Making conservation physiology relevant to policy makers and conservation practitioners

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Abstract

The recognition that physiological tools and knowledge have the potential to inform conservation policy has led to the definition of the nascent discipline of "conservation physiology." Indeed, conservation physiology has much to offer policy makers because of the rigorous experimental approach and the focus on elucidating cause-and-effect relationships. However, there remain a number of challenges that might retard the adoption of this approach. Here, we identify these challenges and suggest a path for both physiologists and conservation practitioners to integrate their respective fields. One issue is that threat assessments and conservation actions tend to focus on populations or species, whereas physiology tends to focus on individuals, cells, or molecules. Physiologists must determine if and how the physiology of individual organisms can influence population-level processes. It is also necessary to validate more tools in the "conservation physiology toolbox," and ensure a thorough understanding of the physiological biomarkers applied to conservation efforts. Research on imperiled taxa will be more useful to those making management decisions, rather than research focused on model species. We also recommend changes in the education of physiologists such that physiologists understand the process of policy making, and the needs of conservation practitioners.

Introduction

In response to threats to global biodiversity, conservation practitioners require science-based information on the causes and consequences of species decline so that they can develop and implement effective strategies to stem this loss. Such a task is complex, particularly given that conservation science is a crisis discipline (Soulé 1986) that often requires decisions to be made without the burden of evidence that one should use to support important policy and management decisions (Sutherland *et al.* 2004). Solutions often require interdisciplinary approaches; as such, the application of traditional fields toward conservation has given rise to a number of subdisciplines (see Appendix S1). The nascent subdiscipline of conservation physiology, defined as "the study of physiological responses of organisms to human alteration of the environment that might cause or contribute to population declines" (Wikelski & Cooke 2006), is one of the most recent formal integrations. Although the recent publication of several synthetic papers (Carey 2005; Tracy *et al.* 2006; Wikelski & Cooke 2006; Cooke & Suski 2008; Pörtner & Farrell 2008) and convening of symposia (e.g., Stevenson *et al.* 2005; Stevenson 2006; Franklin 2009) suggests growing interest in applying physiology to conservation issues, it is questionable whether conservation physiology is informing policy. Here we adopt a proactive approach to address what we regard as some of the challenges facing conservation physiology. Our thesis is that physiology has the potential to contribute to identifying and solving complex conservation problems, but there are a number of challenges that are preventing the full realization of this opportunity. First we provide a brief overview of the state of conservation physiology, recognizing that more complete treatments exist elsewhere (e.g., Wikelski & Cooke 2006). We then discuss a series of challenges facing conservation science and propose a framework for addressing them such that conservation physiology can be relevant to policy makers and managers.

Role of physiology in conservation policy and action

Although the term "conservation physiology" was only formally coined in 2006 (i.e., Wikelski & Cooke 2006), there was clearly research conducted before that time that fell within the realm. Indeed, some of the pioneering work in conservation physiology arose in the 1960s as physiologists and toxicologists studied the decline in raptor hatching success resulting from DDT (reviewed in Grier 1982). However, it is difficult to determine if scientific studies in the conservation–physiology interface influence policy or inform management decisions. The lack of direct connection indicates that conservation planning would benefit from explicit and extensive discussion of the relevance of scientific research to policy.

Even when scientific advice is available, there is a tendency for policy makers to focus more on experience than on science because many management interventions remain unevaluated and, even where data are available, much is not readily accessible in a suitable form (Sutherland *et al.* 2004). As noted by Caro (2007) in his retrospective analysis of progress (or lack thereof) in the conservation and behavior interface, it is necessary to demonstrate clearly through concrete examples how information from a subdiscipline can be used to inform decisions. Moreover, what policy makers consider to be the challenges in incorporating information of a physiological nature, should it exist, needs appraisal. Indirect or complex physiological relationships are less likely to be incorporated into policy than direct relationships where the causes-and-effects of the physiological relationships are well described. To date, only one paper on conservation physiology (i.e., Tracy *et al.* 2006) has discussed conceptually how physiological knowledge can be translated to management action. They suggest that physiological knowledge is typically used as part of informed opinion, which is then used to guide management decisions. Tracy *et al.* (2006) argue that physiological knowledge and theory can be used to generate hypotheses and that experimental data arising from hypothesis testing could serve as the basis for conservation decisions. The authors used resource acquisition in threatened desert tortoises as a model, but most importantly, they evaluated resource acquisition at several levels and from different perspectives including physiological, behavioral, and ecological. While Tracy *et al.* (2006) present a useful perspective and a relevant success story, one big question remains: with such concrete examples of how conservation physiology might be useful to managers and decision makers, why are there so few examples of physiological knowledge being used in conservation decision making?

Obtaining more relevant physiological knowledge

For conservation physiology to be effective, physiological parameters (or biomarkers) must be both physiologically and ecologically relevant, and preferably should be repeatable and minimally invasive. Here we summarize a number of research needs and issues that must be addressed to understand the fundamental role of physiology in conservation and to improve the ability of physiological knowledge to inform decisions.

Physiological relevance

To ensure that physiology becomes and remains useful as a policy tool, it is necessary to identify and measure physiologically relevant biomarkers. By necessity, biomarkers need to be linked to population-level processes, such as mortality and fecundity, in order to address fundamental problems in conservation. At the population level, there are many factors (e.g., density dependence, behavioral responses, compensatory growth) that can buffer or negate changes to an individual's lifespan or reproductive success (Calow & Sibly 1990). To understand physiology within an ecologically relevant framework, it is necessary to conduct a parallel body of experimental research on the factors that influence and modulate the stress response in wild populations. This link has so far been relatively unexplored, but has the potential to be important and beneficial for ecology, evolutionary biology, and conservation science.

Conservationists seek to maintain biodiversity and ecologically relevant numbers of a given species, and to maintain healthy individuals within a species, so that each species is able to retain a role in ecosystem functioning (e.g., providing a food source, regulating population density, or providing a service such as pollination for another species; Soulé 1986). Therefore, biomarkers should provide not just an assessment of whether individuals are able to survive and reproduce successfully, but also whether a population is able to fulfill its ecological function. Due to the important role of hormones in coordinating the physiological and whole-organism responses of living things to their environment, endocrinology has provided some of the most prominent and successful set of biomarkers for conservation physiologists (e.g., Wingfield *et al.* 1997; Denver *et al.* 2009). Hormone measurements are particularly valuable for providing information on the reproductive status and stress of individuals within populations of interest (reviewed in Denver *et al.* 2009). As an indicator of the popularity of endocrine measurements, and in particular, stress hormone measurements, more than 80% of the papers that have cited Wikelski & Cooke (2006) have used glucocorticoids (the primary stress hormones in vertebrates) as indicators (according to a Web of Science search conduced on January 26, 2010). However, the application of stress hormones to conservation science remains imperfect, largely because relationships involving stress hormones and are complex and highly context dependent (reviewed in Busch & Hayward 2009).

Other biomarkers at various levels of biological organization (e.g., cellular or whole-animal) have the potential to be useful and directly applicable to fitness and population dynamics. Any biomarker that can be understood within a quantifiable cause-and-effect framework and linked to measurable fitness and population outcomes can be applied to conservation biology. Measures of whole organism performance (e.g., running performance, swimming performance, or metabolic scope in animals; photosynthetic capacity, respiration, or transpiration in plants) incorporate many physiological systems, and might be more directly applicable to fitness at the individual level. For example, Farrell *et al.* (2008) have described how aerobic scope models generated using swim tunnels equipped with respirometry sensors can be used to predict migration failure of adult Pacific salmon in the face of climate change.

Genetic and genomic markers and tools also have the potential to yield direct predictions of survival and therefore fitness, and can be applied at both the individual and population levels. Ryder (2005) describes the field of conservation genomics, which has roots and relevance to both conservation genetics and physiology. Gene arrays, a tool in functional genomics, can profile the expression of thousands of genes at once, enabling the identification of metabolic pathways and regulatory elements involved in organismal response to environmental stressors on a genome-wide scale (Ryder 2005). Additional research that links any of these easily measurable physiological parameters to fitness will have benefits for the field of conservation physiology.

Scale

One fundamental problem with making conservation physiology applicable to managers is providing information at a scale that is relevant. Conservation physiology shares this challenge with behavioral approaches to conservation; Beissinger (1997) pointed out that behavioral data are often collected at a scale that is most relevant to the conservation of local populations and species, while protecting global biodiversity will most likely occur at broader scales (see Beissinger 1997 for examples). One way to think about scale is to consider fine-filter versus coarse-filter approaches to conservation science, keeping in mind that both approaches still measure the physiological responses of individuals (Chown & Gaston 2008). However, the choice of individuals to sample, and the application of knowledge, can differ widely; "fine-filter" approaches focus on tools to recover endangered species or populations, while "coarse-filter" approaches focus on preventing the loss of biodiversity and operate at the level of the community or ecosystem. Conservation physiology, like behavior, has typically focused on the "fine-filter" approach. However, we contend that conservation physiology has much potential to contribute to both strategies. At the fine scale, physiological tools have proven invaluable for toxicological studies across taxa (e.g., Scott & Sloman 2004). As a coarse-filter example, a recent synthesis by Chown & Gaston (2008) considered how whole-organism physiology could provide insight into the mechanisms underlying, and consequences of, environmental change. They focused on five key drivers of environmental change and concluded that macrophysiology (i.e., "the investigation of variation in physiological traits over large geographical, temporal, and phylogenetic scales" [Chown & Gaston 2008]) can elucidate the impacts of these drivers and their interactions, and also provide insights into previously unrecognized threats to biodiversity. Indeed, macrophysiology is primarily a "coarse-filter" approach, dealing with spatial scales that are relevant to managers (Helmuth 2009). Macrophysiology has the potential to shift conservation physiology from merely identifying stressed or unhealthy organisms to a more epidemiological approach, using broad-scale patterns in physiology to predict and therefore potentially alleviate biodiversity issues. Conservation physiology can provide useful tools to monitor widespread threats to biodiversity such as in the case of wildlife threatened with infectious disease (e.g., Daszak *et al.* 2000) or to determine the physiological tolerances of organisms, and therefore to predict the responses of organisms to climate change (e.g., Visser 2008). Physiologists and ecologists have provided a theoretical framework for linking individual physiological tolerances and responses to population-level processes (e.g., Calow & Sibly 1990; Ricklefs & Wikelski 2002). While there are a handful of studies that have attempted to cross this bridge (e.g., Porter *et al.* 2000; Pörtner & Farrell 2008), it is conceptually difficult to attempt to move from what is going on at the level of the individual (or below; e.g., cellular, organ system) to the population and widespread empirical examples on a range of taxa are still lacking.

Field-based research

Consistent with the proposed focus of conservation physiology is the need to increase the number of physiological field studies. Although physiologists have been collecting data outside of the laboratory for many years, technological advances such as improved telemetry and biologging devices, infrared thermometers, and field diagnostic tools for blood samples have renewed interest in field physiology with several synthetic papers summarizing the various tools and challenges (Goldstein & Pinshow 2002). Much value can be gained from monitoring the in situ stress responses of organisms to their environment (e.g., Vance *et al.* 2003) and most of the recent advances in this realm have come from the use of biotelemetry and biologging devices (Cooke *et al.* 2004). These devices are increasingly being coupled with sensors (e.g., depth, heart rate, electromyograms, temperature, acceleration) that provide information on how a wide range of animals (from marine invertebrates to birds) are responding to environmental change and disturbance (Cooke *et al.* 2004). When studied in isolation in the laboratory, it is often not possible to eliminate holding artifacts or replicate the many complexities of the wild. There is value in controlled laboratory experimentation for isolating different effects. However, where possible we believe that conservation physiology should be focused where problems are observed—in the field.

We encourage physiologists to view conservation problems as experimental designs, something that has been done by conservation biologists with great success (reviewed in Gordon & Bartol 2004). Classifying anthropogenic activity as a "stressor," it is possible to look at comparisons and gradients of stress while providing results that are relevant to conservation. As an example, Homan *et al.* (2003) evaluated the glucocorticoid responsiveness in spotted salamanders (*Ambystoma maculatum*) from urban and exurban areas and determined that responsiveness was lowest in those individuals captured in urban areas. This suggests that they did not have the ability to respond to additional stress or were experiencing chronic stress. Hasler *et al.* (2009) describe how hydropower facilities on rivers provide opportunities for studying the physiological consequences of variable flows, something with relevance to ecology and conservation (i.e., assisting regulators in determining appropriate water flow restrictions for hydro utilities). In these examples, the researchers were able to use a gradient of existing conditions rather than experimentally manipulating either forest cover (in the case of Homan *et al.* 2003) or water flows (in the case of Hasler *et al.* 2009), experiments that would have otherwise been logistically difficult and costly.

Minimally invasive

The importance of minimally invasive techniques has already received a great deal of attention (e.g., Wingfield *et al.* 1997). When handling organisms, especially the endangered animals that conservation biologists often study, measures should be taken to minimize handling-related stress. Tissue biopsy is one such minimally invasive technique. However, for other particularly vulnerable or sensitive groups, a sampling method that does not require capturing the animal is usually necessary. For example, analyzing fecal samples can be used for measuring hormone concentration, and require no contact with the study organism (Millspaugh & Washburn 2004). In some situations, measures of physiology can include remote measures of performance (e.g., video of animal locomotion, calling rates of some animals). Metrics like these, that incorporate whole-animal physiology, are preferable in that they are likely more ecologically and physiologically relevant (i.e., more likely to predict in situ mortality or reproductive success), and if they can be measured remotely (e.g., through biotelemetry; Cooke *et al.* 2004), could prove to be ideal tools of conservation physiologists.

Translating physiological knowledge into conservation policy and action

Transforming science (whether theoretical or empirical) into information and tools that can be used by decision makers remains a major challenge in conservation biology (Possingham *et al.* 2001). Although there is a growing body of quantitative tools to support conservation planning and decision making, these tools have yet to be universally embraced by conservation practitioners and still have a number of limitations (McDonald 2009).

Conservation physiology has not existed as a formal discipline long enough to be incorporated into traditional management strategies. Moreover, physiology papers often end up in peer-reviewed journals that are not regularly viewed by conservation practitioners. Of course, the exception would be instances in which management agencies engage physiologists to address a question on their behalf (e.g., Farrell *et al.* 2008). Such perspectives clarify the need for actively engaging practitioners and highlighting the success of conservation physiology.

What did you learn in a study and what does it mean for the conservation manager? There is a burden on physiologists to reach conservation managers that could use their information. For example, physiologists could approach managers and openly discuss the opportunities for using physiology to address the problems. Such interactions could help to generate in-kind (e.g., access to samples, access to field sites) or financial support to facilitate conservation physiology research. The professional societies to which physiologists belong (e.g., Society for Integrative and Comparative Biology, Society for Experimental Biology) could also take a role in encouraging special symposia and celebrating successful examples of conservation physiology in their outreach materials (e.g., websites, newsletters). The Society for Experimental Biology has recently moved to incorporate a thematic session on conservation physiology (Craig Franklin, The University of Queensland, Brisbane, pers. comm.). Leaders of professional societies can also rally their members, as when Hannah Carey, the President of the American Physiology Society, encouraged her members to produce science that informs conservation policy and management (Carey 2007). The theme for the 2010 meeting of the American Physiological Society, "Global Change and Global Science: Comparative Physiology in a Changing World" reflects a growing interest in applying physiological tools to applied problems. Such examples provide hope that there will be more physiologists engaged in providing science to support the work of conservation practitioners in the future.

Not all of the burden must fall on the physiologist. Indeed, there has been much criticism levied toward managers for not using the appropriate types of evidence to support decision making (Sutherland *et al.* 2004). However, physiologists can make it easier for them to do so. Carey (2005) argues that one of the unique attributes of physiologists is their expertise in examining cause-and-effect relationships through rigorous experimentation. Indeed, she suggests that physiologists could be helpful in setting standards for the type of evidence that would constitute compelling proof of cause-and-effect relationships. Such data would be the ideal type of information to support evidence-based conservation (Sutherland *et al.* 2004), particularly when attempting to understand the interaction of multiple stressors (Carey 2005).

There is a general belief that physiologists are hesitant to become involved in applied science (Carey 2005). This is likely to do with a poor understanding of policy needs. Alm (2002) conducted a survey of natural scientists and revealed that they do not have confidence that either scientists or policy makers have the ability or desire to understand each other's way of thinking, although there is indeed interest in doing so (e.g., Gibbons *et al.* 2008). Some disciplines, such as conservation genetics (see Appendix S1) have overcome these problems, so why would physiology be any different? Perhaps it is because only recently have the tools existed to enable field physiology to occur with relative ease. With many physiological tools now being readily available for conservation applications, we contend that the most immediate and productive approach is through changes in training. Opportunities for training policy makers and managers require inclusion of the value and need for evidence-based conservation including an appreciation for cause-and-effect relationships. Also needed is a broad training in organismal biology with components that address ecological and evolutionary physiology. This approach will help decision makers to understand the full suite of tools available to support their decision making. For students enrolled in physiologically oriented disciplines, including applied components that emphasize the potential for physiological knowledge to contribute to conservation is recommended. Textbooks in conservation science, policy, and physiology should include examples relevant to conservation physiology. Professional societies could offer continuing education workshops to nonstudents on conservation physiology, focusing on opportunities and limitations. Moreover, education efforts also need to extend to the general public. This can be accomplished through outreach and science promotion, highlighting the success and exciting innovations arising from conservation physiology.

Conclusion

We have attempted to identify the challenges and limitations with conservation physiology and provide means of overcoming or addressing the challenges (Table 1). To conclude, we are not advocating an isolated and distinct field. Instead, we urge greater communication among physiologists and conservation practitioners, as well as dedicated integrative research on the topic of conservation physiology. Both the fields of conservation science and physiological ecology have been the subject of change and redefinition in recent years (Somero 2000; Groves *et al.* 2002; Denver *et al.* 2009) with renewed interest in integration and understanding. With these commonalities, one could easily envision integration between physiology and conservation. In fact, conservation science might serve to bridge the gap between many disciplines resulting in a more complete and rejuvenated integrative biology.

Table 1 Summary of the constraints and challenges that limit the ability of conservation physiology to generate, translate, or contextualize information that could be used by policy makers and managers. For each constraint or challenge, we provide a list of potential remedies and opportunities. We also provide a relative ranking of priority (high, moderate, low) and an indication of the cost (high, moderate, low) for addressing the constraints and challenges. Note how many of these are inexpensive, relatively simple fixes that deal less with the mechanics of conservation physiology (although still important) and more with training of appropriate personnel.

Constraints and challenges	Remedies and opportunities	Priority	Cost
Conservation physiology will not always provide information that is needed by managers and policy makers	Encourage publishing of failed accounts so that other practitioners can learn from experiences	High	Low
Conservation physiology papers rarely end up in journals that are regularly consulted by conservation practitioners and policy makers	Expand the scope of conservation science journals to include relevant physiological studies; Encourage physiologists to publish applied accounts in applied journals	High	Low
Policy makers and managers may not have the training to understand or incorporate physiologically based data into action	Revise training at the undergraduate level to include conservation physiology in conservation courses (and textbooks); Recognize the importance of training in basic physiology; Develop life-long learning opportunities to train practitioners via workshops or other professional development outlets	High	Moderate
Baseline physiological values from undisturbed systems are increasingly difficult to obtain	Time-series approaches (long-term monitoring) lend themselves to detecting trends including shifting baselines in the wild	High	High
Conflict between invasive/lethal physiological sampling and the ethical aspects of harming threatened organisms	Develop and validate nonlethal tools and techniques that can be applied without touching the animal	High	High
There is a fundamental problem in linking the physiology of an individual organism to fitness and population-level processes beyond the theoretical realms and this makes it difficult for practitioners to incorporate physiological data into decision making	Conduct fundamental empirical research on understanding the relationship between organismal physiology (from genes to cells to organs; including tolerances, response to stressors, regulate, and variability), fitness, and population-level processes (demography); Devote particular attention to understanding the role of stress across multiple scales to determine if individuals can be used as a proxy for populations and communities	High	High
There is a general lack of appreciation of physiological diversity (variation) and more importantly the role of this diversity in ecology and evolution	Conduct fundamental research on the role of physiological diversity related to rarity of species, informing captive breeding and reintroduction programs, and in understanding how organisms will respond to stressors and environmental change	High	High
There is a perceived disconnection in scale because physiology tends to focus on individuals whereas conservation science tends to focus on populations, species, and ecosystems	Continue efforts to understand macro-ecological processes and the role of physiological diversity at the landscape level	High	High
Many of the model organisms/systems currently used in ecological, comparative, and evolutionary physiology are common and not threatened and questions tend to be of a basic nature	Select study models/systems and questions that are of direct relevance to conservation (e.g., threatened); Applied research opens doors for additional funding opportunities	Moderate	Low
The general public (i.e., voters, philanthropists, and individuals that can alter their behavior in response to information) are unaware of what conservation physiology is and what it has to offer	Develop outreach materials (brochures, videos, websites) that include examples of conservation-oriented information with a physiological basis; Disseminate press releases at time of publication on studies that highlight conservation success stories using conservation physiology	Moderate	Low
To date, there has been a general failure to openly discuss and debate the opportunities and challenges associated with conservation physiology, particularly with a broad group of practitioners and scientists	Organize conferences, symposia, and workshops to address problems and opportunities in conservation physiology; Develop books and white papers that serve as resources for conservation practitioners	Moderate	Low

Continued.

Table 1 Continued.

Constraints and challenges	Remedies and opportunities	Priority	Cost
Determining which of the many possible physiological parameters to measure	Focus on relevant biomarkers that have the potential to bridge the gap between the organism and fitness/population processes; Where possible and scientifically logical, efforts should focus on the highest level of organization (e.g., metabolic rate) as these concepts tend to be most directly relevant to conservation	Moderate	Moderate
The conservation physiology "tool box" is not always useful in field settings	Additional efforts are needed to develop tools that can be used in sometimes remote field settings; Additional sensor development for use on biotelemetry and biologging devices	Moderate	High

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1: Further reading pertaining to conservation science. The application of traditional fields toward conservation science has given rise to a number of subdisciplines, and for brevity, only the references directly related to conservation physiology were included in the main text of this policy perspective. However, this appendix provides a brief overview of some of the most relevant and recent papers in other areas, for those interested in learning more about integrative conservation science.

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