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Short Note

Biological invasions and scientific objectivity: Reply to Cassey *et al.* (2005)

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Abstract We disagree with the assertion that recent human-caused invasions differ substantially from historic natural invasions in their magnitudes and impacts on ecological processes. The position that exotic species are inherently 'bad' and should be eradicated is an ethical judgement, usually based on the naturalist fallacy or xenophobic prejudice; it is not a scientific judgement. The role of scientists in studying invasive species should be to gather, interpret and communicate information as accurately and objectively as possible.

Key words: aliens, biotic exchange, exotics, scientific ethics, scientific role.

INTRODUCTION

We appreciate the effort and thought that Cassey, Blackburn, Duncan and Chown (CBDC hereinafter) have put into their reply to our paper (Brown & Sax 2004). Clearly, exotic species are a topic worthy of much attention and discussion by research scientists, managers, policy makers and lay people. CBDC address three main issues: (i) the differences between natural and anthropogenic invasions; (ii) the biological consequences of recent anthropogenic invasions; and (iii) the role of science and scientists in studying invasions. We will address each of these in turn. Although we agree with many of the points raised in their reply, there are fundamental differences in how we perceive these issues. It is valuable to air these differences, because they are representative of the diverse perspectives held by scientists who study biological invasions.

HOW DIFFERENT ARE RECENT HUMAN-CAUSED AND HISTORIC NATURAL INVASIONS?

The first point raised by CBDC is that the relatively recent invasions of exotic species that have occurred as a consequence of human activities are different from those that occurred historically without human assistance. This is true, both for anthropogenic invasions as a general class and for each individual human-assisted naturalization event. Never before in earth's history has there been a single species that has moved other organisms in the same ways and over the same paths and distances as humans. From both local and global perspectives, the biotic exchanges occurring currently as a consequence of exotic species invasions are in some ways unique and unprecedented in the history of the earth. It is also true, however, that each of the major biotic exchanges and each of the countless long-distance colonizations and range expansions of individual species that occurred earlier in earth history, before the advent of humans, was a unique event. So the critical questions are how great are the differences in quality and magnitude of these invasions, and how do they affect biodiversity and ecological processes on local, regional and global scales. We suggest that the differences are not as large as CBDC claim, and that many consequences are not unprecedented. For example, more than half the 'native' taxa now occurring in some regions are descended from invaders that colonized as a consequence of historic biotic exchanges (Vermeij 2005); similar magnitudes of exotic invasion have only been reached on remote oceanic islands and long-isolated bodies of fresh water. The recent 'Lessepsian interchange' of biota between the Mediterranean Sea and the Red Sea through the human-constructed Suez Canal (Golani 1993; Vermeij 2005) has many similarities with the 3.5 million-year-old 'Great American interchange' of biota between North and South America across the newly formed Panama land bridge (Webb & Marshall 1982; Brown & Lomolino 1998). Both interchanges resulted in asymmetrical invasions of many species, but many

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endemic species did not cross to colonize the other area. By most measures, including time of previous isolation, number of species colonizing and impact on continental- or ocean-scale biogeography, the accurately named Great American interchange has to date been of much greater magnitude than the anthropogenic Lessepsian interchange. CBDC are undoubtedly correct that extremely long-distance dispersal events are much more common now than in the past. But long-distance dispersal without human assistance was sufficiently frequent in the past to populate remote islands and archipelagos with their many native lineages. Finally, CBDC offer no evidence to support their claim that rates of range expansion by exotic species after colonization are exceedingly fast and without precedent. We know of no theoretical or empirical reason why a species introduced to a continent, island, or body of water by humans would be expected to spread any faster than a comparable species that colonized a similar area without human assistance. Despite the real differences between natural and human-assisted dispersal, we hypothesize that by most measures there is more overlap than separation in the magnitudes and consequences of these events. This is a testable hypothesis that can be evaluated by compiling and analysing the increasingly detailed and accurate data on both anthropogenic and prehuman invasions.

WHAT ARE THE CONSEQUENCES OF HUMAN-CAUSED INVASIONS FOR BIODIVERSITY AND ECOLOGICAL PROCESSES?

The second issue raised by CBDC concerns the consequences of anthropogenic invasions for biodiversity at local, regional and global scales. There is little doubt that human activities have begun to 'homogenize' the earth's biota. Many exotic species now have widespread, near-cosmopolitan distributions and many locally and regionally endemic species have gone extinct. The replacement of endemic natives by naturalized exotics has been greatest on isolated oceanic islands and comparable freshwater habitats. We called attention to a very general but probably not universal consequence of the spread of exotic species: local and regional species diversity often increases while global diversity has almost invariably decreased (Sax *et al.* 2002; Sax & Gaines 2003). CBDC counter by questioning whether the species is necessarily an appropriate unit to measure geographical patterns and temporal trends in biodiversity. This point is debatable, but because of the nested nature of the phylogenetic or taxonomic hierarchy, any trends observed at the species level will often apply to levels above the species as well. Nevertheless, it is certainly true that many species and a smaller number of ancient endemic lineages have indeed been lost in the last few hundred years as a consequence of human activities. We would urge caution, however, in simplistically attributing these losses to a single cause – invading exotic species – because nearly all invaded habitats and biotas have experienced other large impacts of modern humans. Similarly, we think that claims of detrimental effects of exotic species on 'ecosystem functioning' should be evaluated carefully, not simply accepted at face value. To do so requires rigorously defining just what is meant by the term 'ecosystem functioning'. It is one thing to document change in ecological processes; it is much more difficult to obtain scientific evidence that some indispensable 'functional ability' has been lost or degraded. To illustrate the magnitude of this problem, imagine that an alien scientist from outer space were to visit both New Zealand and Great Britain, would this individual be able to distinguish which species are native and exotic, and would it be able to demonstrate that invaders have caused more damage or disruption to ecological processes than natives?

WHAT IS THE PROPER ROLE FOR SCIENTISTS?

Finally, CBDC discuss the role of scientists in studying human-caused biological invasions. In doing so, they come dangerously close to committing the naturalist fallacy. This is the belief that what is 'natural' should be equated with what is positive, good, or acceptable. A corollary is that there exists a pure 'natural state' that can and should be preserved. This conflicts with accepted moral values and present day ecological realities. When applied to human behaviour, such thinking is generally considered to be immoral or inappropriate. So, for example, traits that may have arisen by natural selection in response to past conditions, such as infanticide, sexual coercion, or xenophobia, are no longer considered good or acceptable. There are similar moral and ethical ambiguities with respect to exotic species. One is that the invasive exotic that has had by far the greatest impact on biodiversity and ecosystems is our own species. Probably only the most zealous naturalists would find it desirable or acceptable to remove all humans, domestic plants and animals, and exotic species from New Zealand, for example, even if this could be accomplished.

The naturalist fallacy is often the basis for management and policy decisions to eradicate or control invasive species; exotics are viewed as an unnatural, undesirable component of the biota and environment. Not all people share this view, however, or believe that it is ethical or desirable to eradicate these organisms. Some believe that all life is sacred and that no individual should be killed unnecessarily – the basis for public outcries against the removal of feral rabbits, cats, horses and other charismatic exotics from invaded habitats. Arguments that some exotics cause enormous economic damage can be countered by examples of native species that do likewise. Another common ethical framework equates good with real or perceived benefits to human health and welfare. Such a world view would favour the eradication of smallpox, malaria-carrying mosquitoes and other species that cause human diseases, even within their native ranges. It would also favour the deliberate spread of pets, domesticated animals and horticultural and agricultural crop plants – even though we biologists know that many such species that were deliberately introduced to benefit humans have become naturalized invaders.

So the impacts of exotic species on native biodiversity and ecosystem processes vary widely in kind and magnitude. Whether these are considered to be positive or negative, good or bad is a subjective value judgement rather than an objective scientific finding. Scientists are no more uniquely qualified to make such ethical decisions than lay people. Scientists are uniquely qualified to collect the facts and interpret their consequences. It is entirely proper for private citizens, including scientists, to be advocates for positions that promote some combination of self-interest and societal welfare. These positions may be based in part on scientific information, such as the documented extent and likely consequences of global warming or a biological invasion. In their professional roles, however, scientists have the obligation to collect, analyse and communicate such information accurately and objectively. When scientists go further and try to impose their own ethical and moral imperatives on society as a whole, they embark on a slippery slope. They risk compromising the principles of unbiased, objective inquiry that are the essence of the scientific method – and the primary reason why society should support and pay attention to scientists.

Don't get us wrong. As private citizens we authors are enthusiastic supporters of actions and policies to reduce the ongoing loss of global biodiversity and homogenization of the earth's biota. We also stand by our comment, however, that many scientists, managers, policy makers and lay people have a deep-seated prejudice against exotic species that comes close to xenophobia. This is apparent in the adjectives used to describe non-native species and their impacts – invasive, alien, plague, foreign, aggressive, catastrophic, insidious, destructive, decimating, devastating, damaging, threatening, assaulting and flooding – to mention just a few. But worse than such words are the unsubstantiated, unscientific tales, too often promulgated by scientists themselves, that biological invasions are somehow unnatural and that as a general rule invading species dominate ecosystems and cause economic losses, wholesale ecological changes and extinctions of native species. Sometimes they do, but the impacts vary enormously with the species of invader and the environmental setting. Moreover, whether these impacts are perceived as positive or negative, good or bad, varies with the moral beliefs of societies and individuals. When scientists claim that their professional credentials uniquely qualify them to make such moral judgements, they exceed their special, time-honoured roles as unbiased collectors, interpreters and communicators of scientific information.

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Short Note

Concerning invasive species: Reply to Brown and Sax

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Abstract Biological invasions have commonly occurred, and to a lesser degree continue to do so, without human assistance. It is, however, a combination of the rate and magnitude, as well as the distances and agency involved, that separates human-driven invasion processes from self-perpetuated colonization events. Exotic species are a pervasive and major component of human-induced global change. Decisions to manage invasive species will require judgements to be communicated from scientists to policy makers, because scientists may often be the only ones in the position to make them.

Key words: biological invasion, ecosystem functioning, exotic species, mass extinction event, scientific role.

INTRODUCTION

In a recent essay, Brown and Sax (2004) addressed a variety of topics concerning invasive species. At the heart of their discussion was their concern regarding the 'visceral emotional response' that invasive species tend to elicit among people. They compared this response to an attitude of xenophobia supposedly common among humans in which we 'treat foreigners . . . with distrust, dislike, even loathing'. While the authors did not advocate the continuing introduction of non-native species, they did argue for what they regard as greater 'scientific objectivity and less emotional xenophobia' in the study of invasive species. They pointed out that invasion is a natural process, just as is extinction, and that in these regards 'the earth has previously experienced changes of a magnitude equal to or exceeding those caused by recent human activities'. Invasive species may provide valuable insights into a range of biological questions. Brown and Sax concluded that scientific questions about the causes and consequences of biological invasions should be separated from moral and social questions about the desirability of such invasions, and that it is 'up to humankind as a whole to decide whether it [biological invasion] is good or bad, and hence what actions should be taken'.

We find much to agree with in Brown and Sax (2004). However, we think that several of their arguments require further consideration, which has prompted this response. Here, we address three issues. First, we consider comparisons between invasions (and related extinctions) as natural *versus* anthropogenic events. Second, we consider the implications of current events for biodiversity. Third, we discuss the role of scientists in studying the processes that have resulted from the transportation and establishment of non-native species.

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NATURAL *VERSUS* ANTHROPOGENIC EVENTS

Brown and Sax observe that 'biological invasions are nothing new', and that 'the earth has experienced many invasions, sometimes in waves of many species, and often in independent single-species colonization events'. They note that the same is true for extinctions, that many prehuman extinctions can be attributed to prehuman invasions, and that many prehuman extinction and invasion events were of at least comparable magnitude to the current one. We think that this view misrepresents the uniqueness of the current events, at least for invasions, in several ways.

First, the current mass invasion event (we use this terminology for parity with the current mass extinction event) is vastly greater in geographical extent than any single event that we know about (or can infer) from the geological past. Our best guess is that there is not a single landmass that is unaffected, from the most biodiverse continent to the most isolated oceanic island. For example, although Antarctica and its surrounding islands are amongst the most isolated places on earth, they now play host to a wide variety of human-introduced species, including marine, freshwater and terrestrial microorganisms, plants, invertebrates and vertebrates, which in several cases are causing widespread changes to these systems (reviewed in Frenot *et al.* 2005). Across the sub-Antarctic islands, which are distributed widely over the Southern Ocean, and differ substantially in the communities they host, many of these colonizers are the same Palaearctic weedy species (Greve *et al.* 2005). This sets the current invasion event apart from events like the Great American Interchange, which only concerned a pair of continents (and a few offshore islands), or recolonization after glaciation, which mainly concerned only the far north (and, we would note, was only a replacement of the little that the glaciers left behind). If all the examples of prehuman invasion that Brown and Sax quoted had occurred simultaneously we would be getting closer in extent to the current event.

Second, the current mass invasion event is unusual in the distance over which invasions have occurred (and indeed are occurring). Natural long-distance dispersal events are not uncommon. For example, vagrant North American birds arrive annually on European shores (and vice versa) after crossing the Atlantic. However, while that exchange must have been occurring for centuries, it has not obviously resulted in colonization. Yet, in the last 150 years 12 species of British passerine bird have established viable populations in New Zealand, antipodal to Britain and well beyond the natural colonization abilities of all but the most exceptional vertebrate species. New Zealand also houses 25 non-volant terrestrial mammal species (excluding humans), established in the last 800 years on islands that no non-volant terrestrial mammal had naturally colonized in 80 million years.

The one natural long-distance colonization event cited by Brown and Sax (2004) concerned the cattle egret, which arguably is an event that has only occurred because of the facilitating effects of humans (e.g. introducing large grazing mammals, and destroying habitat and introducing plant species to accommodate them). The one example of non-anthropogenic global colonization that we can think of concerns the tendency for unicellular organisms to be global in their distribution (Fenchel & Finlay 2004). However, this is also contentious (Franzmann 1996; Lachance 2004; and references therein).

Third, the current mass invasion event is unusual in the timescale over which invasions have occurred. Brown and Sax cite the example of rapid tree recolonization following the retreat of the glaciers: 'within a few thousand years, tree species had spread hundreds of kilometres from glacial refugia to occupy their current ranges'. Those rapid events seem positively pedestrian in comparison to events such as the rapid colonization of the Black Sea by the American comb jelly, *Mnemiopsis leidyi* (Carlton 2000), the virtually global spread of the isopod *Porcellio scaber* over a few hundred years (Wang & Schreiber 1999; Slabber & Chown 2002) and the invasion by pines of the southern hemisphere over the past 50 years (Richardson & Higgins 1998). Brown and Sax do cite an example of faster colonization, but since this refers to spread of bird species into agricultural habitat it is hardly a convincing historical precedent.

The relative rates of natural and anthropogenic colonization have been quantified for the pterygote insect fauna of Gough Island by Gaston *et al.* (2003). They found that 71 of the 99 species recorded from Gough were established introductions, even though Gough has only been landed on approximately 233 times in the 325 years since its discovery by humans. This suggests a successful establishment rate of 218 exotic species per thousand years. Gough island is estimated to be 2–3 million years old, and 21 colonization events could account for the indigenous fauna (Gaston *et al.* 2003). Assuming uniform colonization rates over the past two million years, this amounts to one colonization every 95 000 years, but if it is assumed that 95% of indigenous species have gone extinct over the period, the rate increases to one successful colonization per millennium. Thus, rates of anthropogenic introduction are still two to three orders of magnitude greater than background levels of net colonization for the island.

Fourth, the current mass invasion event is unusual in the agency of dispersal. Natural colonization events rely on the dispersal powers of the organisms themselves, which for many taxa are limited. Moreover, arriving at a new site is just the first hurdle that needs to be overcome: individuals of sexual species then need to find mates. Although there are examples of natural colonization events resulting from the arrival of large propagules (e.g. Clegg *et al.* 2002), most natural propagule sizes are likely to be small (one or two individuals) and (as we noted above) infrequent. These founders then have to survive the perils that bedevil small populations, such as demographic stochasticity, environmental stochasticity and inbreeding. In contrast, human-mediated dispersal events frequently concern large numbers of individuals, or repeated releases that are often directly introduced to suitable habitat. Exotic pasture weeds that are dispersed as pasture seed contaminants, for example, end up being sown in their ideal pasture habitat. This much higher propagule pressure and habitat matching means that the problems of small populations are greatly reduced (Williamson 1996), as larger releases ameliorate demographic stochasticity and inbreeding (but see Briskie & Mackintosh 2004) while repeated releases ameliorate environmental stochasticity (Lockwood *et al.* 2005). While difficult to test (but see Gaston *et al.* 2003), it seems likely that the probability of successful establishment is greatly enhanced as a result.

Brown and Sax are not the first to note that extinction and invasion are natural processes. The literature frequently compares exotic establishment to natural colonization and it is therefore simply a combination of the rate and magnitude, as well as the distances and agency involved, that separates human-driven invasion processes from self-perpetuated colonization events. The earth's present biodiversity took hundreds of millions of years to evolve, with each land mass as home to different biotas. Now, every major zoo in the world can have an elephant (the largest terrestrial mammal) thanks to the ease with which species, of all shapes and sizes, are transported. The extent of this human-induced biotic exchange would be limitless if it wasn't for the fact that, despite our efforts, not all species transported and released have successfully established.

We do concede that the current mass extinction event pales into insignificance compared to mass events in the geological past. However, we do not find it particularly reassuring that our role in driving extinctions globally does not yet approach that of an asteroid impact. As Brown and Sax point out, in some places it virtually dose.

CONSEQUENCES OF ANTHROPOGENIC INVASIONS

If current human-driven invasions are not simply the modern expression of a natural process, it follows that the consequences of those invasions should also differ from those of natural colonization events. One expression of this is in the decrease in the distinctiveness of biotas in different biogeographical regions.

Species recently lost to extinction tend to be range-restricted local endemics, and so unique to local areas (e.g. single islands) (Lawton & May 1995). For example, there is a positive relationship between taxonomic level of endemism and probability of extinction for bird species inhabiting New Zealand at the time of first human colonization (McDowall 1969; Duncan & Blackburn 2005). By contrast, successful invaders tend to be more widely distributed than species that fail to establish exotic populations (e.g. Blackburn & Duncan 2001a), while some species have repeatedly invaded a range of exotic locations (e.g. Long 1981, 2003). These patterns are resulting in biotic homogenization (Elton 1958; Lockwood & Mckinney 2001). Thus, 800 years ago Britain and New Zealand shared no breeding bird species in common. Now they share 37 (Blackburn & Duncan 2001b). In that same period New Zealand lost 62 breeding bird species, or almost half of its avifauna, mainly driven extinct by exotic mammalian predators (Blackburn & Gaston 2005; Duncan & Blackburn 2005). A unique fauna shaped by evolution over 80 million years has now been transformed such that, over much of New Zealand, most of the birds that a visitor from the UK encounters are the same as back home. The same is true for floras and faunas around the world. It is the biological equivalent of flying from Seattle to Paris and going to Starbucks for your coffee.

When discussing the loss and gain of species among regions we frequently refer to the term 'biodiversity'. In its simplest definition, biodiversity refers to the number of species per unit area. However, it is obvious that this definition does not satisfactorily account for the diversity of life (Purvis & Hector 2000), or for the processes of ecological interaction and evolution that maintain existing species and are critical for generating new life (Bøhn & Amundsen 2004). Homogenization may not result in biodiversity loss in terms of simple numbers, but may do so significantly in terms of identities (see also Vane-Wright *et al.* 1991) and ecosystem processes (Loreau *et al.* 2001; Kinzig *et al.* 2002). For example, it has been suggested that different species perform the same functional role in ecosystems such that changes in species diversity should not necessarily affect ecosystem functioning ('functional redundancy': Lawton & Brown 1993). However, several controlled experiments have instead found evidence of functional complementarity, resulting from processes such as resource partitioning and facilitation, among at least some of the species involved (e.g. Hector *et al.* 1999; Cardinale *et al.* 2002). Thus, species turnover through homogenization may be far from positive in terms of altering the functional ability of ecosystems in ways that remain exceedingly difficult to predict.

Brown and Sax correctly point out that many of the ecosystems that are currently being impacted by humans have already been greatly modified by human intervention in the past. Thus, the notion of 'pristine' ecosystems should largely be discarded (Gaston & Blackburn 2003). Yet, that is not to equate past and current human influences. Aboriginal cultures were certainly responsible for many extinctions (e.g. Milberg & Tyrberg 1993), but for exotic introductions the rates of transport, distances traversed and numbers of species involved have all increased dramatically since the initial period of European exploration (e.g. Pimm *et al.* 1995).

Thus, we think it a questionable choice of language when Brown and Sax describe losses to extinction as being 'more than offset' by the gains from invasion. It is not clear to us that they are, in any sense except in terms of pure local species numbers. Yet, in the accountancy of global change, simply totting up the net change in species numbers is probably the least useful way of assessing profit and loss. Moreover, we would note that choice of the term 'more than offset' is no less value-laden than the emotive language that Brown and Sax argue against. It implies to us a positive benefit of biotic homogenization with which we think few scientists would agree. This brings us to our final set of points.

THE ROLE OF SCIENTISTS

Brown and Sax state that the aim of their essay 'is not to suggest that modern humans should let nature take its course and elect not to intervene in the dynamics of dispersal and extinction, and the resulting impacts on biodiversity, ecosystem function and the economy'. However, that statement raises a number of important questions, perhaps most notably why should humans intervene, when and how? We believe that these are rightly questions for scientists. Only with the benefit of the knowledge provided by rigorous, impartial and objective science can society (or its elected representatives) take informed decisions over what action to take best to manage the environment for biodiversity, ecosystem function and the economy (with their concomitant effects of 'quality of life').

Moreover, while Brown and Sax argue that 'deciding what is good or bad is a moral and social issue', we see questions of 'good' and 'bad' as equally valid in a scientific context. For example, if the question is 'what is the impact of invasive species on the ability of a plant community to recover after drought?' or 'what is the impact of invasive species on the health of the human population of a country?', there are clear grounds for equating answers in the negative as 'bad'. Certainly, management decisions based on the answers to such questions will require value judgements to be communicated from scientists to policy makers, because scientists may often be the only ones in the position to make them. Thus, it would seem to us to be the responsibility of science to inform society. (Indeed, it has often been argued that the exasperation voiced by scientists over the poor level of scientific literacy in the general public, and the poor level of scientific debate in the media, is precisely because that communication is currently inadequate.) And given that policy makers are quite willing to ignore those scientific value judgements even when they are clearly communicated (e.g. in failing to ratify the Kyoto Protocol, or denying a connection between HIV and AIDS), the idea that such decisions will be taken on the basis of the raw facts is naïve at best.

As scientists, however, we also recognize that the processes which form and structure ecological assemblages are incompletely understood and remain controversial (e.g. Lawton 1999; Chave 2004; Simberloff 2004a; Gaston & Chown 2005). Exotic species are pervasive, and studying their evolutionary ecology and the consequences of their successful establishment is one way in which an understanding of these processes may be advanced: indeed, the explosion of interest in the study of invasive species has itself been compared to an 'invasion' of the scientific literature (Simberloff 2004b). We agree with Brown and Sax that invasive species are an opportunity to be exploited, albeit an opportunity that we do not think will be impaired by a growing environmental awareness to 'stem the tide' of invading exotic species. It is encouraging at this point in history to believe that invasions really could be a force for good. Nevertheless, regardless of whether we consider invasions (and extinctions) 'good' or 'bad', we study them, and are funded to do so in part (and we believe for good reason) because it is widely concluded that they are undesirable for maintaining the function of natural ecological and evolutionary patterns and processes. How many funding applications propose studying invasive species for their intrinsic interest alone?

When people treat foreigners 'with distrust, dislike, even loathing', it is because they believe that those foreigners are a threat, be that to their possessions, livelihoods, quality or way of life, or perhaps even to their life itself. With notable exceptions – invading armies, for instance – those threats are more imagined than real. That is not the case for biological invasions, which have been (and continue to be) a genuine threat to the livelihoods, way of life and life itself, of populations and species on every landmass on earth (see also Simberloff 2003). It is possible for scientists to study these processes with objectivity, but we should not confuse scientific objectivity with moral neutrality. After all, Albert Einstein laid the foundation for the development of nuclear weapons, yet argued for nuclear disarmament. His standing is not diminished as a result. Consequently, we congratulate any individual who, like Marilyn Fox (Brown & Sax 2004), against the flood (an unabashedly emotive term for a large order or magnitude of particles) of non-native species, still has the strength to believe it is worthwhile to stop the car and pull out exotic plant pest species in a region specifically preserved for natural heritage.

In conclusion, species have gone and are going extinct (Lawton & May 1995). Most recent extinctions can be attributed to drivers of human-induced global change (Avise 2003). One of these drivers, which is leading to local and global extinction, is the transportation and establishment of exotic species (Vitousek *et al.* 1997). In addition, when the dual processes of extinction and invasion overlap in a common region they can lead to increased biological homogenization where species similarity increases (and species distinctiveness decreases) among a set of communities through time (McKinney & Lockwood 1999; Olden & Poff 2003). Scientists have not yet provided any compelling evidence that either of these processes is slowing down, although the rates and magnitudes are indeed changing among some taxa. The fact that we can look forward to ecological systems recovering from these assaults in the next 10 million years or so is not one that we consider a great consolation.

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