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Letter to the Editor

REPTILE TOXICOLOGY: CHALLENGES AND OPPORTUNITIES ON THE LAST FRONTIER IN VERTEBRATE ECOTOXICOLOGY

To the Editor:

In the wake of a changing global environment, reptile populations, like those of other vertebrates, appear to be declining [1]. The Partners in Amphibian and Reptile Conservation recently identified six major threats to reptile populations, most of which were anthropogenic in nature [1]. Environmental pollutants were among the threats identified, but little empirical evidence currently exists to document the frequency and severity of their contamination. Although reptiles surely face a multitude of challenges when exposed to chemicals in the environment, they have remained poorly studied in ecotoxicology. Therefore, the purpose of this letter is to identify reptiles as grossly underexamined vertebrate taxa that deserve immediate attention from ecotoxicologists. In addition, this letter will discuss the biological traits that make reptiles excellent study organisms for certain ecotoxicological investigations and future research priorities and challenges in reptile toxicology.

Reptiles are the least studied group of vertebrates (mammals, birds, fish, amphibians, and reptiles) with regard to environmental contaminants. Over the last 10 years of *Environmental Toxicology and Chemistry* (*ET&C*), 933 studies published (36% of total papers in *ET&C*) addressed contaminant effects on vertebrate species. However, only 12 studies on reptiles (0.4% of total papers, 1.3% of vertebrate studies) were published in *ET&C* during the same time period (Table 1). If reviews of wildlife toxicology (three published in 1998) that mention reptiles are excluded, the number of reptile studies expressed as a percentage of vertebrate studies decreases to less than 1%. Previous comprehensive reviews of reptile toxicology corroborate the problem identified in the limited literature survey presented here [2–4] and also reveal that previous reptile toxicological research has primarily focused on American alligators (*Alligator mississippiensis*) and snapping turtles (*Chelydra serpentina*). Moreover, ecotoxicological studies on reptiles often document tissue concentrations of contaminants but seldom provide adequate insight into the biological significance of the tissue burdens observed [5].

Even though amphibians and reptiles are sometimes considered collectively in broad toxicological discussions, amphibian ecotoxicological studies outnumber reptile studies by a factor of 5 (Table 1). The increasing number of amphibian studies published during the latter portion of the decade undoubtedly, and justifiably, arises from recent concern over their susceptibility to contaminants and the status of global amphibian populations. Fortunately, the past 2 years have brought increased awareness, often from amphibian toxicologists, that reptile toxicology desperately needs attention. However, because of the paucity of data on reptile toxicology and the recent focus on amphibians, reptiles remain underrepresented in forums that consider the two vertebrate classes collectively. For example, only two papers (20%) presented at the 1998 SETAC symposium on amphibian and reptile toxicology included original research on reptiles. Clearly, it is critical to identify reptiles as vertebrates that deserve attention by ecotoxicologists without riding the coattails of amphibian issues [1].

Understanding the unique features of reptiles is key to overcoming the tendency to group amphibians and reptiles and critical for shaping appropriate research protocols in the future. Amphibians and reptiles each exhibit distinct biological traits and therefore have very different requirements for study within an ecotoxicological framework. The complex life cycles and permeable integument of amphibians have provided much of the impetus for recent amphibian ecotoxicological investigations. Reptiles do not share these traits, but exhibit a suite of other life-history and biological characteristics that make them vulnerable to contaminants.

REPTILIAN LIFE HISTORY AND BIOLOGICAL TRAITS

Much of the reluctance to pursue reptiles in ecotoxicology likely stems from life-history traits and aspects of their biology that make them appear less tractable for traditional ecotoxicological studies. Unlike most model species in toxicology, reptiles do not typically exhibit short generation times, they do not produce large numbers of offspring at short intervals, and they are often mistakenly considered difficult to maintain in captivity. Ironically, the characteristics that make reptiles appear difficult to study actually present scientists with a singular opportunity to create new and ecologically meaningful paradigms in environmental toxicology. Reptiles may be unique models for answering questions that historically have been difficult to address using traditional study species and techniques.

The carnivorous dietary preferences of many reptiles, combined with their site fidelity relative to other vertebrate carnivores, presents opportunities to compare contaminant accumulation in individuals inhabiting polluted and reference sites within a narrow geographical area. In areas in which point discharge of contaminants can be identified, impacts of pollutants in adjacent habitats are sometimes traditionally addressed using invertebrate models. High trophic level vertebrates such as birds and mammals that inhabit aquatic, semiaquatic, and terrestrial systems are often not practical for such studies because they tend to move too frequently across considerable distances. Some reptiles, on the other hand, have relatively narrow home ranges and therefore may be well suited for approaching such problems. The trophic status of many reptiles may make them particularly useful in evaluating sites contaminated with compounds transferred via trophic mechanisms; reptiles from contaminated sites have been shown to accumulate trace elements, organic contaminants, and radionuclides [3,5–6].

Because of the prolonged time to sexual maturity in many reptiles, studies of toxicants that affect reptilian reproductive parameters also have great potential. Although species that

Table 1. Vertebrate studies published in *Environmental Toxicology and Chemistry* from 1990 through 1999 categorized by class of vertebrate studied[a]

Year	Birds	Mammals	Fish	Amphibians	Reptiles
1990	16 (24)	3 (5)	45 (68)	2 (3)	1 (2)
1991	15 (24)	12 (19)	38 (60)	1 (2)	0 (0)
1992	13 (19)	8 (12)	52 (78)	2 (3)	0 (0)
1993	22 (30)	9 (12)	44 (60)	3 (4)	1 (1)
1994	23 (25)	16 (17)	52 (57)	7 (8)	0 (0)
1995	19 (19)	10 (10)	60 (60)	6 (6)	2 (2)
1996	22 (25)	10 (11)	57 (64)	3 (3)	0 (0)
1997	26 (21)	12 (10)	80 (66)	8 (7)	3 (2)
1998	36 (29)	13 (10)	69 (56)	15 (12)	4 (3)[b]
1999	28 (20)	18 (13)	81 (59)	16 (12)	1 (1)
Totals	220 (24)	111 (12)	578 (62)	63 (7)	12 (1)

[a] Numbers in parentheses in rows 1990–1999 represent percentage of total number of vertebrate studies published that year. Numbers in parentheses for Totals represent percentage of total number of vertebrate studies published in decade ($N = 933$). Sum of percentages for year/decade exceeds 100% because more than 50 studies examined more than one vertebrate class.

[b] Denotes year in which three of four studies that included reptiles were actually reviews of wildlife toxicity issues and included all five vertebrate classes in the discussion.

reach reproductive age rapidly are well suited for multigenerational lab-based studies, long-lived reptiles may be well suited for field studies concerned with extended exposure to reproductive toxicants. While many snake species reach reproductive age within 2 to 5 years, most species of turtles and crocodilians do not reach maturity for 5 to 20 years. Thus, in an area in which aquatic organisms are chronically exposed to a suite of persistent reproductive toxicants in relatively low doses, a carnivorous fish species that reaches sexual maturity in 1 to 3 years may suffer less severe (and perhaps even undetectable) reproductive consequences than a carnivorous turtle that attains sexual maturity in 10 to 15 years. The toxicity of persistent compounds in reptiles could be further exacerbated if reptiles are more sensitive to xenobiotics or more likely than other vertebrates to accumulate toxic compounds. Of course, such scenarios remain speculative because insufficient data address reproductive toxicants in reptiles.

Reptiles may also differ from traditional study species in their ability to recover from catastrophic events such as oil spills, chemical dumping, and release of radionuclides. Longevity and delayed sexual maturity have the potential to present reptile populations with an inability to recover from episodes of acute toxicity. For example, high mortality naturally occurs in turtle and alligator eggs and hatchlings but not in juveniles and adults. If high concentrations of contaminants were introduced into a habitat and subsequent mortality in adult turtles and alligators was high, the number of juveniles required for population recovery would become unrealistically high [7]. Moreover, when populations are reduced by environmental impacts, recovery due to immigration from other habitats may not occur because many reptiles do not disperse widely. From a population-level perspective, studies that assess population parameters following contamination of habitats of long-lived reptile species would be valuable. Unfortunately, reptiles are not typically included in monitoring programs that evaluate ecosystem recovery or responses to innovative remediation technologies.

FUTURE RESEARCH CHALLENGES

Even the most basic toxicological issues, many of which have been thoroughly studied in other vertebrate taxa, remain underevaluated in reptiles. Important areas for future research include the following:

Model species. Squamates (lizards and snakes) may be particularly useful as experimental model species because, compared to crocodilians and turtles, they are easier to maintain in large, laboratory-based experimental manipulations. Despite this advantage, squamates remain the most understudied reptiles in ecotoxicology. As with all model species, extreme caution should be exercised when attempting to predict contaminant effects on other reptiles based on responses expressed by reptilian models.

Bioaccumulation. Little is known about uptake rates and accumulation of toxic compounds by reptiles. Experimental assessments of uptake and depuration rates in reptiles can be conducted using squamate models and may provide important insight into susceptibility of reptiles compared to other vertebrates. Because such studies require the sacrifice of numerous individuals, researchers could utilize introduced reptiles (e.g., ecological pest species in Florida) as surrogate species for such manipulations.

Toxicity thresholds. No adequate criteria for predicting risk to reptile populations currently exist because reptile responses to different concentrations of contaminants are unknown. Comparative studies examining parameters such as detoxification enzyme activity, vitellogenin production, stress protein production, DNA damage, and acetylcholinesterase activity of reptiles (particularly squamates) and vertebrates of similar trophic status would be valuable for assessing relative sensitivity of reptiles.

Endocrine disruption. Although endocrine disruption has been evaluated in alligators and snapping turtles, much remains to be learned concerning the impact of endocrine-disrupting compounds on other reptiles. Because many reptiles have temperature-dependent sex determination, experimental manipulations of reptilian systems may provide insight into mechanisms by which estrogenic compounds exert their effects.

Behavioral toxicology. Many squamate reptiles exhibit well-defined territorial and courtship behaviors. Studies examining the effect of anthropogenic compounds on these reptilian behaviors, as well as predator–prey interactions, will be important for linking pollutant-induced biochemical and cellular changes to alterations in meaningful organism-level processes.

Nonlethal sampling techniques. Because reptile populations may currently be threatened by environmental perturbations, it is imperative that nondestructive sampling techniques be developed [3]. These will enable investigators to sample repeatedly the same individuals over extended periods of time.

Tropical reptile toxicology. Many of the most disruptive anthropogenic compounds currently banned in the United States, such as DDT and its derivatives, remain in use in tropical regions. Reptiles are extremely abundant in tropical regions and may be at risk in developing nations where agriculture and mining practices are destroying tropical habitats.

Population and community models. Perhaps the most important and most difficult task for ecotoxicologists concerned with reptiles is to document population- and community-level impacts of xenobiotics. Following pollutant exposure, measurement of organism-level parameters such as growth and reproduction may provide data necessary for developing meaningful population models.

CONCLUSION

Because ecotoxicology remains a relatively young, developing discipline, many research challenges remain unconfronted. Among vertebrates, no organismal subdiscipline remains as conspicuously underexamined as the ecotoxicology of reptiles. Twenty years after Hall first identified reptile ecotoxicology as an understudied field [2], little progress has been made to properly address the hazards of toxicants to most reptiles. Progress has been further impeded by inadequate funding initiatives to support the long-term research projects sometimes necessary for the study of reptiles. If the ultimate goal of ecotoxicology is to understand how contaminants affect populations, communities, and ecosystems, all components of the ecosystem must be examined. As ecotoxicologists move forward and define new fields of interest in the next millennium, reptiles should become an important priority.

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