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The challenges to conservation in a changing world: putting processes on the map

ANDREW BALMFORD, GEORGINA M. MACE AND JOSHUA R. GINSBERG

INTRODUCTION

By common consensus, a single species, somewhat inappropriately named *Homo sapiens*, is now on the verge of precipitating an extinction event which may rival the Big Five mass extinctions of the geological past (Pimm *et al.*, 1995; May & Tregonning, this volume). Recent estimates are that impending rates of species loss are between three and five orders of magnitude higher than background extinction levels (May *et al.*, 1995; Pimm *et al.*, 1995). In tropical forests alone, human activities are probably committing between 0.1 and 0.3% of species to extinction every year. From the perspective of providing goods and services, populations are more important than species, yet new work suggests that extinction rates of populations are far higher, with annual losses running at around 0.8% (equivalent to about 1800 populations every hour: Hughes *et al.*, 1997).

The causes underlying these losses are well established, and are succinctly reviewed by Russ Lande in Chapter 2. The chief anthropogenic threats responsible for the current extinction crisis are habitat clearance and degradation (including pollution and habitat fragmentation), overexploitation (itself exacerbated by unregulated access to common-property resources and by economic discounting), and the myriad impacts of introduced species (Vitousek *et al.*, 1997). Once populations are substantially reduced by these deterministic challenges, they may in turn become vulnerable to both intrinsic threats such as the stochastic demographic and genetic perils of small population size, and extrinsic threats such as chance environmental fluctuations, and random catastrophes (Lande, this volume).

Conservation biologists have responded to this stark situation in three main ways. Most fundamentally, a great deal of effort has been devoted to

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identifying and attempting to reverse the likely causes of species decline – an empirical approach which, in his lucid review of the state of the field, Graeme Caughley labelled the declining population paradigm (Caughley, 1994; Caughley & Gunn, 1996). In addition, since the founding of modern conservation biology in the late 1970s, theoretically based work in both genetics and demography has examined the effects of small population size itself (an approach dubbed the small population paradigm by Caughley). The third, most recent wave (reviewed in depth by Paul Williams in Chapter 10) links empiricism with computer-based algorithms in an effort to identify priority areas where nature reserves and other *in situ* conservation initiatives could be most efficiently concentrated.

In our view, these approaches, while extremely valuable, suffer from an important limitation: they are very largely based on contemporary patterns of the distribution of biodiversity and the threats which it faces. Concerns about processes are generally limited to the internal dynamics of small and isolated populations. Yet the world is dynamic at broader scales as well. Conserving biodiversity requires more than just representing its more tangible elements (such as species or intraspecific genetic variation) in static protected areas. Rather, it requires maintaining the dynamic genetic and ecological processes which characterize and sustain free-ranging communities (see T. B. Smith *et al.*, 1993). Beyond this, humans are also changing the world in novel ways. Future threatening processes will not simply be current threats writ larger. Conservation strategies must, wherever possible, anticipate future threats as well as address contemporary ones if they are to prove effective over the long term.

This book is about starting to identify the sorts of natural and anthropogenic processes which we as biologists should think about when designing strategies to meet the challenge of conservation in a changing world. This opening chapter provides a brief overview of what we consider to be some of the book's emergent themes, and tries to embed them in the context of the recent literature. We begin by presenting evidence indicating that process-related concerns are inadequately reflected in current work. The bulk of the paper then highlights what we see as the key process-related issues that we need to address, and examines the likely consequences of failing to do so, before closing with a series of critical recommendations for planners and practitioners.

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THE PROBLEM

Clear evidence that a conservation agenda based solely on contemporary patterns often fails to tackle process-related concerns comes from thinking about how we identify priority sites for conservation. This work is critical to ensuring limited conservation resources are focused efficiently, and as Paul Williams shows in Chapter 10, area-selection methods have become extremely sophisticated in recent years. They are now capable of identifying near-optimum networks of sites which contain as much biodiversity (measured in different ways) as is practically possible within limits set by the availability of land or resources (see also Csuti *et al.*, 1997). However, the input to these algorithms consists, in the main, of simple snapshots of where different organisms are found at a particular time (Flather *et al.*, 1997). The analyses take little or no account of any dynamic features of the systems under study, such as movements of individuals, the temporal viability of different populations, the population processes that contribute to longer-term viability, or ecological interactions within communities.

This, in turn, is reflected in the output of these sorts of procedures (Nicholls, this volume). Selected sites commonly fail to include the core of species' ranges, where populations may be most abundant and most resilient to anthropogenic activities (see also below). Moreover, patterns of occupancy may be sufficiently fluid that key sites picked in one year turn out, with the benefit of hindsight, to be alarmingly poor at representing the same species or populations even in subsequent years (Margules *et al.*, 1994; Nicholls, this volume). This problem is likely to be greatly amplified over the much greater timescales that characterize most ecological and evolutionary processes. Further quantitative studies of the consequences of neglecting process-related issues during priority-setting are clearly needed, but the message from work to date is that by themselves, pattern-based algorithms may generate only rather limited solutions to long-term (and necessarily process-dependent) conservation goals.

A second way in which we can examine the mismatch between contemporary conservation biology and perceived conservation need is to compare the sorts of questions conservation practitioners ask with the types of questions conservation biologists are presently answering. Here, data on questions asked come from a survey conducted by Hilary Swain and colleagues of 50 conservation managers in Florida (Swain *et al.*, 1996); data on the sorts of questions that are answered come from an analysis of the abstracts of 214 contributed papers appearing in the journal *Conservation Biology* be-

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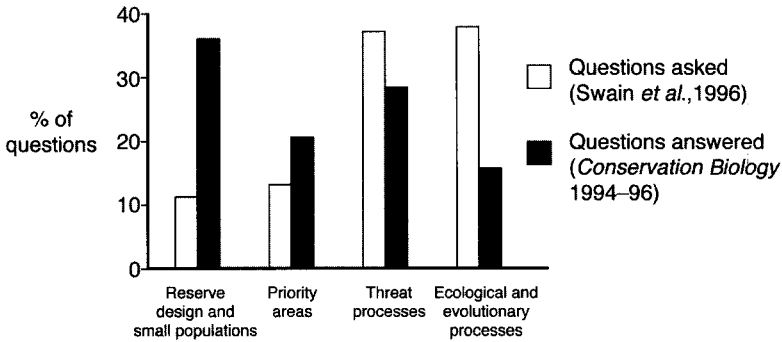
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Fig. 1.1 Differences between the kinds of questions conservation practitioners are asking and those which conservation biologists are answering. Data on questions asked come from a survey of 50 conservation managers in Florida (Swain *et al.*, 1996). Information on questions answered comes from an assessment of 214 papers contributed to *Conservation Biology*. Results are qualitatively similar if data are taken from *Biological Conservation* instead.

tween 1994 and 1996. Sorting questions into four broad categories (three of which correspond to the main approaches discussed above) reveals a clear disparity between the problems managers feel they want answered, and the research activities of professional biologists (Fig. 1.1).

Questions relating to the detailed design of reserves and the fate of small populations are evidently more interesting to scientists than to conservation practitioners. The same appears true, although to a lesser extent, of questions linked to the identification of overall spatial priorities for conservation. In contrast, two sorts of questions are answered less often than they are raised. Both are explicitly process related: questions dealing with the dynamics of the threats to different species; and questions involving the ecological and evolutionary dynamics of the systems of conservation concern. Managers are clearly very worried about how interactions will be maintained in small reserves, and how both natural and anthropogenic processes in the wider landscape will impinge on the contents of protected areas. As yet, conservation biologists are not providing the answers.

WHAT SORTS OF PROCESSES ?

In broad terms we suggest that the key process-linked issues which conservation biologists should think more about fall into three groups (see Table 1.1): threatening processes; dynamic responses of organisms to external

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[More information](#)**Table 1.1***Some process-related concerns of importance for the conservation of biological diversity in a changing world**Threatening processes*

Established threats are changing over time in different ways

Threatening processes operate over wider temporal and spatial scales than we commonly think

Cumulative effects can be unpredictable

Novel threats are emerging

Dynamic responses to external challenges

Species have coped with past environmental change by shifting ranges, but this is now hampered by the rate of change and by habitat fragmentation

Adaptive evolution to new challenges requires large population sizes

To persist, some species may now depend on continued exposure to natural or anthropogenic challenges to which they are adapted

Intrinsic ecological and genetic processes

Maintenance of metapopulation dynamics requires multiple, clustered habitat patches separated by a relatively benign matrix

Migratory populations depend on the conservation of all their habitats

Some communities rely on dispersal over very large distances

Long-term genetic viability of small populations can be threatened by stochastic problems of inbreeding depression, excessive loss of genetic variation, and mutational meltdown

Genetic integrity of sympatric species requires the maintenance of mechanisms of reproductive isolation

Certain kinds of areas ('species factories') may be disproportionately responsible for the generation of evolutionary novelty

challenges (either natural or anthropogenic); and intrinsic ecological and genetic processes by which free-ranging populations and communities persist. We will now look at examples of each of these sorts of processes, and think in particular about why they may be inadequately dealt with in a conservation agenda driven largely by consideration of present-day patterns.

Threatening processes

As the conservation status of more and more species is assessed by IUCN and other agencies using new, quantitative criteria (IUCN SSC, 1994), we are acquiring an increasingly detailed picture of current levels and causes of threat (see IUCN, 1996; G. M. Mace & A. Balmford, unpublished data). To the extent that the new categories of threat can nominally be equated

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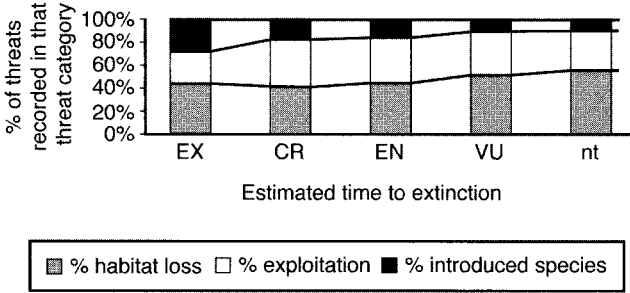
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ISLANDS

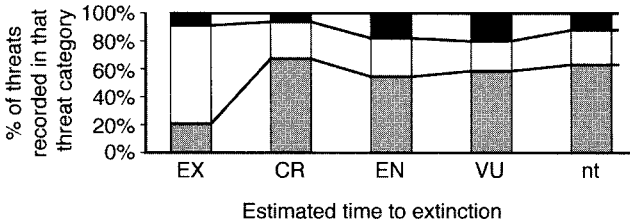


Fig. 1.2 Likely changes in the time course of different threatening processes to continental and island mammals. Species are classified according to their IUCN threat category, with the estimated time to extinction increasing from left to right. EX = extinct; CR = critical; EN = endangered; VU = vulnerable; nt = near-threatened. The analysis deals only with those species for which threats have been published. Island species are those entirely restricted to islands; continental species are all others.

with fixed probabilities of extinction within a given time frame (Mace, 1994), it is tempting to try to use these assessments to predict the future course of anthropogenic extinctions. However, our ability to infer future losses (and their causes) from existing patterns of threat is limited by several important considerations.

First, there are major temporal (as well as spatial and taxonomic) differences in the relative impacts of different threats. Figure 1.2 illustrates this point with data derived from an analysis of threatened mammals. Using the IUCN categories of threat as rough measures of the relative time before different species are likely to go extinct, we see that, among mammal species on continents, the relative importance of losses due to introduced species is likely to decline in future, while the proportion of extinctions due

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to habitat loss is likely to increase. The picture is further complicated by consideration of mammals restricted to islands. Here, habitat loss is again set to increase in relative importance, but the threat classification data indicate that introduced species are likely to present a continuing (rather than declining) threat. Any meaningful extrapolation of the future impact of existing threats must take these sorts of detailed variations in the dynamics of particular threatening processes into account.

There is also growing evidence that, so far, we have underestimated the wide-ranging, long-term and sometimes unpredictable impacts of certain sorts of contemporary threats. For instance, detailed dissection by Audrey Mayer and Stuart Pimm in Chapter 3 of the possible causes of the decline of the Cape Sable seaside-sparrow (*Ammodramus maritimus mirabilis*) reveals that the most likely reasons involve recent and profound changes to the hydrology (and associated fire phenology) of the Everglades National Park. The whole of the seaside-sparrow's range is contained within a reserve network totalling over 9000 km². Yet, despite this formal protection, extensive flooding in the western part of the park, and desiccation (and hence increased incidence of fires) in the eastern part – both brought about by activities in agricultural zones beyond the park's boundaries – have between them greatly decreased the availability of breeding habitat. Threatening processes can evidently operate over much wider spatial scales than we sometimes think.

Shifting to a temporal scale, even well-known threats can also have cumulative and unpredictable effects. Long-term consequences of sustained anthropogenic pressures on natural ecosystems may often be characterized by discontinuous, threshold (rather than linear) responses (Ehrlich & Holdren, 1971; Myers, 1995). A good example of this comes from a recent reassessment by Jeremy Jackson of the most likely cause of the collapse of coral reefs in the Caribbean (Jackson, 1995, 1997; see Fig. 1.3). Newly synthesized historical evidence clearly demonstrates that, prior to the arrival of Europeans, the region supported extraordinary densities of large vertebrates, including green and hawksbill turtles (*Chelonia mydas* and *Eretmochelys imbricata*), sharks, rays, groupers, manatees and monk seals (Jackson, 1997). Their combined biomass probably exceeded that recorded for all ungulates in the Serengeti by at least one or two orders of magnitude, yet by the time modern reef ecology began in the late 1950s, intense overexploitation meant that all these species were already reduced to a fraction of their previous abundance. Nevertheless, this dramatic faunal collapse apparently had little if any immediate impact on the struc-

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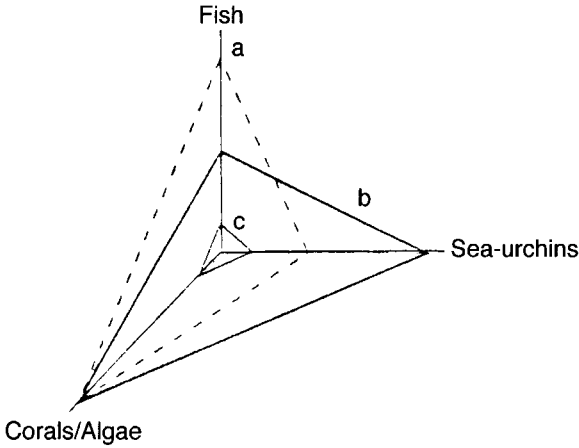
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Fig. 1.3 Schematic representation of the apparent response of Caribbean reef communities to overexploitation of fish (leading to an increase in sea-urchins and a shift from plane a to plane b) and subsequent sea-urchin disease (leading to overgrowth of corals by macroalgae, and collapse of the system from plane b to plane c). (From Jackson 1995, by permission of Oxford University Press.)

ture of Caribbean reef communities (Jackson 1995). Smaller fish continued to consume both macroalgae and *Diadema* sea-urchins (plane a in Fig. 1.3), and only after these smaller species themselves became the target of overexploitation (during the course of the twentieth century) did pronounced changes in community composition take place. Overfishing and the ensuing decline in fish predation on sea-urchins allowed *Diadema* to increase in abundance. Even then, because this urchin is a heavy grazer on macroalgae, the ratio of corals to algae remained high (plane b in Fig. 1.3). It was not until disease decimated *Diadema* populations in 1983 that the underlying fragility of this now simplified system was fully revealed. The ensuing precipitate reduction in grazing pressure released macroalgae, which have since been overgrowing corals throughout the Caribbean. The region's reefs now appear locked into a low diversity, algal-dominated state (plane c in Fig. 1.3), but the sudden nature of the switch to this condition belies the chronic and cumulative nature of its underlying cause.

One final reason why basing conservation strategies solely on present-day human impacts is inadequate is that entirely new threatening processes are emerging, and will continue to do so. Probably the most important of these to have been documented to date is climate change (Huntley,

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this volume). Despite continued lack of clarity in the details of how global warming is expected to proceed, there is growing consensus surrounding the overall picture (IPCC Working Group I, 1996; Mahlman, 1997). Human activities have already warmed the earth by an average of around 0.5°C this century, and by 2100 continued emissions of CO_2 and other greenhouse gases are likely to have led to a further increase in mean surface temperatures of between 1.5 and 5°C , with a consequent mean rise in sea levels of 50 ± 25 cm. More precise estimates will hinge on resolving the many uncertainties in existing climate models, and will be strongly affected by exactly when and by how much we decide to curb greenhouse emissions. But, given the evidence (for review see Huntley in Chapter 4) that macroclimatic conditions play a primary role in determining the distribution of many species, the impacts of global warming on biological diversity are very likely to be substantial.

Dynamic responses to external challenges

The overall effect of any external challenge on a population will be determined not just by the magnitude of the challenge itself but also by the population's own capacity to respond in an adaptive manner. Natural populations have always been subject to external challenges of one sort or another, yet some have evidently persisted despite them. We therefore need to think in more detail about the kinds of dynamic responses which have conferred resilience to environmental challenges in the past. Climate change again provides a useful arena in which to examine these process-related concerns.

As Brian Huntley describes in Chapter 4, the global climate has oscillated dramatically over the course of the Quaternary, and new palaeoecological analyses yield valuable insights into how species have coped. One very common response to changed environmental conditions has been a shift in the geographical ranges of species. As climate zones have moved latitudinally and/or altitudinally, species have persisted by tracking these shifts, in effect occupying the same envelope of climatic conditions through time, in spite of global climatic instability. A striking illustration of this sort of response is provided by G. R. Coope's work on fossil beetles (Coope, 1995). Of more than 2000 species recovered from Quaternary deposits in Britain, well over 99% are still extant, but the great majority are nowadays restricted to other parts of Palearctic, which are either colder or warmer than contemporary Britain (depending on whether

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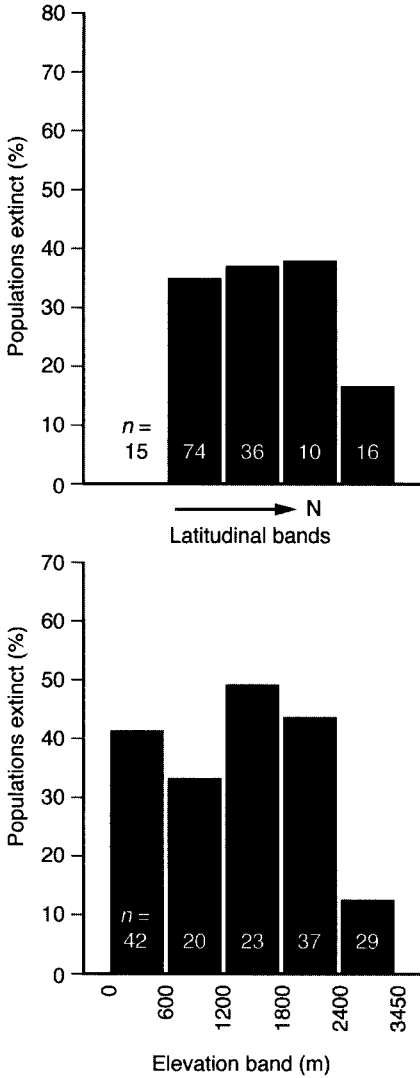
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Fig. 1.4 Relative loss of 151 historical populations of Edith's checkerspot butterfly in western North America, as a function of latitude and elevation. Populations at the warmer margins of the species' historical range (i.e. those at low latitudes and altitudes) exhibited higher extinction than others. (Reprinted with permission from Parmesan, 1996, © Macmillan Magazines Ltd, 1996.)