The complementarity of single-species and ecosystem-oriented research in conservation research

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There has been much debate about the relative merits of single-species vs ecosystem-oriented research for conservation. This debate has become increasingly important in recent times as resource managers and policy makers in some jurisdictions focus on ecosystem-level problems. We highlight the potential strengths and limitations of both kinds of research, discuss their complementarity and highlight problems that may arise where competition occurs between the two kinds of research.

While a combination of approaches is ideal, a scarcity of funding, time, and expertise means it is impossible to study and manage each species, ecological process, or ecological pattern separately. Making decisions about priorities for the kinds of research, priorities for the kinds of conservation management, and associated allocation of scarce funds is a non-trivial task. We argue for an approach whereby limited resources for conservation research are targeted at projects most likely to close important knowledge gaps, while also promoting ongoing synergies between single-species and ecosystem-oriented research.

The magnitude of biodiversity losses, coupled with a need to address large-scale problems with limited budgets, has meant that resource managers and policy makers in some jurisdictions are increasingly focused on ecosystem-oriented research and management in lieu of traditional forms of single-species work (Simberloff 1999, Greene 2005, Anonymous 2006). In this short communication, we argue that disregarding single-species research and management ignores the important complementarity that arises from maintaining a mix of approaches in research and management. We first highlight the potential strengths and limitations of different approaches and emphasize the need for a range of strategies to conserve biodiversity. We demonstrate the potential for complementarity between different research approaches with case studies, and urge that complementarity be considered as part of funding decisions. We note that funding for conservation research and management is limited, making prioritisation critical to ensuring that funding is expended in the most efficient way possible (Stem et al. 2005, Field et al. 2005). We discuss how the choice of research projects may be effectively guided by strategically identifying key knowledge gaps, while maintaining the potential for complementarity between different research approaches.

Different research approaches

Although the various approaches to conservation and research management are best represented by a continuum, it remains useful to distinguish between the two broad categories; single-species approaches (Simberloff 1998) and ecosystem approaches (Hunter 1993,
Walker and Salt 2006). While the advantages and disadvantages of single-species and ecosystem-oriented research are readily distinguished (Table 1), the complementary outcomes that can arise from the simultaneous application of both types of approaches, are less often recognized (Table 1; below).

**Case studies highlighting complementarity**

**Arboreal marsupials in southeastern Australia**

Studies in the ashy-type eucalypt forests of the central highlands of Victoria (southeastern Australia) emphasize the complementarity between species-oriented and ecosystem-oriented research approaches. An initial investigation, which commenced in 1983, focused on the habitat requirements of a single species, the endangered Leadbeater’s possum, *Gymnobelideus leadbeateri*. Work quickly evolved to include the habitat requirements of other species, and ecosystem-oriented investigations of disturbance regimes. Ecosystem-oriented studies focused particularly on wildfire and logging and how they affect stand structural complexity, landscape heterogeneity and the long-term dynamics of critical forest structures (Lindenmayer et al. 1997). For example, relationships were quantified between wildfires and the location of old-growth patches (Mackey et al. 2002); the structural composition of multi-aged stands (Mackey et al. 2002); and the spatial distribution and abundance of large trees that were influencing the composition and abundance of avian and marsupial communities (Lindenmayer et al. 1991). This ecosystem-oriented forest research led to the recognition that disturbances were, in turn, major factors significantly influencing the abundance and population dynamics of not only Leadbeater’s possum but also entire assemblages of forest-dependent fauna (Lindenmayer and Franklin 2002). Detailed understanding of the habitat requirements of individual species coupled with an ecosystem-level understanding of natural disturbance dynamics has been critical for forest management, and has contributed to the development of new, more ecologically sensitive silvicultural systems (Lindenmayer and McCarthy 2002). These changes in conservation management would not have been possible from one research approach alone.

**The red-cockaded woodpecker in the southeastern US**

Another example of complementary single-species and ecosystem management approaches is the endangered red-cockaded woodpecker, *Picoides borealis*, in the southeastern United States. Research on its restricted habitat requirements is the key to ensuring this species’ survival. The species constructs cavities in old dying longleaf pine, *Pinus palustris*, trees, but such trees have become rare as longleaf pine forests have been dramatically reduced in area over the last century (Tebo 1985, Simberloff 2004). Even within apparently suitable forest, hardwood midstorey encroachment leads birds to abandon cavities. Concurrently, the loss of old trees and increasing isolation of populations in the fragments of otherwise highly suitable habitat have led to difficulties in finding mates and acceptable nesting trees (Conner et al. 2001). The 2003 management plan for the red-cockaded woodpecker (Anonymous 2003) successfully combines both single-species activities and ecosystem management. At the single-species level, individuals are moved to more suitable locations for successful breeding, and artificial cavities are installed to supplement the limited number of suitable breeding hollows in large trees. Ecosystem management includes altering fire regimes to minimize hardwood encroachment and ensure the preservation of large, old trees that, when diseased, will support suitable cavities (James et al. 2003).

**Global amphibian declines**

The initial recognition of a global pattern of amphibian declines and the subsequent assessments of hypothesized causal processes has only been possible because of the wealth of data provided by studies that span the continuum of single-species to broader ecosystem-oriented approaches.

The possibility that declining amphibian populations represented a global phenomenon was first given serious consideration in 1989 at the World Congress of Herpetology, Canterbury, England and at the National Research Council symposium on declining amphibian populations held in Irvine, California, 1990 (Bury 1999). The primary cause for alarm was that amphibian populations were rapidly declining from within relatively pristine environments on at least three continents (Gardner 2001). In the late 1980s and early 1990s, scientists in Australia and the Americas began observing dramatic declines of individual species. Concurrently, whole communities of amphibians were experiencing population declines in the cloud forests of Costa Rica (Lips 1998), the Central Valley of California (Fisher and Schaffer 1996) and along the north-eastern ranges of Australia (Laurance et al. 1996). The extent of the problem was revealed by researchers conducting detailed single species research and noting wider ecosystem-level responses (Crump et al. 1992), as well as by workers conducting ecosystem-level surveys and noting declines in the numbers or presence of certain species (Richards...
Table 1. Strengths and limitations of single-species and ecosystem management-based approaches to conservation research. Opportunities for cross-fertilisation between single-species research and ecosystem-oriented research are also listed.

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<th>Strengths</th>
<th>Limitations</th>
<th>Opportunities for cross-fertilisation</th>
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<td>Single species research</td>
<td>• Can elucidate causal processes underpinning declines of individual species</td>
<td>• Detailed information on a limited number of species — other species may be overlooked</td>
<td>• Can highlight links with other species, especially if functional roles are studied</td>
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<td>• Can provide useful information for policy and management, especially for threatened species, keystone species and invasive species</td>
<td>• “Cute and cuddly syndrome” – not all species receive the same attention</td>
<td>• Research on keystone species benefits understanding of entire ecological communities</td>
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<td>• Has a strong history and methodological basis</td>
<td>• Many relationships are highly species-specific or site-specific, which can make generalisation difficult</td>
<td>• Invasive species research and research on disease carrying species have ecosystem implications</td>
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<td>• Yields detailed understanding of relationships between a species and its environment; mechanistic understanding can sometimes provide insights applicable to other species (“the model system approach”)</td>
<td>• Can be overly reductionist and produce insights of limited direct benefit</td>
<td>• Charismatic species may attract funding for conservation, including for activities that benefit many species simultaneously</td>
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<td>Ecosystem-oriented research</td>
<td>• Encapsulates many species, so many species may gain from the research</td>
<td>• Lack of detail may hamper effective conservation</td>
<td>• Charismatic species can act as focal or flagship species thereby fostering public interest in biodiversity conservation</td>
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<td>• Identifies key management priorities that may benefit many species simultaneously</td>
<td>• Specialised or wide-ranging species may be overlooked or undervalued</td>
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<td>• Often involves species counts so it is immediately quantitative</td>
<td>• History of ecosystem-orientated management is recent and controversial</td>
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<td>• Cost-effective to look at many species at one time if high level of detail is not required</td>
<td>• Can confuse correlation and causation</td>
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<td>• Some general patterns and therefore management strategies may apply across many different ecosystems</td>
<td>• Patterns are often site-specific</td>
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<td>• Often seeks “simple” answers that may directly translate into tangible advice for policy and management</td>
<td>• Risk of “averaging” too broadly across species with differing requirements</td>
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et al. 1993). Both types of studies (ecosystem-oriented approaches and single-species approaches) provided vital information regarding the geographic spread and spatial variability of declines, rates of decline, and taxon-specific vulnerability or resistance to decline (Alford and Richards 1999, Gardner 2001). Assessment of these patterns suggested a range of possible underlying causal processes, including disease, climate change, acid precipitation, increased UV-B irradiation or various combinations thereof. Other studies provided increasing evidence that natural population fluctuations were unlikely to account for the extent of these patterns (Pechmann and Wilbur 1994), since entire suites of species were being affected across a wide range of locations (Trenerry et al. 1994, Houlanan et al. 2000). Laboratory analyses isolated the detrimental effects of abiotic variables such as by subjecting different life stages of individual species of amphibians to varying conditions, including increased levels of UV-B (Ovaska et al. 1997) and decreased levels of pH (Freda and Danson 1986). Collation of data from field stations correlated climate change with community level amphibian declines (Heyer et al. 1988), while histological assessment of moribund and dead specimens collected from Central America and Australia lent weight to the view that chytrid fungus, *Batrachochytrium dendrobatidis*, was playing an
important role in the declines of multiple species. Pounds et al. (2006) recently combined species-level and ecosystem-level research to provide convincing support for the view that global warming may be optimizing conditions for catastrophic outbreaks of chytrid fungus in the American tropics.

Other examples of complementarity

Evidence for the synergistic benefits of combining single-species and ecosystem-oriented approaches is further provided by the emerging fields of research on ecosystem function and resilience. Resilience can be broadly defined as “...the capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, identity, and feedbacks.” (Folke et al. 2004, p. 558). This research has established explicit links between the overall function and resilience of ecosystems and the various functional roles of different species (Elmqvist et al. 2003, Allen et al. 2005). While increasing species richness may benefit ecosystem function and resilience, it is becoming clear that the diversity of functional roles filled by different species, and the diversity of spatial scales over which they operate, are more robust predictors of ecosystem functioning and resilience than species richness per se (Allen et al. 2005, Hooper et al. 2005). Research on ecosystem functioning and resilience highlights the potential value of species-specific knowledge as well as more general knowledge on the number of species and community composition. Without single-species research to understand the functional roles of individual species, multi-species analyses of ecosystem function or resilience would not be possible.

Other areas of research such as on keystone species highlight synergies between single-species research and ecosystem-oriented research. Keystone species are those that exert a disproportionate influence on community composition and diversity, relative to their population density (Paine 1969, Power et al. 1996). In such studies, understanding the interactions of particular individual species can reveal key underlying processes that facilitate the existence of complex and bio-diverse communities (Estes and Palmisano 1974, Ebenman and Jonsson 2005).

Problems where the lack of complementarity between single-species and ecosystem-orientated research is not recognised

We believe that a lack of appreciation of complementarity between single-species and ecosystem-orientated research may lead to competition between the two broad kinds of approaches and lead to major failures in conservation and resource management. For instance, there is a large literature on the problems associated with the indicator species and umbrella species approaches (Landres et al. 1988, Lindenmayer et al. 2000), particularly where they: (1) fail to result in the maintenance of desired ecosystem processes, (2) fail to address a key threatening process, or (3) fail to result in the conservation of larger biotic assemblages of management concern. As an example, early research on the bivalve mollusc *Veselusio ambiguus* in Australian rivers suggested that the species would be a useful indicator species reflecting the integrity of aquatic ecosystems through highlighting the extent of heavy metal pollution (Walker 1981). Subsequent work at the ecosystem level found that the uptake of heavy metals by *V. ambiguus* did not reflect the extent of pollution in the surrounding river system, making the mollusc an unreliable and unsuitable indicator species (Millington and Walker 1983, Maher and Norris 1990). In other examples of problems that arise where a focus on single species research can produce poor ecosystem-based outcomes, Caro (2001) showed that protected areas set aside for large mammals in east Africa did not conserve small mammals. He also found that small reserves in Belize selected on the basis of conserving flagship species were not effective at conserving other elements of the biota and were no better than reserves selected using non-flagship taxa (Caro 2004).

Problems also can arise where a focus on ecosystem-based approaches fails to tackle specific key threatening processes for a particular taxon of conservation concern. For example, the conservation of large consolidated patches of native vegetation is an objective of many ecosystem-based conservation strategies. This can be valuable, but it can fail badly in addressing key threatening processes or conserving some key taxa of conservation concern. This is well illustrated in the heavily cleared agricultural ecosystems of southeastern Australia. Scattered paddock trees that exist in agricultural areas outside large consolidated patches of native vegetation are keystone structures (sensu Manning et al. 2006). They are critical for a wide range of species including vulnerable taxa such as the superb parrot, *Polytelis swainsonii*, that nest and feed almost exclusively in the agricultural matrix (Manning et al. 2004). The ongoing loss of scattered paddock trees is a major problem (Gibbons and Doak 2002) that is threatening the long-term persistence of the superb parrot (Manning et al. 2004) but which cannot be addressed by such traditional ecosystem-based approaches as reserving large patches of remnant vegetation.

Discussion

Knowledge to support biodiversity conservation is best derived through a combination of approaches, focusing
on both spatial patterns and ecological processes at multiple levels of ecological organisation. For example, ecosystem-based research programs can be a powerful means of detecting broad patterns and highlighting management strategies required to reverse or arrest the agents of change which may, in turn, benefit many species simultaneously (Bunnell 1995). However, the links between cause and effect are often only speculative in such broad-scale studies, and single-species studies are often needed to elucidate causal processes critical for the targeted management of a particular taxon (Caughley and Gunn 1996, Lindenmayer and Fischer 2006). While single-species research often yields knowledge immediately applicable to the management of the target species (and occasionally also others), such studies may miss patterns operating across larger scales that affect a much broader range of species. In addition, management strategies derived from conservation research on one species may generate conservation practices that are detrimental to the conservation of others (Simberloff 1998, Baker 2000). Thus, successful biodiversity conservation remains a major challenge because many factors need to be understood to develop effective management strategies (Gaston and Spicer 2004). Therefore, we believe that it will often be prudent to employ a mix of strategies to produce more complete insights into biodiversity conservation than to focus efforts on either approach in isolation.

While a combination of approaches is ideal, a scarcity of funding, time and expertise means it is impossible to study and manage each species, ecological process and ecological pattern. This limits the scope and number of research programs that can be conducted. Making key decisions about priorities for the kinds of research, priorities for the kinds of conservation management, and associated allocation of scarce funds is a non-trivial task. The “ecological triage” approach (Possingham 2001, Hobbs and Kristjanson 2003) advocates directing limited resources for conservation funding at problems where management success is most likely. Possingham (2001) argues that such an approach is essential for single endangered species work because too many resources in the past have been directed to species on the brink of extinction and doomed in the long run, and too few have been targeted at declining taxa that are still recoverable. Hobbs and Kristjanson (2003) believe that ecosystem restoration efforts similarly should be directed at landscapes where there is a high probability of success. However, not everyone agrees with the ecological triage approach. Some argue that it makes species extinction and landscape degradation acceptable and allows decision-makers to get away with allocating insufficient resources to address environmental problems (Cameron and Soderquist 2002). Such debates about the potential application of ecological triage are important to stimulate discussion among scientists, the public, policy-makers and politicians.

![Diagram](https://example.com/diagram.png)

**Fig. 1.** Different scenarios for knowledge of single-species (SS) and ecosystems (E) and ways that funding might be prioritized to address key knowledge gaps. While ideally both species-oriented and ecosystem-oriented knowledge would be balanced and would continuously increase (middle), funding limitations may require prioritisation. In scenario (a), existing knowledge is highly skewed towards ecosystem-level insights (left side); for this reason new funding should primarily support species-specific work (right side). In contrast, in scenario (b) existing knowledge is perceived to be well-balanced between species-oriented and ecosystem-oriented insights (left side). In this situation, new funding would aim to generate a mix of research approaches (right side).
about the trajectory of conservation, priorities for management action and expenditure of finite resources, including those for conservation research.

Complementarity of single species and ecosystem-based research is often discovered in an ad hoc way, and frequently found only after the research is completed. To promote increased and more systematic links between the two kinds of approaches, we highlight opportunities for cross-fertilisation between them in Table 1. For example, targeted research on species with keystone roles would yield greater understanding of entire ecological communities and key ecological processes that have ecosystem-wide effects (Foster and Orwig 2006). Conversely, focused ecosystem-based work might reveal cases where targeted research is needed on a particular taxon of significance. On this basis, Fig. 1 contains an outline to foster complementarity when planning further conservation research. It illustrates two hypothetical scenarios for the present status of different kinds of knowledge and the allocation of new funding (Fig. 1). We suggest there is a need to identify the strategic knowledge gaps whose closure is most likely to advance effective conservation management. Identifying such knowledge gaps requires an assessment of what is already known about a particular problem. If existing knowledge is strongly biased towards one end of the continuum of research approaches described in this paper (e.g. ecosystem-oriented research) new funding may be most efficiently spent on studies at the other end of the continuum (e.g. single-species research). In contrast, if existing knowledge is perceived to be relatively balanced between the two broad types of research, new resources may be best allocated by funding research in a way that best meets particular conservation objectives. The exact balance between the two broad types of research will depend on context; it might for example be 70% focussed on single-species work if conservation targets are the management of threatened species. However, most real-world scenarios would benefit from not having a complete focus on single-species research or ecosystem-oriented research. In the long term, this approach optimizes the potential for synergistic insights arising from a strategic mix of ecosystem-oriented and single-species research projects. We argue that this approach increases the potential for successful conservation outcomes, while acknowledging the reality of funding limitations for conservation research.

References


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