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ORIGINAL PAPER

Climate change, conservation and management: an assessment of the peer-reviewed scientific journal literature

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Abstract Recent reviews of the conservation literature indicate that significant biases exist in the published literature regarding the regions, ecosystems and species that have been examined by researchers. Despite the global threat of climatic change, similar biases may be occurring within the sub-discipline of climate-change ecology. Here we hope to foster critical thought and discussion by considering the directions taken by conservation researchers when addressing climate change. To form a quantitative basis for our perspective, we assessed 248 papers from the climate change literature that considered the conservation management of biodiversity and ecosystems. We found that roughly half of the studies considered climate change in isolation from other threatening processes. We also found that the majority of surveyed scientific publications were conducted in the temperate forests of Europe and North America. Regions such as Latin America that are rich in biodiversity but may have low adaptive capacity to climate change were not well represented. We caution that such biases in research effort may be distracting our attention away from vulnerable regions, ecosystems and species. Specifically we suggest that the under-representation of research from regions low in adaptive capacity and rich in biodiversity requires international collaboration by those experienced in climate-change

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research, with researchers from less wealthy nations who are familiar with local issues, ecosystems and species. Furthermore, we caution that the propensity of ecologists to work in essentially unmodified ecosystems may fundamentally hamper our ability to make useful recommendations in a world that is experiencing significant global change.

Keywords Global warming · Biodiversity · Climate change · Conservation priorities

Introduction

To track shifts in conservation research priorities, researchers need to be aware of the research already being conducted within different areas as well as current research gaps. Based on this information, deficits in our understanding can be identified and addressed effectively. Periodic assessments of the scientific journal literature can help streamline this process (Lawler et al. 2006). Two general reviews of conservation biology journal articles have been published recently, one with the explicit aim of assessing the relevance of conservation research to policy and management (Fazey et al. 2005a), and one that assessed how well conservation scientists were tracking key conservation priorities over the last 20 years (Lawler et al. 2006). Both studies identified significant biogeographic and taxonomic gaps in the peer-reviewed conservation science literature.

The first scientific papers specifically considering the impacts of anthropogenic climate change on ecosystems were published 20 or more years ago (Peters and Darling 1985; Graham 1988). Since then, it has been established that climate change is affecting the phenology of numerous organisms (Walther et al. 2002; Parmesan 2006), altering the composition and dynamics of communities (Hughes 2000; Walther et al. 2002), and causing altitudinal or pole-ward range shifts of species (Parmesan and Yohe 2003). Sufficient time has elapsed to warrant looking over the efforts to date, to explore whether there may be biases in the focus of research being published and, if necessary, what can be done about them.

We set out to determine whether or not similar biases in research focus identified in the general conservation science literature (see Fazey et al. 2005a; Lawler et al. 2006) also were occurring within the conservation-related climate change science literature. Our aim was not to comprehensively survey the ecological literature on climate change (as per Parmesan 2006), produce a systematic review (Pullin and Stewart 2006), or to conduct a meta-analysis (Osenberg et al. 1999). Instead, our aim was to provide a quantitative basis for discussing current research efforts in relation to regions, ecosystems or species in a world of anthropogenic climatic change.

We considered a sample of peer-reviewed climate change research, published in scientific journals, that addressed the conservation or management of biodiversity and ecosystems. We had six main aims. Specifically, we assessed whether there were disparities in the relative number of publications presenting research on different (1) climatic zones and continental regions, (2) ecosystems and (3) taxonomic categories. We assessed whether publications considered (4) existing versus future trends, and (5) the interaction of climate change with other anthropogenic disturbance processes. Finally, (6) we compared their resultant recommendations for policy and management. We hope that our results will spur critical discussion among ecologists about how research should be prioritised to provide a sound scientific basis to manage ecosystems that are being affected by climate change.

Methods

We used the ISI Web of Science database to search for articles that focused on climate change and the conservation or management of biodiversity. To ensure that climate change was a core focus of the study, we limited our search to articles with "climate change", or related phrases (i.e. "global warming", "climate warming", "change in climate") in the title. This was done to avoid including the large number of papers that merely contained short topical statements on the implication of their research under climatic change. We then narrowed our focus to a subset of these papers containing in their abstracts, titles or keywords the terms "biodiversity", "biology", "ecology", or "species", as well as "conservation", "management", or "recommendation". When relevant alternative suffixes existed for a search term, we used the asterisk wildcard (e.g. "conserv*" or "ecolog*"). All papers resulting from this search were considered for review. Our search was conducted on the 28th of September 2006, and yielded 288 papers spanning the years from 1988 to 2006. From the initial set of 288 candidate articles, we excluded 40 papers which were book reviews, methods papers, or replies.

Each paper was evaluated by two reviewers using a survey consisting of multiple choice questions. Prior to collecting data, we calibrated all survey questions by evaluating the consistency of reviewer responses to the same papers. All questions that resulted in reviewer discrepancies were re-written. Any remaining discrepancies were overcome by including only those responses to questions that were ticked by both reviewers.

Caveats associated with our methods are as follows. First, a large body of literature exists with the specific aim of synthesizing the scientific literature for management purposes that is not published in the scientific journals (e.g. Johnson and Marshall 2007). Therefore, it would be incorrect to interpret our results as suggesting that detailed management-related literature is not available on a given issue merely on the basis that it was not comprehensively addressed in journal articles. Second, our results are intended to identify the relative proportions of surveyed studies that can be appropriately grouped within given categories of interest. Because the results from such assessments are by definition relative, they only provide an indication about the relative (but not absolute) coverage a topic is being given. Finally, our survey addressed only the English-language scientific literature. Studies from non-English speaking regions were therefore underrepresented.

We are acutely aware that not all papers which are relevant to conservation and management issues include associated terminology in the abstract. However, we reasoned that the presence of explicit statements regarding conservation or management in the abstract would ensure that we would assess primarily those papers with an explicit focus on applied, rather than fundamental questions. This approach enabled a rapid and directed overview of an increasingly vast literature, and we considered it appropriate for detecting the types of broad patterns we were interested in.

Results and discussion

Aim 1: geographical coverage

Approximately 50% of all studies were conducted within the world's temperate zones (Fig. 1). The majority of studies were based on research conducted in North America (29%) and Europe (24.6%). This geographical bias has been noted previously for

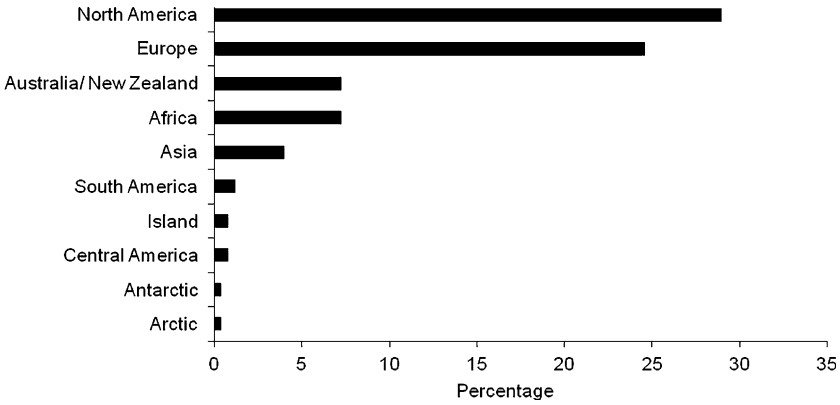

Fig. 1 Percentage of studies from the reviewed climate change literature that considered the conservation management of biodiversity and ecosystems within different regions

biological studies of climate change impacts (Parmesan 2006; IPCC 2007b), and is pervasive throughout the conservation literature (Fazey et al. 2005b; Lawler et al. 2006) and broader scientific literature (Brambrink et al. 2000). The bias is likely to be driven by discrepancies in the scientific and technological research capabilities of nations (May 1997; Teodorescu 2000; Fazey et al. 2005b).

Because rapid climatic change is being observed within the higher latitudes of the northern hemisphere, the relative immediacy of the threat in these regions also may be contributing to this observed skew in research publications (IPCC 2007c).

Aim 2: ecosystem coverage

Conservation research is biased towards terrestrial environments (Abell 2002; Fazey et al. 2005a). This pattern appeared to be repeated for climate change studies, with forested environments representing a large proportion of all studies (38%; Fig. 2). The bias towards forest ecosystems was nearly double that found by Fazey et al. (2005a) in their general study of conservation journal publications (20.5%). We suggest that climate change related impacts on forested environments have attracted disproportionate research attention due to their direct relevance to North American and European funding and research bodies, including the economically-important forest industries in those regions. For example, there are expectations that temperate and boreal plant species may be displaced by 200–1,200 km pole-ward by 2,100 (Skre et al. 2002; Moen et al. 2004).

Aim 3: existing versus future trends

Almost half of the articles relied primarily on the modelling of future trends (46%). We also found that a substantial proportion (25%) of the literature was of a qualitative nature (e.g. review). At best, this bias towards modelling and qualitative discussion results from the relatively small number of species that are threatened by current levels of climate change (Parmesan 2006), compared with the future projections of species loss (Thomas et al. 2004). However, these results may also be indicative of a paucity of long-term data sets and monitoring sites with which to provide empirical evidence of climatic impacts on threatened taxa and ecosystems. This potential lack of empirical data also may be

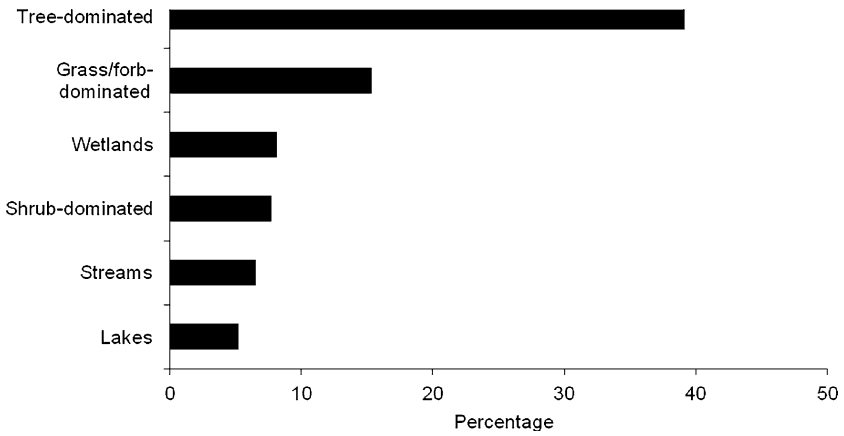

Fig. 2 Percentage of studies from the reviewed climate change literature that considered the conservation management of biodiversity and ecosystems within different terrestrial environments

contributing to the overall paucity of studies in the conservation biology literature that address climate change (< 5%) as a threatening process (Fazey et al. 2005a; Lawler et al. 2006).

Aim 4: taxonomic coverage

Trees were the primary taxonomic focus of the majority of studies (Fig. 3). This result was indicative of the identified bias towards conducting studies in forested ecosystem. Studies

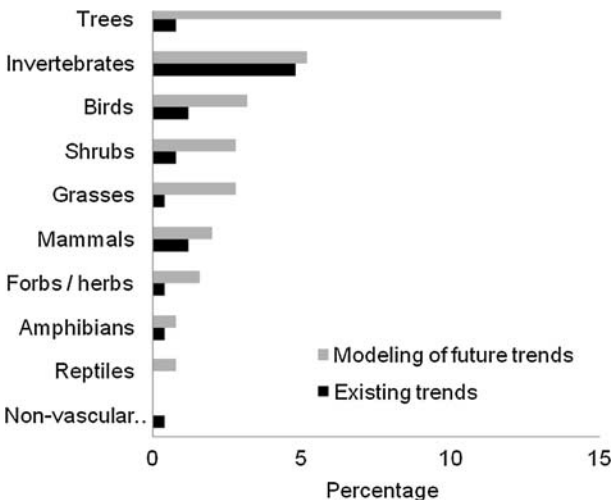

Fig. 3 Percentage of studies from the reviewed climate change literature that considered the conservation management of biodiversity and ecosystems that were conducted on different taxa. Division is based upon whether results stem from observed responses (field based data or assessment of existing collections such as museum records), or was based upon predictions using simulations or modeling techniques

that involved trees were heavily skewed towards the use of modelling, but this pattern was not consistent across other taxonomic groups.

Compared to the general conservation literature (Fazey et al. 2005a), a large proportion of studies addressed invertebrates. This taxonomic grouping had the highest proportion of studies based on observational findings. As a large number of invertebrates possess relatively short generation times and high degrees of mobility, they can be particularly well suited to studies addressing species responses to climate change. A substantial percentage of these studies was conducted on butterflies. Butterflies are thought to be useful for assessing responses to existing degrees of climate change because of their relatively short generation times, high level of climatic sensitivity, and the prevalence of accurate historical records (Parmesan 2001).

Several taxa were under-represented in the literature, potentially highlighting an important area for increased conservation science effort. For instance, the highly threatened status of a large number of amphibian species (IUCN 2004; Stuart et al. 2004) combined with their apparent sensitivity to climate change (Pounds et al. 2006), and relatively short generation times, makes them obvious candidates for further research.

Aim 5: interaction with other anthropogenic threats

Roughly half of the studies surveyed did not address climate change in the context of other anthropogenic threats (46%; Fig. 4). This is not unexpected as studies often consider a specific threat or stressor in isolation (Fazey et al. 2005a). However, the treatment of climate change in isolation from other human disturbances can be a limitation. Climate change impacts on species and ecosystems are expected to exacerbate (and in turn be exacerbated by) habitat loss and fragmentation (Opdam and Wascher 2004; Pyke 2004), the over-harvesting of species (He et al. 2002), exotic and invasive species (Dukes and Mooney 1999), and pollution (Moore et al. 1997; Hughes et al. 2003).

For those studies that did consider other threatening processes, the majority addressed the issues of vegetation fragmentation and land degradation (22%; Fig. 4). This outcome is likely to be related to the extent of forest ecosystem coverage discussed above. The trend

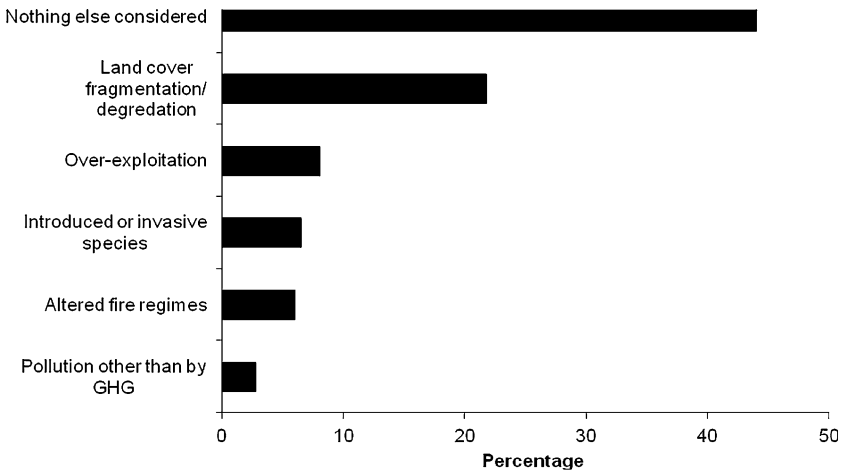

Fig. 4 Percentage of studies from the reviewed literature that focused on the interaction of climate change with other anthropogenic disturbance processes

towards publishing studies on forest ecosystems also accounts for the large percentage of studies that identified a need for altering patterns of land use outside reserves, such as the maintenance or enhancement of landscape connectivity and landscape heterogeneity (Fig. 4). The need for such approaches reflects the extent that humans have extensively modified terrestrial landscapes (Sanderson et al. 2002). For example, crop and pastoral lands alone now occupy approximately 40% of the Earth's terrestrial surface (Ramankutty and Foley 1999).

Aim 6: recommendations for policy and management

Because our search criteria directly targeted those papers that would be relevant to conservation and management issues, it was notable that over 10% of papers did not contain any recommendations for policy or management (Fig. 5). The tendency of scientists to avoid making broad policy prescriptive recommendations may account for why over 90% of papers made no mention of the need to reduce greenhouse gas emissions.

Of the papers that did make recommendations, more than half advocated an increase in monitoring and research (Fig. 5). This was the case even for those studies dealing with the most intensively researched regions. For studies conducted in North America and Europe, 57% recommended more research and 27% recommended more monitoring. Although vested interest may play a part, we suggest that even in the most studied regions, there is insufficient data on species responses to current levels of climate change, and more research and monitoring is needed (see Lovett et al. 2007). As recently as 2001, less than 3% of papers published within the leading conservation journals addressed climate change (Fazey et al. 2005a). We emphasise that merely considering the number of studies conducted can overlook whether or not there is a paucity of well-designed studies addressing

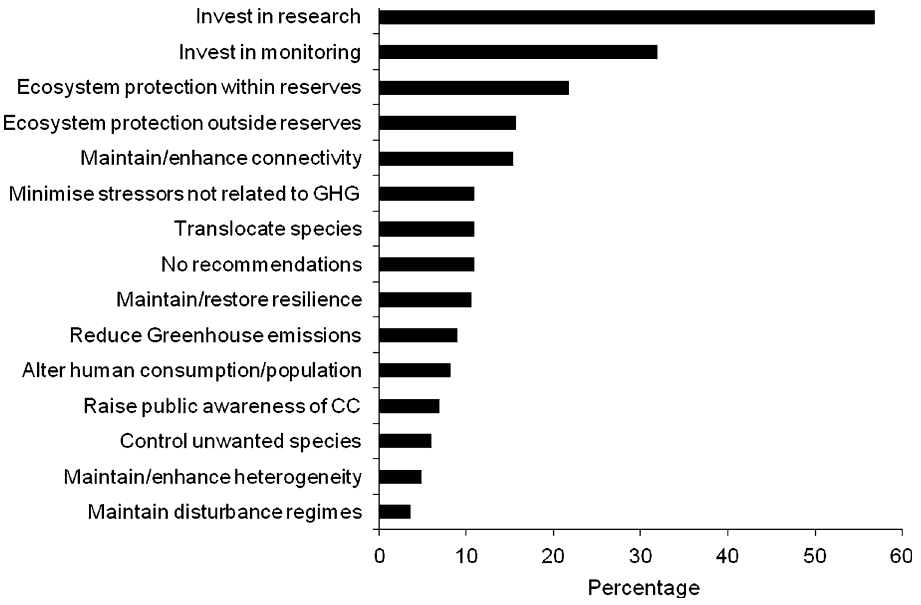

Fig. 5 Percentage of studies from the reviewed climate change literature with recommendations. (CC = climate change)

climate change. This issue has been raised by Parmesan (2006) in relation to how few well-designed studies there are of species range shifts.

Due to the prevalence of conservation studies in relatively unmodified environments (Fazey et al. 2005a), it is understandable that over 20% of studies recommended increasing ecosystem protection within reserves (Fig. 5). Recent research supports the view that protecting areas is a key conservation action for ameliorating the impacts of climate change (Hannah et al. 2007).

A large percentage of studies identified the need to alter patterns of land use outside reserves, such as the maintenance or enhancement of landscape connectivity and landscape heterogeneity (Fig. 5). The need for such approaches is a reflection of the extent that humans have modified terrestrial landscapes (Sanderson et al. 2002). Crop and pastoral lands alone occupy approximately 40% of the Earth's terrestrial surface (Ramankutty and Foley 1999). Extensive landscape modification may impact on the ability of some species to migrate in response to climate change (Opdam and Wascher 2004). This may in turn be influencing the number of papers that are recommending the costly—and risky—option of translocating species (10%; Fig. 5).

Future directions

The normative, financial, and logistical incentives to work on different issues, and in different regions and ecosystems, are not equal. For this reason it is both understandable and expected that for each category assessed, the relative number of peer-reviewed scientific publications was not evenly distributed. As such, our principle finding was not that a bias occurred, but rather empirical quantification of the nature and extent of this bias.

It is tempting to use these results to advocate that increased consideration should be paid to those ecosystems or taxa which appear to be under-represented in the climate change literature (Fig. 1b). We would not be alone in our concerns to do so (see Abell 2002). Nevertheless, despite our concerns regarding particular ecosystems and taxa, such advocacy on our behalf would be overstepping both our data and the expertise of the authors. We do suggest though, that based on our findings, it is appropriate to outline the potential repercussions of regional biases in climate change research, and of treating climate change in isolation from other anthropogenic threatening processes.

We found relatively few published peer-reviewed scientific research emanating from South and Central America, with similar findings raised for some regions within Africa and Asia (IPCC 2007a). The majority of the world's species occur within the tropics, as do the majority of the world's threatened taxa (IUCN 2004). These taxa are primarily distributed within the tropical and subtropical broadleaf forests of the world (IUCN 2004). Recent research into the thermal tolerance of terrestrial insects, which represent the majority of terrestrial biodiversity, suggests that the greatest extinction risks from climate change are in the lower rather than higher latitudes (Deutch et al. 2008). Many tropical species are thought to possess restricted niches, and are potentially susceptible to even small alterations in climatic conditions (Bush and Hooghiemstra 2005; Deutch et al. 2008). For example, some of the first climate change related extinctions noted worldwide occurred within Latin America (Pounds et al. 1999; Pounds 2001; Pounds et al. 2006). Current predictions are for significant biodiversity loss throughout Latin America by the middle of this century (IPCC 2007b).

Any impact that results from a continued geographical and ecosystem bias in research activities will be further accentuated by regional differences in adaptive capacity. Adaptive

capacity is the "general ability of institutions, systems, and individuals to adjust to potential damage, to take advantage of opportunities, or to cope with the consequences" (Millennium Ecosystem Assessment 2005). Low adaptive capacity is characteristic of regions with low per capita income and large population growth rates. Unfortunately, low adaptive capacity coincides with large areas of biodiverse Latin America, Africa and South Asia (IPCC 2007a). Africa is considered one of the most vulnerable continents to climate change, in part because of its low adaptive capacity (IPCC 2007a). Coupled with increasing human populations, resultant increases in land clearance for agricultural production can be expected to take further tolls on species and ecosystems already stressed by climate change (IPCC 2007a). The result is a coupling of escalating threats to some of the most biodiverse regions on Earth, with the effectiveness of adaptation efforts potentially hampered by a lack of scientific information.

We suggest that collaborative efforts, at both international and regional levels, could contribute to rectifying the current situation. Although it is unlikely that the observed disparity in the proportion of studies conducted in different regions will be rectified in the near future, strategic partnerships providing high quality research specifically aimed at targeting key knowledge gaps may go some way to alleviating the problem. Collaboration can avoid the pitfalls often associated with international aid, such as donor dependence, and could provide benefits for first world scientists that go far beyond an increase in research opportunities (Western 2003). We suggest that ecologists with expertise in climate change need to partner with scientists from the regions of the world that: (1) support some of the most biodiverse ecosystems and assemblages, and (2) are the least resourced to conduct the necessary research to ensure appropriate adaptive or mitigation strategies.

We also suggest that based on our findings, where possible, consideration may need to be given to the cumulative or synergistic effects of climate change with other anthropogenic threatening processes (see Brook et al. 2008). A high proportion of the Earth's terrestrial environment is now altered by human activities (Sanderson et al. 2002) and researchers need to consider climate change as being intimately linked with other key threatening processes. The adaptability of species to climate change will be strongly determined by whether or not a species' population is fragmented, reduced by human exploitation, or prevented from undertaking adaptive large-scale movements due to urban or agricultural barriers (Opdam and Wascher 2004). If our results are indicative of the wider literature, then continuing to isolate climate change from other human impacts on species and ecosystems will only impair the ability to make appropriate recommendations to policy makers.

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