FRAMEWORK FOR ASSESSMENT AND MONITORING OF AMPHIBIANS AND REPTILES IN THE LOWER URUBAMBA REGION, PERU

JAVIER ICOCHEA[1], ELIANA QUISPITUPAC[2], ALFREDO PORTILLA[3] and ELIAS PONCE[2,4]

[1] *Ap. 14-219, Lima 14, Peru;* [2] *Facultad de Ciencias Biológicas, Universidad Nacional Mayor de San Marcos, Lima, Peru;* [3] *Facultad de Ingenieria Ambiental, Universidad Nacional de Ingenieria, Lima, Peru;* [4] *Facultad de Ciencias Biológicas, Universidad Nacional San Agustín, Arequipa, Peru*

Abstract. Populations of amphibians and reptiles are experiencing new or increasing threats to their survival. Many of these threats are directly attributable to human activity and resource development. This presents the increasing need for worldwide amphibian and reptile assessments and effective, standardized monitoring protocols. Adaptive management techniques can assist managers in identifying and mitigating threats to amphibian and reptile populations. In 1996, Shell Prospecting and Development, Peru initiated a natural gas exploration project in the rainforest of southeastern Peru. The Smithsonian Institution's Monitoring and Assessment of Biodiversity Program worked closely with Shell engineers and managers to establish an adaptive management program to protect the region's biodiversity. In this manuscript, we discuss the steps we took to establish an adaptive management program for amphibian and reptile communities in the region. We define and outline the conceptual issues involved in establishing an assessment and monitoring program, including setting objectives, evaluating the results and making appropriate decisions. We also provide results from the assessment and discuss the appropriateness and effectiveness of protocols and criteria used for selecting species to monitor.

Keywords: adaptive management, amphibians, assessment, development, monitoring, reptiles, tropical forests

1. Introduction

Amphibians (frogs, salamanders, caecilians) and reptiles (crocodilians, turtles, lizards, snakes) are diverse groups of animals that occur throughout the world and reach their greatest diversity in tropical regions (Frost, 1985; Pough *et al*., 1998). Like most vertebrate groups, amphibians and reptiles are experiencing new or increasing threats to their survival. However, unlike many mammals and birds, we have yet to assess the conservation status of these vertebrates in a comprehensive manner (IUCN, 1996). This emphasizes the need for global assessments of amphibian and reptile populations as well as the need to establish effective, standardized monitoring protocols.

There are many causes of decline in amphibian and reptile populations. Habitat loss, fragmentation and degradation are the most widely reported reasons (Hanski

Environmental Monitoring and Assessment **76:** 55–67, 2002.

et al., 1995; IUCN, 1996; Pechmann and Wake, 1997). Recent declines in amphibian populations have been particularly alarming, and scientists have put much effort into examining this phenomenon (Blaustein and Wake, 1990; Phillips, 1990; Wyman, 1990; Wake, 1991; Blaustein *et al.*, 1994a; Houlahan *et al.*, 2000). In addition to theories regarding habitat alteration (Lannoo *et al.*, 1994; Delis *et al.*, 1996), research indicates that acid precipitation (Wyman, 1988; Sadinski and Dunson, 1992), UV-B radiation (Blaustein *et al.*, 1994b), pathogens (Blaustein *et al.*, 1994c; Anderson, 1995), the introduction of exotic species (Schwalbe and Rosen, 1988; Fisher and Shaffer, 1996), harvesting by humans (Hayes and Jennings, 1986), chemical pollutants (Berrill *et al.*, 1993; Stebbins and Cohen, 1995) and natural population fluctuations (Pechmann *et al.*, 1991) are also taking a toll on amphibians.

In 1991, the World Conservation Union (IUCN) established its Declining Amphibian Populations Task Force (DAPTF) to address declines in herpetile populations. The primary goal is to establish effective and standardized methodologies and protocols for gathering baseline data on the status of amphibians around the world (Heyer *et al.*, 1994). Blaustein *et al.* (1994c) also argued for long-term population data to rigorously evaluate the significance of global amphibian decline.

Herein, we outline the concepts and protocols for a long-term (10- to 20-year) standardized monitoring study proposed for amphibians and reptiles in a neotropical rainforest. We describe an assessment and monitoring program for amphibians and reptiles within an adaptive management framework, based on our experience in the Amazonian forests of Peru. We believe that the results are important to the continued evaluation of the worldwide decline in populations of these vertebrates.

2. Background

The authors and other scientists investigated the herpetofauna of a section of the Peruvian Amazon during 1997 and 1998 (Reynolds *et al.* 1997; Icochea and Mitchell, 1997; Icochea *et al.*, 1998, 1999). We worked as part of a project sponsored by the Smithsonian Institution's Monitoring and Assessment of Biodiversity program (SI/MAB) in a remote, virtually untouched area known as the Lower Urubamba Region (LUR). This area was the focus of a natural gas exploration project by Shell Prospecting and Development, Peru (SPDP). To reduce potential effects of this development on biodiversity, SI/MAB worked to design and implement a multi-taxa assessment and monitoring program to guide decisions regarding development and avoid possible impacts on biodiversity (Dallmeier and Alonso, 1997).

The Lower Urubamba Region covers a 20×30 kilometer (km) area along the foothills of the Andes Mountains near where the Urubamba, Camisea and Cashiriari rivers meet (12°S latitude, 73°W longitude). Vegetation in the area is oldgrowth, lowland, non-flooded, tropical rainforest with extensive areas dominated by bamboo (*Guadua sarcocarpa*) (Comiskey *et al.*, 2001).

The study focused on four natural gas drilling sites: San Martin-3 (Sanm-3), Cashiriari-2 (Cash-2), Cashiriari-3 (Cash-3) and Pagoreni (Pag). At each well site, SI/MAB scientists conducted comprehensive assessments of the vegetation, aquatic systems, arthropods, amphibians and reptiles, birds and mammals (Dallmeier and Alonso, 1997; Alonso and Dallmeier, 1998, 1999). SI/MAB used data from the assessments to establish management goals and monitoring protocols, which were designed to assist SPDP in protecting biodiversity through continuous evaluation of management strategies and objectives. This process is known as adaptive management (Holling, 1978).

3. The Lower Urubamba Region Monitoring Framework

3.1. Adaptive management

Adaptive management is a systematic, cyclical process for improving management policies and practices based on lessons learned from operational programs (Comiskey *et al.*, 2000). Because there is uncertainty involved in actions applied to managing for the conservation of biodiversity, the planning process requires constant feedback of information so that management actions can be evaluated in regard to established goals (Noss, 1999; Comiskey *et al.*, 2000). The cyclical process involves four steps: setting the goals and objectives, assessment and monitoring, evaluation and decision-making (Holling, 1978; Walters, 1986). Goals and objectives identify the aim of management strategies and provide benchmarks that these strategies are intended to reach. The assessment provides initial data regarding the status and distribution of species present, descriptions of the habitat and literature reviews (Spellerberg, 1991; Dallmeier and Comiskey, 1998). Monitoring furnishes data needed to ensure that the effects of management are within the desired range identified in the objectives (Dallmeier, 1997). Assessment and monitoring lead to evaluation of management strategies and their impacts on the ecosystem. Based on the evaluation, managers make decisions about whether to continue, terminate or adapt the management strategies (Holling, 1978; Dallmeier and Comiskey, 1998; Elzinga *et al.*, 1998; Comiskey *et al.*, 2000).

3.2. Management strategies

Management strategies in the LUR were broadly defined. SPDP and SI/MAB intended to manage the natural gas exploration project so as to create the least impact on biodiversity in the region. This included minimal forest edge surrounding the well sites, placement of facilities in the least environmentally sensitive areas, no external roads into the sites, reduction of thermal and chemical pollution and of siltation of aquatic systems and revegetation of indigenous species atop a buried natural gas pipeline (Alonso and Dallmeier, 1999).

3.3. Objectives

The objectives of this study were to (1) establish an inventory of the species at each site, (2) evaluate the effects of the development project on natural communities at each well site and (3) measure and evaluate long-term trends in amphibian and reptile community structure and species distributions relative to habitat changes brought about by the natural gas project. The objectives were met through monitoring protocols outlined by Heyer *et al.* (1994) and adapted to the topography and logistical support system that was in place at the well sites.

3.4. Assessment

We assessed the composition and distribution of the amphibian and reptile communities in relation to the four well sites during 1997 and 1998. Assessments were conducted at Sanm-3 and Cash-2 from March to June, 1997, at Cash-3 from October to December, 1997 and at Pag from April to May, 1998 (Reynolds *et al.*, 1997; Icochea and Mitchell, 1997; Icochea *et al.*, 1998; Icochea *et al.*, 1999). The assessment also involved literature searches and descriptions of habitats.

We used a variety of methods, including visual and audible searches along transects and within quadrats, sticky traps and pit-fall traps (Heyer *et al.*, 1994; Icochea *et al.*, 2001). We conducted the assessment in a subjective manner, selecting sites to ensure adequate sampling of all habitats and therefore maximizing the number of species encountered. We assessed herpetiles in and around the areas of disturbance (the well sites) and in undisturbed, interior forest in the vicinity and of the same forest type as at the well sites. The results of the assessment provided the baseline data needed for managers to evaluate the consequences of management practices (Spellerberg, 1992).

We confirmed the presence of 63 species of amphibians from 3 orders at the 4 sites. Among the 4 sites, Cash-3 and Sanm-3 were the most diverse – 49 species each, followed by Pag and Cash-2 – each with 39 species (Icochea *et al.*, 2001). Frogs (Anura) were the most speciose group with 59 species, followed by caecilians (Gymnophiona) and salamanders (Caudata), each with 2 species (Icochea *et al.*, 2001). Studies from Manu National Park (Pakitza), Cusco Amazónico and the Iquitos region (all in Peru) describe similar distributions among the taxa, but higher richness (Morales and McDiarmid, 1996; Duellman and Salas, 1991; Rodriguez and Duellman, 1994). In part, the lower species richness in the LUR study may reflect less sampling. Our study was of shorter duration than the others. Despite the high richness of frogs in the LUR, nearly all of the species were from two families, Hylidae and Leptodactylidae (Table I). The former is primarily arboreal, and the latter is primarily terrestrial and arboreal on low vegetation. This pattern has been described for other lowland tropical rainforests in Peru (Table I).

TABLE I

Comparison of the known anuran fauna for four sites in the Lower Urubamba Region (LUR), Peru (Reynolds *et al*., 1997; Icochea *et al*., 2001) and three additional sites in Peru: Manu National Park, Pakitza (Morales and McDiarmid, 1996); Cusco Amazónico (Duellman and Salas, 1991); and Iquitos Region (Rodriguez and Duellman, 1994)

Family	Lower Urubamba Region (LUR)					Manu (Pakitza)	Cusco Amazónico	Iquitos Region
	San Martin-3	Cashiriari-2	Cashiriari-3	Pagoreni	Total			
Bufonidae	2	3	4	2	4	3	3	7
Centrolenidae	3	0	3	2	3	1	0	0
Dendrobatidae	4	3	3	2	5	6	3	8
Hylidae	14	14	13	12	21	27	32	50
Leptodactylidae	22	16	21	19	24	26	19	37
Microhylidae	2	1	2	0	2	4	4	7
Pipidae	0	0	0	0	0	0	1	2
Pseudidae	0	0	0	0	0	0	1	0
Ranidae	0	0	0	0	0	0	0	1
Total	47	37	46	37	59	67	63	112
Area surveyed (km^2)	64	64	64	64	256	40	100	U

All sites are described as lowland tropical rainforest; U = area not provided by authors; data shown are numbers of species per family.

We confirmed the presence of 81 species of reptiles from 3 orders at the 4 sites (Icochea *et al*., 2001). Among the 4 sites, Sanm-3 had the most species with 51, followed by Cash-3 (47), Pag (46) and Cash-2 (39). The Order Squamata was the most speciose group with 78 species (Table II). Suborders of Squamata – Amphisbaenia, Sauria and Serpentes – had 1, 28 and 49 species, respectively (Icochea *et al*., 2001). The reptile fauna in the LUR was similar to that of other regions in southwestern Amazonia (Table II) (Morales and McDiarmid, 1996; Duellman and Salas, 1991; DaSilva and Sites, 1995).

3.5. Monitoring

The conceivable effects of natural gas exploration on the amphibian and reptile community of the LUR are habitat alteration and pollution of local waters. Habitat alteration in this case concerned the area cleared – a 3-hectare (ha) zone – for each well site and the forest edge habitat that was created by the clearing. Potential pollution involved siltation of streams as soil and other materials run off from the disturbed sites.

Forest fragmentation and the resulting increase in forest edge can affect the distribution and abundance of amphibians and reptiles. The forest along the edge is subject to more sunlight, higher temperatures, desiccation and wind. These changes

TABLE II

Comparison of the known Squamata fauna for four sites in the Lower Urubamba Region (LUR), Peru (Reynolds *et al*., 1997; Icochea *et al*., 2001) and three additional sites in Peru: Manu National Park, Pakitza (Morales and McDiarmid, 1996); Cusco Amazónico (Duellman and Salas, 1991); and Iquitos Region (Da Silva and Sites, 1995)

Family	Lower Urubamba Region (LUR)					Manu (Pakitza)	Cusco Amazónico	Iquitos Region
	San Martin-3	Cashiriari-2	Cashiriari-3	Pagoreni	Total			
Amphisbaenia								
Amphisbaenidae	0	1	1	0	1	1	1	2
Sauria								
Gekkonidae	3	3	2	2	3	4	3	6
Gymnophthalmidae	6	6	4	7	8	5	6	11
Hoplocercidae	1	0	0	1	2	1	0	2
Iguanidae	0	0	0	0	0	0	0	1
Polychrotidae	7	4	4	5	8	3	4	8
Scincidae	1	0	1	1	1	1	1	1
Teiidae	3	2	2	2	3	3	5	5
Tropiduridae	3	3	2	3	3	5	4	4
Serpentes								
Aniliidae	0	0	0	1	1	0	1	1
Boidae	2	1	0	2	2	2	4	5
Colubridae	19	14	27	12	35	22	38	65
Elapidae	1	1	1	4	5	4	3	8
Leptotyphlopidae	1	0	1	1	1	0	1	0
Typhlopidae	0	0	0	1	1	0	0	3
Viperidae	2	3	1	4	4	3	2	6
Total Amphisbaenia	0	1	1	0	1	1	1	2
Total Sauria	24	18	15	21	28	22	23	38
Total Serpentes	25	19	30	25	49	31	49	88
Total Squamata	49	38	46	46	78	54	73	128
Area surveyed (km^2)	64	64	64	64	256	40	100	U

All sites are described as lowland tropical rainforest; U = area not provided by authors; data shown are numbers of species per family.

in environmental conditions affect the physiology and habitats of amphibians and reptiles. Vitt *et al*. (1997) found that lizards were common along forest edge and small forest openings and that they used the increased sunlight in these areas for basking. On the other hand, forest edge has been shown to decrease the abundance of amphibians (Marsh and Pearman, 1997; Gibbs, 1998; Demaynadier and Hunter, 1998, 1999).

One of the more alarming effects of forest fragmentation and edge is a reduction or elimination of normal dispersal patterns (Reddinguis and Den Boer, 1971; Hansson, 1991). This is a known cause of extinction in natural populations (McPeek and Holt, 1992) because the inability to disperse leads to fragmentation and insularization of populations, making them more vulnerable to local extinctions (MacArthur and Wilson, 1967). This may be especially relevant to species such as amphibians and reptiles that have limited dispersal abilities. Forest fragmentation and edge have been shown to restrict dispersal patterns in both amphibians (Dupuis *et al.*, 1995; Gibbs, 1998; Demaynadier and Hunter, 1999) and reptiles (Sarre *et al.*, 1995; Lecomte and Clobert, 1996).

During the initial stage of this project, the edge effect was minimal. The total area cleared for the well sites was approximately 15 ha out of 60 000 ha available in the study area.

Siltation affects streams by increasing turbidity and altering the chemical composition. This too has been shown to have negative effects on amphibian and reptile communities (Hecnar and McCloskey, 1996). Most amphibians have bi-phasic life cycles that involve an aquatic larval stage and a terrestrial adult stage. In typical species, each individual is dependent on aquatic environments at some point during its lifetime. In addition, the permeable skin used for respiration and osmoregulation (Duellman and Trueb, 1986) make amphibians particularly vulnerable to water pollution (Berrill *et al.*, 1993; Stebbins and Cohen, 1995).

SPDP devised a comprehensive plan for cleaning and treating the water for organic and chemical compounds, which proved to be effective (Salcedo *et al.*, 2001), and siltation was not a concern in the small streams throughout the study area. The abundance of apparently healthy tadpoles and immature fresh water invertebrates supported this finding.

SPDP's management strategy was designed to minimize forest edge and siltation in streams. Because fragmentation and edge can have potentially harmful impacts on the herpetile community, however, future monitoring should focus on this issue. By monitoring species in relation to such impacts, we can evaluate whether the management strategy is effective.

It is not possible to monitor all species found in an area because of time, financial and logistical constraints. That means we must select a set of species to monitor. Frogs are particularly amenable to surveys because of certain behavioral traits – most frogs are readily visible at night, and males produce species-specific vocalizations (Duellman and Trueb, 1986) that are relatively simple to identify. In addition, standardized monitoring techniques based on frog vocalizations are available (Heyer *et al.*, 1994; Green, 1997). The long-term monitoring program will focus on 4 species of frogs – *Epipedobates macero*, *Bufo* cf. *typhonius, Ischnocnema quixensis* and *Hemiphractus johnsoni*. We chose these species because during the assessment, they were common, widely distributed and easy to identify. These traits will assist researchers in collecting adequate, quality data regarding abundance.

We also plan to monitor all of the anuran community in relation to relative abundance. Snakes and lizards have characteristics that make them appropriate for monitoring. Emphasis will be on 2 species – the snake *Atractus major* and the lizard *Anolis trachyderma*, again because they were common, widely distributed and easy to identify.

We plan to monitor components of the environment as well. Amphibians have critical habitat needs for different life stages. One is wetlands, ranging from small, ephemeral puddles to permanent lakes and streams. The quantity and quality of these wetlands has an impact on the richness, distribution and abundance of amphibian populations. During the assessment phase, potential breeding sites were mapped, and water quality was measured (Salcedo *et al*., 2001).

Among the many techniques for monitoring amphibians and reptiles (Heyer *et al*., 1994), we used visual encounter surveys (VES) (Campbell and Christman, 1982; Corn and Bury, 1990; Crump and Scott, 1994), audio strip transects (AST); (Zimmerman, 1994) and quadrat surveys (Reynolds *et al*., 1997). The quadrat surveys were effective, but labor intensive. VES and AST were the most effective methods for sampling amphibian populations, and VES was highly effective for reptiles.

VES requires that research teams move throughout a survey zone for a fixed period of time, intensively searching for amphibians and reptiles that may be on the ground or vegetation. For this assessment, transects were of variable width and length. For future monitoring, we established permanent transects 100 meters (m) in length and decided on a search distance of 2 m either side of each transect (Campbell and Christman, 1982; Corn and Bury, 1990). We established a series of these transects extending through forest edge habitat and continuing 2 km into the undisturbed forest. The resulting data can be used to determine species richness and to estimate relative abundance.

Continual monitoring of these transects will allow us to evaluate the effects of forest edge by comparing species composition and relative abundance between the forest edge and the forest interior. But VES alone is not a reliable method for estimating density because not all individuals actually present will be observable at the same time. Donnelly (1989) describes a technique for estimating density by combining VES with mark-recapture methods. These methods will be used to monitor the 6 focal species. We note that VES is the most effective method to monitor forest understory anurans and to survey rare species (Crump and Scott, 1994).

During breeding periods, male frogs use species-specific vocalizations to attract mates. AST monitors frog communities by exploiting this behavior. Monitoring teams listened for and counted calling male frogs along the transects described above. We recorded and identified frogs by their vocalizations 10 or more meters from each transect.

Males of many tropical frogs are widely dispersed in the forest or occur in small enough groups that one can audibly count the number of calling individuals.

AST provides an assessment of species richness and habitat use, and an estimate of the relative abundance of calling males. AST is a rapid and effective monitoring technique for all forest strata and micro-habitats and in gathering data on fossorial and canopy-dwelling species with similar efficacy as for ground-dwelling species (Zimmerman, 1991; 1994). Because males are most active and vocal during breeding periods, which generally occurs during the first month of the rainy season (Duellman, 1978; Morales and McDiarmid, 1996), this is the best time to monitor frog populations.

As with other taxonomic groups, the life history of amphibians and reptiles is closely associated with climatic variables. Therefore, monitoring of climatic data in conjunction with monitoring of biotic data is essential. We recorded maximum and minimum temperatures and rainfall, and we recommend that instruments be installed at each site for regular use in recording climate data, including data on relative humidity, barometric pressure, soil and water pH, wind speed and wind direction. These data will provide insight on the effects of climate on changes in amphibian and reptile populations and may indicate the most appropriate time for sampling.

3.6. Voucher specimens

Voucher specimens provide documentation for the occurrence of a species and are permanent records from a particular site (McDiarmid, 1994). We used the following protocols in preparing specimens: euthanization of sampled specimens, tagging of each specimen with a unique code, preservation of each specimen in a small quantity of diluted formaldehyde and storage of each specimen in alcohol. We deposited vouchers at the Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Peru (MUSM) and the Smithsonian Institution, National Museum of Natural History, Washington, DC.

3.7. Evaluation and decision-making

A primary goal of monitoring is to detect trends in populations over time, if in fact they are occurring. Populations of many species of amphibians vary radically over short periods of time (Pechmann *et al.*, 1991). So, even after many years, monitoring may not realize the true extent of variability in a population (Pechmann and Wilbur, 1994). Hayes and Steidl (1997) used power analysis to examine variability in populations of neotropical amphibians and suggested that 10 to 20 years of monitoring is necessary to determine if a trend has occurred. Therefore, long-term monitoring and evaluation of results are necessary to make appropriate decisions regarding management strategies.

In the LUR, our assessment provided the baseline data to meet the initial objectives. Monitoring will continue for the duration of the project, and the status of amphibian and reptile populations will be evaluated. After each evaluation, managers must make decisions. If the data determine that trends in the parameters under study are within acceptable ranges, then monitoring and management strategies might continue with little or no adjustment. If population values decline to unacceptable levels, then managers will need to make decisions to either adapt the monitoring protocols, adapt the management objectives or adapt the management strategy (Dallmeier and Comiskey, 1998; Comiskey *et al*., 2000), thus completing the adaptive management cycle.

Acknowledgments

We wish to thank all those who made this project possible. We thank Shell Prospecting and Development Peru for its support. We thank the Smithsonian Institution, Monitoring and Assessment of Biodiversity Program for managing the project. And we thank the anonymous reviewers for their valuable comments.

References

Alonso, A. and Dallmeier, F. (eds): 1998, *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: Cashiriari-3 Well Site and the Camisea and Urubamba Rivers*, SI/MAB Series #2, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Alonso, A. and Dallmeier, F. (eds): 1999, *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: Pagoreni Well Site, Assessment and Training*, SI/MAB Series #3, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Anderson, I.: 1995, 'Is a virus wiping out frogs?', *New Scientist* (January), **7**.

Berrill, M., Bertram, S., Wilson, A., Louis, S., Brigham, D. and Stromberg, C.: 1993, 'Lethal and sublethal impacts of pyrethroid insecticides on amphibian embryos and tadpoles', *Environ. Toxicol. Chem.* **12**, 525–539.

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

Blaustein, A. R., Wake, D. B. and Sousa, W. P.: 1994a, 'Amphibian declines: Judging stability, persistence, and susceptibility of populations to local and global extinctions', *Conserv. Biol.* **8**, 60–71.

Blaustein, A. R., Hoffman, P. D., Hokit, D. G., Kiesecker, J. M., Walls, S. C. and Hays, J. B.: 1994b, 'UV repair and resistance to solar UV-B in amphibian eggs: A link to population declines?', *Proc. Nat. Acad. Sci.* **91**, 1791–1795.

Blaustein, A. R., Hokit, D. G., O'Hara, R. K. and Holt, R. A.: 1994c, 'Pathogenic fungus contributes to amphibian losses in the Pacific Northwest', *Biol. Conserv.* **67**, 251–254.

Campbell, H. W. and Christman. S. P.: 1982, 'Field Techniques for Herpetofaunal Community Analysis', in N. J. Scott Jr. (ed.), *Herpetological Communities*, Wildlife Research Report 13, U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

Comiskey, J. A., Dallmeier, F. and Alonso. A.: 2000, 'Framework for Assessment and Monitoring of Biodiversity', in S. Levin (ed.), *Encyclopedia of Biodiversity*, Vol. 3, Academic Press, London.

Comiskey, J. A., Campbell, P., Alonso, A., Mistry, S., Dallmeier, F., Nuñez, P., Beltran, H., Baldeon, S., Nauray, W., De la Colina, R., Acurio, L. and Udvardy, S.: 2001, 'Vegetation Assessment of the Lower Urubamba Region, Peru', in F. Dallmeier, A. Alonso and P. Campbell (eds), *Biodiversity of the Lower Urubamba Region, Peru*, SIMAB Series 7, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Corn, P. S. and Bury, R. B.: 1990, 'Sampling Methods for Terrestrial Amphibians and Reptiles', *General Technical Report*, U.S. Department of Agriculture, Forest Service, PNW-GTR-256, Portland, Oregon.

Crump, M. L. and Scott Jr., N. J.: 1994, Visual Encounter Surveys, in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek and M. S. Foster (eds), *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, Smithsonian Institution Press, Washington, DC.

Da Silva Jr., J. N. and Sites Jr., J. W.: 1995, 'Patterns of diversity of netropical squamate reptile species with emphasis on the Brazilian Amazon and the conservation potential of indigenous reserves', *Conserv. Biol.* **9**(4), 873–901.

Dallmeier, F.: 1997, 'Biodiversity Assessment and Monitoring for Adaptive Management', in F. Dallmeier and A. Alonso (eds), *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: San Martin-3 and Cashiriari-2 Well Sites*, SI/MAB Series #1, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Dallmeier, F. and Alonso, A. (eds): 1997, *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: San Martin-3 and Cashiriari-2 Well Sites*, SI/MAB Series #1, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Dallmeier, F. and Comiskey, J. A.: 1998, 'Forest Biodiversity Assessment, Monitoring, and Evaluation for Adaptive Management', in F. Dallmeier and J. A. Comiskey (eds), *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies*, Man and the Biosphere Series, Vol. 20, UNESCO, Paris and Parthenon Publishing Group, New York.

Delis, P. R., Mushinsky, H. R. and McCoy, E. D.: 1996, 'Decline of some west-central Florida anuran populations in response to habitat degradation', *Biod. Conserv.* **5**, 1579–1595.

Demaynadier, P. G. and Hunter Jr., M. L.: 1998, 'Effects of silvicultural edges on the distribution and abundance of amphibians in Maine', *Conserv. Biol.* **12**(2), 340–352.

Demaynadier, P. G. and Hunter Jr., M. L.: 1999 'Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine', *J. Wildlife Manage.* **63**(2), 441–450.

Donnelly, M. A.: 1989, 'Demographic effects of reproductive resource supplementation in a territorial frog, *Dendrobates pumilio*', *Ecolog. Monogr.* **59**, 207–221.

Duellman, W. E.: 1978, *The Biology of an Equatorial Herpetofauna in Amazonian Ecuador*, Miscellaneous Publication 65. University of Kansas, Museum of Natural History, Laurence, Kansas.

Duellman, W. E. and Salas, A.: 1991, 'Annotated checklist of the amphibians and reptiles of Cuzco Amazonico, Peru', *Univ. Kansas Natur. Hist. Museum Occ. Paper* **143**, 1–13.

Duellman, W. E. and Trueb, L.: 1986, *Biology of Amphibians*, McGraw-Hill, New York.

Dupuis, L. A., Smith, J. N. M. and Bunnell, F.: 1995, 'Relation of terrestrial-breeding amphibian abundance to tree-stand age', *Conserv. Biol.* **9**, 645–653.

Elzinga, C. L., Salzer, D. W. and Willoughby, J. W.: 1998, *Measuring and Monitoring Plant Populations*, United States Department of the Interior, Bureau of Land Management, Denver, Colorado.

Fisher, R. N. and Shaffer, H. B.: 1996, 'The decline of amphibians in California's Great Central Valley', *Conserv. Biol.* **10**, 1387–1397.

Frost, D. R. (ed.): 1985, *Amphibian Species of the World: A Taxonomic and Geographical Reference*, Allen Press, Inc. and Association of Systematic Collections, Lawrence, Kansas.

Gibbs, J. P.: 1998, 'Amphibian movements in response to forest edges, roads, and streambeds in southern New England', *J. Wildlife Manage.* **62**(2), 584–589.

Green, D. M.: 1997, 'Amphibians in decline: Canadian studies of a global problem', *SSAR Herpetolog. Conserv.* **1**, 1–340.

Hanski, I., Clobert, J. and Reid, W.: 1995, 'Ecology of Extinction', in V. H. Heywood (ed.), *Global Biodiversity Assessment*, Cambridge University Press, Cambridge, U.K.

Hansson, L.: 1991, 'Dispersal and Connectivity in Metapopulations', in M. E. Gilpin and I. Hanski (eds), *Metapopulation Dynamics: Empirical and Theoretical Investigations*, Linnean Society of London and Academic Press, London.

Hayes, M. P. and Jennings, M. R.: 1986, 'Decline in ranid frog species in western North America: Are bullfrogs (*Rana catesbeiana*) responsible?', *J. Herpetol.* **20**, 490–509.

Hayes, J. P. and Steidl, R. J.: 1997, 'Statistical power analysis and amphibian population trends', *Conserv. Biol.* **11**, 273–275.

Hecnar, S. J. and McCloskey, R. T.: 1996, 'Amphibian species richness and distribution in relation to pond water chemistry in south-western Ontario, Canada', *Freshw. Biol.* **36**(1), 7–15.

Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C. and Foster, M. S. (eds): 1994, *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, Smithsonian Institution Press, Washington, DC.

Holling, C. S. (ed.): 1978, *Adaptive Environmental Assessment and Management*, John Wiley & Sons, New York.

Houlahan, J. E., Findlay, C. S., Schmidt, B. R., Meyer, A. H. and Kuzmin, S. L.: 2000, 'Quantitative evidence for global amphibian population declines', *Nature* **404**(6779), 752–755.

Icochea, J. and Mitchell, J.: 1997, 'Amphibians and Reptiles II. Biodiversity Assessment in the Lower Urubamba Region', in F. Dallmeier and A. Alonso (eds), *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: San Martin-3 and Cashiriari-2 Well Sites*, SI/MAB Series #1. Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Icochea, J., Quispitupac, E. and Portilla, A.: 1998, 'Amphibians and Reptiles: Biodiversity Assessment in the Lower Urubamba Region', in A. Alonso and F. Dallmeier (eds), *Biodiversity Assessment and Long-Term Monitoring of the Lower Urubamba Region, Peru: Cashiriari-3 Well Site and the Camisea and Urubamba Rivers*, SI/MAB Series #2. Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Icochea, J., Portilla, A., Quispitupac, E., Aguilar, E., Ponce, E. and Fernandez, R.: 1999, 'Amphibians and Reptiles: Biodiversity Assessment at the Pagoreni Well Site', in A. Alonso and F. Dallmeier (eds), *Biodiversity Assessment and Long-Term Monitoring of the Lower Urubamba Region, Peru: Pagoreni Well Site: Assessment and Training*, SI/MAB Series #3, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Icochea, J., Quispitupac, E., Portilla, A. and Ponce, E.: 2001, 'The Amphibian and Reptile Fauna of the Lower Urubamba Region, Peru', in F. Dallmeier, A. Alonso and P. Campbell. (eds), *Biodiversity of the Lower Urubamba Region, Peru*, SIMAB Series 7, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

IUCN: 1996, *1996 IUCN Red List of Threatened Animals*, IUCN, Gland, Switzerland.

Lannoo, M. J., Lang, K., Waltz, T. and Phillips, G. S.: 1994, 'An altered amphibian assemblage: Dickenson County, Iowa, 70 yr after Frank Blanchard's survey', *Amer. Midl. Natural.* **131**, 311–319.

Lecomte, J. and Clobert, J.: 1996, 'Dispersal and connectivity in populations of the common lizard *Lacerta vivipara*: An experimental approach', *Acta Oecol.* **17**(6), 585–598.

MacArthur, R. H. and Wilson, E. O.: 1967, *The Theory Of Island Biogeography*, Princeton University Press, Princeton, New Jersey.

McPeek, M. A. and Holt, R. D.: 1992, 'The evolution of dispersal in spatially and temporally varying environments', *Amer. Natural.* **140**, 1010–1027.

Marsh, D. M. and Pearman, P. B.: 1997, 'Effects of habitat fragmentation on the abundance of two species of Leptodactylid frogs in an Andean montane forest', *Conserv. Biol.* **11**(6), 1323–1328.

McDiarmid, R. W.: 1994, 'Preparing Amphibians as Scientific Specimens', in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek and M. S. Foster (eds), *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, Smithsonian Institution Press, Washington, DC.

Morales, V. R. and McDiarmid. R. W.: 1996, 'Annotated Checklist of the Amphibians and Reptiles of Pakitza, Manu National Park Reserve Zone, with Comments on the Herpetofauna of Madre de Dios, Peru', in D. E. Wilson and A. Sandoval (eds), *Manu: The Biodiversity of Southeastern Peru*, Smithsonian Institution Press, Washington, DC.

Noss, R. F. 1999, 'Assessing and monitoring forest biodiversity: A suggested framework and indicators', *Forest Ecol. Manage.* **115**, 135–146.

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

Pechmann, J. H. K. and Wake, D. B.: 1997, 'Declines and Disappearances of Amphibian Populations', in G. K. Meffe and C. R. Carroll (eds), *Principles of Conservation Biology*, 2nd ed., Sinauer Associates Inc., Sunderland, Massachusetts.

Pechmann, J. H. K. and Wilbur, H. M.: 1994, 'Putting declining amphibian populations in perspective: Natural fluctuations and human impacts', *Herpetologica* **50**, 65–84.

Phillips, K. 1990, 'Where have all the frogs and toads gone?', *Bioscience* **40**, 422–424.

Pough, H. F., Andrews, R. M., Cadle, J. E. and Crump, M.: 1998, *Herpetology*, Prentice Hall, Upper Saddle River, New Jersey.

Reddinguis, J. and Den Boer, P. J.: 1971, 'Simulation experiments illustrating stabilization of animal numbers by spreading risk', *Oecologia* **5**, 240–284.

Reynolds, R., Fritts, T., Gotte, S., Icochea, J. and Tello, G.: 1997, Amphibians and Reptiles I, in F. Dallmeier and A. Alonso, (eds), *Biodiversity Assessment and Long-term Monitoring of the Lower Urubamba Region, Peru: San Martin-3 and Cashiriari-2 Well Sites*, SI/MAB Series #1. Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Rodiguez, L. O. and Duellman, W. E.: 1994, 'Guide to the Frogs of the Iquitos Region, Amazonian Peru', *Special Publication 22*, University of Kansas, Natural History Museum, Topeka, Kansas.

Sadinski, W. J. and Dunson, W. A.: 1992, 'A multilevel study of effects of low pH on amphibians in temporary ponds', *J. Herpetol.* **26**, 413–422.

Salcedo, N., Hildago, M., Minaya, P., Castro, E., Acosta, R. Reyes, D., Leon, J. and Udvardy, S.: 2001, 'Biodiversity Assessment of the Aquatic Systems of the Lower Urubamba Region, Peru, in A. Alonso, F. Dallmeier and P. Campbell (eds.), *Urubamba: the Biodiversity of a Peruvian Rainforest*, SI/MAB Series 7, Smithsonian Institution/MAB Biodiversity Program, Washington, DC.

Sarre, S., Smith, G. T. and Meyers, J. A.: 1995, 'Persistence of two species of gecko (*Oedura reticulata* and *Gehyra variegata*) in remnant habitat', *Biol. Conserv.* **71**(1), 25–33.

Schwalbe, C. R. and Rosen, P. C.: 1988, 'Preliminary Report on Effect of Bullfrogs on Wetland Herpetofaunas in Southeastern Arizona', in C. S. Szaro, K. E. Severson and D. R. Patton (eds), *Management of Amphibians, Reptiles, and Small Mammals in North America*, General Technical Report RM-166, U.S. Department of Agriculture, Forest Service, Washington, DC.

Spellerberg, I. F.: 1991, *Monitoring Ecological Change*, Cambridge University Press, Cambridge, U.K.

Spellerberg, I. F.: 1992, *Evaluation and Assessment for Conservation*, Chapman and Hall, London.

Stebbins, R. C. and Cohen, N. W.: 1995, *A Natural History of Amphibians*, Princeton University Press, Princeton, New Jersey.

Vitt, L. J., Zani, P. A. and Lima A. Claudia, M.: 1997, 'Heliotherms in tropical rainforest: The ecology of *Kentropyx calcarata* (Teiidae) and *Mabuya nigropunctata* (Scincidae) in the Curua-Una of Brazil', *J. Tropical Ecol.* **13**(2), 199–220.

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

Walters, C. J.: 1986, *Adaptive Management of Renewable Resources*, McGraw Hill, New York.

Wyman, R. L.: 1988, 'Soil acidity and moisture and the distribution of amphibians in five forests of south central New York', *Copeia* **1988**, 394–399.

Wyman, R. L.: 1990, 'What's happening to the amphibians?', *Conserv. Biol.* **4**, 350–352.

Zimmerman, B. L.: 1991, 'Distribution and Abundance of Frogs in a Central Amazonian Forest', *Unpublished Ph.D. dissertation*, Florida State University, Tallahassee, Florida.

Zimmerman, B. L.: 1994, 'Audio Strip Transects', in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek and M. S. Foster (eds), *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, Smithsonian Institution Press, Washington, DC.