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POINT OF VIEW

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"EYE OF NEWT AND TOE OF FROG": HERPETOLOGY IN 21ST CENTURY SCIENCE

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ABSTRACT: Herpetology and herpetologists have the potential for forward-thinking leadership in the science of the 21st century. By examining old questions with new tools and by developing new, synthetic questions and approaches, the field continues to advance many areas of biological science and science more generally. At the same time, some paradigms need change, and herpetologists would benefit from greater activism in effecting those changes. Such areas include more integrative approaches to research and education, more effective collaboration in research and in effecting a more unified voice for the meaning and value of science, and more attention to the responsibility to the public that all scientists share.

Key words: Collaboration; Communication; Contributions; Herpetology; Integrative Biology; Responsibilities

Incantation Of The Three Witches
in Shakespeare's (1605) *Macbeth*, Act IV, Scene I:

All: Double, double toil and trouble;
fire burn and cauldron bubble.
Second Witch: Fillet of a fenny snake,
in the cauldron boil and bake;
eye of newt, and toe of frog,
wool of bat, and tongue of dog,
adder's fork, and blind-worm's sting,
lizard's leg, and howlet's wing,
for a charm of powerful trouble,
like a hell-broth boil and bubble.

The vision of Macbeth's witches dancing around their cauldron and chanting about the eye of newt and toe of frog as magical elements is very provocative to this herpetologist, especially because I believe that we retain today much interest in the mysteries inherent in the biology of amphibians and reptiles. That interest makes herpetologists, sensu lato, especially qualified in many elements important to 21st century science.

My title also reflects three themes that I wish to develop in this essay:

1. Research in herpetology has long involved an examination of the parts of amphibians and reptiles, the organisms themselves—how they work, where they are, how they come to be, and their interactions with each other and with their environments, and it continues today with new tools and new perspectives.
2. It is a curious fact that those of us who look at animals and their parts, and how they develop, maintain themselves, interact, and evolve have long been considered "witches"—bizarre, mysterious, even nasty people who probably should be eliminated—and that is particularly true of attitudes toward scientists and science today.
3. We have a particular responsibility as herpetologists (and ichthyologists, and other taxon-based scientists) (a) to advance our science by our advocacy of our focus on our taxa of choice, (b) to advance the well-being of the kinds of science that we do as well as of the organisms themselves, in the context of scientific developments of the 21st century, and (c) to convey to the public and to policy-makers what our science, and science in general is all about, especially in terms of the contributions of "pure", "curiosity-driven", nonbiomedical research to society today.

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This is a personal perspective, one that I feel deeply about, and that I hope can contribute to a renewed commitment to new ideas about collaboration, integrative science, and educating the public and policy-makers.

The Science of Herpetology

First, we need to think about what the science of herpetology is, and what it contributes to 21st century science. Is 'herpetology' a science in and of itself? I argue that it is, but that it is both more and less than the sum of its parts, depending on how one construes it.

Herpetology, as our societies' mission statements agree, is the scientific study of amphibians and reptiles. Herpetologists are those people, usually professionals but also nonprofessionals, who do that scientific study of amphibians and reptiles. However, more people study amphibians and reptiles than call themselves herpetologists, and many people who study amphibians and reptiles also study other organisms. Another dimension to this consideration is that many people who study amphibians and reptiles do not call themselves herpetologists, but adopt the problem- or area-of-study appellation and call themselves morphologists, behaviorists, systematists, ecologists, etc., or even integrative biologists. Some study herps because of interest in the organisms, some because of interest in the scientific problems and questions herps are amenable to answer. However, this distinction is a matter of degree—most herpetologists, despite their initial framework, merge developing interests in the organisms and the questions. This attribute fosters two qualities:

1. Interest in knowing as much as possible about the organisms—all facets of their biology—and
2. A fascination with them, even a love for them, that maintains curiosity, a willingness to protect and nurture them, and to broadcast to the world (usually students, sometimes the public and policy-makers) what is interesting about them and their position in the grand scheme of things.

It is important to have that fascination—it keeps us going when the grants dry up, it provides part of our drive, as well as our empirical data.

I believe that it doesn't matter which of the terms one uses as one's primary identifier, so long as we understand and respect the terms and their uses and meanings to different audiences, and so long as we uphold certain premises that follow from our choices of animals of study—that is, we study them as means to answer questions at several different levels in order to contribute to science, and we appreciate them as organisms with a distinct place in nature and their need for conservation.

Our fascination with our animals, and our quest for understanding as much of their biology as possible often guides our more specialized studies; I assert that we should be sure to continue to instill that perspective in our students. I have seen too many young specialists recently who wouldn't know much more about the animals for which they have taken cells or amplified extracts than how many legs they have, and some might not be sure of that… At the same time, many students are still being trained with the breadth that encourages them to construct their own research questions, acquire the techniques to do their own lab *and* field work, in ways so that they can really know the organisms, their habitats, and their interactions—and thereby can bring a diversity of perspectives to bear on good questions. We are also seeing that our enthusiasm for our creatures is transferable to colleagues trained in problem orientations—endocrinology, development, ecology; they are increasingly recognizing that species do matter; variation and evolution, as well as fundamental mechanisms and processes, are important and they need both our expertise on the biology and systematics of the animals and the acquired ability to train their students more broadly.

Let's look at the science of herpetology—note how many of the animals mentioned in the witches' incantation are herps—the fenny snake, newt, frog, adder, blind-worm, lizard—vs. bat, dog, and howlet. Herps have been observed and objects of interest, mystery, legend, and use for thousands of years. The witches didn't include any bony fishes in the cauldron, perhaps because they were known nutritional sources, rather than mysterious…though the third witch did add the maw of a salt-sea shark… Herps and their parts have been viewed as dangerous, or possessed of mystical attributes, or even

useful, based on some experience with such attributes as venoms, skin toxins, etc., often followed by assumptions and extrapolations.

Some of our science today reflects old questions about those animals and the same parts that the witches used; this implies that we still seek an understanding of what things are, how they work, and how they come to be, albeit with new tools in a new research-oriented paradigm. "Toe of frog" is reflected in work on the genetic basis of limb development, evolutionary modification of such patterns, and what the digital arch is all about in manus and pes development and evolution. I don't worry about toes in caecilians, but I do worry about body elongation and tail loss. I look at "eye of caecilians" and patterns and processes of evolutionary modification of sensory systems, including mechanisms, and I use the research of others as guideposts, such as Bill Jeffrey and colleagues' lovely work on eye development and degeneration in blind cave fish (Jeffery, 2001; Jeffery et al., 2003; Yamamoto et al., 2000, 2001) so that I have some ideas about candidate genes as I explore caecilian eye-tentacle development and evolution. I use morphology and development to generate testable hypotheses about mechanisms, and about evolution, but also about the physiology, behavior, and ecology of the animals, and to find new characters of systematic utility. I do morphological and molecular systematics for themselves, as well as to have the phylogenetic framework to assess patterns of evolution. I try to be an integrative biologist.

Integrative Biology and Herpetology

I said that I would return to integrative biology—it is a 21st century science as I defined it, and research and training models are changing to accommodate and facilitate it. It is a concept that I have spent a lot of time promoting, as have others. It's more than just words; it is a conceptual framework, and I think it is important to herpetology, ichthyology, and 21st century science. Herpetology (and ichthyology) are fields that can thrive in and contribute to integrative biology, both as models and pragmatically.

What is integrative biology? "Integrative Biology" has had many different definitions (see Wake, 2003; Ripoll et al., 1998). To some workers, it emphasizes multidisciplinary research (cross-disciplinary, transdisciplinary; including the incorporation of physics, chemistry, engineering, sociology, economics, etc., as appropriate). Multidisciplinarity for those scientists especially emphasizes the bringing together of researchers with different, but specific, areas of expertise to address particular questions. To others, it means using a diversity of techniques and approaches in one's own research program; and to yet others, the emphasis is on hierarchical approaches to questions and techniques, or even just working on more than one taxon. There are almost as many conceptions of "integrative biology" as there are people interested in the idea; this results in those people considering themselves to be "integrative biologists" without any clarification of or agreement upon the central themes of the concept.

Why, then, is "integrative biology" becoming the label of choice for research programs in biology and medicine, universities and institutes, units in funding agencies, and programs in NGOs? For some, it is merely a label meant to replace taxon-based names now deemed "old-fashioned", unfortunately. In the more progressive units, though, the label has real meaning because it reflects an ongoing change in research and educational paradigms. Integrative biology—integrative science—bridges disciplines, and works within and across levels of biological organization and across diverse taxa over time, short (physiological) and long (evolutionary), and with many new applications, insights and styles—it is changing research paradigms (Goldstein, 1997; Kafatos and Eisner, 2004; Lakhotia, 2001; Liu, 2005; Murray, 2000; Paton, 2002; Pennisi, 2000; Vaudry, 1998; Wake, 1990, 1995, 1998, 2001, 2003, 2004, 2008).

More importantly, integrative biology is both an approach to and an attitude about the practice of science, as well as a description of a way of doing science (Barbault et al., 2003; Lakhotia, 2001; Wake, 2000, 2001, 2003). It deals with integration across all levels of biological organization, from molecules to the biosphere, and diversity across taxa, from viruses to plants and animals. It provides both a philosophy and a mechanism for facilitating science at the interfaces of

"horizontally" arrayed disciplines, in both research and training. Work at interfaces involves discussion of significant problems among scientists with diverse expertise and perspectives. It finds appropriate techniques, often from unanticipated sources, and it makes appropriate, often novel, choices of taxa for observation and experimentation (so that it need not be taxon-bound). It particularly stresses an approach to problems and questions from diverse perspectives, so that the explication of the research protocol has the potential to be innovative and integrative, as appropriate to the question being addressed. It can convey a "competitive advantage" over a unilateral approach by facilitating more data and new perspectives generated by collaboration across disciplinary lines. I've written a lot about integrative biology and its general principles and attributes (see Wake, 2000, 2001, 2003, 2008, for summaries). The principles include: (1) the delineation of complex questions; (2) the organization of expertise to tease apart the questions hierarchically [reductionistic approaches, the comparative method, taxa, etc., retain significant places in a hierarchical and flexible/adaptable approach]; (3) the exploration of several levels of the hierarchy of biological organization; (4) extensions of expertise into nontraditional arenas; and (5) development of new educational/training modes. It is not just any one of these, or looking at more than one species, or using multiple techniques. It is flexible, as the questions being investigated demand, and diverse expertise can contribute in new and different ways.

Herpetology as a field, a profession, deals with those tenets—workers are centered in both a taxon and a problem area, but with an understanding of other organisms and of other relevant biological processes. Furthermore, many herpetologists combine laboratory and fieldwork, based on and contributing to breadth of knowledge. They are masters of a diversity of techniques, and they have broad perspectives, often derived from field study and lab application. We are primed for it; many of us have been doing it for years, before the label became more fashionable.

I'll show you just a few examples of integrative biology for which herps are the focal animals:

1. Karen Warkentin's lovely work on *Agalychnis* timing of development, in which she has shown that tads hatch earlier if they have reached a critical stage so that they can perceive the presence of a predator, either approaching or attacking sibs; she is looking at development, behavior, ecology, and sensory biology, now using physical simulation techniques (snake movement vs. rainfall) to see what the composition of cues is, and how they are perceived. (See Gomez et al., 2006; Touchon et al., 2006; Vonesh and Warkentin, 2006; Warkentin, 1995, 1999*a*,*b*, 2000*a*,*b*, 2005; Warkentin et al., 2001, 2005, 2006*a*,*b*, 2007).
2. The whole body of research on the problem of the global declines of amphibian populations and species is integrative biology—it interplays ecology, development, epidemiology, microbiology, immunology, systematics, evolution. Colleagues at Berkeley study the effects of introduced fishes on frog survival (pristine high Sierras lakes, seeded with trout that outcompeted the resident frogs; when the nonnative fish were removed the frogs recovered (Vredenburg, 2004), and also examine the epidemiology of chytridomychosis and the immune systems of the susceptible frogs (Briggs et al., 2005; Knapp et al., in press; Raschowitz and Vredenburg, 2004; Raschowitz et al., 2005, 2006; Rollins Smith et al., 2006; Vredenburg and Wake, 2007; Vredenburg et al., 2007, in press). They conduct their work in communication with that going on in many other labs (e.g., Brunner et al., 2004, 2005; Collins and Halliday, 2005; Collins et al., 2004; Lips et al., 2006; Mendelson et al., 2006). These scientists don't always agree with each other, but their different perspectives are advancing research, and potential solutions, by leaps and bounds.
3. Anne Peattie, a graduate student in Robert Full's lab at Berkeley, is doing beautiful work on adhesion of gekko toes, in which she is doing sophisticated force analysis on single setae, and putting her work in comparative and phylogenetic contexts, rather new for biomechanics (see Autumn and Peattie, 2002; Autumn et al., 2002; Chen et al. 2007; Peattie, 2007).
4. One of the questions we examine in my lab is that of the evolution of derived modes of reproduction. We look at viviparous members of all three orders of amphibians; the example here is that of our collaboration on the *Salamandra salamandra* adelophagy system. Most populations of *S. salamandra* are ovoviviparous, giving birth to large numbers of larvae that are yolk-dependent for nutrition. Some, in northern Spain, however, have developed intrauterine cannibalism as a viviparous mechanism; fewer develop, but they are born fully metamorphosed in less time. Colleagues at Madrid and Berkeley have used genetic markers to assess the phylogeography of the system (García París et al., 2003); cannibalism is sweeping over northern Spain. In my lab now, a postdoc from Spain and I are looking at the heterochronic patterns of development and searching for mechanisms for the evolution of the system. Fifty percent of fertilized ova of the viviparous, cannibalistic salamanders arrest at blastula; the survivors develop more rapidly and

somewhat differently than the ovoviviparous forms. Nutrition plays a role, but is not causal, we think (Buckley et al., 2007). We have some new insights…

Many more examples of integrative biology are ongoing in many places; I just know these well. Note that these examples are highly collaborative, involve graduate students and postdocs, and I admire their diversity…

Changing Paradigms

To turn to a different focus, I do have some concerns, though, about integrative biology and herpetology in 21st century science. I'm going to preach a little about this. Please bear with me; I've heard similar concerns from many colleagues. I will address a few concerns and problems, as I see them, briefly. One crucial area is the relationship of science, training, and change. I interweave aspects of these concerns throughout this essay.

Education, Jobs, and Change

Some, but not all, herpetologists who are integrative themselves train their students to be multi-dimensional and to think and act integratively. However, many do not. The standard model of graduate education is still that of an independent scholar staking out a unique realm of investigation, becoming steeped in techniques for both data generation and analysis and a sense of "ownership" of a taxon or an area, and with limited to no interest in collaboration. Some of the reasons given for maintaining this model include: (1) the job market—jobs being described in terms of specific attributes; (2) inertia of the "it worked for me" variety; (3) the constraints of curriculum; (4) inability to have breadth because of the literature explosion; and (5) the reward system that promotes independence. I applaud all who are training students to be trans-disciplinary, to recognize what their expertise can contribute to multi-dimensional questions, and to be part of a team that meshes expertise as necessary and appropriate to the scientific problem being studied. I especially congratulate the students who are developing and refining their integrative skills, whether on their own initiative or as part of their training. I believe that the reasons that we maintain the old model are spurious—**we** design curriculum, **we** establish and describe the job market, **we** know the reward system is often less than ideal (for example, I think impact factors are a joke, and the scramble for numbers of publications that is emerging because of them is a travesty for science). The literature explosion is real, but should not be thought of as so formidable—the computer-aided tools that facilitate the explosion are also those for accessing and organizing the literature, so that its exploration can be efficient and timely in ways that never existed before. Just do not be deluded into thinking that the literature began in 1989 or 1952 or however far back a search engine has put references on line; it is still well worth going to the library, and exploring five feet (or more) on either side of the journal number you are looking for…that is still a part of scholarship. Finding the unanticipated can occur in the literature, as well as at the lab bench and in the field… Also, it is important to recognize that some of the "older" work is still the best and most accurate that exists; for example, Erdmann's (1933) descriptions of the development of *Rana* and *Triturus* should be in the lexicon of all amphibian evo-devo researchers.

It is up to us to be proactive about change, and that, too, is not part of our training, except in aspects of our research. Those of us most steeped in our independence are often least likely to be strongly collaborative voices in initiating change, because we are used to having control over our science and our activities. However, we are good at complaining when we feel ill-served by the system, but not at banding together with others who share the concern to voice it, and to come up with constructive plans for changes and their rationales. I do realize that some of us are involved in doing this, and more of us all the time. We must band together more frequently and openly, forming coalitions of like-minded colleagues. I do not advocate ideological camps, but issue-based, self-organizing and dissolving, groups that see problems and their solutions, and have the will, drive, and credibility to make changes that make research and education more flexible and more timely.

Herpetological Leadership

To get back to the question whether herpetology is a science, I answer that yes it

is, because it meets the definition of science in that it contributes to knowledge and understanding. But we must also think of herpetology in the context of the practice of 21st century science, and the kinds of questions that are being asked. We have a tendency to appear modest and content with our science, even though in many ways, we are far from content. Like all scientists, we constantly strive to incorporate new and useful techniques, new ideas and approaches, new ways of doing our science. At the same time, we, wisely in my opinion, strive to continue those practices that make us herpetologists, rather than other kinds of biologists—that respect for the animals, the desire to know as much about them as possible in order to understand the parts we are concentrating on, appreciation for the animals in their habitats, and for their aesthetic value. We are perfectly capable of using the tools that we and our colleagues develop to increase the scope and currency of our work and to answer biological questions that have the potential to be at least as far-reaching as those of others of our colleagues (though we are not good at articulating this, all too often). We are the holders of the power of the comparative method, and we need to continue to convey its utility in 21st century science. It is fundamental to evo-devo analysis; it is the way to assess phylogenetic history. Comparison knows no end. For example, as we add more outgroups, we learn more about relationships at all levels. Conversely, the inclusion of a phylogenetic framework for comparative biology of all sorts has been a highly significant step allowing many advances in understanding evolutionary patterns (see, e.g., Brooks and McLennan, 1991; Wainwright and Reilly, 1994).

Herpetologists and ichthyologists are among the leaders in advancing understanding of the national and international need for collections, museums (university, governmental, and free-standing), and for the space and expertise that necessarily go with them. We must continue this, however. A molecular biologist doesn't have to justify lab space or massive animal care quarters; why should a university museum and its faculty have to justify their space and facilities time and time again? We need frame our justifications in terms of national needs, and we can. I'll come back to this below.

Responsibility to the Public That Supports Us

Another problem, and one of my themes, is that we, as scientists, are thought to be the witches of today in many quarters. Much of the public, that amorphous body that we cannot define but are also part of, think that we have a mystical authority, and many fear and resent our prognostications—after all, who gave us this authority? The problem is that science itself is misunderstood and mistrusted. So, that fact assigns us a huge responsibility for the survival of our science, and science in general—my third theme. We must be proactive, and stop expecting "others" to take care of the situation for us. We cannot just rest on the quality of our research, and letting "others" articulate what our research contributes to the general good. We can all contribute in our own ways. We lead privileged lives and careers, by and large; we can be students all our lives, and be paid to do it; we set our own hierarchies and do what we choose with relatively limited constraints compared to many other kinds of careers; we often travel extensively for various reasons; and, yes, we work hard because we usually love what we are doing. However, we need to keep in mind two major concepts: we must acknowledge and involve the public that financially supports our efforts, and we must deal more directly with the implications for and contributions to society of our work, both our teaching and our research.

We have not done a great job as educators, as we see in the current state of the understanding of science. It is not just the evolution situation; it is the understanding of science as a process—the nature of evidence and how to assess it, how to generate an hypothesis (and what an hypothesis is), and how to draw a conclusion, and critical thinking generally. As long as our government spokespeople keep doing things like withholding parts of data to make their points, and assuming that scientists and ethicists are automatically in opposition, we see some of the extent of the problem.

We should be able to explain and justify our research to the public that pays for it. We

should take every opportunity to tell them about it, and what it contributes to science, and what science is. We can do it *better* than some of our colleagues can because we can walk in with a jar of tadpoles or fishes, a bag of salamanders or lizards, or snakes, a turtle; we can capture the attention of our audience with REAL LIVE ANIMALS. We can then tell people about their biology, and why they are important to science, and more to the point, to us as citizens—e.g., the value of biodiversity and what the animals contribute to the good of the ecosystem, and therefore to us. Most people have no concept of what animals and plants in nature really mean to the well-being of the human species, and how the human species is damaging it. Real-home examples make the point, with a five-year-old and her parents, and with the congressional staffer on the Hill. I know this; I and a number of colleagues have talked with such folks, with our local groups and with our national and international leaders. For example, I had the privilege of having tea with the President of Taiwan a few years ago when I was Secretary General of the International Union of Biological Sciences, and our conversation revolved around biodiversity and its conservation. The interesting point was that the President was familiar with the concept and Taiwan's efforts, but hadn't a clue about what animals and plants were in his country, where they were, how they interacted, and what they contributed to the health of the nation, including its economic health. He became fascinated, continued the discussion long past our allotted time, and directed the President of Academia Sinica to develop information materials for his aides. I've done the usual trips to the Hill on "Visit your Congressperson Day" several times for several organizations… It is interesting; one learns a lot by doing it, and contributes a lot as well.

Breadth of Herpetological Outreach

I urge that those of us at R1 universities stop telling our graduate students that a research and teaching job at another R1 university is the only way for them to succeed. I am a firm believer that we need well-trained Ph.D.s in many areas, not just teaching in colleges and universities, and "nonacademic" jobs ought to be valued, rather than something to do if the university position doesn't come along. We need our kinds of scientists in congress, on staffs of governmental and nongovernmental agencies, working in foundations, working in industry, and teaching at all levels and in diverse venues.

Graduate students can start early to make contributions to the public understanding of science, and to thinking about the kinds of contributions they might like to make later, whether in academia or in another arena. More and more universities are encouraging graduate students to participate in public outreach programs. To offer an example, my own department and its affiliated museums are doing a lot of this. Our University of California Museum of Paleontology (UCMP) developed the "Understanding Evolution" website that is so good that it has been the focus of lawsuits against the authors, the University, and NSF; the museum is expanding the site into one for "Understanding Science". It employs graduate students from all parts of the department of Integrative Biology, and several others, to write and produce pieces for the site, and then to evaluate them. We also have one of NSF's K–12 training and education grants, through our Museum of Vertebrate Zoology, UCMP, and the Essig Museum of Entomology. Graduate students are employed to develop teaching materials under the attention of professors and K–12 teachers, and to test the materials on site in local schools. Integrative Biology has long had a "Graduate Survival" seminar that gives a lot of pragmatic information about Berkeley (balancing teaching and research, grant writing, presentation of one's research to different venues, professional and public, etc.), and it constantly asks the question "What is your research contributing that is new to science, and how does it help society?" Sometimes that is far from easy to answer, but we should think a lot more about it.

Young scientists should become involved in the committees and mechanics of their universities, although not too much, because it can be swamping. Why? Because one learns how the institution functions, thereby being able to correct the rumor mill and especially

to contribute perspective to how it should be run. Such service is also an opportunity to meet people from other departments, and that can be very healthy. Young scientists should also become involved in professional societies. Youth gives the life-blood to our societies; we need to style our societies according to the needs and interests of our successors. However, we need to know what those needs are. Professional societies are in danger now if their main functions have been to hold an annual meeting that brings colleagues together to hear the latest science, and to produce a journal that presents those scientific accounts. With new steps in informatics, and internet access to the literature usually outside the bounds of the societies that produce the journals, the value of hard copy is diminished, and membership in societies is dropping yearly; it is membership dues and library subscriptions that have supported the publication enterprise. Several societies are deeply concerned about this situation, and have organized meetings with publishers and consortia to try to find ways of preserving societies and journals while proceeding with more open access. I and our AIBS team organized such a meeting recently when I was President, and our council members, all representing member societies, including HL, ASIH, SSAR, and AFS, asked penetrating questions of the people developing the access mechanisms. They had not thought of some of the issues, so it was a productive session. Again, we need to be more proactive, both about our societies and their functions and our science.

There are many things that we can do, and each of us should take on areas that interest us and in which we think we can be useful. Speaking to small groups, working with schools, science fairs, leading field trips, all are the venues that engage people and give us a chance to talk about our science and what it contributes. A major contribution can be made through service to our professional societies and to ngos; these are well-respected voices for the profession, and can carry a lot of weight, so long as they do not make biology look fragmented. Impressions are important; we do need our piece of the pie, but we are better off joining with other like-minded groups, so that we **all** get the **whole** pie. Some committees and boards are really worth serving on, because you contribute an important perspective and you learn a lot. I know that I am preaching to the choir; many of the people taking the time to read this are involved in some activism. But we need to tell our colleagues more about it, and generally be more communicative. This is especially important at national and international levels—there are groups that are not well known, except to their participants, but that are doing a lot of work on the issues that concern us. Sometimes they are not as well informed as we would like to see, though. Consequently, they need more input from working scientists—new examples, new ideas, and new people.

Communication and Collaboration

Herpetology is indeed a science, and it is also part of a larger sphere of science. As 21st century science is dealing with larger, more encompassing questions, as funding declines, as more good people are available, we have to think more in terms of collaborative efforts and of multi-disciplinary approaches. We as herpetologists, no matter what our taxon-bases and our problem-area centers are, have a great deal to contribute to ways of addressing questions of all sorts, to the advancement of science, and to teaching and training highly qualified students who are capable of dealing with this rapidly changing scientific climate.

Biology appears fragmented, compared to physics, chemistry, and astronomy. The latter scientific arenas get what they need by speaking with one voice, and acting together. It is time for us as biologists to speak with one voice, rather than as individual areas, in most contexts. I believe that the bio-medical vs. "curiosity-driven" science division is a false dichotomy, but we need to reinforce what *we* contribute. The issue is the well-being of humans, of all species, of the planet, and of science. For example, our concern about biodiversity—what it is, how it works, what it contributes—is important to sustainability—of humans, and of the planet, including its physical components and interactions, as we now know well from emerging global change data. Herpetologists have a major investment

in this and we contribute a lot to the scientific discussion. We need to "speak with one voice" within herpetology as well; in my opinion, the time for "ownership" of taxa and research areas is long past. Collaboration in order to reach our common goals of accuracy, predictivity, and testability is demanded now for science to progress, including our own. This is true for all the sub-fields of biology. Pulling together, we are ***biologists***, and that gives herpetology even more credibility because of the greater presence and effectiveness of its contributions to science. Our place at the table is secure, but our voice should be heard more often, and more collaboratively, at all levels of discussion of science and policy.

In conclusion,

1. Biology, and herpetology, need to speak with unified voices.
2. Our contributions should be better known and understood, and it is up to us to make it happen.
3. Our work should be ever more collaborative, as 21st century science approaches complex problems and issues, scientific and societal. We have much to offer.
4. We, as taxon-based scientists, have developed and represent some of the best possible approaches to integration and synthesis, and dynamic science, that exist.
5. Our science is thriving, and it will continue to do so through creative research and better public understanding of its contributions.

I am proud to be a herpetologist, and to try to contribute scientifically, academically, and in terms of service to the profession. I do not think it is naïve to say that our contributions to science really are helping to make a better world.

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