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What does biodiversity actually do? A review for managers and policy makers

ROSS THOMPSON[1,2,*] and BRIAN M. STARZOMSKI[1]
*[1]Biodiversity Research Centre, University of British Columbia, 6270 University Blvd., Vancouver BC, Canada V6T 1Z4; [2]Present address: School of Biological Sciences, Monash University, Clayton, Victoria 3800, Australia; *Author for correrspondence (e-mail: ross.thompson@sci.monash.edu.au; phone: +61-613-9905-5633; fax: +61-613-9905-5613)*

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Abstract. Conservation managers and policy makers must often justify the need for protection of biodiversity. However, results of scientific studies testing for a positive value of biodiversity in terms of community stability and ecosystem function have been complex and inconsistent. We review recent information on the consequences of loss of biodiversity for natural systems. The relationships described vary with scale of interest – for instance, biodiversity at local scales typically has strong effects on ecosystem function, although the opposite relationship is often found at regional scales. These inconsistencies lead to some concern as to whether these relationships can be used to justify biodiversity protection. This is particularly relevant to policy, where holistic protection of biodiversity has most often been mooted and justified. For managers, who most often work to protect single species, communities or ecosystem functions, biodiversity research has failed to address questions of critical concern such as consequences of the loss of rare species or the identification of functional keystone species. For the general public, we believe that the confusion and debate surrounding biodiversity and ecosystem function relationships is in danger of eroding the positive value society places on biodiversity. We further warn that using those relationships in policy documents as justifications for biodiversity protection is fraught with difficulties. Finally, we contend that biodiversity research has largely not addressed issues of concern to conservation managers, and list a set of priorities for relevant research on the consequences of biodiversity loss.

Introduction

Biodiversity is a term that is used increasingly in environmental management, and its use abounds in scientific literature and in international, national and local policy. Despite international commitments to biodiversity protection, it is unclear how current research in this area may be applied to management. Studies exploring the functional consequences of biodiversity were a major feature of the last decade. The results of these studies have recently been summarized in terms of their consequences for agricultural ecosystems and other ecosystem services (Hooper et al. 2005; Millennium Ecosystem Assessment 2005). It is timely, therefore, in the context of conservation policy and management to take stock of where more than 10 years of definitional debate and scientific studies have brought us. In this paper we review the notable progress made in terms of defining the meaning and function of biodiversity. More importantly, we seek to relate that progress back to the conservation arena, where the need to justify biodiversity protection is most critical.

What is biodiversity?

The term biodiversity is of relatively recent origin, becoming widespread in usage only after the American National Forum on BioDiversity in 1986 (Wilson 1997). This period was characterized by an increasing global awareness of concern over the loss of organisms, communities, and entire ecosystems, and led to a rapid adoption of the term by biologists, policy-makers, and the media. Uses of the term in policy have tended to follow the lead of the Rio Convention on Biological Diversity (1992) which defines biodiversity as "…the variability among living organisms from all sources including … terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

In the scientific arena most attention has focused on studying biodiversity in terms of the number of species present at a place. Defining the spatial limits of biodiversity has spawned a further group of terms; α (alpha), β (beta) and γ (gamma) diversity. This group of terms differentiates between local species richness (α diversity, the number of species at a location), the regional species pool (γ diversity, the number of different species that could be at a location) and variability between localities (β diversity). Concentrating on the number of species alone reduces biodiversity to a simple metric which is easy to comprehend. In ecological terms, however, this aspect of biodiversity can be more correctly defined as species richness, and describes only in the barest terms the biodiversity patterns which are present on the planet. Patterns of abundance within species, and the way in which these change in time and space are obviously of fundamental concern for conservation, and are an important component of biodiversity. Biodiversity within species (genetic biodiversity) is the underlying material upon which evolution acts, and is therefore crucial to a species' ability to adapt to its environment. Scientific definitions therefore have largely followed Wilson (1992), who defines biodiversity as: "… all hereditarily based variation at all levels of organization, from the genes within a single local population, to the species composing all or part of a local community, and finally to the communities themselves that compose the living parts of the multifarious ecosystems of the world." Reassuringly, definitions adopted in policy and science incorporate the same general themes.

Trends in biodiversity

Based on this general definition of biodiversity, there is no doubt that all of its components are under threat from a variety of factors resulting from increasing human populations and resulting generation of waste and demand for food. Considerable effort has been spent documenting declines in a number of components of biodiversity (e.g. Pimm et al. 1995; Vitousek et al. 1997; Sala et al. 2000) and we will not review those studies in detail here. The pertinent fact is that levels of extinction over the last 300 years are at least several hundred times greater than expected based on the geological record (Dirzo and Raven 2003). Although the number of species lost in the last 1000 years is not greater than the number lost in previous mass extinction events, the rate of species loss is much greater than anything experienced historically. The question therefore is not whether we are losing biodiversity, but what the likely effects of that biodiversity loss are.

Despite a global perception of declining biodiversity, managers are frequently presented with situations where biodiversity is increasing due to the arrival of invasive species. Sax et al. (2002) have demonstrated that the number of species' naturalizations exceeds extinctions on islands worldwide. In some taxa (birds), the number of naturalizations equals the number of extinctions, and the total number of species present on the islands remains the same. In other taxa (vascular plants), naturalizations greatly exceeded extinctions, and the number of species on islands studied increased dramatically (in some cases doubling). Biodiversity is declining on two scales- β diversity (the difference in biodiversity between regions – species identities in more and more locations are becoming similar) and γ diversity (global biodiversity is declining), but at particular locations α diversity may be *increasing* due to the addition of invaders (Sax et al. 2002; Sax and Gaines 2003). Sax and Gaines (2003) make clear that this phenomenon is not restricted to islands – rather, local biodiversity is increasing in many continental locations as well. Changes in biodiversity are occurring in two ways, through changes in numbers of species, and in the identity of those species (through the loss of rare species and the addition of invasive species).

It is important, therefore, to differentiate between species loss, which is the local or global extinction of particular species, and changes in diversity which describes changes in the number of species. While these two are generally correlated, species loss may not result in changes in biodiversity (if an exotic species moves into an area). To the public and conservation managers, the loss of particular species is of concern, more so than net changes in biodiversity.

Consequences of changes in biodiversity

Biodiversity and ecosystem function

Considerable ecological research has concentrated on the effects of biodiversity (BD) on ecosystem functioning (EF) and vice versa. Studies exploring BD–EF relationships have generally involved the manipulation of diversity of plant communities and measurement of biomass produced as a proxy for productivity (see Loreau et al. 2002 for a review). Diversity has been changed by either assembly (sequentially adding random species) or disassembly approaches (sequentially removing species at random). The assembly approach has been criticized because it is sensitive to sampling effects. If a single species ('species A') contributes disproportionately to EF, as more and more species are added to a community, the chance that species A will be included increases. Therefore it becomes impossible to differentiate the effects of increasing diversity from the increased probability of including species A. Disassembly approaches are difficult logistically because removing species from plant communities generally causes disturbance which increases as more species are removed. Despite the limitations of these studies, they have provided valuable insights into the way in which biodiversity and EF interact on local scales in the face of random species loss.

Do these experiments provide us with a clear justification for the protection of biodiversity? If this were true, then we would hope to observe a clear, positive relationship between biodiversity and ecosystem function. Experiments manipulating biodiversity have tended to show a strong positive relationship which plateaus at higher diversity levels, while most observational studies have shown a hump-backed relationship (see Kinzig et al. 2001 for a review). Schwartz et al. (2000), in a review of BD-EF studies to 1998, found that seven of 12 observational studies showed positive effects of biodiversity on EF, while the remainder found negative relationships or no relationship. For experimental studies, 17 showed a positive effect, and eleven negative or no effect. Since 1998 there have been a number of additional studies carried out over a wider range of ecosystems (Table 1). Our review shows that of 51 new studies, 29 show a positive relationship between biodiversity and ecosystem function, four show a negative relationship and 18 have equivocal results (Table 1). Given that there is likely to be a publication bias against non-significant results, it appears that a positive relationship between biodiversity and ecosystem function may be overstated.

Biodiversity-EF studies mimic a process of random species loss. In the real world, however, species loss is non-random and biased towards species which are rare initially, have low rates of population growth and occur at high trophic levels in food webs (Petchey et al. 2004). There have been few studies on whether species with these characteristics are likely to have strong or weak effects on ecosystem function, although it is known that functions such as flower pollination and seed dispersal (Memmott et al. 2004; Sekercioglu et al. 2004) can be strongly influenced by rare species. Smith and Knapp (2003) found in a grassland study that if dominant species (those numerically dominant in undisturbed communities) are maintained, EF is maintained in the face of loss of rare species. Species which increase local diversity by invading can also disproportionately influence ecosystem function (e.g. Asner and Beatty 1996; Hooper and Vitousek 1998; Hall et al. 2003; Simon et al. 2004). Invasive species typically share characteristics such as high rates of reproduction and generalist habitat preferences (Kolar and Lodge 2001; Marchetti et al. 2001).

Table 1. Biodiversity–ecosystem function experiments since 1998.

Study	Nature of system	Ecosystem function	Relationship between BD–EF	Important effect
Bullock et al. (2001)	Hay meadow	Forage crop biomass	Positive	Species-rich hay mixtures have higher biomass production after 2 years of growth
Engelhart and Ritchie (2001)	Wetland mesocosm	Biomass	Positive	Increased species richness equals increased biomass in mesocosms
Downing and Leibold (2002)	Wetland mesocosm	Productivity	Unclear	Composition of communities can have more of an effect than diversity *per se*
Hooper and Dukes (2004)	Serpentine grassland	Productivity	Sometimes positive, sometimes negative	Diversity effect overwhelmed by composition
Caldeira et al. (2001)	Mediterranean grassland	Biomass/water use	Positive	Higher water use shown in higher species richness plots that already showed increased biomass with species richness; suggests complementarity and facilitation as mechanism
Duffy et al. (2001)	Marine mesocosm	Grazing success or biomass accumulation	Negative- monocultures showed highest EF	Difficult to assign redundancy to species
Cardinale et al. (2002)	Stream mesocosm	Feeding success	Positive	Facilitation increases EF
Pfisterer and Schmid (2002)	European grassland	Perturbation resistance	Negative	Lower species richness increases perturbation resistance
Allison (2004)	Rocky intertidal algae	Perturbation resistance	Negative	Higher species richness plots have more to lose from perturbation
Allison (2004)	Rocky intertidal algae	Resilience	Positive	Higher resilience if species can re-invade from the regional pool

Table 1. Continued.

Study	Nature of system	Ecosystem function	Relationship between BD–EF	Important effect
Bolam et al. (2002)	Intertidal benthos	Sediment Stabilization/ nutrient flux	Dominant species drives relationship	Processes in soft sediment very complex
Emmerson et al. (2001)	Marine coastal	Complementary resource use	Positive, but idiosyncratic	Idiosyncratic effects
Finke and Denno (2004)	Coastal marsh community/ greenhouse microcosms	Damped trophic cascades	Positive	Predator diversity decreases the effects of trophic cascades
Finke and Denno (2004)	Coastal marsh community/ greenhouse microcosms	Productivity	No effect of predator diversity	Predator diversity does not change the amount of primary productivity
Griffiths et al. (2000)	Soil microbes	Various	Idiosyncratic	Various parameters measured, some positive, some negative effects of species richness
Heemsbergen et al. (2004)	Soil microcosms	Mass loss and respiration	Depends on functional diversity	Functional diversity, not species richness, explains ecosystem function
Jonsson and Malmquist (2000)	Boreal streams	Leaf-litter decomposition	Positive	Species richness more important than species identity
Jonsson et al. (2001)	Boreal streams	Leaf-litter decomposition	Positive	Species richness increases EF
Jonsson and Malmquist (2003)	Boreal streams	Leaf-litter decomposition	Positive	Loss of any species negatively affects EF
Morin and McGrady-Steed (2004)	Aquatic microbial microcosms	Variability of CO_2 fluxes	Positive	Increased species richness of microbes decreases the variability of an EF

Naeem et al. (2000)	Freshwater microcosms	Algal biomass	Complex, with interactions between producer and decomposer diversity	Neither producer nor decomposer diversity explains algal biomass
Petchey et al. (2002)	Aquatic microbial microcosms	Temporal change in community biomass	Idiosyncratic	Neither constant nor fluctuating environments had a positive effect of species richness
Rafaelli et al. (2003)	Shallow coastal marine	Nutrient concentration	Variable	Variable effects
Reich et al. (2001)	Grassland	Biomass accumulation	Positive	Biomass accumulates more slowly in species-poor than species-rich assemblages in response to elevated CO2
Ruesink and Srivastava (2001)	Stream	Leaf-litter decomposition	Positive/Negative	The diversity–EF relationship occurs depending on the strength of numerical and/or per-capita responses of species
Sankaran and MacNaughton (1999)	Grassland	Compositional stability	Overwhelmed by historical and abiotic effects	Ecological history and species identity more important than richness per se in explaining compositional stability of a grassland
Smith and Knapp (2003)	Grassland		None	Rare species cannot compensate
Tilman et al. (2001)	Grassland	Biomass	Positive	Increased species richness increases biomass, and the effects do not decrease with time
van Ruijven and Berendese (2003)	Experimental plant community	Biomass	Positive	Niche complementarity increases productivity

Table 1. Continued.

Study	Nature of system	Ecosystem function	Relationship between BD–EF	Important effect
Wohl et al. (2004)	Microbial microcosms	Cellulose decomposition	Positive	Increased species richness promoted increased numbers of individuals and increased cellulose decomposition
Zak et al. (2003)	Plant/soil community	Microbial biomass, Respiration, fungal biomass	Positive	Plant species richness and the coupled increased productivity increases microbial biomass, respiration, and fungal biomass
Invasion resistance				
Crawley et al. (1999)	Grassland	Invasion resistance	Idiosyncratic	Species identity more important than diversity per se
Dukes (2001)	Grassland microcosm	Invasion resistance	Idiosyncratic	High functional diversity decreases invasions, not high species diversity per se
Dukes (2001)	Grassland microcosm	Invasion impact	Positive	Invader suppressed growth of species-poor communities more than species-rich communities
Dukes (2002)	Grassland microcosm	Invasion resistance	Positive	Local communities with higher species richness decreased invasion success and the impact of an invader on a community, though species identity important as well

Kennedy et al. (2002)	Grassland	Invasion resistance	Positive	Local species richness decreases invasion success
Levine (2000)	Riparian plant community	Invasion resistance	Negative	Local species richness negatively correlated with invasion success; at the community level, most diverse assemblages most likely to be invaded
Levine et al. (2004)	Meta-analysis; various	Invasion resistance	Positive	Meta-analysis shows positive effect of species richness on invasion resistance
Lyons and Scwartz (2001)	High altitude meadow	Invader establishment	Positive	Higher richness plots had lower numbers of invader species, though low richness plots also heavily invaded
Stachowicz et al. (1999)	Sessile marine invertebrates	Invasion resistance	Positive	Species-rich communities more completely use space and resources
Stachowicz et al. (2002)	Sessile marine invertebrates	Invasion resistance	Positive	Species-rich communities more completely use space and resources
van Ruijven et al. (2003)	Grassland	Invasion resistance	Positive	Higher species richness plots better resist invaders
Zavaleta and Hulvey (2004)	Grassland	Invasion resistance	Positive	Plant functional groups disappear faster than expected by chance, leading to increased invasion with decreased richness rare species cannot compensate
Theoretical studies				
Solan et al. (2004)	Marine soft sediment	Bioturbation	unclear	Dominant species accounts for most EF

Table 1. Continued.

Study	Nature of system	Ecosystem function	Relationship between BD–EF	Important effect
Bond and Chase (2002)		Theoretical	Scale dependent	Hump shaped relationship at local scales, linear increase at regional scale
Mouquet et al (2002)			Positive/Negative/no relationship	The shape of the BD–EF relationship depends on the mechanisms generating species diversity
Borvall et al. (2000)		Extinction risk	Positive	
Fonseca and Ganade (2001)		Loss of functional group	Positive	Increased species richness decreases the probability of losing a functional group
Petchey et al. (2004)			Unclear	the effects of species richness on EF are dependent on what trophic level the species are lost from
Hughes and Roughgarden (2000)		Biomass stability	Positive	Increased BD buffers the change in productivity when species added or removed
Ives et al. (2000)		Stability	Positive	Diversity increases community resistance to perturbation only when species that respond differentially are included in the community (Insurance effect)
Yachi and Loreau (1999)		Productivity	Positive	Increased BD buffers against temporal variance in productivity, and increases productivity as well

Whether these characters are positively correlated with impacts on ecosystem function is unknown. Effects on ecosystem function in real systems affected by realistic patterns of species loss and gain are of great interest and have been little explored. In our opinion, much evidence points to a strong role for dominant species (e.g., keystone species or ecosystem engineers) in controlling ecosystem function, rather than biodiversity *per se*. We currently have neither empirical nor theoretical understanding of how this affects the remaining species and the functioning of ecosystems, from global to local scales.

A final limitation when applying the results of biodiversity–EF relationships to applied questions is the simplistic nature of the communities studied to date. Whereas species losses and invasions are embedded within a complex food web of species, biodiversity-EF studies have concentrated on the effects of biodiversity at a single trophic level. Recent studies have shown that food web context is important in determining the effect of species loss on ecosystem function (Borrvall et al. 2000; Raffaelli et al. 2003; Petchey et al. 2004), as is community assembly history (Fukami and Morin 2003). The loss of a single species may also result in the loss of further species through direct and indirect interactions within the food web (the ‘extinction cascade’) (Petchey et al. 2004). Empirical studies, although rare, have suggested that diversity changes at different trophic levels can interact to alter ecosystem function (e.g. Petchey et al. 1999, Naeem et al. 2000). Studies looking at multi-trophic level effects of biodiversity on ecosystem function are needed (Srivastava 2002; Hooper et al. 2005).

Based on results published to date it is clear that there is not a universal positive relationship between biodiversity and ecosystem function. Hooper et al. (2005) divide the relationships observed into two groups, those of which they are ‘certain’ and those in which they have ‘high confidence’. They express certainty that effects of species on ecosystem function depend on species functional traits, and that effects of species loss can vary depending on the species, the community it is lost from and the ecosystem function of interest. They have high confidence that biodiversity increases the ability of systems to cope with environmental change and resist invasion.

Biodiversity and system stability

Historically, one of the most evocative arguments for biodiversity protection was the assertion that systems which were more biodiverse were more stable (resistant to change or resilient following change). This assertion is largely founded on the work of MacArthur (1955) and Elton (1958), who observed that real ecological systems were unbelievably complex, yet persisted through time. Mathematical modeling approaches in the 1970s challenged whether higher numbers of species (higher complexity) did engender stability (e.g. May 1973). The current synthesis suggests that complex communities are maintained by a web of strong and weak interactions which provide a set of balancing forces (McCann et al. 1998; Berlow 1999). The role of biodiversity as a stabilizing component within this complexity has been the subject of considerable interest.

The role of biodiversity in maintaining stability has been the subject of a number of analogies that serve to illustrate the potential role of species in an ecosystem. The Rivet Hypothesis (Ehrlich and Ehrlich 1981) imagines an ecosystem as a large structure, and assumes that all species are equally important in maintaining system stability. Schwartz et al. (2000) found little support for this hypothesis, with only three of 20 studies showing this sort of relationship. The 'Drivers and Passengers Hypothesis' (Walker 1992), in contrast, assumes that in most ecosystems certain species have a disproportionate role on system stability ('drivers') while others have a negligible effect ('passengers'). This hypothesis predicts that losing most species from a system may have little effect – but the loss of some species may result in dramatic destabilization. A recent study by Solan et al. (2004), shows this in dramatic fashion – virtually all of the bioturbation of sediments, a critical process underlying the continued existence of the community, was due to one species. For conservation managers, under the Driver and Passenger Scenario it becomes crucial to identify which species are likely to have disproportionate effects if they are lost. In conservation terms, therefore, it is crucial to protect species which have no functional equivalent, and to maintain diversity within functional groups. Interestingly, most conservation efforts concentrate on rare species which may not interact strongly with other species in the ecosystem, nor be able to replace the effect of a dominant species (Smith and Knapp 2003).

In addition to the role of biodiversity in contributing to system stability at a moment in time, biodiversity could also contribute to stability of systems through time. The 'Portfolio Effect' (Doak et al. 1998) surmises that having multiple species in a community is akin to having multiple stocks in an investment portfolio, acting as insurance against variability in the environment affecting a single species. Evidence for this exists both theoretically (Lhomme and Winkel 2002) and empirically (e.g. Ives et al. 1999; Scheffer et al. 2001). For example in the Alaska salmon fishery, species within the catch fluctuated year to year, but over all years the total catch of all species remained relatively constant (Hilborn et al. 2003). Additional studies have shown that biodiversity in grazing lands maintains productivity in response to stressors such as drought (Tilman and Downing 1994) and pests (Altieri 1999). In an environment where ecosystems are increasingly affected by global climate change, the ability of communities to respond to this is of particular interest. On a global scale the role of biodiversity in increasing overall resistance to rapid environmental change such as eutrophication and global warming is of particular relevance (Hooper et al. 2005). Therefore species loss may not be important in terms of the role of that species now, but rather in terms of that species being available to fulfill a functional role in a future environment.

The second management area where the ability of systems to resist change is of interest is in the area of invasion biology. The evidence for the effects of biodiversity on invasions of exotic species is equivocal. Sax and colleagues (Sax et al. 2002; Sax and Gaines 2003) have demonstrated that biodiversity is changing differently on different scales. Similarly, it appears that there is a scale-dependent effect of biodiversity on invasibility. At local scales, increased diversity may enhance invasion success (Levine and D'Antonio 1999), while at large scales, increased biodiversity may decrease invasion success (Levine 2000). There is some support for species-rich systems excluding invading species more than species-poor systems (Dukes 2001, 2002; Kennedy et al. 2002; Levine et al. 2004). However, there is also evidence that species taxonomic or functional identity (Crawley et al. 1999; Dukes 2001; Hooper et al. 2005), rather than species richness *per se*, may be the important factor in excluding invaders. It appears that both of these patterns can be overcome by propagule pressure – that is, if the number of invader propagules is high enough at any scale, then success may be independent of species diversity. Much further work is needed in this area for conclusions of conservation value to be drawn. For instance, it remains to be seen what the extent of propagule pressure is in facilitating invasion. Nor do we have a good knowledge of the role of species traits in invasion resistance (Hooper et al. 2005).

Social perceptions of biodiversity

While the onus for scientists is to understand the effects of biodiversity in terms of quantifiable scientific relationships, policy and management justifications for biodiversity protection exist within the public sphere. We believe that for biodiversity conservation, the importance of social perceptions of biodiversity has been greatly under-appreciated. Wilson (1984) coined the phrase 'biophilia' to reflect his belief that across a variety of cultures there is an underlying positive value attributed to biodiversity. In North America there is evidence that while a clear understanding of biodiversity is only held by approximately 40% of the population, positive aesthetic values are attributed to the concept (Belden and Russonello 1996; Turner-Erfort 1996; Belden et al. 2002). European studies have generally shown similar results (see Van den Born et al. 2001 for a review; UNEP 2003). In the West this has given rise to the field of ecological economics, which seeks to incorporate positive perceptions of biodiversity into cost-benefit analyses (e.g. El Serafy 1998; Figge 2004). Indigenous peoples have long been considered to have positive views of biodiversity, often associated with attributing a spiritual value to intact systems (e.g. Posey 1996; Toledo 2001; Laird 2002; Murray 2003). Quantitative surveys are rare, but there is evidence of a concern for biodiversity constraining indigenous activities in Africa (e.g. Smith and Wishnie 2000), Asia (Campbell et al. 2002), Australasia (e.g. Taiepa et al. 1997) and in native American groups (e.g. Zimmerman et al. 2001). Recent reinterpretations of Judaeo-Christian texts (Livingstone 1994) and appraisals of Muslim culture (Kula 2001) point towards a religious imperative with regard to environmental stewardship. Across cultures biophilic views are in part utilitarian in nature, and can be attributed to a belief that biodiversity is the basic stuff from which future resources will be extracted (Posey 1996; Turner-Erfort 1996). However, even when societies attribute no future use to particular components of biodiversity, positive spiritual values are still associated with those components (Wilson 1984; Posey 1996; Van den Born et al. 2001).

Biophilic views may stem in part from a recognition that biodiversity represents a form of human heritage. Feelings of responsibility or stewardship over inherited natural systems were a feature of studies of attitudes to nature (e.g. Toledo 2001; Van den Born et al. 2001; Belden et al., 2002). The use of the concept of heritage as a driver for environmental protection has been widely used in policy at national and international levels (e.g. New Zealand Ministry for the Environment 1997; UNESCO 1972; Environment Canada 2003) and has been invoked by scientists for protection of genetic diversity (Bowen 1999) and species (Fricke 2001). We suggest that the idea of heritage contributes to positive views of biodiversity that are independent of any particular use for biodiversity, and compliments scientific justifications for biodiversity protection. However, there is an ongoing challenge to maintain a positive view of biodiversity in the face of increasing demands for space and food for growing human populations, which may require a strengthening of arguments using scientific justifications.

Where to from here?

Current studies of the role of species richness for ecosystem function, and attempts to understand the effects of species loss, are crucial to predicting the likely impact of species loss on the global ecosystem. Nevertheless, attempts (and most crucially, failures) to find a positive ecological function for the presence of more species distracts from the immediate need to address species loss. Based on our review we make the following conclusions:

1. The evidence for a positive relationship between biodiversity and ecosystem function is building, but is not yet conclusive and may not be consistent across scales and systems.
2. Biodiversity may be positively associated with the ability of systems to deal with changing environments, but not all systems with higher biodiversity will be more stable.
3. It appears that dominant species are often the main contributors to ecosystem function, consistent with the ‘Drivers and Passengers’ analogy.
4. γ and β diversity are declining; α diversity is often stable or increasing due to non-native invader species. We emphasize the importance of native species over non-native species, independent of BDEF theory.
5. There is an underlying positive value associated with biodiversity that is independent of utilitarian viewpoints.

These conclusions have different implications for policy makers and conservation managers. In policy there has been considerable emphasis on the need to protect biodiversity universally, and the potential benefits that this may have for ecosystem function. We offer the warning that while in some cases biodiversity does positively influence some ecosystem functions, this relationship is not universal. Public support for maximizing biodiversity is the driving force for biodiversity maintenance and conservation, and is based on aesthetic, ethical, and spiritual values. These values should not be underestimated. Where biodiversity protection can be justified through proven positive effects on ecosystem function, then this is an additional argument. There is currently not sufficient evidence to conclude that relationships between biodiversity and ecosystem function and biodiversity and system stability are, by themselves, sufficient to justify biodiversity protection.

Conservation managers in general manage single species either as endangered or invasive species, and only rarely manage for either biodiversity or ecosystem function. We believe that biodiversity science can offer managers assistance in a number of areas. Identifying the species traits that indicate important players in ecosystem function could advise managers on priority species for conservation. Rare species which contribute disproportionately to ecosystem function or system stability should be conservation priorities. Equally, invasive species which alter ecosystem function or destabilize communities should be priorities for management. There is a general lack of research into the relationships between species' functional traits and ecosystem function (Hooper et al. 2005). In the case of loss of rare species there is a unique opportunity to understand the effects of species traits on function because we often have extensive knowledge of the traits of species of conservation interest. For managers, where rare or invasive species can be attributed a strong effect on ecosystem function or stability this provides added leverage to gain funding for conservation efforts. This requires a better understanding of the effects of non-random patterns of species change on ecosystem function and stability.

Biodiversity is a buzzword that is often cited as a positive trait of natural communities, and is subsequently used in arguments for conserving wild nature, and as a goal to strive for in managing systems heavily influenced by humans. Justifications for biodiversity protection are based on human values, although in some cases additional benefits for ecological systems may exist. We urge policy makers to carefully consider the scientific case for biodiversity protection as well as the intrinsic social values, and biodiversity scientists to address the consequences of real patterns of biodiversity change for ecosystem function and stability.

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