying theme for the declines; however, infectious disease agents or toxins have not been adequately studied and cannot be ruled out as possible causative factors.

G. About 5,000 species of amphibians have been described throughout the world, with most species being found in the tropics. In general, little is known about the status of most species. However, evidence is available from a wide variety of sources to support the main finding of decline in many species and in many areas.

II. ANTHROPOGENIC FACTORS

A. Anthropogenic factors have been and continue to be important in population declines and local extinctions in most areas. These include acid precipitation, heavy metal discharge and mobilization, pesticide release, deforestation, hydrological modification and changes in patterns of land-use (urbanization, changed agricultural practices, extention of agriculture to wetlands, release of irrigation waters, and the like).

B. Wildlife management practices, such as the stocking of previously pristine lakes and streams with fish that are predators of amphibians, have contributed substantially to declines in some areas.

C. In two cases (western North America and eastern Australia), the introduction and subsequent proliferation of non-native anurans (the Bullfrog, *Rana catesbeiana*, for food and sport, and the Cane Toad, *Bufo marinus*, as a biological control of insect pest) have contributed to the decline of native amphibians. Populations of the Bullfrog (even introduced populations) are now in decline in many areas, but the Cane Toad is thriving and has become a pest itself in Australia.

III. SPECIAL PROPERTIES OF AMPHIBIANS

A. Amphibians are sensitive *bioindicators* of environmental change because of their physiological and behavioral characteristics, life-historical and morphogenetic patterns, and features of their population biology.

B. The skin of amphibians is highly permeable to gases and liquids in the environment; as a result amphibians are intimately exposed to materials in the water, air, and terrestrial substrate.

C. High fecundity, complex life cycles (with larval and adult stages usually occupying different habitats), and fragmented but interconnected population structures may render amphibians sensitive to diverse environmental factors relative to other vertebrates. Biotic and abiotic factors impinge on amphibians in many ways. Development in many frogs takes place in water, and tadpole consume mostly plant materials. Special conditions must be met in order for metamorphosis to succeed. Metamorphosed animals typically are terrestrial or semi-terrestrial, and invertebrates (especially insects) are major prey. Accordingly, those factors that affect riparian and aquatic vegetation and insects can also affect larval and adult amphibians. In some regions, adults may also undergo seasonal aestivation and hibernation, and they are thus subject to additional environmental factors. Populations often occur as subpopulations in neighboring ponds, and individuals may breed in one pond during one year, but another the next. These features combine to expose amphibians to a wide variety of influences during their lives.

While the life history outlined above is well known and is typical of many species, amphibians are a very diverse group. Most caecilians, about one-half of the species of salamanders, and hundreds of species of frogs are strictly terrestrial throughout their lives, and other species of all three groups are strictly aquatic. Some salamanders are permanent larvae, and many species in all groups have direct development with no larval stage. A few frogs and salamanders are live-bearing, and most caecilians are viviparous. This diversity in development, life history and ecology adds to the suitability of the group as a whole for studies of biodiversity.

D. The additive or synergistic effects among a number of global, regional and local factors may result in substantial declines.

E. Environmental acidity appears to play a major role in declines of amphibian populations. Some species have evolved in low pH environments, but many others have not experienced acidity in their evolutionary history and so are especially sensitive to lowering of pH, and the toxicity of metals such as aluminum that are biologically active at low pH, during specific phases of embryogenesis.

RECOMMENDATIONS

The stresses on most declining amphibians and their habitats are of human origin. Anthropogenic effects on the scale of global to local environment are complex, and their remediations will require an understanding of ecosystem functions. The pursuit of such studies depends on the knowledge, skills and cooperation of scientists from many disciplines. Such research will inevitably be labor-intensive and will require use of modern technology. This will demand a broad range of new human and financial resources.

Recommendations are grouped in four general categories.

I. LONG-TERM STUDIES OF AMPHIBIAN POPULATIONS ARE NEEDED, WITH SPECIAL EMPHASIS ON THE FOLLOWING

A. *Studies focusing on the significance of amphibians in ecosystems*

The significance of salamanders in ecosystems needs clarification. In some ecosystems (e.g., at Hubbard Brook, N.H.), amphibians have been shown to have the greatest animal biomass, but little information is available for other areas. New studies should focus on the role of both larval and adult amphibians in the food web, and the unique potential of amphibians as indicators of the health of the ecosystem. Such studies should be established at selected strategic sites around the world, or incorporated into ongoing programs. Ideally, these studies will be conducted within the context of long-term population studies.

Amphibians have properties which make them especially useful *bioindicators* in ecosystem studies. Specific reasons are listed below.

(1) Most species have complex life cycles, with both aquatic and terrestrial phases.

(2) Amphibians have permeable skins, which result in large and rapid material exchange with the environment including water, air, and terrestrial substrate. Because of their susceptibility to different factors, they are especially sensitive early-warning indicators of certain types of environmental changes.

(3) Amphibians are small to intermediate-sized vertebrates; their fate has direct relevance to that of other vertebrates, including humans. They are high in the food web, and their decline is a signal of deeper ecosystem deterioration, including factors reducing populations of invertebrates and plants.

(4) Amphibian biomass constitutes an appreciable fraction of many terrestrial ecosystems; they have been shown to be the dominant vertebrate group in some ecosystems.

(5) The demise of amphibians has inevitable, major effects on other components of ecosystems.

B. *Studies focusing on the population biology of amphibians*

We recommend that long-term population studies be conducted to identify abiotic and biotic factors that account for temporal patterns of diversity and abundance of amphibians under unaltered conditions, so that baseline data can be generated and amphibians can serve as indicators of environmental change in ecosystems. Depending on local diversity, these studies will deal with entire assemblages or with focal species. Such studies should be distributed geographically to take into account patterns of diversity based on differences in latitude, elevation, habitat, and taxonomy. Of special importance is the interaction between habitat fragmentation and population structure. Long-term monitoring in these studies should focus on:

(1) Population dynamics, including age-specific birth and death rates, mechanisms of population regulation, and demographic responses to pollutants.

Of special importance is an understanding of the spatial and temporal patterns of

fluctuation in population size through time, which relates directly to long-term persistence and vulnerability of isolated populations and populations inside nature preserves that are surrounded by degraded habitats.

(2) The relationship of physical and chemical variables in the environnement to the changes in the amphibian populations being studied.

Care must be taken to standardize the collection and analysis of physical variables and to design population studies to allow for the unique characteristics of each system. Experiments should be designed to test hypotheses generated by long-term monitoring studies. Success of this phase requires formal and regular communication among research groups as well as dependable long-term support. Attempts should be made to integrate population and ecosystem studies, where feasible. Renewable funding intervals should extend over periods of five years or longer, because life spans of amphibians are relatively long and the dynamics of population cycles (related to variable weather and other factors) must be understood over a relatively long time frame to allow valid interpretations of the data.

C. *Studies focusing on the relationship of chemical and physical factors to individual organisms and populations*

Efforts must be made to identify possible chemical and physical causes of amphibian decline on a broad scale. Because different causes probably account for the decline of different populations, we propose the careful selection of specific populations with documented declines for special study. The target of such studies should be species with complex life cycles. Embryonic and larval development should be compared in water where the eggs were found, and in water of known high quality. The water samples should be analyzed for their chemical constituents, including major ion concentrations, pesticides, herbicides, and other components of the environment. Selected individuals should be followed from early development through sexual maturity, in order to detect possible stage-specific effects. Meteorological conditions such as temperature, humidity, rainfall, ultraviolet intensity and atmospheric ozone at the collection sites should be monitored continuously.

Moribund and dead specimens should be collected for pathological studies, to include histologic, microbiologic, and toxicologic analyses. Healthy control animals should be submitted for study at the same time.

II. Compilation of information, and use of historical data

Many past studies contain critical information about amphibians, including historical occurrence, population density, survivorship of various life history stages, and other variables. We recommend that as far as possible future studies be designed to take advantage of these prior investigations, which can serve as baselines. Such information will

be especially valuable in regions where amphibian populations are known or suspected to be in decline.

A. *Much useful information can be derived from museum records and the literature*

There is a rich data base in the collections of the natural history museums of the world, and in publications. There are also some other sources of information, such as records of field stations and long-term but unpublished studies by individual investigators. These sources should be utilized thoroughly. We recommend that full advantage be taken of bibliographic and museum data, so that we might be better able to detect changes in amphibian populations that occur over long time intervals (decades or even centuries). This method would take advantage of the large, existing data sources and would be particularly useful in detecting both changes in distribution and relative abundance, given an understanding of the limitations and advantages of such data. Most important, identified changes then could be correlated with a variety of morphological, ecological, climatic, geographic and phylogenetic parameters that can assist in identifying problem groups, areas, or conditions, and relevant factors responsible for such declines and extinctions.

B. *Ecological and population data from previous studies should be evaluated to determine if they can be used as a base for comparative studies*

This is an approach that will develop a series of samples from two or more periods of time. If such studies are amplified sufficiently they will produce enormous quantities of information at relatively low cost. The following sampling approaches should be undertaken:

(1) Resurvey of previously studied populations.

In many instances it may be possible to resurvey the exact sites at which prior studies were conducted, and it may be possible to convince the original investigators to return to these sites so as to control as much as possible for methods of sampling.

(2) Surveys of historical localities derived from museum and literature records, and from unpublished field notes of investigators.

Areas to be studied would be selected to represent diverse taxa and geography, and would include areas showing population declines. Protocols for sampling must be developed for each taxon and region in order to assess accurately the presence or absence of a population, and in certain cases, aspects of population structure. This is especially important because many amphibians are secretive organisms, difficult to find except when they are breeding.

III. INVESTIGATE THE FEASIBILITY AND DESIRABILITY OF ESTABLISHMENT OF A NEW ORGANIZATION, WHICH WOULD BE FOCUSED ON ISSUES OF MAINTENANCE OF BIODIVERSITY

Existing environmental organizations and governmental organizations often fail to respond appropriately and promptly to the kinds of crises and challenges described here. Institutional structural changes or innovations may be needed. We recommend that the Board on Biology examine this problem, and initiate one or more formal studies with the following parts:

A. An analysis of the benefits and disadvantages of different institutional models, both governmental and non-governmental, for the support and funding of research of the following general kinds:

(1) The discovery, testing, and utilization of taxa and interacting subsets of communities and ecosystems that will permit and facilitate early detection of environmental deterioration.

(2) The development of guidelines aimed at the management of natural systems and for remedial actions in such systems.

B. An analysis of organizational mechanisms that would maximize the flexibility and efficiency of institutions; among these might be peer review processes, rotation of advisory board membership, and establishment of program priorities and directions.

A proposal has been made by another group of concerned individuals for the establishment of a National Institute for the Environment (N.I.E.). It is possible that one role of such an organization would be the function we have outlined. Accordingly, an alternative recommendation is that the Board on Biology conduct a study based on the proposal for N.I.E.

IV. DESIGN AND DEVELOPMENT OF EDUCATIONAL PROGRAMS THAT WOULD KEEP THE PUBLIC INFORMED CONCERNING THE STATUS OF POPULATIONS AND SPECIES OF CRITICAL TAXA (SUCH AS AMPHIBIANS) AROUND THE WORLD, AND OF THEIR SIGNIFICANCE FOR ISSUES IN BIODIVERSITY

V. IN ADDITION TO THE MAIN LONG-TERM RECOMMENDATIONS, SEVERAL IMMEDIATE ACTIONS SHOULD BE TAKEN

A. Distribute a summary of the main results of this workshop in appropriate outlets.

B. Distribute the main findings and recommendations of this workshop to appropriate organizations and individuals, including workshop participant.

C. Convene a more specialized workshop, symposium or meeting with the tentative title: *Declining amphibian populations: biomonitoring, analyses of factors and future*

directions. Such a meeting would: (1) compile and analyze the current data on declining populations, using present trends to predict future changes in species richness and diversity; (2) identify critical areas in need of intensive study; (3) develop a protocol for long-term monitoring of selected amphibian populations, species and communities, with consideration of the relationship of amphibians to the dynamics of ecosystems, the patterns of amphibian population dynamics, and the identification of critical physical and chemical parameters for amphibian life history; and (4) study and recommend sources of funding for long-term investigations. The workshop should include both amphibian biologists and experts in the subject areas relevant to the problems considered (e.g., ecotoxicology, climatology, water quality, physiology, development, population biology, wildlife and fisheries, systematics).

D. Establish a committee to organize a large-scale international symposium and seek funding for it [perhaps under the aegis of the International Society for the Study and Conservation of Amphibians (ISSCA)].

E. Improve communication among members of the biological community concerned with amphibian diversity, population biology and ecology. The International Society for the Study and Conservation of Amphibians is an existing organization that might well serve this function.

APPENDIX

WORKSHOP PARTICIPANTS

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