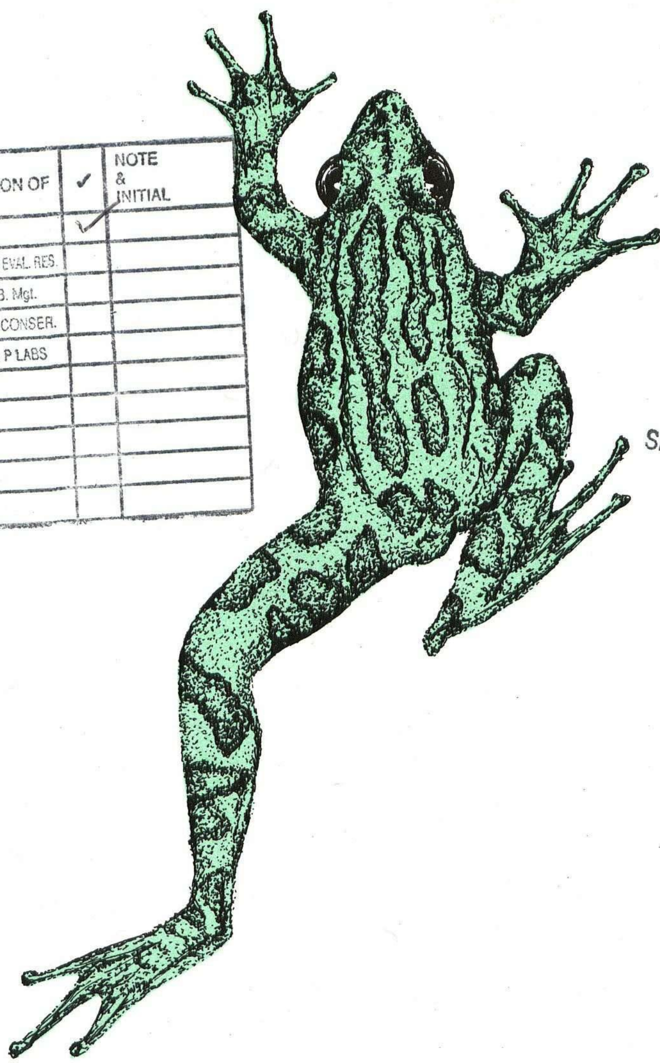
Christine A. Bishop
Karen E. Pettit
(editors)

Declines in Canadian amphibian populations: designing a national monitoring strategy

Occasional Paper
Number 76
Canadian Wildlife Service



Environment Canada | Environnement Canada
Canadian Wildlife Service | Service canadien de la faune

Christine A. Bishop[1]
Karen E. Pettit[2]
(editors)

Declines in Canadian amphibian populations: designing a national monitoring strategy

Occasional Paper
Number 76
Canadian Wildlife Service

Proceedings of a workshop sponsored by the Canadian Wildlife Service (Ontario Region) and the Metropolitan Toronto Zoo, held in Burlington, Ontario, 5–6 October 1991

Published for the workshop sponsors by the Canadian Wildlife Service

[1]CWS, Canada Centre for Inland Waters, Burlington, Ontario L7R 4A6

[2]Pettit-Kay Biological Consultants, 193 Hatt Street, Dundas, Ontario L9H 2G7

Cover drawing: Stylized frog by Joanne Wotherspoon

Published by Authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue No. CW69-1/76E
ISBN 0-662-20038-1
ISSN 0576-6370

The Canadian Wildlife Service
The Canadian Wildlife Service of Environment Canada handles wildlife matters that are the responsibility of the Canadian government. These include protection and management of migratory birds as well as nationally significant wildlife habitat. Other responsibilities are endangered species, control of international trade in endangered species, and research on wildlife issues of national importance. The service cooperates with the provinces, territories, Canadian Parks Service, and other federal agencies in wildlife research and management.

For more information about the Canadian Wildlife Service or its other publications, please write to:

Publications
Canadian Wildlife Service
Environment Canada
Ottawa, Ontario
K1A 0H3
(819) 997-1095

Canadian Cataloguing in Publication Data

Main entry under title:

Declines in Canadian amphibian populations: designing a national monitoring strategy

(Occasional paper, ISSN 0576-6370; no. 76)
Includes abstracts in French.
"Proceedings of a workshop sponsored by the Canadian Wildlife Service (Ontario Region) and the Metropolitan Toronto Zoo, held in Burlington, Ontario, 5–6 October 1991."
Includes bibliographical references. ISBN 0-662-20038-1
DSS cat. no. CW69-1/76E

1. Amphibians — Ecology — Canada. 2. Endangered species — Canada. 3. Nature conservation — Canada. 4. Wildlife conservation — Canada. I. Bishop, Christine Annette, 1960– . II. Pettit, Karen E. III. Canadian Wildlife Service. IV. Series: Occasional paper (Canadian Wildlife Service); no. 76.

QL654.D52 1992 597.6′0971 C92-099780-5

Contributors

Michael Berrill
Department of Biology, Trent University, Peterborough, Ontario K9J 7B8

Susan Bertram
Watershed Ecosystems Graduate Program, Trent University, Peterborough, Ontario K9J 7B8

Christine A. Bishop
Canadian Wildlife Service (Ontario Region), Canada Centre for Inland Waters, P.O. Box 5050, 867 Lakeshore Road, Burlington, Ontario L7R 4A6

James P. Bogart
Department of Zoology, University of Guelph, Guelph, Ontario N1G 2W1

Joël Bonin
Société d'histoire naturelle de la vallée du St-Laurent, 21,111, Bord-du-lac, Sainte-Anne-de-Bellevue, Québec H9X 1C0

Deneen Brigham
5 – 228 Ontario Street, Thunder Bay, Ontario P7B 3G8

Ronald J. Brooks
Department of Zoology, University of Guelph, Guelph, Ontario N1G 2W1

Victoria Campbell
Department of Biology, Trent University, Peterborough, Ontario K9J 7B8

Karen L. Clark
Biota Environmental Contractors, P.O. Box 21, Dorset, Ontario P0A 1E0

Francis R. Cook
Curator of Herpetology, Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa, Ontario K1P 6P4

Graham J. Crawshaw
Metropolitan Toronto Zoo, P.O. Box 280, West Hill, Ontario M1E 4R5

William Freedman
Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4H7

David M. Green
Redpath Museum, McGill University, 859 Sherbrooke Street West, Montreal, Quebec H3A 2K6

T.B. Herman
Department of Biology, Acadia University, Wolfville, Nova Scotia B0P 1X0

Bob Johnson
Curator of Amphibians and Reptiles, Metropolitan Toronto Zoo, P.O. Box 280, West Hill, Ontario M1E 4R5

Doug Kay
193 Hatt Street, Dundas, Ontario L9H 2G7

William Koonz
Manitoba Wildlife Branch, P.O. Box 14, 1495 St. James Street, Winnipeg, Manitoba R3H 0W9

Donald F. McAlpine
Natural Sciences Division, New Brunswick Museum, 277 Douglas Avenue, Saint John, New Brunswick E2K 1E5

Roy W. McDiarmid
Biological Survey, U.S. Fish and Wildlife Service, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560

Martyn E. Obbard
Wildlife Research Section, Ontario Ministry of Natural Resources, P.O. Box 5000, Maple, Ontario L6A 1S9

Michael J. Oldham
Ontario Ministry of Natural Resources, Aylmer District, 353 Talbot Street West, Aylmer, Ontario N5H 2S8

Stan A. Orchard
Nearctic Zoophiles Inc., 27 – 2891 Craigowan Road, Victoria, British Columbia V9B 1M9

Wayne Roberts
Museum of Zoology, University of Alberta, Edmonton, Alberta T6G 2E9

Frederick W. Schueler
Bishops Mills, R.R. #2, Oxford Station, Ontario K0G 1T0

F.W. Scott
Natural History Section, Nova Scotia Museum, Halifax, Nova Scotia B3H 3A6

Carolyn N.L. Seburn
Department of Zoology, University of Alberta, Edmonton, Alberta T6G 2E9

N.L. Shackell
School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia B3H 4J1

Pat Tosswill
Department of Biology, Trent University, Peterborough, Ontario K9J 7B8

James L. Vial
Coordinator of IUCN/SSC Declining Amphibian Populations Task Force, c/o Center for Analysis of Environmental Change, 200 South West 35th Street, Corvallis, Oregon 97333

Richard Wassersug
Department of Anatomy, Dalhousie University, Sir Charles Tupper Building, Halifax, Nova Scotia B3H 4H7

Wayne F. Weller
Suite 504, 66 High Street East, Mississauga, Ontario L5H 2H5

Contents

Preface

Since 1989, there has been a growing realization that amphibian populations have been declining at an alarming rate. For many years before that, direct habitat loss such as infilling of wetlands was acknowledged as the major causative factor of a general loss of global biodiversity, including a loss of absolute and species numbers in the class Amphibia. However, the recent formation of the Declining Amphibian Populations Task Force (DAPTF) by the Species Survival Commission of the World Conservation Union (IUCN) was triggered by the disappearance of or drastic decreases in some populations of amphibians where suitable habitat appeared to remain, which indicated that things were even worse than we had thought. Scientists could not explain these declines because worldwide, and Canada-wide, there has been a dearth of monitoring of changes in amphibian populations and stresses that regulate those populations. Herpetologists and governments in all parts of the world are now beginning to work cooperatively to determine which species are in decline and the causative factors for these declines.

In Canada, 70 people participated in a workshop held in Burlington, Ontario, on 5–6 October 1991 to examine the data related to declines in Canadian amphibian populations and associated causes and, in particular, to develop a protocol to address this issue in Canada. The workshop participants were invited by the Canadian Wildlife Service (Ontario Region) and the Metropolitan Toronto Zoo to present reports on the current status of knowledge on amphibians in Canada, particularly species that appear to be threatened. Summaries of this information are presented in Part 1 of this report. Many factors that may be contributing to fluctuations in amphibian populations were presented and discussed (Part 2). In the context of a national monitoring strategy, methodologies and tribulations involved in accurately assessing amphibian population size and recruitment were presented (Part 3). This all occurred within the first day of the workshop! To develop a strategy for nationwide monitoring, Bill Freedman presented a useful framework for environmental monitoring that was generally adopted by the workshop (Part 4). It was agreed that a data base for historical amphibian data and data sources in Canada was needed (Part 4). Most importantly, two types of amphibian research and monitoring—intensive and extensive—should be initiated along with complementary studies or data collection on factors that may influence amphibian survivorship (Part 4).

The participants in the workshop (Appendix A) were primarily professional herpetologists along with various veterinarians, toxicologists, ecologists, wildlife managers, and policymakers. Regardless of their title, they shared a history of concern for amphibians and reptiles in Canada. A core of volunteer provincial and national coordinators was established (Appendix B) that will start to implement this monitoring and seek funding to support this strategy. However, volunteer efforts and time can stretch only so far, and new research and monitoring cannot be initiated without secure, long-term funding. The enthusiastic attendance and debate at the workshop and the efficiency with which authors submitted their papers to the proceedings attest to the wealth of interest in this issue in Canada. We hope that these proceedings will be enlightening and inspiring to all, especially those who can influence funding for a national strategy to address declines in amphibian populations.

Christine Bishop
Karen Pettit

Préface

Depuis 1989, on est de plus en plus conscient du fait que les populations d'amphibiens diminuent à une vitesse alarmante. Pendant de nombreuses années, le déclin de la diversité biologique globale, notamment la diminution en nombre absolu et en nombre d'espèces de la classe des amphibiens, a surtout été attribué à la perte directe d'habitats causée, entre autres, par le remblayage des terres humides. Cependant, la création récente du Groupe de travail sur les populations d'amphibiens en déclin par la Commission de la sauvegarde des espèces de l'Alliance mondiale de la nature (UICN) a été provoquée par la disparition ou la forte diminution de certaines populations d'amphibiens là où des habitats appropriés semblaient continuer d'exister, indiquant que la situation était encore plus grave que prévu. Les scientifiques n'ont pas été en mesure d'expliquer ces déclins étant donné, qu'aux échelles mondiale et canadienne, le suivi des changements subis par les populations d'amphibiens ainsi que des stress qui affectent ces populations avait été insuffisant. Les herpétologistes et les gouvernements du monde entier travaillent maintenant en collaboration pour déterminer quelles espèces connaissent un déclin et quelles sont les causes de ce déclin.

Au Canada, 70 personnes ont participé à un atelier tenu les 5 et 6 octobre 1991 à Burlington (Ontario) pour analyser les données sur les diminutions de population chez les amphibiens du Canada et les causes associées et, surtout, pour élaborer un protocole de solution du problème au Canada. Les participants de l'atelier ont été invités par le Service canadien de la faune (région de l'Ontario) et le Zoo de la communauté urbaine de Toronto à présenter des rapports sur l'état des connaissances actuelles sur les amphibiens du Canada, particulièrement sur les espèces qui semblent être menacées. Ces données sont résumées dans la partie 1 du présent rapport. Les nombreux facteurs qui peuvent faire fluctuer les populations d'amphibiens ont été présentés et discutés (partie 2). Dans le contexte d'une stratégie de suivi nationale, les méthodologies utilisées pour évaluer avec exactitude la taille et le recrutement des populations d'amphibiens et les problèmes qu'elles soulèvent ont été présentées (partie 3). Tout cela a eu lieu pendant le premier jour de l'atelier! Dans le but d'élaborer une stratégie de suivi nationale, Bill Freedman a présenté un cadre utile pour mener un suivi environnemental, qui a reçu l'approbation générale des participants de l'atelier (partie 4). Il a été convenu de la nécessité de mettre sur pied une base de données pour y emmagasiner les données historiques sur les amphibiens et les sources de données au Canada (partie 4). Fait encore plus important, il a été proposé que deux types de recherche et de suivi des amphibiens - intensif et extensif - soient entrepris concurremment avec des études complémentaires ou une cueillette de données sur les facteurs qui peuvent influer sur la survie des amphibiens (partie 4).

Les participants de l'atelier (annexe A) étaient surtout composés d'herpétologistes professionnels ainsi que de vétérinaires, de toxicologues, d'écologistes, de gestionnaires de la faune et de décideurs. Ils ont tous, quel que soit leur titre, partagé leurs préoccupations face à la situation des amphibiens et des reptiles au Canada. Un noyau de coordonnateurs provinciaux et nationaux a été formé (annexe B) pour réaliser bénévolement ce suivi et pour trouver les fonds nécessaires à l'appui de cette stratégie. Cependant, comme on ne peut pas compter indéfiniment sur leur contribution et leur temps libre, il faudra obtenir un financement à long terme pour entreprendre des travaux de recherche et de suivi. La participation enthousiaste des participants à l'atelier et la célérité avec laquelle les auteurs ont présenté leur manuscrit témoignent de l'immense intérêt que soulève cette question au Canada. Nous espérons que les présents comptes rendus seront une source d'information et d'inspiration pour tous, en particulier pour ceux et celles qui peuvent exercer une influence sur le financement d'une stratégie nationale visant à freiner le déclin des populations d'amphibiens.

Christine Bishop
Karen Pettit

Acknowledgements

A great deal of thanks goes to Bob Johnson for cochairing the workshop and to Doug Kay, Nancy Mahony, and Murray Sindall, who volunteered their time to help at the workshop. Their efforts made the workshop enjoyable and useful for all of us. During the initial stages of plans for the workshop and its organization, we appreciated the interest and support of Chip Weseloh and Keith Marshall.

This publication was produced by the Scientific and Technical Documents Division of the Canadian Wildlife Service. The following people were responsible:
Pat Logan, Chief — coordination and supervision;
Sylvie Larose, Computer Publishing Specialist — layout;
Marla Sheffer, Contract Editor — scientific editing; and
Gilles Bertrand, Production Officer — printing. We are grateful to all of them for their time, commitment, and attention to detail in the publication process. Thanks also go to Andrea Bishop, who assisted with the typing of this report.

Part 1:
Status of knowledge on amphibian populations in Canada, and species of concern

Amphibian population declines in British Columbia

Stan A. Orchard

Abstract

Nine families of the class Amphibia are represented in British Columbia. Eighteen species are native, and at least two nonnatives have become established. Among the native species are a number of habitat specialists whose declines are clearly attributable to habitat destruction through human disturbance. These include the Northern Pacific Giant Salamander (*Dicamptodon tenebrosus*), Coeur d'Alene Salamander (*Plethodon idahoensis*), Tiger Salamander (*Ambystoma tigrinum*), Tailed Frog (*Ascaphus truei*), and Great Basin Spadefoot Toad (*Scaphiopus intermontanus*). In addition, the population densities of the Spotted Frog (*Rana pretiosa*) and Northern Leopard Frog (*Rana pipiens*) are declining even though their habitats have remained free from human disturbance. It is suggested that predation and competition from increasing populations of introduced fish and Bullfrogs (*Rana catesbeiana*), as well as from managed populations of native waterfowl, may have contributed to the decline of these species.

Résumé

Neuf familles de la classe des Amphibiens sont représentées en Colombie-Britannique. Dix-huit espèces sont indigènes, et au moins deux espèces y sont désormais implantées. Parmi les espèces indigènes, on trouve un certain nombre devenues préférentes pour certains habitats et dont le déclin est nettement attribuable à la destruction de leur habitat par les activités humaines. Ce sont *Dicamptodon tenebrosus* (Grande Salamandre), *Plethodon idahoensis, Ambystoma tigrinum* (Salamandre tigrée), *Ascaphus truei* (Grenouille-à-queue) et *Scaphiopus intermontanus* (Crapaud du Grand Bassin). En outre, les densités des populations de *Rana pretiosa* (Grenouille maculée) et de *Rana pipiens* (Grenouille léopard) indiquent une tendance à la baisse en dépit du fait que leur habitat est resté libre de toute intervention humaine. Il semblerait que la prédation et la compétition résultant tant de l'augmentation de la population de poissons non indigènes et de *Rana catesbeiana* (Ouaouarons), que du contrôle exercé sur les populations de sauvagine, aient contribué au déclin de ces espèces.

Introduction

Nine families of the class Amphibia are represented in British Columbia. Eighteen species are native, and at least two nonnatives have become established (Table 1). Among the native species are a number of habitat specialists. This group is composed of species that are readily displaced by industries such as forestry, fisheries, agriculture, and urbanization. The declines of three salamanders—Northern Pacific Giant Salamander (*Dicamptodon tenebrosus*), Coeur d'Alene Salamander (*Plethodon idahoensis*), and Tiger Salamander (*Ambystoma tigrinum*)—and two frogs—Tailed Frog (*Ascaphus truei*) and Great Basin Spadefoot Toad (*Scaphiopus intermontanus*)—are clearly attributable to habitat destruction through human disturbance.

The decline of another group is, however, not so easily explained. The population densities of two species of aquatic, marsh-dwelling ranid frogs—the Spotted Frog (*Rana pretiosa*) in southwestern British Columbia and the Northern Leopard Frog (*Rana pipiens*) throughout its B.C. distribution—are noticeably lower today than 20 years ago, and at sites that appear to have changed very little during that time.

Northern Pacific Giant Salamander, Tailed Frog, and Coeur d'Alene Salamander

The Northern Pacific Giant Salamander and Tailed Frog share a peculiar and exceptionally vulnerable microhabitat on the western slopes of the Cascades and Coast mountain ranges. Tailed Frogs also occur in the southeast on the western slopes of the Rocky Mountains. Both species inhabit small streams that descend suddenly from great altitudes to the valley floor, often through steep-sided ravines. Insulated by the shade of mature forest, the temperature of the rushing water remains low throughout the year. These streams, for much of their length, are a torrent, periodically obstructed by rocks and downfallen timber; these, in turn, create an almost continuous series of turbulent rapids, falls, and splash pools. These natural obstructions to water flow form effective barriers to fish migration, preventing fish from ascending the stream. Northern Pacific Giant Salamanders and Tailed Frogs thus escape the effects of competition and predation from fish.

The Coeur d'Alene Salamander occurs on the western slopes of the Purcell Mountains, where a few small and isolated cascading streams flow into Kootenay Lake. Unlike Northern Pacific Giant Salamanders and Tailed Frogs, Coeur d'Alene Salamanders do not live in the stream proper but prefer the associated splash zones and seepages.

Table 1
A list of the amphibians of British Columbia

Order Caudata: Salamanders	
Family Salamandridae: Newts and their relatives	
Taricha Gray, 1850	
Taricha granulosa (Skilton, 1849)	Rough-skinned Newt
Family Ambystomatidae: Mole salamanders	
Ambystoma Tschudi, 1838	
Ambystoma gracile (Baird, 1859)	Northwestern Salamander
Ambystoma macrodactylum Baird, 1849	Long-toed Salamander
Ambystoma tigrinum (Green, 1825)	Tiger Salamander
Family Dicamptodontidae: Giant and olympic salamanders	
Dicamptodon Strauch, 1870	
Dicamptodon tenebrosus (Baird and Girard, 1852) (=*Dicamptodon ensatus*)	Northern Pacific Giant Salamander
Family Plethodontidae: Lungless salamanders	
Aneides Baird, 1849	
Aneides ferreus Cope, 1869	Clouded Salamander
Ensatina Gray, 1850	
Ensatina eschscholtzi Gray, 1850	Ensatina Salamander
Plethodon Tschudi, 1838	
Plethodon idahoensis Slater and Slipp, 1940 (=*Plethodon vandykei idahoensis*)	Coeur d'Alene Salamander
Plethodon vehiculum (Cooper, 1860)	Western Red-backed Salamander
Order Anura: Frogs and toads	
Family Leiopelmatidae: Leiopelmatids and tailed frogs	
Ascaphus Stejneger, 1899	
Ascaphus truei Stejneger, 1899	Tailed Frog
Family Pelobatidae: Spadefoot toads and their relatives	
Scaphiopus Holbrook, 1836	
Scaphiopus intermontanus Cope, 1883 (=*Spea intermontana*)	Great Basin Spadefoot Toad
Family Bufonidae: True toads and their relatives	
Bufo Laurenti, 1768	
Bufo boreas Baird and Girard, 1852	Western Toad
Family Hylidae: Treefrogs and their relatives	
Hyla Laurenti, 1768	
Hyla regilla Baird and Girard, 1852 (=*Pseudacris regilla*)	Pacific Treefrog
Pseudacris Fitzinger, 1843	
Pseudacris triseriata (Wied-Neuwied, 1838)	Western Chorus Frog
Family Ranidae: True frogs and their relatives	
Rana Linnaeus, 1758	
Rana aurora Baird and Girard, 1852	Red-legged Frog
Rana catesbeiana[a] Shaw, 1802	Bullfrog
Rana clamitans[a] Latreille in Sonnini and Latreille, 1801	Green Frog
Rana pipiens Schreber, 1782	Northern Leopard Frog
Rana pretiosa Baird and Girard, 1853	Spotted Frog
Rana sylvatica Le Conte, 1825	Wood Frog

[a] Not native to British Columbia.

Shade from mature riparian forest creates a cool and deep but very localized environment that nevertheless remains stable throughout the summer.

Ironically, if the habitat of Northern Pacific Giant Salamanders, Tailed Frogs, and Coeur d'Alene Salamanders was shared by predatory game fish, then the stream and its edges would automatically be accorded legal protection. However, because these amphibians concentrate in streams without fish, their habitat has been deemed to be of no wildlife management value. Hence, the mandatory forest buffer left to protect the water quality and integrity of the streambed for game fish does not apply. The clear-cut is permitted to extend to the water's edge, and logging equipment is free to move across the stream.

It is unknown what effect many common silvicultural techniques, such as overspraying with pesticides, have on the amphibian residents of these streams, but the consequences of logging are clearly catastrophic. The stream and adjacent ground are laid bare by clear-cutting. The stones of the streambed, once scoured clean by the rushing water, are now exposed to direct sunlight and become coated and submerged in silt and algae. Tailed Frog tadpoles whose disc-shaped mouths are adapted to adhering to clean rock surfaces are easily washed away. The summer temperature of the water can now increase beyond these species' physiological tolerance, and the once-permanent stream may periodically dry up. Rehabilitation of the site will take decades, and extinction of local populations is unavoidable.

Tiger Salamander and Great Basin Spadefoot Toad

Populating environments far different from the damp, cool, coastal rain forest, Tiger Salamanders and Great Basin Spadefoot Toads occur only in the hot, dry Okanagan and Thompson valleys of south-central British Columbia. These long, narrow strips of semidesert are sometimes collectively referred to as the Ponderosa Pine – Bunchgrass Biogeoclimatic Zone. Arable sections of the valley bottom have hitherto been given over to orchards and vineyards, and cattle have ranged on the low hills and rocky slopes above the valley floor. Lately, however, the land has been increasingly developed for human recreation and retirement. Consequently, human population densities have grown suddenly, and the rate at which biological communities are being disarranged has intensified.

Tiger Salamanders can exhibit two possible developmental states at sexual maturity. Their eggs are deposited in lakes, ponds, and intermittent pools and will hatch into gill-breathing larvae. If the spawning lake is intermittent or too shallow, all of the larvae must metamorphose into a lung-breathing, semiterrestrial form or perish. However, if spawning occurs in a permanent lake of sufficient depth, then those larvae that do not transform will survive and attain sexual maturity while retaining all other larval characteristics such as fins and gills. The phenomenon is known as neoteny, and the individuals are called neotenes. Hence, the neotenous part of the population lives an entirely aquatic existence, whereas the metamorphous form spends most of the year on land (underground in rodent burrows) and migrates to water each spring only to spawn.

During periods of drought, shallow and intermittent spawning pools can dry up, and the rains that are vital for nocturnal migrations to and from the spawning sites may not materialize. These intervals of natural calamity will select against the metamorphous form because it is unable to reproduce, and its generation may become fatally trapped in a rapidly dehydrating environment. Neotenes, on the other hand, have a survival advantage during these times. In the larger lakes, their environment remains relatively stable with respect to food and cover, and spawning continues unabated. Thus, at times, the survival of the Tiger Salamander gene pool may depend on the neotenous subpopulation. For example, it is theorized that an interval of prolonged dryness is responsible for obligate neoteny and the disappearance of the metamorphous form from the Mexican Axolotl (*Ambystoma mexicanum*). A comprehensive long-term conservation strategy for Tiger Salamanders must therefore address the needs of both the metamorphous and the neotenous phases.

Tiger Salamanders tend to spawn in pothole basins and spring-fed lakes above the valley floor. Isolated from the interconnected lakes of the valley bottom, these water bodies have no natural ichthyofauna, and the salamanders are thus relieved of the pressures of predation and competition from fish. Accordingly, there is a strong correlation between neoteny and the absence of fish. In the last century, game fish have been introduced into virtually every water body in southern British Columbia that can support them. An additional number of lakes have been artificially aerated to improve game fish survival. There is no doubt that the fish are eating the salamanders. In one sample from a small lake, the Recreational Fisheries Branch found that 40% of the trout with identifiable stomach contents had consumed salamanders (Matthews 1986). This lake had also become infested with sunfish, originally brought to the lake by anglers, which were also preying upon and competing with salamanders. For the sake of the trout, the lake was poisoned to remove the competing sunfish prior to reintroducing a monoculture of trout. Incidental to that operation was the annihilation of the surviving neotenous Tiger Salamanders.

Over the last 40 years, this scenario, sometimes called "lake rehabilitation," has been played out at many of the spawning lakes of Tiger Salamanders in British Columbia. Lakeside developments, overgrazing of rangeland, rodent control programs, water channelling, road kills, pollutants (Harshbarger et al. 1989; Harte and Hoffman 1989; Worthylake and Hovingh 1989), and pesticides (Harfenist et al. 1989) all contribute to the decline of this amphibian, but the introduction of predatory fish into lakes where Tiger Salamanders spawn has unquestionably had the most pernicious effect.

Great Basin Spadefoot Toads are also remarkably well adapted to living in very dry conditions. They burrow easily into loose soil to find moisture, and they emerge at the surface primarily at night and especially during warm rains to forage and to spawn. They will spawn in some permanent lakes, but their eggs and larvae may be preyed upon by Tiger Salamander larvae and fish. More commonly, they congregate to reproduce in shallow puddles filled by thunderstorms. Reproduction is an uncertain event. The puddles may fill only once in several years, and, when conditions are right, the toads must be prepared to spawn immediately. The first eggs to achieve fertilization will have the best chance at completing metamorphosis before their aquatic nursery succumbs to the dehydrating effects of sun, soil, and air. Thus, in spite of an extraordinarily rapid embryonic and larval development, many generations will be lost through failure to complete this first phase of their life cycle.

Survival for this amphibian has been further complicated by the introduction of range cattle into its habitat. The cattle gather at temporary pools and use them as drinking stations. Vegetation surrounding the pools is subjected to severe trampling and overgrazing. The cattle wander through the water, polluting it and stirring up mud, and their hooves make deep pits in the pool substrate and along its margin. Many tadpoles are trampled outright, and others will die from the choking effects of the slurry. In a naturally formed pool, the edges grade down to the lowest point so that, as the water level decreases, the tadpoles are able to move towards the bottom of the basin, thereby extending their lives. However, the cratering effect of the cattle's hooves on the substrate subdivides the pool floor and its edges into a honeycomb of isolated, mud-rimmed pockets of water that effectively trap tadpoles and prevent them from escaping to deeper water.

Lately, all-terrain vehicles have become an additional potent threat to the spawning habitat of Great Basin Spadefoot Toads. Drivers of off-road motorcycles and four-wheel-drive vehicles have discovered the entertainment value of sliding and splashing through these shallow, muddy basins. In this way, the mud becomes thoroughly churned and produces a heavily rutted, muddy gel in which tadpoles cannot survive.

Spotted and Northern Leopard frogs

Reclamation projects across southern British Columbia over the last century have converted vast areas of valley bottom marshland into agricultural land. Fortunately, a few choice areas have been protected and set aside as habitat for waterfowl. It has been a maxim of wildlife management that if you manage for game species (i.e., game fish, waterfowl, deer) and preserve their habitat, then all other species within that habitat will naturally profit. At odds with this popular fallacy is the fact that Spotted Frogs and Northern Leopard Frogs are disappearing from wildlife reserves that are free from overt symptoms of human encroachment.

For example, 20 years ago, Lawrence Licht, currently at York University in Toronto, studied the ecology of

Spotted Frogs at Campbell Valley Park, near White Rock in southwestern British Columbia (Licht 1972). He recently revisited those study sites and was unable to find any Spotted Frogs (L. Licht, pers. commun.). What was evident, however, was an abundance of Bullfrogs (*Rana catesbeiana*). Bullfrogs are not native to British Columbia and were released into the wild several decades ago by erstwhile frog farmers after abandoning their hopeless enterprise. Bullfrogs are large and voracious predators. They occupy the same habitat and ecological niche as Spotted Frogs and inevitably compete with them for space and food. In addition, large Bullfrogs are easily capable of preying on their smaller cousins, and undoubtedly do prey on them.

In eastern British Columbia, the Northern Leopard Frog ranges up the Kootenay and Columbia river valleys and also occurs in the vicinity of Creston at the southern end of Kootenay Lake. It has become well-known for its dramatic population decline in the last 20 years throughout North America. In British Columbia, although not well documented, there exists some evidence that populations here have also retrogressed alarmingly. For example, a collecting expedition for the National Museum of Natural Sciences had no difficulty finding this species 15 years ago, and Northern Leopard Frogs were still common at the Creston Valley Nature Centre in the early 1980s. Nevertheless, my brief annual attempts to find Northern Leopard Frogs were all unsuccessful from 1988 until the fall of 1991, when I discovered four at one site north of Creston.

Fortunately, Bullfrogs have not been introduced into eastern British Columbia and so are not a factor in the decline of Northern Leopard Frogs; however, many predators have been introduced. Catfish, bass, and sunfish are all exotic to this province but have all established themselves prolifically in the aquatic habitats of both Northern Leopard and Spotted frogs. Furthermore, various organizations are actively engaged in interconnecting and reshaping waterways and establishing hatcheries in order to maximize the densities of sport fish therein. At the same time, other private and governmental agencies are resolved to boosting the densities of waterfowl. Over $1.5 billion was invested in this effort in North America in 1990 (Victoria Times-Colonist 1991). I strongly suspect that predation and competition from increasing populations of introduced fish and Bullfrogs, as well as from managed populations of native waterfowl, may have contributed greatly to the decline of Northern Leopard and Spotted frogs. With increasing numbers of predators competing for ever-diminishing wetland habitat, it is not unreasonable to suppose that predator pressure could be a fundamental cause of dwindling amphibian populations. This provides an unlikely explanation for the sudden disappearance of Northern Leopard Frogs. Nonetheless, the intensively managed populations of batrachophagous predators may very well suppress or defeat amphibian populations in their effort to recover from natural catastrophes.

It is notable as well that all of the life stages of Northern Leopard and Spotted frogs are highly aquatic, and this could increase their sensitivity to very subtle changes in water quality.

Conclusion

Most of the historical information relating to the distribution and abundance of amphibians in British Columbia has been compiled. However, this data set is primarily a compilation of the results of sporadic collecting efforts and occasional sightings. It documents the distributional limits of amphibians in British Columbia, but it offers only limited insight into current population status or long-term trends.

Literature cited

Harfenist, A., T. Power, K.L. Clark, and D.B. Peakall. 1989. A review and evaluation of the amphibian toxicological literature. Can. Wildl. Serv. Tech. Rep. Ser. No. 61, Ottawa. 222 pp.

Harshbarger, J.C., F.L. Rose, and L.J. Cullen. 1989. Neoplasms in neotenic *Ambystoma tigrinum* from a sewage lagoon. Herpetopathologica 1(1):19–27.

Harte, J. and E. Hoffman. 1989. Possible effects of acidic deposition on a Rocky Mountain population of the tiger salamander *Ambystoma tigrinum*. Conserv. Biol. 3(2):149–158.

Licht, L. 1972. Ecology and co-existence of ranid frogs in southwestern British Columbia. Univ. of British Columbia, Vancouver.

Matthews, S. 1986. A proposal to chemically rehabilitate Burnell Lake (South Okanagan) for fisheries enhancement. Unpubl. rep., Fish and Wildlife Branch, B.C. Ministry of Environment, Penticton.

Victoria Times-Colonist. 1991. Monday, 26 August:B16.

Worthylake, K.M. and P. Hovingh. 1989. Mass mortality of salamanders (*Ambystoma tigrinum*) by bacteria (*Acinetobacter*) in an oligotrophic seepage mountain lake. Great Basin Nat. 49(3):364–372.

Declines in amphibian populations in Alberta

Wayne Roberts

Abstract

Some amphibian species in Alberta occur in great abundance, including Wood Frogs (*Rana sylvatica*), Boreal Chorus Frogs (*Pseudacris maculata*), and Tiger Salamanders (*Ambystoma tigrinum*). Because of their abundance and the failure of many people to distinguish between different species, together with a lack of historical data on population sizes, the decline in numbers of other species of amphibians has proceeded relatively unnoticed. However, there is evidence that at least three species of amphibians in Alberta—the Northern Leopard Frog (*Rana pipiens*), Spotted Frog (*Rana pretiosa*), and Canadian Toad (*Bufo hemiophrys*)—are in varying states of decline.

Résumé

On note en Alberta, l'abondance de certaines espèces d'amphibiens, dont une abondance de *Rana sylvatica* (Grenouille des bois), *Pseudacris maculata* et *Ambystoma tigrinum* (Salamandre tigrée). Du fait de cette abondance et de l'incapacité d'un grand nombre de personnes à faire la distinction entre différentes espèces, combinées à l'insuffisance de données historiques sur les populations, le déclin des populations des autres espèces d'amphibiens est un phénomène qui est passé relativement inaperçu. Il existe toutefois des éléments d'information permettant de conclure au déclin, à un stade plus ou moins avancé, de trois espèces d'amphibiens en Alberta, soit *Rana pipiens* (Grenouille léopard), *Rana pretiosa* (Grenouille maculée) et *Bufo hemiophrys*.

Introduction

Some amphibian species in Alberta are doing well over much of their respective ranges. Wood Frogs (*Rana sylvatica*), Boreal Chorus Frogs (*Pseudacris maculata*), and Tiger Salamanders (*Ambystoma tigrinum*) often occur in great abundance. As it is these species that most people see—or hear, in the case of the frogs—it is difficult to convince people that there is in fact a decline in numbers of other species of amphibians. Much of the problem is a result of the failure of many people (including naturalists and biologists) to distinguish between different species and a lack of any concept of what population sizes have been or could be. Wood Frog sightings are frequently reported as "leopard frogs," for example; thus, the common perception is that "frogs" are doing just fine. There is sufficient evidence that at least three species of amphibians in Alberta are in varying states of decline.

Northern Leopard Frog

The total disappearance of the Northern Leopard Frog (*Rana pipiens*) from much of its range in Alberta was noted in 1979—from sites where species had been not only present, but abundant a year earlier (Roberts 1981). Locality records for the Northern Leopard Frog are shown in Figure 1. Just north of 51°N latitude, all known populations in central Alberta disappeared. South of this line, populations have disappeared or are restricted to small areas around springs, seeps, creeks, or small ponds. The status of populations in the extreme northeast of Alberta is uncertain; however, Northern Leopard Frogs have not, during this century, been known to occur widely or abundantly within this area. Loss of spawning and overwintering sites appears not to be a factor in the disappearance of most populations in central Alberta. Although high mortality attributed to red leg was *locally* evident in 1976, only individuals died, not entire populations. Populations surviving in the southern part of the province are surrounded by extensive arid or semiarid habitat and thus exist as islands. Even at sites where numerous young are produced, the populations may be limited by habitat and lack of opportunity for dispersal. Monitoring of select populations has been initiated. Two reintroductions to central Alberta sites have been made, and monitoring by the author will be an ongoing long-term project.

Spotted Frog

The Spotted Frog (*Rana pretiosa*) is reported to be absent from ponds where it has been found in the past and to be less abundant than before in areas where it is still found. It occurs in mountain passes and valleys where it is not regularly seen without special effort, and thus there is little information on the species. Known populations are shown in Figure 2, most of which occur in four clusters within national or provincial parks. The populations are confined to narrow strips (watercourses) within the enclosed areas on the map. Most of the foothills and mountains of Alberta do not support populations of Spotted Frogs. Like the Northern Leopard Frog, the Spotted Frog spends the winter underwater and may be subject to the same stresses and problems as this species. Spotted Frog populations should

Figure 1
Population distribution of *Rana pipiens*

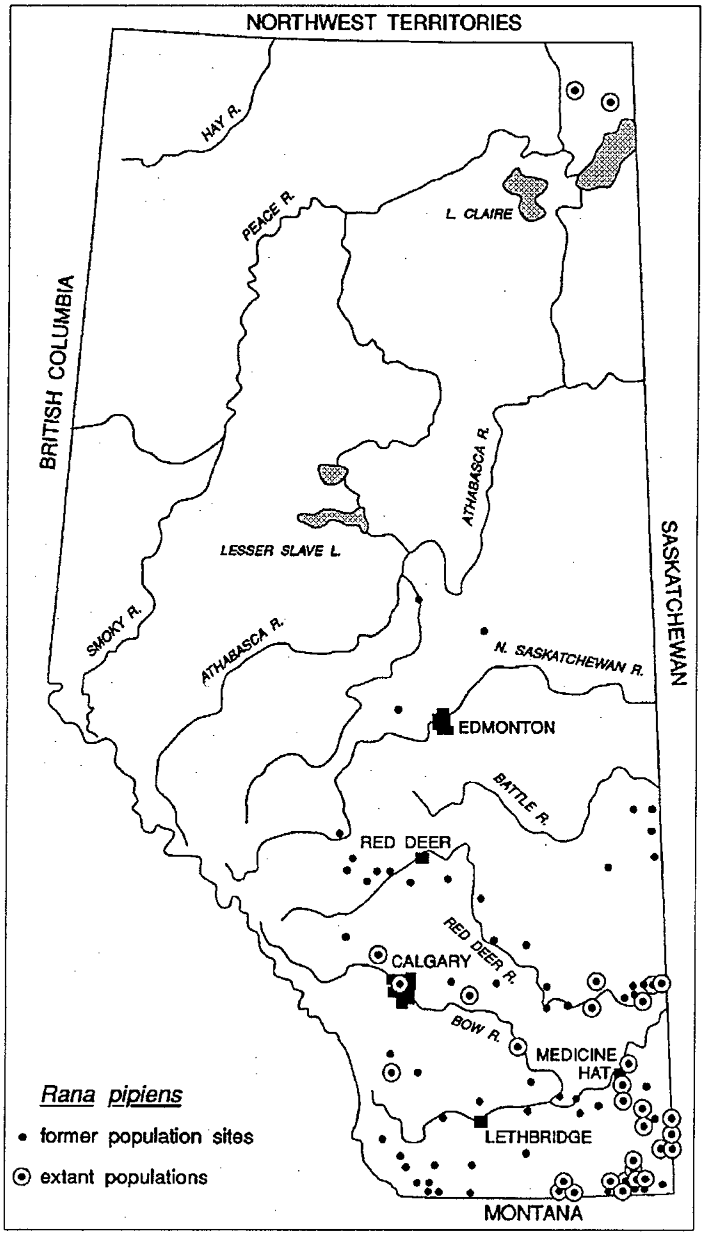
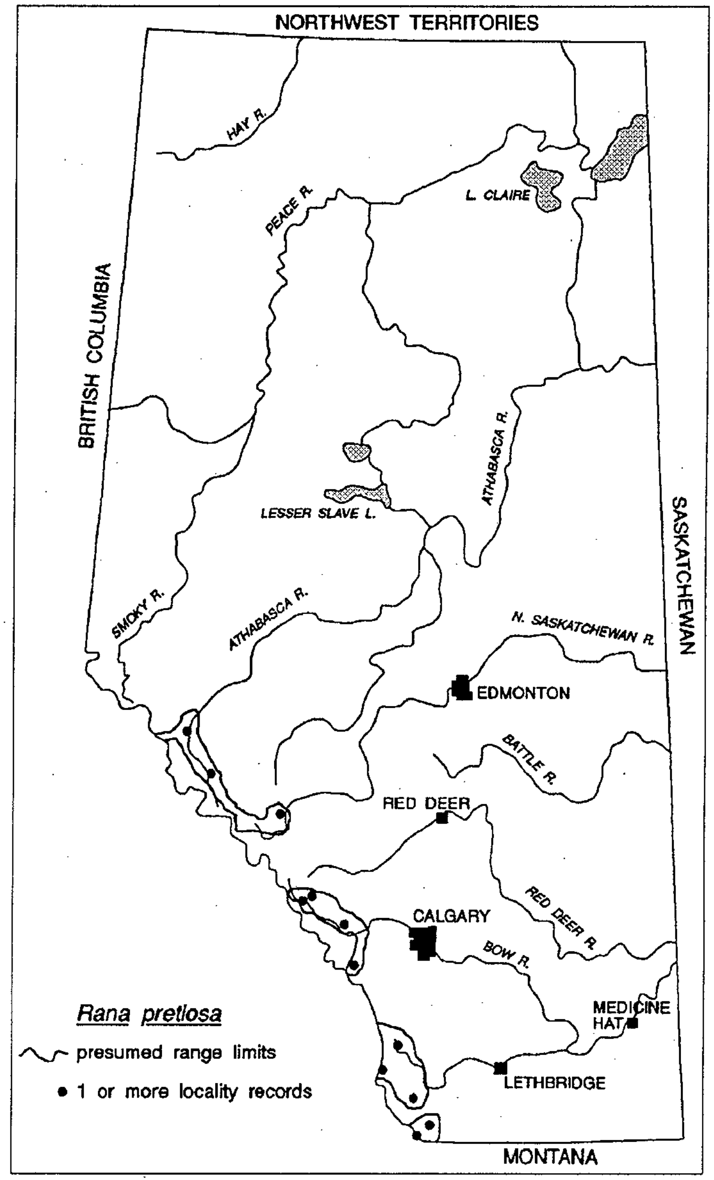


Figure 2
Population distribution of *Rana pretiosa*



be monitored to determine population trends. Salt (1977) provided baseline data for populations in Kananaskis country southwest of Calgary.

Canadian Toad

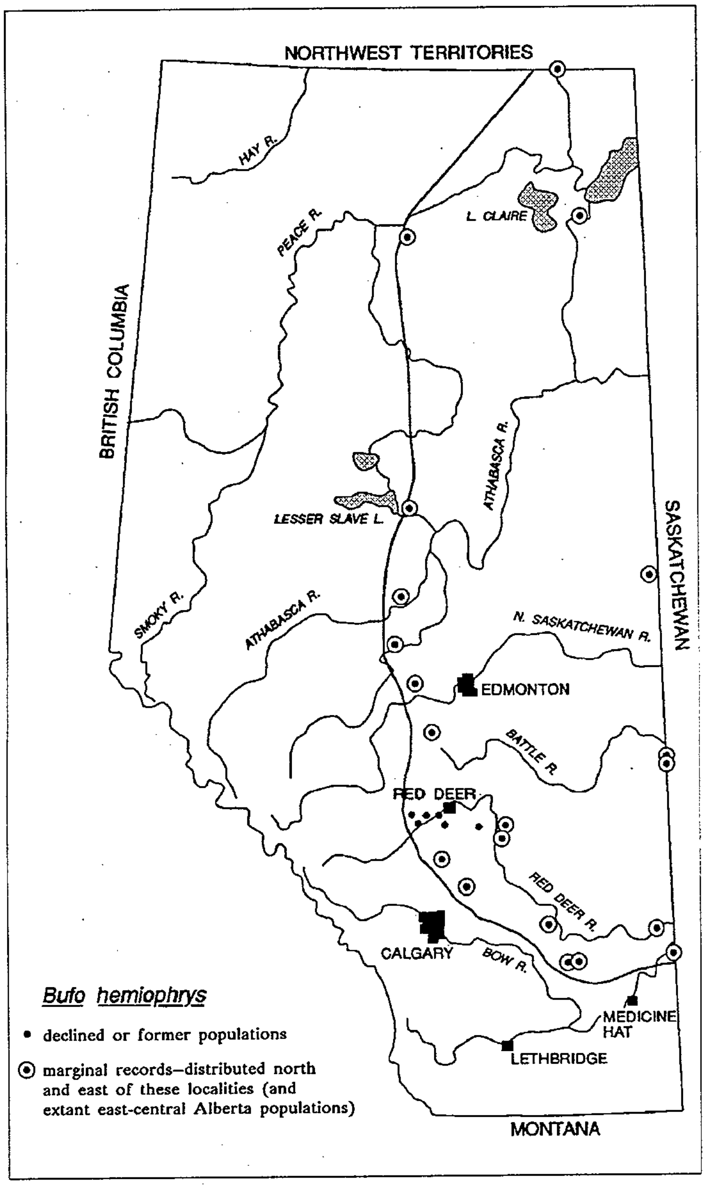
The Canadian Toad (*Bufo hemiophrys*) has exhibited the most recent decline among Alberta's amphibians. As recently as 1986, this species was thought to be maintaining healthy populations (Cottonwood Consultants 1986). Its distribution is shown in Figure 3. Populations (indicated by circled dots) have disappeared from areas within this range, notably cultivated areas and adjacent wetlands in central and south-central Alberta. They do, however, persist within portions of large river valleys, such as the badlands of the Red Deer River and along the North Saskatchewan River at Edmonton. Scattered populations still occur within the boreal forest and in east-central Alberta. Toads appear to be as abundant today at some but not all locations. In most cases, we simply do not have adequate historical data, nor have there been adequate recent surveys.

Populations at Ghostpine Springs Sanctuary, southeast of Red Deer, which have been monitored regularly for the past decade, declined during the 1980s. In 1990, only two males were heard calling. During 1991, no breeding males called, and no individuals were seen. In 1987, the author saw a single adult along the Red Deer River west of Innisfail—the only specimen seen on numerous regular visits during 1987–91. Although the decline was noted in agricultural areas, it is not necessarily confined to these areas, and the status of other populations should be investigated. Roberts and Lewin (1979) provided baseline data for a number of boreal forest sites. These sites, censused during 1976 and 1977, could be censused again.

Great Plains Toad

The Great Plains Toad (*Bufo cognatus*) has declined in numbers during the past decade, but this is attributed to habitat loss owing to land use practices. The status of this

Figure 3
Population distribution of *Bufo hemiophrys*



species has been reviewed by Sweetgrass Consultants (1991).

Literature cited

Cottonwood Consultants. 1986. An overview of reptiles and amphibians in Alberta's grassland and parkland natural regions. Prepared for Wild West Program, World Wildlife Fund Canada, Toronto. 63 pp.

Roberts, W.E. 1981. What happened to the leopard frogs? Alberta Nat. 11(1):1–4.

Roberts, W. and V. Lewin. 1979. Habitat utilization and population densities of the amphibians of northeastern Alberta. Can. Field-Nat. 93(2):144–154.

Salt, J.R. 1977. Report on the vertebrate fauna of Kananaskis Provincial Park. Vol. 2. Annotated checklists, etc. From field data collected by J. Salt and colleagues. Prepared by Peregrine Research Ltd. for Resource Assessment and Management, Alberta Recreation, Parks and Wildlife. 405 pp. & illus.

Sweetgrass Consultants. 1991. Status report on the Great Plains Toad in Alberta—1990. Prepared for World Wildlife Fund Canada (Prairie for Tomorrow), Alberta Forestry, Lands and Wildlife.

The status of amphibian populations in Saskatchewan

Carolyn N.L. Seburn

Abstract

The status of amphibians in Saskatchewan has not been well studied. Seven species are known to occur. Tiger Salamander (*Ambystoma tigrinum*), Canadian Toad (*Bufo hemiophrys*), Boreal Chorus Frog (*Pseudacris maculata*), and Wood Frog (*Rana sylvatica*) are widespread and abundant. Plains Spadefoot Toad (*Scaphiopus bombifrons*) and Great Plains Toad (*Bufo cognatus*) are considered rare, and numbers of Northern Leopard Frogs (*Rana pipiens*), once considered widespread and abundant, reached a low in the 1970s and are beginning to recover in some areas.

Résumé

La situation des amphibiens en Saskatchewan n'a pas fait l'objet d'études fouillées. Sept espèces ont été recensées. *Ambystoma tigrinum* (Salamandre tigrée), *Bufo hemiophrys*, *Pseudacris maculata* et *Rana sylvatica* (Grenouille des bois) sont des espèces répandues et abondantes. *Scaphiopus bombifrons* (Crapaud des Plaines) et *Bufo cognatus* (Crapaud des steppes) sont considérées comme des espèces rares. Les populations de *Rana pipiens* (Grenouille léopard), autrefois considérées comme répandues et abondantes, et qui ont connu un déclin des plus marqués dans les années 1970, connaissent un rétablissement dans certains secteurs.

Introduction

The status of amphibians in Saskatchewan has not been well studied (Secoy 1976). Seven species are known to occur: Tiger Salamander (*Ambystoma tigrinum*), Plains Spadefoot Toad (*Scaphiopus bombifrons*), Canadian Toad (*Bufo hemiophrys*), Great Plains Toad (*Bufo cognatus*), Boreal Chorus Frog (*Pseudacris maculata*), Wood Frog (*Rana sylvatica*), and Northern Leopard Frog (*Rana pipiens*) (Cook 1966).

None of these species has any legislative protection or any listed status at the federal or provincial level. There is no known commercial exploitation of amphibians in Saskatchewan (D. Hjertaas, pers. commun.).

Tiger Salamander

Saskatchewan's only salamander species is widespread and abundant throughout prairie and aspen parkland habitats. It is limited to the north by the boreal forest.

Plains Spadefoot Toad

This species is at the extreme northern edge of its range in Saskatchewan and is therefore considered rare (Secoy 1987). The Plains Spadefoot Toad is found in both the sandhills of southwestern Saskatchewan and the valley areas of the grasslands. Despite heavy rains in 1991, no breeding aggregations were reported, although a few adults were seen (W. Harris, pers. commun.). In contrast, breeding choruses were reported from two (possibly three) areas in southern Alberta (pers. obs.; D. Klassen, pers. commun.).

Canadian Toad

These toads are widespread and locally abundant near wetlands in the aspen parklands. W. Roberts (pers. commun.) reported finding them in 1991 in the vicinity of Cold Lake and Reflex Lake in both Saskatchewan and Alberta.

Great Plains Toad

This dry grassland species is limited to the southwestern corner of Saskatchewan and is therefore considered rare (Secoy 1987).

Boreal Chorus Frog

Boreal Chorus Frogs are widespread and abundant throughout most of the province, except for the extreme northeast corner. Populations in the grasslands may have declined as a result of habitat loss (Secoy 1987). Relatively low numbers of chorus frogs were heard in the wet meadow at the west end of Cypress Lake in 1991 (W. Harris, pers. commun.).

Wood Frog

Widespread and abundant throughout its range, the Wood Frog is found north of the short-grass prairie region. Population levels are considered relatively low in some areas (W. Harris, pers. commun.), although large numbers were seen in the Cold Lake and Reflex Lake areas in 1991 (W. Roberts, pers. commun.).

Northern Leopard Frog

Northern Leopard Frogs were formerly considered widespread and abundant. Population levels reached a low in the early to mid-1970s and are beginning to recover in some areas (K. Roney, pers. commun.). Heard (1985) reported a range extension to Bompas Lake, northeast of its previous limit at Lake Athabasca. Northern Leopard Frogs were common in Grasslands National Park in 1991 (W. Roberts, pers. commun.), but numbers were still low in the vicinity of Cypress Hills, Saskatchewan.

Summary

The statuses of the Plains Spadefoot Toad, the Great Plains Toad, and the Northern Leopard Frog appear to be of particular concern.

Acknowledgements

The following people assisted in compiling this information: Dale Hjertaas (Saskatchewan Fish and Wildlife), Dianne Secoy (University of Regina), Keith Roney (Saskatchewan Museum of Natural History), Wayne Harris (Prairie Environmental Services), and Wayne Roberts (University of Alberta, Museum of Zoology).

Literature cited

Cook, F.R. 1966. A guide to the amphibians and reptiles of Saskatchewan. Sask. Mus. Nat. Hist. Pop. Ser. No. 13, Regina. 40 pp.

Heard, S. 1985. Leopard Frog at Bompas Lake, Saskatchewan. Blue Jay 43(1):17.

Secoy, D.M. 1976. Distribution and population status of Saskatchewan's amphibians and reptiles. Report to the Saskatchewan Department of the Environment.

Secoy, D.M. 1987. Status report on the reptiles and amphibians of Saskatchewan. Prov. Mus. Alberta Nat. Hist. Occas. Pap. 9:139–141.

Amphibians in Manitoba

William Koonz

Abstract

Manitoba contains 15 known species of native amphibians. Of most economic significance is the Northern Leopard Frog (*Rana pipiens*), used in research and biology laboratories. Manitoba's Northern Leopard Frog populations crashed in 1975–76. Small isolated populations remained until 1983, when some recovery was detected. Since then, Northern Leopard Frogs have moved back into much of their traditional Manitoba range but have not approached the densities they once had. The massive Northern Leopard Frog die-offs that occurred without an identifiable cause should have generated extreme concern, as amphibian populations are good indicators of deteriorating environmental conditions. Frog population monitoring is needed across Canada.

Résumé

On trouve au Manitoba 15 espèces connues d'amphibiens indigènes. *Rana pipiens* (Grenouille léopard), utilisée dans les laboratoires de recherche et de biologie, est l'espèce la plus prisée au point de vue économique. Les populations de cette espèce ont connu une baisse importante en 1975–1976. De petites populations isolées se sont maintenues jusqu'en 1983, année où l'on a noté une certaine forme de rétablissement. Elles ont depuis réintégré la plus grande partie de leur aire de répartition sans toutefois afficher les mêmes densités qu'auparavant. Une très grande vigilance devrait être exercée du fait des nombreuses mortalités survenues au sein de cette espèce et qui n'ont pu être attribuées à aucune cause connue et compte tenu du fait que les populations d'amphibiens constituent de bons indicateurs biologiques. Il y aurait lieu de procéder également à une surveillance des populations d'anoures à l'échelle nationale.

Manitoba's richness

Manitoba contains 15 known species of native amphibians. Ranges and basic species information are contained in Bill Preston's (1982) book, "Amphibians and reptiles of Manitoba." The most abundant and widespread species are the Wood Frog (*Rana sylvatica*), Northern Leopard Frog (*Rana pipiens*), Boreal Chorus Frog (*Pseudacris maculata*), and Canadian Toad (*Bufo hemiophrys*). Of most economic significance is the Northern Leopard Frog, used in research and biology laboratories. The Wood and Boreal Chorus frogs are currently being studied to determine their techniques for surviving super cooling; they do not go to water or burrow but simply find riparian depressions in which to hibernate.

Commercial activities

Manitoba traditionally supplied a large portion of North America's Northern Leopard Frog market, shipping as many as 50 000 kg of frogs to U.S. biological supply houses for use in biology classes (Table 1). Manitoba's large shallow lakes with huge marsh areas provided habitat for a large frog population. Manitoba frogs were larger (20–26/kg) and hardier (held live until the spring term) than frogs from other areas. Most frogs were captured in the fall after "hardening in" (September). They were typically caught along Lake Manitoba beaches by hand with the aid of miners' lights. Several local dealers bought frogs annually from hundreds of pickers. Pickers were generally local, typically native or Métis.

There was some winter frog picking (December–March) done in artesian wells where huge frog concentrations existed. Frogs were scooped from those wells with long-handled nets into 200-L barrels, then

Table 1
Manitoba's reptile and amphibian harvest (from dealer records)

Year	Frogs (kg)	Snakes (number)	Salamanders
1971	31 067	24 800	No record
1972	49 907	56 465	No record
1973	19 940	68 621	No record
1974	5 900	63 429	No record
1975	0	30 370	No record
1976	0	48 142	No record
1977	0	34 745	No record
1978	0	43 667	No record
1979	0	23 220	No record
1980	0	30 000	No record
1981	0	37 409	No record
1982	0	64 992	No record
1983	1 323	43 440	No record
1984	5 935	57 245	No record
1985	13 710	90 080	No record
1986	15 983	71 569	No record
1987	16 355	68 497	No record
1988	4 127	82 268	41 kg
1989	1 144	No season	No record
1990	1 612	No season	
1991		No season	

Note: Records are minimal, as sales go unrecorded annually.

transported to trucks for shipment to U.S. markets. Much of the frog picking after 1971 was tied to the Red-sided Garter Snake (*Thamnophis sirtalis parietalis*) season, as many of the buyers wanted both snakes and frogs, and pickers typically hunted both species (Table 1). There was extreme pressure put on the pickers to have a maximum number of frogs and snakes by day 1 of the snake season (1 September). Buyers typically had quotas, and, once these were reached, no more frogs or snakes were purchased. This led to considerable illegal picking and infighting among the pickers.

The Northern Leopard Frog die-off

The North American leopard frog die-off (according to B. Lemburger, a Wisconsin frog dealer, buyer, and shipper and supported by Dr. Robert Mason, Oregon State University, Cordley Hall, Corvallis, Oregon) began in the early 1970s and spread quickly. Centres of highest frog densities in the upper midwest were the first areas where the die-off was identified. Within a year or so, leopard frogs in Mexico (*Rana pipiens* and *Rana blairi*) were also affected. Frog populations away from the major population centres seemed to survive up to four years (Alberta) before large die-offs were documented, but losses appeared to affect the whole North American leopard frog range, including the southern and northern races.

Manitoba Northern Leopard Frogs began dying off in 1975 and were virtually gone from the major centres of population by 1976. Piles of dead and dying frogs were reported from many Lake Manitoba shorelines, whereas heaps nearly a metre high were recorded from the major frog hole areas. The die-offs were most complete where populations were most dense. Large marshes along Lake Manitoba were silent of Northern Leopard Frog calls, and egg masses were absent. Dipping into the frog holes produced only small fish and aquatic vegetation. The provincial die-off resulted in no frogs being exported from Manitoba in 1976–83 (Table 1), despite excellent market conditions.

Small, isolated Northern Leopard Frog populations (golf courses, stock ponds, islands) survived through to 1983, when some populations' recovery was detected. Since then, Northern Leopard Frog populations have increased in some areas while remaining extremely low in others. They have not reoccupied the frog holes and appear to be only slowly occupying what were their major habitats in Manitoba. Although Northern Leopard Frogs have moved back into much of their traditional Manitoba range, they have not approached the densities they once had. Habitats once supporting the highest frog densities continued to show considerable population fluctuations.

Recent increases in leopard frog populations in the United States have depressed the market for Manitoba frogs. The animal rights movement and an increase in computer use in education have also brought about a decrease in frog demand.

Causes and effects

Manitoba biologists anticipated the leopard frog die-offs in the mid-1970s, monitoring populations and performing lab analyses on sick and dying frogs. Dr. Ken Stewart (University of Manitoba) had students working with frog populations and attempted to determine possible causes for the die-offs. Researchers in Madison, Wisconsin, and Manitoba were unable to pinpoint the cause of death. The typical reason given for death was "red leg," a term derived from the fact that blood vessels were autolysed and body fluids accumulated in the semitransparent tissues on the undersides of the hind legs. This condition is a symptom of kidney failure but is not a disease in itself.

Although leopard frogs died off throughout Europe and most of North America, no one disease or parasite factor appeared responsible. That fact makes us look at environmental stress factors that may have been severe enough to allow normally benign factors to suddenly combine to kill off population masses throughout entire habitat ranges. Frogs are extremely vulnerable to airborne and waterborne pollutants because they breathe through their skin. The massive leopard frog die-offs that occurred without an identifiable cause should have generated extreme concern for the human environment. Amphibian populations will react quickly to environmental changes and should be much more highly regarded as indicators of deteriorating global environmental conditions. Frog population monitoring is needed across Canada, and I commend the organizers of this workshop for finally recognizing this need.

Possible survey methods for Manitoba

Information may be obtained from a number of existing data-gathering sources:

(1) Owl surveys are expected to take place annually in southeast Manitoba. Volunteers stop each 0.5 km to play owl tapes and record owls. This survey could easily include recording frog calls if survey members were provided with frog-calling tapes.

(2) Road surveys are done for breeding birds throughout much of Manitoba. Frog calls could be recorded at each survey stop.

(3) Several Manitoba naturalists spend much of their time in the field, viewing, recording, photographing, and searching for birds throughout the province. These people could be encouraged to record frog calls, especially if they were provided with the appropriate calls on tape.

Is this a valuable undertaking?

Millions of dollars are being spent worldwide to study frog populations, most of it to determine if recent population declines are part of a long-term cycle or the result of global changes. People such as Dr. Andy Blaustein (Oregon State University) should be contacted regarding the potential for monitoring frog populations in specific sites.

Literature cited

Preston, W. 1982. Amphibians and reptiles of Manitoba. Museum of Man and Nature, Winnipeg. 128 pp.

Ontario Herpetofaunal Summary: compiling information on the distribution and life history of amphibians and reptiles in Ontario

Michael J. Oldham and Wayne F. Weller

Abstract

The Ontario Herpetofaunal Summary (OHS) began in 1984 as a volunteer project to collect and disseminate information on the distribution and life history of amphibian and reptile species in Ontario. More than 52 000 records have been received from over 2700 contributors thus far for the period of 1984–90, inclusive, and it is expected that an additional 19 000 records will be provided by individuals, the literature, and museum and university collections for the period prior to 1984. The results of the seven-year field program will be published in a four-volume set of species accounts. Organizers of the OHS will continue to solicit information on amphibians and reptiles in Ontario; such information could be used as baseline data for monitoring amphibian and reptile distribution and population trends in Ontario.

Résumé

Le bilan constitué sous le nom de l'Ontario Herpetofaunal Summary (OHS), amorcé en 1984, est le fruit d'un programme de bénévolat visant la collecte et la diffusion de données sur la répartition et l'histoire naturelle des espèces d'amphibiens et de reptiles de l'Ontario. De 1984 à 1990, plus de 52 000 mentions d'observation ont été reçues de plus de 2 700 collaborateurs, et on prévoit que 19 000 autres mentions d'observation couvrant la période antérieure à 1984 nous proviendront de particuliers, de l'examen de la documentation et des collections muséologiques et universitaires. Les résultats de ce programme de recherche échelonné sur sept ans seront publiés sous forme de répertoire constitué de quatre volumes d'observations sur les espèces. Les responsables de l'OHS prévoient continuer de solliciter d'autres informations sur les amphibiens et reptiles de l'Ontario; ces informations pourront constituer les données de référence nécessaires au suivi de la répartition des amphibiens et des reptiles et de l'évolution des populations de l'Ontario.

Introduction

The Ontario Herpetofaunal Summary (OHS) began in 1984 as a volunteer project to collect and disseminate information on amphibian and reptile species in Ontario. There are no paid staff, but funding has been provided by the Ontario Ministry of Natural Resources, World Wildlife Fund Canada, Canadian Amphibian and Reptile Conservation Society, and Essex Region Conservation Authority for computerizing records and producing observation cards.

Objectives

The objectives of the Ontario Herpetofaunal Summary are:

(1) to gather and publish information on the distribution of Ontario amphibians and reptiles using a 10-km by 10-km UTM grid following the format of the Atlas of the Breeding Birds of Ontario project;

(2) to gather and publish information on such ecological and life history aspects as dates of entry into and emergence from hibernation, calling and breeding periods, larval periods, habitat, behaviour, etc.; and

(3) to provide baseline data for future field surveys and studies and to monitor populations of (particularly) rare, threatened, and endangered species in Ontario.

Field observation records

Contributors were asked to record field observations on sightings cards for the seven-year period of 1984–90, inclusive. Information on date and location together with remarks on habitat, behaviour, etc. were submitted to the OHS at year-end. Some contributors sent in their observations in computerized format. Records were reviewed and entered into a data base format (dBase III+) for easy storage and retrieval. Additional information was solicited from individuals for the period prior to 1984. Information from museums and universities and from the published and unpublished literature will also be used in final publications.

More than 52 000 records have been received from over 2700 individuals thus far for the seven-year period of 1984–90. It is expected that an additional 15 000 records from museum and university collections and the literature and 4000 records of field observations from individuals will be provided for the period prior to 1984. Included among the results is documented evidence of the Northern Dusky Salamander (*Desmognathus fuscus fuscus*) in the Niagara region of southwestern Ontario and unconfirmed but apparently reliable reports of Cope's Gray Treefrog (*Hyla* *chryoscelis*) from the Rainy River area of northwestern Ontario, which would be a new species for Ontario.

Publications

Three annual reports for the years 1984, 1985, and 1986 have been published so far. Each report summarizes the information received in that year. Preparation of the annual reports was discontinued after 1986 in favour of a more comprehensive publication, as part-time staff did not have the time required to summarize the increasingly large volume of information received. To date, 3477 records have been received for 1984, 4700 records for 1985, 6241 records for 1986, 9374 records for 1987, 10 587 records for 1988, 11 771 records for 1989, and 6031 records so far for 1990.

It is planned to publish the results of the seven-year field program supplemented with other information in a four-volume set of species accounts. Species accounts will include comments on description, taxonomy, range in North America and distribution and abundance in Ontario, habitat, behaviour, reproduction, status and legislative protection, and conservation and research recommendations. A summary of records compiled to produce each account will also be included. Each species account will include a photograph, computer-generated distribution map(s) using UTM grid coordinates, and a graph showing the seasonal distribution of records received for 1984–90. The compilation of an annotated (to species and location), computerized bibliography of published and unpublished literature on Ontario herpetology is ongoing and now totals over 1300 entries.

Potential authors are being contacted to participate in the preparation of the species accounts. Volume 1 will include turtles and lizards and will be available, we hope, in 1992. Volume 2 (snakes), Volume 3 (frogs and toads), and Volume 4 (salamanders) will follow as time permits.

Future activities

Organizers of the OHS will continue to solicit information on the distribution and life history of amphibians and reptiles in Ontario for the foreseeable future. This information will be incorporated into updates to species accounts and will be available to conservation and protection projects. Information gathered by the OHS program could be used as baseline data for monitoring amphibian and reptile distribution and population trends in Ontario.

Status of amphibian populations in Quebec

Joël Bonin

Abstract

The most important contribution to current knowledge on the status and population trends of amphibians and reptiles in Quebec is the "Atlas des amphibiens et reptiles du Québec," which compiles all available herpetofaunal records from museums, literature, government technical reports, and individual contributors. The records of 16 less common species of amphibians and reptiles have been included in a Quebec Natural Heritage data bank called "Centre de données sur le patrimoine naturel du Québec."

Two species of frogs are of major concern in Quebec because of their restricted distribution and what appears to be a decline in their populations: *Rana palustris* (Pickerel Frog) and *Pseudacris triseriata* (Western Chorus Frog). Population trends of other amphibians, such as common species of frogs and terrestrial salamanders, are poorly known. A long-term monitoring strategy should be developed for amphibians in Quebec. Such monitoring is needed to document declines before causes (other than habitat loss) can be determined. As a first step, old localities of the species of concern should be surveyed to ascertain local declines and habitat change or loss.

Résumé

« L'Atlas des amphibiens et reptiles du Québec » représente la plus importante contribution à l'état actuel des connaissances sur la situation et la dynamique des populations d'amphibiens et de reptiles du Québec. L'Atlas répertorie en effet toutes les fiches herpétologiques établies soit par les musées ou des particuliers, soit à partir de la documentation scientifique existante et des rapports techniques gouvernementaux. Les fiches portant sur 16 espèces plus rares d'amphibiens et de reptiles ont été intégrées à une banque de données désignée sous le nom de « Centre de données sur le patrimoine naturel du Québec ».

La situation de deux espèces d'anoures suscite de vives préoccupations en raison de leur répartition limitée et de ce qui semble être une baisse de leurs populations : *Rana palustris* (Grenouille des marais) et *Pseudacris triseriata* (Rainette faux-grillon). La dynamique des populations d'autres amphibiens, tels que les espèces communes de grenouilles et de salamandres terrestres, n'est pas très bien connue. Il y aurait lieu d'élaborer une stratégie de surveillance à long terme des amphibiens du Québec. La réalisation d'études de suivi de ces déclins est nécessaire si l'on veut pouvoir en déterminer les causes (autres que les pertes d'habitat). Il conviendrait, dans une première étape, d'inventorier les anciens lieux d'occurrence de ces espèces qui font problème afin d'en confirmer le déclin et, s'il y a lieu, les modifications ou pertes d'habitat.

Quality of available population data

The most important contribution to current knowledge on the status and population trends of amphibians and reptiles in Quebec is the development of the "Atlas des amphibiens et reptiles du Québec," which began in 1988.

"Atlas des amphibiens et reptiles du Québec"

Three editions of this atlas have been prepared by the St. Lawrence Valley Natural History Society, presided over by Dr. Roger Bider of McGill University (Macdonald campus) in Montreal. This work has been funded by the Ministère du loisir, de la chasse et de la pêche du Québec. The atlas compiles all available herpetofaunal records from museums, literature, and government technical reports, the oldest records dating back to 1834. Furthermore, since 1988, additional records have been collected from persons involved in natural history, education, and herpetological science. In 1990, 202 contributors produced 753 records. The 1990 atlas includes 7394 records, 5057 of which date prior to 1988. Nevertheless, we are far from having a precise image of the distribution of amphibians in Quebec (Bider 1990).

The precision and details of each record are variable, and the sampling effort varies in time and space. Therefore, trends in species abundance cannot be obtained except in some isolated cases. The data do, however, depict trends in species distribution and help to identify possible local extinctions.

The atlas data should be put into a data base in the near future. Up until now, unpublished annual reports with distribution maps and lists of records for each species have been reproduced and distributed by the ministry. More detailed information about records is available from the original "atlas cards." The records of 16 less common species of amphibians and reptiles have been included in a Quebec Natural Heritage data bank called "Centre de données sur le patrimoine naturel du Québec."

"Centre de données sur le patrimoine naturel du Québec"

This is the first implementation of the Natural Heritage Program in Canada. This system has been developed in U.S. states by the Nature Conservancy. It deals with all members of the fauna and flora and with natural communities. In our Quebec data bank, general information on ecology and zoogeography is available for 40 species of herpetofauna (some of these being reported or introduced species). However, an exhaustive list of records is produced only for 16 less common species of amphibians and reptiles. Six hundred records are now in the data bank, which represent almost 100% of all known locations of those 16 uncommon species.

Species are classified according to their rarity: S1 to S5 (S being for state, here Quebec), SE (endemic or introduced), and SR (reported but no longer present). The rarity of a species is established from the number of its locations in the province, its range, abundance, trends and threats, and the number of protected populations. Global rarity over their distribution range in the world is similarly listed G1 to G5 (G for general).

The aim of this data bank is to have an updated image of the distribution and rarity (and some other parameters: ecology, behaviour) of every wildlife species in the province. It can be used to select the most important sites to protect in the province or for project impact evaluation.

Each record is called an element occurrence (EO). If there are two records, say 1964 and 1991, of the same species for a single location, there will be only one EO telling us the species was present there as recently as 1991. Therefore, the aim is not to indicate trends in population density or species distribution, even if this was feasible. In the data field called "source" (sources of the mentions), both 1964 and 1991 mentions would be listed with the collector or author references.

The EOs can be sorted by MRC (municipalité régionale de comté, or regional county municipality), watershed and ecological region (classification of ecological regions made by the Ministère d'énergie et ressources du Québec), or various other parameters. This data bank will soon be coupled with a program generating distribution maps.

Status of amphibian populations in Quebec

Anuran species of concern

Two species of frogs are of major concern in Quebec because of their restricted distribution and what seems to be a decline in their populations: *Rana palustris* (Pickerel Frog) and *Pseudacris triseriata* (Western Chorus Frog). Both have been reported in few localities since the beginning of the atlas in 1988, whereas they had been previously recorded in many counties.

Pseudacris triseriata was stated as common in the St. Lawrence lowlands and rare in the Gatineau valley by Bleakney in 1958. It is now rare in the St. Lawrence valley, with few known localities. Recent surveys seldom produce more than 10 males calling at the same breeding pond. The loss of habitats seems in large part responsible for the decline of this species. Survival and reproductive success of the isolated populations of this short-lived frog are probably severely limited by successive dry springs and summers. Succession from old fields to forests and competition or predation of eggs and larvae by other anurans (e.g., *Rana sylvatica* [Wood Frog]) are other possible factors. This species needs to be surveyed, and attention should be given to previously known and recent localities to assess changes in the habitat and frog species assemblage. A first effort to protect its habitat on île Perrot (southwest of Montreal Island) was undertaken in 1991 by the St. Lawrence Valley Natural History Society. With the agreement of landowners, habitat succession (forestation) will be controlled, and populations might be reintroduced in other habitats in the near future.

The status of *R. palustris* is not clear. Some consider it common, whereas others consider it rare. In fact, populations seem highly localized in Quebec, mostly associated with cool and clear lakes, ponds, or brooks. The species has not been reported recently from previously known localities in the Eastern Townships (Appalachian Mountains in southwestern Quebec). The species was stated as common in southwestern Quebec and the Gaspé Peninsula by Bleakney in 1958. This species needs to be resurveyed, and we need to learn more about its breeding habitat, hibernation requirements, and niche partitioning with its close relative *Rana pipiens* (Northern Leopard Frog) (Bider 1988).

Common species of anuran

The decline of a species is noticeable from the atlas survey only when the species is extirpated from a wide area. Rare species are susceptible to such an event. In the case of common species, trends are hardly identifiable using the atlas, as sampling effort is not constant through time and we often refer only to distribution data. Therefore, trends in common species of frogs (e.g., *R. pipiens*, *Rana catesbeiana* [Bullfrog], etc.) are poorly known. Declines in frogs are being reported by some hunters. Overhunting and changes in agricultural practice are probably major causes; however, this is not documented in Quebec.

Localities should be repetitively surveyed over many years to assess local extinctions or local population declines. The atlas could be a useful tool for identifying previously surveyed locations that have some precise population estimates of the different species. These sites should be surveyed first to give a quick view of local population trends. Frog hunters should be surveyed too, as they usually have "sampled" frog populations at the same site for a long period of time.

Mudpuppy

Population trends of *Necturus maculosus* (Mudpuppy) are unknown. The species seems well established in the St. Lawrence River and its tributaries from the Ontario boundary to Quebec City.

Terrestrial salamanders

Population trends in woodland salamanders are unknown. Small-scale forest cutting (pers. obs.) and sugar maple forest decline (Y. Maufette, pers. commun.) seem to have had a limited effect on *Plethodon cinereus* (Redback Salamander) population abundance in southern Quebec. However, the weakness of the relationships observed might be due to our poor control of microhabitat conditions during sampling. Surveys of some St. Lawrence valley and Eastern Townships peat lands have been conducted recently and have extended the known distribution range of an extremely uncommon species, *Hemidactylium scutatum* (Four-toed Salamander) (pers. obs.). Long-term monitoring of permanent stations is needed. Rapid sampling methods that do not disturb the habitat need to be developed.

Stream salamanders

Four species of stream salamanders are now known in Quebec: *Eurycea bislineata* (Two-Lined Salamander—widespread), *Gyrinophilus porphyriticus* (Spring Salamander—restricted to the extreme south of Quebec), *Desmognathus fuscus* (Dusky Salamander—mainly restricted to south of the St. Lawrence), and the recently discovered *Desmognathus ochrophaeus* (Mountain Dusky Salamander—only one locality known in the foothills of the Adirondacks). Their general distribution is fairly well known, as these stream salamanders were intensively collected for several years because of their novelty in the Canadian herpetofauna (Bider 1988). Recent works have been conducted on stream salamander distribution and habitat in southwestern Quebec, and a compilation of all streams systematically searched during previous surveys in southern Quebec is under way. Old sites should be revisited to assess habitat changes and population status, as development has been accelerated in this part of the province in the last 10 years (Bider 1988).

Contribution of scientific research and projects

In Quebec, major studies on frog population dynamics are done under the supervision of Dr. Raymond Leclair, Jr., at the Université du Québec à Trois-Rivières. Population dynamics of ranids (*R. pipiens*, *R. catesbeiana*, and *Rana clamitans* [Green Frog]) around Lac Saint-Pierre (St. Lawrence River) have been undertaken since 1983. In 1989, a study on ranid population dynamics was undertaken in a protected area of the Laurentian highlands to determine, among other things, the stability of the community structure. Forty lakes have been surveyed, and others should be added in the scope of this long-term study. Frogs are not collected, but they are measured in the field and a toe is sampled by a skeleto-chronology technique for age determination. To date, only 25% of the variance in the community structure has been explained by the variance in abiotic conditions. Therefore, many questions have been raised about interspecific relations, the immigration–emigration conditions, and the stability of the community structure.

At McGill University, research on amphibians is oriented to population genetics, systematics and zoogeography (Dr. David Green, Redpath Museum), and ecology (Dr. Roger Bider, Macdonald campus at Ste-Anne-de-Bellevue).

Dr. Jean-Luc Desgranges from the Canadian Wildlife Service, Quebec Region, is planning research on sustainable development (toxicology, monitoring of environmental and wildlife population changes). A data bank is currently being developed on habitat, vegetation, and cultivation history (over the last 20 years) for 175 locations used in the Breeding Bird Survey in the St. Lawrence lowlands. A survey of amphibian populations within those sites is planned, and long-term monitoring could be set up subsequently.

Conclusion

The atlas has been an important step in clarifying amphibian status in Quebec. The Ministère du loisir, de la chasse et de la pêche du Québec has contributed to this work and has shown an increasing interest in previously forgotten herpetofauna. Future participation by this ministry along with the Canadian Wildlife Service and other research institutions will be needed to set up a long-term monitoring strategy for amphibians in Quebec. Such monitoring is needed to document declines before causes (other than habitat loss) can be determined. As a first step, old localities of the species of concern should be surveyed to ascertain local declines and habitat change or loss.

Literature cited

Bider, R. (ed.). 1988. Atlas des amphibiens et reptiles du Québec. 1st ed. St. Lawrence Valley Natural History Society.

Bider, R. (ed.). 1990. Atlas des amphibiens et reptiles du Québec. 3rd ed. St. Lawrence Valley Natural History Society.

Bleakney, J.S. 1958. A zoogeographic study of the amphibians and reptiles of eastern Canada. Natl. Mus. Can. Bull. No. 155. 119 pp.

The status of New Brunswick amphibian populations

Donald F. McAlpine

Abstract

Although the distributions of most amphibians occurring in New Brunswick are generally known, quantitative data on populations are virtually nonexistent. There is evidence that the aerial application of the insecticide DDT to 120 ha of northern New Brunswick forests in 1952 led to considerable mortality of larval amphibians. There is no evidence that reduced dosages of DDT applied after this date, or various other forest insecticides sprayed over large areas of New Brunswick during the last four decades, have had any direct impact on amphibian populations. Although it is estimated that less than 10% of freshwater wetlands in New Brunswick have disappeared in the last 100 years, information now available is insufficient to suggest whether provincial amphibian populations are declining, increasing, or stable.

Résumé

Même si l'aire de répartition de la plupart des amphibiens du Nouveau-Brunswick est généralement connue, il n'existe pratiquement pas de données quantitatives sur leurs populations. Certaines conclusions d'observations permettent d'affirmer que la pulvérisation en 1952 de DDT sur des forêts du nord du Nouveau-Brunswick, d'une superficie totale de 120 ha, a entraîné la mort d'un grand nombre de larves. Aucun élément d'information ne nous permet d'affirmer que la décision prise après cette date de limiter les pulvérisations de DDT ou que la pulvérisation d'autres insecticides forestiers sur de grandes superficies de la province depuis les 40 dernières années aient eu un impact direct sur les populations d'amphibiens. Même si l'on estime que moins de 10 % des milieux d'eau douce du Nouveau-Brunswick ont disparu au cours des cent dernières années, les éléments d'information dont nous disposons actuellement ne nous permettent pas de conclure au déclin, à l'accroissement ou au maintien des populations d'amphibiens.

Introduction

There is virtually no information on trends in New Brunswick amphibian populations, and there have been few studies of the life histories of amphibians in the province. In addition, detailed distribution maps describing the provincial ranges of amphibians in New Brunswick have yet to be published. However, a provisional provincial atlas is in preparation (unpubl. data), and the ranges of amphibians in the 206-km^2 Fundy National Park have been plotted (Woodley and Rosen 1988).

Fresh water and, by extrapolation, the freshwater habitats on which all New Brunswick amphibians depend constitute only a fraction of the area of the eastern and northeastern sections of the province. However, in the extreme southwest, this area of fresh water rises to 6–7%, whereas fresh water covers 1–3% in the remainder of the province (Department of Energy, Mines and Resources 1974). Although there are no specific statistics reporting the extent of loss of freshwater wetlands in New Brunswick, it is estimated that less than 10% of the province's freshwater wetland habitats have disappeared in the last 100 years (L. Roberts, pers. commun.). Conversely, road construction and extensive clear-cutting of forests have created many small, ephemeral pools. Such habitats can provide ideal breeding sites for species such as the Wood Frog (*Rana sylvatica*), Spring Peeper (*Hyla crucifer*), and Yellow-spotted Salamander (*Ambystoma maculatum*). It has also been reported that as much as 14% of remaining diked salt marsh is being actively converted to freshwater marsh through the impoundment of water behind existing dikes (Environment Canada 1986).

While keeping the general lack of information on the life histories and abundances of New Brunswick amphibians in mind, it is the intent of this review to provide an overview of the status of New Brunswick amphibians. Sixteen species are native to the province: the Eastern Newt (*Notophthalmus viridescens*), Blue-spotted Salamander (*Ambystoma laterale*), Yellow-spotted Salamander, Dusky Salamander (*Desmognathus fuscus*), Two-lined Salamander (*Eurycea bislineata*), Four-toed Salamander (*Hemidactylium scutatum*), Redback Salamander (*Plethodon cinereus*), American Toad (*Bufo americanus*), Tetraploid Gray Treefrog (*Hyla versicolor*), Spring Peeper, Wood Frog, Northern Leopard Frog (*Rana pipiens*), Pickerel Frog (*Rana palustris*), Green Frog (*Rana clamitans*), Mink Frog (*Rana septentrionalis*), and Bullfrog (*Rana catesbeiana*).

The nature of the historical data base

Although Gesner (1847) noted that seven species of amphibians populated New Brunswick (two frogs, two toads, and three salamanders), systematic study of New Brunswick amphibians did not begin in earnest until the last decade of the 19th century, with the investigations of Philip

Cox (1898, 1899a, 1899b, 1899c, 1907). A hiatus in study following this period lasted until the 1950s, when J. Sherman Bleakney began his pioneering work on the zoogeography of the eastern Canadian herpetofauna. In 1965, Stanley W. Gorham joined the New Brunswick Museum, initiating distributional surveys of New Brunswick amphibians that built on the previous work of Bleakney (1958) and culminated in a short guide to provincial amphibians (Gorham 1970). In addition, Gorham established a herpetological collection at the New Brunswick Museum for the first time. This collection, and specimens obtained by Bleakney and now housed at the Canadian Museum of Nature in Ottawa, are the principal sources of historical data on New Brunswick amphibian populations.

In addition to specimen collections, the field notes of investigators describing excursions in search of New Brunswick amphibians are held at both the New Brunswick Museum and the Canadian Museum of Nature. When combined, these notes provide a discontinuous record of about 40 years of field study of New Brunswick amphibians. During the last three decades, the New Brunswick Museum has also maintained records of unpublished observations and photographs on New Brunswick amphibians; however, additions to these files have been limited. One can also find anecdotal reports on spring calling dates for New Brunswick frogs and other observations of amphibians in the province in two local newsletters for naturalists (Nature News, 1950–69; N.B. Naturalist, 1970–present).

As a result of the investigations of Bleakney and Gorham, there is now a good general understanding of the distributions of most New Brunswick amphibians. Nonetheless, gaps in our understanding of the fine details of the provincial ranges of some species remain, particularly with respect to the north of the province, where relatively little field study of amphibians has been carried out. The following two examples illustrate these points.

The Four-toed Salamander was first reported in the province from Fundy National Park, situated along the south coast of the province, in 1983 (Woodley and Rosen 1988). This salamander has not been observed in New Brunswick since, although the distribution of the species in Maine, Nova Scotia, and Quebec suggests it must be much more common than the single record would indicate. Much habitat suitable for the Four-toed Salamander exists throughout New Brunswick, particularly in the northeast.

The true range of the Tetraploid Gray Treefrog in New Brunswick has proven to be particularly difficult to establish. Until recently, the species appeared confined to a single marsh in the centre of the province (McAlpine et al. 1980) and was considered a prime candidate for protection under the New Brunswick Endangered Species Act (Majka 1981; Clayden et al. 1984). Field surveys carried out in 1988, 1989, and 1990 located 13 new localities for this frog in southwestern New Brunswick (McAlpine et al., in press). Most of the sites are ponds or marshes created by road construction, excavation of gravel, or the flooding of lake margins through the activities of humans or beavers. These observations suggest that the abundance of the Tetraploid Gray Treefrog in New Brunswick may have been enhanced by human activities.

Scope of studies on New Brunswick amphibian populations

With very few exceptions, nearly everything published on New Brunswick amphibians to date has been concerned with species distributions. There is a virtual dearth of quantitative data on New Brunswick amphibian populations or the factors that might influence the natural abundance of amphibians in the province.

However, a number of studies have attempted to assess the impact of pesticides on the abundances of New Brunswick amphibians. Pearce and Price (1975) reviewed most of these studies, which examined the impact of such pesticides as phosphamidon, zectran, matacil, DDT, and fenitrothion on amphibians in New Brunswick. Only the last two insecticides have been widely used over a period of many years in the province.

Considerable mortality of larval amphibians was noted in pools in cutover areas in northwestern New Brunswick in 1952, when DDT was sprayed over 120 ha at the rate of 1.1 kg/ha. Although the number of acres of New Brunswick sprayed after 1952 increased markedly, the operational dosage of DDT in New Brunswick was reduced to 92 mL/ha after 1952 and was later lowered to 46 mL/ha, applied once or twice a season. Pearce and Price (1975) felt that it was unlikely that the high amphibian mortality rates reported earlier would have recurred in the major DDT spray operation that continued in New Brunswick through the late 1960s. Nonetheless, in central New Brunswick forests, where a cumulative total of DDT of about 4.5 kg/ha had been sprayed in the 10 years preceding 1967, substantial residues were found in Redback Salamanders, American Toads, Spring Peepers, and Green Frogs. When the same site was resampled in 1971, four years after the last application of DDT, no residues were detected in Redback Salamanders, a Spring Peeper, and a Green Frog (I.W. Varty, pers. commun., cited in Pearce and Price 1975).

Since its first experimental application in 1965, fenitrothion has been used to control spruce budworm on nearly a million or more hectares of New Brunswick forestland annually. Dosages have varied, but fenitrothion has generally been applied at the rate of 210 g/ha once or twice a season during the last decade (Kettela 1980; D. Busby, pers. commun.). Amphibian monitoring has been associated with several fenitrothion spray programs. In 1969, counts of frogs, principally the Green Frog, were made in and around a pond on the floodplain of the Southwest Miramichi River in northeastern New Brunswick. By request, the pond was sprayed once with a fenitrothion emulsion at an emitted dosage of 23 mL/ha. Pearce and Temple (1969) reported that census data were variable but did not indicate any population depression two days after spraying. A more intensive amphibian monitoring program was conducted in Fundy National Park in 1970, where a fenitrothion emulsion was applied in two sprays of 23 mL/ha each, nine and 17 days apart (Rick and Gruchy 1970). No mortality of caged Green Frogs, Mink Frogs, or American Toads (adults or tadpoles) was detected, and no unusual activity was noted among free-living amphibians, including three species of salamanders, six frog species, and frog and salamander larvae. During the study period, no depression of Green Frog populations at 14 selected ponds within the park was observed (C.H. Buckner, pers. commun., cited in Pearce and Price 1975).

Aquatic invertebrate responses in forest streams and ponds following fenitrothion spraying have been reported as quite variable (summarized in Fairchild and Eidt 1988). However, invertebrates in bog ponds have been shown to be especially sensitive to fenitrothion. Fairchild (1990) reported that freshwater arthropod benthos populations in such habitats may be reduced by as much as 50% and that recovery may take more than 12 months. Impacts are of such magnitude as to substantially alter energy flow through these ecosystems. This has raised some concerns that abundances of aquatic amphibians in forest ponds and lakes may be reduced indirectly through a reduction of prey species.

Acting on these concerns, the Canadian Wildlife Service initiated a field program in 1991 to determine the abundance of frogs in areas of New Brunswick subjected to long-term spraying with fenitrothion. Using transect surveys, densities of frogs at 10 sites in northern New Brunswick were determined in June, July, and August. Only Mink Frogs were abundant enough to provide figures sufficient for analyses. Mean summer densities of Mink Frogs at sites censused varied widely (range: 0.99–68.75 frogs/100 m^2). Mink Frog densities were positively correlated with the abundance of submergent vegetation and negatively correlated with the frequency of fenitrothion spraying in preceding years and with the amount of sulphate in the pond water.

Since 1985, amphibian egg mass surveys have been carried out at four sites in Fundy National Park. These surveys grew out of the 1985 Park Conservation Plan for Fundy National Park in which concern for the effects of acidic precipitation were expressed (Woodley and Taylor 1985). The project is designed to monitor reproductive effort in the Yellow-spotted Salamander and the Wood Frog in relation to the pH of breeding sites. Results to date have shown some minor fluctuations in numbers of egg masses at sites, but there have been no major changes in pH, and pH values known to inhibit hatching of eggs have not been recorded (L. Collingwood, pers. commun.). It is worth noting that egg counts taken since 1989 are not strictly comparable with counts taken from 1985 to 1988. Only shorelines were surveyed up until 1988, whereas a rubber boat has been used to survey entire ponds since that time.

Life history data on New Brunswick amphibians, a critical ingredient in any plan to conserve these animals or their habitats in the province, are extremely limited. Gorham (1964) reported observations, collected mostly during the years 1948–53, on spring emergence and calling dates for amphibians around Browns Flat, in the southern Saint John River valley. McAlpine and Dilworth (1989) provided detailed quantitative information on microhabitat use and prey size in Bullfrogs, Green Frogs, and Northern Leopard Frogs at a site in central New Brunswick.

Conclusion

In conclusion, information now available is insufficient to demonstrate, or even suggest, whether New Brunswick amphibian populations are declining, increasing, or stable. Although there is an obvious need for long-term monitoring of amphibian populations in Canada, there is an equally pressing need to learn a great deal more about amphibian habitat use. Coupling monitoring programs with research designed to reveal the kinds of natural factors that regulate and influence amphibian densities could be a useful approach.

Acknowledgements

I am grateful to Neil Burgess and Dan Busby, Canadian Wildlife Service, Lorie Collingwood, Fundy National Park, and Lorrie Roberts, Fish and Wildlife Branch, New Brunswick Department of Natural Resources and Energy, each of whom graciously complied with my short-order requests for information during the course of preparing this review.

Literature cited

Bleakney, J.S. 1958. A zoogeographic study of the amphibians and reptiles of eastern Canada. Natl. Mus. Can. Bull. No. 155. 119 pp.

Clayden, S.R., D.F. McAlpine, and C. Guidry. 1984. Rare and vulnerable species in New Brunswick. N.B. Mus. Publ. Nat. Sci. No. 2. 95 pp.

Cox, P. 1898. Batrachia of New Brunswick. Bull. Nat. Hist. Soc. N.B. 41:64–66.

Cox, P. 1899a. A preliminary list of the batrachia of the Gaspé Peninsula and the Maritime provinces. Ottawa Nat. 13:194–195.

Cox, P. 1899b. Freshwater fishes and batrachia of the peninsula of Gaspé, P.Q. and their distribution in the Maritime provinces of Canada. Trans. R. Soc. Can. 5:141–154.

Cox, P. 1899c. The Anura of New Brunswick. Proc. Miramichi Nat. Hist. Assoc. 1:9–19.

Cox, P. 1907. Lizards and salamanders of Canada. Proc. Miramichi Nat. Hist. Assoc. 5:46–55.

Department of Energy, Mines and Resources. 1974. National atlas of Canada. Ottawa. 254 pp.

Environment Canada. 1986. Wetlands in Canada: a valuable resource. Lands Directorate Fact Sheet 86-4, Ottawa. 8 pp.

Fairchild, W.L. 1990. Perturbation of the aquatic invertebrate community of acidic bog ponds by the insecticide fenitrothion. Ph.D. thesis, Univ. of New Brunswick, Fredericton. 174 pp.

Fairchild, W.L. and D.C. Eidt. 1988. Perturbation of the aquatic invertebrate community of acidic bog ponds by fenitrothion and aminocarb. Page 44 *in* Sexsmith, W.A. (ed.), Environmental Monitoring of Forestry Control Operations (EMOFOCO). New Brunswick Department of Municipal Affairs and Environment. 70 pp.

Gesner, A. 1847. New Brunswick; with notes for emigrants. Simmonds and Ward, London. 388 pp.

Gorham, S.W. 1964. Notes on the amphibians of the Browns Flat area, New Brunswick. Can. Field-Nat. 78:154–160.

Gorham, S.W. 1970. The amphibians and reptiles of New Brunswick. N.B. Mus. Monogr. Ser. No. 6. 30 pp.

Kettela, E.G. 1980. Aerial spray regimes. Pages 19–23 *in* Varty, I.W. (comp.), Environmental surveillance in New Brunswick 1978–1979; effects of spray operations for forest protection. Department of Forest Resources, Univ. of New Brunswick, Fredericton. 76 pp.

Majka, M. 1981. Gray Treefrog; an endangered species in New Brunswick. N.B. Nat. 11:45–46.

McAlpine, D.F. and T.G. Dilworth. 1989. Microhabitat and prey size among three species of *Rana* (Anura: Ranidae) sympatric in eastern Canada. Can. J. Zool. 67:2244–2252.

McAlpine, D.F., S.W. Gorham, and A.D.B. Heward. 1980. Distributional status and aspects of the biology of the gray treefrog, *Hyla versicolor*, in New Brunswick. J. N.B. Mus. 1980:92–102.

McAlpine, D.F., T.J. Fletcher, S.W. Gorham, and I.T. Gorham. In press. Distribution and habitat of the tetraploid gray treefrog, *Hyla versicolor*, in New Brunswick and eastern Maine. Can. Field-Nat.

Pearce, P.A. and I.M. Price. 1975. Effects on amphibians. Pages 301–305 *in* Prebble, M.L. (ed.), Aerial control of forest insects in Canada. Environment Canada, Ottawa. 329 pp.

Pearce, P.A. and S.M. Temple. 1969. Effects of forest spraying of sumithion on birds and amphibians in New Brunswick. Department of Indian Affairs and Northern Development/Canadian Wildlife Service, Pesticides Section. Ms. Rep. 19. 7 pp.

Rick, A.M. and I.M. Gruchy. 1970. Effects on amphibians. *In* Summary of Canadian Wildlife Service supported projects; 1970 New Brunswick spruce budworm control program; Appendix XX. Interdepartmental Committee on Forest Spray Operations, Ottawa. 16 pp.

Woodley, S.J. and M. Rosen. 1988. First record of the four-toed salamander, *Hemidactylium scutatum*, in New Brunswick. Can. Field-Nat. 102:712.

Woodley, S. and E. Taylor. 1985. Amphibian egg mass survey; spring 1985; Fundy National Park. Fundy National Park Ms. Rep. 15 pp.

Declines in Blanchard's Cricket Frog in Ontario

Michael J. Oldham

Abstract

Blanchard's Cricket Frog (*Acris crepitans blanchardi*) has always been a rare species in Canada, occurring only in extreme southwestern Ontario. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has recently designated the species Endangered in Canada. Confirmed Canadian records are only from Point Pelee and Pelee Island. Blanchard's Cricket Frog underwent a dramatic decline on Pelee Island during the 1970s, and it has been detected at only a single site in recent years. The reasons for this decline are puzzling, as populations of other amphibian species on the island do not appear to have declined; in fact, some have actually increased. Declines in Blanchard's Cricket Frog populations have been noted elsewhere in the northern portions of their range.

Résumé

Acris crepitans blanchardi (une s.-esp. de la Rainette grillon) s'est toujours avéré une espèce rare au Canada, observée seulement dans l'extrême sud-ouest de l'Ontario. Le Comité sur le statut des espèces menacées d'extinction au Canada (CSEMDC) a récemment accordé à cette espèce la désignation d'espèce en danger de disparition. Les seules mentions d'observation vérifiées dont nous disposons proviennent de la pointe Pelée et de l'île Pelée. Les effectifs de cette sous-espèce ont connu une baisse dramatique dans l'île Pelée durant les années 1970, et la sous-espèce a été localisée à un seul endroit au cours des dernières années. Les motifs à l'origine de ce déclin constituent un mystère, d'autant plus que les populations d'autres espèces d'amphibiens observées dans l'île ne semblent pas être en baisse et que quelques-unes ont en réalité connu une hausse. D'autres baisses ont été constatées dans les effectifs de la sous-espèce dans des secteurs situés au nord de son aire de répartition.

Introduction

Although it is widespread and locally common in eastern North America, the Northern Cricket Frog (*Acris crepitans*) has been confirmed in Canada only from Point Pelee National Park and nearby Pelee Island in Lake Erie, both in extreme southwestern Ontario. The subspecies occurring in Canada is Blanchard's Cricket Frog (*A. c. blanchardi*). There are a few auditory reports by experienced and reliable observers from elsewhere in southwestern Ontario (Oldham and Campbell 1986), but recent intensive work in the area by the Ontario Herpetofaunal Summary project has failed to record any populations away from Pelee Island (Weller and Oldham 1988; Oldham 1990; Ontario Herpetofaunal Summary files). At Point Pelee, the species was collected once by P.A. Taverner in 1913 (National Museum of Canada specimen catalogue) and once by E.B.S. Logier in 1920 (Logier 1925), but since then there has been only a single auditory report in 1972 (Rivard and Smith 1973). Unsuccessful searches by several experienced naturalists in the 1980s make it unlikely that Blanchard's Cricket Frogs still occur there.

Historical populations

In 1950, James L. Baillie of the Royal Ontario Museum visited Pelee Island and found Blanchard's Cricket Frogs to be common and widespread (Oldham and Campbell 1986). No further information is available on Blanchard's Cricket Frog numbers on Pelee Island until 1970, when Craig Campbell began visiting the island. In the early and mid-1970s, Blanchard's Cricket Frogs were still widespread, and Campbell recorded the species from 20 different sites on Pelee Island between 1970 and 1977 (Oldham and Campbell 1986). During the 1970s, Blanchard's Cricket Frogs could be found at several places in the island's deep drainage canals and also in natural marshes and abandoned quarries. Since 1977, Blanchard's Cricket Frog has been found at only a single site, a natural marsh at Fish Point near the southern tip of the island. During the 1980s, several complete searches of all 20 historical localities revealed Blanchard's Cricket Frogs only at Fish Point (Oldham 1983). Even there, they appear to exist in small numbers and in some years are not detected at all. In 1986, a detailed biological inventory of several significant natural areas on Pelee Island, including Fish Point, was conducted by an experienced field biologist. This survey included specific searches for Blanchard's Cricket Frogs, but none was detected (J. Kamstra and M.J. Oldham, unpubl. data). However, in 1987, Blanchard's Cricket Frog was again heard at Fish Point by a reliable observer (Ontario Herpetofaunal Summary files). I am not aware of any Canadian Blanchard's Cricket Frog reports since 1987, nor have any sightings been submitted to the Ontario Herpetofaunal Summary since then.

Reasons for declines in the population

Reasons for the Blanchard's Cricket Frog decline on Pelee Island are unclear. Potential factors are many and varied, including fluctuating water levels in Lake Erie, causing flooding and scouring of shoreline lagoons; dredging and draw-down of the drainage canals inhabited by Blanchard's Cricket Frog; periodic drought affecting some breeding sites; canals and lagoons becoming overgrown with vegetation, creating too much shade for reproduction and development; breaching of lakeshore pools, allowing predatory fish and Common Carp (*Cyprinus carpio*) to degrade Blanchard's Cricket Frog spawning grounds; extensive predation by herons and other wading birds; extensive predation by Bullfrogs (*Rana catesbeiana*); former grazing of aquatic vegetation by cattle, and trampling of banks at one site; bait fishing, especially for bass, using Blanchard's Cricket Frog as lures; dumping, filling, and dredging of shoreline properties for cottages and flood protection; bad weather for overwintering and chorusing; pollution of drainage canals by fertilizers and pesticides; siltation; and spraying of oil in one site (to control large numbers of Northern and Lake Erie water snakes [*Nerodia sipedon sipedon*; *Nerodia s. insularum*]). Campbell (1976, 1977) reported a greater than 50% decline in Blanchard's Cricket Frogs on Pelee Island between 1970 and 1975. Major flooding took place on the island in November 1972 and March 1973, which probably resulted in the elimination of several populations.

Trends in other species at Pelee Island

Interestingly, populations of other species of amphibians on Pelee Island do not appear to have declined during the same time period, and two have actually increased. Several common amphibian species on the adjacent Ontario mainland have apparently always been rare or absent on Pelee Island—for example, Redback Salamander (*Plethodon cinereus*), Spring Peeper (*Pseudacris crucifer*), Western Chorus Frog (*Pseudacris triseriata*), Gray Treefrog (*Hyla versicolor*), Northern Leopard Frog (*Rana pipiens*), and Green Frog (*Rana clamitans*). Mole salamanders (*Ambystoma laterale* [Blue-spotted Salamander], *A. texanum* [Smallmouth Salamander], and their hybrids) are common on Pelee Island, and no decline in their numbers has been noted. American Toads (*Bufo americanus*) and Bullfrogs are both common and widespread on Pelee Island and have actually increased in numbers over the past two decades. Fowler's Toad (*Bufo woodhousei fowleri*) appears to have disappeared from the island, but its decline and disappearance occurred prior to that of Blanchard's Cricket Frog. Fowler's Toads are known from Pelee Island only from museum specimens collected in 1950 and 1960.

Populations outside Canada

Elsewhere in the northern portions of its range, similar declines in Cricket Frog populations have been reported. Recent declines have been noted in New York (A. Breisch, pers. commun.), Michigan (J.A. Fowler, pers. commun.), and Wisconsin (Vogt 1981), although the species is reported to be common and widespread farther south in its range (Oldham and Campbell 1986).

Literature cited

Campbell, C.A. 1976. Preliminary ecological report on Lighthouse Point, Fish Point and East Sister Island Nature Reserves, Essex County, Ontario. Unpubl. rep., Ontario Ministry of Natural Resources, Chatham. 115 pp.

Campbell, C.A. 1977. Some threatened frogs and toads in Ontario. Pages 130–131 in Mosquin, T. and C. Suchal (eds.), Canada's threatened species and habitats. Canadian Nature Federation, Ottawa.

Logier, E.B.S. 1925. Notes on the herpetology of Point Pelee. Can. Field-Nat. 39(5):91–95.

Oldham, M.J. 1983. An update on the status of the Blue Racer (*Coluber constrictor foxi*), Lake Erie Water Snake (*Nerodia sipedon insularum*), Blanchard's Cricket Frog (*Acris crepitans blanchardi*), and Smallmouth Salamander (*Ambystoma texanum*) on Pelee Island, Ontario. Unpubl. rep., Ontario Ministry of Natural Resources, Toronto. 105 pp.

Oldham, M.J. 1990. Ontario Herpetofaunal Summary. Pages 195–205 *in* Allen, G.M., P.F.J. Eagles, and S.D. Price (eds.), Conserving Carolinian Canada. Univ. of Waterloo Press, Waterloo, Ontario.

Oldham, M.J. and C.A. Campbell. 1986. Status report on Blanchard's Cricket Frog, *Acris crepitans blanchardi*, in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. 79 pp.

Rivard, D.H. and D.A. Smith. 1973. A herpetological inventory of Point Pelee National Park, Ontario. Unpubl. rep., Parks Canada, Ottawa. 127 pp.

Vogt, R.C. 1981. Natural history of amphibians and reptiles of Wisconsin. Milwaukee Public Museum, Milwaukee, Wisconsin. 205 pp.

Weller, W.F. and M.J. Oldham. 1988. Ontario Herpetofaunal Summary 1986. Ontario Field Herpetologists, Cambridge. 221 pp.

Is there a Bullfrog decline in Ontario?

Michael Berrill, Susan Bertram, Pat Tosswill, and Victoria Campbell

Abstract

Evidence from a variety of sources, including commercial harvesters, Ministry of Natural Resources census data, and field studies, indicates that Bullfrogs in Ontario are less common now than they were in previous decades, and larger ones are particularly hard to find. Possible explanations for this decline include increased predator pressure, loss of wetland habitats, harvesting, and poaching. Sensitivity to low pH and contaminants may also be important. Natural population oscillations in response to other environmental factors may also occur, confounding the issue of whether the decline is temporary or potentially terminal. Carefully selected long-term studies are needed to determine what is happening to Bullfrog populations in Ontario.

Résumé

Des témoignages provenant de diverses sources, dont les exploitants commerciaux, les données de recensement du ministère des Ressources naturelles et les études de terrain, indiquent que les Ouaouarons de l'Ontario sont moins nombreux que durant les dernières décennies et qu'il est particulièrement difficile d'en trouver de grande taille. Parmi les explications possibles de cette baisse, on trouve une pression de prédation accrue, la perte d'habitats humides, l'exploitation commerciale et le braconnage. La sensibilité aux milieux caractérisés par un bas pH et aux contaminants peut également constituer un motif important de déclin. Il s'agit peut-être de fluctuations naturelles de la population liées par d'autres facteurs écologiques, ce qui nous empêche pour l'instant de conclure si cette baisse est provisoire ou le signe d'une extirpation possible de l'espèce. Des études à long terme portant sur des sujets soigneusement déterminés devront être réalisées afin de permettre de juger du sort des effectifs de l'espèce en Ontario.

Introduction

As with all examples of potential amphibian decline, there are two questions:

(1) Is there any convincing evidence of a Bullfrog decline in Ontario?

(2) If so, what are the possible causes of the decline?

Evidence of a decline

(1) *Summary of a statement from a native harvester:* His people have hunted Bullfrogs in the region south of Peterborough for the past several hundred years, probably much longer. He and others have hunted Bullfrogs for the past several decades. Just 15–20 years ago, he and his friends could fill their freezers and still have a few hundred kilograms to sell in Toronto. Ten years ago, they had trouble filling their freezers. Five years ago, they quit hunting to allow recovery for a couple of years. They have not noticed any recovery.

(2) *Summary of a statement from a commercial harvester:* He has been a serious harvester for the last 15 years in the Belleville area, although he harvested intermittently for the 15 years prior to that. He has noticed oscillations in both size and number over the years but now is finding it harder and harder to find the larger individuals.

(3) *Statement from cottager:* She remembers the roar of Bullfrogs from the summers of her youth 30 years ago in the Kawartha Lakes, and now there is silence. (There are many such memories; the obvious, midsummer breeding season makes these memories more reliable than most.)

(4) *Ministry of Natural Resources data:* Bullfrogs were censused in Carleton Place district in 1977 and again in 1984–85. Populations apparently declined from 20% to 80% per location during that period.

(5) *Nogies Creek Site:* E.J. Crossman reports that Bullfrogs are much less common at the Nogies Creek site now than when he did extensive mark and recapture work in 1977–80. A new and detailed monitoring effort would be worth initiating at that site.

(6) *Algonquin Park:* In 1987, L. Shirose and R. Brooks captured 75 male Bullfrogs of a chorusing population in Algonquin Park. Male snout-vent length ranged from 90 to 130 mm, with a mean of 105 mm. That corresponds to a mean weight of about 110 g, which is not particularly large for a chorusing Bullfrog: adults of 300 g should be common in a chorusing population. The other data Shirose and Brooks have from their 1985–87 study indicate slower growth rate and greater age at first

reproduction by Bullfrogs in the Algonquin Park population than by more southerly populations, but there is as yet no clear evidence of decline. Like the Nogies Creek population, it is now a population worth following.

(7) *Our 1990–91 data on size of chorusing males:* During the summer of 1991, we captured, weighed, and released all chorusing male Bullfrogs on single night visits at three sites in the Kawartha Lakes region: one was Nogies Creek, the second was a large beaver pond, and the third was a piece of Pigeon River. All provided a similar profile, in turn similar to the Algonquin Park data. The Pigeon River profile is what one might predict of a harvested population (Fig. 1).

The Pigeon River population was harvested until several years ago, definitely ceasing prior to 1989. The chorusing males at that site were captured and weighed in 1990 as well, and we predicted that we would notice an increase in size of chorusing males in 1991. Such an increase did not occur (Fig. 2).

We weighed all chorusing males on a single night visit to a fourth population, near Lake Opinicon, with quite different results: the males were much larger. Smaller males the size of those chorusing at the other sites were also missing: either they were silent or eliminated from the chorus, or they were still immature, implying that the other three populations were stunted. The differences are striking enough to warrant further exploration (Fig. 3).

Conclusion

No matter the source, the result is the same. Bullfrogs are less common now than they were in previous decades, and larger ones are particularly hard to find. Despite probable oscillations, the overall trend in southern Ontario is decline. To understand what is happening in these populations, long-term studies are necessary.

Assuming the decline is real, what are its causes?

(1) *The native harvester:* "We haven't changed our practices in the last few hundred years. We have always been sensitive to the numbers of animals, and do not overhunt. The frogs have disappeared because the Ministry of Natural Resources keeps stocking the lakes with fish that are predators of the frogs."

(2) *The commercial harvester:* "I haven't changed my methods. I don't break the law. I'd be crazy to take everything. The frogs are going because their habitats are being destroyed by cottagers."

(3) *A poacher one of us met one day:* "I know it's not legal, but a couple of times a summer my buddies and I go up around Nogies Creek and north of Stony Lake and grab a pile of the big ones. Nothing better than frog legs on the barbeque."

Increased predator pressure, loss of wetland habitats, harvesting, and poaching are obvious factors that will result in Bullfrog decline. Can they account for all of the observed decline? Like some other ranids, Bullfrogs are also likely to be sensitive, especially as embryos and tadpoles, to low pH and contaminants, such as low levels of pesticides. We do not know at present how important such sensitivity may be in affecting Bullfrog growth, reproduction, or survival. However, as with all other examples of amphibian decline, there are clearly a number of interacting factors contributing to the apparent decline of Bullfrogs in south-central Ontario. Natural population oscillations in response to other environmental factors no doubt also occur, confounding the issue of whether the observed decline is temporary and not unusual or in fact unusual and potentially terminal. Once again, only carefully selected long-term studies will answer the many questions.

Figure 1
Weight of chorusing male Bullfrogs at three locations

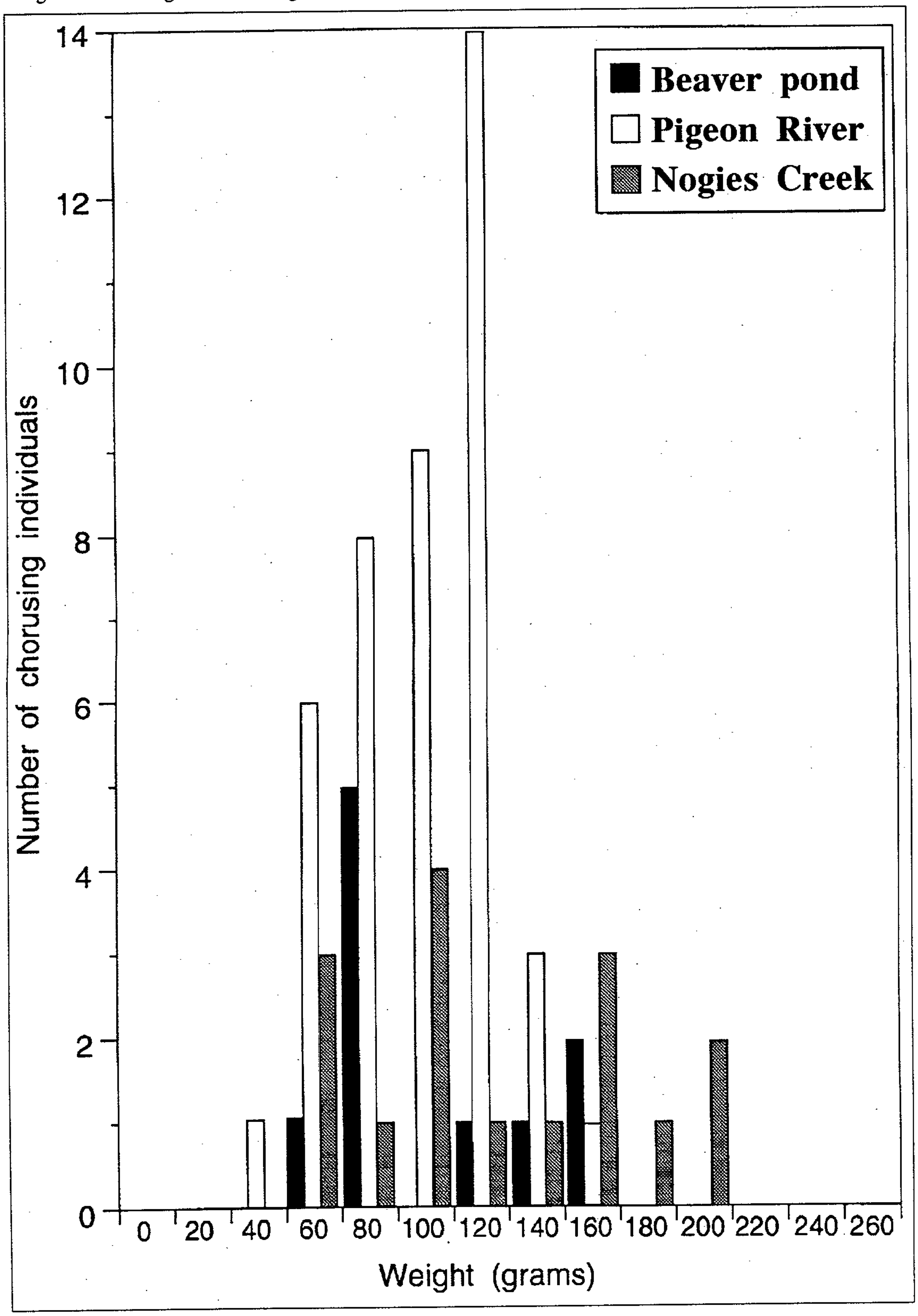


Figure 2
Weight of chorusing male Bullfrogs at Pigeon River in 1990 and 1991

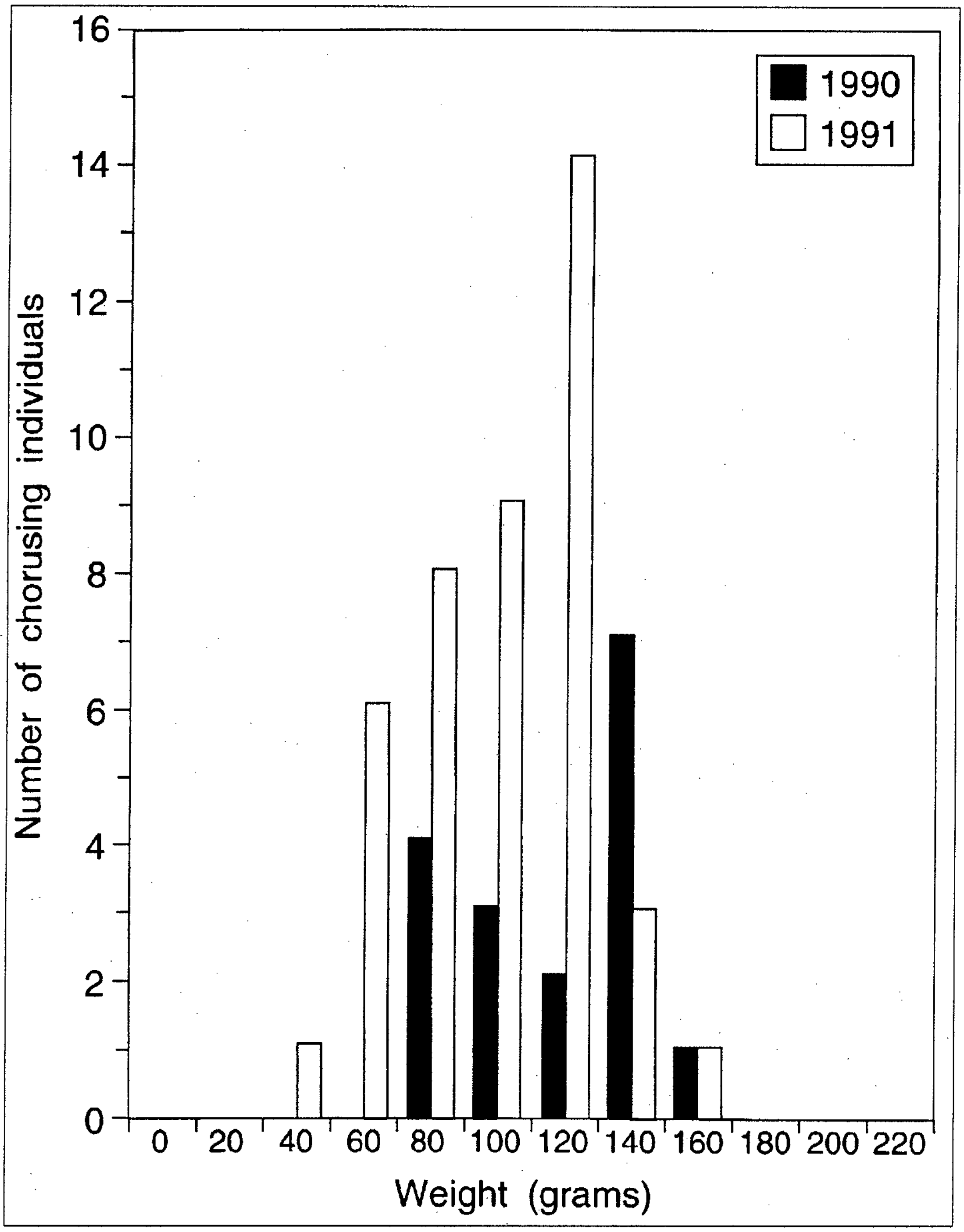
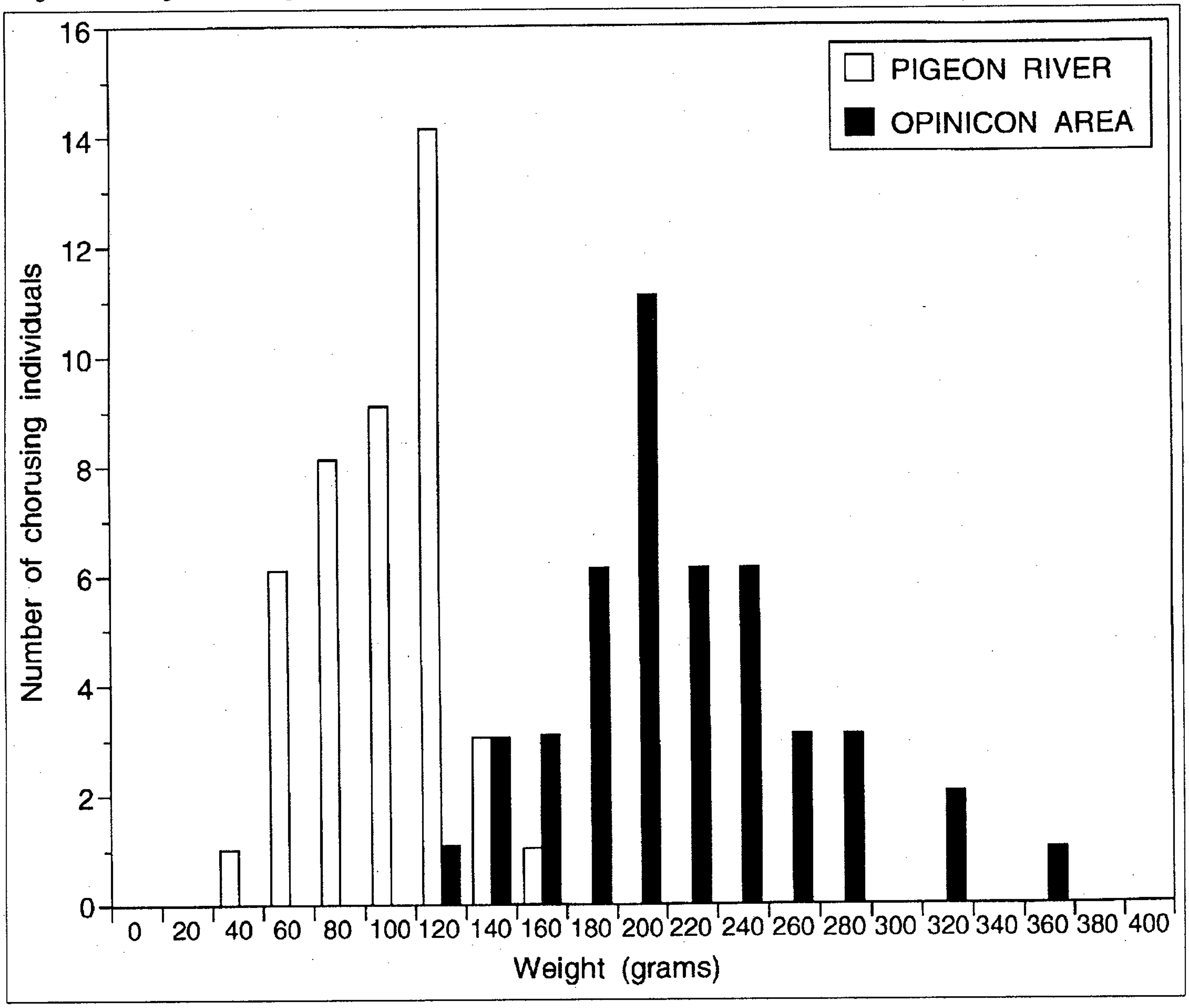


Figure 3
Weight of chorusing male Bullfrogs from Pigeon River and the Opinicon area



Fowler's Toads (*Bufo woodhousei fowleri*) at Long Point, Ontario: changing abundance and implications for conservation

David M. Green

Abstract

Fowler's Toad (*Bufo woodhousei fowleri*) activity and abundance were surveyed during the four consecutive breeding seasons of 1988–91. Calling male abundance rose markedly from 11 toads in the survey area in 1988 to over 245 in 1991. Mark/recapture surveys of noncalling males, adult females, and juveniles showed a similar trend. The population density of toads along a 1-km stretch of Lake Erie beach at Thoroughfare Point was estimated at 1800 toads/km in 1991. The high water levels in Lake Erie in the mid-1980s that could have produced less favourable conditions for tadpole development and survivorship may have been responsible for the previous decline in toad abundance. The extent of human disturbance does not appear to have radically changed throughout the cycle of decline and recovery, but it is probable that the toads found at the western base of the point are migrants from a reservoir population farther to the east along the point. Although they have been intensively monitored for only four years, the Fowler's Toads at Long Point are one of the few Canadian amphibian populations for whom multiple-year censuses—critical data necessary for addressing concerns over apparently global declines in amphibian populations—are available.

Résumé

Un relevé de l'activité et de l'abondance de *Bufo woodhousei fowleri* (une s.-esp. du Crapaud de Woodhouse) a été effectué durant quatre saisons de reproduction consécutives, entre 1988 et 1991. Le nombre de mâles chanteurs a connu une hausse significative et est passé, dans l'aire d'étude, de 11 crapauds en 1988 à plus de 245 individus, en 1991. La même tendance a été constatée à la suite de relevés de marquage et de reprise des mâles non chanteurs, des femelles adultes et des juvéniles. L'indice de densité de crapauds recensés le long d'une bande de 1 km, sur une plage du lac Érié jusqu'à la pointe Thoroughfare, a été évalué en 1991 à 1 800 individus par kilomètre. Il est possible que le niveau élevé des eaux du lac Érié constaté au milieu des années 1980 ait été à l'origine de conditions moins favorables au développement et à la survie des têtards et puisse expliquer la baisse antérieure notée dans l'abondance des spécimens. Même si le degré de dérangement causé par l'activité humaine ne semble pas avoir connu de variations marquées tout au long de ce cycle de déclin et de rétablissement, il est probable que les crapauds observés dans le secteur ouest de la pointe provenaient d'un bassin de population situé le long de la pointe un peu plus loin à l'est. En dépit du fait qu'elles ont été l'objet d'un suivi intensif durant seulement quatre ans, les populations de *B. w. fowleri* constituent l'une des rares populations canadiennes d'amphibiens pour lesquelles l'on dispose de données de recensement échelonnées sur plusieurs années, ces données étant toutes absolument nécessaires pour faire face aux questions soulevées par le déclin apparemment général des populations d'amphibiens.

Introduction

There has been considerable concern over apparent declines in amphibian populations throughout the world (Wake 1991). This has prompted the convening of several congresses and symposia in the past two years to discuss the problem. Ironically, one of the prevailing conclusions reached at these meetings has been that there are very few hard data on amphibian population abundance. Most records of amphibian declines are, at heart, anecdotal and require concerted scientific studies to back them up. Detailed annual surveys of amphibian populations designed rigorously to chart changes in population size are rare. However, the population of Fowler's Toads (*Bufo woodhousei fowleri*) at Long Point, Ontario, has been surveyed annually, beginning in 1988, to determine population sizes and trends, largely to study interactions with syntopic American Toads (*Bufo americanus*). These data can also be used to check for any evident fluctuations in their abundance.

Fowler's Toads are found in Canada only along the northeast shore of Lake Erie (Green 1989), with the largest population at Long Point. Museum and field records, although patchy and largely anecdotal, provide some picture of the history of population abundance, especially for the decade preceding 1988 (Oldham and Sutherland 1986; Oldham 1988; Green 1989). In the late 1970s and early 1980s, Fowler's Toads appeared to be reasonably abundant. However, Fowler's Toad numbers evidently crashed around 1986 (Green 1989). This decline coincided with unusually high water levels in Lake Erie and several severe winter storms in 1985–86.

The first concerted survey of Fowler's Toad numbers at Long Point in 1988 (Laurin and Green 1990) was undertaken in the region from Hahn Beach at the western end of Hastings Drive to the Thoroughfare Point unit of the Canadian Wildlife Service just east of Long Point Provincial Park (Fig. 1). Every calling male Fowler's Toad was marked and observed every night throughout the entire breeding season from early May until early June. Only 11 calling males were located at that time. Three more surveys in 1989, 1990, and 1991 intensively surveyed the same region throughout the breeding season. In contrast to the general picture of global decline in amphibian populations, these four years of study cumulatively demonstrate that Fowler's Toad numbers at Long Point have steadily risen. This, in turn, invites consideration of possible factors involved.

Materials and methods

The methods used to survey the toads have been steadily refined from 1988 to 1991 but do not differ substantially from those described by Laurin and Green (1990) for the 1988 field season. All study sites (Fig. 1) were inspected nightly throughout the period of 4 May to 12 June 1991. Air temperatures were recorded on a drum-type recording thermometer, and rainfall was measured with a tipping bucket rain gauge. All toads were weighed with a Pesola spring scale, measured (snout-vent length) with dial calipers, marked, and released. Body temperatures were taken with a quick-reading mercury thermometer (Miller and Weber Co.). Both calling males and breeding females were recorded and individually marked.

Animals were individually marked by toe-clipping using a scheme modified after Martof (1953) and Twitty (1966). Because toe-clipping, unless minimized, has been known to impair survivorship to some extent (Clarke 1972), the system used concentrated on the less critical toes of the hind feet and, following Briggs and Storm (1970), avoided cutting the innermost front toe (the thumb), which is important to males in amplexus. The additive numbering scheme (Fig. 2) enables toads to be numbered consecutively from 101 to 1599, while cutting no more than two toes on each hind foot and one toe on each front foot and never cutting the thumb. This provides enough numbers for several years' study before the numbers have to be reused.

Beginning in 1989, a 1-km stretch of Lake Erie beach along the Thoroughfare Point unit was marked every 200 m for a mark/recapture survey of nonbreeding toads. As observed by Breden (1988) in Indiana, juveniles and nonbreeding adults forage along the beach during the summer months and can be easily caught and marked during the evening. Toads along the beach were measured, marked, and recorded. Individual numbers were not assigned; instead, one interdigital web of one hind foot was clipped for all toads on a given evening so that, upon recapture, they could be identified as toads caught previously on a particular night.

Results

Detailed results of each year's surveys are presented in a series of reports to the Canadian Wildlife Service and Ontario Ministry of Natural Resources (Laurin and Green 1990; Green and Cantin 1990; Green and Porebski 1991; Green et al. 1991). Here I present only a summary comparison of the four years' results.

Fowler's Toads usually emerged by the second week of May (Table 1), coincident with a soaking rain and evening temperatures above 14°C. On subsequent nights, the toads would not sing with body temperatures below about 14°C but nevertheless could be found foraging at temperatures down to 10°C. Calling activity of male Fowler's Toads usually occurred in waves, each over a few successive nights and coincident with suitable temperatures. For example, during the first and most intense wave of breeding activity in 1991, from 10 to 16 May, there were very warm daytime temperatures (up to 31°C on 16 May) and evenings above 14°C, although overnight minimum temperature dropped to 6°C on the morning of 11 May. However, when the overnight low temperature on the night of 17/18 May fell to 5°C accompanied by cold rain, breeding temporarily halted for several nights, only to resume on 20 May when the temperature rose again.

The numbers of calling males captured and marked during the breeding season rose from 11 in 1988 to 245 in

Figure 1
Study area

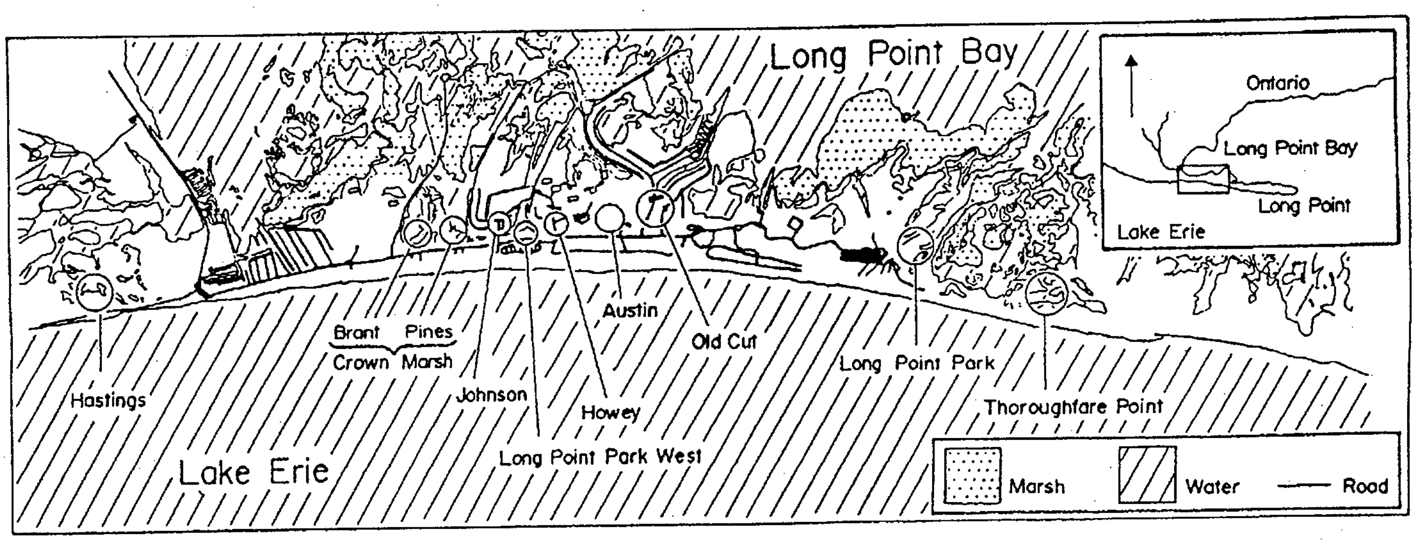
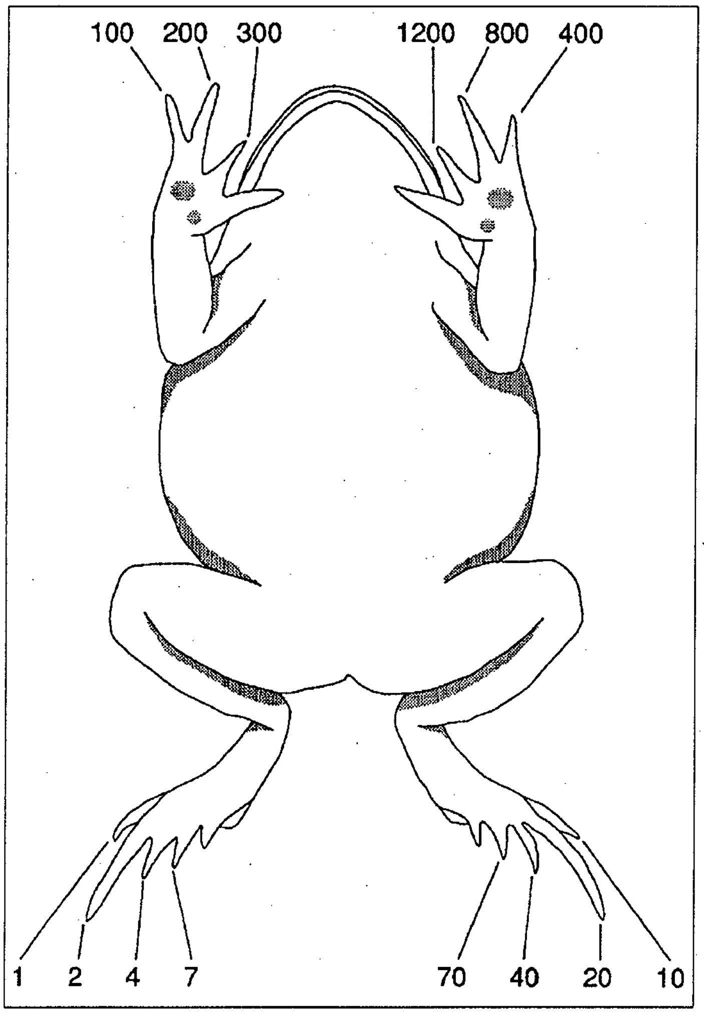


Figure 2
Numerical designations of clipped toes used for individual marking of toads



1991. These figures (Table 1) are probably the most accurate estimates of abundance, as all, or nearly all, calling males were located. Males exhibited considerable site fidelity during the breeding season; the same male would consistently be found in the same place on successive nights. The only shifts noted were the presence of some marked males found foraging along the beach later in the season. It thus appears that the males move from their calling sites to foraging habitats as the breeding season wanes, as noted by Breden (1988). The size distributions (Figs. 3–6) indicate two age/size classes among the adult males, which can be interpreted as two-year-olds versus three-year-olds and older. The few instances of year-to-year recaptures were males in the larger size class. Most of the toads were evidently two-year-olds, the age of first breeding. The proportion of two-year-olds to older toads dropped over the four years, indicating a growing population. The preponderance of younger toads may also indicate that they are migrants that have moved into the study area from elsewhere.

In addition to the adult males, females and yearling juveniles of both sexes were also captured and marked. Yearlings greatly outnumbered adults of both sexes. Assuming a minimum adult size of 48 mm for females, based on the minimum size of adult males and the distribution of discernible size classes (Figs. 3–6), the proportion of juveniles also rose over the four years of study. Although near-equal numbers of adult females (of at least two size classes) and juveniles were captured in 1988 and 1989, the proportion of juveniles greatly increased in 1990 and 1991 (Table 1). Thus, the age structure of the population, both male and female, shifted towards younger animals over the four years. Lincoln estimates of numerical abundance (Seber 1973) rose from 130 toads/km of beach in 1989 to 900/km in 1990 to 1800/km in 1991. There was a consistent skewed ratio of captures between adult males and females, due largely to the superabundance of males relative to females in the breeding sites and the males' higher visibility. On the beaches, however, captures of females always exceeded captures of males by at least a factor of 2:1.

Table 1
Summary figures for annual surveys of Fowler's Toad activity and abundance at Long Point, Ontario, 1989–91

	1988	1989	1990	1991
Survey				
Start date	2 May	3 May	3 May	4 May
End date	2 June	20 June	6 June	12 June
First emergence of toads	15 May	17 May	9 May[a]	10 May
No. of males				
Calling males	11	42	60	245
Noncalling males	3	4	2	49
No. of females (>48 mm)	34	37	17	113
No. of juveniles (<49 mm)	29	37	172	472
Total no. of toads caught	77	120	251	879
Estimate (toads/km beach)	n/a	130	900	1800

Note: Calling males were encountered in the marsh on the north side of the point, and noncalling males were found foraging on the beach on the south side of the point. Females and juveniles can collectively be distinguished from adult males by their white throats; the division into adult females greater than 48 mm and juveniles of both sexes below 49 mm is based on the distribution of size classes (Figs. 3–6) and the minimum size of recognizably adult males.

[a] Toads had been reported calling as early as 27 April in 1990, before surveying began.

Discussion

Despite accumulating evidence of declines in amphibian populations throughout the world, the Fowler's Toads at Long Point have gone up in number and appear to have a remarkable ability for population recovery after a decline. Green (1989) suspected this to be true as, by direct count, an individual female Fowler's Toad may carry 6000 or more ovarian eggs, all of which may be laid in a single season.

Fowler's Toads in Ontario are at the far northern limit of their range and are thus approaching the limits of their tolerance for cold temperatures. Inevitably, there will be some years when temperatures at breeding sites are too cold for optimal developmental success. During the 1980s, the water level of Lake Erie was very high, reaching its peak in 1985–86. This flooded the low-lying marshes, altering their shorelines and reducing the shallows where the toads might breed. If the high water levels resulted in cooler than usual temperatures for the tadpoles in the marshes, it may have had the effect of diminishing tadpole success and juvenile recruitment over several years. Preliminary experiments (Green and Cantin 1990) indicated that tadpole development is substantially slower at cooler temperatures for Fowler's Toads relative to American Toads. Lessened recruitment and lowered tadpole success would result in an age distribution among adults skewed towards older individuals. The vulnerability of the tadpoles may have been far more important than the possible effects upon

Figure 3
Size distribution histogram of all toads captured in 1988. Females and juveniles are plotted together, separate from recognizable adult males. .

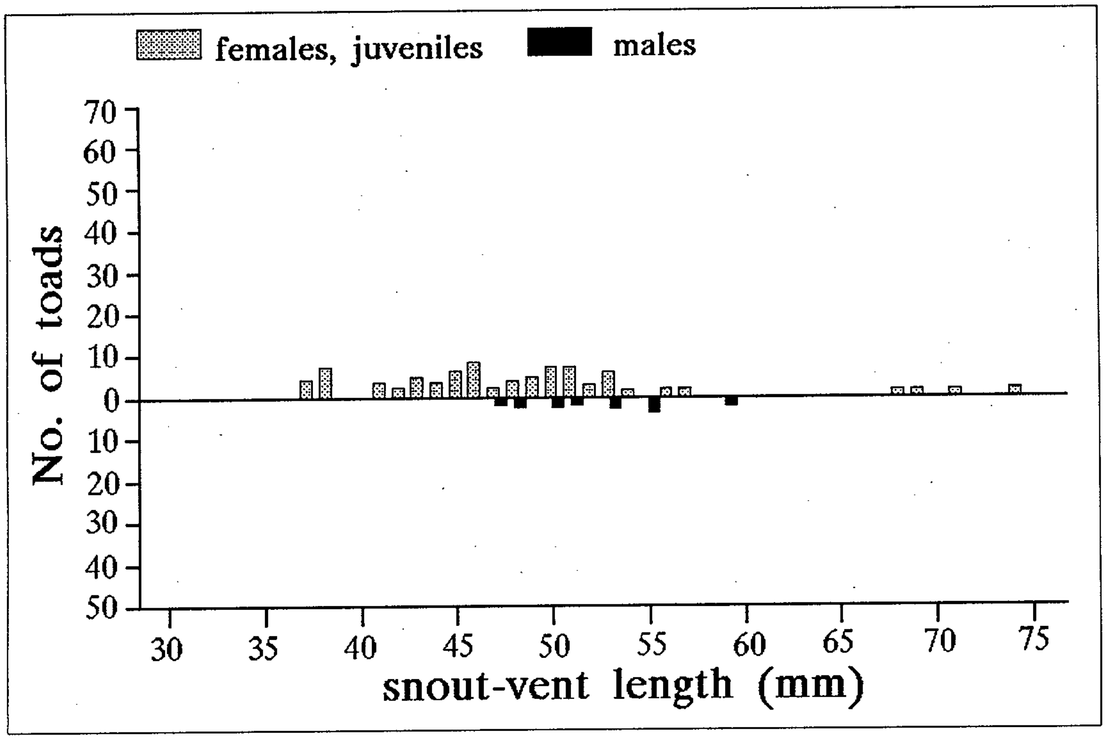


Figure 4
Size distribution histogram of all toads captured in 1989, as in Figure 3

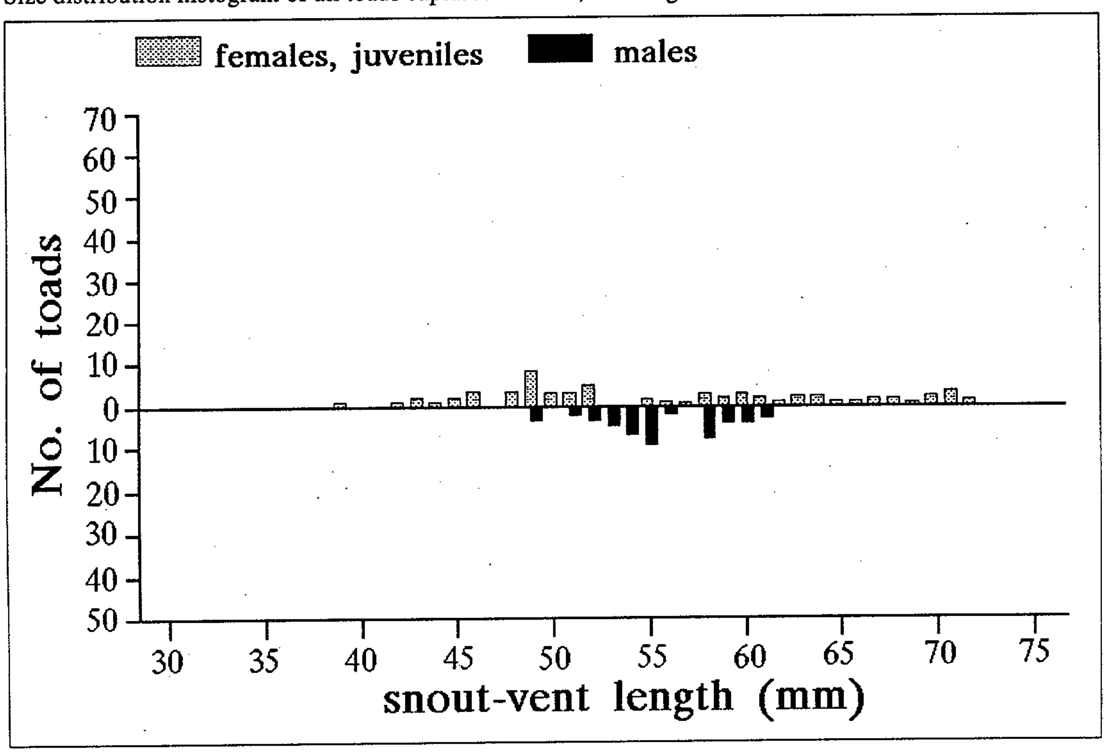


Figure 5
Size distribution histogram of all toads captured in 1990, as in Figure 3

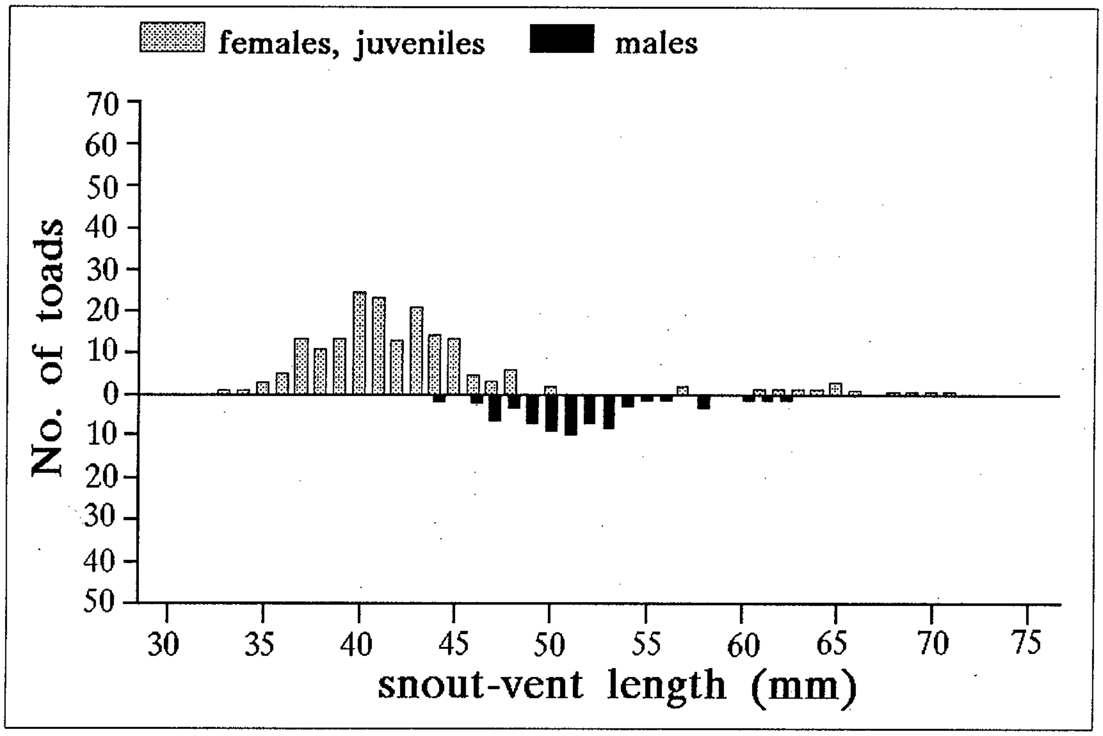
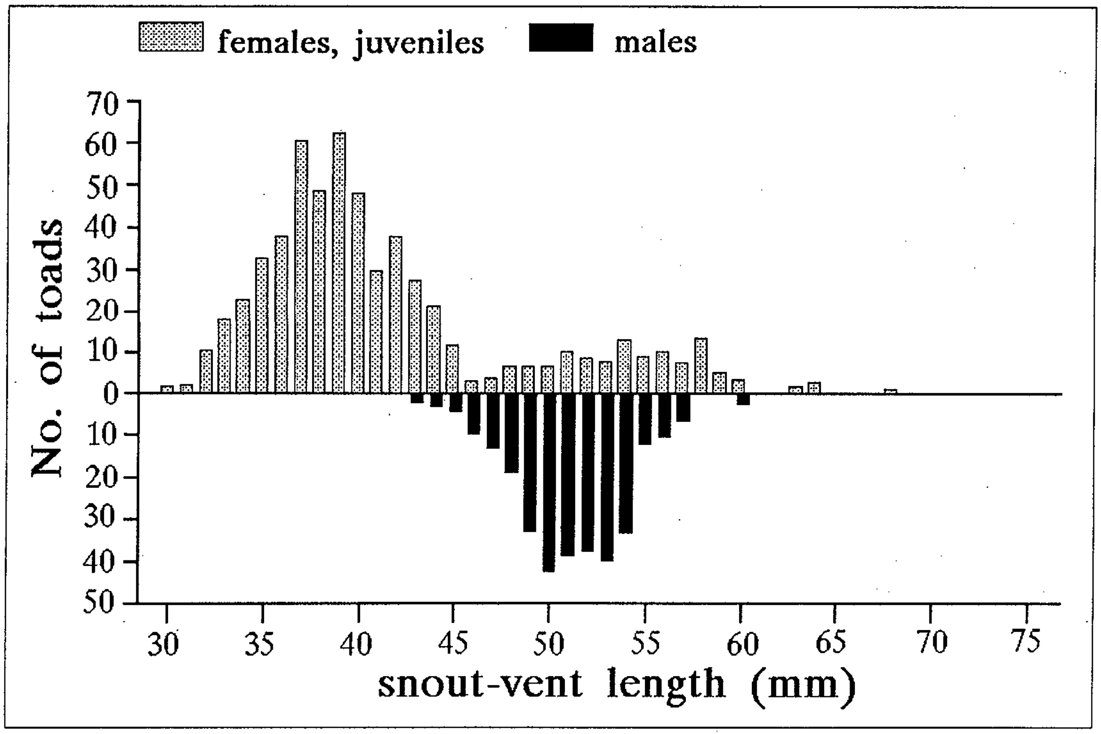


Figure 6
Size distribution histogram of all toads captured in 1991, as in Figure 3



hibernating adults of the severe winter storms of 1985–86. Anecdotal records (Oldham and Sutherland 1986; Oldham 1988) hint that the decline had begun before the winter of 1985–86, when water levels were already high. As Breden (1988) showed, mortality is highest for tadpoles and newly metamorphosed toadlets, and it will be necessary to pay close attention to tadpole survivorship and the success of metamorphosed toadlets to understand the dynamics of toad population fluctuations.

Other factors might also contribute to the Fowler's Toad population fluctuations. The impact of predation pressure from Eastern Garter Snakes (*Thamnophis sirtalis sirtalis*), Eastern Hognose Snakes (*Heterodon platyrhinos*), and Raccoons (*Procyon lotor*) is undocumented. Habitat degradation is often justifiably implicated in population declines. However, human disturbance does not appear to have dramatically changed at Long Point over the past decade, as cottages are confined to a limited area at the base of the point, and most of the point is natural preserve. Pollution in Lake Erie has declined over the past decade.

The observation that most of the toads in the study area are two-year-olds may indicate that they are largely emigrants from a core breeding population located elsewhere. Certainly, the toads found along Hastings Drive and Hahn Beach in 1991 were not the result of evident prior breeding in that area, because no Fowler's Toads were observed calling west of the Causeway in 1988, 1989, or 1990, although there have been some other reports of toads (M. Gartshore, pers. commun.). In 1989, toads on the Courtright Ridge east of Thoroughfare Point were reported in much greater densities than in the Crown Marsh or Long Point Park. It is likely that the optimal breeding habitat and greatest numbers of toads are well east of the study site and that the toads we observe are spillovers that have moved from this reservoir population.

The rise in Fowler's Toad numbers is especially interesting because these toads have been known to hybridize naturally with co-occurring American Toads at Long Point (Green 1982, 1984). The last known instances of hybridization were observed at a time of apparently high population densities for both species and temporal overlap in their respective breeding seasons. Hybrids have not been reliably observed since 1981. Although there have been anecdotal reports since (Oldham and Sutherland 1986; Oldham 1988), it is often easy to mistake unusually marked toads for hybrids. Electrophoretic evidence of limited genetic exchange between the species (Green 1984) indicated at the time that hybridization was ongoing but that introgression was minimal and had little impact upon the genetic structure of either population. A rise in population size in both species may be a requisite for the recurrence of hybridization. As the density of breeding males increases, the proportion of males actively searching for mates increases (Arak 1983). This would tend to diminish any effect of female choice in mate selection (Sullivan 1983) and lead to a higher probability of mismatings.

The Fowler's Toad population at Long Point may naturally fluctuate to a considerable degree. Numbers of adult toads were very low in 1988, yet the potential for recovery remained. Consideration of worldwide amphibian population declines is complicated by the probable occurrence of such natural fluctuations in animal abundance. Normal fluctuations in Fowler's Toad numbers may be driven both by abiotic conditions, such as water levels in Lake Erie, and by biotic factors, such as predator–prey interactions between the toads and the snakes that prey upon them. Catastrophic declines in some amphibian populations throughout the world, however, may be the synergistic results of chronic depression of natural cycles of population abundance (Pechmann et al. 1991). The immediate causes of natural, cyclical population declines may differ from causes of chronic depression of population fluctuations. It is the chronic insults that will result in widespread population losses and global declines. Yet, inevitably, by the time a population decline is identified, it will already be too late to witness the conditions that precipitated it. Sorting the immediate from the chronic will be difficult and assailable only through long-term monitoring programs.

Acknowledgements

Permission to collect and study toads at Long Point was granted by the Ontario Ministry of Natural Resources and the Canadian Wildlife Service. I thank Genevieve Laurin, Li Fanglin, Tim Sharbel, Joelle Boudreault, Danielle Cantin, Sue Porebski, Alia El-Yassir, and Cliff Zeyl for help in the field. The research was funded by operating grants from the World Wildlife Fund Endangered Species Recovery Fund and the Natural Sciences and Engineering Research Council of Canada (NSERC).

Literature cited

Arak, A. 1983. Male–male competition and mate choice in anuran amphibians. Pages 181–210 *in* Bateson, P.P.G. (ed.), Mate choice. Cambridge Univ. Press, Cambridge.

Breden, F. 1988. The natural history and ecology of the Fowler's toad (*Bufo woodhousei fowleri*) (Amphibia: Bufonidae), in the Indiana Dunes National Lakeshore. Fieldiana Zool. 49:1–16.

Briggs, J.L. and R.M. Storm. 1970. Growth and population structure of the cascade frog (*Rana cascadae*) Slater. Herpetologica 26:283–300.

Clarke, R.D. 1972. The effect of toe-clipping on survival in Fowler's toad (*Bufo woodhousei fowleri*). Copeia 1972:182–185.

Green, D.M. 1982. Mating call characteristics of hybrid toads (*Bufo americanus* × *Bufo fowleri*) at Long Point, Ontario. Can. J. Zool. 60:3292–3297.

Green, D.M. 1984. Sympatric hybridization and allozyme variation in the toads *Bufo americanus* and *B. fowleri* in southern Ontario. Copeia 1984(1):18–26.

Green, D.M. 1989. Fowler's toad (*Bufo woodhousei fowleri*) in Canada: biology and population status. Can. Field-Nat. 103:486-496.

Green, D.M. and D. Cantin. 1990. Spring emergence and breeding activity of Fowler's toads (*Bufo woodhousei fowleri*) at Long Point, Ontario. Unpublished report to Canadian Wildlife Service and Ontario Ministry of Natural Resources.

Green, D.M. and Z.S. Porebski. 1991. Breeding activity of Fowler's toads (*Bufo woodhousei fowleri*) at Long Point, Ontario, in 1990. Unpublished report to Canadian Wildlife Service and Ontario Ministry of Natural Resources.

Green, D.M., C.W. Zeyl, and A. El-Yassir. 1991. Spring emergence and abundance of Fowler's toads (*Bufo woodhousei fowleri*) at Long Point, Ontario in 1991: implications for conservation. Unpublished report to Canadian Wildlife Service and Ontario Ministry of Natural Resources.

Laurin, G. and D.M. Green. 1990. Spring emergence and male breeding behaviour of Fowler's toads (*Bufo woodhousei fowleri*) at Long Point, Ontario. Can. Field-Nat. 104:429–434.

Martof, B.S. 1953. Territoriality in the Green Frog (*Rana clamitans*). Ecology 34:165–174.

Oldham, M.J. 1988. 1985 Ontario Herpetofaunal Summary. Ontario Ministry of Natural Resources.

Oldham, M.J. and D.A. Sutherland. 1986. 1984 Ontario Herpetofaunal Summary. Essex Region Conservation Authority and World Wildlife Fund Canada.

Pechmann, J.H.K., D.E. Scott, R.D. Semlitsch, J.P. Caldwell, L.J. Vitt, and J.W. Gibbons. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science 253:892–895.

Seber, G.A.F. 1973. The estimation of animal abundance and related parameters. Hafner Press, New York. 506 pp.

Sullivan, B.K. 1983. Sexual selection in Woodhouse's toad (*Bufo woodhousei*). II. Female choice. Anim. Behav. 31:1011–1017.

Twitty, V.C. 1966. Of scientists and salamanders. W.H. Freeman, San Francisco.

Wake, D.B. 1991. Declining amphibian populations. Science 253:860.

Part 2:
Factors that affect amphibian survivorship in the context of a national monitoring strategy

Assessing the vulnerability of amphibians to climatic warming

T.B. Herman and F.W. Scott

Abstract

We present an approach for analyzing the vulnerability of amphibians in Nova Scotia to climatic warming. Most global circulation models predict decreased summer precipitation, increased winter precipitation (especially rainfall), and higher average winter temperatures in this region. We adapted the scoring system of Millsap et al. (1990) for evaluating general vulnerability of vertebrate species. We incorporated our own scoring system for estimating sensitivities of species to the predicted consequences of global warming (e.g., lower summer soil moisture, reduced snow and ice cover, increased minimum winter temperatures, increased winter stream flow, higher water temperature). Our scoring system was based on an evaluation of the shape and size of present ranges, life histories, general biology, and degree of specialization for each. The model is generalizable to other regions, other vertebrate groups, and other environmental changes. An analysis of scores for Nova Scotian amphibians shows that, in addition to climatic sensitivity *per se*, our ignorance of species' biology and their responses to environmental changes contributes to their general vulnerability.

Résumé

Les auteurs décrivent une méthode d'analyse de la vulnérabilité des amphibiens de la Nouvelle-Écosse au réchauffement climatique. Les prévisions formulées par la plupart des modèles globaux de circulation atmosphérique vont dans le sens d'une baisse des précipitations estivales, d'une hausse des précipitations hivernales (notamment une augmentation de la pluviosité) ainsi que d'une élévation des températures moyennes hivernales dans cette région. Le système de cotation adopté pour évaluer la vulnérabilité globale des espèces de vertébrés est celui de Millsap et al. (1990). Les auteurs ont conçu leur propre système de cotation destiné à évaluer la vulnérabilité des espèces aux conséquences prévisibles du réchauffement global (p. ex. déshumidification des sols en été, diminution de la couverture de neige et de glace, élévation des températures minimales en hiver, augmentation des courants d'air en hiver, élévation de la température de l'eau). Le système de cotation des auteurs est basé sur une évaluation des limites et de la superficie des aires de répartition actuelles des espèces, ainsi que de l'histoire naturelle, de la biologie générale et du niveau de spécialisation de chacune d'entre elles. Le modèle peut être appliqué à d'autres régions, d'autres groupes de vertébrés et d'autres modifications des conditions écologiques. Il ressort de l'analyse des cotations produites pour les amphibiens de la Nouvelle-Écosse que la vulnérabilité globale de ces espèces ne dépend pas seulement de leur sensibilité aux changements climatiques en soi, mais que notre ignorance de la biologie de ces espèces et de leurs réactions aux modifications des conditions écologiques joue également un rôle à cet égard.

Introduction

Global warming appears to be inevitable over the next three to five decades. The only real uncertainties are how rapidly it will occur and how far it will progress. Most global circulation models generally agree that warming at mid-latitudes in the northern hemisphere could be as much as twice the mean generally predicted global increase of 3.5–4.5°C and that total precipitation will increase, although summer precipitation will decrease. The effects of these changes include lower summer soil moisture, reduced snow and ice cover, increased minimum winter temperatures, increased winter stream flow, and higher water temperature (Abrahamson 1989). It is estimated that every 1°C of warming will shift temperature zones 160 km northward (Abrahamson 1989). A mid-latitude warming of 3.5°C would thus shift those zones 560 km north; twice the mean warming would shift them 1120 km.

We set out to develop a method to evaluate, at the local level, the vulnerability of our terrestrial and aquatic vertebrates (excluding birds) to global warming. We present here the preliminary results of that attempt for amphibians, with an emphasis on approach and methodology. A more thorough presentation of the model, including an analysis of the vulnerability of reptiles and mammals, can be found in Herman and Scott (1992).

Methods

In 1990, while we were designing our system, Millsap et al. (1990) introduced an assessment and scoring scheme for measuring general vulnerability, particularly to land use changes associated with increasing human population and development, in Florida vertebrates. This included an assessment of what is known about each species, the extent to which each was managed, and the degree of taxonomic uniqueness. Although the last is not relevant to vulnerability, it does reflect the genetic value of the species. Such information gauges our ability to mitigate the effects of environmental change and should be part of any system for evaluating vulnerability. We adapted their variables to Nova Scotian conditions and the smaller diversity of vertebrate groups (Table 1).

In 1989, we began developing a system for scoring climatic sensitivity in our terrestrial and aquatic vertebrates, in order to estimate their vulnerability to the environmental changes associated with global warming. Because we were concerned with relative vulnerability, we assessed costs only, not benefits. Table 2 presents the variables that we defined as significant.

When the paper by Millsap et al. (1990) appeared, the value of combining their general approach to scoring vulnerability to environmental change with our own approach, specifically focused on climatic sensitivity, became clear. From the combination of these two scoring systems, we generated species/variable matrices for Nova Scotia's terrestrial and aquatic mammals, amphibians, and reptiles. A matrix for freshwater fishes is also in preparation. Matrix values are derived from a mix of literature review (both field and experimental studies), analysis of range shape and size (particularly latitudinal extent), personal observations and data, expert opinion from authorities on particular taxa, and, when data were totally lacking, educated guesses based on what is known about the biology of the taxonomic group concerned.

Results and discussion

Our analysis of climatic sensitivity in amphibians focuses largely on summer factors. Winter factors seemed either unlikely to affect most species (owing to deep hibernation) or actually to confer a benefit. In contrast to mammals and reptiles (Herman and Scott 1992), climatic sensitivity values for amphibians were less variable among species (Table 3). The range of amphibians was most similar to that of insectivorous mammals (Herman and Scott 1992).

Because our scoring scheme is relative, it is probably more instructive to look at results for groups rather than for single species. Total scores for amphibians (Table 3) varied little, with all but two species falling in the 40–49 range. The exceptions were the Red-spotted Newt (Notophthalmus viridescens viridescens), with a score of 57, and the terrestrial Four-toed Salamander (*Hemidactylium scutatum*), with a score of 75. In contrast, mammals ranged evenly from 13 to 75, and reptiles from 36 to 79. Among the major component scores, biological scores for amphibians were moderately skewed to the left. In contrast, biological scores for mammals and reptiles were normally distributed. Systematic scores of amphibians as well as reptiles and mammals are highly skewed to the left. Low systematic scores reflect relatively low taxonomic uniqueness among all Nova Scotian vertebrate groups. Action scores of mammals ranged widely (from 8 to 35), as the status of economically important species is relatively well known. In contrast, action scores of amphibians were all relatively high (Table 3).

This may be the most striking element from the above analysis. For amphibians in particular, our ignorance of species' biology and their responses to environmental changes, and not just climatic sensitivity *per se*, contributes to their general vulnerability.

Table 1
Variables adapted from Milsap et al. (1990) used to score general vulnerability of Nova Scotian terrestrial and aquatic vertebrates to climatic change

Biological variables	Score
1. Population size: the estimated number of adults in Nova Scotia.	
a) 0–300	10
b) 301–3000, or size unknown but expected to be small	7
c) 3001–30 000, or size unknown but expected to be moderate	3
d) >30 000, or size unknown but expected to be large	0
2. Population trend: the overall change in number of individuals within taxon's range in NS within last 20 years. If direct data are unavailable, indirect data (such as habitat loss) can be used.	
a) population size known to be decreasing	10
b) trend unknown, but population size suspected to be decreasing	8
c) population formerly experienced serious decline but is currently stable or increasing	6
d) population size stable	4
e) population size suspected to be increasing	2
f) population size known to be increasing	0
3. Range size: the size of the area within NS over which taxon is distributed when distribution is most seasonally restricted (maximum = 57 000 km^2).	
a) <200 km^2 (<0.35%)	10
b) 201–2000 km^2 (0.35–3.5%)	7
c) 2001–20 000 km^2 (>3.5–35%)	3
d) 20 001–57 000 km^2 (>35–100%)	0
4. Distribution trend: % change (since European settlement) in areas of NS occupied by taxon. High values reflect significant range fragmentation.	
a) area occupied has declined by 90–100%	10
b) area occupied has declined by 75–89%	8
c) area occupied has declined by 25–74%	5
d) area occupied has declined by 1–24%	2
e) area occupied is stable or has increased	0
5. Population concentration: the degree to which individuals in the population concentrate or aggregate seasonally or daily (hibernacula, roosts).	
a) majority concentrates at a single location	10
b) majority concentrates at 2–25 locations	6
c) majority concentrates at >25 locations	2
d) majority does not concentrate	0
6. Reproductive potential for recovery: the ability of the taxon to recover from serious population declines.	
A- Average no. of eggs or live young produced per female per year.	
a) <1 per female per year	5
b) 1–9 per female per year	3
c) 10–100 per female per year	1
d) >100 per female per year	0
B- Minimum age at which females typically first reproduce.	
a) >8 years	5
b) 3–8 years	3
c) 1–2 years	1
d) <1 year	0
7. Dietary specialization, including specialization in foraging space or substrate, prey type, prey size, or prey behaviour.	
a) highly specialized	4
b) moderately specialized	2
c) not specialized	0
8. Reproductive specialization, including specialized requirements for breeding sites and/or conditions for rearing young.	
a) highly specialized	4
b) moderately specialized	2
c) not specialized	0
9. Habitat specialization, including dependence on special moisture regimes, plant/animal communities, or special habitat structure or physiography, such as talus formations.	
a) highly specialized	4
b) moderately specialized	2
c) not specialized	0

Table 1 (Continued)
Variables adapted from Milsap et al. (1990) used to score general vulnerability of Nova Scotian terrestrial and aquatic vertebrates to climatic change

Action variables	Score
1. **Knowledge of distribution** in NS (*survey score*).	
a) distribution is extrapolated from a few locations, or knowledge is limited to general range maps	10
b) broad range limits or habitat associations known, but local occurrences cannot be predicted accurately	5
c) distribution is well-known, and occurrence can be accurately predicted throughout the range	0
2. **Knowledge of population trends** in NS (*monitoring score*).	
a) not currently monitored	10
b) monitored locally intermittently	7
c) monitored intermittently province-wide or regularly locally	5
d) monitored regularly province-wide without statistical sensitivity	3
e) monitored regularly province-wide with statistical sensitivity	0
3. **Knowledge of factors limiting populations** in NS, including inference from data on non-NS populations (*research score*).	
a) factors affecting population size and distribution are unknown or unsubstantiated	10
b) some factors affecting population size and distribution are known, but one or more factors are unknown	5
c) most major factors affecting population size and distribution are known	0
4. **Present management activities** in NS (*management score*).	
a) none directed entirely or primarily at the taxon	10
b) management mostly related to conservation of populations or habitats	5
c) some direct management in addition to enforcement of conservation laws	0

Supplemental variables	Score
1. **Systematic significance** of the taxon (select all applicable categories).	
a) monotypic family	4
b) monotypic genus	3
c) monotypic species	2
d) disjunct population	1
e) no significance	0
2. **Percentage of taxon's total range** that occurs in NS.	
a) 51–100% of total range in NS	5
b) 26–50% of total range in NS	4
c) 16–25% of total range in NS	3
d) 5–15% of total range in NS	2
e) <5% of total range in NS	1
3. **Harvest of taxon** in NS.	
a) harvested without legal protection	4
b) harvested under regulation	3
c) harvested by accidental take or by killing of nuisance animals	2
d) harvest prohibited by regulation	1
e) no harvest	0

Table 2
Variables used in scoring climatic sensitivity in Nova Scotian aquatic and terrestrial vertebrates. Scoring for all variables (except 1 and 7f) is the same: greatly reduced/increased or very costly = 2; moderately reduced/increased or moderately costly = 1; unreduced/unincreased or no cost = 0.

1. **Life history environments:** the number of different environments (i.e., terrestrial, aquatic) occupied during development or seasonally during adulthood (amphibians and reptiles only). The more environments occupied, the greater the likelihood that a species will be affected.
2. **Reduced summer soil moisture** and its *direct* impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**
   c) **habitat reduction or loss of quality**
   d) **exposure to predation**
   e) **physiological stress** (including water, oxygen, or thermal stress)
3. **Lower summer water table** and its *direct* impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**
   c) **habitat reduction or loss of quality**
   d) **exposure to predation**
   e) **physiological stress** (including water, oxygen, or thermal stress)
4. **Reduced summer rainfall** (amphibians and reptiles only), the physical or other *direct* effects on the rainfall itself (separate from 2 or 3), and their impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**
5. **Lower summer stream flow rates** and their *direct* impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**
   c) **habitat reduction or loss of quality**
   d) **exposure to predation**
   e) **physiological stress** (including water, oxygen, or thermal stress)
6. **Increased summer water surface temperature** (amphibians and reptiles only) and its *direct* impact on:
   e) **physiological stress** (including water, oxygen, or thermal stress)
7. **Increased summer soil temperature** (the result of increased insolation because of reduced summer rainfall) and its *direct* impact on:
   e) **physiological stress** (including water, oxygen, or thermal stress)
   f) **skewing of hatchling sex ratios** (turtles only)
   likely to be skewed = 2
   not likely to be skewed = 0
8. **Increased winter water bottom temperature** (amphibians and reptiles only) and its *direct* impact on:
   e) **physiological stress** (including water, oxygen, or thermal stress)
9. **Reduced snow and ice cover** and its *direct* impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**
   d) **exposure to predation**
   e) **physiological stress** (including water, oxygen, or thermal stress)
10. **Increased winter/spring flooding** and its *direct* impact on:
   a) **food supply or access to food supply** (including foraging mobility)
   b) **dispersal mobility**

The future

Our evaluation system is still under development. We would like to consider prehistoric range shifts during the most recent glaciation episode, but the existing data base is limited. We would also like to incorporate in the reproductive potential score the typical number of reproductive years in females.

The scoring scheme of Millsap et al. (1990) is largely unweighted; we did not change their approach and, in fact, extended it to our climatic sensitivity scoring. Although in the real world all environmental variables are not created equal, the relative importance of each is difficult to evaluate and will not be the same for all taxa. As an example, longevity and generation time are highly relevant to a species' ability to cope with rapid climatic change and vary among taxa.

Conclusions

We have outlined above an approach and framework for estimating the vulnerability of species to climatic warming and, indeed, to any other environmental changes. Being new, the method is undoubtedly unbalanced and imperfect. It is also a *species* rather than an *ecosystem* approach, and it is debatable which one is the more appropriate for a regime of rapid climatic change. There are arguments on both sides, and at present we take no position on the issue.

Although a significant amount of climatic warming seems to be inevitable, we believe that its impact on at least *some* species and *some* habitats can be mitigated by appropriate management. Assessing the vulnerability of species to such warming is only a first step, but it is absolutely essential in order to rationally allocate scarce management resources.

Table 3
All amphibian variables scored

Variable	Caudata spp.[a]					Anura spp.[b]							
	al	am	nv	pc	hs	ba	hc	rca	rcl	rse	rsy	rpi	rpa
Biological variables													
Life history environments	2	2	3	2	2	2	2	1	1	1	2	2	2
Population size	0	0	0	0	3	0	0	0	0	0	0	0	0
Population trend	4	4	4	4	4	4	4	4	4	4	4	4	4
Range size	3	0	0	0	3	0	0	0	0	3	0	3	3
Distribution trend	2	2	2	2	2	2	2	2	2	2	2	0	0
Population concentration	0	0	0	0	0	0	0	0	0	0	0	0	0
Reproductive potential	1	1	3	2	2	3	1	3	3	1	3	3	3
Reproductive specialization	0	0	2	0	4	0	0	0	0	0	0	0	0
Dietary specialization	0	0	4	4	0	0	0	0	0	0	0	0	0
Habitat specialization	2	0	0	0	2	0	0	0	0	0	0	0	0
Climatic sensitivity	9	7	13	11	7	4	5	2	10	3	9	11	10
Biological score	**23**	**16**	**31**	**23**	**29**	**15**	**14**	**12**	**20**	**14**	**20**	**23**	**22**
Action variables													
Distribution knowledge	0	5	5	5	10	5	5	5	5	5	5	5	5
Population trend knowledge	5	5	5	5	8	5	5	5	5	5	5	5	5
Limiting factor knowledge	5	5	5	5	10	5	5	5	5	5	5	5	5
Management activities	10	10	10	10	10	10	10	10	10	10	10	10	10
Action score	**20**	**25**	**25**	**25**	**38**	**25**	**25**	**25**	**25**	**25**	**25**	**25**	**25**
Supplemental variables													
Systematic significance	3	0	0	0	6	0	0	0	0	0	0	0	0
% total range in NS	1	1	1	1	2	1	1	1	1	2	1	1	1
Harvest in NS	0	0	0	0	0	0	0	4	0	0	0	0	0
Supplemental score	**4**	**1**	**1**	**1**	**8**	**1**	**1**	**5**	**1**	**2**	**1**	**1**	**1**
Total score	**47**	**42**	**57**	**49**	**75**	**41**	**40**	**42**	**46**	**41**	**46**	**49**	**48**

[a] al = *Ambystoma laterale* (1,8,9); am = *Ambystoma maculatum* (8,9); nv = *Notophthalmus viridescens viridescens* (2,8,9); pc = *Plethodon cinereus* (3,8,9); hs = *Hemidactylium scutatum* (8,9). Major references consulted for each species (see footnote *c*) given in parentheses.

[b] ba = *Bufo americanus* (8,9); hc = *Hyla crucifer* (8,9); rca = *Rana catesbeiana* (8,9); rcl = *Rana clamitans* (4,8,9); rse = *Rana septentrionalis* (5,8,9); rsy = *Rana sylvatica* (6,8,9); rpi = *Rana pipiens* (8,9); rpa = *Rana palustris* (7,8,9). Major references consulted for each species (see footnote *c*) given in parentheses.

[c] References: (1) Uzell 1967; (2) Mecham 1967; (3) Smith 1963; (4) Stewart 1983; (5) Hedeen 1977; (6) Martof 1970; (7) Schaaf and Smith 1971; (8) DeGraaf and Rudis 1983; (9) Gilhen 1984.

Acknowledgements

We thank S. Bleakney, S. Boates, J. Gilhen, B. Wright, an anonymous reviewer, and, in particular, C.G. van Zyll de Jong for their comments on an expanded version of this manuscript; S. Bondrup-Nielsen for ideas on the subject; and an Acadia University Faculty Association grant to TBH for financial support.

Literature cited

Abrahamson, D.E. (ed.). 1989. The challenge of global warming. Island Press, Washington, D.C.

DeGraaf, R.M. and D.D. Rudis. 1983. Amphibians and reptiles of New England. Univ. of Massachusetts Press, Amherst, Mass. 85 pp.

Gilhen, J.A. 1984. Amphibians and reptiles of Nova Scotia. Nova Scotia Museum, Halifax. 162 pp.

Hedeen, S.E. 1977. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 202.1.

Herman, T.B. and F.W. Scott. 1992. Global change at the local level: assessing the vulnerability of vertebrate species to climatic warming. Pages 353–367 *in* Willison, J.H.M., S. Bondrup-Nielsen, C. Drysdale, T.B. Herman, N.W.P. Munro, and T.L. Pollock (eds.), Science and the management of protected areas. Elsevier, Amsterdam.

Martof, B.S. 1970. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 86.1.

Mecham, J.S. 1967. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 53.1.

Millsap, B.A., J.A. Gore, D.E. Runde, and S.I. Cerulean. 1990. Setting priorities for the conservation of fish and wildlife in Florida. Wildl. Monogr. 111:1–57.

Schaaf, R.T. and P.W. Smith. 1971. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 117.1.

Smith, P.W. 1963. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 5.1.

Stewart, M.M. 1983. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 337.1.

Uzell, T. 1967. Catalogue of American amphibians and reptiles. Am. Soc. Ichthyol. Herpetol. 48.1.

Monitoring genetic diversity

James P. Bogart

Abstract

There is little information to suggest that Canadian amphibian populations are declining for reasons other than habitat destruction. Amphibians have a long history of adaptive evolution and possess attributes that render them ideal subjects to test hypotheses that relate to population genetics. Long-term studies are needed for monitoring population fluctuations, and these studies should include genetic analyses. Genetic comparisons across and within populations, analysis of genetic adaptation to particular environments, and analysis of genetic fitness components would provide important information that could be used to distinguish populations in need of more detailed information. Basic genetic information has been suggested as a prerequisite in the development of monitoring strategies; so far, however, no comprehensive genetic studies have been undertaken by participants that are studying declining amphibian populations.

Résumé

Il existe peu d'éléments d'information qui tendent à indiquer que le déclin des populations d'amphibiens du Canada est attribuable à d'autres motifs que la destruction de leur habitat. L'évolution adaptative des amphibiens a nécessité des millions d'années, et ils possèdent des attributs qui en font des sujets tout choisis pour pouvoir se prêter à la vérification d'hypothèses liées à la génétique des populations. Il faudra procéder à des études de suivi à long terme sur les fluctuations des populations, et ces études devraient tenir compte des analyses génétiques. Les comparaisons génétiques effectuées d'une population à l'autre et au sein d'une même population, l'analyse de l'adaptation génétique à des milieux particuliers et l'analyse des éléments d'adaptation génétique permettraient de recueillir des éléments d'information significatifs qui pourraient servir à identifier les populations qui nécessitent une recherche plus approfondie. Il a été suggéré de procéder à la collecte des renseignements génétiques de base à titre d'étape préalable à l'élaboration de stratégies de surveillance; à ce jour, toutefois, aucune étude génétique globale n'a été réalisée par les praticiens qui étudient le déclin des populations d'amphibiens.

Introduction

The first major concerns that amphibian populations were declining on a global level were voiced at the First World Congress of Herpetology, which was held in Canterbury, England, in 1989. Since that time, symposia and workshops have been held at the joint annual meetings of the Society for the Study of Amphibians and Reptiles (SSAR) and the Herpetologists' League (HL) in 1990 and 1991. The Species Survival Commission (SSC) established the Declining Amphibian Populations Task Force (DAPTF) with Dr. James L. Vial (Center for Analysis of Environmental Change, Corvallis, Oregon) as its chair, and its mandate is to coordinate investigators and agencies on a global scale to document and to determine the causes of the declines. The DAPTF will also identify critical habitats and priorities for research. The aim of the task force is to prescribe uniform protocols by which studies of different species and habitats can be compared. Overseeing the activities of the task force will be an international board of directors that will be responsible for establishing policies, determining priorities, and raising funds. A global monitoring program with electronic input and access is being established, and a newsletter (FROGLOG) will be issued at frequent intervals. Start-up funds for the task force have been provided through a grant to the World Conservation Union (IUCN) by the U.S. government and the Chicago Zoological Society. The objectives and function of the DAPTF have been outlined by Vial (1991, and this volume).

Compared with many other countries, Canada has relatively few species of amphibians (only 41) and does not have any endemic species. Most of the species in Canada have a more extensive range in the United States and are restricted to the most southern portions of Canada, southwestern Ontario, and southern British Columbia, the areas of greatest urbanization and habitat alteration. It is obvious that anthropogenic factors have contributed to the reduction of amphibian populations in areas of greatest species diversity. However, even though Canada has an impoverished amphibian fauna with respect to species diversity, some species are represented by large numbers of individuals that range over extensive areas. Certain areas in Canada are still relatively undisturbed, and the amphibians that reside in these areas may provide basic information that can be used to test hypotheses related to anthropogenic effects.

Relevant data concerning the decline in amphibian populations in Canada are meagre at best. In fact, most of the information that is not obviously related to habitat destruction is anecdotal. No single factor has been found that could serve as a causative agent for reduction of amphibian populations, and it would appear that the situation is very complex. If it is assumed that amphibian populations are in decline and that the decline foreshadows problems that will cause other animals to follow similar patterns of extirpation, it is fortunate that the problem has received attention from the scientific community, naturalists, and governmental agencies. Amphibians, more than any other vertebrate group, are most amenable for the testing of hypotheses related to intrinsic and extrinsic variables. They are a diverse group of highly adapted vertebrates that must be considered survivors. Frogs have a 200-million-year history (100 times that of humans). In 200 million years of independent evolution, this lineage has experienced and dealt with global variation and fluctuations that other vertebrate groups could not tolerate, thus becoming extinct. If amphibians are in trouble at the present time, there should be serious concerns about all vertebrate taxa. A concerted effort must be made to understand and to diminish factors that may be responsible for declining amphibian populations, for these same factors are certain to be detrimental to many other living organisms.

I suggest that we make use of the genetic attributes of amphibians together with data derived from extrinsic, especially anthropogenic, factors to monitor amphibian populations. Such data are certainly needed for any possible translocation, relocation, or repatriation experiments and could possibly provide some answers concerning the decline of individual species or genotypes in particular populations.

Genetic characterization of populations

Isozyme analysis is a rapid method that is used to estimate and analyze genetic variability in populations. The number of loci that can be surveyed is determined mostly by the time and funds that are available for the project. Such basic genetic information from a large number of populations should form a data base for selected species. The species chosen should be widespread and occur in a variety of habitats. They should also be species that are polymorphic and have a reasonably high level of heterozygosity. Heterozygosity and polymorphism are necessary prerequisites for comparing wide-ranging and subdivided populations. Only those loci that demonstrate polymorphism are useful in such analyses. Levels of heterozygosity vary among species and taxonomic groups. Amphibian heterozygosity is significantly correlated with life zones and habitat type (Nevo and Beiles 1991). The Bullfrog (*Rana catesbeiana*), for example, would not be a good choice. This species has a very low level of heterozygosity. However, the Tetraploid Gray Treefrog (*Hyla versicolor*) has one of the highest levels of heterozygosity known for vertebrates. Toads, other hylids, and some *Rana* would all be good candidates. Simple population genetic analyses can be used to provide information concerning isolation and gene flow. Populations that have undergone severe reduction in numbers should demonstrate a comparative reduction in heterozygosity. This "bottleneck" phenomenon could be used to carefully monitor selected populations in order to determine the factors that were responsible for a suspected population crash. Allele frequencies might reflect genetic adaptation to certain environments (such as a reduction in pH). Even though the electrophoretically detectable alleles may not be under selective pressure, there may be closely linked alleles that are affected by the environment. Long-term studies on selected populations should continue in order to examine year-to-year shifts, trends, and the analysis of cohorts.

Other methods, such as sequence analyses or restriction enzyme digests, could be used in order to detect useful variation that is not revealed through isozymes. These methods are too time consuming and expensive for a general survey but may be very effective for an in-depth analysis of particular populations that have been identified as being of critical importance.

Adaptations of individuals (selected environments)

All of the amphibian species that live in Canada have the capacity to rapidly increase their population densities. They all produce a large number of eggs, and the adult population represents a very small fraction of the eggs laid. The number of adults reflects extrinsic variables that were experienced by the larval and juvenile stages. Fluctuations in population densities of adults are to be expected when environmental conditions vary and are not predictable. It is also expected, under such a system, that adaptation to less variable extrinsic factors can be very rapid. In any population, individuals that are not selected against would be expected to have a genetic constitution that is highly adapted to their present environment.

Experiments that attempt to attribute environmental contaminants to amphibian decline must recognize and deal with possible adaptations. For example, research that attempts to examine an amphibian's ability to tolerate low pH should not involve just individuals from populations that tolerate normal pH. Tests should also be run using individuals from several populations that are exposed to a range of pH values.

Ideally, offspring from reciprocal crosses using individuals from a number of populations should be used in such experiments. Comparisons can then be made between siblings of "hybrid" and control individuals from the test populations.

Fitness components

The absolute number of adult individuals in a population at any given time is not necessarily a good indicator of the health of that population. Large numbers of treefrogs and toads may call around, and breed in, chlorinated swimming pools, but their eggs and tadpoles do not survive. As well, it is not known whether there is some critical population size that amphibians must maintain to avoid extirpation (Shaffer and Samson 1985). The health and sustained, predictable survival of amphibians rely on fitness components that affect their complete life histories. A healthy population contains individuals that are successful breeders, producing normal eggs that develop into normal larvae that transform into normal juveniles. What is "normal" can be determined only by monitoring the life history parameters of several populations. Fitness of individuals in any population can then be compared with expected values. Even though genetic variation among individuals in a population may be an indicator of fitness, there are no empirical data to support this contention

(Simberloff 1988). If it can be determined that a population contains individuals with disparate fitness components, a genetic analysis would seem appropriate. Chromosome studies, isozyme electrophoresis, and mtDNA analyses might all be useful techniques that could be used in conjunction with mating experiments.

Conclusions

Monitoring the genetic diversity of amphibian populations is not a task that can be taken lightly. If a species is being extirpated through interspecific hybridization or if individuals in a population that is declining demonstrate environmentally induced chromosome mutations, a cursory genetic examination would reveal these facts.

Otherwise, genetic monitoring will probably not provide simple answers that relate to the reduction of present amphibian populations. We have little or no genetic information on Canadian amphibian populations, and the analysis of single, isolated populations is meaningless without a comparative base. The accumulation of genetic information has been a suggested plan of action at the DAPTF workshops, but no major genetic studies have been initiated. Certainly, any information that can be obtained at the present time will provide a base for future studies, and it would be most efficient to coordinate the activities of investigators such that a genetic component would be included in a monitoring strategy for Canadian amphibians.

Literature cited

Nevo, E. and A. Beiles. 1991. Genetic diversity and ecological heterogeneity in amphibian evolution. Copeia 1991:565–592.

Shaffer, M.L. and F.B. Samson. 1985. Population size and extinction: a note on determining critical population sizes. Am. Nat. 125:144–511.

Simberloff, D. 1988. The contribution of population and community biology to conservation biology. Annu. Rev. Ecol. Syst. 19:473–511.

Vial, J.L. 1991. Declining Amphibian Populations Task Force. Species 16 (June): 47–48.

On assessing environmental factors affecting survivorship of premetamorphic amphibians

Richard Wassersug

Abstract

Recent reports suggest that anuran populations are declining in many regions of the world, including north temperate North America. To arrest this decline, it is important to establish what factors are most responsible. Because all amphibians that occur in Canada meet the limits of their range here, Canada affords a special opportunity to study amphibians where they are most likely to be in jeopardy, at the margins of their ranges.

In this report, I concentrate on premetamorphic anurans. I argue that conclusions derived from previous laboratory studies directed at identifying environmental factors that put embryos and larvae at risk may be of little generalizable value because of the species selected for study. Environmentalists have made disproportionate use of *Rana temporaria* and *Rana sylvatica* in such investigations. Both species are early-spring breeders in temporary ponds and normally lay their eggs when these sites are naturally most acidic. They appear to have evolved greater tolerance to low pH than most other anurans.

I suggest that there is a natural pattern of inverse accessibility to premetamorphic and postmetamorphic anurans, at least at breeding sites in eastern Canada. A conspicuous abundance of one stage at a site often testifies to the cryptic nature and inaccessibility of the other stage. The ease with which herpetologists can find and collect anurans in either their aquatic or terrestrial stage may say more about the risk of predation on that stage than the vitality of the population overall.

Two conclusions come from these observations. First, experimental studies on factors affecting anuran survivorship will need to be performed on a greater diversity of species. More data on species with a long larval period and long time to the age of first reproduction are essential if biologists are going to be able to set realistic limits on the environmental stresses anurans can tolerate. Secondly, surveying one life stage (eggs, larvae, or adults) may give a biased opinion of the health of a population even when the surveying extends over several years. For assessing the impact of predators, including humans, more than one life stage and more than one life cycle are essential. I briefly review methods for surveying larval anurans and mention inherent weaknesses in current techniques.

It is only with long-term, multispecies surveys that the causes for declines in anuran populations can be identified and arrested.

Résumé

Des rapports récents semblent indiquer que les populations d'anoures sont en baisse dans de nombreuses régions du globe, notamment dans les régions tempérées septentrionales de l'Amérique du Nord. Il importe pour contrer ce déclin d'en cerner les facteurs les plus déterminants. La plupart des amphibiens canadiens se trouvant ici à la limite de leur aire de répartition, le Canada constitue un lieu de prédilection pour l'étude des amphibiens, car c'est ici, en périphérie de leur aire de répartition, qu'ils risquent d'être confrontés aux situations les plus périlleuses.

L'auteur du présent rapport porte surtout son attention sur les anoures pré-métamorphiques. Il fait valoir que les conclusions formulées à partir des résultats des études antérieures en laboratoire sur la caractérisation des facteurs écologiques de risque pour les embryons et larves peuvent difficilement se prêter à l'extrapolation, vu le type même d'espèces étudiées. Les écologistes ont trop eu recours aux espèces *Rana temporaria* et *Rana sylvatica* dans le cadre de ces investigations. Ces deux espèces se reproduisent tôt au printemps dans des étangs temporaires et pondent normalement leurs oeufs au moment où les lieux de reproduction présentent le plus haut taux d'acidité. Elles semblent donc avoir développé plus que toute autre espèce d'anoures une plus grande tolérance aux milieux caractérisés par un bas pH.

L'auteur laisse entendre qu'il existerait un modèle naturel d'accessibilité aux anoures pré-métamorphiques inversement proportionnel à l'accessabilité aux anoures post-métamorphiques et ce au moins dans les lieux de reproduction de l'est du Canada. L'abondance manifeste d'une forme biologique d'anoures à un endroit donné coïncide souvent avec l'éclipse ou la disparition de la forme suivante. La facilité avec laquelle les herpétologistes peuvent trouver et capturer les anoures parvenus à tel stade de développement aquatique ou terrestre est un meilleur indicateur du risque de prédation à ce stade que de la vitalité de l'ensemble de la population.

Ces observations donnent lieu à deux conclusions. Il y aurait lieu de réaliser pour un plus grand nombre d'espèces des études expérimentales sur les facteurs de survie des anoures. Il est essentiel de procéder à la collecte d'un plus grand nombre de données sur les espèces caractérisées par une durée plus longue de la forme larvaire et une période de préfertilité plus longue si les biologistes veulent être en mesure de déterminer des limites réalistes aux contraintes d'ordre écologique que les anoures peuvent tolérer. Par ailleurs, le relevé d'une population à un stade donné (oeufs, larves ou stade adulte) peut avoir pour effet de fournir une évaluation biaisée sur l'état de santé d'une population même si le relevé est échelonné sur plusieurs années. Afin d'évaluer l'impact de la prédation, notamment de la prédation humaine, il est essentiel d'évaluer des populations parvenues à des stades et à des cycles biologiques différents. L'auteur passe brièvement en revue les méthodes de relevé des anoures au stade larvaire et indique les lacunes inhérentes à ces diverses méthodes. Seule la réalisation de relevés échelonnés sur une longue période et portant sur de nombreuses espèces nous permettra de déceler et de contrer les causes du déclin des populations d'anoures.

Introduction

There are several working premises in this report on premetamorphic amphibians. First, I take it as a given that anuran populations are declining in many parts of the world, including parts of Canada, and that the reasons for these declines are not known. Acid rain is a major suspect, but not the only one. A second premise is that identification of the primary causes and management of the declines will require both laboratory and field investigations.

My focus is primarily on anurans rather than salamanders. At the moment, anurans appear to be in greater distress than urodeles (Wake 1991), but this may be an artifact of the more conspicuous nature of anurans. The range for salamanders and their species diversity (particularly for those with aquatic larvae) in Canada are approximately half those of the anurans (Cook 1984). And, frankly, I know more about tadpoles than about salamander larvae.

I discuss here three distinct topics:

(1) species biases in past laboratory investigations on factors affecting amphibian embryos and larvae;

(2) the relationship between the conspicuousness of larvae versus adults at field sites, as it pertains to sampling procedures; and

(3) the pros and cons of various field sampling procedures for anuran larvae.

In the end, I try to derive some conclusions that pertain to the development of a monitoring program for Canadian amphibians.

Species biases in laboratory studies

Table 1 presents a summary of recent studies that have examined the effects of low pH on the development of north temperate embryonic and larval Anura. I present this table for two reasons. First, it shows that studies on the effect of environmental stresses, such as acidification, on amphibian development are hardly new or rare. Secondly, it reveals certain biases in the amphibian species selected for such studies in environmental toxicology. Figure 1 is a pie graph that gives the percentage of studies on acid tolerance for north temperate anuran embryos and larvae by species. Although I have identified 13 species that have been used in over 50 experiments, three species alone account for over half of the experiments.

Table 1
Studies on the effects of low pH on the development of north temperate embryonic and larval Anura

Species	No. of studies	References[a]
Pseudacris triseriata	1	1
Hyla crucifer	3	1,2,8
Bufo boreas	1	6
Bufo woodhousei	3	4,7,25
Bufo americanus	7	1,2,3,5,20,24
Rana virgatipes	1	8
Rana palustris	2	2,8
Rana arvalis	3	9,10,11
Rana catesbeiana	3	8,12,28
Rana clamitans	4	7,8,21,28
Rana pipiens	5	1,4,22,23,28
Rana temporaria	7	9,11,16,17,18,19,29
Rana sylvatica	15	1,2,3,4,8,13,14,15,20,22,24,25,26,27,30

[a] References: (1) Karns 1983; (2) Dale et al. 1985b; (3) Clark and LaZerte 1985; (4) Freda and Dunson 1985b; (5) Clark and LaZerte 1987; (6) Porter and Hakanson 1976; (7) Freda and Dunson 1986b; (8) Gosner and Black 1957; (9) Leuven et al. 1986; (10) Andrén et al. 1989; (11) Andrén et al. 1988; (12) Saber and Dunson 1978; (13) Tome and Pough 1982; (14) Pierce et al. 1984; (15) Pierce and Sikand 1985; (16) Beebee and Griffin 1977; (17) Tyler-Jones et al. 1989; (18) Cummins 1986; (19) Hagstrom 1980; (20) Dale et al. 1985a; (21) McDonald et al. 1984; (22) Freda and Dunson 1985a; (23) Schlichter 1981; (24) Clark and Hall 1985; (25) Freda and Dunson 1986a; (26) Pierce et al. 1987; (27) Pierce and Harvey 1987; (28) Freda and Dunson 1984; (29) Cummins 1989; (30) Ling et al. 1986.

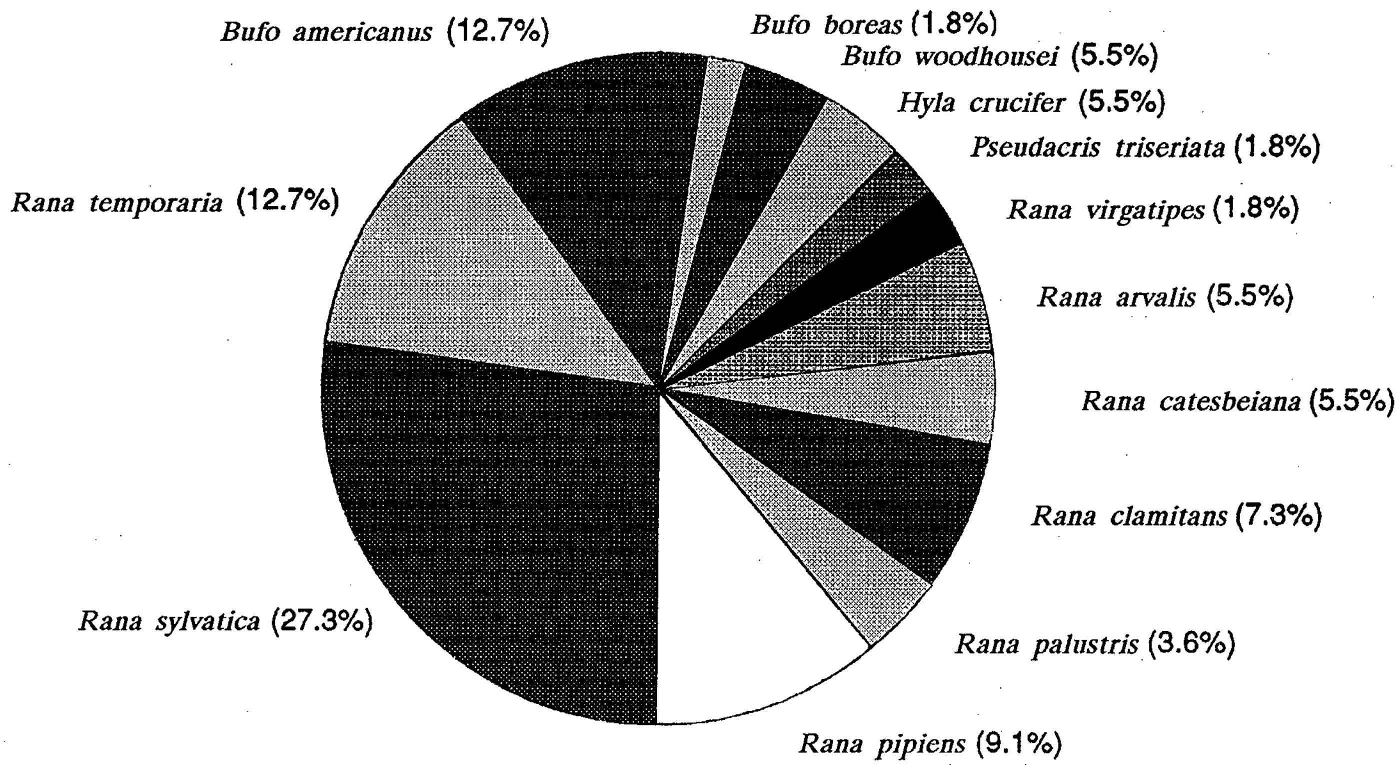
The three most frequent anuran species in investigations of the effect of acidity on development have been *Rana sylvatica* and *Bufo americanus* in North America and *Rana temporaria* in Europe. One could argue that these species are commonly studied simply because they range widely. However, if that were the primary reason for their popularity, then one would expect more studies with other, similarly wide-ranging species—for example, *Rana catesbeiana* and *Rana clamitans*.

What *R. sylvatica*, *R. temporaria*, and *B. americanus* have in common is that they all develop rapidly. The speed with which a species reaches metamorphosis appears to enhance the likelihood of it being the subject of investigation. I suggest that this results more from convenience than from any intrinsic fascination of ecotoxicologists with rapid-developing amphibians.

Consider the fact that the majority of studies are conducted by students. Any student who hopes to explore the effects of a particular factor on an organism's development, and also to graduate in a timely fashion, should select a model species with rapid development. Furthermore, given the nature of the academic year, with a break in the summer, students who hope to take a summer vacation should select species that breed early in spring and develop in only a few weeks, rather than over many months.

Rana sylvatica and *R. temporaria* are closely related species (Hillis and Davis 1986) with similar reproductive biology. They breed in the early spring in temporary pools filled with snowmelt. Their early reproduction and rapid development make them convenient species for experimental work. Their eggs are deposited in large, conspicuous masses, and the tadpoles reside in relatively small ponds at a time of year when those ponds are not overgrown with vegetation. This makes the eggs and tadpoles of *R. sylvatica* and *R. temporaria* easier to locate, approach, and sample than those of most other northern *Rana*. *Bufo americanus* breeds a bit later in the spring, but

Figure 1
The proportion of studies on the effect of low pH on embryonic and larval development of north temperate anuran species. Most studies (left side of diagram) have concentrated on species that commonly breed early in the year in small, temporary bodies of water. These species are convenient for study because of their rapid rate of larval development but may be naturally more resistant to environmental stresses than species that breed later in the year or have longer larval periods. The studies on which this figure is based are listed in Table 1.



its black eggs and black larvae are also conspicuous in the shallow clear water where it typically breeds. Thus, premetamorphic stages of *B. americanus* are similarly easy to locate and collect.

A problem arises because surface waters in north temperate North America and Europe are typically most acidic in early spring when the snowpack melts (see Harte and Hoffman 1989; see also papers cited in Freedman 1989). Therefore, *R. sylvatica* and *R. temporaria* appear to be naturally adapted for developing at low pH. The fact that both species utilize temporary pools further suggests that they may be more tolerant of variation in other potential stressors (e.g., temperature, oxygen deficits, other soluble ions) than species that breed in larger, more permanent, and consequently more physicochemically stable bodies of water.

The only North American anurans that have been reported to be more tolerant of low pH than *R. sylvatica* are *Rana virgatipes* and *Hyla andersoni* from the Pine Barrens of New Jersey.[1] These species breed in ponds associated with sphagnum bogs that are naturally very acidic. One north European species, *Rana arvalis*, may have slightly superior tolerance to low pH than *R. temporaria* (Andrén et al. 1988). However, in terms of ecology, morphology, and behaviour, these two members of the *R. temporaria* species group are very similar (Nikol'skii 1918).

Although I have focused on anurans, a similar story could be developed for salamanders. Almost all studies on the effects of environmental stresses, especially acidity, on North American salamanders have used species in the genus *Ambystoma*, which are contemporaneous with *R. sylvatica* in vernal ponds. *Ambystoma* eggs and larvae have the same advantages as test subjects for ecotoxicological studies. One may expect them, too, to be more adapted to lower pH than other salamanders living in larger bodies of water and breeding later in the year. It should be noted that the opposite view has been expressed: namely, that "amphibians which breed in temporary ponds may be the group most vulnerable to acidic precipitation" (Harfenist et al. 1989:54). This view does not consider evolutionary potential. That topic has been explored by Pierce and his colleagues (see Pierce and Harvey 1987), whose work suggests that such evolution is possible for anurans, although it has not yet been established for urodeles (see Tome and Pough 1982).

In sum, utilitarian considerations, rather than the importance of any particular amphibian within its terrestrial or aquatic community, seem to determine which species get the attention of experimentalists. Species favoured for study in the past happen to be those that are naturally most exposed to certain stresses, particularly low pH. Whether these species are at a greater or lesser risk from acid rain and other stresses is unresolved. However, one point is clear: in assessing factors that detrimentally affect amphibian development and survival, one has to be particularly cautious about generalizing from existing

[1] One study (Dale et al. 1985b) found 50% survival for *Rana clamitans* larvae after a two-week exposure to pH 3.3 at room temperature: i.e., a greater tolerance than *Rana sylvatica* tadpoles have exhibited. However, mortality for the *R. clamitans* larvae was 100% at 5°C; when these tadpoles overwinter in Canada, they are consistently exposed to temperatures lower than that. Amphibian larvae in general are less sensitive to low pH than are their embryos (see various papers cited in Freda 1986; see also Harte and Hoffman 1989). Tome and Pough (1982) demonstrated that amphibians are at greatest risk during the postcleavage stages of embryonic development.

studies to other amphibians that breed in different habitats and at other times of the year.

Sampling in field studies

A hypothesis on inverse accessibility and its implications for surveying anuran populations

The only Canadian anuran larva that is torrent-adapted and consequently difficult to collect is that of *Ascaphus truei* in southwestern Canada; all others breed in either standing or gently flowing water. Most lay their eggs in reasonably accessible situations, and all have tadpoles that are, even in the extreme, only minor variants of typical pond tadpoles.[2]

Compared with other tetrapods, our anurans are unquestionably r-selected. For the 13 species of true frogs (Ranidae), treefrogs (Hylidae), and toads (Bufonidae) found in eastern Canada, the median clutch size is greater than 1000 eggs, with a mean clutch size around 3500 (ranging from about 250 in *Acris crepitans* to >20 000 in large *R. catesbeiana*).[3] Thus, when a single anuran breeds in the eastern half of Canada, one can expect to find hundreds to thousands of eggs and, similarly, hundreds to thousands of tadpoles—even at sites where the local population may be declining or already on the brink of extinction (i.e., down to *one* breeding female).

Because of the ecological autonomy of the different life stages for anurans (see Wassersug 1975), premetamorphic abundance rarely, if ever, guarantees postmetamorphic abundance. In fact, my experience in Nova Scotia suggests that there is a pattern of inverse accessibility to pre- and postmetamorphic stages. At sites where I find adult frogs in abundance, it is often difficult to observe and collect their tadpoles in great numbers. These ponds have unstable banks, steep drop-offs, or excessively thick, marginal vegetation that resists penetration. These features make it difficult to reach the tadpoles and to sample them without risk of damage to either habitat or herpetologist. Alternatively, at ponds where tadpoles are conspicuous and easy to net, relatively few frogs may be observed either early in the season, as breeding adults, or later in the season, as postmetamorphic juveniles.

I believe that this impression of inverse accessibility reflects a real phenomenon, particularly in situations where predation is a major determinant of mortality. After all, if the younger aquatic stages are easy for herpetologists to approach and collect, they should be similarly easy for other predators to locate and exploit. The result may be precipitous declines in a cohort before metamorphosis is reached, resulting in relatively few postmetamorphic individuals emerging at that site. Conversely, if the larvae are protected from predation by the structural complexity of their aquatic and surrounding terrestrial environment, the result may be reduced predation on the larvae. Few larvae may actually be observed at the site by herpetologists or likewise be discovered by the natural predators. The expected result would be disproportionately large numbers of tadpoles surviving to become juvenile frogs.

The biology of pond tadpoles supports the underlying assumption that predation is a major selective force on anurans before metamorphosis. Large clutch size itself suggests high mortality. Except for species in the genus *Bufo* (Wassersug 1973) and possibly *R. catesbeiana* (Kruse and Francis 1977), our tadpoles have little defence against predators except to flee. None, however, is well designed for sustained locomotion in open water (Wassersug 1989). They can accelerate rapidly over short distances (see Hoff 1987 on tadpoles and Shaffer et al. 1991 on salamander larvae), but some cover is essential if they are going to survive when pursued by larger, visually oriented predators. Temperate amphibians that are palatable or lack some form of chemically mediated predator avoidance either do not breed in habitats rich in piscine predators or do so successfully only when there is some refuge (Kats et al. 1988). Size may ultimately provide some defence but is of little help when amphibian larvae are young and small (Formanowicz 1986; Werner 1986).

Rana clamitans tadpoles in Nova Scotia are strongly diurnal; they hide in vegetation during most of the day and come out only late in the day and at night (Warkentin, in press). Even during times when they are most numerous in the open, the majority of the tadpoles still stay under cover. Several recent laboratory studies have confirmed that amphibian larvae retreat to cover in the presence of a variety of predators and decrease their activity, which, in turn, can decrease their growth rate (Petranka et al. 1987; Werner 1991).

If I am correct about this pattern of inverse accessibility, then it has implications for any monitoring program designed to assess the vigour of anuran populations. Simply stated, conspicuous abundance of any one stage or the other at a site *cannot* be used alone to conclude that a population is healthy overall. Either abundance of both pre- and postmetamorphic stages must be independently assessed, or the population must be followed for multiple generations. Studies that have surveyed ponds solely either for eggs and tadpoles or for breeding adults in the short term say little about reproductive success at that site, even for a single generation. The potential for gene flow must be taken into consideration, yet rigorous studies in the area of amphibian biology are woefully few (cf. Gill 1978; Breden 1987; Berven and Grudzien 1990; Reading et al. 1991).

In selecting sites for long-term monitoring, ecologists might consider at the outset whether the structural complexity of the habitat is more or less likely to favour high predation on larvae or adults. Unfortunately, if the pattern of inverse accessibility is valid, habitats that are most likely to favour sustained high density overall are going to be ones that have much structural complexity and are mechanically most difficult to survey.

Sampling procedures

The previous point leads into the topic of sampling procedures. Methods for sampling amphibian larvae have been thoroughly reviewed by Shaffer et al. (in press). They discuss the four principal methods—seining, dip-netting, trapping, and enclosure sampling—used when one wishes to determine either species richness or the size of a population at a site. Furthermore, Shaffer et al. (in press) cover most of

[2] Among the more extreme and cryptic tadpoles elsewhere in the world are semiterrestrial, fossorial, and arboreal forms. In addition, approximately one-tenth of all anurans have abandoned the free-living larval stage altogether and have direct development instead. No Canadian species have such exotic development (see Duellman and Trueb 1986 for a review of anuran larval types and reproductive biology).

[3] Data extracted from several sources (e.g., Wright and Wright 1949; DeGraaf and Rudis 1983; Gilhen 1984; Duellman and Trueb 1986), with preference given to sources from Canada or the northern United States.

the strengths and weaknesses of these techniques. Rather than repeat their conclusions and recommendations, I offer here supplemental comments only.

Two methods that Shaffer et al. (in press) do not discuss lie at the extremes of what is acceptable and effective. Nevertheless, they should be mentioned. These methods are extermination and direct observation.

Poisoning small bodies of water or local sections of a stream with respiratory blockers, such as the biocide rotenone, was a common method used by museum collectors in past decades to drive fish to the surface. For capturing aquatic amphibians, however, this approach, which is now considered unconscionable by naturalists (certainly those concerned about population declines), is likely to be ineffective for two reasons. First, although low aquatic pO_2, or anything that deters aquatic respiration, will drive amphibians to the surface, most Canadian amphibian larvae develop lungs early[4] and can use them for aerial respiration when aquatic respiration is constrained. Secondly, virtually all of our amphibians are negatively buoyant; thus, if they are anaesthetized or asphyxiated, they will sink, not float. Other lethal procedures (electroshock, explosives) are likely to be similarly ineffective.

In rare circumstances, larvae can be counted by direct observation. If the animals are few and stationary in small, clear bodies of water, a simple count may be possible. Otherwise, photographs can be taken for later assessment (Dodd 1979). My impression is that the circumstances in which direct observation, with or without photographic assistance, is practical are very few. Generally, census by direct observation has been limited to behavioural studies of aposomatic and/or social larvae (e.g., *Bufo*—Dodd 1979; *Phyllomedusa*—Branch 1983).

It may be possible to rig up an elegant camera system to automate photographic surveying and make it more effective where lighting and cover prohibit clear visibility from shore. I know of no studies of amphibian larvae that have attempted this. In principle, this approach has one advantage over the invasive procedures reviewed by Shaffer et al. (in press): it causes far less habitat disturbance.

A point that Shaffer et al. (in press) make, which should be emphasized, is the trade-off between effective sampling and habitat destruction. Not only do amphibian larvae hide *on* the bottom, but, where the bottom is penetrable, they hide *in* it. Few tadpoles spend all of their time in the open. Most are cryptic and seek cover when pursued (Wassersug 1989). Macrophytes are important cover for tadpoles even when they are not used as food. To capture tadpoles with nets, one typically must sweep through the bottom and associated vegetation. I know of no studies that have examined the effect of churning up the bottom in natural ponds on the ultimate growth rate and survivorship of resident amphibian larvae. However, in light of the work by Sih et al. (1988; see also Werner 1991), any disruption of cover in ponds cannot help but alter amphibian predator–prey relationships and otherwise degrade the habitat.

If one avoids seine or dip-net sweeps because of concern over the disruption they cause, one is left with enclosure ("stove pipe") sampling and trapping. A recent study using enclosure sampling is that of Warkentin (in press), which involved the capture of tadpoles in cylindrical nets and the return of marked animals to those same enclosures (for a study of *in situ* feeding rates). Warkentin's (in press) study confirms how difficult it is to secure all of the animals within a vertical cylinder, even when the bottom is fairly level. When the bottom is uneven or vegetated, as is the common situation in eastern Canada, given the region's glacial history, this type of enclosure is unreliable.

Finally, there are traps. Unbaited funnel traps have been used effectively with larger *Rana* tadpoles in Canada (Calef 1973), but their reliability has not been verified for other Canadian genera. For most anuran larvae, which suspension-feed, it is not clear how well simple funnel traps might work or whether more complicated, baited traps might be more suitable. On the other hand, it is not clear what, if anything, would be effective as bait. For any trap, there is the risk of small aquatic predators entering along with the amphibian larvae, which would require that the traps be checked regularly.

It may be that trapping has the best promise of providing reliable survey data on aquatic amphibians with the least habitat destruction. However, there is much work that needs to be done first on assessing the efficiency of various trap designs.

My conclusion is that most sampling procedures for amphibian larvae either are of unproven effectiveness or are clearly disruptive to the habitat in ways that may be detrimental to the amphibian populations in the long run.

This may lead one to conclude that any long-term monitoring program must concentrate on the adults. Pechmann et al. (1991) recently showed that long-term monitoring of adult amphibian populations with drift fences is possible. These authors, of course, are not the first to use drift fences successfully. I, however, have two reservations about this approach.

First, as recently pointed out by Dodd (1991), the reliability of any drift fence has to be carefully checked. Sex and metamorphosis are powerful stimulants for movement in amphibians. The desire to get into and out of ponds has led to some remarkable feats of burrowing and climbing by frogs and salamanders that otherwise never exhibit such locomotor skills. Secondly, the Carolina bays at the Savannah River Ecological Laboratory (SREL), where Pechmann et al. (1991) did their research, are not like most ponds in Canada outside of the prairies. The SREL ponds are in sandy soil on relatively smooth ground. They are highly protected from human disturbance and easy to drift-fence. In contrast, comparably sized natural ponds in much of Canada are formed in bedrock with little topsoil. As a result, the pond margins are uneven and tree roots are near the surface, or the margins may be soft and peaty. In either case, such ponds are unquestionably more difficult to secure with a drift fence than those that have made SREL famous.

A final comment

If there has been a major trend in our understanding of the biology of amphibian larvae over the past 20 years, it is a realization of how sensitive these organisms are to their biotic world. We now know, for example, that certain tadpoles alter their activity in response to siblings versus nonsiblings, to both vertebrate and nonvertebrate competitors, and to predators even when they are not attacking (for recent reviews in these areas, see Brönmark et al. 1991; Griffith 1991; Waldman 1991; Werner 1991).

[4] The exceptions are those larvae associated with streams, such as *Ascaphus* and plethodontids, or in the genus *Bufo*.

Given the sensitivity that these organisms have to their environment, we must be concerned that survey efforts are not themselves a cause of the decline of amphibian populations.

Acknowledgements

Luc Bourque and Monika Fejtek helped with many aspects of the preparation of this report, including data compilation and analysis. My perspectives on tadpole ecology have been enriched by discussions with (among others) Bill Freedman, Janalee Caldwell, Marty Crump, W. Ronald Heyer, and Karen Warkentin. I thank Luc Bourque, Monika Fejtek, Bill Freedman, and Karen Warkentin for critical comments on early drafts of this manuscript, and I am grateful to the Natural Sciences and Engineering Research Council (NSERC) for their continued support of my research on anuran larval biology.

Literature cited

Andrén, C., L. Henrikson, M. Olson, and G. Nilson. 1988. Effects of pH and aluminum on embryonic and early larval stages of Swedish brown frogs: *Rana arvalis, R. temporaria*, and *R. dalmatina*. Holarct. Ecol. 11:127–135.

Andrén, C., M.M. Marden, and G. Nilson. 1989. Tolerance to low pH in a population of moor frogs (*Rana arvalis*) from an acid and neutral environment: a possible case of rapid evolutionary response to acidification. Oikos 56:215–223.

Beebee, T.J.C. and J.R. Griffin. 1977. A preliminary investigation into natterjack toad (*Bufo calamita*) breeding site characteristics in Britain. J. Zool. (Lond.) 181:341–350.

Berven, K.A. and T.A. Grudzien. 1990. Dispersal in the wood frog (*Rana sylvatica*): implications for genetic population structure. Evolution 44:2047–2056.

Branch, L.C. 1983. Social behaviour of the tadpoles of *Phyllomedusa vaillanti*. Copeia 1983:420–428.

Breden, F. 1987. The effect of post-metamorphic dispersal on the population genetic structure of Fowler's toad. Copeia 1987:386–395.

Brönmark, C., S.D. Rundle, and A. Erlandsson. 1991. Interactions between freshwater snails and tadpoles: competition and facilitation. Oecologia (Berlin) 87:8–18.

Calef, G.W. 1973. Natural mortality of tadpoles in a population of *Rana aurora*. Ecology 54:741–758.

Clark, K.L. and R.J. Hall. 1985. Effects of elevated hydrogen ion and aluminum concentrations on the survival of amphibian embryos and larvae. Can. J. Zool. 63:116–123.

Clark, K.L. and B.D. LaZerte. 1985. A laboratory study of the effects of aluminum and pH on amphibian eggs and tadpoles. Can. J. Fish. Aquat. Sci. 42:1544–1551.

Clark, K.L. and B.D. LaZerte. 1987. Intraspecific variation in hydrogen ion and aluminum toxicity in *Bufo americanus* and *Ambystoma maculatum*. Can. J. Fish. Aquat. Sci. 44:1622–1628.

Cook, F.R. 1984. Introduction to Canadian amphibians and reptiles. National Museum of Natural Sciences, Ottawa. 200 pp.

Cummins, C.P. 1986. Effects of aluminum and low pH on growth and development in *Rana temporaria* tadpoles. Oecologia (Berlin) 69:248–252.

Cummins, C.P. 1989. Interaction between the effects of pH and density on growth and development in *Rana temporaria* L. tadpoles. Funct. Ecol. 3:45–52.

Dale, J.M., B. Freedman, and J. Kerekes. 1985a. Acidity and associated water chemistry of amphibian habitats in Nova Scotia. Can. J. Zool. 63:97–105.

Dale, J.M., B. Freedman, and J. Kerekes. 1985b. Experimental studies of the effects of acidity and associated water chemistry on amphibians. Proc. N.S. Inst. Sci. 35:35–54.

DeGraaf, R.M. and D.D. Rudis. 1983. Amphibians and reptiles of New England: habitats and natural history. Univ. of Massachusetts Press, Amherst, Mass. 85 pp.

Dodd, C.K., Jr. 1979. A photographic technique to study tadpole populations. Brimleyana 2:131–136.

Dodd, C.K., Jr. 1991. Drift fence-associated sampling bias of amphibians at a Florida Sandhills temporary pond. J. Herpetol. 25:296–301.

Duellman, W.E. and L. Trueb. 1986. Biology of amphibians. McGraw-Hill, New York. 670 pp.

Formanowicz, D.R., Jr. 1986. Anuran tadpole/aquatic insect predator–prey interactions: tadpole size and predator capture success. Herpetologica 42:367–373.

Freda, J. 1986. The influence of acidic pond water on amphibians: a review. Water Air Soil Pollut. 30:439–450.

Freda, J. and W.A. Dunson. 1984. Sodium balance of amphibian larvae exposed to low environmental pH. Physiol. Zool. 57:435–443.

Freda, J. and W.A. Dunson. 1985a. Field and laboratory studies of ion balance and growth rates of ranid tadpoles chronically exposed to low pH. Copeia 1985:415–423.

Freda, J. and W.A. Dunson. 1985b. The influence of external cation concentration on the hatching of amphibian embryos in water of low pH. Can. J. Zool. 63:2649–2656.

Freda, J. and W.A. Dunson. 1986a. Effects of low pH and other chemical variables on the local distribution of amphibians. Copeia 1986:454–466.

Freda, J. and W.A. Dunson. 1986b. The effect of prior exposure on sodium uptake in tadpoles exposed to low pH water. J. Comp. Physiol. B 156:649–654.

Freedman, B. 1989. Environmental ecology: the impacts of pollution and other stresses on ecosystem structure and function. Academic Press, San Diego. 424 pp.

Gilhen, J. 1984. Amphibians and reptiles of Nova Scotia. Nova Scotia Museum, Halifax. 162 pp.

Gill, D.E. 1978. The metapopulation ecology of the red-spotted newt (*Notophthalmus viridescens*) (Rafinesque). Ecol. Monogr. 48:145–166.

Gosner, K.L. and I.H. Black. 1957. The effects of acidity on the development and hatching of New Jersey frogs. Ecology 38:256–262.

Griffith, R.A. 1991. Competition between common frog (*Rana temporaria*), and natterjack toad (*Bufo calamita*), tadpoles: the effect of competitor density and interaction level on tadpole development. Oikos 6:187–196.

Hagstrom, T. 1980. Reproductive strategy and success of amphibians in waters acidified by atmospheric pollution. Pages 55–57 *in* Proceedings of the European Herpetology Symposium, Cotswold Wild Life Park, Oxford.

Harfenist, A., T. Power, K.L. Clark, and D.B. Peakall. 1989. A review and evaluation of the amphibian toxicological literature. Can. Wildl. Serv. Tech. Rep. No. 1, Ottawa. 222 pp.

Harte, J. and E. Hoffman. 1989. Possible effects of acidic deposition on a Rocky Mountain population of the tiger salamander *Ambystoma tigrinum*. Conserv. Biol. 3:149–158.

Hillis, D.M. and S.K. Davis. 1986. Evolution of ribosomal DNA: fifty million years of recorded history in the frog genus *Rana*. Evolution 40:1275–1288.

Karns, D.R. 1983. Toxic bogwater in Northern Minnesota peatlands: ecological and evolutionary consequences for breeding amphibians. Ph.D. thesis, Univ. of Minnesota, Minneapolis.

Kats, L.B., J.W. Petranka, and A. Sih. 1988. Antipredator defenses and the persistence of amphibian larvae with fishes. Ecology 69:1865–1870.

Kruse, K.C. and M.G. Francis. 1977. A predation deterrent in larvae of the bullfrog, *Rana catesbeiana*. Trans. Am. Fish. Soc. 106:248–252.

Leuven, R.S.E.W., C. denHartog, M.M.C. Christiaans, and W.H.C. Heijligers. 1986. Effects of water acidification on the distribution pattern and the reproductive success of amphibians. Experientia 42:495–503.

Ling, R.W., J.P. VanAmberg, and J.K. Werner. 1986. Pond acidity and its relationship to larval development of *Ambystoma maculatum* and *Rana sylvatica* in Upper Michigan. J. Herpetol. 20:230–236.

McDonald, D.G., J.L. Ozog, and B.P. Simons. 1984. The influence of low pH environments on ion regulation in the larval stages of the anuran amphibian, *Rana clamitans*. Can. J. Zool. 62:2171–2177.

Nikol'skii, A.M. 1918. Fauna of Russia and adjacent countries: amphibians [translation]. Israeli Program for Scientific Translations, Jerusalem. 225 pp.

Pechmann, J.H.K., D.E. Scott, R.D. Semlitsch, J.P. Caldwell, L.J. Vitt, and J.W. Gibbons. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science 253:892–895.

Petranka, J.W., L.B. Kats, and A. Sih. 1987. Predator–prey interactions among fish and larval amphibians: use of chemical cues to detect predatory fish. Anim. Behav. 35:420–425.

Pierce, B.A. and J.M. Harvey. 1987. Geographic variation in acid tolerance of Connecticut wood frogs. Copeia 1987:94–103.

Pierce, B.A. and N. Sikand. 1985. Variation in acid tolerance of Connecticut wood frogs: genetic and maternal effects. Can. J. Zool. 63:1647–1651.

Pierce, B.A., J.B. Hoskins, and E. Epstein. 1984. Acid tolerance in Connecticut wood frogs (*Rana sylvatica*). J. Herpetol. 18:159–167.

Pierce, B.A., M.A. Margolis, and L.J. Nirtaut. 1987. The relationship between egg size and acid tolerance in *Rana sylvatica*. J. Herpetol. 21:178–184.

Porter, K.R. and D.E. Hakanson. 1976. Toxicity of mine drainage to embryonic and larval boreal toads (Bufonidae: *Bufo boreas*). Copeia 1976:327–331.

Reading, C.J., J. Loman, and T. Madsen. 1991. Breeding pond fidelity in the common toad (*Bufo bufo*). J. Zool. (Lond.) 225:201–211.

Saber, P.A. and W.A. Dunson. 1978. Toxicity of bogwater to embryonic and larval anuran amphibians. J. Exp. Zool. 204:33–42.

Schlichter, L.C. 1981. Low pH affects the fertilization and development of *Rana pipiens* eggs. Can. J. Zool. 59:1693–1699.

Shaffer, H.B., C.C. Austin, and R.B. Huey. 1991. The consequences of metamorphosis on salamander (*Ambystoma*) locomotor performance. Physiol. Zool. 64:212–231.

Shaffer, H.B., R. Alford, B. Woodward, S.J. Richards, R. Altig, and C. Gascon. In press. Standard techniques for inventory and monitoring. *In* Heyer, W.R., M.A. Donnelly, R. McDiarmid, and L.A. Heyek (eds.), Standard methods for measuring biological diversity of amphibians. Smithsonian Press, Washington, D.C.

Sih, A., J.W. Petranka, and L.B. Kats. 1988. The dynamics of prey refuge use: a model and tests with sunfish and salamander larvae. Am. Nat. 132:463–483.

Tome, M.A. and F.H. Pough. 1982. Responses of amphibians to acid precipitation. Pages 245–254 *in* R.E. Johnson (ed.), Acid rain/fisheries. American Fisheries Society, Bethesda, Md.

Tyler-Jones, R., R.C. Beattil, and R.J. Aston. 1989. The effects of acid water and aluminum on the embryonic development of the common frog (*Rana temporaria*). J. Zool. (Lond.) 219:355–372.

Wake, D.B. 1991. Declining amphibian populations. Science 253:860.

Waldman, B. 1991. Kin recognition in amphibians. Pages 162–219 *in* Hepper, P.G. (ed.), Kin recognition. Cambridge Univ. Press, Cambridge.

Warkentin, K.M. In press. Microhabitat use and feeding rate variation in green frog tadpoles (*Rana clamitans*). Copeia 1992.

Wassersug, R.J. 1973. Aspects of social behaviour in anuran larvae. Pages 273–297 *in* Vial, J.L. (ed.), Evolutionary biology of the anurans. Univ. of Missouri Press, Columbia, Mo.

Wassersug, R.J. 1975. The adaptive significance of the tadpole stage with comments on the maintenance of complex life cycles in anurans. Am. Zool. 15:405–417.

Wassersug, R.J. 1989. Locomotion in amphibian larvae (or "Why aren't tadpoles built like fishes?"). Am. Zool. 29:65–84.

Werner, E.E. 1986. Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation. Am. Nat. 128:319–341.

Werner, E.E. 1991. Nonlethal effects of a predator on competitive interactions between two anuran larvae. Ecology 72:1709–1720.

Wright, A.H. and A.A. Wright. 1949. Handbook of frogs and toads. Comstock Publ. Assoc., Ithaca, N.Y. 625 pp.

The role of disease in amphibian decline

Graham J. Crawshaw

Abstract

Although there have been several reports of naturally occurring outbreaks of disease in wild amphibians, little is known of the impact of infectious and noninfectious agents on wild populations. Disease in amphibians results from a failure to maintain homeostasis in the face of physical, chemical, or microbial challenge. Infectious agents, such as *Aeromonas hydrophila*, the most frequent cause of red leg, are commonly found as normal inhabitants of the amphibian environment. Amphibians remain healthy because of their immune competence, which will be compromised by a variety of extrinsic stressors. Disease monitoring and pathophysiological studies in both healthy and diseased populations are essential components of any study into the causes of local or generalized amphibian loss.

Résumé

En dépit de l'existence de rapports sur l'apparition de maladies provenant de causes naturelles chez les amphibiens à l'état sauvage, on dispose de peu de données sur l'incidence des agents infectieux et non infectieux sur ces populations. Les maladies des amphibiens sont provoquées par le défaut de conserver leur équilibre homéostatique à la suite de modifications éprouvantes du milieu physique, chimique ou microbien. Des agent infectieux tels que *Aeromonas hydrophila*, la cause la plus fréquente du syndrome dit de « la patte rouge », se retrouvent fréquemment dans le milieu amphibien. Leur immunité permet aux amphibiens de conserver la santé, mais cette immunité peut être compromise par une variété de facteurs externes de stress. Des études sur la prophylaxie et la physiopathologie des populations saines et infectées doivent être intégrées aux études sur les causes de la diminution locale ou généralisée des populations d'amphibiens.

Introduction

Disease in amphibians results from a failure to adapt or defend against injury, be it physical, chemical, or microbial. Knowledge of pathophysiological processes in amphibians is still poor, and reports of naturally occurring disease remain few. Careful monitoring of both normal healthy and potentially diseased populations is essential to reverse the present trends.

More so than other vertebrates, amphibians are dependent on their environment for all aspects of their physiology. Because of their dependence on water, their highly permeable skins, and their reproductive strategies, they are particularly susceptible to environmental changes. They remain healthy by virtue of physiological and behavioural responses to insult and stress. When they are unable to respond to stress, whatever the nature, then disease results.

Rarely is disease in amphibian populations going to be evidenced by large numbers of dead animals. Most effects are likely to be more subtle—increased egg or juvenile mortality, reduced longevity, or immune system depression leading to gradual declines in populations. The major problem in the investigation of subacute disease rather than epidemics for animals such as amphibians is a lack of material available for examination. Even large die-offs, which should present better opportunities for examination and diagnosis, may be unrewarding in amphibians owing to their small size, secretive nature, and rapid decomposition.

Careful examination combined with the appropriate microbiological, toxicological, and microscopic examination can usually determine the organ system affected and the final, if not the underlying, cause of mortality. In order to obtain the maximum information in an investigation of a disease, it is essential to collect the appropriate samples. For worthwhile results, autopsies should be performed on very freshly dead animals. Amphibians autolyse rapidly, making examination of any but recent deaths unrewarding. A standard and systematic postmortem examination should be performed with samples of all organs collected in 10% buffered formalin for histopathology. Other fixatives may be needed for special studies such as electron microscopy. Samples of heart blood, liver, lung, kidney, etc. should be taken with sterile technique for microbiological examination.

Heart blood smears can be made for hemoparasite examination, feces can be collected, and the gastrointestinal tract can be opened for parasite identification. Macroscopic parasites or lesions may be seen in almost any organ, but rarely are clinical or gross pathological findings in amphibians diagnostic. In most cases, microscopic and microbiological or toxicological studies are essential for definitive diagnoses, and, even then, correlation of pathological findings with a particular etiology can be difficult.

If laboratory facilities are not available, specimens should be preserved until they can be examined.

Refrigeration will delay autolysis, but not indefinitely. Freezing will prevent bacterial decomposition and preserve most microorganisms but can seriously affect the quality of histopathology samples. Immediate fixation preserves tissue integrity but negates microbial culture. If several animals are available, some should be frozen and others refrigerated or placed in formalin for future examination. Further examination of the specimens should preferably be carried out by a pathologist who is familiar with amphibian morphology and disease. If potentially significant factors in mortality or reproductive depression are identified, duplication of the situation in a controlled experiment in either the field or the laboratory is essential. Amphibians have been kept, and in some cases bred, in laboratories for many years, but, for the most part, the purpose of the research has been directed towards learning more about human and other mammalian physiology, rather than for the benefit of the amphibians themselves.

Infectious disease

Most of the organisms responsible for amphibian disease are readily found within the amphibian environment (usually the water), but amphibians survive by virtue of the competence of their immune systems—they have components similar to those of higher vertebrates. A variety of stressors (environmental, social, toxic, nutritional, infectious) can depress immune function, leading to infectious disease. Alternatively, environmental changes can alter the microbial balance, resulting in abnormally high levels of pathogenic organisms (Schotts et al. 1972).

An example of how intimate infectious, environmental, and immune factors interact is the case of the Lucke tumour virus, a herpesvirus of *Rana pipiens* (Northern Leopard Frog) that causes kidney tumours and that has been extensively studied in cancer research. The virus within the frog, and hence the pathology that it causes, undergoes seasonal cyclicity. At temperatures above 22°C, the virus does not replicate, and inclusion bodies (the structures within the cell containing viral particles) are not detectable. During the winter, however, viral replication occurs, with the appearance of inclusion bodies, mature virus, and tumour development (McKinnell 1984).

Numerous other viruses have been detected in amphibians, but an association with disease is not always clear. The polyhedral cytoplasmic viruses (iridoviruses) have been found in various species and locations, including Ontario. One such virus, named the tadpole edema virus, causes mortality in larval and juvenile *Rana catesbeiana* (Bullfrog) and can be transmitted to other species, but in other instances these viruses may not be pathogenic, particularly within their host.

In captivity, and presumably in the wild as well, bacteria are a major cause of amphibian morbidity and mortality. Red leg is the best-known amphibian disease, but it is not a single entity. Usually associated with *Aeromonas hydrophila*, red leg or a similar syndrome of septicemia can be caused by a number of gram-negative, or even gram-positive, bacteria (Glorioso et al. 1973). Signs of the disease vary from peracute death without evidence of illness to depression, anorexia, varying degrees of skin congestion, hemorrhage, and ulcerations, particularly of the limbs and the ventral surface, as well as a variety of other syndromes. Outbreaks of red leg have been seen in wild amphibians in various parts of the world, but the causative organisms may also be cultured from healthy animals (Hird et al. 1981).

Salmonella can be isolated quite commonly from amphibian feces and can be pathogenic. Chlamydia, organisms responsible for disease in many animals including humans, have been found in amphibians, especially *Xenopus*, causing a syndrome similar to red leg. Sporadic infection with mycobacteria (tuberculosis) can also occur and is usually secondary to stress and injury.

Fungal infections are very common and again likely represent some breakdown in immune function. In the wild, particularly the tropics, both pathogenic and nonpathogenic fungi can be found in the tissues of healthy animals. What is not certain is what the triggers or specific stressors are that make a latent infection become patent. Two types of fungal infections are seen: localized infections in the skin, and a more generalized visceral form that is often fatal.

Parasites are ubiquitous, and there have been numerous reports and studies on parasites of all kinds. For the most part, amphibians tolerate parasitic burdens well, although in heavy infections they can be significant or can cause clinical disease or death when environmental or nutritional conditions are less than optimal.

In captive situations, infection with the nematode lungworm *Rhabdias* can be pathogenic, whereas *Capillaria* has caused disease and death in *Xenopus*. Protozoa are particularly common in wild amphibians. Large numbers of blood protozoa, such as *Hemobartonella* and trypanosomes, and intestinal forms, such as *Entamoeba* and *Balantidium*, may be found.

Noninfectious disease

Amphibians are susceptible to a huge range of noninfectious problems. Predation and trauma are major causes of mortality. Also, amphibians, by virtue of their permeable skins and lack of major water loss protection, are highly susceptible to desiccation, with their lifestyles reflecting dependence on either water itself or at least a high humidity.

Another consequence of skin permeability is a susceptibility to environmental contaminants. Many elements, such as heavy metals, as well as organic and inorganic compounds are potentially toxic. Ammonia, chlorine, copper, iodine, pesticides, and many other compounds have proven lethal, as have extremes of pH. With the exception of the Lucke tumour, neoplasms occur sporadically, but they have been found in amphibians in polluted waters and would be expected to develop more frequently under the influence of certain chemicals.

Summary

Disease investigation is an important component in the monitoring of amphibian decline. As global pressures increase and amphibian populations become smaller and more fragmented, the implication of diseases will also increase. Isolation of small populations leads to loss of genetic variability, which may reduce inherent resistance to disease and the ability to adapt to environmental pressures. Smaller and more isolated populations are also in greater peril of being eliminated by endemic or introduced pathogens. Very little is known about the effect of diseases on amphibian numbers. It is easy to suggest that physical or chemical changes in the environment may either directly or indirectly be having an adverse effect on some stage of the amphibian life cycle. Proving it will be considerably more difficult.

Literature cited

Glorioso, J.C., G.F. Amborski, and D.D. Culley. 1973. Microbiological studies on septicemic bullfrogs (*Rana catesbeiana*). Am. J. Vet. Res. 335:1241–1245.

Hird, D.W., S.L. Diesch, R.G. McKinnell, E. Gorham, F.B. Martin, S.W. Kurtz, and C. Dubrovolny. 1981. *Aeromonas hydrophila* in wild-caught frogs and tadpoles (*Rana pipiens*) in Minnesota. Lab. Anim. Sci. 31:166–169.

McKinnell, R.G. 1984. Lucke tumour of frogs. Pages 581–605 *in* Hoff, G.L., F.L. Frye, and E.R. Jacobson (eds.), Diseases of amphibians and reptiles. Plenum Press, New York.

Schotts, E.B., J.L. Gains, L. Martin, and A.K. Prestwood. 1972. *Aeromonas*-induced deaths among fish and reptiles in a eutrophic inland lake. J. Am. Vet. Med. Assoc. 161:603–607.

Monitoring the effects of acidic deposition on amphibian populations in Canada

Karen L. Clark

Abstract

In Canada, the aquatic habitats most susceptible to acidification are on the Canadian Shield in central Ontario and southern Quebec and in southern Nova Scotia and parts of New Brunswick. For 16 of the 17 species found in these areas, over 50% of their ranges in Canada are being affected by acidic deposition. Surveys of amphibian distribution in Ontario and Quebec relative to pond pH have shown that *Rana catesbeiana*, *Rana clamitans*, *Hyla crucifer*, *Ambystoma maculatum*, and *Rana sylvatica* population sizes are positively correlated with pH.

Long-term studies need to be conducted to monitor the responses of amphibian populations to any potential recovery as sulphate emissions are reduced. *Ambystoma maculatum* would be the best species to study to detect any response to changes in atmospheric input of hydrogen ions, for several reasons:

(1) *Ambystoma maculatum* is one of the most sensitive species to the direct toxic effects of low pH.

(2) It breeds in temporary ponds, which are the habitats most vulnerable to acidification.

(3) Over 75% of its range in Canada is being affected by acidic deposition.

(4) Abundance and reproductive success are relatively easy to measure in the field.

(5) A number of surveys of abundance and reproductive success relative to pond pH that have already been conducted in Ontario could be used as baseline data.

Résumé

Au Canada, les habitats aquatiques les plus susceptibles d'acidification sont situés dans les régions du bouclier canadien situées dans le centre de l'Ontario et le sud du Québec, ainsi que dans la partie sud de la Nouvelle-Écosse et certaines parties du Nouveau-Brunswick. Plus de 50 % de l'aire de distribution au Canada de 16 des 17 espèces trouvées dans ces régions est affecté par les dépôts acides. Les études sur la distribution des amphibiens en Ontario et au Québec en fonction du pH des étangs ont montré que les populations de *Rana catesbeiana*, *Rana clamitans*, *Hyla crucifer*, *Ambystoma maculatum* et *Rana sylvatica* sont en corrélation positive avec le pH.

Il faut réaliser des études à long terme pour suivre la réponse des populations d'amphibiens à tout progrès potentiel associé à la réduction des émissions de sulfate. *Ambystoma maculatum* constituerait la meilleure espèce pour détecter toute réponse à un changement dans les apports atmosphériques des ions hydrogène, et cela pour différentes raisons :

(1) *Ambystoma maculatum* constitue l'une des espèces les plus sensibles aux effets toxiques directs d'un bas pH.

(2) Cette espèce se reproduit dans des étangs temporaires, soit les habitats les plus sensibles à l'acidification.

(3) Plus de 75 % de l'aire de distribution de cette espèce au Canada est affecté par les dépôts acides.

(4) L'abondance et la réussite de la reproduction sont facilement mesurables sur le terrain.

(5) Un certain nombre de relevés de l'abondance et du succès de la reproduction en fonction du pH des étangs ont été effectués en Ontario; les résultats pourraient servir de valeurs de référence.

Introduction

Acidic deposition has led to the acidification of aquatic habitats in many parts of Canada. Susceptibility to acidification is dependent on two factors: the atmospheric loading of hydrogen ions, and the surficial geology that influences the buffering capacity of the surface waters. In Canada, the aquatic habitats most susceptible to reductions in pH are on the Canadian Shield in central Ontario and southern Quebec and in southern Nova Scotia and parts of New Brunswick. For 16 of the 17 species found in these areas, over 50% of their ranges in Canada are in the areas being affected by acidic deposition (Table 1).

Amphibians are particularly vulnerable to negative impacts from acidic precipitation, because many species inhabit and reproduce in aquatic habitats. Although there are no historical data to document declines in amphibian populations relative to increased habitat acidity, surveys of amphibian distributions have shown that populations are

Table 1
Sensitivity of amphibian species to reduced pH levels and the percentage of their range in Canada affected by acidic precipitation[a]

Species	Lethal pH	Critical pH	Range affected[b] (%)	Reference[c]
Ambystoma maculatum	4.0–4.5	4.5–5.0	>75	2,3,4,9,15
Ambystoma jeffersonianum	4.0–4.5	4.5–5.0	<50	2,3,7,8
Rana pipiens	4.2–4.5	4.6	50–75	1,9
Rana palustris	4.0–4.5	4.3–4.5	50–75	1,13
Pseudacris triseriata	4.2	—	50–75	6
Rana catesbeiana	3.9	4.3	50–75	1,16
Hyla versicolor	3.8	4.3	50–75	1
Hyla crucifer	3.8–4.2	4.2	>75	1,9
Bufo americanus	3.8–4.2	4.0–4.2	50–75	6,10,11,14,15
Rana clamitans	3.7–3.8	4.1	50–75	1,7,16
Rana sylvatica	3.5–4.0	3.9–4.25	25–50	1,4–12,15
Rana septentrionalis			>75	
Ambystoma laterale			>75	
Eurycea bislineata			>75	
Notophthalmus viridescens			50–75	
Necturus maculosus			50–75	
Hemidactylium scutatum			50–75	

[a] Table modified from Freda (1986), in which lethal pH causes 100% mortality in embryos and critical pH refers to the highest pH that significantly increases mortality above control levels.
[b] Using range maps in Cook 1984.
[c] References: (1) Gosner and Black 1957; (2) Pough and Wilson 1978; (3) Cook 1983; (4) Tome and Pough 1982; (5) Pierce et al. 1984; (6) Karns 1983; (7) Freda and Dunson 1986; (8) Freda and Dunson 1985b; (9) Dale et al. 1985; (10) Clark and Hall 1985; (11) Clark and LaZerte 1985; (12) Gascon and Planas 1986; (13) Saber and Dunson 1978; (14) Freda and Dunson 1985b; (15) Clark and LaZerte 1987; (16) Gascon and Bider 1985.

Table 2
Mean pH of temporary ponds in Canada

Location	No. of ponds	pH Mean	pH Range	Reference
Quebec	12	5.65	4.31–6.77	Gascon and Planas 1986
Killarny, Ont.	16	4.92	4.15–6.77	Freda et al. 1990
Muskoka, Ont.	6	5.32	4.41–6.29	Clark and Hall 1985
Muskoka, Ont.	20	5.64	4.45–6.37	Clark 1986a
Muskoka, Ont.	40	5.59	4.44–6.63	Clark 1986b

Table 3
pH levels of temporary ponds from random surveys in Canada

Location	% of ponds with pH: <4.5	4.5–5.0	>5.0–5.5	>5.5	N	Reference
Muskoka, Ont.	0	10	25	65	20	Clark 1986a
Muskoka, Ont.	5	10	35	50	40	Clark 1986b
Killarny, Ont.	14	25	NR	NR	91	Freda et al. 1990

NR = not reported

smaller in low-pH ponds. In Ontario, densities of nonbreeding adult *Rana catesbeiana* and *Rana clamitans* declined with pH in 20 ponds with pH levels ranging from 4.55 to 6.37 (Clark 1986b). In the same ponds, densities of calling male *Hyla crucifer* and *Ambystoma maculatum* egg masses (an estimate of the breeding population) were positively related to pond pH (Clark 1986a, 1986b). In another 40 ponds, densities of *Rana sylvatica* egg masses declined in lower-pH ponds (pH range 4.44–6.63) (Clark 1986b). Similar results were found for *R. sylvatica* egg densities in 12 ponds in Quebec with pH levels ranging from 4.31 to 6.77 (Gascon and Planas 1986).

Habitat susceptibility to acidification

Different habitats have varying susceptibility to declines in pH. The most vulnerable are temporary ponds, because they are small and usually consist of acidic water from spring snowmelt and rainfall that has had little opportunity for buffering by adjacent soils. Surveys of temporary ponds in Canada show that many are already very acidic (Tables 2 and 3). These ponds are used for breeding by over half of the species that occur in areas being affected by acidic deposition in Canada. Breeding in temporary ponds occurs early to allow time for larval development before the ponds dry in early to mid-summer. Early spring is also the time when the hydrogen ion concentrations are the greatest, as pH usually increases with pond drying (Pierce et al. 1984; Freda and Dunson 1985a; Freda 1986).

Headwater streams are also highly susceptible to acidification and are inhabited by many of the plethodontid salamanders. Very little is known about the effects of acidification on any of these species.

Permanent ponds and lakes are inhabited by many amphibians, including the larger ranid species and newts. Ponds and lakes are susceptible to pH depressions during spring snowmelt and to general acidification but at a slower rate than temporary ponds, because they contain water that has greater opportunity for buffering. For example, in New York, 12 temporary ponds had a mean pH of 4.5 (range 3.5–7.0), whereas six permanent ponds in the same geographic area had a mean pH of 6.1 (range 5.5–7.0) (Pough and Wilson 1978). The only study in Canada that has measured amphibian distributions relative to pH in permanent ponds and lakes was conducted in Nova Scotia. Dale et al. (1985) found no relationship between species presence and pond or lake pH.

There is strong evidence that terrestrial salamanders may be affected. The natural acidification process of soils may be accelerated by acidic deposition, and the pH of soils strongly affects the distribution of terrestrial salamanders (Wyman and Hawksley-Lescault 1987). In New York, *Plethodon cinereus* densities were drastically reduced in areas with soil pH below 3.7.

Direct toxicity of elevated hydrogen ion concentrations

Declines in amphibian populations in acidic ponds are likely due to both direct effects of elevated hydrogen ion concentrations as well as indirect effects. The life stage most sensitive to direct hydrogen ion toxicity is the embryo. Hydrogen ion concentrations at very high lethal levels cause immediate mortality. At lower levels, the normal expansion of the perivitelline membranes during development is inhibited. Embryos become tightly coiled, leading to developmental deformities and in some species difficulty in hatching (Gosner and Black 1957; Pierce et al. 1984; Clark and LaZerte 1985; Freda and Dunson 1985a, 1985b). The inhibition of hatching is likely due to the deactivation of the hatching enzyme (Urch and Hedrick 1981; Robb and Toews 1987).

Low pH levels affect larvae by disrupting sodium and chloride balance (McDonald et al. 1984; Freda and Dunson 1984, 1985a, 1985b). This can lead to direct mortality, and growth rates are reduced at sublethal levels.

Direct toxicity of reduced pH varies greatly among species (Table 1). Of the species that have been tested, *Ambystoma jeffersonianum* and *A. maculatum* are the most sensitive, and these species breed in temporary ponds, the habitats most vulnerable to pH declines.

Another factor that affects the toxicity of low pH is the concentrations of other chemical components of the water, such as calcium, aluminum, and dissolved organic compounds (reviewed by Freda 1986). For some species, aluminum, calcium, and sodium can, at low concentrations, ameliorate the toxicity of elevated hydrogen ion concentrations. Aluminum at higher concentrations is itself toxic at low pH levels (Clark and Hall 1985; Clark and LaZerte 1985, 1987; Freda and Dunson 1985a, 1985b, 1986). Similarly, natural organic acids are themselves toxic, but they can, at sublethal levels, reduce the toxicity of aluminum (Clark and Hall 1985; Freda and McDonald 1990).

Indirect effects of reduced pH

Little is known about the indirect effects of acidification on amphibians, but they are likely significant. Amphibians are subjected to shifts in food resources (e.g., changes in periphyton and zooplankton biomass and species composition) and alteration of habitat characteristics (e.g., growth of the alga *Mougeotia*) as ponds acidify. Reduced larval growth rates at sublethal pH levels can have ecological implications, as smaller larvae can have reduced ecological fitness (Wilbur 1980). There is also evidence that embryos are more vulnerable to fungal infestations at reduced pH levels (Gascon and Planas 1986).

Long-term monitoring

When designing a long-term study to monitor the effects of acidic precipitation on amphibians, the following factors should be considered:

(1) the acid sensitivity of the species;

(2) the vulnerability of the breeding habitat to acidification;

(3) ease of measuring population size and reproductive success;

(4) geographical distribution of the species; and

(5) availability of historical data.

The species that best satisfies most of the above criteria is *A. maculatum*. *Ambystoma maculatum* is one of the most sensitive species that has been tested, and it frequently breeds in temporary ponds—the habitats most vulnerable to acidification. Also, over 75% of its range in Canada is affected by acidic deposition. Temporary ponds are often numerous and are usually easily accessible. *Ambystoma maculatum* abundance and reproductive success are relatively easy to measure in the field. By visiting a pond weekly during the breeding season, it is possible to count the number of egg masses (an estimate of the number of females that have bred in the pond) and determine hatching success if egg mass locations are marked. Egg deposition occurs early in the spring, with all eggs being laid within about three weeks, and hatching occurs within three to four weeks. Each female lays one egg mass, which is about 5–10 cm in diameter, with 50–100 eggs per mass attached to a submerged branch or twig. Egg masses are easy to locate, and development can be monitored. A number of surveys of population size and breeding success relative to pond acidity that have been conducted in central Ontario could be used as background data. A study in which *A. maculatum* egg mass number, hatching success, and key pond characteristics—e.g., pH and concentrations of calcium, sodium, magnesium, potassium, sulphate, nitrate, dissolved organic carbon, and total aluminum—are measured would allow detection of changes in *A. maculatum* breeding populations in response to any changes in pond chemistry.

Conclusion

There is strong evidence that amphibian populations in Canada have been negatively affected by acidic deposition. A long-term monitoring program is needed to determine the status of amphibian populations relative to acidification of their breeding habitats, as well as to monitor any potential recovery as sulphate emissions are reduced.

Literature cited

Clark, K.L. 1986a. Responses of spotted salamander *Ambystoma maculatum* populations in central Ontario to habitat acidity. Can. Field-Nat. 100:463–469.

Clark, K.L. 1986b. Distributions of anuran populations in central Ontario relative to habitat acidity. Water Air Soil Pollut. 30:727–734.

Clark, K.L. and R.J. Hall. 1985. Effects of elevated hydrogen ion and aluminum concentration on the survival of amphibian embryos and larvae. Can. J. Zool. 63:116–123.

Clark, K.L. and B. LaZerte. 1985. A laboratory study of the effects of aluminum and pH on amphibian eggs and tadpoles. Can. J. Fish. Aquat. Sci. 42:1544–1551.

Clark, K.L. and B. LaZerte. 1987. Intraspecific variation in hydrogen ion and aluminum toxicity in *Bufo americanus* and *Ambystoma maculatum*. Can. J. Fish. Aquat. Sci. 44:1622–1628.

Cook, F. 1984. Introduction to Canadian amphibians and reptiles. National Museum of Natural Sciences, Ottawa. 200 pp.

Cook, R. 1983. Effects of acid precipitation on embryonic mortality of *Ambystoma* salamanders in the Connecticut Valley of Massachusetts. Biol. Conserv. 27:77–88.

Dale, J., B. Freedman, and J. Kerekes. 1985. Acidity and associated water chemistry of amphibian habitats in Nova Scotia. Can. J. Zool. 63:97–105.

Freda, J. 1986. The influence of acidic pond water on amphibians: a review. Water Air Soil Pollut. 71:439–450.

Freda, J. and W. Dunson. 1984. Sodium balance of amphibian larvae exposed to low environmental pH. Physiol. Zool. 57:435–443.

Freda, J. and W. Dunson. 1985a. Field and laboratory studies of ion balance and growth rates of ranid tadpoles chronically exposed to low pH. Copeia 1985:415–423.

Freda, J. and W. Dunson. 1985b. The influence of external cation concentration on the hatching of amphibian embryos in water of low pH. Can. J. Zool. 63:2649–2656.

Freda, J. and W. Dunson. 1986. Effects of low pH and other chemical variables on the local distribution of amphibians. Copeia 1986:454–466.

Freda, J. and D. McDonald. 1990. Effects of aluminum on the leopard frog *Rana pipiens*: life stage comparisons and aluminum uptake. Can. J. Fish. Aquat. Sci. 47(1):210–216.

Freda, J., V. Caydek, and D. McDonald. 1990. Role of organic complexation in the toxicity of aluminum to *Rana pipiens* embryos and *Bufo americanus* tadpoles. Can. J. Aquat. Sci. 47(1):217–224.

Gascon, C. and J. Bider. 1985. The effect of pH on bullfrog and green frog tadpoles. Can. Field-Nat. 99:259–261.

Gascon, C. and D. Planas. 1986. Spring pond water chemistry and the reproduction of the wood frog *Rana sylvatica*. Can. J. Zool. 64:543–550.

Gosner, K. and I. Black. 1957. The effects of acidity on the development and hatching of New Jersey frogs. Ecology 38:256–262.

Karns, D. 1983. Toxic bog water in northern Minnesota peatlands: ecological and evolutionary consequences for breeding amphibians. Ph.D. thesis, Univ. of Minnesota, Minneapolis, Minn.

McDonald, D., J. Orzog, and B. Simons. 1984. The influence of low pH environments on ion regulation in the larval stages of the anuran amphibian, *Rana clamitans*. Can. J. Zool. 62:2171–2177.

Pierce, B., J. Hoskins, and E. Epstein. 1984. Acid tolerance in Connecticut wood frogs. J. Herpetol. 18:159–167.

Pough, F. and R. Wilson. 1978. Acid precipitation and reproductive success of *Ambystoma* salamanders. Water Air Soil Pollut. 7:531–544.
Robb, L. and D. Toews. 1987. Effects of low ambient pH on perivitelline fluid of *Ambystoma maculatum* eggs. Environ. Pollut. 44:101–107.
Saber, P. and W. Dunson. 1978. Toxicity of bog water to embryonic and larval anuran amphibians. J. Exp. Zool. 204:33–42.
Tome, M. and F. Pough. 1982. Responses of amphibians to acid precipitation. Pages 245–254 *in* Haines, R.A. and R. Johnson (eds.), Acid rain/fisheries. American Fisheries Society, Bethesda, Md.
Urch, W. and J. Hedrick. 1981. Isolation and characterization of the hatching enzyme from the amphibian *Xenopus laevis*. Arch. Biochem. Biophys. 206:424–431.
Wilbur, H. 1980. Complex life cycles. Annu. Rev. Ecol. Syst. 11:67–93.
Wyman, R.L. and D. Hawksley-Lescault. 1987. Soil acidity affects distribution, behaviour and physiology of the salamander *Plethodon cinereus*. Ecology 68:1819–1827.

The effects of pesticides on amphibians and the implications for determining causes of declines in amphibian populations

Christine A. Bishop

Abstract

Reproduction, behaviour, growth and survival, and essential biochemical processes of amphibians are sensitive to exposure to a number of top-selling pesticides in Canada. However, more studies of the effects of pesticides under field conditions and using native species are necessary to determine the extent to which environmental contamination contributes to declines in amphibian populations. It is argued that pesticides probably change the quality and quantity of amphibian food and habitat. Direct and indirect effects of pesticides on amphibians should be incorporated into a monitoring strategy to determine the causes of declines in amphibian populations and into any attempt to assess ecosystem health.

Résumé

La reproduction, le comportement, la croissance et la survie ainsi que les processus biochimiques essentiels des amphibiens sont sensibles à l'exposition à un bon nombre des pesticides les plus populaires au Canada. Toutefois, il est nécessaire de procéder à de nouvelles études sur les effets des pesticides sur le terrain, au moyen d'espèces indigènes, si l'on veut déterminer dans quelle mesure la contamination du milieu contribue au déclin des populations d'amphibiens. L'auteur fait valoir que les pesticides modifient probablement la qualité et la quantité d'aliments et d'habitats des amphibiens. Les effets directs et indirects des pesticides sur les amphibiens devraient être intégrés à une stratégie de surveillance afin que soient déterminées les causes du déclin des populations d'amphibiens et être aussi intégrés à toute tentative d'évaluer l'état des écosystèmes.

Introduction

The health of amphibians can suffer from exposure to pesticides (Harfenist et al. 1989). Because of their semipermeable skin, the development of their eggs and larvae in water, and their position in the food web, amphibians can be exposed to waterborne and airborne pollutants in their breeding and foraging habitats. In the past, amphibians have been thought to be less sensitive than fish to the effects of contaminants, and recent research seems to support this assumption (Touart et al. 1991). However, relative to the amount of toxicological study devoted to the effects of environmental contaminants on invertebrates—fish and birds, for example—very little information on the impact of pollution on amphibian populations has been documented (Harfenist et al. 1989). Amphibians constitute a large part of the vertebrate biomass in many ecosystems and are important as predators and prey (Burton and Likens 1975). Therefore, impacts of pollution upon this class of animals are relevant to an understanding of ecosystem health. Furthermore, some declines in amphibian populations are currently unexplained (Wake 1991). Scientific inquiry regarding the importance of exposure to environmental pollution as a contributing factor to these declines has been largely overlooked.

As an example of the need for more research and to highlight the effects of pesticides on amphibians, I have chosen to summarize the extent of toxicological study and reported effects of the herbicides, insecticides, and fungicides that accounted for 80% of the total sales in Canada in 1988 (Environment Canada 1990). The effects of these chemicals on amphibians can be classed into five categories: acute toxicity (i.e., direct mortality), sublethal effects such as reduced growth and development, and effects on reproduction, behaviour, and biochemical homeostasis. Ultimately, this information will be used to describe important initiatives necessary in monitoring the effects of pollution within a national monitoring effort to document causes of declines in amphibian populations.

Acute toxicity

The most basic 24- to 96-hour static exposure tests in water to determine the concentration required to kill 50% of the test sample have been performed on only 13 of the 26 (50%) top-selling pesticides (Table 1).

Growth and development

Growth and development of tadpoles are sensitive to exposure to some of these pesticides. Delayed metamorphosis, paralysis, reduced growth rates, and mortality of tadpoles have been documented after exposures of eggs and larvae to 2,4-D (Buslovich and Borushko 1976), maneb (Bancroft and Prahlad 1973; Zavanella et al. 1984), carbaryl (Marian et al. 1983), fenitrothion (Mohanty-Hejmandi and Dutta 1981), dimethoate (Mizgireuv et al. 1984), and lindane (Marchal-Segault and Ramade 1981).

Delayed growth may have serious implications for recruitment in an amphibian population located in or near an agricultural area receiving significant amounts of runoff. Many amphibians in Canada—for example, *Rana sylvatica*

Table 1
Top-selling pesticides in Canada in 1988 (in no particular order of sales totals)[a]

Insecticides	Herbicides	Fungicides
Azinphos-methyl[b] (1)	Atrazine	Captan[b] (2)
Carbaryl[b] (3)	2,4-D[b] (4)	Carbathiin
Carbofuran	Bromoxynil	Chlorothalonil
Chlorpyrifos	Dicamba[b] (10)	Mancozeb
Dimethoate[b] (5)	Diclofopmethyl	Maneb[b] (6)
Fenitrothion[b] (2,7)	Glyphosate	Metiram
Fonofos	MCPA[b] (8)	
Lindane[b] (1)	Metolachlor[b] (2)	
Malathion[b] (1,9)	Triallate	
Terbufos	Trifluralin[b] (1)	

[a] References: (1) Sanders 1970; (2) Hashimoto and Nishiuchi 1981; (3) Marian et al. 1983; (4) Vardia et al. 1984; (5) Sloof and Canton 1983; (6) Zaffaroni et al. 1978; (7) Lyons et al. 1976; (8) Zaffaroni et al. 1986; (9) Kaplan and Glaczenski 1965; (10) Johnson 1976.
[b] At least one static exposure test has been performed using amphibian eggs, larvae, or adults and this chemical.

(Wood Frog), *Rana pipiens* (Northern Leopard Frog), *Bufo americanus* (American Toad), and *Ambystoma maculatum* (Spotted Salamander)—have evolved to metamorphose into adults within months of egg laying (Wright 1914; Cook 1984). A delay in metamorphosis may place larvae at greater risk of predation and dehydration, as ephemeral ponds dry through the year. Moreover, delays in metamorphosis would increase the exposure of larvae to pesticide runoff.

Effects on reproduction

The hatching success of eggs and occurrence of deformed tadpoles during pesticide exposures are common end points in studies of reproductive effects in amphibians. Carbaryl, malathion, lindane, maneb, and atrazine have been associated with reduced hatching success of eggs and malformations in larvae.

Tail deformations and edema occur when tadpoles of *Rana temporaria* (Common Frog) and *Xenopus laevis* (African Clawed Frog) at stages 19–25 are exposed to carbaryl at concentrations of parts per hundred to parts per thousand in water (Rzehak et al. 1977). Malathion is more toxic, causing abnormalities in the head, trunk, and tail at 1 ppm in water when embryos of *Microhyla ornata* (Ornate Narrow-mouthed Toad) are exposed at the yolk plug stage (Pawar et al. 1983). Tadpoles of *X. laevis* exposed for four to six weeks to lindane at 0.5–2 ppm frequently show morphological abnormalities at all concentrations, whereas the control group does not (Marchal-Segault and Ramade 1981). Growth retardation, reduction of pigmentation in eyes, shortened tails, and notochord waviness occur in *Xenopus* embryos at the yolk plug stage exposed for 1–10 days to 1–5 ppm maneb (Bancroft and Prahlad 1973). Atrazine was implicated as a cause of poor reproduction in amphibians when spawn failed to hatch when placed in water containing atrazine or water containing mud from a pond contaminated with atrazine. There had been no hatching success in the pond for two years (Hazelwood 1969).

Effects on behaviour

Poor swimming ability, twitching, loss of balance, and changes in rates of feeding in amphibian larvae are the reported behavioural effects of laboratory exposures to maneb (Bancroft and Prahlad 1973), carbaryl (Rzehak et al. 1977; Marian et al. 1983; Keshavan and Deshmukh 1984), carbofuran (Takeno et al. 1977; Flickinger et al. 1980), and malathion (Kowsalya et al. 1987). Behavioural effects are not surprising, as most of these pesticides are formulated to be neurotoxic. It is also known that behavioural changes of those types increase the chances of predation by newts on frog tadpoles (Cooke 1970). Of these studies, only the effects of carbofuran have been examined under field conditions.

Biochemical indicators of stress

Although amphibians are known to be very resistant to cholinesterase inhibition associated with pesticide exposure (Wang and Murphy 1982), exposure to dimethoate, carbaryl, carbofuran, chlorpyrifos, and maneb can alter the levels of vital chemicals such as vitamin A (Keshavan and Deshmukh 1984) and can reduce melanogenesis (Arias and Zavanella 1979). Tolerance to low temperature can be reduced significantly (Johnson 1980). This may have serious implications for amphibian survival in field conditions. It has not been determined how these subtle changes might affect the long-term survival of a population, but chronic stress may make them susceptible to disease or predation.

Effects of pesticides on food and habitat quality and quantity

The amount and quality of food and shelter for amphibians may be reduced when insecticides and herbicides contaminate wetland ecosystems. Most of the top-selling insecticides are toxic to nontarget invertebrates (Pimental 1971; Wallace et al. 1973). Herbicides can be acutely toxic to algae and aquatic macrophytes (Butler 1977; Kosinski 1984; Moorhead and Kosinski 1986; Glen and Angle 1987). Through direct application and/or overspraying and through agricultural and urban runoff of water and sediment, pesticides can enter watercourses (McEwen and Stephenson 1979). Pesticides can be found in measurable levels in many watersheds in Canada (Wauchope 1978). The effects of pesticides may be coupled with reduction or changes in algal and invertebrate populations often associated with high concentrations of nitrogen and phosphorus (Hynes 1966) in agricultural and urban runoff in wetlands. The loss of algae as food for tadpoles, loss of invertebrates as food for amphibian adults and larvae, and loss or reduction of macrophytes that provide shade and shelter from predators (Wassersug 1989) would presumably have devastating impacts on amphibian populations. At present, studies relating these potential secondary impacts to loss of amphibians or reduction in diversity of amphibians in wetlands have not been performed.

A need for field studies

In this case, pesticides have been used as an example of the need for research on and monitoring of toxic chemical impacts upon amphibians. It is obvious that studies on the effects of pesticides have been conducted primarily in laboratory settings, and very few species native to Canada are routinely tested. The concentrations of pesticides used in sublethal tests involving amphibians are often at parts per million levels and sometimes higher. Pesticide residues in watercourses are generally measurable only at parts per billion levels or less, and only maximum concentrations occur at parts per million levels (Wauchope 1978). There is a need to conduct experiments using environmentally realistic concentrations, to perform exposures under field conditions, and to test native species. There is some evidence that the sensitivity of *R. pipiens* and *Rana catesbeiana* (Bullfrog) to dieldrin is similar to that of *X. laevis* (Schuytema et al. 1991). However, more studies should examine the value of *X. laevis* as a surrogate for species native to Canada, which are more difficult to culture. This will increase the value of the very many laboratory studies involving *Xenopus*. The secondary effects of pesticides on ecosystem health in wetlands need to be examined more closely.

Trace metals, acidic deposition, and organochlorine pesticides cause reproductive and behavioural effects in amphibians similar to those described for the top-selling pesticides discussed here (Cooke 1970, 1972; Clark and Hall 1985; Freda 1986). Considerably more work has been published on the effects of those contaminants on amphibians relative to the effects of organophosphate and carbamate pesticides (Harfenist et al. 1989). Even less study of the effects of polychlorinated hydrocarbons such as PCBs and related compounds has been performed. Nevertheless, the current results suggest that pesticides, alone or in combination with other anthropogenic stresses, could contribute to amphibian population declines. However, within laboratory and field studies for all types of contaminants, it would be useful to develop more rigorous approaches to noting symptoms of toxicity. Exposure of amphibians to contamination in any form appears to provoke similar symptoms, although the contaminants themselves have different chemical structures and activities. Perhaps more detailed study, especially of the effects on behaviour, would delineate responses.

Recommendations for monitoring and research

Monitoring of hatching success, deformity rates, and behavioural anomalies coupled with an assessment of habitat quality and quantity for amphibians in pesticide- and nutrient-stressed watersheds should be conducted. This could be done through a general survey of levels of nitrogen and phosphorus and pesticides used in selected watersheds. These watersheds would be those that are expected to be heavily exposed to agricultural and/or urban runoff with comparison sites in more pristine areas with similar soil types and within the same ecozone. This information, in combination with the known toxicity of various pesticides to native amphibians, algae, invertebrates, and macrophytes, would be a useful start towards understanding impacts of both pesticides as well as other stresses on amphibian populations.

Literature cited

Arias, E. and T. Zavanella. 1979. Teratogenic effects of manganese ethylenebisdithiocarbamate (Maneb) on forelimb regeneration in the adult newt, *Triturus cristatus carnifex*. Bull. Environ. Contam. Toxicol. 22:297–304.

Bancroft, R. and K.V. Prahlad. 1973. Effect of ethylenebis (dithiocarbamic acid) disodium salt (nabam) and ethylenebis (dithiocarbamato) manganese (maneb) on *Xenopus laevis* development. Teratology 7:143–150.

Burton, T.M. and G.E. Likens. 1975. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. Copeia 1975:54–56.

Buslovich, S.Y. and N.V. Borushko. 1976. Chloroderivatives of phenoxyacetic acid as antagonists of thyroid hormones. Farmakol. Toksikol. 39:481–483.

Butler, G.L. 1977. Algae and pesticides. Residue Rev. 66:19–62.

Clark, K.J. and R.J. Hall. 1985. Effects of elevated hydrogen ion and aluminum concentration on the survival of amphibian embryos and larvae. Can. J. Zool. 63:116–123.

Cook, F.R. 1984. Introduction to Canadian amphibians and reptiles. National Museum of Natural Sciences, Ottawa. 200 pp.

Cooke, A.S. 1970. The effects of p,p′-DDT on tadpoles of the common frog (*Rana temporaria*). Environ. Pollut. 1:57–71.

Cooke, A.S. 1972. Selective predation by newts on frog tadpoles treated with DDT. Nature 229:275–276.

Environment Canada. 1990. Pesticide registrant survey, 1988. Commercial Chemicals Branch, Ottawa. 87 pp.

Flickinger, E.L., K.A. King, W.F. Stout, and M.M. Mohn. 1980. Wildlife hazards from Furadan 3G applications to rice in Texas. J. Wildl. Manage. 44:190–197.

Freda, J. 1986. The influence of acidic pond water on amphibians: a review. Water Air Soil Pollut. 71:439–450.

Glen, S. and J.S. Angle. 1987. Atrazine and Simazine in runoff from conventional and no-till corn watersheds. Agric. Ecosyst. Environ. 18:273–280.

Harfenist, A., T. Power, K.L. Clark, and D.B. Peakall. 1989. A review and evaluation of the amphibian toxicological literature. Can. Wildl. Serv. Tech. Rep. Ser. No. 61, Ottawa. 222 pp.

Hashimoto, Y. and Y. Nishiuchi. 1981. Establishment of bioassay methods for the evaluation of acute toxicity of pesticides to aquatic organisms. Jpn. J. Pestic. Sci. 6:257–264.

Hazelwood, E. 1969. Frog pond contaminated. Br. J. Herpetol. 4:177–184.

Hynes, H.B.N. 1966. The biology of polluted waters. Liverpool Univ. Press, Liverpool, England. 202 pp.

Johnson, C.R. 1976. Herbicide toxicities in some Australian anurans and the effect of subacute dosages on temperature tolerance. Zool. J. Linn. Soc. 59:79–83.

Johnson, C.R. 1980. The effects of five organophosphorus insecticides on thermal stress in tadpoles of the Pacific Tree Frog, *Hyla regilla*. Zool. J. Linn. Soc. 69:143–147.

Kaplan, H.M. and S.S. Glaczenski. 1965. Hematological effects of organophosphate insecticides in the frog (*Rana pipiens*). Life Sci. 4:1213–1219.

Keshavan, R. and P.B. Deshmukh. 1984. Vitamin A concentrations in liver and serum of the frog, *Rana tigrina*, treated with DDT and sevin. Indian J. Comp. Anim. Physiol. 2:32–36.

Kosinski, R.J. 1984. The effect of terrestrial herbicides on the community structure of stream periphyton. Environ. Pollut. Ser. A 36:165–189.

Kowsalya, T., K.S.P. Rao, and K.V.R. Rao. 1987. Effect of malathion on some kinesiological parameters of the gastrocnemius muscle of frog, *Rana hexadactyla* (Lesson) and the antagonistic action of atropine. Toxicol. Lett. 39:215–221.

Lyons, D.B., C.H. Buckner, B.B. McLeod, and K.M.S. Sundaram. 1976. The effects of fenitrothion, matacil, and orthene on frog larvae. Chem. Control Res. Inst. Rep. CC-X-129, Environment Canada, Ottawa.

Marchal-Segault, D. and F. Ramade. 1981. The effects of lindane, an insecticide, on hatching and postembryonic development of *Xenopus laevis* (Daudin) anuran amphibian. Environ. Res. 24:250–258.

Marian, M.P., V. Arul, and T.J. Pandian. 1983. Acute and chronic effects of carbaryl on survival, growth, and metamorphosis in the bullfrog (*Rana tigrina*). Arch. Environ. Contam. Toxicol. 12:271–275.

McEwen, F.L. and G.R. Stephenson. 1979. The use and significance of pesticides in the environment. John Wiley & Sons, New York. 538 pp.

Mizgireuv, I.V., N.L. Flax, L.J. Borkin, and V.V. Khudoley. 1984. Dysplastic lesions and abnormalities in amphibians associated with environmental conditions. Neoplasma 31:175–181.

Mohanty-Hejmandi, P. and S.K. Dutta. 1981. Effects of some pesticides on the development of the Indian bull frog *Rana tigrina*. Environ. Pollut. Ser. A 24:145–161.

Moorhead, D.L. and R.J. Kosinski. 1986. Effect of atrazine on the productivity of artificial stream algal communities. Bull. Environ. Contam. Toxicol. 37:330–336.

Pawar, K.R., H.V. Ghate, and M. Katdare. 1983. Effect of malathion on embryonic development of the frog *Microhyla ornata* (Dumeril and Bibron). Bull. Environ. Contam. Toxicol. 31:170–176.

Pimental, D. 1971. Ecological effects of pesticides on non-target organisms. U.S. Government Printing Office, Washington, D.C. 220 pp.

Rzehak, K., A. Maryanska-Nadachowska, and M. Jordan. 1977. The effect of Karbatox 75, a carbaryl insecticide, upon the development of tadpoles of *Rana temporaria* and *Xenopus laevis*. Folia Biol. (Krakow) 25:391–399.

Sanders, H.O. 1970. Pesticide toxicities to tadpoles of the western chorus frog *Pseudacris triseriata* and Fowler's Toad *Bufo woodhousei fowleri.* Copeia 2:246–251.

Schuytema, G.S., A.V. Nebeker, W.I. Griffis, and K.N. Wilson. 1991. Teratogenesis, toxicity and bioconcentration in frogs exposed to dieldrin. Page 201 *in* Abstracts, 12th Annual Meeting of Society of Environmental Toxicology and Chemistry, 3–7 November.

Sloof, W. and J.H. Canton. 1983. Comparison of the susceptibility of 11 freshwater species to 8 chemical compounds. II. (Semi) chronic tests. Aquat. Toxicol. 4:271–282.

Takeno, K., K. Nishimura, J. Parmentier, and T. Narahashi. 1977. Insecticide screening with isolated nerve preparations for structure–activity relationships. Pestic. Biochem. Physiol. 7:486–499.

Touart, L., G. Susanke, H. Mansfield, and D. Baluff. 1991. Adequacy of existing guidelines for protecting reptiles and amphibians. Page 234 *in* Abstracts, 12th Annual Meeting of Society of Environmental Toxicology and Chemistry, 3–7 November.

Vardia, H.K., P.S. Rao, and V.S. Durve. 1984. Sensitivity of toad larvae to 2,4-D and endosulfan pesticides. Arch. Hydrobiol. 100:395–400.

Wake, D. 1991. Declining amphibian populations. Science 253:860.

Wallace, R.R., A.S. West, A.E.R. Downe, and H.B.N. Hynes. 1973. The effects of experimental blackfly (Diptera: Simuliidae) larviciding with Abate, Dursban, Methoxychlor on stream invertebrates. Can. Entomol. 105:817–831.

Wang, C. and S.D. Murphy. 1982. Kinetic analysis of species difference in acetylcholinesterase sensitivity to organophosphate insecticides. Toxicol. Appl. Pharmacol. 66:409–419.

Wassersug, R.J. 1989. Locomotion in amphibian larvae (or "Why aren't tadpoles built like fishes?"). Am. Zool. 29:65–84.

Wauchope, R.D. 1978. The pesticide content of surface water draining from agricultural fields: a review. J. Environ. Qual. 7:459–472.

Wright, A.H. 1914. North American Anura: life histories of the Anura of Ithaca, New York. Carnegie Inst. Washington Publ. No. 197, Washington, D.C. 98 pp.

Zaffaroni, N.P., E. Arias, G. Capodanno, and T. Zavanella. 1978. The toxicity of manganese ethylenebisdithiocarbamate to the adult newt, *Triturus cristatus*. Bull. Environ. Contam. Toxicol. 20:261–267.

Zaffaroni, N.P., T. Zavanella, M.L. Ferrari, and E. Arias. 1986. Toxicity of 2-methyl-4-chlorophenoxyacetic acid to the adult crested newt. Environ. Res. 41:201–206.

Zavanella, T., N.P. Zaffaroni, and E. Arias. 1984. Abnormal limb regeneration in adult newts exposed to the fungicide Maneb 80. A histological study. J. Toxicol. Environ. Health 13:735–745.

Habitat loss and declining amphibian populations

Bob Johnson

Abstract

Despite our understanding of the impact of habitat loss on amphibian populations, the process continues. International and local amphibian conservation programs illustrate degrees of management options dependent on the degree to which habitats have been altered. Studies of four bufonid species and their relationship to critical habitats are outlined. In addition, the synergistic effects of habitat loss and stochastic events on the expansion and contraction of amphibian populations are outlined. The techniques developed for the management of small populations are being utilized increasingly as amphibians become isolated in habitat islands. Ultimately, public education and political action will determine the quantity and quality of amphibian habitat.

Résumé

Malgré notre connaissance des effets des pertes d'habitat sur les populations d'amphibiens, ce mécanisme continue à s'exercer. Des programmes internationaux et locaux de conservation des populations d'amphibiens constituent différents exemples de types de gestion conçus en fonction de la perturbation des habitats. On donne un aperçu d'études sur quatre espèces de bufonidés et sur leurs relations avec des habitats vulnérables. De plus, la synergie entre les pertes d'habitat et des phénomènes stochastiques relatifs à l'expansion et à la diminution des populations d'amphibiens est sommairement décrite. On a de plus en plus recours aux techniques de gestion applicables aux petites populations à mesure que les amphibiens deviennent isolés dans des habitats discontinus. En définitive, ce sont l'éducation du public et les interventions politiques qui détermineront la quantité et la qualité de l'habitat des amphibiens.

Habitat

Amphibian populations undergo cyclical fluctuations in population numbers. These are in part the result of endogenous cycles, such as the mass of fat bodies, which in turn are a function of environmental influences. The demographic structure, such as rates of recruitment, will also affect population dynamics. Superimposed on these population dynamics are broad climatic patterns that may cause years of decline followed by range expansions that may result from even a single year of reproductive success.

Amphibians are prolific and coadapted to these changes. Anecdotal accounts of decline must be tempered by data on the significance of these factors, to date not well understood. Synergistic effects complicate the identification of causes of declines. In addition, normal downtrends in populations may be pushed beyond recovery thresholds when the populations are under additional environmental stress. The impact of environmental contaminants or atmospheric changes will be measured by individual species' tolerance of rapid environmental change and the resilience of populations—a resilience perhaps already compromised in Canada, where species are at the northern limits of range extensions, by the challenges of cold-stressed environments.

Clearly, habitat loss and degradation are the most important, and best understood, causes of species decline. Yet, by attrition, habitat and amphibian populations continue to decline. Even with the simple connection between habitat loss and species decline, we are often unable to address this issue. This, in part, highlights the complexity of halting or correcting population declines with anecdotal evidence or even with evidence of some global factor. The crash of some amphibian populations in pristine environments where there is no perceived change in the quality of habitat confounds the issue. Whether these declines are merely normal extirpations due to stochastic events or actually hastened by anthropogenic factors defines the issue of declining amphibian populations.

Stable populations require recruitment to the population to maintain population demographic structures, reservoirs in which amphibian populations can be maintained during years of contraction in range, and migratory corridors and marginal habitats that facilitate the expansion of amphibian populations. An inhospitable environment not only prevents range expansion but creates islands in which qualitative change in habitat results in local extirpations.

For example, the Bufonidae has more species in peril than any other family. Many bufonid species exploit seasonally flooded habitats. They are explosive breeders and are often the first to invade and colonize new or disturbed habitats. As habitats recover from anthropogenic impacts, bufonid reintroduction and conservation programs may serve as models for the recovery of other anuran species.

Management alternatives

Habitat degradation or fragmentation will increase our dependence on techniques utilized to manage small populations. The importance of this residuary captive population is proportional to the size and range of isolated wild populations. Four bufonid species exemplify a range of management options that have integrated captive and wild population conservation initiatives.

Houston Toad

The decline of Houston Toads (*Bufo houstonensis*) in abundance and distribution may be attributed to drought and a subsequent loss of habitat from land development. The continued loss of habitat has suppressed recovery of Houston Toad populations during wet years when range expansion might be expected.

Stable populations have been identified in Bastrop State Park, where ponds constructed to provide water for forest fire prevention and ponds constructed by local landowners serve as breeding sites. Human-made stock ponds are important factors in the continued survival of this species. While the expansion of local development has a quantifiable impact on toad habitat, forest fires in the pine forests characteristic of this area are stochastic events that have unpredictable impacts on toad populations and habitat. Texas Parks and Wildlife has undertaken a long-term study of the critical habitat, and toad population dynamics and current population have stabilized.

Local land use practices that impact on the toad are being monitored, with the expectation that toads can be accommodated on private lands adjacent to the park. A number of the protected breeding ponds were created by diking natural drainage channels or borrow pits. These human-made structures are abundant in the current range of the toad.

Natterjack Toad

Management of the Natterjack Toad (*Bufo calamita*) in the United Kingdom has focused on improving the quality of toad habitat by constructing and rehabilitating breeding ponds and preventing the continual fragmentation of toad populations and heathland in general. The slow acidification of oligotrophic breeding ponds is being addressed by removing peat buildup. Tree cover is being reduced, and new ponds are being scraped into sand dunes and heathland. Initial attempts at reintroduction failed primarily because of the acidity at chosen release sites. This emphasizes the need to characterize the critical habitat and the importance of fieldwork prior to release.

The translocation of wild tadpoles and release of captive-bred tadpoles and toadlets have contributed to the establishment of new populations in the wild. In perhaps the best example of *ex situ* breeding potential, Marwell Zoo has reconstructed an outdoor heathland habitat in which toads will be released as part of their captive breeding program.

The limited acceptance of new breeding ponds requires further study as to why particular ponds are accepted or overlooked. The short-term loss of learned behaviours such as migration routes and critical habitat for feeding, hibernation, or egg laying is likely to be far more critical than genome loss (Western 1986).

Certainly, the conservation of all amphibians has benefitted from the publicity and actions of those in the United Kingdom associated with toad crossings and tunnels.

Wyoming Toad

The Wyoming Toad (*Bufo hemiophrys baxteri*) is in need of immediate assistance from both *in situ* and *ex situ* conservation programs. A captive population would ensure a backup population in the event of extinction of the subspecies and provide a source of animals to establish satellite populations.

All known populations are within 50 km of Laramie, Wyoming. Floodplain breeding sites have been eliminated by diverting river water to supply the demand of water rights. Irrigation has increased the salinity of many ponds and flooded pastures. The aerial spraying of the pesticide betex to control mosquitos no longer occurs over known breeding sites.

From a population numbering in the thousands, the most recent counts have found only 90 adult toads at Mortenson Lake. In 1990, drought forced the owner of the lake to lower water levels by a few metres in order to irrigate fields. This population was located in 1987 and remains the only known breeding site. In 1991, only three females bred, and developing tadpoles were in constant threat as water levels receded in the reservoir. The transfer of the lake to the public domain will ensure control over water levels in future years. Breeding in 1991 was restricted to tire ruts in the mud and two depressions in the lakeside marsh caused by boats stored there over the winter. Any increase in shallow open water areas might provide additional egg laying sites.

In a bold attempt at reintroduction, female toads are overwintered in captivity; once a male is located from Mortensen Pond in the spring, it is paired with the female within a breeding "cage" at Lake George, once the site of breeding toads. The involvement of some of these toads, overwintered in captivity, in a captive breeding program would expand the population at a rate faster than that of the wild. Surplus captive animals could be the focus of research projects and used to establish satellite populations. *Ex situ* programs parallel *in situ* recovery objectives. If necessary, an ecological substitute or closely related surrogate species, in this case perhaps the Canadian Toad (*Bufo hemiophrys hemiophrys*), can be used to answer some of the questions related to survival in the target species.

Puerto Rican Crested Toad

The recovery of the Puerto Rican Crested Toad (*Peltophryne lemur*) in the wild includes captive propagation and research projects on the critical habitat, ecology, postreproductive movement, and genetic separation of two known populations. The return of captive-bred animals to the wild is an essential component in the conservation of the Puerto Rican Crested Toad. The Puerto Rican Crested Toad conservation program could be reassessed in 10 years if satellite populations are established from both wild translocations and captive-bred releases. In the tenth year as an American Association of Zoological Parks and Aquariums (AAZPA) Species Survival Plan (SSP), 13 zoos currently hold the species, which has been bred at the Metropolitan Toronto and Buffalo zoos.

The Puerto Rican Crested Toad breeds in one pond on the southwest coast and in no more than four human-made cattle troughs in the northwest. The southern population is estimated at 3000 toads, and the northern population at no more than 25. Preliminary data (A. Goebel, pers. commun.) suggest that these populations have significant differences in mitochondrial DNA, reflecting the geographical separation of the populations. If present trends continue, the northern population is doomed.

In the south, toads breed in the Tamarindo section of the Guanica State forest. The breeding pond is located in a precarious location within 100 m of the sea and could be breached or inundated by heavy seas during severe storms or hurricanes. The site serves as a parking lot for users of a nearby beach during the dry season and is closed during breeding episodes. In fact, until 1984, the flooded parking area was regularly drained by well-meaning employees of the nearby town of Guanica. As a result, there was not enough water remaining for the tadpoles to complete their 18-day larval period before metamorphosing. Recruitment to the Guanica population during this period was not possible, and the only other breeding pond was destroyed by hurricane in 1985.

The importance of the discovery of a breeding population of toads in Guanica State forest by Miguel Canals cannot be underestimated, nor can the series of actions he initiated to secure this site for subsequent breedings. The ditch that each year drained the flooded parking area in which the toads bred was dammed; a series of posts prevented cars from driving into the breeding area and from destroying vegetation used by the toads during egg laying; and the road to the parking lot is closed to prevent contamination of the water during the three-week breeding period. A public information campaign through local schools and newspapers has resulted in local acceptance of the changes that have occurred in this high-use area to ensure the survival of the toad itself. The survival of the crested toad thus far has been dependent to a large extent on the goodwill of the citizens of Guanica and on the efforts of the Department of Natural Resources and its Forest Manager, Miguel Canals.

Amphibians migrate if components of their critical habitat are spatially separated (Sinsch 1990). It is apparent that we cannot underestimate the importance of site fidelity. The range of homing ability coincides with the natural migratory range of the species. Intraspecific variation suggests that orientation behaviour is adapted to special habitat features. Studies of temperate bufonid activity may help in understanding the behaviour of tropical bufonids in which annual spatial and temporal behaviours may not be synchronized.

The Common Toad (*Bufo bufo*) may also subdivide its annual migration to breeding ponds into a fall segment occurring during periods of favourable weather and a second migration that is concluded in the spring (Sinsch 1990). Nonreproductive toads hibernate in the summer range. This habitat segregation would reduce competition for hibernation sites. To complete migration in a nonrandom way, Sinsch (1990) suggested a two-step process. Mapping determines the position of the toad relative to its destination, and compassing determines direction to reach the destination. In some cases, piloting by using visual or acoustic cues may be utilized. Given the sophistication of orienting behaviour, we must also consider the importance of landmarks in the captive environment.

Toads are constrained by evaporative water loss. However, males have a lower threshold for migration and move at every opportunity, often under less than optimum conditions. Females move only under optimum conditions. As a result, there tend to be more males present, although the same number of females may breed, and varying numbers breed each year in correlation with the number of opportunities for migration. Because favourable conditions for migration occur sporadically, those hibernating or estivating at some distance may not reach the natal ponds in a single trek. As a result, there is a series of waves of migrants represented at the pond in a cumulative manner. If conditions are not favourable, some migrating animals may never reach the breeding pond. One can envision that, in a series of poor years, a proportion of the population at some given range may not contribute to recruitment for several years.

Site fidelity may be recognized in natal ponds, home ranges, and hibernation/estivation sites. This fidelity is easily understood when there are no alternative sites. There are many accounts of amphibians crossing one pond to breed in another. It has been suggested that at least some amphibians utilize corridors within which they migrate in a straight line (Shoop and Doty 1972). Toads have selected some human-made ponds as alternative breeding sites once forced to breed there once (Podloucky 1989). However, range expansion can occur only when new sites are selected. In fact, some breeding ponds may be secondary sites, with preferred sites unavailable owing to annual weather changes or habitat alteration (lowering of water tables).

The loss of a breeding pond for the Puerto Rican Crested Toad occurred in 1984 when Hurricane Hugo dumped 33 cm of water on the Guanica Hills. This water exploded out of the hills and washed out a pond and all the toads breeding there. Since this time, no new toads have used this site only 1 km away. It is just such short-term or stochastic events, perhaps superimposed on long-term change, that cause local declines and extirpations.

After waiting two years before there was enough rainfall to stimulate emergence and reproduction, a research team from the Metropolitan Toronto Zoo tracked postreproductive movements for 20 days. Much as expected, the toads utilized crevices and solution holes in the limestone as daytime retreats from the dehydrating effects of ground temperatures, which soar to 50°C during the day. Toads migrated up to 2 km during our study period. After a three-day period of activity in which the distance travelled averaged 150 m per 24-hour period, toads settled into an area, and movement was reduced to an average of 6 m per night.

Data on pH, salinity, calcium, and temperature were collected at Guanica by a Metropolitan Toronto Zoo research team in 1990. It is essential that the chemistry and ecological characteristics of the breeding ponds be characterized. First, a pond profile would allow managers to maintain its essential character given sudden or long-term changes that may adversely affect the present population. Secondly, the need to identify existing ponds suitable for crested toad reproduction is imperative. Failing this, it will be necessary to construct breeding ponds that would include the essential components of the present pond.

In the south, it is anticipated that new ponds, whether naturally formed during rains or human-made to fill during rain, would receive tadpoles from two sources. Some tadpoles would be translocated from the present breeding pond to adjacent ponds outside the migratory range of the crested toad, and a second pond would receive captive-bred tadpoles returned to Puerto Rico for release. Identifying future release sites remains a high priority for the recovery of this species.

Given the prolific reproductive output of amphibians, there is a very real possibility of genetically swamping wild populations if releases represent the contribution of a small number of founders. To reduce this possibility, it may be necessary to utilize as many founder animals as possible or to limit the representation from each breeding pair and to release tadpoles, the life stage with the highest mortality.

Captive breeding and translocations should not replace the need to restore habitat or protect existing ponds and breeding populations. The provision of satellite ponds so that a core population can naturally extend its range from any natural surplus is preferable to utilizing naive captive-bred animals. The relative merits of utilizing numerous tadpoles or fully grown but naive toads (Johnson and Paine 1989) require further field trials to determine the life stage most likely to survive to replace itself. The long-term survival of the crested toad is dependent upon protection of existing breeding sites and establishment of satellite populations. There are no plans for further releases to the wild until suitable sites with release ponds, either natural or human-made, can be identified.

The success rate for nongame translocations will be low until trials can be conducted and analyzed. A period of relatively poor establishment must be anticipated, and this should not negatively impact on the consideration of species for further introduction attempts (Johnson 1990). The release of captive-bred animals and habitat restoration are management tools that will increasingly be the last resort for a number of species. The potential of success in release programs must be considered as only one management strategy among others in stemming the rapid and catastrophic loss of amphibian species diversity.

Conclusion

These four programs illustrate management options that are required as a result of environmental change. For species such as the Golden Toad (*Bufo periglenes*), management may be required to act as fail-safe populations that maintain options until the causes of decline are fully understood. Many bufonids quickly exploit changing and altered habitats. They are quick to exploit local sources of water, but shifts in populations to newly created habitats must be measured in geological time. Recent changes to environments have occurred largely within this century, perhaps too rapidly for even this taxon (Pounds 1991).

The traditional selection of animals on the basis of rarity emphasizes those species with restricted range, endemics, and specialists (Western 1986). If action is taken to reverse the degradation of wild habitat, these sensitive species may be preserved. However, disturbed, secondary, and reconstituted habitats are likely to be the legacy of our impact on ecosystems. Along with rare species, the importance of common species may be considered in light of their role in ecosystem energetics and self-contained processes responsible for ecological integrity. It is important to consider the ecological role of the anuran. It is not enough to preserve a genome without prospects for a "place" for evolutionary change.

We must be careful to design reserves that account for shifting ecotypes in response to gradual environmental change and with sizes large enough to preserve a species and the ecological processes that guarantee its long-term survival (Frankel 1983). The short-term preservation of biodiversity may be achieved through captive breeding programs; in the long term, however, the preservation of ecological processes *in situ* will determine the fate of the population. In terms of anuran faunas, conservation of declining populations is characterized by crisis management and techniques suited to short-term objectives. However, even in short-term programs, the loss of learned behaviours such as migration routes and critical habitat for feeding, hibernation, or egg laying is likely to be more significant than longer-term concerns over the loss of rare alleles (Western 1986).

Ten years of plotting the distribution of amphibian populations in Metropolitan Toronto have highlighted the importance of ravine systems and wetlands. These serve as refuges during years of range contraction and as reservoirs for the repopulation of tablelands during years of range expansion. Backyard ponds have been documented as suitable breeding sites for at least the American Toad (*Bufo americanus*). The importance of restoration ecology for the creation and management of new habitat cannot be underestimated. As communities mature, amphibian habitat is often reconstituted, but the loss of migratory pathways limits recolonization and range expansion. Hydro corridors, for example, are often the only remaining habitat for many species of urban wildlife. These, with some modification, also serve as excellent migratory corridors.

Metropolitan Toronto Zoo has developed an "Adopt a Pond" program for 5000 schools. Every school in the province of Ontario is being asked to adopt a pond on or near school property or to construct a pond under our guidance. We make a logical connection between habitat alteration, the loss of wetlands, and the decline of amphibian populations. To date, the response to this program has been overwhelming, with schools very willing to participate. Some are purchasing an acre (0.4 ha) of wetland through donations to the Nature Conservancy, and we have had landowners contact us who are looking for a school to adopt wetlands on their property.

Long-term monitoring of habitat will identify significant wetlands and those that link migratory corridors. Some understanding of population demographics and survival rates is essential. The identification, protection, and, if necessary, restoration of critical habitat are essential to the survival of amphibian populations. The United Kingdom has well-developed awareness and monitoring strategies that measure, for example, density of water bodies, vegetation encroachment, sites with any amphibians, sites with common species, sites with rare species, and the percentage of ponds lost.

Changes to planning acts and provincial wetland policy must recognize the importance of remaining wetlands. It is not enough to protect regionally significant wetlands while ignoring those significant to local communities or the importance of a network of unclassed wetlands in their entirety and their role in local ecosystem dynamics. Development and habitat protection can go hand in hand if our commitment to do so is embodied in planning acts. Any loss of habitat can be mitigated. Mitigation will never replace the functional wetland but does place a cost on habitat loss. The loss of habitat means not only the local extirpation of species but the extinction of experience with wildlife species and habitat.

We must educate ourselves on the relationship between healthy wetlands and healthy amphibian populations. More importantly, we must provide the political will for action and conservation strategies that provide for wildlife and sustainable development.

Acknowledgements

Rick Paine, Miguel Canals, Jorge Moreno, Dianne Devison, Tom Thome, Andrew Price, David Withers, Robert Wiese, the Metropolitan Toronto Zoo, and Wyoming Game and Fish contributed data or support necessary for the completion of this paper. Their contributions are gratefully acknowledged. John Carnio and Dianne Devison reviewed the paper and provided helpful comments.

Literature cited

Frankel, O.H. 1983. The place of management in conservation. Pages 1–14 *in* Schonewald-Cox, C.M., S.M. Chambers, B. MacBryde, and L. Thomas (eds.), Genetics and conservation. Benjamin/Cumming, London.

Johnson, R.R. 1990. Release and translocation strategies for the Puerto Rican crested toad. Pages 54–57 *in* Jones, S. (ed.), Captive propagation and reintroduction: a strategy for preserving endangered species. Endangered Species Update Special Issue Vol. 8(1).

Johnson, R.R. and F.L. Paine. 1989. The release of captive bred Puerto Rican crested toads: captive management implications and the cactus connection. Pages 962–967 *in* American Association of Zoological Parks and Aquariums (AAZPA) Regional Conference Proceedings, Wheeling, W. Va.

Podloucky, R. 1989. Protection of amphibians on roads—examples and experiences from lower Saxony. Pages 15–28 *in* Langton, T.E. (ed.), Amphibians on roads. ACO Polymer Products Ltd., Shefford, England.

Pounds, J.A. 1991. The secret Sahara. BBC Wildl. (June):381.

Shoop, C.R. and T.L. Doty. 1972. Migratory orientation by marbled salamanders near a breeding area. Behav. Ecol. A 7(1):131–136.

Sinsch, U. 1990. Migration and orientation in anuran amphibians. Ethol. Ecol. Evol. 2:65–79.

Western, D. 1986. The role of captive populations in global conservation. Pages 13–20 *in* Benirschke, K. (ed.), Primates. The road to self-sustaining populations. Springer-Verlag, New York.

Part 3: Monitoring amphibian populations

IUCN/SSC Declining Amphibian Populations Task Force[1]

James L. Vial

Abstract

The Declining Amphibian Populations Task Force operates within the framework of the Species Survival Commission of the World Conservation Union. The board of directors, whose composition is as yet incomplete, defines policies, establishes priorities, and is responsible for developing funding strategies. The coordinating council is made up of chairpersons of the issue-specific, regional monitoring, and U.S. regional working groups. Task force operations are funded primarily by the Chicago Zoological Society, the U.S. Department of State, and the Center for Analysis of Environmental Change.

Résumé

Le Groupe de travail sur les populations d'amphibiens en déclin oeuvre dans le cadre de la Commission pour la sauvegarde des espèces de l'Alliance mondiale de la nature. Le Conseil de direction, dont la composition n'est pas encore achevée, définit les politiques, détermine les priorités et a le mandat d'élaborer des stratégies de financement. Le Conseil de coordination est composé des présidents des différents groupes de travail régionaux des États-Unis, des divers comités de surveillance régionale et des groupes à vocation spécialisée. Les activités du Groupe de travail sont principalement financées par la *Chicago Zoological Society*, le *U.S. Department of State* ainsi que le *Center for Analysis of Environmental Change.*

Composition of the Task Force

The Declining Amphibian Populations Task Force (DAPTF) operates within the framework of the Species Survival Commission (SSC) of the World Conservation Union (IUCN). The task force organization is three tiered. A board of directors, with international representation, defines policies, establishes priorities, and is responsible for developing funding strategies; the coordinating council is composed of working group chairpersons and others who may have special commitments to the program. As coordinator, my role is to facilitate the organization and operations of the task force and to serve as liaison between the board and the working groups.

Apart from this formalized structure, we are actively recruiting a large cadre of communicators. These will be concerned professional biologists and private individuals who have an active interest in the DAPTF program but, for whatever reason, are not affiliated with a working group. Such persons can be invaluable sources of information as to the status of local populations that they might monitor or, indeed, have already monitored for extended periods. In many cases, this would be information otherwise unobtainable.

Board of directors

The composition of the board is as yet incomplete but at present is represented by the following persons:

Robert Johnson	Canada	Metropolitan Toronto Zoo
William Branch	South Africa	Port Elizabeth Museum
Jaime Pefauer	South America	Universidad de los Andes, Venezuela
Alain Dubois	Western Europe	Le Musée National d'Histoire Naturelle, Paris
Michael Tyler	Australia	University of Adelaide
James Murphy	USA	Dallas Zoo
John Wright	USA	Los Angeles County Museum
William Winner	USA	Center for Analysis of Environmental Change; *ex officio*
David B. Wake	USA	University of California, Berkeley; Chair

Working groups

Issue-specific groups

Protocols for Monitoring Amphibian Populations
R. Heyer, National Museum of Natural History, Smithsonian Institution, Washington, D.C., Chair. To be succeeded by R.W. McDiarmid (U.S. Fish and Wildlife Service)

[1] Excerpted from the FROGLOG newsletter of the DAPTF.

Regional monitoring groups

Lower Central America (Costa Rica–Panama)
  J.M. Savage, University of Miami, Coral Gables, Fla., Chair
Western Europe
  A. Zuiderwijk, Institute of Taxonomy, Amsterdam, Chair
Australia
  M. Tyler, University of Adelaide, Adelaide, Chair
South America
  J. Pefauer, Universidad de los Andes, Meridia, Venezuela, Chair
Canada
  D. Green, McGill University, Montreal, National Coordinator

(as of 6 October 1991 workshop on this topic)

United States regional working groups

Pacific Northwest (including Alaska)
  A. Blaustein, Oregon State University, Corvallis, Oreg.
  R. Kiester, U.S. Forest Service—Pacific Northwest, Cochairs
CalNeva
  G. Fellers, U.S. National Park Service, Point Reyes, Calif., Chair
Rocky Mountains
  P.S. Corn and R.B. Bury, National Ecology Research Laboratory, Fort Collins, Colo., Cochairs
Southern Plains
  J. Caldwell, University of Oklahoma, Norman, Okla., Chair
Northern Plains
  J. Platz, Creighton University, Omaha, Nebr., Chair
Mississippi Delta
  R. Altig, Mississippi State University, Mississippi State, Miss., Chair
Southeastern
  C.K. Dodd, Jr., National Ecology Research Laboratory, Gainesville, Fla., Chair
Appalachians
  R. Bruce, Highlands Biological Station, Highlands, N.C., Chair
Northeastern
  R. Wyman, Edmund Niles Huyck Preserve, Rensselaerville, N.Y., Chair
Southwestern
  N.J. Scott, Jr., U.S. Fish and Wildlife Service, Albuquerque, N.M., Chair

We are still in need of regional working group chairpersons for the central USA (Iowa, Missouri, Illinois, Indiana, Ohio) and the Great Lakes area (Wisconsin, Minnesota, Michigan). We are also soliciting the participation of scientists and technical personnel as members of the issue-specific working groups as they are formed. Such groups ideally would consist of conational or multinational cooperating units addressing large-scale environmental events having potential for impacting upon amphibian populations: e.g., acid rain, UV radiation, heavy metals, and other contaminants. A priority has been given to organization of a working group for the compilation of a comprehensive bibliography of prior studies relating to the status of amphibian populations. This resource will be invaluable for making comparisons with contemporary studies.

Support status

To date, the DAPTF operations have been funded primarily by the Chicago Zoological Society, the U.S. Department of State (Agency for International Development), and the Center for Analysis of Environmental Change. We have been fortunate to have additional support from interested parties such as the Frog Leap Winery and private individuals. Several grant applications are pending that, if successful, will enable us to provide seed grants for projects or proposals prioritized by the board of directors. Announcements as to availability of these grants will be made in issues of the FROGLOG newsletter. FROGLOG will serve as an international networking medium for information relating to the activities of participants in the DAPTF.

Standard methods for measuring and monitoring biological diversity of amphibians

Roy W. McDiarmid

Abstract

Amphibians are important components of terrestrial and freshwater habitats, especially in tropical regions of the world. Loss of amphibian diversity through habitat destruction or global declines is a major concern. To provide quantitative baseline data on the distribution and abundance of amphibians, standardized sampling techniques for inventorying and monitoring are needed. Quantitative techniques are recommended for inclusion in a National Monitoring Program for Canadian Amphibians. A book describing these methods is in preparation.

Résumé

Les amphibiens sont des éléments importants des habitats terrestres et d'eau douce, notamment dans la zone tropicale. La perte de diversité par destruction de l'habitat ou par un déclin mondial est une source de graves préoccupations. Afin de réunir les données chiffrées de référence sur la distribution et l'abondance des amphibiens, il faut mettre au point des techniques standardisées d'échantillonnage en vue de l'inventaire et du suivi des populations. L'auteur recommande des techniques de dénombrement à inclure dans un Programme national de suivi des amphibiens au Canada. Un guide descriptif de ces méthodes est en voie de publication.

Introduction

Amphibians are abundant and functionally important elements in most terrestrial and many freshwater ecosystems and therefore constitute a significant component of the world's biota. Outside of developed countries, however, little information exists on the geographical and ecological distributions of amphibians. As well, almost nothing is known about their relative abundances, especially in tropical and subtropical regions where they reach their highest diversity. Yet, details of what organisms occur where and in what abundances have provided the foundation for a considerable body of basic theory in ecology and biogeography. Often, even when data on the species richness of amphibians in an area are available, they were collected using assorted sampling methodologies. Such disparities make temporal and spatial comparisons difficult, if not impossible. Until recently, there was little urgency to reduce this procedural variation. However, widespread habitat destruction and the worldwide loss of biodiversity have demonstrated the pressing need for standardized sampling methodologies for documenting biodiversity.

A distinctive characteristic of amphibians is their complex life cycle. This attribute and the fact that adults and larvae usually occupy totally different habitats at the same site probably account for the relatively high fecundity of amphibians. Certainly, the complexity of an amphibian life cycle subjects most amphibians to a greater array of physical, chemical, and biological factors in the terrestrial and aquatic environments than those experienced by most other vertebrates. The highly permeable skin probably renders amphibians particularly susceptible to rapid but perhaps subtle changes in the physical and chemical elements of their aquatic, aerial, and terrestrial environments. These traits, together with other behavioural, ecological, and population characteristics, may make amphibians especially good bioindicators of environmental change.

Concerned with the significant worldwide loss of biodiversity through habitat destruction, especially of tropical forests, and the apparent need for quantitative data on distributions and abundances of species for sound management and conservation decisions, scientists recently organized a project to develop a series of manuals on standardized sampling methods for biodiversity. The effort was begun in the National Museum of Natural History by the Biological Survey, U.S. Fish and Wildlife Service, and the BIOLAT Biodiversity Program, Smithsonian Institution. In response to the recent realization that amphibian populations in many areas may be declining sharply (Barinaga 1990; Blaustein and Wake 1990), amphibians were selected as the subject for the first volume in the series. The need for but absence of quantitative data on the status of amphibian populations throughout the world is paramount. At the same time, a workshop on declining amphibians (Anonymous 1991) underscored the need for standardized long-term monitoring protocols.

The potential for major losses of amphibian biodiversity through destruction of expanses of tropical wet forests, the biome with the highest amphibian diversity, and freshwater wetlands, for many amphibian species a crucial habitat that has experienced major losses especially in temperate regions, was a major concern in the early stages of planning the volume. Effective and standardized inventory protocols were obviously needed immediately. This concern, combined with the potential of a global decline and the absence of baseline data, indicated the need for standardized population monitoring techniques for amphibians.

The approach

Our goal was to develop and write a manual of standardized sampling methodologies for the inventorying and monitoring of amphibian populations worldwide. In our initial planning, we assumed that quantitative statements about an assemblage of organisms are more useful than qualitative statements and that quantitative procedures yield a qualitative product, such as a species list, but that the reverse was not true. Although monitoring target populations for several years might constitute the best approach to obtain baseline data for studying biodiversity, we recognized that only a single sample or inventory was possible in some cases. Even so, we thought that the sampling design should be quantitative and thereby allow the expansion of an inventory to a monitoring program, should the opportunity arise. A quantitative approach also facilitates between-site comparisons of data from initial stages of monitoring studies and inventory projects.

The guidelines we recommend emphasize the inventorying and monitoring of assemblages of amphibians. This approach is of greatest value in tropical areas but can be used everywhere. Many procedures are also suitable for studying single-species populations. Finally, we designed the book to stand alone so that anyone with training equivalent to a college degree in biology could use it to monitor or inventory amphibians without having to consult many other references.

Four factors influence the inventorying and monitoring procedures:

(1) A species list is an enumeration of the alpha diversity at a site and can be used for comparison of amphibian assemblages among sites. How closely the list actually approximates the actual species composition depends on the complexity of the fauna, the duration of the inventory, and the availability of appropriate sampling techniques. A complete list of all species in a complex assemblage probably requires years of fieldwork.

(2) The complexity and diversity of an amphibian assemblage often are a reflection of the spatial distribution and availability of habitats within each site. Therefore, the identification of different microhabitats at each site and the distribution of animals within and among these habitats are essential elements of an inventory. For amphibians, breeding and nonbreeding habitats must be included.

(3) Amphibian activity, especially breeding, is influenced by changes in environmental parameters, such as temperature and rainfall. Because sampling is often dependent upon amphibian activity, temporal variation in the factors that influence activity must be considered in selecting a sampling technique and in comparing results between samples. Minimally, data on diel (diurnal/nocturnal) and seasonal (wet/dry) activity need to be included in inventorying and monitoring programs. Ideally, sampling should extend over several years. In addition, precipitation and maximum–minimum daily temperatures should be recorded and included in analyses, whenever possible.

(4) Data on the abundance of species, when gathered appropriately, allow for more robust comparisons among habitats and sites than comparison of species lists alone and should be an integral part of inventory or monitoring. Included should be such data as abundance for each life stage and sex ratios.

The book

More than 40 amphibian biologists contributed to the book, titled "Standard methods for measuring biological diversity of amphibians." The volume contains nine chapters, an extensive literature cited, a glossary, and several appendices. Following a general introduction, which gives the rationale behind the project and discusses the intended audience and origin of the publication, is an introduction to amphibians. This chapter summarizes the major groups of living amphibians and their distinguishing ecological and life history traits and provides a general review of the habitats used by each family. This coverage should make it easier to select suitable inventorying or monitoring techniques for specific groups and specific areas.

The next chapters deal with the essentials of standardization and quantification (Chapter 3) and provide a guide to research design for studies of amphibians (Chapter 4) and a guide to analysis of sampling data on amphibians (Chapter 5). Chapter 3 reviews standardization and how to pose a study question; discusses sampling, randomization, bias, and replication; and outlines methods for data reporting. The importance of voucher collections is discussed here and elsewhere. Chapter 4 takes the reader through the many issues of research design and sampling methods for amphibians. Chapter 5 follows with an in-depth discussion of ways to analyze sampling data for species richness, species abundance, species density, and species diversity.

Chapter 6 presents a set of guidelines for technique selection, and Chapter 7 reviews important considerations prior to initiation of a project. Included in the latter are discussions about the importance of recording weather data at the study site, data and specimen standards, microhabitat analyses and classifications, and considerations relative to species identifications and specimen repositories.

Chapter 8 contains six sections on inventorying and monitoring techniques. Ten recommended field survey techniques are described in the first section. Each description includes a discussion and consideration of the objective of the technique, target organisms and habitats, background theory and assumptions, experimental design, field methods, kinds of data to be collected and recommended formats, data analysis and interpretation, special considerations or recommendations, personnel and material needs, and a relevant bibliography. The 10 techniques and some factors important in their selection are listed in Table 1. We view the information content (= relative value) of a technique as increasing from measures of species richness through relative abundance to density, and we point out that measures of relative abundance and density also estimate species richness. The relative costs, on a scale of low, medium, or high in terms of time, money, and personnel, are listed for each technique.

The next section of Chapter 8 reviews the techniques for estimating population size with mark and recapture and with temporary removal sampling and discusses marking techniques for amphibians. Section 3 covers ancillary

Table 1
Factors to consider in selecting standard techniques

Techniques	Information gained	Time	Money	Personnel
Complete inventory	Species richness	High	Low	Low
Visual encounters	Relative abundance	Low	Low	Low
Aural transects	Relative abundance	Medium	Medium	Medium
Quadrat sampling	Density	High	Low	Medium
Transect sampling	Density	High	Low	Medium
Patch sampling	Density	High	Low	Medium
Drift fence/pitfall	Relative abundance	High	High	High
Survey breeding site	Relative abundance	Medium	Low	Medium
Drift fence breeding site	Relative abundance	High	High	High
Aquatic sampling	Density/relative abundance	Medium	Medium	Medium

techniques, including the use of artificial habitats, acoustic monitoring from fixed sites, tracking (radio, radioactive, and trailing devices), and night driving. Section 4 reviews automated data acquisition, section 5 looks at Geographic Information Systems (GIS) applications for amphibians, and the final section recommends organized group activities, including field trips and regional surveys, as useful inventorying and monitoring tools.

The book ends with general recommendations, an extensive literature cited, a glossary of terms, and five appendices. Included in the latter are techniques for preparing amphibians as scientific specimens, for recording frog calls, and for sampling tissues. Also appended are a list of vendors (for supplies and equipment) and a random numbers table.

In summary, this manual provides guidelines and describes sampling protocols for the study of amphibian populations. The recommended standard techniques for inventorying and monitoring amphibian populations provide a basis for obtaining quantitative data important to understanding amphibian biodiversity and long-term baseline data to evaluate the status of amphibian populations throughout the world and to detect global declines.

Acknowledgements

I want to thank my coeditors, Ronald Heyer, Maureen Donnelly, and Lee-Ann Heyek; the Program Director and series editor, Mercedes Foster; the workshop participants; and all authors and contributors to the Standard Methods volume. Without their help, I would not have had much to contribute to this workshop. I also want to thank Christine Bishop and the Canadian Wildlife Service for the opportunity to participate in this important workshop and contribute to this volume.

Literature cited

Anonymous. 1991. Declining amphibian populations—a global phenomenon? Findings and recommendations. Alytes 9(2):33–42.

Barinaga, M. 1990. Where have all the froggies gone? Science 247:1033–1034.

Blaustein, A.A. and D.B. Wake. 1990. Declining amphibian populations: a global phenomenon. Trends Ecol. Evol. 5:203–204.

Pitfalls in quantifying amphibian populations in Canada

Francis R. Cook

Abstract

North temperate amphibians are seasonal breeders, and males of most Canadian frog species utter loud distinctive advertisement calls that may carry considerable distances, facilitating site and individual monitoring. Despite this, long-term studies at one locality are few and largely anecdotal. In southeastern Ontario (1971–91), I marked more than 20 000 individual amphibians and reptiles of 18 species. Population variations within and between years are indicated for nine anurans and seem largely due to climatic fluctuations and habitat modifications. In a 0.2-ha pond, breeding males of a representative species, *Hyla versicolor* (Gray Treefrog), ranged from 281 in 1974 (4.6% pre-1974 returns) to 95 in 1977 (47.3% pre-1977). Seasonal activity varied; in 1973, calling spanned 59 nights, but on 20 nights no frogs called, and on seven nights no more than two called. Females were found on only 17 nights. These and other data emphasize that surveys must be planned, consistent, intensive, daily, and within optimal activity periods and must span many years for comparative data that would reliably detect real declines, if any. Monitoring outside breeding periods is less comprehensive for individuals present. Spring–fall collections of foraging *Bufo americanus* (American Toad) gave immature growth but little subsequent survival estimates, and summer–winter marking of *Rana pipiens* (Northern Leopard Frog) showed local winter die-off, estimated at 3800 in 1979–80, without lessening volume of local choruses in subsequent springs.

Résumé

Les amphibiens des régions tempérées septentrionales se reproduisent à certaines périodes. Les mâles de la plupart des espèces canadiennes d'anoures émettent un chant d'appel puissant et distinctif, qui porte sur des distances considérables; cette caractéristique facilite la surveillance des sites et des sujets. Malgré ce fait, il y a peu d'études à long terme dans des localités précises, et elles ont souvent un caractère anecdotique. Dans le sud-est de l'Ontario (1971–1991), l'auteur a marqué plus de 20 000 amphibiens et reptiles appartenant à 18 espèces. Les variations de population d'une année à l'autre et au cours d'une année sont indiquées pour neuf anoures; elles semblent largement attribuables à des fluctuations climatiques et des modifications de l'habitat. Dans un étang de 0,2 ha, le nombre de mâles reproducteurs d'une espèce représentative, *Hyla versicolor* (Rainette versicolore) a varié entre 281 en 1974 (retour de 4,6 % de sujets d'avant 1974) à 95 en 1977 (47,3 % de sujets d'avant 1977). L'activité saisonnière a varié : en 1973, la période des signaux d'appel a couvert 59 nuits, mais il y a eu 20 nuits où aucune grenouille n'a émis son appel et sept nuits où pas plus de deux ont émis leur appel. Les femelles n'ont été trouvées que lors de 17 nuits. Ces résultats et d'autres indiquent que les dénombrements doivent être planifiés, uniformes, intensifs, quotidiens et se faire durant les périodes d'activité optimales; en outre, ils doivent s'échelonner sur un bon nombre d'années, de façon à obtenir des données comparatives qui permettraient de détecter de façon fiable un déclin réel, s'il y en avait. La surveillance hors des périodes de reproduction conduit à de moins bons dénombrements. Les captures, au printemps et à l'automne, de sujets de *Bufo americanus* (Crapaud d'Amérique) en train de s'alimenter ont révélé une croissance incomplète, mais ont fourni très peu d'estimations de la survie, et le marquage à l'été et à l'hiver de *Rana pipiens* (Grenouille léopard) a révélé une mortalité locale hivernale estimée à 3 800 en 1979–1980, sans qu'il y ait eu réduction du volume des chants en choeur lors des printemps subséquents.

Introduction

Amphibians are attractive for use as environmental monitors. This is particularly so for Canadian frogs, as they are often abundant and seasonal aquatic breeders. Males of most species utter advertisement calls that often carry considerable distances. These calls allow easy detection of the location of both sites and individuals within them (at least on suitable nights). Although they seem quite literally to cry out for quantification, this seldom is done, even for a single species over any extended time, and especially for a suite of species using the same site.

From 1971 to 1991, I conducted field studies, often peripheral to other projects. Initially, studies focused on the effects of sampling and provided a baseline for interpreting existing museum collections taken at random points in breeding seasons across Canada. As further questions and hypotheses were raised, studies were expanded. Here, selections from the data are used to illustrate some representative variation, the pitfalls that can frustrate such studies, and the need for caution in accepting declines based

Table 1
Amphibians and reptiles marked in 1973 (all sites)

Species	Individuals	Marked in a prior year	Recaptures	Total captures
Ambystoma laterale Blue-spotted Salamander	1	(0)	0	1
Bufo americanus American Toad	109	(7)	143	252
Hyla crucifer Spring Peeper	560	(8)	295	855
Hyla versicolor Gray Treefrog	182	(45)	612	794
Pseudacris triseriata Western Chorus Frog	139	(0)	9	148
Rana clamitans Green Frog	55	(0)	82	137
Rana pipiens Northern Leopard Frog	105	(0)	10	115
Rana septentrionalis Mink Frog	3	(0)	5	8
Rana sylvatica Wood Frog	113	(0)	23	136
Chelydra serpentina Snapping Turtle	1	(0)	0	1
Chrysemys picta Painted Turtle	23	(7)	14	37
Emydoidea blandingi Blanding's Turtle	2	(0)	0	2
Nerodia sipedon Northern Water Snake	3	(0)	0	3
Storeria occipitomaculata Redbelly Snake	1	(0)	0	1
Thamnophis sirtalis Garter Snake	30	(1)	4	34
	1327	(68)	1197	2524

on short-term observations. More formal analyses of the full data will be presented elsewhere.

Study area and methods

The study area is in southeastern Ontario, approximately 70 km southwest of Ottawa, in Wolford Township, Grenville County. This relatively flat region is part of the lowlands of the Rideau and Ottawa valleys and was once flooded by the western edge of the postglacial Champlain Sea. It is underlain by limestone that is, in places, exposed at the surface or sparsely covered with soil and, in others, buried under many feet of sand and topsoil. Original Great Lakes – St. Lawrence ecotone forest is now largely replaced by second-growth mixed-hardwood woodland interrupted by farmland. Tracts of low swamp and marsh are a common feature. The immediate area was largely unsettled until 1840 but was probably cleared to a greater extent by the 1890s than at present. Since the 1960s, agriculture has been gradually ceasing on many economically marginal farms.

The study sites are particularly suited for baseline frog population monitoring, as they are relatively unpolluted (except by agricultural use of pesticides and herbicides in some few active adjoining farms) and also presumably somewhat buffered against acid rain effects by the limestone substrate. Sampling sites had the tactical advantage of being adjacent to where I live ("Maplestone Farm") and therefore quickly accessible daily. The latter is essential for any intensive long-term study.

More than 20 000 individual amphibians and reptiles have been marked in 21 years. Totals for 1973 (Table 1) from all area sites are typical. In subsequent years, *Rana catesbeiana* (Bullfrog), *Plethodon cinereus* (Redback Salamander), and *Opheodrys vernalis* (Smooth Green Snake) were added.

Primarily in spring, but all through the active season until winter, investigation was initially concentrated on a single artificial 0.2-ha pond that had been a local gravel pit during the 1930s. This pond filled in spring to a maximum depth of about 1.5 m but, except for one deep hole, was comfortably negotiable if chest waders were worn. Large areas were covered with only 0.6 m or less of water. By midsummer, the pond dried nearly or completely. The pond edge was dominated by cedar whose lower branches overhung the water and in many places often touched its surface during high water.

All frogs were measured (snout-vent and tibia lengths), marked individually (by toe-clipping), and released, sometimes immediately after collecting, but usually the next day or (more rarely) several days later. After 1986, they were also weighed at each capture. In March–July 1973, one hour soon after dark was spent collecting every frog possible, with particular attention to calling males, thus giving a relative measure of the number of males active each evening. All were individually located and "hand-picked" or dip-netted. In some studies by others, drift fences and pitfall traps have been used to monitor amphibian populations. However, fences and pitfalls are selective of species that cannot readily climb, and two major breeders in this study were treefrogs (Hylidae). Fences and pitfalls also sample animals only when they enter and leave the pond and thus do not measure relative activity night by night within a pond. Other difficulties regarding their use at this particular site were the site's location along a rural road, which made it vandal-prone, periodic patrolling of its edge by predatory raccoons, and edge disruption by active landscaping by a series of different owners.

Results and discussion

Six species bred in this pond each spring in 1971–91. All are widespread in eastern Ontario, and all but two (*Pseudacris triseriata* [Western Chorus Frog] and *Hyla versicolor* [Gray Treefrog]) occur throughout southeastern Canada. The relative duration and peaks of activity in 1973 are representative. Calling by *P. triseriata* was between 15 March and 23 May (peak night 19 April: 27 males captured); *Rana sylvatica* (Wood Frog), 30 March and 19 April (1 April: 32); *Hyla crucifer* (Spring Peeper), 31 March and 3 June (3 May: 99); *Rana pipiens* (Northern Leopard Frog), 14 April and 7 May (23 April: 2); *Bufo americanus* (American Toad), 18 April and 17 June (21 May: 13); and *H. versicolor*, 10 May and 7 July (30 May: 61). Typically, the relatively warmest and most humid nights earliest within the breeding period for each species produced the activity peaks reflected in the number of calling and exposed males and the number of females and amplectic pairs found.

Hyla versicolor can be selected for patterns in a single species. It called over a period of 59 nights in 1973,

Table 2
Calling dates for all area breeding sites, 1971–91

Species	First calls, earliest/latest	Last calls, earliest/latest
Pseudacris triseriata Western Chorus Frog	15 March 1973/27April 1975	18 April 1977/2 June 1973
Rana sylvatica Wood Frog	25 March 1979/16 April 1978	15 April 1988/6 May 1975
Hyla crucifer Spring Peeper	30 March 1977/22 April 1975	22 May 1988/17 June 1985
Rana pipiens Northern Leopard Frog	4 April 1989/28 April 1975	2 May 1985/27 May 1990
Bufo americanus American Toad	6 April 1988/27 April 1984	16 May 1985/24 June 1981
Hyla versicolor Gray Treefrog	18 April 1976/20 May 1984	28 June 1975/19 July 1982
Rana clamitans Green Frog	22 May 1991/3 July 1988	20 July 1989/15 August 1981
Rana septentrionalis Mink Frog	29 May 1991/26 June 1990	23 July 1988/12 August 1981
Rana catesbeiana Bullfrog	9 June 1982/3 July 1988	20 July 1989/5 August 1981

but on 20 of these it was silent, and on seven nights no more than two frogs were vocal. Females (single or amplected) were found on 17 nights. This emphasizes that extensive surveys (where only a few visits are made to the same pond in a season) may be useful for simple presence evaluations but that daily monitoring of the same pond throughout a breeding season is essential to establish the actual numbers using it and to produce comparative data that will reliably detect real population explosions and declines, if any.

In 1973, the distribution of both previously marked and unmarked *H. versicolor* in daily samples showed that, although unmarked individuals continue to appear over the entire season, most are found in the first third of the breeding period. Between one and 22 unmarked males were present in nightly samples of one to 61 frogs up to 5 June, but only one to three unmarked frogs in nightly samples of four to 44 frogs thereafter. "Experienced" breeders, those marked in 1971 and 1972, were not among the first frogs to call. In 1973, the snout-vent range of 133 male *H. versicolor* was 37–57 mm. The range for 33 that had been first marked in 1972 was 45–53 mm, and that for six first marked in 1971 was 47–55 mm. Although the 1971 and 1972 animals recaptured in 1973 were all in the upper part of the size distribution and the 21 unmarked breeders below 45 mm therefore clearly recruits-of-the-year, 73 other first-found frogs were 45 mm or more. New large individuals could be those with fast growth rates, those that transformed late and took an extra growing season before breeding, or those newly moved in from adjacent areas. In samples from neighbouring ponds, however, no marked animals from the main pond have been found, and only rarely have individuals first marked elsewhere subsequently moved to this pond. There were also fluctuations between years in number of breeding individuals and in the proportion that had been marked in prior years. For example, total male *H. versicolor* ranged from 281 in 1974 (with only 13 [4.6%] marked in previous years) to 95 in 1977 (with 45 [47.3%] marked in previous years) but increased again in subsequent years.

In the late 1980s, after catfish had been introduced, there was a reduction of all species. Over various ownerships, clearing was also instigated around the margins. Finally, a smaller pond of more uniform depth was created by the most recent owners, and this has been circumscribed by a stone retaining wall. During this reconstruction, the catfish were eliminated and frog breeding populations began to recover. Fairly good choruses were present in 1991, primarily in spring flooding outside the stone enclosure. Late spring drying subsequently eliminated this, and the normal retreat of tadpoles to deeper water was blocked by the stone wall. Apparently, there was no successful metamorphosis of any species in 1991. Obviously, studies for long-term monitoring are better carried out in areas that are protected from such habitat manipulation and destruction. The latter events are probably a major cause of perceived local frog declines.

There were also large differences between years in the beginning and ending of breeding seasons. Peripheral to the detailed studies, I have regularly driven a box transect of surrounding rural roads and monitored presence/absence of calling frogs for all species. The results clearly document wide fluctuations and that the same calendar dates do not compare the equivalent points in breeding seasons between years (Table 2).

Frog numbers can also be estimated in nonbreeding seasons, but comparable data between years can be more easily frustrated by fluctuating conditions. Large concentrations of tadpoles are present in successful breeding locations, but quantifying their numbers is difficult. In some years and sites, they may be wiped out by premature site drying. I have made little attempt to compare tadpole populations because of time and logistical constraints.

Significant numbers of transformed frogs of all ages can often be found from spring to fall. Sampling these yields data on seasonal growth, but success often varies widely between years. By searching, usually just after dark, on the 184 days from 2 May to 1 November 1973 along a 0.5-km partly tree-lined laneway and the yard area above it, and supplementing this with individuals picked up in the area at other times of the day, 81 individual toads and 52 recaptures were obtained on 72 days. In the previous year, 94 individuals (but only 34 recaptures) were found on 36 days. Both years were optimal for warm humid nights and time available. The following year, 1974, was neither, and only eight individuals were taken. Six 1972 toads were recaptured in 1973, and one 1973 toad was recaptured in 1974. Repeatability of both available time and occurrence of optimal weather for activity is vital to valid comparisons, and clearly these were not duplicated between years. However, estimates from numbers calling in the area as a whole suggested a local decline in toads through the 1970s. This was reversed, subsequently, by an apparent recovery by 1991.

In 1979, 963 predominantly juvenile *R. pipiens* were marked from fields around my house and the adjacent creek between 23 July (when they first appeared there) until their last terrestrial activity on 1 November. Weekly minnow trapping in the creek by F.W. Schueler from 7 November to 10 February 1980 yielded 48 live frogs, three of which were marked. On 17 February, eight frogs, including one marked and half of the group, were dead. On 24 February, 68 frogs were recovered from the bottom of the creek, all but one dead, 17 of them marked that summer. If all marked frogs attempted to winter in this area, the proportion of marked to unmarked among those dead indicates that more than 3800 frogs perished. The likely cause was anoxia, as oxygen measurements taken at the site by Schueler were zero in the latter part of February. The annual summer population of immature frogs on fields around my house continued to be high in subsequent years, although we have never repeated quite the same level of sampling. Similar die-offs appear to be occurring each winter. Local *R. pipiens* numbers are likely maintained by optimal breeding conditions in an upstream cattail marsh where huge choruses are heard each spring. These frogs must have had access to a well-oxygenated overwintering site. Although catastrophic for individuals, localized winter die-offs need not be so for regional populations if sources of reproductive surpluses survive unaffected nearby.

Because oscillations are likely common in frog populations, reports of declines based on short-term and local observations should be viewed with caution. However, these should heighten our promotion of more detailed studies. Declines due to environmental problems that may precede extinctions may be hard to distinguish from transient declines, which may or may not be cyclic. The difficulties underscore the vital importance of maintaining and increasing intensive long-term population monitoring.

A comparison of three methods of monitoring frog populations

Michael Berrill, Susan Bertram, Deneen Brigham, and Victoria Campbell

Abstract

We tested the reliability of both human ears and remote tape recorders as means of monitoring an anuran population. We selected a single population of the Gray Treefrog (*Hyla versicolor*) to monitor through an entire breeding season. We compared estimates of the number of calling males by human listening and by remote recording, with the number of calling males determined to be present by intensive observation involving identification of every male every night. The numbers of calling male frogs estimated by both human listening and remote recorders were significantly correlated with the actual number of calling individuals ($r^2 = 0.77$ and 0.88, respectively, $p < 0.0001$). We therefore can have confidence in the estimates of size of a calling male population of treefrogs provided by both listening methods, provided they are calibrated by a single intensive study. We propose that the most efficient method of monitoring, in terms of time, cost, and energy, combines the three methods we used. A remote recorder that turned on for five minutes at the same time each night, coupled with a single weekly visit to the site, would allow human listening to corroborate the recorded calls. A single night of intensive monitoring in the middle of the breeding period would allow the calibration factor to be assessed. Although there are constraints on the suitability of such monitoring methods, they should be useful in monitoring many anuran species.

Résumé

Les auteurs ont évalué la fiabilité de l'appareil auditif et des magnétophones télécommandés pour assurer le suivi d'une population d'anoures. Une population prédéterminée de *Hyla versicolor* (Rainette versicolore) a ainsi été suivie durant toute une saison de reproduction. Les estimations du nombre de mâles chanteurs repérés par l'appareil auditif humain et par téléenregistrement ont été comparées au nombre repéré à la suite d'une surveillance approfondie requérant l'identification visuelle de tous les mâles chaque nuit. Une corrélation positive a été établie entre le nombre de mâles chanteurs évalué par les deux premières méthodes susmentionnées et le nombre réel de sujets émettant des signaux sonores ($r^2 = 0{,}77$ et 0,88, respectivement, $p < 0{,}0001$). La fiabilité des estimations des populations de mâles chanteurs fournies par les deux méthodes de détection a été établie, à condition de procéder à l'étalonnage des résultats en ayant recours à la surveillance approfondie. Les auteurs estiment que la méthode la plus efficace de surveillance au point de vue de l'économie de temps, d'argent et d'énergie, est celle qui combine les trois méthodes susmentionnées. L'utilisation d'un magnétophone fonctionnant chaque nuit durant le même intervalle de cinq minutes, combiné à une seule visite hebdomadaire sur le site d'observation, permettrait de corroborer les résultats obtenus par écoute humaine. Une surveillance approfondie effectuée durant une seule nuit choisie au milieu de la période de reproduction permettrait d'évaluer la valeur du facteur d'étalonnage. En dépit des contraintes qui influent sur la pertinence de ces méthodes de surveillance, celles-ci devraient s'avérer utiles pour la surveillance de nombreuses espèces d'anoures.

Introduction

During the spring and summer of 1991, we attempted to count the number of calling male frogs of eight species at eight sites in Peterborough County in southern Ontario. We made the following assumptions:

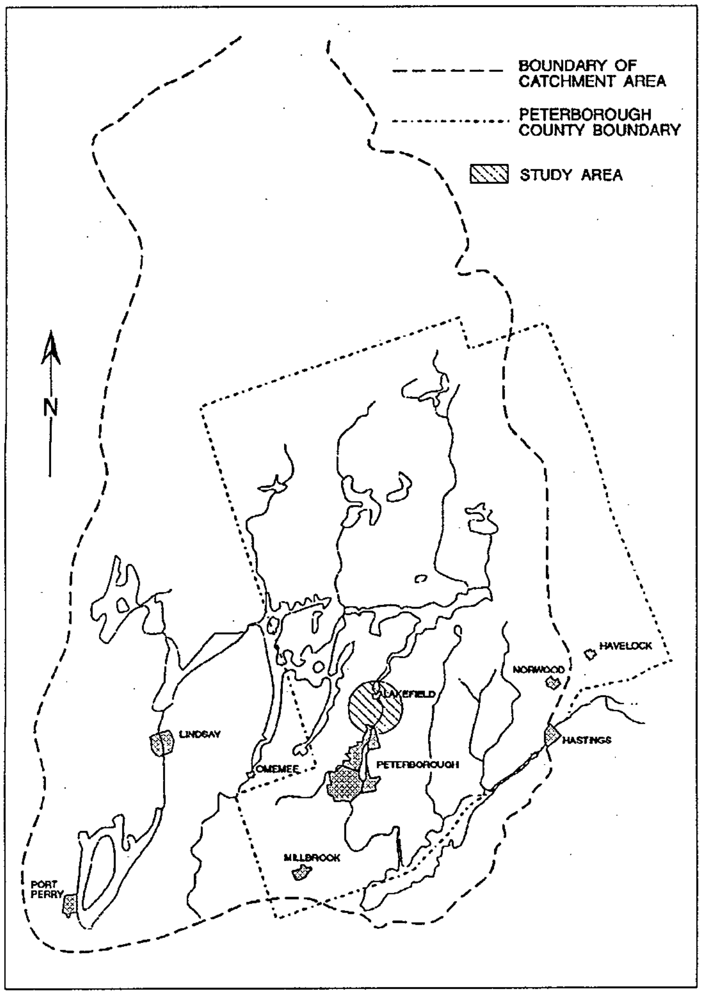
(1) Frog populations can be assessed with most accuracy by counting the number of calling males during the breeding season. Assessment outside of the breeding season is particularly difficult for nonaquatic species.

(2) Counting the number of calling males at a site during the breeding season reflects the density of adults at that site. This assumes an equal sex ratio, which in fact is unlikely to be true of all species.

(3) A change in the number of calling males at a particular site from year to year reflects real changes in density of adults at that site.

We monitored three ponds, three marshes, and two ephemeral swamps in Peterborough County (Fig. 1) from early April until mid-July. These sites allowed us to listen to at least three populations of seven species—Spring Peeper (*Hyla crucifer*), Gray Treefrog (*Hyla versicolor*), Western Chorus Frog (*Pseudacris triseriata*), American Toad (*Bufo americanus*), Northern Leopard Frog (*Rana pipiens*), Wood Frog (*Rana sylvatica*), and Green Frog (*Rana clamitans*) (Fig. 2)—and one population of Bullfrogs (*Rana catesbeiana*).

Figure 1
Location of Peterborough County where three ponds, three marshes, and two ephemeral swamps were monitored



We counted calling frogs in three different ways:

(1) *Human listening.* Two people (DB and one other) listened at each of the eight sites, four nights per week. Each site visit lasted 15 minutes, and the listeners estimated the number of calling males of each frog species. Sites were visited in a different order on different nights, beginning after dark.

(2) *Remote recording.* We set up tape recorders at four of the sites. Each recorder was connected to a sensitive microphone and to a timer that turned the recorder on for one minute every half-hour: a 90-minute tape therefore lasted two days. Microphone, recorder, and timer were all powered by batteries. We turned or replaced tapes every 24 hours and later transcribed them, estimating the number of calling males of each species.

(3) *Intensive monitoring.* As part of her M.Sc. thesis, S. Bertram identified every calling male of a population of the Gray Treefrog every night during the breeding season at one of the sites, identifying each male by its unique dorsal pattern.

Each method allowed us to test the validity of the other two methods, and each, of course, allowed us to collect rather different data about each population. We attempted to answer the following questions:

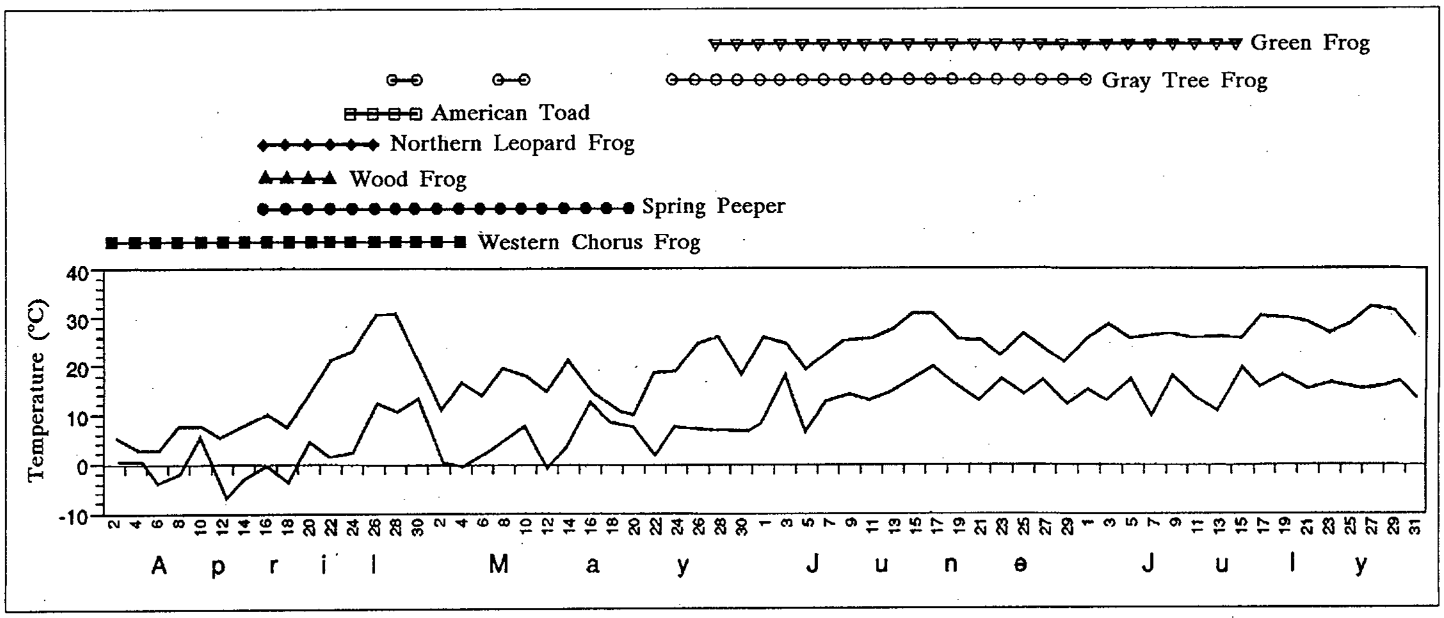
(1) Are the calling activities of different populations of the same species similar between sites during the calling season?

(2) Can remote recorders provide information comparable to what human listeners can provide?

(3) Does either human listening or remote recording give an accurate estimate of the true number of calling males in a population?

(4) What is the most efficient method of assessing population density of calling males with an acceptable margin of error?

Figure 2
Time periods in which males of seven species were heard calling in Peterborough County and associated air temperatures



Methods and results

Human listening

Numbers of males were easy to assess when they were low but became increasingly difficult to estimate as they became larger; accuracy certainly decreased. The variation that occurred in estimated numbers between sites and between nights must be considered with care, if used at all, for the time of visiting a site confounds other critical effects, such as temperature or time in breeding season.

On the other hand, human listening allows accurate assessment of seasonal patterns of onset, period of peak activity, and cessation of calling. Despite the potential inaccuracy at high densities of calling males, it allows an estimate of relative numbers that is likely to be useful.

By monitoring as frequently as four times per week, then averaging the number of calling males per night per week, a fairly clear picture of the season emerges. Our data indicate that a single species will call with a similar seasonal pattern at different sites, as illustrated by the seasonal calling activity of Spring Peepers at three sites (Fig. 3).

Remote recording

The four recording units functioned relatively well, particularly once we became accustomed to their limitations. The sensitive microphones were also sensitive to high humidity, and April was very wet. We also had to learn from experience how long the various batteries would last, and, as a result, none of the four units ran nonstop for the two- to three-month period. Estimating the number of calling males by listening to the tapes is challenging—estimates are probably accurate when numbers of callers are low but increasingly less accurate as numbers increase beyond about 10.

Besides providing an estimate of the number of calling males of each species at each of the four sites, the tapes provide detailed data on the diurnal calling activity of each species. The tapes also make it possible to assess with some confidence the effect of temperature or stage in breeding season on relative numbers of calling males. An example is a comparison of the estimated number of calling males of a population of Gray Treefrogs on two nights, one cool and one warm (Fig. 4).

Intensive monitoring of one population

The quality of data obtained by monitoring every calling individual of a population every night for the entire breeding season is, of course, unusually good. Such monitoring is also labour intensive, demands a high level of commitment, and restricts observations to a single site. It does, however, give us an idea of the true number of males calling in a breeding population, in comparison with the estimates provided by the other two methods. Once again using the Gray Treefrog as our example, intensive monitoring indicated that 84 different males called at a site during the breeding season, some individuals calling on many more nights than others (Fig. 5). The other two methods simply could not provide that information, telling us only that 30 or more males might be calling on any one night (Fig. 6).

Although such intensive monitoring is unrealistic to expect of anyone except a graduate student, it really needs to be done at least once per species in order to "calibrate" any other method involving estimations; the detailed data the method provides may radically modify the whole picture

Figure 3
Seasonal calling activity of Spring Peepers at three sites

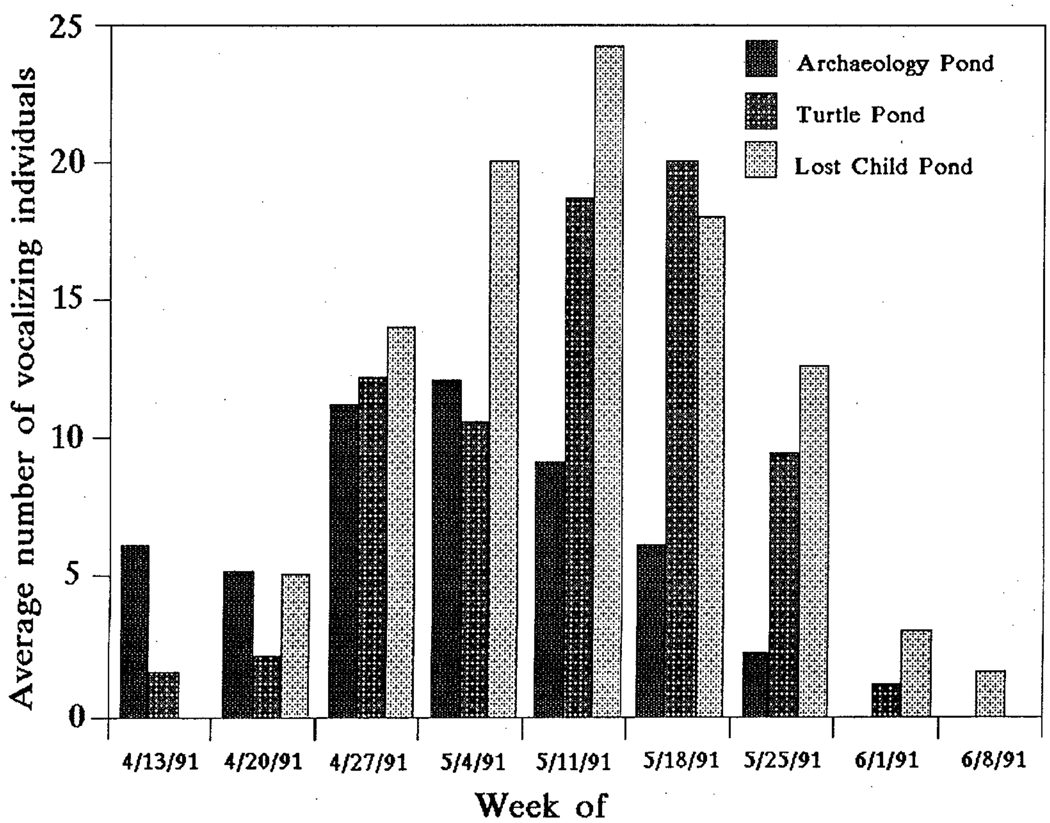


Figure 4
Estimated number of calling males of a population of Gray Treefrogs on two nights of monitoring

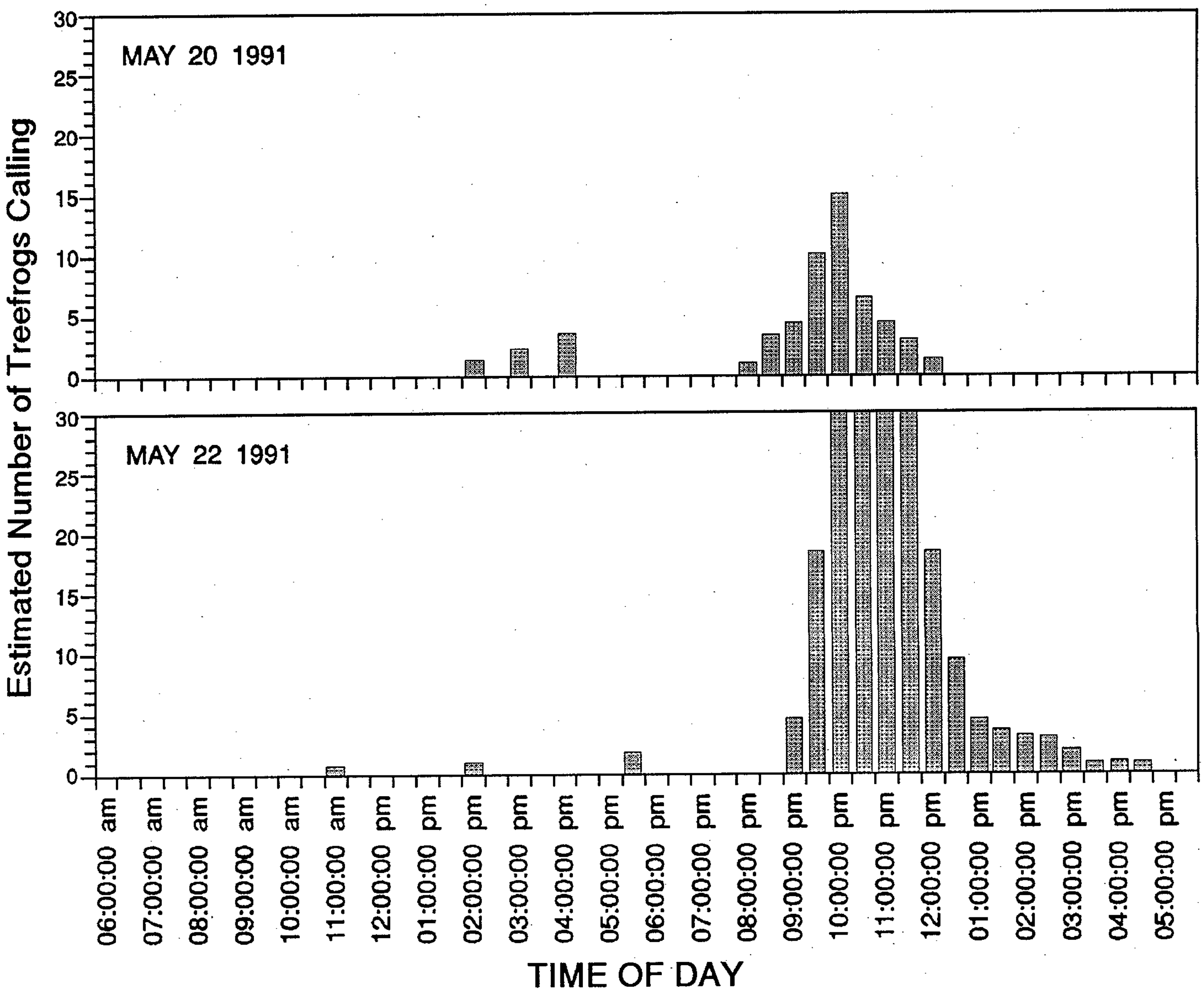


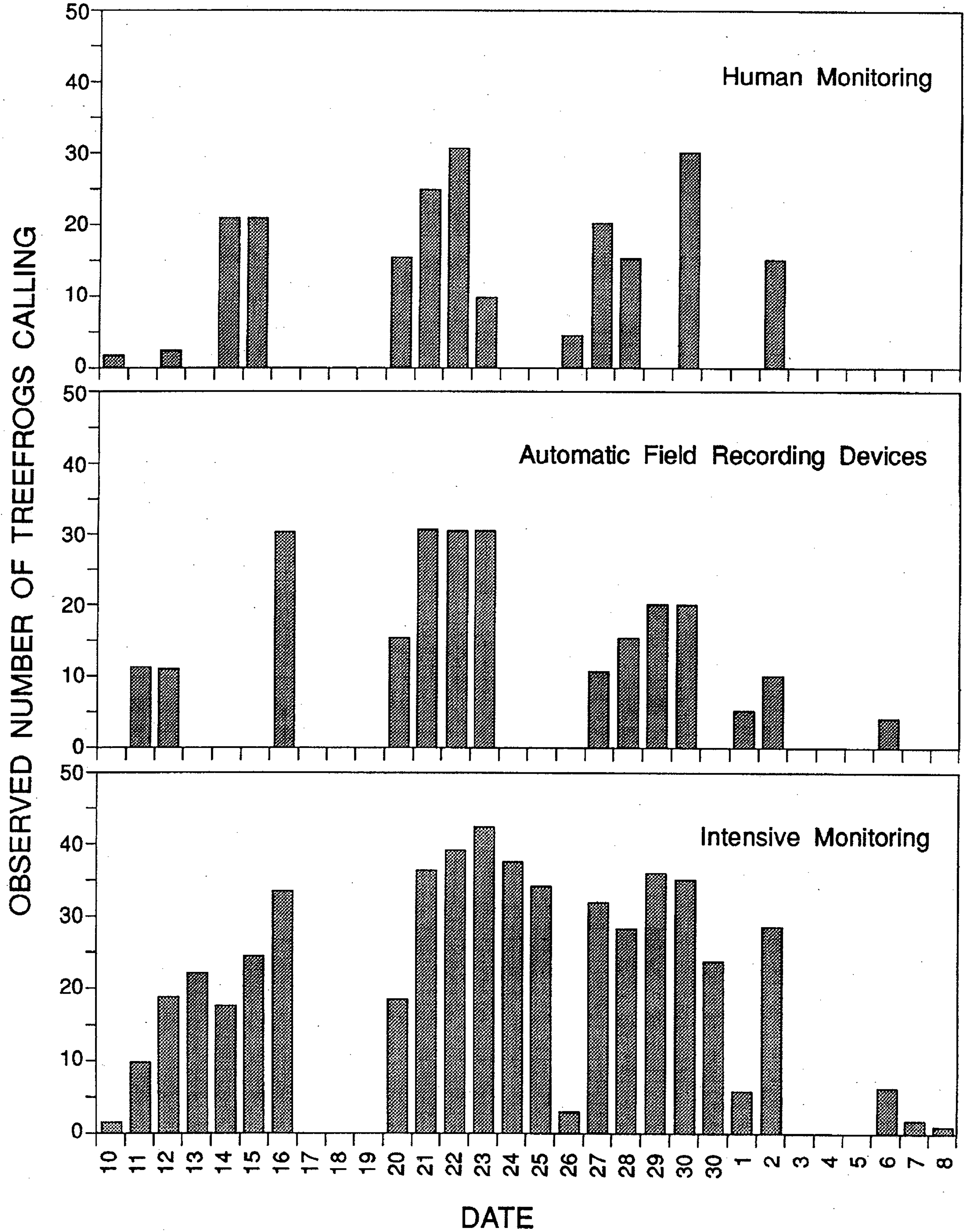
Figure 5
Results of intensive monitoring, indicating that 84 different males called at one site. Occurrence of calling by each male is represented by P.

May 10, 1991 — June 8, 1991

DATE

	05-10	05-11	05-12	05-13	05-14	05-15	05-16	05-17	05-18	05-19	05-20	05-21	05-22	05-23	05-24	05-25	05-26	05-27	05-28	05-29	05-30	05-31	06-01	06-02	06-03	06-04	06-05	06-06	06-07	06-08
SIMON	P	P	P	P	P	P	P				P	P	P	P	P	P			P	P	P	P								
NADER	P	P	P	P											P	P		P	P		P	P								
SAMMY		P	P	P									P					P												
MICHAEL		P	P	P	P		P				P	P	P	P	P		P	P	P		P	P		P						
MARCUS		P	P		P	P	P					P		P		P														
PATRICK		P	P	P		P	P					P	P	P				P	P	P	P	P	P							
FREDERICK		P	P	P	P	P	P					P	P	P	P	P		P	P	P	P	P	P	P						
RAY		P	P	P	P	P						P	P	P		P		P		P	P	P								
BRUCE		P																												
JAKE			P	P	P	P	P					P	P	P					P	P	P	P		P						
KEITH			P	P	P		P				P		P	P	P			P		P	P	P		P						
JULIAN			P	P	P		P				P	P	P	P	P			P	P	P	P	P		P						
THE FAT MAN			P	P												P				P										
PERCEY			P	P		P	P					P	P	P	P	P		P	P	P	P	P		P						
FRED			P	P																										
TOM W.			P	P																										
JEREMY			P	P		P																								
PETER			P		P		P					P	P	P	P		P	P	P	P	P			P						
MARK			P		P	P					P	P	P	P		P		P			P			P						
BART				P	P	P											P		P											
STEPHAN				P	P		P						P				P	P	P	P	P	P	P						P	
ALEX				P	P		P				P		P	P		P			P	P	P			P					P	
ARNOLD				P		P								P										P						
STEVEN				P		P	P					P					P	P												
PUKE				P		P	P				P	P	P	P	P					P	P	P	P	P				P		
LUCKY					P	P	P					P	P	P	P			P			P			P						
OLIVER					P	P								P						P				P						
DANIEL					P										P			P												
NICHOLAS					P		P					P		P	P	P			P	P		P		P						
WILLY						P	P					P	P	P		P		P	P	P	P									
GEORGE						P	P					P			P									P						
TED						P	P						P	P	P			P												
CHARLES						P	P								P	P		P	P	P	P	P								
BOB						P	P									P	P	P	P	P	P	P	P							
GRAMPS						P	P																							
WALLY						P	P				P	P	P	P	P					P	P	P		P						
SANDY						P	P					P		P	P	P		P		P	P	P	P	P				P		
TIM						P							P																	
ANDREW							P						P	P						P	P	P								
SYLVESTOR							P								P					P										
CHRISTOPHER							P					P	P					P												
AL							P				P		P	P	P			P	P	P	P			P						
JIM							P									P				P	P			P						
BARRY							P									P					P									
DUCKY							P					P	P	P	P	P		P	P	P	P	P								
PAUL							P				P	P	P	P	P	P		P	P	P	P			P						
CO-CO							P				P	P	P	P					P	P		P	P							
JOSHUA											P	P	P	P	P	P		P	P	P	P	P	P							
SCOTTY											P	P	F	P	P	P	P	P		P	P	P		P						
DAVID											P	P	P	P	P	P		P	P	P	P	P	P							
JEROME											P	P		P	P	P		P	P	P	P	P	P	P				P	P	P
FINLIN											P	P																		
WEIRD											P			P		P		P	P		P			P						
GERRY												P	P	P	P	P	P													
VAN												P	P	P	P	P	P	P	P	P	P		P							
WOODY												P	P	P	P	P		P	P	P	P	P		P				P		
WHITEY												P	P	P	P	P		P	P	P										
GHANDI												P	P	P	P	P		P		P	P	P		P						
QUACK												P		P		P		P	P		P	P								
BRANDY												P																		
ROGER												P		P	P	P		P	P	P	P	P							P	
KERMIT													P								P	P								
GUATEMALA													P					P												
HOMER													P		P				P											
SPOTTY													P																	
CAIRO													P	P	P	P		P		P	P	P		P						
HAWAII													P				P		P	P	P	P		P						
TINY														P	P			P												
MORRISON															P					P										
MARSH																	P	P	P		P	P	P	P						
NICOSIA																		P		P	P		P	P						
CYPRUS																		P		P										
KAI-KHALKER																			P	P	P	P		P						
DAHAB																			P	P				P			P	P	P	
FINEGAN																			P											
TOBI																			P		P	P		P				P		
FENNEL																			P		P									
INDIA																			P	P	P	P								
COSTA-RICA																			P	P	P	P	P				P		P	
SANTA																			P	P		P	P				P		P	
LINDROS																					P	P								
CHEEKS																						P	P							
PORTUGAL																						P								
IAN																												P		

Figure 6
Comparison of numbers of Gray Treefrogs heard calling by three monitoring methods



for that species. Some species would be much more difficult than others to monitor in such detail, but even a single night of intensive monitoring could be useful: for example, a single evening of monitoring all males in a small population of the American Toad indicated that the number of callers present was several times larger than the number estimated by our other monitoring methods.

Overall conclusions

If we compare the three methods of monitoring Gray Treefrogs at the single site where all three were used, asking only how many males were calling each night, when did the breeding season begin, and how long did it last, the methods provide quite similar data. Much of the night-to-night detail that the recording units can provide is probably not relevant. However, a recorder that listens to a calling population for just one to two minutes a night would be considerably easier and cheaper to maintain than a human listener, especially in more remote sites. A human could visit the site once a week to service the recording unit and listen to calls, but more frequent visits and more extensive recording may not be necessary. It is true, however, that a very dense and loud population of one species could mask the calls of uncommon species, and the recording units should be used judiciously. Additionally, however, each species, in each region, also needs intensive monitoring at least once, even briefly, in order to provide some correction factor that can be applied to the other monitoring methods to make them meaningful.

Monitoring wildlife populations in long-term studies

Ronald J. Brooks

Abstract

We know that Canadian amphibian populations are declining because of widespread habitat loss, but we cannot test the hypothesis that populations are disappearing from undisturbed habitat because we have no long-term data on amphibian population sizes. In this paper, I briefly outline the objectives, advantages, and difficulties of long-term ecological research in investigating such problems as the disappearance of amphibian species. Long-term studies of amphibians are needed so that we can separate natural fluctuations of populations from fluctuations or declines induced by human factors. Also, long-term studies can identify those stages of complex life cycles of amphibians that are most disrupted by humans. In long-term monitoring, it is imperative to determine the population dynamics of amphibians themselves before we can test hypotheses about causes of declines or fluctuations. Therefore, the Declines in Amphibian Populations Workshop, supported by secure funding commitments, should support the need for long-term research and monitoring on stable, protected sites and emphasize that although monitoring selected parameters of the biophysical environment can be useful, monitoring the amphibians themselves is urgent.

Résumé

Si nous savons que le déclin des populations d'amphibiens canadiens est attribuable à de vastes pertes d'habitat, nous ne pouvons par contre vérifier l'hypothèse selon laquelle les populations disparaissent également des habitats non perturbés, vu l'absence de données à long terme sur les tailles de ces populations. L'auteur du rapport décrit brièvement les objectifs, les avantages et les inconvénients des recherches écologiques à long terme menées sur des problèmes tels que la disparition des espèces d'amphibiens. Il faudra mener des études à long terme sur les populations d'amphibiens de façon à pouvoir distinguer les fluctuations naturelles des populations des fluctuations ou des déclins dus à l'activité humaine. Ce type d'études permet également de discerner quelles étapes vitales du cycle évolutif complexe des amphibiens sont les plus vulnérables aux perturbations causées par les humains. Dans ce type d'études, il est en effet impératif de pouvoir évaluer la dynamique même des populations d'amphibiens avant d'essayer de vérifier les hypothèses sur les causes des déclins ou des fluctuations. Les travaux du Colloque sur les déclins des populations d'amphibiens devraient pouvoir s'appuyer sur des engagements financiers fermes et être orientés vers la nécessité de recherches et d'un suivi à long terme sur des sites prédéterminés et protégés. On devrait y mettre l'accent sur l'urgence de procéder à un suivi des populations mêmes d'amphibiens en dépit de l'utilité reconnue de surveiller des paramètres prédéterminés du milieu physique.

Introduction

Most ecologists would agree that long-term studies are valuable and even necessary to understand the complex interactions that make up natural populations of organisms. Similarly, most ecologists would agree that amphibians are wildlife and represent an interesting taxon worthy of detailed investigation because, among other attractions, they are widespread, have highly varied life histories, make up a large part of the vertebrate biomass in many ecosystems (Burton and Likens 1975; Pechmann et al. 1988), and may be sensitive indicators of climatic or other changes in the environment (Wyman 1990; Wake 1991). Despite these commonly held sentiments, an examination of the scientific literature, particularly that in the Journal of Wildlife Management (the journal of the Wildlife Society), indicates that these views do not, apparently, reflect reality. Several recent surveys of papers published in the Journal of Wildlife Management show that, over the past 50 years, there have been virtually no papers published on amphibians (Gibbons 1988; T. Nudds, unpubl. data), and a survey of Journal of Wildlife Management abstracts over the past decade indicates an almost complete absence of terms associated with long-term studies on amphibians or any other taxa (J. Brown, unpubl. data). Therefore, in practice at least, the Wildlife Society eschews both long-term studies and amphibians. Similarly, although amphibians constitute a widespread and important vertebrate group in Canada, there are very few published, refereed papers on quantitative, long-term field studies on the population biology of Canadian amphibians.

Therefore, in this paper, I outline the value of long-term studies, particularly as they would contribute to the conservation of amphibians via a better understanding of life history, population trends and processes, and habitat requirements. Also, I outline some of the problems associated with long-term studies and suggest a few methods by which these problems may be circumvented. I illustrate points by examples from the literature and from my experience with long-term field studies on turtles, mice, and lemmings and from a medium-term (six-year) study on populations of three species of frogs. I do not discuss monitoring *per se*, as this topic is covered in several other papers in this volume.

What should a long-term study be?

By their nature, long-term studies lend themselves to investigators with a "collector" mentality, and this has produced some debate as to whether such studies should emphasize a largely empirical "collect all the data you can and see what they say" approach or whether these studies should focus only on data to be used to test a specific hypothesis. In his recent book on slider turtles, Gibbons (1990:x) made a brief, but fervent, defence of the first approach: "We just took measurements that seemed like they might provide some level of enlightenment." He went on to argue that "if we all waited until the right hypothesis came by, we would have no data for theory to stand on." Of course, one need not wait for a hypothesis.

The opposite approach is supported strongly by Tinkle (1979:717). He was adamant that long-term studies are required, but not "just any long-term study," only those "directed toward testing predictions from theory through the accumulation of quantitative data on individuals and population ecology over a time sufficient to measure variances in the relevant parameters." I must say I prefer this definition to the first one, particularly for its emphasis on the individual organism with its implication of the central importance of individual variation, which is the key to relative fitness and to measurement of the genetic and nongenetic variation so important in adaptation. Interestingly, proponents of both views cite Darwin in support, and indeed Darwin did say, at different times for different audiences, that he favoured both the Baconian and hypothetico-deductive methods. Suffice it to say, data are required to test a hypothesis, but to collect everything one can without hypotheses is largely a waste of time.

Value and necessity of long-term studies

(1) Long-term studies are essential to study long-lived organisms if one intends to follow individuals or cohorts and wants to understand life history or the effect of the stochastic nature of extrinsic influences such as predation, food abundance, climate, and so on (Gibbons 1990; Pechmann et al. 1991). Based on my 20-year study of turtle populations in Algonquin Park, it is easy to see that a two- to four-year study will provide conclusions quite different from those obtained from a 20-year study. Estimates of growth, longevity, survivorship, sex ratio, and many correlates of age and body size have all altered as the study has continued. Only by doing a long-term study have we discovered that even limited harvesting of adults from northern populations of turtles will drive these populations towards extinction (Brooks et al. 1991).

(2) Long-term studies are required, in most instances, to test hypotheses about long-term processes in ecology and evolution (Callahan 1984). For example, long-term trends in temperature have significant effects on reproductive success in amphibians and reptiles (Gibbons 1990). Predictions of these effects can be tested only using long-term data.

(3) Long-term studies can detect long-term population trends or a series of repeated short-term events such as population cycles (Falls and Falls 1987). A short-term data set may reveal a single event that is interesting, but in most science this single unreplicated event is simply an anecdote. If they have no replicates, are three- to four-year field studies not rigorous science or not science at all? Today, some journals, such as Ecology, often do not accept studies without replicates, but these replicates are often different short-term studies that add confounding new variables. Bruce Falls' 35-year study of numbers of deer mice (*Peromyscus*) and chipmunks (*Tamias*) in Algonquin Park provides a good example of the power of long-term studies (Falls and Falls 1987). Repeated population fluctuations provide 10 replicates, and these have repeated characteristics. Thus, rates of growth and age of maturity differ consistently between years of low numbers and years of peak numbers. Over the 35 years, numbers of *Peromyscus* and *Tamias* are correlated, and both are correlated positively with the maple (*Acer*) seed crop in the previous year, with temperature fluctuations two years earlier, and with the harvest of the rodents' predators (martens [*Martes*]) in the winter of the same year. A three-year study might show these correlations, but as a single example they would have little scientific credibility.

(4) The demand for long-term research is very broad; as the data set expands, it can be used to test ideas that never occurred to the researcher at the beginning, or perhaps at any time, of the study. A favourite example is the hypothesis of W.D. Hamilton that bright colour and complex song in passerine birds are caused by sexual selection in relation to resistance to parasites. He tested this rather bizarre hypothesis using a long-term data set collected in Algonquin Park by parasitologists (Hamilton and Zuk 1982). Needless to say, the parasitologists did not measure parasite load in Algonquin Park birds with this idea in mind.

(5) Long-term studies are needed to follow up translocation–reintroduction "experiments." At present, most of these efforts either seem unsuccessful or are not followed long enough to determine success or to determine why they succeeded or failed (Dodd and Seigel 1991). Enthusiasm and funding often die out before we find out that the introduced population suffered the same fate.

(6) Long-term studies often reveal unexpected and spectacular changes in a species. For example, Whit Gibbons recounted that, after 25 years and over 500 000 captures of reptiles and amphibians at the Savannah River Ecology Site, new species still turn up (Gibbons 1990). Bruce Falls first captured rock voles (*Microtus*) on his standard trap lines after 20 years of trapping. My studies at Churchill revealed huge differences in small mammal abundance and diversity during the study and in comparison with work done there 15 years earlier.

(7) Long-term studies allow valid assessment of effects of harvesting on populations. Most wildlife biologists and, indeed, most biologists accept as fact the statement that populations produce an "excess" that can be

harvested without affecting the population. This hypothesis has never been tested (T.D. Nudds, pers. commun.) and can be tested properly only with long-term research.

(8) Long-term research allows us to measure the variability of the response of local populations to variations in local environments. This provides a means of testing whether variations represent genetic differences or different phenotypic responses of a "single" genotype.

(9) In their 27-year study of checkerspot butterflies (*Euphydryas* spp.), Ehrlich and Murphy (1987) identified several other lessons for conservation: for example, it is important to determine the structure and mating patterns in demographic units, migration and gene flow often are not congruent, it is important to identify reservoir populations and the role of subtle habitat features, and environmental (biotic and abiotic) stochasticity plays a key role in the extinction of small populations. Finally, their work indicates that it is important, but difficult, to protect metapopulations and to introduce populations into empty patches of habitat. Their long-term work also suggested that the size of reserves needed to preserve populations is much larger than thought previously and, again, that long-term research is invaluable to conservation biologists.

(10) Finally, long-term research shows clearly that populations often undergo huge fluctuations that do not necessarily indicate that the population is abnormally stressed or unusual. For example, populations of lemmings vary over 1000-fold, and our work on ranid frogs in Algonquin Park indicates that large changes in abundance occur within and among years, within and among species.

Problems with long-term studies

Although it is almost a dogma with field biologists that long-term studies are wonderful, it is also true that very few of them are done, certainly none on Canadian amphibians. This dearth seems to be a result of a reluctance by funding agencies to support research that will not provide a "result" in a reasonably short time. Similarly, students do not wish to work 30–40 years to obtain their graduate degree. Although some funding agencies such as the Natural Sciences and Engineering Research Council (NSERC) are now providing support up to five years, this is exceptional and still not long-term. Another problem is that long-term studies are often perceived as mere repetitive data collection that uses up money and does not produce good science. Again, funding agencies usually operate on the premise that a researcher is only as good as his current curriculum vitae. Often, when one conducts a long-term study, there is a reluctance to publish until one gets one or two more years of data. This reluctance soon proves fatal to the study.

Some suggestions for long-term research

(1) The problems outlined above may be overcome in some instances by building short-term projects into the long-term study. This tactic allows one to publish regularly and thereby show productivity, and it also allows the empirical and hypothesis testing approaches to be woven together, avoiding the criticisms directed at exclusive use of either one of these approaches.

(2) Not only do many short-term studies in ecology and conservation biology suffer by being anecdotal and unscientific, but they often are descriptive and superficial, and thus their conclusions can do little more than state what was obvious before the study began or, worse, merely reflect the preconceptions of the researcher. In my opinion, this condemnation describes many so-called impact studies and status reports. They rarely test hypotheses, and the former are usually too superficial to be worthwhile, whereas the latter, given the natural fluctuations of populations, are hardly reliable. It would be valuable to funnel some of the vast funds that go towards these sorts of studies into long-term research (Tinkle 1979).

(3) Areas should be set aside and protected for long-term research (Bildstein and Brisbin 1990). This is being done at present in the United States. In Canada, national and provincial parks should do this, but there are no national or provincial guidelines, and, in many cases, research in these parks seems to be subject to the personal whim of senior park administrators. In general, scientific research has a low priority in park objectives or in the public perception of park functions. It is important that these perceptions be changed to set aside protected, undisturbed areas for long-term research.

(4) Long-term studies on species or other taxa or ecological entities with broad distribution should be coordinated and should have clearly stated goals and assumptions (Landres et al. 1988). This also would be a valuable function for the Declines in Amphibian Populations Workshop. Research projects could be coordinated, and researchers could cooperate to approach major funding sources.

(5) Long-term, cooperative research programs also must deal with problems of leadership, multiple-site protection, control of data, publication, and turnover of trained personnel. Coordinators for the Canadian Working Group on Declining Amphibian Populations could be involved in solving these organizational problems.

Summary

Many people have noted that most long-term studies develop originally from short-term studies and as such are often unplanned, unprepared, and funded for no more than three years (e.g., Callahan 1984). However, this does not mean they are not valuable. On the contrary, they are essential in dealing with long-term problems that require historical data or in testing of most hypotheses in ecology. Short-term projects cannot form the basis for solving environmental, biological conservation problems, nor can they advance a science that investigates long-term processes. Ecology requires long-term studies. These studies require protected sites and long-term funding. Both these requirements should be a future concern of the Declines in Amphibian Populations Workshop.

Literature cited

Bildstein, K.L. and I.L. Brisbin, Jr. 1990. Lands for long-term research in conservation biology. Conserv. Biol. 4:301–307.

Brooks, R.J., G.P. Brown, and D.A. Galbraith. 1991. Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (*Chelydra serpentina*). Can. J. Zool. 69:1314–1320.

Burton, T.M. and G.E. Likens. 1975. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. Copeia 1975:541–546.

Callahan, J.T. 1984. Long-term ecological research. BioScience 34:363–367.

Dodd, C.K., Jr. and R.H. Seigel. 1991. Relocation, repatriation and translocation of amphibians and reptiles: are they conservation strategies that work? Herpetologica 47:336–350.

Ehrlich, P.R. and D.D. Murphy. 1987. Conservation lessons from long-term studies of checkerspot butterflies. Conserv. Biol. 1:122–131.

Falls, J.B. and A. Falls. 1987. Populations of small mammals in Algonquin Park. Unpublished report for the Ontario Ministry of Natural Resources. Meeting for Ontario Renewable Resources Granting Program.

Gibbons, J.W. 1988. The management of amphibians, reptiles and small mammals in North America: the need for an environmental attitude adjustment. Pages 4–10 *in* Szaro, R.C., K.E. Severson, and D.R. Patten (eds.), Proceedings of a Symposium on the Management of Amphibians, Reptiles, and Small Mammals in North America. USDA For. Serv. Gen. Tech. Rep. RM-166.

Gibbons, J.W. (ed.). 1990. The ecology and life history of Slider Turtle. Smithsonian Press, Washington, D.C.

Hamilton, W.D. and M. Zuk. 1982. Heritable true fitness and bright birds: a role for parasites. Science 218:384–387.

Landres, P.B., J. Verner, and J.W. Thomas. 1988. Ecological uses of vertebrate indicator species: a critique. Conserv. Biol. 2:316–328.

Pechmann, J.H.K., D.E. Scott, J.W. Gibbons, and R.D. Semlitsch. 1988. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetlands Ecol. Manage. 1:1–9.

Pechmann, J.H.K., D.E. Scott, R.D. Semlitsch, J.P. Caldwell, L.J. Vitt, and J.W. Gibbons. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science 253:892–895.

Tinkle, D.W. 1979. Long-term field studies. BioScience 29:717.

Wake, D. 1991. Declining amphibian populations. Science 253:860.

Wyman, R.L. 1990. What's happening to amphibians? Conserv. Biol. 4:350–352.

Part 4: Recommendations

Introduction

Christine A. Bishop

The first paper in this section (Freedman and Shackell) describes the general background for a national monitoring survey of amphibian populations and factors associated with their population fluctuations. The four papers following it describe the specific protocols and recommendations of the workshop participants for a national monitoring strategy.

The first three aspects of a monitoring strategy (a historical data base, intensive monitoring protocols, and extensive monitoring protocols) were developed within subgroups at the workshop and modified and agreed upon by the rest of the participants in a general discussion. It was also agreed that, within the intensive and extensive monitoring efforts to quantify and study amphibian populations, factors that are postulated to affect amphibian survivorship should also be studied and monitored. Therefore, the fourth topic (intensive and extensive monitoring of factors that affect amphibian survivorship) is included in these proceedings. However, all participants agreed that to expand current research efforts on amphibian life history in Canada (which is desperately needed; see Brooks, this volume) and to incorporate monitoring of parameters such as water quality and habitat change will require a substantial infusion of funding specifically designated to these efforts. The implementation of an extensive monitoring strategy such as roadside surveys can be initiated with knowledgeable, volunteer naturalists. However, funding for professional surveys in some geographical areas and a national secretariat to coordinate this nationwide effort will be necessary.

Provincial, national, and international coordinators and associated research coordinators have volunteered to form the Canadian Working Group on Declining Amphibian Populations, and a list of these persons is provided at the end of these proceedings (Appendix B).

Amphibians in the context of a National Environmental Monitoring Program

B. Freedman and N.L. Shackell

Abstract

Environmental monitoring is conducted to detect changes over time and space in indicators of the distribution and abundance of biota and in the quality of air, water, and soil. When changes are detected, question-oriented research is used to investigate the causes of observed changes and to better understand the consequences. In this paper, indicators relevant to the status of amphibians are discussed, with reference to a proposed framework for a National Environmental Monitoring Program in Canada.

Résumé

Le suivi environnemental vise à déceler les changements spatiaux et temporels influant sur la répartition et l'abondance des biotes ainsi que sur la qualité de l'air, de l'eau et du sol. Quand des changements sont décelés, on a recours à un type de recherche orientée vers des questions précises en vue de déceler les causes des changements observés et d'en mieux évaluer les conséquences. Le présent rapport traite des indicateurs de la situation des amphibiens, par rapport au cadre de travail conçu aux fins du Programme national de suivi environnemental.

Introduction

In the late 1970s, the Northern Leopard Frog (*Rana pipiens*) suffered a widespread and catastrophic collapse of abundance over much of its range in western Canada. This phenomenon was first observed in Manitoba in 1976, then in Alberta in 1979. There were many local extinctions of the species, and recovery has been slow in many areas.

This biological change was so obviously catastrophic that there is no doubt about the veracity of the population collapse of Northern Leopard Frogs. However, little is known about the environmental context of the phenomenon. Relevant questions are as follows:

(1) Have there been previous diebacks of Northern Leopard Frogs, and, if so, how quickly did the frogs recover? This question is important because there may be a longer-term stability of the population dynamics of Northern Leopard Frogs, in spite of extraordinary dynamics over shorter time periods.

(2) Were there roughly contemporaneous diebacks of Northern Leopard Frogs in other parts of its range? This question is relevant to the broader spatial pattern of the dieback.

(3) What caused the dieback of Northern Leopard Frogs? Were there simultaneous changes in the physical, chemical, or biological environment that could have triggered the population collapse—for example, severe drought or a widespread change in agricultural practices, such as a change in crops, a change in tillage, or introduction of a new pesticide? Or could there have been an epidemic of some amphibian disease, such as red leg?

Some of these questions are relevant to environmental monitoring, and some to research that might be pursued to further investigate changes observed during monitoring programs.

Environmental monitoring is a conceptually simple exercise in which relatively direct hypotheses are investigated with the aim of detecting change over time and space. An ultimate goal of environmental monitoring is to provide information relevant to deteriorations of ecological integrity or of environmental quality. Monitoring is accomplished using indicators, which are surrogates for a complex of related characteristics or processes. Monitoring is performed to detect changes in biota or their environment.

The consequences of monitored changes are evaluated on the basis of a cumulative knowledge of ecological principles, gained from research. Of particular relevance is knowledge of the ecological effects of stress and disturbance (Freedman 1989).

The causes of change are not usually studied during monitoring, in part because they may be multiple or perhaps extrinsic to the monitored ecosystem. However, once change is detected, reasonable hypotheses can be generated regarding the nature of the causal agent, and subsequent research can then explore cause-and-effect relationships. For example, reasonable hypotheses might be erected about the causes of the dieback of Northern Leopard Frogs, and these could then be examined through research in the laboratory and field.

In the following, we describe a framework of a National Environmental Monitoring Program (NEMP) that we have developed for the State of the Environment (SOE) Reporting group of Environment Canada (Shackell and Freedman 1991). We prepared this framework through library research, interviews with scientists involved in environmental monitoring, regional workshops on design of a NEMP that we organized, and our own opinions and experience.

Framework of a National Environmental Monitoring Program

The Canadian system of Ecological Land Classification characterizes terrain on the basis of geology, soil, physical landform, and flora and fauna. The system is hierarchical, ranging in spatial scale from relatively small and detailed ecoelements to much larger ecozones (Anonymous 1982). A Canadian NEMP would be organized by ecozone, of which 15 have been designated for the terrestrial parts of the nation.

The initial stage in application of the framework is to assemble the following information for each ecozone:

(1) a list of important stressors affecting the ecozone, so that relevant monitoring questions can be identified. In the sense used here, stressors are pollutants, pesticides, climatic change, forest harvesting, etc. Stressor indicators are mostly associated with human activities, but they can also include natural sources such as forest fire, hurricanes, volcanic eruption, etc.;

(2) a catalogue of existing, environmental monitoring data bases of provincial, national, and private agencies;

(3) an evaluation of the suitability of existing data bases for SOE reporting. There are many selection criteria. Some prominent ones include a preference for indicators to be regionally representative, from an existing monitoring program, correlated to changes in other ecosystem components, cost effective, technically easy to sample with acceptable error, capable of retrospective analysis and of anticipating future change, capable of being related to target threshold levels, policy oriented, and understandable by the general public (Hunsacker and Carpenter 1990; Shackell and Freedman 1991). It is impossible that a single indicator could fulfill such diverse needs, so a suite of indicators would usually be required to satisfy all selection criteria;

(4) a list of deficiencies in the available information; and

(5) a list of potential indicators to address the information gaps. From this list, operational indicators would be selected for monitoring on the basis of criteria such as those listed above, and monitoring protocols would be developed by teams of experts (Shackell and Freedman 1991).

Two categories of monitoring sites are proposed for each ecozone: intensive sites, with detailed, multi-disciplinary monitoring, and extensive sites, with monitoring of fewer variables but at more sites. Wherever possible, intensive and extensive sites would be located close to existing stations of monitoring networks of air or water quality, to facilitate determination of cause-and-effect relationships among indicators.

Intensive monitoring sites

Intensive monitoring sites would be the locale of integrated, multidisciplinary monitoring and research designed to detect changes in sites along a stress gradient, including:

(1) situations that are relatively unstressed by humans and that provide a regional, ecological reference that monitors the effects of natural stressors such as wildfire, floods, irruptions of defoliating insects, etc., as well as global stressors such as climatic change or stratospheric ozone depletion; and

(2) situations in which controlled, experimental perturbations are designed to examine the ecological effects of agriculture, forestry, or other industrial or management activities.

In addition to their function in detecting change, intensive monitoring sites are used to refine currently used indicators and develop new or better indicators; detect changes in structural and/or functional attributes of monitored ecosystems; and develop predictive models of ecosystem dynamics that would allow for distinction of natural and anthropogenic causes of change.

Intensive monitoring sites would ideally be located in protected situations. Sites monitored to provide reference information should be located in a national park, provincial park, or some other ecological reserve. At each site, measurements would be made of air, soil, and water quality, in addition to diversity, abundance, and productivity of the biota.

It will often be desirable to monitor ecosystems that are relatively mature and stable, so that detected changes most strongly reflect regional or global environmental changes, rather than successional dynamics. This is important because changes due to succession in young ecosystems might overwhelm the incremental effects caused by anthropogenic stressors. However, younger seral stages would be examined when monitoring questions specifically address species that require early-successional habitat.

Ideally, there would be at least three intensive monitoring sites in each ecozone. Although redundancy is expensive, it is necessary to ensure against the catastrophic loss of particular sites. A network of integrated monitoring sites does not yet exist, but a precedent for such a program is the five calibrated watershed sites for acidic deposition research in eastern Canada.

Extensive monitoring sites

Extensive monitoring sites are designed to:

(1) monitor the effects of widespread human activities such as agriculture, forestry, or mining, compared with reference (intensive) sites or with a known historical condition; and

(2) monitor changes in the ecological character of the ecozone, as a result of changes in the nature of land use.

A great deal of relevant information is already available from national and provincial agencies. These routinely collect sectoral data on economically important indicators in order to calculate allowable forest harvests, hunting and fishing limits, etc. Such data are already a major source of information for SOE reporting.

Extensive indicators would be (and are) monitored in permanent sampling sites throughout the ecozone, in various ecosystems (e.g., forests, agroecosystems, wetlands).

Biological indicators could include the productivity, abundance, and diversity of selected species (usually of economic value), whereas nonbiological measurements might include chemical quality of air and water, hydrology, and forest and agricultural site capability.

The number and distribution of extensive sample sites are dependent on the question being asked. For example, endangered Pacific Giant Salamanders (Dicamptodon tenebrosus) need only be sampled in small, cold, cascading streams in southwestern British Columbia, whereas monitoring the response of more widespread amphibians such as Northern Leopard Frog, Wood Frog (*Rana sylvatica*), or Spotted Salamander (*Ambystoma maculatum*) to global warming or some other large-scale change requires much more extensive sampling designs.

In general, extensive sampling sites for amphibians would be preferentially chosen to be close to monitoring stations of air and water quality. Aggregation of indicator measurements is advantageous, because it allows the description of relationships among indicators.

The sampling design of extensive biological monitoring is partially dependent on the particular stressors of interest. Sites in the ecozone will vary in their sensitivity to particular stressors, a feature that can be mapped to portray risks (the technology of Geographic Information Systems [GIS] is especially appropriate for this function). The various sample sites should express a range of sites of low and high sensitivity.

Modelling and interpretation

Modelling is an important aspect of monitoring programs, because it allows the prediction of change at similar sites and/or in the future. It is not possible to monitor all aspects of all ecosystems throughout an ecozone. An important purpose of intensive monitoring sites is to elucidate the complexities of ecosystem structure and function, so that relationships among stressors and biological responses can be examined. That information could then be used to hypothesize relationships at extensive sites, where fewer variables are measured.

For example, it is much easier to extensively measure a decrease in surface water pH caused by acid rain than it is to extensively monitor changes in acid-sensitive amphibian communities. All relevant variables can be measured at intensive sites and their relationships used to predict amphibian responses at comparable extensive sites where only pH is measured. Data from intensive monitoring programs facilitate the development of models by providing initial parameter values and by identifying key variables.

In order to predict a future event, we must have confidence in the existing data series. Important issues are the accuracy and precision of measurement and the calculation of confidence limits. *Accuracy* of measurement is the degree to which the data represent true values. Accuracy can be investigated by using different but reliable methodologies and examining the similarity of the estimates. *Precision* is the repeatability of methodology or the degree to which the same methodology used in other locations or at other times will yield comparable results. Precision can be addressed by repeated measurements of the same variable, using some accurate methodology. *Confidence limits* are calculated for data sets having replicate measurements, in the proper statistical sense.

Some indicators relevant to monitoring of amphibians in Canada

Large-scale changes in the abundance of amphibians in Canadian ecozones could be detected by extensively monitoring a few widespread species. The list of species and the monitoring protocols would be developed by a consensus of experts, and the monitoring would occur at many locations distributed within and among ecozones, where appropriate.

Some examples of widely distributed amphibian species in Canada are Wood Frog, Northern Leopard Frog, Green Frog (*Rana clamitans*), Bullfrog (*Rana catesbeiana*), American Toad (*Bufo americanus*), Canadian Toad (*Bufo hemiophrys*), Spotted Salamander, Tiger Salamander (*Ambystoma tigrinum*), and Redback Salamander (*Plethodon cinereus*).

The monitoring protocols would involve repeated sampling using some reliable and preferably noninvasive census technique. Monitoring would be done using a permanent network of sampling sites. For example, the same set of ponds would be searched each year to determine the species of anurans calling and the numbers of egg masses present, or the same transects of habitat would be traversed to determine an index of anuran abundance by a call census.

Intensive monitoring would occur at far fewer sites and would be intended to study and monitor amphibian autecology and synecology in more detail. Ideally, intensive monitoring would examine all life history stages, not just prominent ones as in extensive monitoring. Where possible, intensive monitoring of amphibians would also involve measures of habitat quality and would be a component of a broader program of integrated monitoring, in which measurements are made relevant to other wildlife, vegetation, and atmospheric, water, and soil quality.

Intensive monitoring would also include research on the effects of anthropogenic stressors on amphibians. This would include longer-term monitoring of the effects of operational or experimental habitat manipulations on amphibians. This could include studies of amphibians in the context of whole-lake or whole-stream acidification experiments or a comparison of the effects of selection-cutting and clear-cutting within streamside riparian zones. In these cases, comparison would always be made with the unperturbed, reference situation.

Monitoring for the status of rare and endangered species of amphibians (or other biota) is a special case. Species such as Blanchard's Cricket Frog (*Acris crepitans blanchardi*), Tailed Frog (*Ascaphus truei*), and Great Basin Spadefoot Toad (*Scaphiopus intermontanus*) would have their own, stratified monitoring programs, with a design appropriate to their ecological requirements and lifestyles. Sampling would be designed to answer species-specific questions, not generic ones related to large-scale amphibian declines.

Summary

Monitoring is conducted to detect changes over time and space in environmental indicators of the distribution and abundance of biota and in the quality of air, water, and soil. Question-oriented research is used to investigate the causes of observed changes and to better understand the consequences.

Indicators relevant to the status of amphibians in Canada could include changes in the distribution and abundance of widespread species, changes in reproductive success and productivity of populations at intensive monitoring sites, longer-term effects of forestry, agriculture, and other anthropogenic stressors on amphibians, and changes in the status of rare and endangered species. Amphibian monitoring should be integrated within a comprehensive environmental monitoring program. This would facilitate the examination of possible relationships between changes in the status of amphibians and changes in other environmental indicators related to pollution, habitat destruction, and climatic change.

Acknowledgements

We are grateful to Richard Wassersug for his insightful comments on a draft of the manuscript. This work was supported in part by a research contract from State of the Environment Reporting, Environment Canada.

Literature cited

Anonymous. 1982. Ecological land survey guidelines for environmental impact analysis. Environmental Conservation Service Task Force, Federal Environmental Assessment and Review Process, Environment Canada, Ottawa.

Freedman, B. 1989. Environmental ecology. Academic Press, San Diego.

Hunsacker, C.T. and D.E. Carpenter (eds.). 1990. Ecological indicators for the Environmental Monitoring and Assessment Program. EPA 600/3-90/060, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, N.C.

Shackell, N. and B. Freedman. 1991. A framework for a National Environmental Monitoring Program. Prepared for State of the Environment Reporting, Environment Canada. School for Resource and Environmental Studies, Dalhousie University, Halifax.

A historical data base of amphibian data and data sources in Canada

Martyn Obbard and Fred Schueler (compilers)

Introduction

Documentation of the historical records on amphibians and reptiles is appropriate given that the Declining Amphibian Populations Task Force established by the World Conservation Union (IUCN) will request such information from each country. This historical information can certainly help to document extirpations; however, the data will be inadequate to document trends within populations.

Tasks

(1) An individual (e.g., provincial coordinator) or institution must accept the task of preparing an account of data sources regarding amphibians and reptiles in its particular geographical area.

(2) Information to be requested:

a. A brief overview of herpetological activity. Descriptions of inventories, expeditions, censuses, species lists, research, etc.

b. Status of information (general)
   (i) Distributional evidence
      - specimens
      - photographs
      - sight records
      - date of collection (...1960s, '70s, '80s, etc.)

   (ii) Inventory/population data
      - quantitative data and date of collection

c. Species accounts
   A detailed account of each species and a statement regarding the quality of the data available. Discuss population trends if hard data are available. If insufficient data are available to discuss trends, then this should be stated. Identify or suggest possible causes if a decline in a population of species is noted.

d. List of sources of data
   Provide a complete list of names and addresses of institutions or individuals from whom data have been collected.

e. Additional data required
   If a change in status is suspected, note whether new information must be collected.

f. Statement of habitat degradation
   A discussion of the loss of classic historical localities or the loss of general wetland or forested areas as it relates to species or communities.

Recommendations

(1) Resampling of sites where there is a reasonable chance of making comparisons, especially where quantitative data or at least some estimates of abundance are available. This is to be accomplished as soon as possible (1992–94); however, this will depend on availability of funding and experienced observers.

(2) Encourage observers in each province to establish a Herpetofaunal Atlas Project for amphibians and reptiles. These projects should include historical data gathering. A computerized data base is essential. The Ontario Herpetofaunal Summary and Canadian Museum of Nature associates will establish a computer data base for all Canadian observations and will begin to accumulate copies of pertinent documents on archival-quality paper. The Canadian Museum of Nature catalogue card files have always been intended to be such a data base and will form the basis around which the computer data base will form. Records and responsibility will devolve to provincial groups as provincial atlases are established.

(3) Encourage retrieval of historical data from sources at risk—for example, older naturalists and data on nonarchival-quality paper—as soon as possible.

Intensive monitoring: biology of amphibians in Canada

Ronald J. Brooks (compiler)

Introduction

It was agreed that "intensive monitoring" should really be termed "research," as monitoring implies only counting animals or recording data, whereas research implies testing of hypotheses and a broader approach.

We agreed to examine:

(1) What? (what to do, which species to examine)

(2) How? (what research methodologies are appropriate)

(3) Who? (who should coordinate studies)

(4) Where? (which sites should be used, based on species distribution, whether sites were being studied at present, long-term protection of sites from disturbance, and logistics, accessibility)

In essence, we devised a list of what should be done, the species that should be studied, and the sites where the studies should be carried out.

What should be done?

(1) The top priority is to obtain basic life history data on selected species using long-term studies. Such data presumably would test for local (e.g., northern latitude) adaptation and provide basic knowledge on body size, age distribution, density, age at maturity, metamorphosis, growth rate, sex ratio, movements, longevity and survivorship, sources of mortality, and specific habitat requirements. Ideally, these basic data should allow construction of life tables, be collected on cohorts of marked individuals, provide useful measures of variance, and be collected over an extended number of years (decades). Without attempting to direct such research, we felt we could recommend that the data be collected to form a quantitative base from which specific hypotheses regarding effects of various factors on amphibian abundance, diversity, and distribution could be tested.

(2) Species (populations) would be selected as preferred subjects for intensive studies based on their potential as indicators of more global change in numbers. We decided that species selection would depend on five criteria (see #5 below).

(3) Site selection was based on species location, researcher location (logistics), and, most important, strong evidence for long-term protection of the site as a relatively undisturbed research venue.

(4) A relationship between intensive and extensive monitoring was deemed important.

(5) Five criteria were used to select species to be investigated. We began by putting all species we thought appropriate into each category. Then we looked at overlap, at which species satisfied more than one criterion, and at special cases and reduced the list to an "essential" list. Below, I list the criteria and the essential species that remained under each criterion after reduction.

a. *Life history*: Representatives of amphibians with larval stages of one year and more than one year; of those that breed in permanent water bodies and those that breed in temporary, vernal ponds; terrestrial and aquatic hibernators; "r"- and "k"-selected species; special cases, e.g., stream dwellers.

Species selected:

Bullfrog (*Rana catesbeiana*)
Green Frog (*R. clamitans*)
Mink Frog (*R. septentrionalis*)
Wood Frog (*R. sylvatica*)
Woodland salamanders (*Plethodon* spp.)
Newts (fam. Salamandridae) (*Notophthalmus* spp.)

b. *Specialized range*: Species that occupy a specialized habitat.

Species selected:

Plains Spadefoot Toad (*Scaphiopus bombifrons*)
Tailed Frog (*Ascaphus truei*)

c. *Taxon*: Representative frogs from each amphibian family occurring in Canada.

Species selected:

Ascaphidae
  Tailed Frog
Pelobatidae
  Plains Spadefoot Toad
Bufonidae
  Fowler's Toad (*Bufo woodhousei fowleri*)
Hylidae
  Gray Treefrog (*Hyla versicolor*)
Ranidae
  Several species (above)
Proteidae
  Mudpuppy (*Necturus maculosus*)
Salamandridae
  newts
Ambystomatidae
  Spotted Salamander (*Ambystoma maculatum*)
Plethodontidae
  Redback Salamander (*Plethodon cinereus*)

d. *Genetic variation*: Some species are known to have considerable genetic variation. These were chosen so that loss of variation due to population declines, bottlenecks, etc., could be detected.

Species selected:

Gray Treefrog
Spotted Salamander

e. *Indicator species*: Species representative of broad ecological tolerance or narrow tolerance.

Species selected:

Broad
Wood Frog (*R. sylvatica*)
Northern Leopard Frog (*R. pipiens*)
Spotted Salamander

Narrow
Fowler's Toad
Plains Spadefoot Toad

Essential list:
Mudpuppy
Spotted Salamander
Redback Salamander
Plains Spadefoot Toad
Fowler's Toad
Tailed Frog
Gray Treefrog
Northern Leopard Frog
Wood Frog
Bullfrog
Green Frog
Mink Frog
Newt sp.

How should it be done?

(1) Establish long-term, protected sites (e.g., in national or provincial parks, nature reserves), especially if these sites had concurrent, long-term collection of data on climatological or other physical data and/or were already the site for ongoing studies of amphibian biology. A potential problem might be resistance to research by park administrators.

(2) Coordination among sites and research personnel should be strongly encouraged and perhaps could be a responsibility of coordinators chosen at the Declines in Amphibian Populations Workshop (see below).

(3) Methods were beyond the scope of our discussion. However, we agreed that it would be desirable if there could be a description of preferred, standard methods for sampling of abundance of various life history stages (tadpoles, juveniles, adults, breeding groups) that could be applied by different researchers, at least for a given species.

By whom should it be done?

A joint committee of coordinators will try to coordinate field life history studies on amphibians for Canada and perhaps draw up a list of priority information, methods, etc. These coordinators are: Francis Cook, David Green, Michael Berrill, and Ron Brooks. Ron Brooks and Francis Cook will initiate this process. Research personnel was beyond the scope of our discussion.

Where should it be done?

(1) We selected seven protected sites at which studies on amphibians are currently under way. These were (approximate number of essential species common at each site is given in parentheses):

a. Mastigouche, Quebec (4)
b. Long Point, Ontario (4)
c. Lake Cowichan, British Columbia (3)
d. Lac St. Pierre, Quebec (3)
e. Kejimkujik Park, Nova Scotia (3–4)
f. Algonquin Park, Ontario (8)
g. Queen's University Biological Station, Opinicon, Ontario (6)

(2) Four areas were selected in which work is not ongoing but that contained essential species:

a. Delta Marsh, Manitoba—Northern Leopard Frog
b. Writing-on-stone, Alberta—Spadefoot Toad
c. Southern British Columbia—Tailed Frog
d. Lake Erie or St. Lawrence River (Ontario, Quebec)—Mudpuppy

(3) Four other sites in which research is being or will be conducted on amphibians but that are not protected (approximate number of species in parentheses):

a. Kawartha Lakes, Ontario (8)
b. Hudson Bay, Quebec (1)
c. Haliburton, Ontario (7)
d. Cypress Hills, Alberta (1–2)

Conclusion

These intensive study sites are unlikely to reveal a decline, global or otherwise, within the next three years or to uncover a cause for such decline, if a decline exists. These studies should establish a long-term data base on the essential species. This data base will form a structure to test hypotheses on the effects of various factors on amphibian populations in Canada and elsewhere. At present, quantitative data on Canadian amphibian life history and long-term changes in abundance are virtually nonexistent.

Extensive monitoring: amphibian populations in Canada

Christine A. Bishop and Douglas F. Kay (compilers)

Two primary questions to answer when defining a monitoring strategy

(1) What species should be monitored?

(2) How should the species be monitored?

Extensive monitoring objectives

(1) Identify changes in abundance and diversity.

(2) Develop and maintain a robust data set.

The ideal monitoring scenario

The ideal monitoring scenario would entail the following:

(1) quantitative data for all amphibian species across Canada

(2) perennial survey

(3) presence/absence of each species confirmed at each sample site

(4) quantified population changes

(5) many sample sites, with replicate sites in each ecozone of Canada

(6) seasonal sampling

(7) confirm all life stages, especially larval, adult

(8) many volunteers/labourers

(9) unlimited funding

The minimum scenario to fulfill objectives

What species should be monitored?

Census only indicator and/or declining species. The species that were designated as being of special interest in the intensive monitoring protocol are to be censused at the extensive monitoring sites. Extensive sampling surveys should be incorporated for all of those species. However, in roadside listening surveys and at permanent pond surveys (see below), other species will be noted when seen or heard, although sampling methodologies for species other than those of special interest would not be included.

How should the species be monitored?

(1) Survey sites

a. Singing males by abundance class
   - census performed at fixed, permanent sites along transects (e.g., roadsides along the same survey routes used by Breeding Bird Survey across Canada)
   - same survey route used by (preferably) the same census person over a long period (e.g., 10 years or more)
   - this information will indicate gross changes in abundance
   - this type of survey could be performed by trained, volunteer naturalists

b. Permanent pond survey
   - more detailed information can be collected at these sites (e.g., number of egg masses, larvae, adults, as well as singing male surveys)
   - this information will indicate gross changes and some quantifiable data, such as hatching success, population size and/or density

Song survey routes and permanent pond survey sites should be visited several times in a year (e.g., during calling period, egg laying, and approximate end of larval development). Surveys should be as noninvasive as possible. These types of surveys will require the skills of professional herpetologists or very knowledgeable, amateur (volunteer) naturalists.

It is not the intention of this report to describe the details of the protocols for each of the above surveys. That information will be available (see McDiarmid, this volume) to the Canadian Working Group on Declining Amphibian Populations. The national and provincial coordinators will define the specific protocols suitable for various ecozones in Canada before extensive monitoring surveys are initiated. These recommendations are meant to provide general direction on the types of techniques that would be suitable for a nationwide survey.

(2) Habitats where monitoring should take place

Surveys should be conducted in the following habitat types, as they have been recognized as habitats

where amphibians are known to breed or to forage.
Replicate sampling sites in the same habitats are critical.

a. Terrestrial habitats
   - interface
      ephemeral ponds
         mesic (forest)
         xeric (semiarid)
      seepage
   - forest floor
      hardwood
      mixed wood
      conifer
   - prairies
      savannah
      tall/short

b. Aquatic habitats
   - riparian
   - wetland
      fen
      bog
      marsh
      swamp
   - open water
      lakes
      oligotrophic
      mesotrophic
   - streams
   - ponds

Intensive and extensive monitoring of anthropogenic stresses associated with amphibian survivorship

Christine A. Bishop (compiler)

Introduction

There is a recognized need to measure, in the field, certain factors that are known or suspected to have negative effects on amphibian survivorship at the same time that, and in the same places where, intensive monitoring and extensive monitoring are performed. There is also a great need for more research in controlled laboratory settings and in the field to quantify the effects of these factors on amphibians. Therefore, it was recommended in both the intensive and extensive monitoring groups and by individuals (see parentheses below) that efforts be made to initiate more research and to collect field data concerning (at least) the following parameters at intensive monitoring sites and at as many extensive monitoring sites as possible where these factors may be important.

Precipitation (seasonal and yearly)	(McDiarmid)
Maximum/minimum daily temperature	(McDiarmid)
pH	(Clark)
Lowest summer soil moisture	(Herman and Scott)
Snow and ice cover	(Herman and Scott)
Minimum winter temperature	(Herman and Scott)
Winter stream flow	(Herman and Scott)
Dissolved oxygen	(Herman and Scott)
Diseases (when symptoms develop)	(Crawshaw)
Pesticides	(Bishop)
Habitat changes (historical versus current and future habitat, where possible)[1]	(Johnson)
Pesticides (in water or sediment, on a case-by-case basis)	(Bishop)
Ultraviolet radiation	
Conductivity	
Water levels	
Chlorophyll a	
Calcium concentration	(Clark)
Aluminum concentration	(Clark)
Dissolved organic carbon concentration	(Clark)
Sodium concentration	(Clark)
Magnesium concentration	(Clark)
Potassium concentration	(Clark)
Sulphate concentration	(Clark)
Nitrate concentration	(Clark)

There is a need to initiate more research to investigate the effects of anthropogenic stresses on amphibian populations—for example:

Logging practices
Pesticide use
Nutrient and sediment loading from urban and agricultural runoff
Introduction of exotic species
Introduction of native predatory fish into areas where these fish species historically did not occur or occurred at low densities
Amphibian population survey methods
Commercial harvesting of amphibians
Disease (how and why do outbreaks occur?)
Drought/irrigation practices

Although this may appear to suggest that everything and anything needs to be monitored when and where amphibian monitoring is performed, that is not the intent. (On the other hand, very little study has been made on any of these topics, so the list is justifiably long.) Certainly, some basic limnological parameters of breeding ponds/lakes, etc., should be measured in addition to pH at all intensive monitoring sites. Ideally, in areas designated for study of habitat changes in the extensive monitoring sites, complementary water quality data should also be collected. In areas where specific concerns about, for example, disease, pesticides, turbidity, and nutrient loading exist, these types of measurements should be taken, or the impacts of these stresses should receive intensive study.

[1] Different habitats and changes in habitats or land use might be monitored in different ecoregions of Canada— for example, agricultural, semiurban, grassland, sloughs, boreal forest.

APPENDIX A:

List of workshop participants

Gary Allen
Ontario Ministry of Natural Resources
P.O. Box 706
Simcoe, Ontario
N3Y 4T2
(519) 426-7650
(519) 426-6041 fax

Michael Berrill
Department of Biology
Trent University
Peterborough, Ontario
K9J 7B8
(705) 748-1455
(705) 748-1649 fax

Susan Bertram
Watershed Ecosystems Graduate Program
Trent University
Peterborough, Ontario
K9J 7B8
(705) 748-1649 fax

Christine A. Bishop
Canadian Wildlife Service (Ontario Region)
Canada Centre for Inland Waters
P.O. Box 5050, 867 Lakeshore Road
Burlington, Ontario
L7R 4A6
(416) 336-4968
(416) 336-6434 fax

Peter Blancher
National Wildlife Research Centre
Canadian Wildlife Service
100 Gamelin Boulevard
Hull, Quebec
K1A 0H3
(819) 997-6086
(819) 953-6612 fax

Michelle Bobyn
Department of Zoology
University of Guelph
Guelph, Ontario
N1E 2W1
(519) 824-4120, Ext. 3944
(519) 767-1656 fax

James P. Bogart
Department of Zoology
University of Guelph
Guelph, Ontario
N1G 2W1
(519) 824-4120, Ext. 8728
(519) 767-1656 fax

Joël Bonin
Société d'histoire naturelle de la vallée du St-Laurent
21,111, Bord-du-lac
Sainte-Anne-de-Bellevue, Quebec
H9X 1C0
(514) 457-8702

Deneen Brigham
5 – 228 Ontario Street
Thunder Bay, Ontario
P7B 3G8
(807) 345-7784

Ronald J. Brooks
Department of Zoology
University of Guelph
Guelph, Ontario
N1G 2W1
(519) 824-4120, Ext. 3944
(519) 767-1656 fax

Mary Burridge
Department of Ichthyology and Herpetology
Royal Ontario Museum
100 Queen's Park
Toronto, Ontario
M5S 2C6
(416) 586-5759
(416) 586-5763 fax

Victoria Campbell
Department of Biology
Trent University
Peterborough, Ontario
K9J 7B8

Peter J. Carson
R.R. #1
Walsingham, Ontario
N0E 1X0
(519) 586-3985
c/o Long Point Bird Observatory (519) 586-3532 fax

Karen L. Clark
Biota Environmental Contractors
P.O. Box 21
Dorset, Ontario
P0A 1E0
(705) 766-9549

Francis R. Cook
Curator of Herpetology
Canadian Museum of Nature
P.O. Box 3443, Station D
Ottawa, Ontario
K1P 6P4
(819) 953-6045
(819) 953-6220 fax

Wanda Cook
92B Waterloo Avenue
Guelph, Ontario
N1H 3H8
(519) 821-2638
(519) 767-1656 fax

Graham J. Crawshaw
Metropolitan Toronto Zoo
P.O. Box 280
West Hill, Ontario
M1E 4R5
(416) 392-5977
(416) 392-4979 fax

Ted Davis
Department of Biology
University of Victoria
P.O. Box 1700
Victoria, British Columbia
V8W 2Y2
(604) 721-8099
(604) 721-7120 fax

Karen Ditz
Department of Ichthyology and Herpetology
Royal Ontario Museum
100 Queen's Park
Toronto, Ontario
M5S 2C6
(416) 586-5759
(416) 586-5763 fax

Garry L. Fletcher
L.B. Pearson College
R.R. #1
Victoria, British Columbia
V8X 1U9

Dina Foscarini
Department of Zoology
University of Guelph
Guelph, Ontario
N1E 2W1
(519) 824-4120, Ext. 3944
(519) 767-1656 fax

William Freedman
Department of Biology
Dalhousie University
Halifax, Nova Scotia
B3H 4J1
(902) 494-3737
(902) 494-3736 fax

Mary E. Gartshore
R.R. #1
Walsingham, Ontario
N0E 1X0
(519) 586-3985
c/o Long Point Bird Observatory (519) 586-3532 fax

John Gilhen
Natural History Section
Nova Scotia Museum
1747 Summer Street
Halifax, Nova Scotia
B3H 3A6
(902) 424-7370
(902) 424-0560 fax

Karen Grant
Department of Biology
York University, Rm. 247, Farquharson Building
4700 Keele Street
North York, Ontario
M3J 1P3
(416) 736-2100, Ext. 33583

David M. Green
Redpath Museum
McGill University
859 Sherbrooke Street West
Montreal, Quebec
H3A 2K6
(514) 398-4088
(514) 398-3594 fax

T.B. Herman
Department of Biology
Acadia University
Wolfville, Nova Scotia
B0P 1X0
(902) 542-2201, Ext. 469
(902) 542-3466 fax

John Howden
224 Lee Avenue
Whitby, Ontario
L1N 5L3
(416) 668-8764
(416) 428-0584 fax

Bob Johnson
Curator of Amphibians and Reptiles
Metropolitan Toronto Zoo
P.O. Box 280
West Hill, Ontario
M1E 4R5
(416) 392-5900
(416) 392-5934 fax

Henrich Kaiser
Redpath Museum
McGill University
859 Sherbrooke Street West
Montreal, Quebec
H3A 2K6
(514) 398-4088

Doug Kay
193 Hatt Street
Dundas, Ontario
L9H 2G7
(416) 628-1072

Mark Kolohon
Department of Biology
Trent University
Peterborough, Ontario
K9J 7B8

William Koonz
Wildlife Branch
Manitoba Department of Natural Resources
P.O. Box 14, 1495 St. James Street
Winnipeg, Manitoba
R3H 0W9
(204) 945-6811
(204) 945-3077 fax

Karen Lampman
c/o Cumming Cockburn Ltd.
180 Columbia Street West
Waterloo, Ontario
N2L 3L3
(519) 885-5440
(519) 885-3959 fax

Raymond Leclair, Jr.
Departement de Chimie-Biologie
Université du Québec à Trois-Rivières
C.P. 500
Trois-Rivières, Québec
G9A 5H7
(819) 376-5053
(819) 376-5012 fax

Lawrence E. Licht
Department of Biology
York University
4700 Keele Street
Downsview, Ontario
M3J 1P3
(416) 763-2100, Ext. 33583

Les Lowcock
Department of Ichthyology and Herpetology
Royal Ontario Museum
100 Queen's Park
Toronto, Ontario
M5S 2C6
(416) 586-5760
(416) 586-5763 fax

Malcomb MacCartney
729 5th Street East
Saskatoon, Saskatchewan
S7H 1G6
(306) 665-6288

Ross MacCulloch
Department of Ichthyology and Herpetology
Royal Ontario Museum
100 Queen's Park
Toronto, Ontario
M5S 2C6
(416) 586-5760
(416) 586-5863 fax

Nancy Mahony
703 – 16 Wilsonview Avenue
Guelph, Ontario
N1G 1V4
(519) 767-0417

Tom Mason
Metropolitan Toronto Zoo
P.O. Box 280
West Hill, Ontario
M1E 4R5
(416) 392-5900
(416) 392-5934 fax

Donald F. McAlpine
Natural Sciences Division
New Brunswick Museum
277 Douglas Avenue
Saint John, New Brunswick
E2K 1E5
(506) 658-1842
(506) 658-1842 fax

Roy W. McDiarmid
Biological Survey
U.S. Fish and Wildlife Service
National Museum of Natural History
Smithsonian Institution
Washington, D.C. 20560
(202) 357-2780
(202) 357-1932 fax

Lise McGillivray
Department of Biology
Trent University
Peterborough, Ontario
K9J 7B8

Ken McIlwrick
c/o Brenda Axon
Halton Region Conservation Authority
2596 Britannia Road West
Burlington, Ontario
L7P 3S9
(416) 336-1158
(416) 336-7014 fax

Margaret McLaren
Wildlife Policy Branch
Ontario Ministry of Natural Resources
90 Sheppard Avenue East
North York, Ontario
M2N 8A1
(416) 314-1054
(416) 314-1049 fax

James McLister
Department of Zoology
University of Guelph
Guelph, Ontario
N1G 2W1
(519) 824-4120, Ext. 6418
(519) 767-1656 fax

Robert W. Murphy
Department of Ichthyology and Herpetology
Royal Ontario Museum
100 Queen's Park
Toronto, Ontario
M5S 2C6
(416) 586-5759
(416) 586-5863 fax

Martyn E. Obbard
Wildlife Research Section
Ontario Ministry of Natural Resources
P.O. Box 5000
Maple, Ontario
L6A 1S9
(416) 832-7132
(416) 832-7149 fax

Michael J. Oldham
Ontario Ministry of Natural Resources
Aylmer District
353 Talbot Street West
Aylmer, Ontario
N5H 2S8
(519) 773-9241
(519) 773-9014 fax

Stan A. Orchard
Nearctic Zoophiles Inc.
27 – 2891 Craigowan Road
Victoria, British Columbia
V9B 1M9
(604) 386-7510

Kristina Ovaska
Department of Biology
University of Victoria
P.O. Box 1700
Victoria, British Columbia
V8W 2Y2

Bruce Pauli
National Wildlife Research Centre
Canadian Wildlife Service
100 Gamelin Boulevard
Hull, Quebec
K1A 0H3
(819) 953-2634
(819) 953-6612 fax

Karen Pettit
Pettit-Kay Biological Consultants
193 Hatt Street
Dundas, Ontario
L9H 2G7
(416) 628-1072
(416) 336-6434 fax

Mike Rankin
Herpetology, Macoun Centre
Canadian Museum of Nature
P.O. Box 3443, Station D
Ottawa, Ontario
K1P 6P4
(819) 953-8524

Leslie Rye
Department of Zoology
University of Guelph
Guelph, Ontario
N1G 2W1
(416) 824-4120, Ext. 8968
(519) 767-1656 fax

Frederick W. Schueler
Bishops Mills, R.R. #2
Oxford Station, Ontario
K0G 1T0
(613) 258-3107

Carolyn N.L. Seburn
Department of Zoology
University of Alberta
Edmonton, Alberta
T6G 2E9
(403) 454-6629 fax

Tim Sharbel
Redpath Museum
McGill University
859 Sherbrooke Street West
Montreal, Quebec
H3A 2K6
(514) 398-4088

Murray Sindall
Canadian Wildlife Service
Canada Centre for Inland Waters
P.O. Box 5050, 867 Lakeshore Road
Burlington, Ontario
L7R 4A6
(416) 336-4968
(416) 336-6434 fax

Sue Sutton
1519 – 51 Alexander Street
Toronto, Ontario
M4Y 1B3
(416) 968-1054
(416) 778-5073 fax

Alison Taylor
1105 – 1530 Rue Dr. Penfield
Montreal, Quebec
H3G 1C1
(514) 931-0441

H.P. Boxton Tosswill
R.R. #1
Bethany, Ontario
L0A 1A0
(705) 277-2766

Pat Tosswill
Department of Biology
Trent University
Peterborough, Ontario
K9J 7B8

James L. Vial
Coordinator of IUCN/SSC Declining Amphibians
Populations Task Force
c/o Center for Analysis of Environmental Change
200 South West 35th Street
Corvallis, Oregon 97333
(503) 757-4798
(503) 757-4799 fax

Richard Wassersug
Department of Anatomy
Dalhousie University
Sir Charles Tupper Building
Halifax, Nova Scotia
B3H 4H7
(902) 494-2244
(902) 494-3750 fax

Wayne F. Weller
Suite 504, 66 High Street East
Mississauga, Ontario
L5H 2H5
(416) 274-0914
(416) 590-2566 fax

Clifford Zeyl
Redpath Museum
McGill University
859 Sherbrooke Street West
Montreal, Quebec
H3A 2K6
(514) 398-4088

Barbara L. Zimmerman
348 Hillsdale Avenue
Toronto, Ontario
M4S 1T8
(416) 487-0879
(416) 982-7121 fax

Chris A. Zoladeski
895 Maple Avenue, Unit 217
Burlington, Ontario
L7S 2H7
(416) 637-1760

APPENDIX B

Canadian Working Group on Declining Amphibian Populations

The following is a list of people who volunteered to participate as coordinators for the Canadian Working Group on Declining Amphibian Populations. Addresses for most of the coordinators are available in the list of workshop participants (Appendix A).

Task Force Coordinator for Canada
David Green
Redpath Museum, McGill University, Montreal

Western Canada
Stan Orchard
Nearctic Zoophiles Inc., Victoria

Eastern Canada
Don McAlpine
New Brunswick Museum, Saint John

British Columbia
Stan Orchard
Nearctic Zoophiles Inc., Victoria

Alberta
Larry Powell[1]
University of Calgary, Calgary

Saskatchewan
Andy Didiuk[2]
Canadian Wildlife Service, Saskatoon

Northwest Territories
Mike Fournier[3]
Canadian Wildlife Service, Yellowknife

Manitoba
Bill Koonz
Manitoba Department of Natural Resources, Winnipeg

Ontario
Mike Oldham
Ontario Ministry of Natural Resources, Aylmer

Wayne Weller
c/o Mike Oldham
Ontario Ministry of Natural Resources, Aylmer

Quebec
Joël Bonin
Société d'histoire naturelle de la vallée du St-Laurent, Sainte-Anne-de-Bellevue

Roger Bider[4]
Macdonald Campus, McGill University, Sainte-Anne-de-Bellevue

New Brunswick
Don McAlpine
New Brunswick Museum, Saint John

Nova Scotia
John Gilhen
Nova Scotia Museum, Halifax

Prince Edward Island
Rosemary Curley[5]
P.E.I. Department of the Environment, Charlottetown

Newfoundland and Labrador
John Maunder[6]
Newfoundland Museum, St. John's

Representative for Canada on IUCN Task Force on Declines in Amphibian Populations
Bob Johnson
Metropolitan Toronto Zoo, West Hill, Ont.

Environmental contaminants
Christine Bishop
Canadian Wildlife Service, Burlington, Ont.

[1] 2500 University Drive NW, Calgary, Alta. T2N 1N4. Phone: 403-220-7258. Fax: 403-289-9311.
[2] 115 Perimeter Rd. S., Saskatoon, Sask. S7N 0X4. Phone: 306-975-4005 or -4087.
[3] Box 637, Yellowknife, N.W.T. X1A 2N5. Phone: 403-920-8530.
[4] 21–111 Lakeshore Road, Sainte-Anne-de-Bellevue, Que. H9X 1C0. Phone: 514-398-7934. Fax: 514-398-7983.
[5] P.O. Box 2000, Charlottetown, P.E.I. C1A 7N8. Phone: 902-368-4807. Fax: 902-368-5471
[6] 283 Duckworth St., St. John's, Nfld. A1C 1G9. Phone:709-729-5077 or -2460. Fax: 709-729-2179.

Other publications in the Occasional Papers series

No. 1
Birds protected in Canada under the Migratory Birds Convention Act/Oiseaux protégés au Canada en vertu de la Loi concernant les oiseaux migrateurs. 1991 edition. Bilingual.
Cat. No. CW69-1/1-1991.
No. 2
Canadian bird names, French, English and scientific. Bilingual.
Cat. No. CW69-1/2. Publ. 1957, rev. 1972.
No. 3
Use of aerial surveys by the Canadian Wildlife Service, by D.A. Benson. Out of print.
Cat. No. CW69-1/3. Publ. 1963, repr. 1966.
No. 4
Queen Elizabeth Islands game survey, 1961, by J.S. Tener.
Cat. No. CW69-1/4. Publ. 1963, repr. 1972.
No. 5
Age determination in the polar bears, by T.H. Manning.
Cat. No. CW69-1/5. Publ. 1964, repr. 1973.
No. 6
A wildlife biologist looks at sampling, data processing and computers, by D.A. Benson. Out of print.
Cat. No. R69-1/6. Publ. 1964.
No. 7
A preliminary report on the effects of phosphamidon on bird populations in New Brunswick, by C.D. Fowle. Out of print.
Cat. No. R69-1/7. Publ. 1965.
No. 8
Birds of Nova Scotia–New Brunswick border region, by G.F. Boyer.
Cat. No. CW69-1/8. Publ. 1966, repr. 1981.
No. 9
Effects of dietary methylmercury on Ring-necked Pheasants, with special reference to reproduction, by N. Fimreite.
Cat. No. R69-1/9. Publ. 1971.
No. 10
Trends in populations of barren-ground caribou over the last two decades: a re-evaluation of the evidence, by G.R. Parker.
Cat. No. CW69-1/10. Publ. 1971, repr. 1972.
No. 11
The Canada migratory game bird hunting permit and related surveys, by D.A. Benson.
Cat. No. R69-1/11. Publ. 1971.
No. 12
Observations on duck hunting in eastern Canada in 1968 and 1969, by H. Boyd.
Cat. No. R69-1/12. Publ. 1971.
No. 13
Evaluation of ecological effects of recent low water levels in the Peace-Athabasca Delta, by H.J. Dirschl.
Cat. No. CW6-1/13. Publ. 1972.
No. 14
The Great Cormorants of eastern Canada, by A.J. Erskine.
Cat. No. CW69-1/14. Publ. 1972.
No. 15
Distribution of barren-ground caribou harvest in north-central Canada, by G.R. Parker.
Cat. No. CW69-1/15. Publ. 1972.
No. 16
Bird migration forecasts for military air operations, by H. Blokpoel.
Cat. No. CW69-1/16. Publ. 1973.
No. 17
Waterfowl populations on the Peace-Athabasca Delta, 1969 and 1970, by D.J. Neiman and H.J. Dirschl.
Cat. No. CW69-1/17. Publ. 1973.
No. 18
Gammarus predation and the possible effects of *Gammarus* and *Chaoborus* feeding on the zooplankton composition in some small lakes and ponds in western Canada, by R.S. Anderson and L.G. Raasveldt.
Cat. No. CW69-1/18. Publ. 1974.
No. 19
A summary of DDE and PCB determinations in Canadian birds, 1969 to 1972, by M. Gilbertson and L. Reynolds.
Cat. No. CW69-1/19. Publ. 1974.
No. 20
Development of a simulation model of Mallard Duck populations, by C.J. Walters, R. Hilborn, E. Oguss, R.M. Peterman and J.M. Stander.
Cat. No. CW69-1/20. Publ. 1974.
No. 21
Use of museum specimens in toxic chemical research, by A.M. Rick.
Cat. No. CW69-1/21. Publ. 1975.
No. 22
Impoundments for waterfowl, by W.R. Whitman.
Cat. No. CW69-1/22. Publ. 1976.
No. 23
Minimizing the dangers of nesting studies to raptors and other sensitive species, by R.W. Fyfe and R.R. Olendorff.
Cat. No. CW69-1/23. Publ. 1976.
No. 24
Waterfowl damage to Canadian grain: current problems and research needs, by L.G. Sugden.
Cat. No. CW69-1/24. Publ. 1976.
No. 25
Census techniques for seabirds of arctic and eastern Canada, by D.N. Nettleship.
Cat. No. CW69-1/25. Publ. 1976.
No. 26
The present status of the polar bear in James Bay and Belcher Islands area, by Charles Jonkel, Pauline Smith, Ian Stirling and George B. Kolenosky.
Cat. No. CW69-1/26. Publ. 1976.
No. 27
Limnological and planktonic studies in the Waterton Lakes, Alberta, by R. Stewart Anderson and Roderick B. Green.
Cat. No. CW69-1/27. Publ. 1976.
No. 28
Birds and mammals of the Belcher, Sleeper, Ottawa, and King George Islands, Northwest Territories, by T.H. Manning.
Cat. No. CW69-1/28. Publ. 1976.
No. 29
Developments in PPS sampling — Impact on current research, by A.R. Sen.
Cat. No. CW69-1/29. Publ. 1976.

No. 30
Dynamics of snowshoe hare populations in the Maritime Provinces, by Thomas J. Wood and Stanley A. Munroe.
Cat. No. CW69-1/30. Publ. 1977.
No. 31
Migration and population dynamics of the Peace-Athabasca Delta goldeye population, by D.B. Donald and A.H. Kooyman.
Cat. No. CW69-1/31. Publ. 1977.
No. 32
The effects of fire on the ecology of the Boreal Forest, with particular reference to the Canadian north; a review and selected bibliography, by John P. Kelsall, E.S. Telfer and Thomas D. Wright.
Cat. No. CW69-1/32. Publ. 1977.
No. 33
The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay, by Ian Stirling, Charles Jonkel, Pauline Smith, Richard Robertson and Dale Cross.
Cat. No. CW69-1/33. Publ. 1977.
No. 34
Canvasback habitat use and production in Saskatchewan parklands, by Lawson G. Sugden.
Cat. No. CW69-1/34. Publ. 1978.
No. 35
The diets of muskoxen and Peary caribou on some islands of the Canadian High Arctic, by Gerald R. Parker.
Cat. No. CW69-1/35. Publ. 1978.
No. 36
Observations of Mallards in the parkland of Alberta, by Michael F. Sorensen.
Cat. No. CW69-1/36. Publ. 1978.
No. 37
The wildlife valuation problem: A critical review of economic approaches, by William A. Langford and Donald J. Cocheba.
Cat. No. CW69-1/37. Publ. 1978.
No. 38
Spatial changes in waterfowl habitat, 1964–74, on two land types in the Manitoba Newdale Plain, by G.D. Adams and G.G. Gentle.
Cat. No. CW69-1/38. Publ. 1978.
No. 39
Patterns of pelagic distribution of seabirds in western Lancaster Sound and Barrow Strait, Northwest Territories, in August and September 1976, by D.N. Nettleship and A.J. Gaston.
Cat. No. CW69-1/39. Publ. 1978.
No. 40
Responses of Peary caribou and muskoxen to turbo-helicopter harassment, Prince of Wales Island, Northwest Territories, by Frank L. Miller and Anne Gunn.
Cat. No. CW69-1/40. Publ. 1979.
No. 41
Avian community structure of six forest stands in La Mauricie National Park, Quebec, by J.-L. DesGranges. Disponible également en français.
Cat. No. CW69-1/41E. Publ. 1979.
No. 42
Population ecology studies of the polar bear in northern Labrador, by Ian Stirling and H.P.L. Kiliaan. Disponible également en français.
Cat. No. CW69-1/42E. Publ. 1980.
No. 43
Census methods for murres, *Uria* species; a unified approach, by T.R. Birkhead and D.N. Nettleship. Disponible également en français.
Cat. No. CW69-1/43E. Publ. 1980.
No. 44
Population ecology studies of the polar bear in the area of southeastern Baffin Island, by Ian Stirling, Wendy Calvert, and Dennis Andriashek. Disponible également en français.
Cat. No. CW69-1/44E. Publ. 1980.
No. 45
Polynyas in the Canadian Arctic, by Ian Stirling and Holly Cleator, eds. Disponible également en français.
Cat. No. CW69-1/45E. Publ. 1981.
No. 46
The Lesser Snow Geese of the eastern Canadian Arctic, by H. Boyd, G.E.J. Smith, and F.G. Cooch. Disponible également en français.
Cat. No. CW69-1/46E. Publ. 1982.
No. 47
The distribution and abundance of seals in the eastern Beaufort Sea, 1974–79, by Ian Stirling, Michael Kingsley, and Wendy Calvert. Disponible également en français.
Cat. No. CW69-1/47E. Publ. 1982.
No. 48
Foraging behaviour of Peary caribou in response to springtime snow and ice conditions, by F.L. Miller, E.J. Edmonds, and A. Gunn. Disponible également en français.
Cat. No. CW69-1/48E. Publ. 1982.
No. 49
A review of some important techniques in sampling wildlife, by A.R. Sen. Disponible également en français.
Cat. No. CW69-1/49E. Publ. 1982.
No. 50
Intensive regulation of duck hunting in North America: its purpose and achievements, by Hugh Boyd. Disponible également en français.
Cat. No. CW69-1/50E. Publ. 1983.
No. 51
Human dimensions of migratory game-bird hunting in Canada, by Shane A.D. Parker and Fern L. Filion. Disponible également en français.
Cat. No. CW69-1/51E. Publ. 1984.
No. 52
Components of hunting mortality in ducks, by G.S. Hochbaum and C.J. Walters. Disponible également en français.
Cat. No. CW69-1/52E. Publ. 1984.
No. 53
The interpretation of aerial surveys for seabirds: some effects of behaviour, by A.J. Gaston and G.E.J. Smith. Disponible également en français.
Cat. No. CW69-1/53E. Publ. 1984.
No. 54
Waterfowl studies in Ontario, 1973–81, by S.G. Curtis, D.G. Dennis, and H. Boyd, eds. Disponible également en français.
Cat. No. CW69-1/54E. Publ. 1985.
No. 55
The reported kill of ducks and geese in Canada and the USA, 1974–82, by Hugh Boyd. Disponible également en français.
Cat. No. CW69-1/55E. Publ. 1985.
No. 56
Population dynamics of the Common Loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario, by J.F. Barr. Disponible également en français.
Cat. No. CW69-1/56E. Publ. 1986.
No. 57
The Ring-billed Gull in Ontario: a review of a new problem species, by H. Blokpoel and G.D. Tessier. Disponible également en français.
Cat. No. CW69-1/57E. Publ. 1986.
No. 58
The birds of the Creston Valley and southeastern British Columbia, by R.W. Butler, B.G. Stushnoff, and E. McMackin. Disponsible également en français.
Cat. No. CW69-1/58E. Publ. 1986.
No. 59
Estimating densities of birds at sea and the proportion in flight from counts made on transects of indefinite width, by A.J. Gaston, B.T. Collins, and A.W. Diamond. Disponible également en français.
Cat. No. CW69-1/59E. Publ. 1987.
No. 60
Waterfowl breeding population surveys, Atlantic Provinces, by A.J. Erskine, ed. Disponible également en français.
Cat. No. CW69-1/60E. Publ. 1987.
No. 61
A survey of Lesser Snow Geese on Southampton and Baffin islands, NWT, 1979, by A. Reed, P. Dupuis, and G.E.J. Smith. Disponible également en français.
Cat. No. CW69-1/61E. Publ. 1987.
No. 62
Studies of the effects of acidification on aquatic wildlife in Canada: waterfowl and trophic relationships in small lakes in northern Ontario, by D.K. McNicol, B.E. Bendell, and R.K. Ross. Disponible également en français.
Cat. No. CW69-1/62E. Publ. 1987.
No. 63
Bison ecology in relation to agricultural development in the Slave River lowlands, NWT, by H.W. Reynolds and A.W.L. Hawley, eds.
Cat. No. CW69-1/63E. Publ. 1987.
No. 64
A simulation model for the Greater Snow Goose population, by J. Gauvin and A. Reed. Disponible également en français.
Cat. No. CW69-1/64E. Publ. 1987.
No. 65
The birds of the Fraser River delta: populations, ecology and international significance, by Robert W. Butler and R.Wayne Campbell.
Cat. No. CW69-1/65E. Publ. 1987.

No. 66
Mortality of migratory barren-ground caribou on the calving grounds of the Beverly herd, Northwest Territories, 1981–83, by Frank L. Miller, Eric Broughton, and Anne Gunn.
Cat. No. CW69-1/66E. Publ. 1988.
No. 67
Studies of the effects of acidification on aquatic wildlife in Canada: Lacustrine birds and their habitats in Quebec, by Jean-Luc DesGranges, ed. Disponible également en français.
Cat. No. CW69-1/67E. Publ. 1989.
No. 68
Studies of high-latitude seabirds. 1. Behavioural, energetic, and oceanographic aspects of seabird feeding ecology, by W.A. Montevecchi and A.J. Gaston, eds.
Cat. No. CW69-1/68E. Publ. 1991.
No. 69
Studies of high-latitude seabirds. 2. Conservation biology of Thick-billed Murres in the Northwest Atlantic, by A.J. Gaston and R.D. Elliot, eds.
Cat. No. CW69-1/69E. Publ. 1991.
No. 70
Habitats of the northeast coast of James Bay, by N. Dignard, R. Lalumière, A. Reed, and M. Julien. Disponible également en français.
Cat. No. CW69-1/70E. Publ. 1991.
No. 71
Key migratory bird terrestrial habitat sites in the Northwest Territories (2nd edition), by Stuart A. Alexander, Robert S. Ferguson, and Kevin J. McCormick.
Cat. No. CW69-1/71E. Publ. 1991.
No. 72
Atlas of pelagic birds of western Canada, by K.H. Morgan, K. Vermeer, and R.W. McKelvey.
Cat. No. CW69-1/72E. Publ. 1991.
No. 73
The Red-throated Loon as an indicator of environmental quality, by D. Lynne Dickson. Disponible également en français.
Cat. No. CW69-1/73E. Publ. 1992.
No. 74
Aerial radio-tracking of Whooping Cranes migrating between Wood Buffalo National Park and Aransas National Wildlife Refuge, 1981–84, by E. Kuyt.
Cat. No. CW69-1/74E. Publ. 1992.
No. 75
The ecology, status, and conservation of marine and shoreline birds on the west coast of Vancouver Island, by K. Vermeer, R.W. Butler, and K.H. Morgan, eds.
Cat. No. CW69-1/75E. Publ. 1992.

CANADA'S GREEN PLAN

Think recycling!

Printed on recycled paper

Canada