Conservation science: a 20-year report card

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We conducted an intensive review of conservation science to find out whether the field has tracked priorities over the past 20 years. A total of 628 papers from the literature, for the years 1984, 1994, and 2004, were surveyed. For each paper, we recorded where conservation research was done and what was studied. We found geographic gaps in conservation research, with marine, tundra, and desert biomes being studied less than other systems. We also found taxonomic gaps, with amphibians being understudied as compared to other, less threatened, taxonomic groups. Finally, we discovered that studies of invasive species are still lacking, despite the magnitude of the threat they pose to global biodiversity. Although there was a weak trend towards filling these gaps between 1984 and 2004, progress has been slow. To be more effective, the research community must quickly redirect research to better match conservation priorities.

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Over the past century, we have witnessed a substantial decline in global biodiversity, much of which is clearly linked to human activities (Millennium Ecosystem Assessment 2005). Land conversion, invasion by exotic species, pollution, and climate change are just a few of the factors that threaten the diversity of life. Conservation biology is the scientific discipline charged with understanding the decline in biodiversity and with providing information critical for balancing resource use with the preservation of functioning ecosystems.

Conservation biology is a crisis-driven discipline (Soulé 1985). To effectively inform policy and management, conservation research must address the most pressing problems and the most threatened systems and organisms. Because threats change over time, conservation biologists should be continually tracking shifts in conservation priorities and addressing problems as they arise. While several studies have identified gaps in ecological research in general (Clark and May 2002; Kochin and Levin 2003), and at least one has described the research published in the major conservation literature (Fazey *et al.* 2005), none have directly addressed the question of whether the field of conservation biology has adequately tracked emerging threats and issues. Using a survey of 628 papers from 14 journals, we conducted an assessment of the gaps in conservation research over a 20-year period and asked whether those gaps were being filled.

Specifically, we addressed two questions: first, where is conservation research being conducted and are those locations representative of the global diversity of ecological systems? Second, which taxonomic groups and which threats to biodiversity are being studied and are those groups and threats consistent with the priorities defined by previous ecological assessments? We measured the degree of disconnect in these two areas to determine whether the gaps we identified have narrowed or expanded over time.

In a nutshell:

- To be effective, conservation research must address the most pressing conservation problems as they arise
- Marine, desert, tundra, and many tropical systems are highly understudied
- Exotic species are poorly studied compared to other threats
- Amphibians are one of the most threatened taxa worldwide, but are one of the least well researched
- Conservation biologists must move faster in targeting research towards major threats and gaps in knowledge

Literature survey

We sampled a wide range of conservation literature by first identifying the top 60% of ecology journals, as ranked by the Journal Citation Reports (Institute for Scientific Information 1984, 1994, 2003). We used 1984 and 1994 rankings to select 1984 and 1994 journals and 2003 rankings to select 2004 journals (2004 rankings were not available at the time of the study). The 60% cut-off corresponded to an ISI impact factor of "1" for the 2003 rankings. From this initial set of candidate journals, we selected those for which at least 50% of the published

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Table 1. Journals included in the literature survey for each of 3 years

1984	*1994*	*2004*
Biological Conservation	*Biological Conservation*	*Agriculture, Ecosystems and the Environment*
Journal of Applied Ecology	*Conservation Biology*	*Animal Conservation*
	Ecological Applications	*Austral Ecology*
	Ecological Economics	*Biodiversity and Conservation*
	Journal of Applied Ecology	*Biological Conservation*
		Conservation Biology
		Ecological Applications
		Ecological Economics
		Ecology Letters
		Ecosystems
		Ecotoxicology
		Global Change Biology
		Journal of Applied Ecology
		Oryx

papers addressed conservation topics. A paper was determined to address a conservation topic if it investigated processes that produce, sustain, or threaten biodiversity in the face of anthropogenic disturbance. These criteria yielded two journals for 1984, five journals for 1994, and 14 journals for 2004 (Table 1). We randomly sampled 40% of all papers from each of the 3 years for each journal because the number of papers published in the two journals from 1984 was relatively small. For all analyses, we included only those papers that addressed conservation topics and excluded all review papers, producing a sample of 42 papers from 1984, 118 from 1994, and 468 from 2004.

For each paper, we recorded the geographic region where the research was carried out and what was studied. Each paper was evaluated by one of 10 observers using a survey of 125 questions addressing 23 aspects of the research. Before collecting the data, we calibrated all survey questions by evaluating two sets of papers to test for observer agreement. The first set consisted of 10 papers that were evaluated by all 10 observers. All questions with less than 70% observer agreement were rewritten. Using a second set of five papers, all 10 observers then re-evaluated these questions. By the end of this calibration process, all questions had at least 70% observer agreement.

To assess whether conservation research is addressing known priorities and threats, we compared the results of our survey to the stated conservation priorities of conservation organizations, as well as to assessments of threats to biodiversity described in a number of different published papers and reports. In each of these studies, the rankings and assessments of threats and taxonomic groups were developed independently of the literature we were sampling, thus eliminating the potential for circularity in our comparisons. We quantified changes in research foci through time by explicitly comparing studies from 1984, 1994, and 2004. We made all between-year comparisons of counts using chi square tests with Monte Carlo simulations to assess significance. For analyses with multiple comparisons, we assessed the significance of differences without a correction. These unadjusted *P* values provide a liberal assessment of the ability of conservation science to track changes in priorities.

Our analysis addressed only published, English-language literature. Although our dataset probably includes some of the most influential conservation research on a global scale, it does not include all prominent conservation research. Because we only sampled English-language literature, studies from non-English-speaking countries are under-represented. However, the authors of our sampled papers were associated with institutions from 70 different countries. Seventy-four percent of the affiliations were in European or North American countries and 60% were in countries in which the primary language is English. Thus, research done by Asian, African, South American, and Middle Eastern institutions are likely to be under-represented in our sample. This bias most strongly affects our analyses of where conservation research is being conducted, but has less influence on our investigations of which taxonomic groups and which threats to biodiversity are being studied. In addition, some of the research on pressing conservation issues is being directly applied by agencies and organizations and is not, therefore, being published in the scientific literature.

We chose to analyze the scientific literature because it is accessible and serves as a general record of scientific progress. Although a comprehensive survey of all of the regional and local biological literature of the world would provide a more complete summary of the state of conservation science, it is beyond the scope of this study.

Where is conservation research being done?

Global biomes

The surface of the Earth is richly patterned with diverse environments, ranging from arctic tundra to equatorial deserts. We investigated how well major ecosystems were represented in the conservation literature by calculating the number of studies conducted in each of the 14 biomes defined by Olson *et al.* (2001; Figure 1a), grouped by nine regions of the world (Figure 1b).

Studies were not equally distributed across biomes. Temperate, broadleafed, mixed forest biomes in North America and Europe were by far the most heavily studied ecosystems, accounting for 14% and 16% of all studies, respectively (Figure 1b). In contrast, deserts, xeric shrublands, and tundra were poorly studied on all continents. There was some evidence that the overall inequity was decreasing over time. For example, there was a significant decrease in the percentage of research conducted in the broad-leaf and mixed forest biome from 52% in 1984 to 28% in 2004 (P = 0.005). There were also smaller increases in the percentage of research being conducted in several of the other biomes, but we did not see a significant increase in any single biome.

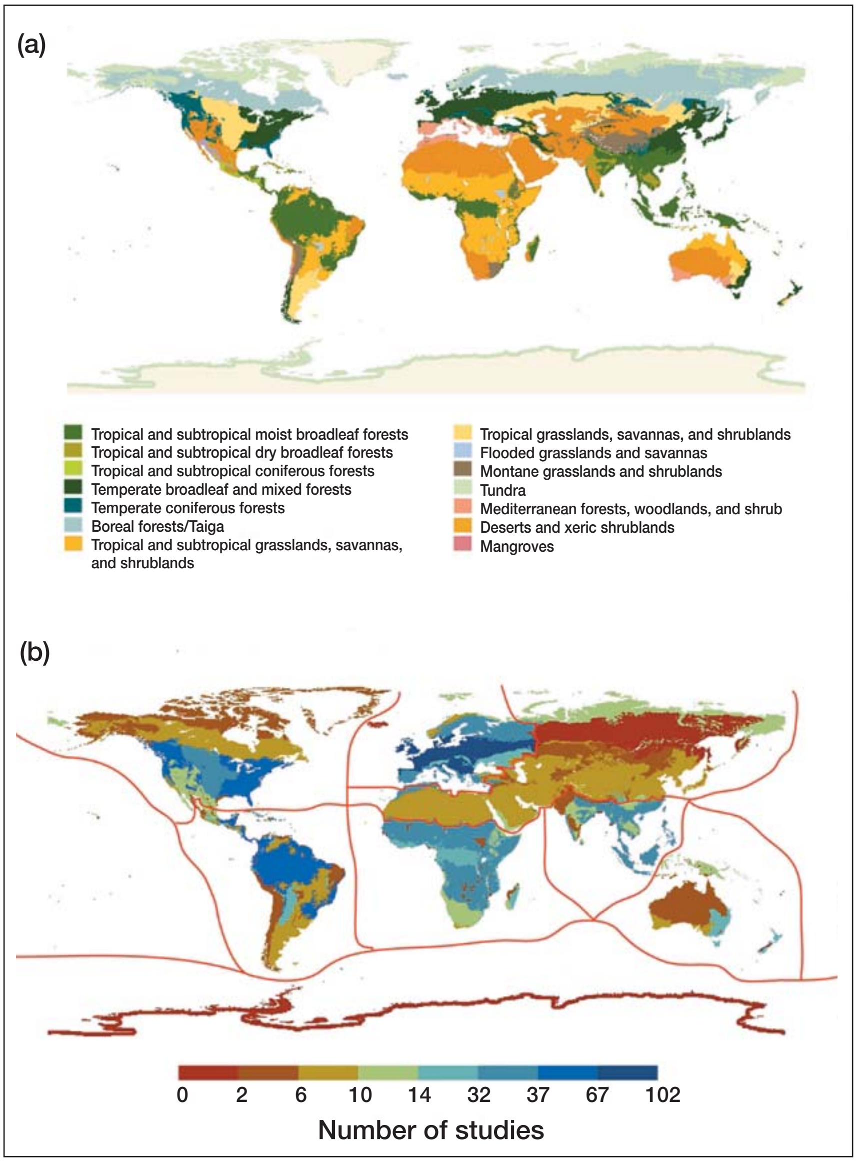

Figure 1. *(a) Biomes of the world (after Olson* et al. *2001). (b) A map of the number of studies conducted in each biome within each of nine regions of the world in 1984, 1994, and 2004.*

Conservation priority areas

One potential explanation for why conservation research has not been evenly distributed across biomes is that biodiversity is not evenly distributed, with some areas of the globe being particularly rich in species and/or harboring rare and endemic species (Myers *et al.* 2000). Many of these areas face threats from human encroachment and have been targeted as priority areas for actions by a number of conservation organizations (Olson and Dinerstein 1998; Halpern *et al.* 2006). One might therefore expect these priority areas to be the site of intense research efforts, aimed at understanding these unique systems and the threats they face.

We compared the conservation priorities of three international non-governmental organizations to the distribution of published conservation research around the globe. For each country, we calculated the average area of all priority sites identified by the World Wildlife Fund, Conservation Inter-national, and Birdlife International. To compare conservation priorities to conservation research efforts, we calculated the ratio of the percentage of all studies conducted in each country to the percentage of world conservation priority areas in that country. We found a mismatch between the distribution of the conservation priority areas of these three organizations and the distribution of conservation studies (Figure 2a). Not surprisingly, research intensity far outweighed conservation priorities in the US, UK, and much of Europe. Research efforts lagged behind conservation priorities in much of Asia, South America, and the Indo-Pacific. Brazil, for example, contains 13% of the priority area designated by the three conservation organizations but was the site of only 1% of conservation research.

There was some evidence that the mismatch between the location of conservation priorities and conservation research may be slowly decreasing (Figure 2b). For example, there was an increase in the percentage of South and Central American studies (2% to 15%; P = 0.014) and a decline in European studies (48% to 29%; P = 0.02), between 1984 and 2004. These were the only significant changes in the geography of conservation research, as sampled by our study.

Although the conservation priority areas used in our analysis represented those of three international conservation organizations, there are several other ways to set conservation priorities. To investigate a different method of prioritization, we compared the distribution of published research across biomes to the relative ranking of biomes based on a recent conservation risk assessment (Hoekstra *et al.* 2005). For each of the biomes of the

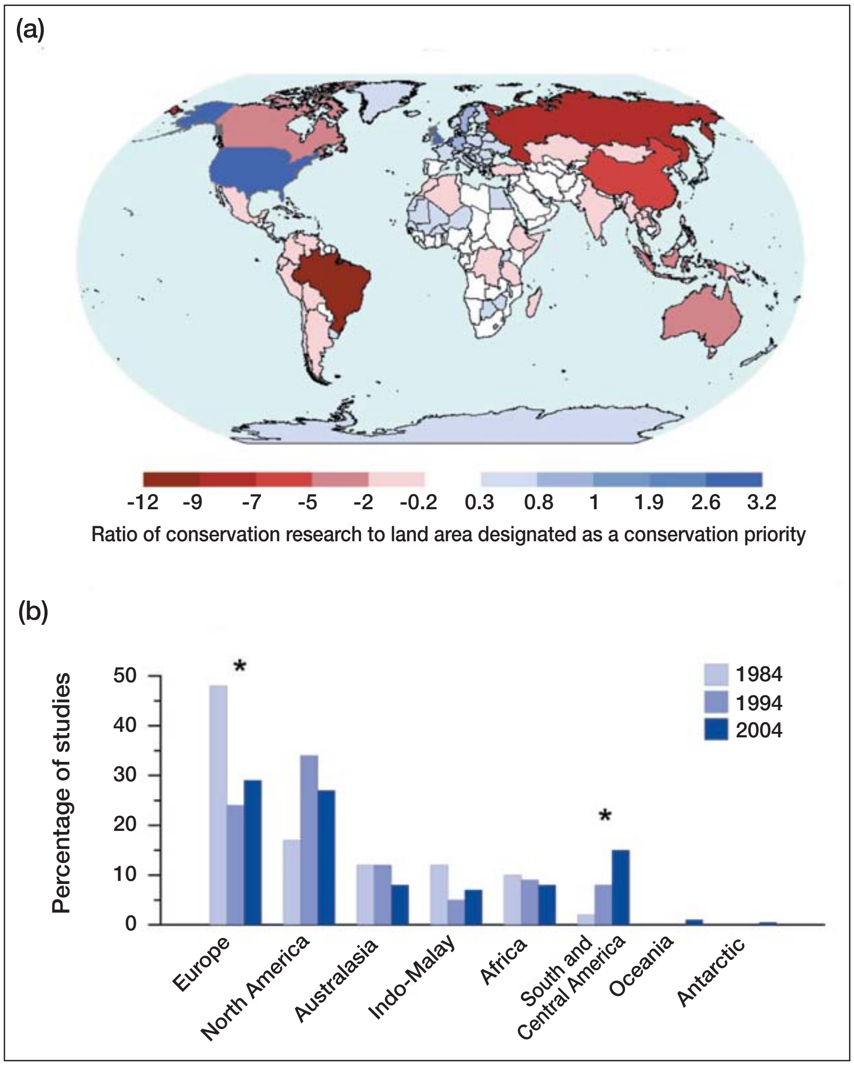

***Figure 2.** (a) Map of the difference in percentage of global conservation priority areas (as defined by three conservation organizations) in a country and the percentage of all conservation research conducted in that country. Blue countries are those with a high ratio of research to conservation priority area and red countries have a low ratio. (b) Percentage of conservation research studies conducted in each of eight different regions of the world in 1984, 1994, and 2004; an asterisk indicates a significant change in the percentage of studies conducted in a region over time* ($P < 0.05$).

world (Figure 1a), Hoekstra *et al.* (2005) calculated a conservation risk index (CRI) value based on the ratio of the percentage of converted land to the percentage of protected land within each biome. We found no association between CRI values and published research efforts($r = 0.443$, n = 13, $P = 0.130$).

Some of the mismatch between conservation priority areas and conservation research can be attributed to the European and North American bias in our English-only literature sample. For example, our analyses indicated that conservation needs outweighed research efforts in much of Asia, Brazil, and the Indo-Pacific. Yet each of these regions has its own, high-quality, native-language literature, which probably has more impact on conservation in these regions than do studies published in international, English-speaking journals. Nonetheless, it is clear that a major portion of the international conservation research effort fails to address these high priority conservation areas.

Aquatic systems

Roughly 71% of the Earth's surface is covered by water. Both recent assessments (eg Pew Oceans Commission 2003; US Commission on Ocean Policy 2004) and older studies (eg GESAMP 1990) have warned of the importance of these systems and the severity of the threats they face. Despite this, we found that only 21% of all conservation research is done on aquatic ecosystems. Marine systems were particularly understudied – only 7% of the studies in our analysis addressed marine environments. Most marine studies focused on nearshore systems, with only 13% of all marine studies conducted in offshore waters (> 200 m deep), which account for > 70% of the area covered by the oceans. Despite numerous calls for more attention to these threatened ecosystems and the important services they provide, there has been no significant change in the proportion of conservation research devoted to either marine (5% in 1984, 7% in 1994, and 11% in 2004) or freshwater (14% in 1984, 13% in 1994, and 16% in 2004) systems between 1984 and 2004 ($P > 0.100$).

What is being studied?

Do more extinction-prone taxonomic groups receive more attention?

Some taxonomic groups are more threatened than others (Wilcove and Master 2005). Amphibians, for example, are more threatened than many other taxa, and amphibian populations are declining at much greater rates than those of other groups (Stuart *et al.* 2004; Whiles *et al.* 2006). We compared the percentage of at-risk species in different major taxonomic groups to the percentage of studies addressing at-risk species in those groups. This analysis was conducted at two scales because we had access to credible risk analyses at both global and national (US) levels. To determine the global status of a taxon, we calculated the percentage of member species that were included in the vulnerable, endangered, or critically endangered categories of the IUCN's Red List (IUCN 2004). Although species from many different taxonomic groups have been red-listed, only amphibians, mammals, and birds have been sufficiently inventoried on a global scale to establish their relative taxonomic risk. Thus, our analysis at the global scale was limited to these three groups.

For the US analysis, we based our comparisons on the threat assessments of Wilcove and Master (2005). In general, there has been a more thorough assessment of the conservation status of species in the US than globally. The conservation status of 95% or more of the amphibians, freshwater fish, vascular plants, reptiles, birds, and mammals in the US have been assessed. We included all of these groups in our US analysis. For both the US and global analyses, we used a broad definition of "at-risk" to identify papers that addressed at-risk species. We classified any species for which some special conservation status was mentioned in the paper as being at-risk; for example, some of these species were red-listed by the IUCN, some were listed as threatened or endangered by the US Federal Government, and some were listed as species of concern by regional or local entities.

There appeared to be a negative relationship between risk of extinction and the proportion of studies in which at-risk species in the different taxonomic groups were studied at the global scale (Figure 3a). However, due to the small sample size, this relationship was not statistically significant (Spearman $r = -1.000$, n = 3, $P = 0.333$). At the US scale, there was a strong negative correlation (Spearman $r = -0.955$, n = 6, $P = 0.017$), indicating that at-risk species in taxonomic groups with more at risk-species were less studied (Figure 3b). For example, 31% of described amphibian species are at risk of extinction and account for 11% of all red-listed species. Despite the severity of the threats they face, they have consistently been one of the least-studied groups over the past 20 years. At the global scale, only 5% of the studies from 1984, 4% from 1994, and 5% from 2004 focused on amphibians. Of the 122 studies in our sample that addressed at-risk species, only 4% addressed amphibians. At the US scale, both amphibians and freshwater fishes were understudied with respect to their threat status (Figure 3b). None of the 20 US studies that focused on at-risk species dealt with amphibians or freshwater fish.

There was no indication that this mismatch in threat status and research effort is decreasing over time. Although there were too few studies addressing at-risk species to break them down by both year and taxonomic group, we did analyze trends in the taxonomic groups covered in all the studies. The only significant change we found was a decrease in the percentage of studies dealing with mammals, from 36% in 1984 to 20% in 2004 ($P = 0.045$). We were unable to detect any temporal trends in the prevalence of studies of other taxa, indicating that, regarding the types of organisms studied, conservation research appears to be relatively static and is not responsive to changing conservation priorities.

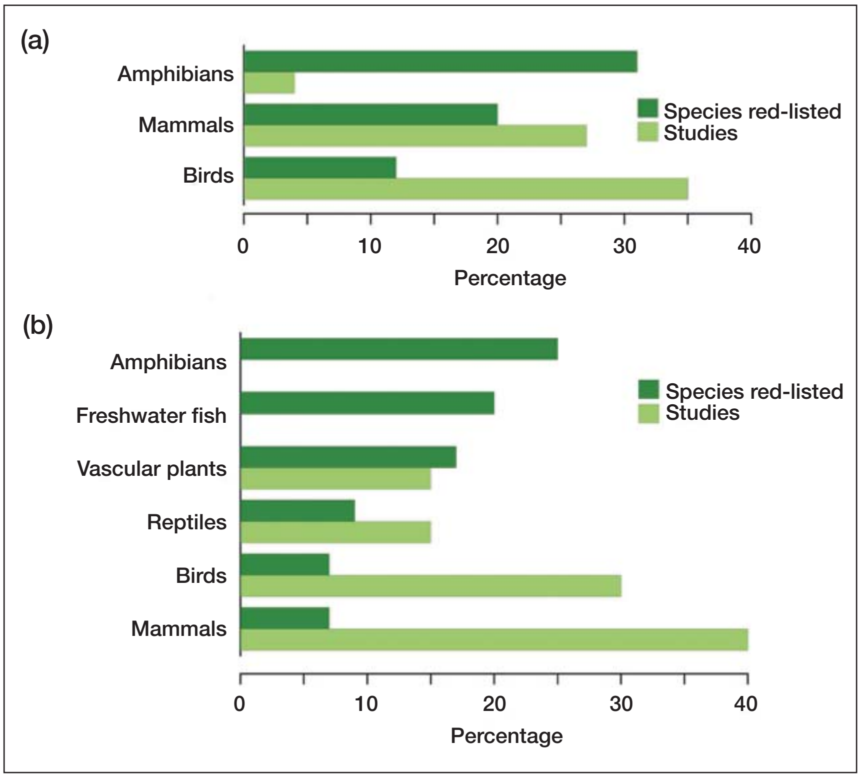

Figure 3. *Comparison of the prevalence of research studies conducted on at-risk species from different taxonomic groups and the degree to which those groups are threatened (a) globally and (b) within the US. At the global scale, darker bars represent the percentage of described species in each taxonomic group that have been red-listed by the IUCN (2004). All described birds and amphibians and 90% of all described mammals have been assessed by the IUCN. For the comparison within the US, darker bars represent percentages of all described species that are considered to be at risk of extinction (Wilcove and Master 2005). Ninety-five percent of the species in each of the taxa within the US have been assessed (Wilcove and Master 2005). For both plots, lighter bars represent the percentage of studies addressing at-risk species in each taxonomic group. Because some studies addressed multiple taxonomic groups, these values do not sum to 100%.*

Are the most pervasive threats the best studied?

Understanding the primary threats to biodiversity is a central goal in conservation biology; we would therefore expect the greatest threats to biodiversity to receive the most research attention in the conservation literature (Figure 4). We asked whether the degree to which different threats were addressed in the literature matched the

(a) Courtesy of T Carlo; (c) Courtesy of NOAA

(b) Courtesy of D Brenner/Michigan Sea Grant; (d) Courtesy of R Salm and S Salm

Figure 4. *Four major threats to biodiversity. (a) Habitat loss is the leading threat to biodiversity (Wilcove* et al. *1998; Lawler* et al. *2002). (b) Exotic species, such as purple loosestrife, often out-compete native species for critical resources. (c) Over-exploitation is the leading threat to marine species (Kappel 2005). (d) Climate change poses substantial threats to many ecological systems (Parmesan and Yohe 2003).*

relative rankings of the importance of those threats. Specifically, we compared the ranking of the prevalence of papers addressing different threats to the ranking of the prevalence of threats facing US species at risk of extinction, as reported by Wilcove *et al.* (1998) and to the ranking of the prevalence of threats facing IUCN red-listed marine species, as reported by Kappel (2005). We consider these studies to represent a scientific consensus with respect to the relative importance of different threats to biological diversity.

Our results show some, but not complete, overlap between the relative importance of different threats to biodiversity and the number of studies addressing these threats (Figure 5). For terrestrial and aquatic systems, habitat loss was both identified as the primary threat to biodiversity and received the greatest attention in the conservation literature. In contrast, the percentages of studies addressing exotic species, pollution, and over-exploitation in no way corresponded to their ranked importance (Figure 5a). On the other hand, in marine systems, we found a strong match between the identified threats and the research devoted to understanding them (Figure 5b). Over-exploitation and habitat loss are considered the top threats to marine biodiversity and are the most studied threats in the literature. However, impacts of exotic species threaten 36% of marine species yet only 8% of the conservation studies published on marine systems dealt with this topic.

We found little evidence of changes in research focus over time, with respect to threats to biodiversity (Figure 6). Habitat loss was consistently the most studied threat, followed by habitat fragmentation and overexploitation. Surprisingly, although exotic species are recognized as an emerging threat to biological diversity (Drake and Mooney 1989), the number of studies on exotic species in the conservation literature showed no significant change. On the other hand, there was a significant increase in the percentage of studies that addressed the emerging threat of climate change ($P = 0.004$). Only 2% of the conservation literature dealt with climate change in 1984, compared to 14% in 2004.

■ Recommendations for the coming decade

The field of conservation biology is growing at an exponential rate. Using criteria based on both journal citation rate and content, we found that the body of conservation literature grew by 280% from 1984 to 1994 and by 400% from 1994 to 2004. This rapid growth provides the potential for addressing many of the world's most pressing conservation problems and for addressing new problems as they arise. In some instances, research efforts have been allocated in accordance with perceived conservation priorities and threats, for example habitat loss, as discussed earlier.

Nevertheless, there is a clear gap between many conservation priorities and conservation research, and in some instances this gap is accompanied by a time lag. With few exceptions, conservation biologists do not appear to be shifting research efforts to address inadequacies and fill gaps. Priority conservation areas in the tropics and in Asia are still highly understudied. Exotic species remain the second greatest threat to biodiversity and their impact is very likely to increase as more species are transported around the globe. Yet exotics are poorly studied compared to other threats. Our results indicate that conservation biology is moving to correct many of these gaps, but progress is slow. In a crisis-driven applied science, there is no room for delays.

We used a number of different criteria to identify potential gaps in conservation research (eg proportion of the species in different taxonomic groups that are at risk of extinction). These criteria provide a rough gauge of the relative importance of different research topics, systems, or taxa. They do not provide an estimate of exactly how much research should be dedicated to a given topic at a given time. Meaningful recommendations about how to apportion conservation research will draw on these and other studies that evaluate the current state of ecological systems (eg Millennium Ecosystem Assessment 2005).

Although it may not be possible to set precise quotas for how much research should be devoted to a given topic or taxon, there are some fundamental ways in which we can close the gaps in conservation research. First, we can ensure that the groups that fund conservation research are aware of the most pressing issues. There are a number of organizations that advise both governments and private foundations on conservation topics. Some actively target key conservation priorities; for example, the IUCN's Invasive Species Specialist Group and the United Nations' and World Meteorological Organization's Intergovernmental Panel on Climate Change (IPCC) are addressing two of the most critical threats to ecological systems. The question remains, however, whether these groups are generally effective in guiding research in the right direction. In addition, funders should not only be aware of research priorities but also of the amount of research being done in different areas, so that deficits can be identified and addressed.

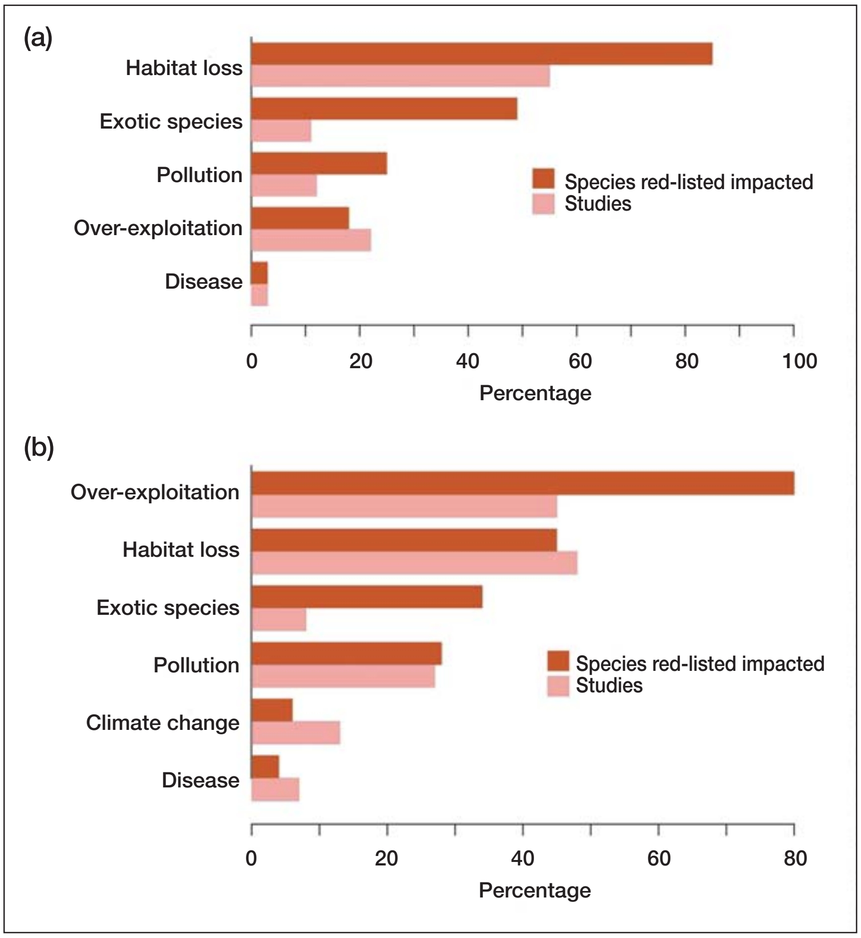

Figure 5. *A comparison of the prevalence of different risks to biodiversity and the degree to which they are reported in the literature, (a) in all systems and (b) in marine systems. The prevalence of threats to species in all systems was derived from Wilcove* et al. *(1998). The prevalence of threats to marine systems was taken from Kappel (2005).*

Secondly, conservation biologists can make it their responsibility to better understand the needs of the conservation community and to direct their research towards answering the most pressing questions. Scientists are often driven by their own interests and may not be letting conservation needs direct their research. Redirecting the thrust of conservation research will inevitably require building tighter links between practitioners and scientists.

Finally, we can reduce the time lag and more quickly fill the gaps in conservation research by conducting periodic progress assessments such as this and other recent reviews (eg Fazey *et al.* 2005), and by reducing the time it takes to publish research. Unfortunately, there is an inherent delay in getting such research published, as it takes longer to publish in many conservation journals than in other ecological journals (Kareiva *et al.* 2002). Although other factors are clearly at work, addressing these three basic issues will more readily minimize the disconnect between conservation research and critical conservation priorities. If scientists are to adequately inform efforts to balance resource use, the protection of biodiversity, and critical ecosystem services, research will have to respond more quickly to the needs of the conservation community.

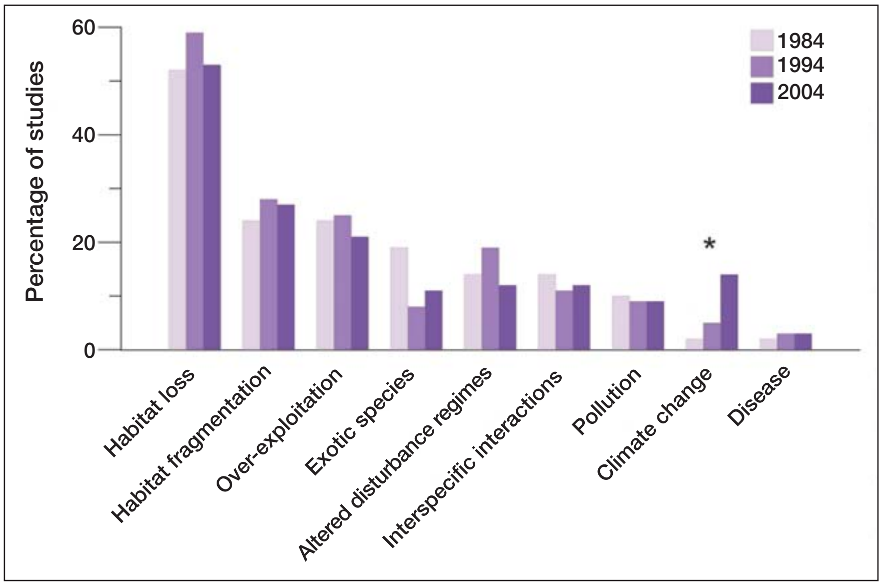

Figure 6. *Percentage of conservation studies addressing each of nine threats to biodiversity in 1984, 1994, and 2004. An asterisk indicates a significant change in the percentage of studies over time* ($P < 0.05$).

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