

CHAPTER 10

Extinctions and the practice of preventing them

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In this chapter, we will outline why we consider species extinction to be the most important problem conservation science must address. Species extinction is irreversible, is progressing at a high rate and is poised to accelerate. We outline the global features of extinctions — how fast and where they occur. Such considerations should guide global allocation of conservation efforts; they do to some extent, though the priorities of some global conservation organizations leave much to be desired.

We conclude by asking how to go from these insights to what tools might be used in a practical way. That requires a translation from scales of about 1 million km² to mere tens of km² at which most conservation actions take place. Brooks (Chapter 11) considers this topic in some detail, and we shall add only a few comments. Again, the match between what conservation demands and common practice is not good.

10.1 Why species extinctions have primacy

“Biodiversity” means three broad things (Norse and McManus 1980; Chapter 2): (i) there is diversity within a species — usually genetic-based, but within our own species, there is a large, but rapidly shrinking cultural diversity (Pimm 2000); (ii) the diversity of species themselves, and; (iii) the diversity of the different ecosystems they comprise.

The genetic diversity within a species is hugely important as an adaptation to local conditions. Nowhere is this more obvious than in the different varieties of crops, where those varieties are

the source of genes to protect crops from disease. Genetic uniformity can be catastrophic — the famous example is the potato famine in Ireland in the 1840s.

We simply do not know the genetic diversity of enough species for it to provide a practical measure for mapping diversity at a large scale. There is, however, a rapidly increasing literature on studies of the genetic diversity of what were once thought to be single species and are now known to be several. These studies can significantly alter our actions, pointing as they sometimes do to previously unrecognized species that need our attention.

Martiny (Box 10.1) argues for the importance of distinct populations within species, where the diversity is measured simply geographically. She argues, *inter alia*, that the loss of local populations means the loss of the ecosystem services species provide locally. She does not mention that, in the USA at least, “it’s the law.” Population segments, such as the Florida panther (*Puma concolor coryi*) or grizzly bears (*Ursus arctos horribilis*) in the continental USA are protected under the Endangered Species Act (see Chapter 12) as if they were full species. Indeed, the distinction is likely not clear to the average citizen, but scientific committees (National Research Council 1995) affirm Martiny’s point and the public perception. Yes, it’s important to have panthers in Florida, and grizzly bears in the continental USA, not just somewhere else.

That said, species extinction is irreversible in a way that population extinction is not. Some species have been eliminated across much of their ranges and later restored. And some of these flourished — turkeys in the eastern USA, for example. Aldo Leopold’s dictum applies: the first law of intelligent

Box 10.1 Population conservation

Jennifer B. H. Martiny

Although much of the focus of biodiversity conservation concentrates on species extinctions, population diversity is a key component of biodiversity. Imagine, for instance, that no further species are allowed to go extinct but that every species is reduced to just a single population. The planet would be uninhabitable for human beings, because many of the benefits that biodiversity confers on humanity are delivered through populations rather than species. Furthermore, the focus on species extinctions obscures the extent of the biodiversity crisis, because population extinction rates are orders of magnitude higher than species extinction rates.

When comparing species versus population diversity, it is useful to define population diversity as the number of populations in an area. Delimiting the population units themselves is more difficult. Historically, populations can be defined both demographically (by abundance, distribution, and dynamics) and genetically (by the amount of genetic variation within versus between intraspecific groups). Luck *et al.* (2003) also propose that populations be defined for conservation purposes as “service-providing units” to link population diversity explicitly to the ecosystem services that they provide.

The benefits of population diversity include all the reasons for saving species diversity and more (Hughes *et al.* 1998). In general, the greater the number of populations within a species, the more likely that a species will persist; thus, population diversity is directly linked to species conservation. Natural ecosystems are composed of populations of various species; as such systems are disrupted or destroyed, the benefits that those ecosystems provide are diminished. These benefits include aesthetic values, such as the firsthand experience of observing a bird species in the wild or hiking in an old growth forest. Similarly, many of the genetic benefits that biodiversity confers to humanity, such as the discovery and improvement of pharmaceuticals and agricultural crops, are closely linked to population diversity. For instance, genetically

uniform strains of the world’s three major crops (rice, wheat, and maize) are widely planted; therefore, population diversity among wild crop relatives is a crucial source of genetic material to resist diseases and pests.

Perhaps the most valuable benefit of population diversity is the delivery of ecosystem services such as the purification of air and water, detoxification and decomposition of wastes, generation and maintenance of soil fertility, and the pollination of crops and natural vegetation (see Chapter 3). These services are typically provided by local biodiversity; for a region to receive these benefits, populations that carry out the ecosystem services need to exist nearby. For instance, native bee populations deliver valuable pollination services to agriculture but only to fields within a few kilometers of the populations’ natural habitats (Kremen *et al.* 2002; Ricketts *et al.* 2004).

Estimates of population extinctions due to human activities, although uncertain, are much higher than species extinctions. Using a model of habitat loss that has previously been applied to species diversity, it is estimated that millions of populations are going extinct per year (Hughes *et al.* 1997). This rate is three orders of magnitude higher than that of species extinction. Studies on particular taxa confirm these trends; population extinctions are responsible for the range contractions of extant species of mammals and amphibians (Ceballos and Ehrlich 2002; Wake and Freedenberg 2008).

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Box 10.1 (Continued)

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tinkering is to keep every cog and wheel (Leopold 1993). So long as there is one population left, however bleak the landscapes from which it is missing, there is hope. Species extinction really is forever — and, as we shall soon present, occurring at unprecedented rates.

There are also efforts to protect large-scale ecosystems for their intrinsic value. For example, in North America, the Wildlands Project has as one of its objectives connecting largely mountainous regions from Yellowstone National Park (roughly 42°N) to the northern Yukon territory (roughly 64°N)—areas almost 3000 km away (Soulé and Terborgh 1999). A comparably heroic program in Africa is organized by the Peace Parks Foundation (Hanks 2003). It has already succeeded in connecting some of the existing network of already large national parks in southern Africa particularly through transboundary agreements. These efforts proceed with little regard to whether they contain species at risk of extinction, but with the clear understanding that if one does maintain ecosystems at such scales then the species within them will do just fine. Indeed, for species that need very large areas to survive — wild dog and lion in Africa — such areas may hold the only hope for saving these species in the long-term.

10.2 How fast are species becoming extinct?

There are ~10 000 species of birds and we know their fate better than any other comparably sized

group of species. So we ask first: at what rate are birds becoming extinct? Then we ask: how similar are other less well-known taxa?

To estimate the rate of extinctions, we calculate the extinction rate as the number of extinctions per year per species or, to make the numbers more reasonable, per million species-years — MSY (Pimm *et al.* 1995; Pimm and Brooks 2000). With the exception of the past five mass extinction events, estimates from the fossil record suggest that across many taxa, an approximate background rate is one extinction per million species-years, (1 E/MSY) (Pimm *et al.* 1995). This means we should observe one extinction in any sample where the sum of all the years over all the species under consideration is one million. If we consider a million species, we should expect one extinction per year. Follow the fates of 10 000 bird species and we should observe just one extinction per 100 years.

10.2.1 Pre-European extinctions

On continents, the first contact with modern humans likely occurred ~15 000 years ago in the Americas and earlier elsewhere — too far back to allow quantitative estimates of impacts on birds. The colonization of oceanic islands happened much more recently. Europeans were not the first trans-oceanic explorers. Many islands in the Pacific and Indian Oceans received their first human contact starting 5000 years ago and many only within the last two millennia (Steadman 1995; Gray *et al.* 2009).

Counting the species known to have and estimated to have succumbed to first contact suggests that between 70 and 90 endemic species were lost to human contact in the Hawaiian Islands alone, from an original terrestrial avifauna estimated to be 125 to 145 species (Pimm *et al.* 1994). Comparable numbers emerge from similar studies across the larger islands of the Polynesian expansion (Pimm *et al.* 1994). One can also recreate the likely species composition of Pacific islands given what we know about how large an island must be to support a species of (say) pigeon and the geographical span of islands that pigeons are known to have colonized. Curnutt and Pimm (2001) estimated that in addition to the ~200 terrestrial bird species taxonomists described from the Pacific islands from complete specimens, ~1000 species fell to first contact with the Polynesians.

Species on other oceanic islands are likely to have suffered similar fates within the last 1500 years. Madagascar lost 40% of its large mammals after first human contact, for example (Simons 1997). The Pacific extinctions alone suggest one extinction every few years and extinctions elsewhere would increase that rate. An extinction every year is a hundred times higher than background (100 E/MSY) and, as we will soon show, broadly comparable to rates in the last few centuries.

10.2.2 Counting historical extinctions

Birdlife International produces the consensus list of extinct birds (BirdLife International 2000) and a regularly updated website (Birdlife International 2006). The data we now present come from Pimm *et al.* (2006) and website downloads from that year. In 2006, there were 154 extinct or presumed extinct species and 9975 bird species in total. The implied extinction rate is ~31 E/MSY — one divides the 154 extinctions by 506 years times the 9975 species (~ 5 million species-years) on the assumption that these are the bird extinctions since the year 1500, when European exploration began in earnest. (They exclude species known from fossils, thought to have gone before 1500.)

As Pimm *et al.* (2006) emphasize, the count of extinctions over a little more than 500 years has an unstated assumption that science has followed the fates of *all* the presently known species of bird over *all* these years. Scientific description though only began in the 1700s, increased through the 1800s, and continues to the present. Linnaeus described many species that survive to the present and the Alagoas curassow (*Mitu mitu*) that became extinct in the wild ~220 years later. By contrast, the po'o uli (*Melamprosops phaeosoma*), described in 1974, survived a mere 31 years after its description. If one sums all the years that a species has been known across all species, the total is only about 1.6 million species-years and the corresponding extinction rate is ~ 85 E/MSY, that is, slightly less than one bird extinction *per year*. This still underestimates the true extinction rate for a variety of reasons (Pimm *et al.* 2006).

10.2.3 Extinction estimates for the 21st century

Birdlife International (2006) lists 1210 bird species in various classes of risk of extinction, that combined we call, “threatened,” for simplicity. The most threatened class is “critically endangered.” Birdlife International (2006) list 182 such species, including the 25 species thought likely to have gone extinct but for conservation actions. For many of these species there are doubts about their continued existence. For all of these species, expert opinion expects them to become extinct with a few decades without effective conservation to protect them. Were they to expire over the next 30 years, the extinction rate would be 5 species per year or 500 E/MSY. If the nearly 1300 threatened or data deficient species were to expire over the next century, the average extinction rate would exceed 1300 E/MSY. This is an order of magnitude increase over extinctions-to-date.

Such calculations suggest that species extinction rates will now increase rapidly. Does this make sense, especially given our suggestion that the major process up to now, the extinction on islands, might slow because those species sensitive to human impacts have already perished? Indeed, it does, precisely because of a rapid increase in extinction on continents where there

have been few recorded extinctions to date. To fully justify that, we must examine what we know about the global extinction process. First, however, we consider whether these results for birds seem applicable to other taxa.

10.2.4 Other taxa: what we don't know may make a very large difference

Birds play an important part in this chapter because they are well-known and that allows a deeper understanding of the processes of extinction than is possible with other taxa (e.g. Pimm *et al.* 1993). That said, birds constitute only roughly one thousandth of all species. (Technically, of eukaryote species, that is excluding bacteria and viruses.) Almost certainly, what we know for birds greatly underestimates the numbers of extinctions of other taxa, both past and present, for a variety of reasons.

On a percentage basis, a smaller fraction of birds are presently deemed threatened than mammals, fish, and reptiles, according to IUCN's Redlist (www.iucnredlist.org), or amphibians (Stuart *et al.* 2004). For North America, birds are the second least threatened of 18 well-known groups (The Nature Conservancy 1996). Birds may also be intrinsically less vulnerable than other taxa because of their mobility, which often allows them to persist despite substantial habitat destruction. Other explanations are anthropogenic.

Because of the widespread and active interest in birds, the recent rates of bird extinctions are far lower than we might expect had they not received special protection (Pimm *et al.* 2006; Butchart *et al.* 2006). Millions are fond of birds, which are major ecotourism attractions (Chapter 3). Many presently endangered species survive entirely because of extraordinary and expensive measures to protect them.

The most serious concern is that while bird taxonomy is nearly complete, other taxa are far from being so well known. For flowering plants worldwide, 16% are deemed threatened among the ~300 000 already described taxonomically (Walter and Gillett 1998). Dirzo and Raven (2003) estimate that about 100 000 plant species remain to be described. First, the majority of these will likely already be rare, since a local distribu-

tion is one of the principal factors in their escaping detection so far. Second, they are also certainly likely to be deemed threatened with extinction since most new species, in addition to being rare, live in tropical forests that are rapidly shrinking. We justify these two assumptions shortly.

Suppose we take Dirzo and Raven's estimate at face value. Then one would add the roughly 48 000 threatened species to the 100 000 as-yet unknown, but likely also threatened species, for a total of 148 000 threatened species out of 400 000 plants — or 37% of all plants.

With Peter Raven, we have been exploring whether his and Dirzo's estimate is reasonable. It comes from what plant taxonomists think are the numbers as-yet unknown. It is a best guess — and it proves hard to confirm. If it were roughly correct, we ought to see a decline in the numbers of species described each year — because fewer and fewer species are left undiscovered.

Consider birds again: Figure 10.1 shows the "discovery curve" — the number of species described per year. It has an initial spike with Linnaeus, then a severe drop (until Napoleone di Buonaparte was finally eliminated as a threat to world peace) and then a rapid expansion to about 1850. As one might expect, the numbers of new species then declined consistently, indicating that the supply of unknown species was drying up. That decline was not obvious, however, until a good half of all the species had been described (as shown by the graph of the cumulative number of species described.)

Interestingly, since 1950 there have been almost 300 new bird species added and the numbers per year have been more or less constant (Figure 10.1) Of these, about 10% were extinct when described, some found as only remains, others reassessments of older taxonomy. Of the rest, 27% are not endangered, 16% are near-threatened, 9% have insufficient data to classify, but 48% are threatened or already extinct. Simply, even for well-studied birds, there is a steady trickle of new species each year and most are threatened. Of course, we may never describe some bird species if their habitats are destroyed before scientists find them.

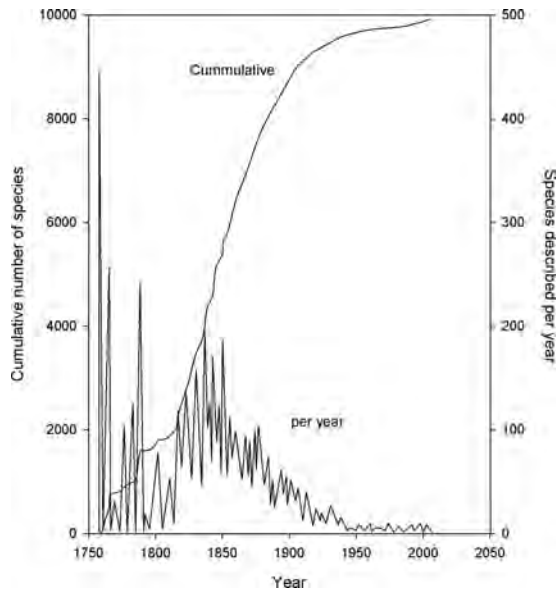


Figure 10.1 Number of bird species described per year and the cumulative number of known bird species. Data from Pimm *et al.* 2006.

Now consider the implications for plants: plant taxonomy has rapidly increased the number of known species since about 1960, when modern genetic techniques became available. For example, there are ~30 000 species of orchids, but C. A. Luer (<http://openlibrary.org/a/OL631100A>) and other taxonomists have described nearly 800 species from Ecuador alone since 1995 — and there are likely similar numbers from other species-rich tropical countries! There is no decline in the numbers of new species — no peak in the discovery curve as there is for birds around 1850.

Might Dirzo and Raven have seriously underestimated the problem given that the half-way point for orchids might not yet have been reached? If orchids are typical, then there could be literally hundreds of thousands of species of as-yet unknown plants. By analogy to birds, most have tiny geographical ranges, live in places that are under immediate threat of habitat loss, and are in imminent danger of extinction. The final caveat for birds applies here, *a fortiori*. Many plants will never be described because human actions will destroy them (and their habitats) before taxonomists find them.

Well, Peter Raven (*pers. comm.*, January 2009) argues that orchids might not be typical of other

plants being under-collected. They are a group for which international laws make their export difficult, while their biology means they are often not in flower when found and so must be propagated. All this demands that we estimate numbers of missing taxa generally and, whenever possible, where they are likely to be.

Ceballos and Ehrlich (2009) have recently examined these issues for mammals, a group thought to be well-known. In fact, taxonomists described more than 400 mammal species since 1993 — ~10% of the total. Most of these new species live in areas where habitats are being destroyed and over half have small geographical ranges. As we show below, the combination of these two powerful factors predicts the numbers of species on the verge of extinction.

10.3 Which species become extinct?

Of the bird extinctions discussed, more than 90% have been on islands. Comparably large percentages of extinctions of mammals, reptiles, land snails, and flowering plants have been on islands too. So, will the practice of preventing extinction simply be a matter of protecting insular forms?

The answer is an emphatic “no” because the single most powerful predictor of past and likely future extinctions is the more general “rarity” — not island living itself. Island species are rare because island life restricts their range. Continental species of an equivalent level of rarity — very small geographical ranges — may not have suffered extinction yet, but they are disproportionately threatened with extinction. Quite against expectation, island species (and those that live in montane areas) are *less* likely to be threatened at range sizes smaller than 100 000 km² (Figure 10.2).

Certainly, species on islands may be susceptible to introduced predators and other enemies, but they (and montane species) have an offsetting advantage. They tend to be much more abundant locally than species with comparable range sizes living on continents.

Local rarity is a powerful predictor of threat in its own right. While species with large ranges tend to be locally common, there are obvious

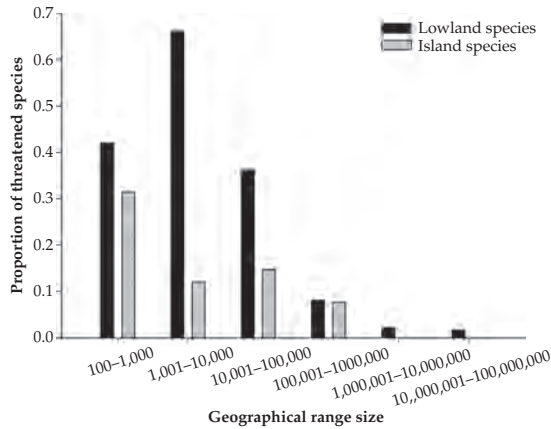


Figure 10.2 The proportion of bird species in the Americas that are threatened declines as the size of a species' geographical range increases. While more than 90% of all extinctions have been on islands, for ranges less than 100 000 km², island species are presently *less* likely to be threatened with future extinction. Simplified from Manne *et al.* (1999).

exceptions—large carnivores, for example. Such species are at high risk. Manne and Pimm (2001) and Purvis *et al.* (2000) provide statistical analyses of birds and mammals, respectively, that expand on these issues. None of this is in any way surprising. Low total population size, whether because of small range, local rarity or both, exacerbated in fragmented populations and in

those populations that fluctuate greatly from year-to-year (Pimm *et al.* 1988), likely brings populations to the very low numbers from which they cannot recover.

Given this importance of range size and local abundance, we now turn to the geography of species extinction.

10.4 Where are species becoming extinct?

10.4.1 The laws of biodiversity

There are at least seven “laws” to describe the geographical patterns of where species occur. By “law,” we mean a general, widespread pattern, that is, one found across many groups of species and many regions of the world. Recall that Wallace (1855) described the general patterns of evolution in his famous “Sarawak Law” paper. (He would uncover natural selection, as the mechanism behind those laws, a few years later, independently of Darwin.) Wallace reviews the empirical patterns and then concludes:

LAW 1. 'the following law may be deduced from these [preceding] facts: — Every species has come into existence coincident both in space and time with a pre-existing closely allied species'.

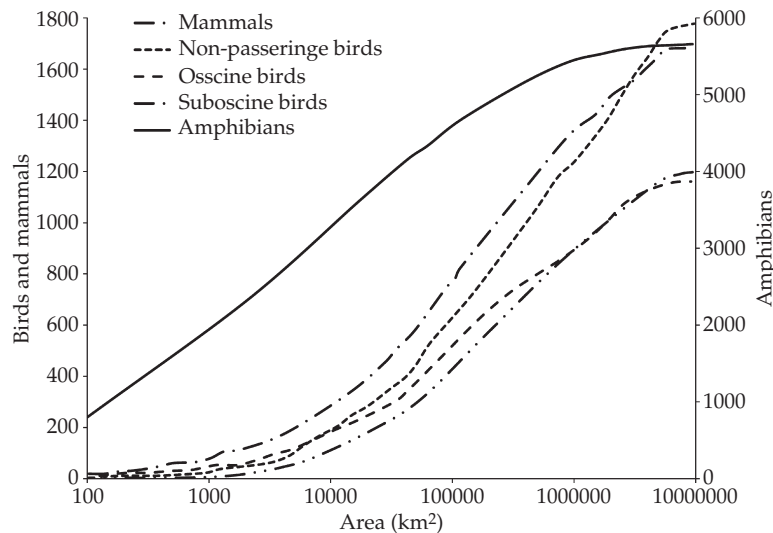


Figure 10.3 Cumulative numbers of species with increasing size of geographical range size (in km²) for amphibians (worldwide; right hand scale), and mammals and three groups of bird species (for North and South America; left hand scale). Note that area is plotted on a log scale.

There are other generalities, too.

LAW 2. Most species' ranges are very small; few are very large.

Figure 10.3 shows cumulative distributions of range sizes for amphibians (worldwide) and for the mammals and three long-isolated lineages of birds in the Americas. The ranges are highly skewed. Certainly there are species with very large ranges — some greater than 10 million km², for example. Range size is so strongly skewed, however, that (for example) over half of all amphibian species have ranges smaller than ~6000 km². The comparable medians for the

other taxa range from ~240 000 km² (mammals) to ~570 000 km² (non-passerine birds).

LAW 3. Species with small ranges are locally scarce.

There is a well-established relationship across many geographical scales and groups of species that links a species' range to its local abundance (Brown 1984). The largest-scale study is that of Manne and Pimm (2001) who used data on bird species across South America (Parker *et al.* 1996). The latter use an informal, if familiar method to estimate local abundances. A species is “common” if one is nearly guaranteed to see it in a day's fieldwork, then “fairly common,” “uncommon”

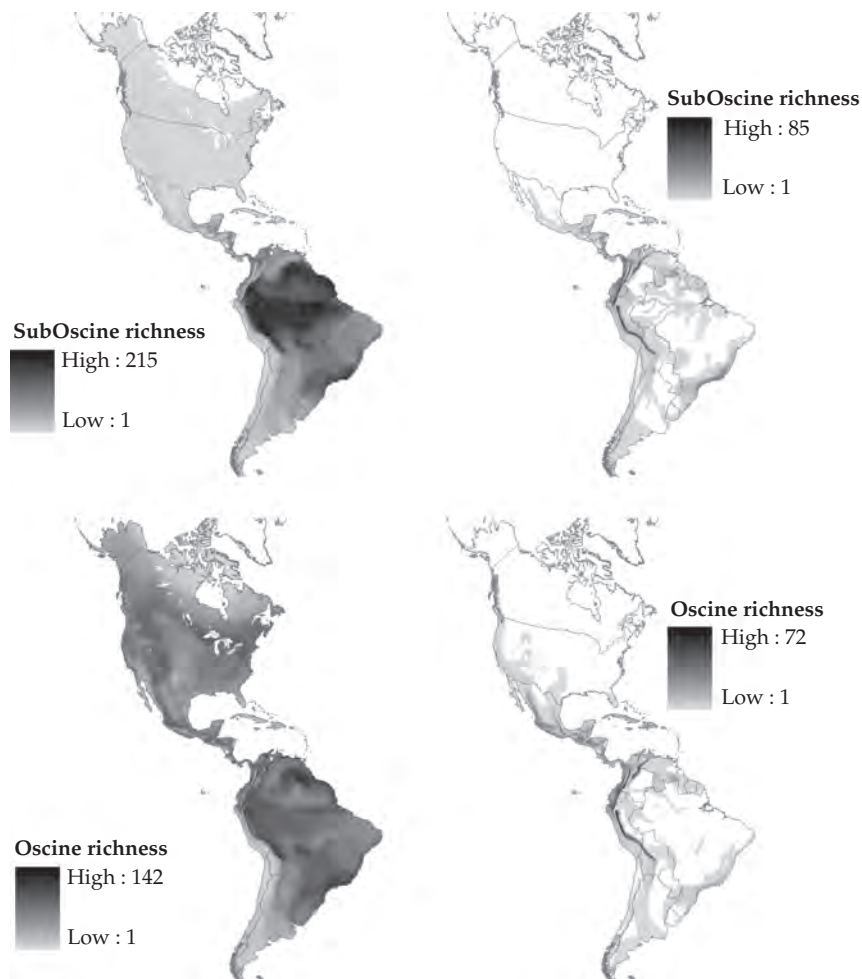


Figure 10.4 Numbers of sub-oscine and oscine passerine birds, showing all species (at left) and those with geographical ranges smaller than the median.

down to “rare” — meaning it likely takes several days of fieldwork to find one even in the appropriate habitat. Almost all bird species with ranges greater than 10 million km² are “common,” while nearly a third of species with ranges of less than 10 000 km² are “rare” and very few are “common.”

LAW 4. The number of species found in an area of given size varies greatly and according to some common factors.

Figure 10.4 shows the numbers of all species (left hand side) and of those species with smaller than the median geographic range (right hand side) for sub-oscine passerine birds (which evolved in South America when it was geographically isolated) and oscine passerines (which evolved elsewhere.) Several broad factors are apparent, of which three seem essential (Pimm and Brown 2004).

Geological history

The long geographical isolation of South America that ended roughly 3 million years ago allowed suboscine passerines to move into North America across the newly formed Isthmus of Panama. The suboscines, nonetheless, have not extensively colonized North America and there are no small ranged suboscines north of Mexico.

Ecosystem type

Forests hold more species than do drier or colder habitats, even when other things (latitude, for example) are taken into consideration. Thus, eastern North American deciduous forests hold more species than the grasslands to their west, while the tropical forests of the Amazon and the southeast Atlantic coast of South America have more species than in the drier, cerrado habitats that separate them.

Geographical constraints

Extremes, such as high latitudes have fewer species, but interestingly — if less obvious — so too do peninsulas such as Baja California and Florida. Colwell *et al.* (2004) show there must be geographical constraints — by chance alone, there will be more species in the middle than at the extremes, given the observed distribution of geographical range sizes.

LAW 5. Species with small ranges are often geographically concentrated and . . .

LAW 6 . . . those concentrations are generally not where the greatest numbers of species are found. They are, however, often in the same general places in taxa with different origins.

Since the results on species extinction tell us that the most vulnerable species are those with small geographical ranges, we should explore where such species occur. The simplest expectation is that they will simply mirror the pattern of all species. That is, where there are more species, there will be more large-ranged, medium-ranged, and small-ranged species. Reality is strikingly different (Curnutt *et al.* 1994; Prendergast *et al.* 1994)!

Figure 10.4 shows that against the patterns for all species, small-ranged species are geographically concentrated, and not merely mirrored. Moreover, the concentrations of small-ranged species are, generally, not where the greatest numbers of species are. Even more intriguing, as Figure 10.4 also shows, is that the concentrations are in similar places for the two taxa *despite their very different evolutionary origins*. Maps of amphibians (Pimm and Jenkins 2005) and mammals (unpublished data) show these patterns to be general ones. At much coarser spatial resolution, they mirror the patterns for plants (Myers *et al.* 2000).

These similarities suggest common processes generate small-ranged species that are different from species as a whole.

Island effects

Likely it is that islands — real ones surrounded by water and “montane” islands of high elevation habitat surrounded by lowlands — provide the isolation needed for species formation. Figure 10.4 shows that it is just such places where small-ranged species are found.

Glaciation history

This is not a complete explanation, for some mountains — obviously those in the western USA and Canada — do not generate unusual numbers of small ranged species. Or perhaps they once did and those species were removed by intermittent glaciation.

Finally, there are simply anomalies: the Appalachian mountains of the eastern USA generate concentrations of small-ranged salamander species, but not birds or mammals. The mountains of western North America generate concentrations of small-ranged mammals but not birds.

10.4.2 Important consequences

Several interesting consequences emerge.

- The species at greatest risk of extinction are concentrated geographically and, broadly, such species in different taxa are concentrated into the same places. As argued previously, similar processes may create similar patterns across different taxa. This is of huge practical significance for it means that conservation efforts can be concentrated in these special places. Moreover, priorities set for one taxonomic group may be sensible for some others, at least at this geographical scale.

- A second consequence of these laws is far more problematical. Europe and North America have highly distorted selections of species. While most species have small ranges and are rare within them, these two continents have few species, very few species indeed with small ranges, and those ranges are not geographically concentrated. Any conservation priorities based on European and North American experiences are likely to be poor choices when it comes to preventing extinctions, a point to which we shall return.

10.4.3 Myers' Hotspots

By design, we have taken a mechanistic approach to draw a conclusion that extinctions will concentrate where there are many species with small ranges — *other things being equal*. Other things are not equal of course and the other important driver is human impact.

Figure 10.5 shows the distribution of threatened species of birds in The Americas. The concentration is in the eastern coast of South America, a place that certainly houses many species with small geographical ranges, but far from being the only place with such concentrations. What

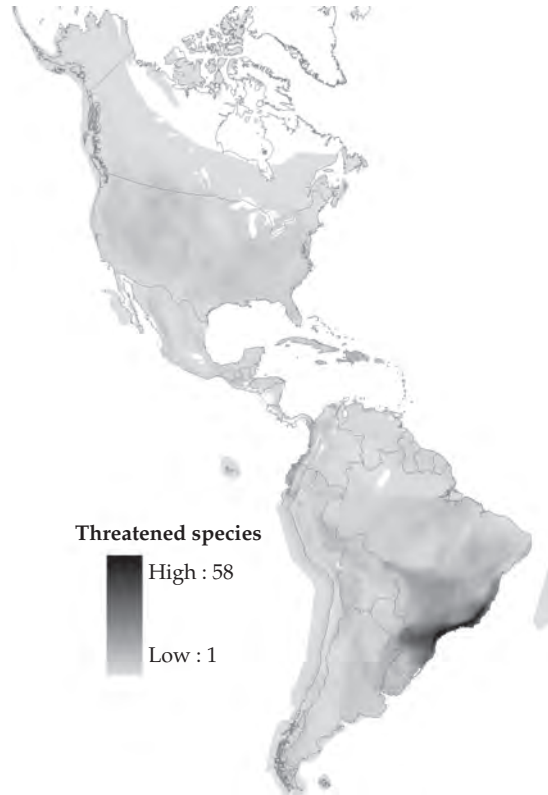


Figure 10.5 The number of species of birds threatened with extinction in the Americas.

makes this region so unfortunately special is the exceptional high levels of habitat destruction.

Myers approached these topics from a “top down” perspective, identifying 10 and later 25 areas with more than 1000 endemic plants (Myers 1988, 1990; Myers *et al.* 2000). There are important similarities in the map of these areas (Figure 10.6) to the maps of Figure 10.4 (which only consider the Americas.) Central America, the Andes, the Caribbean, and the Atlantic Coast forests of South America stand out in both maps. California and the cerrado of Brazil (drier, inland forest) are important for plants, but not birds.

Myers added the second — and vital criterion — that these regions have less than 30% of their natural vegetation remaining. Myers’ idea is a very powerful one. It creates the “number of

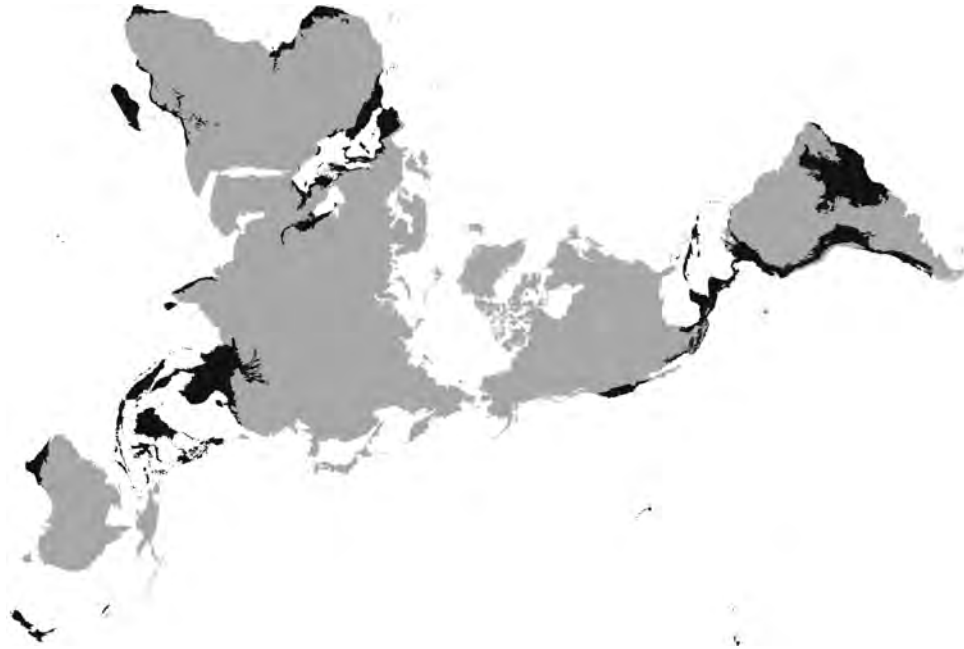


Figure 10.6 The 25 hotspots as defined by Myers *et al.* 2000 (in black). The map projection is by Buckminster Fuller (who called it Dymaxion). It has no "right way" up and neither does the planet, of course.

small ranged species times habitat loss equals extinction" idea with another key and surprising insight. What surprises is that there are few examples of concentrations of small-ranged species that do not also meet the criterion of having lost 70% of more of their natural habitat. The island of New Guinea is an exception. Hotspots have disproportionate human impact measured in other ways besides their habitat loss. Cincotta *et al.* (2000) show that hotspots have generally higher human population densities and that almost all of them have annual population growth rates that are higher (average = 1.6% per annum) than the global average (1.3% per annum).

10.4.4 Oceanic biodiversity

Concerns about the oceans are usually expressed in terms of over-exploitation of relatively widespread, large-bodied and so relatively rare species (Chapter 6) — such as Steller's sea cow (*Hydrodamalis gigas*) and various whale populations. That said, given what we know about extinctions on the land, *where else* would we look for extinctions in the oceans?

As for the land, oceanic inventories are likely very incomplete. For example, there are more than 500 species of the lovely and medically important genus of marine snail, *Conus*. Of the 316 species of *Conus* from the Indo-Pacific region, Röckel *et al.* (1995) find that nearly 14% were described in the 20 years before their publication. There is no suggestion in the discovery curve that the rate of description is declining.

The first step would be to ask whether the laws we present apply to the oceans. We can do so using the data that Roberts *et al.* (2002) present geographically on species of lobster, fish, molluscs, and corals. Figure 10.7 shows the size of their geographical ranges, along with the comparable data for birds. Expressed as the cumulative percentages of species with given range sizes, (not total numbers of species as Figure 10.3), the scaling relationships are remarkably similar. For all but corals, the data show that a substantial fraction of marine species have very small geographical ranges. The spatial resolution of these data is coarse — about 1 degree latitude/longitude or $\sim 10\,000\text{ km}^2$ — and likely overestimates actual ranges. Many of the species depend on

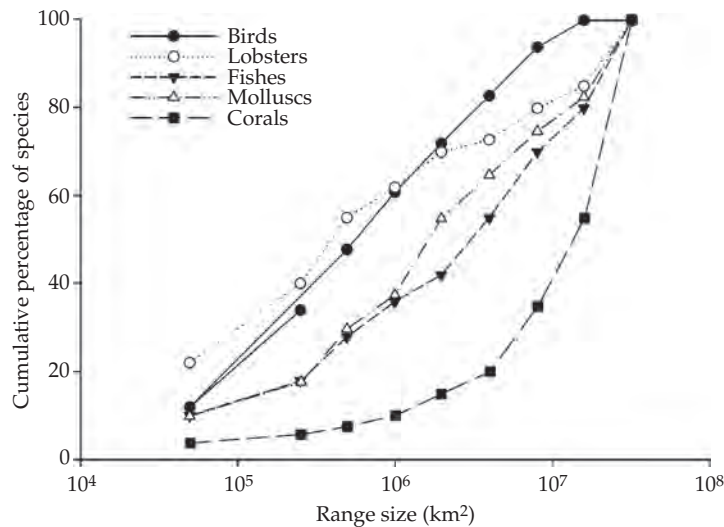


Figure 10.7 The cumulative number of species of marine organisms (lobsters, fishes, molluscs, and corals) with birds for comparison (data from Roberts *et al.* 2002). Unlike Figure 10.3, these are scaled to 100% of the total number of species.

coral reefs, for example, that cover only a small fraction of the area within the 1-degree latitude/longitude cell where a species might occur.

The interesting generality here is that there are large fractions of marine species with very small geographical ranges — just as there are on land. The exception are the corals, most of which appear to occupy huge geographical ranges. Even here, this may be more a reflection of the state of coral taxonomy than of nature itself.

Roberts *et al.* (2002) also show that the other laws apply. Species-rich places are geographically concentrated in the oceans (Figure 10.8). They further show that as with the land, a small number of areas have high concentrations of species with small ranges and they are often not those places with the greatest number of species. Certainly, the islands between Asia and Australia have both many species and many species with small ranges. But concentrations of small range species also occur in the islands south of Japan, the Hawaiian Islands, and the Gulf of California — areas not particularly rich in total species. Finally, Bryant *et al.* (1998) do for reefs what Myers did for the land — and show that areas with concentrations of small-ranged species are often particularly heavily impacted by human actions.

Were we to look for marine extinctions, it would be where concentrations of small-ranged species

collide with unusually high human impacts. Given that the catalogue of *Conus* species is incomplete, that many have small geographical ranges, and those occur in areas where reefs are being damaged, it seems highly unlikely to us that as few as four *Conus* species (<1%) are threatened with extinction as IUCN suggest (www.iucnredlist.org).

10.5 Future extinctions

10.5.1 Species threatened by habitat destruction

The predominant cause of bird species endangerment is habitat destruction (BirdLife International 2000). It is likely to be so for other taxa too. While large tracts of little changed habitat remain worldwide, most of the planet's natural ecosystems have been replaced or fragmented (Pimm 2001). Some species have benefited from those changes, but large numbers have not. The most important changes are to forests, particularly tropical forests for these ecosystems house most of the world's bird species (and likely other taxa as well). We now show that the numbers of extinctions predicted by a simple quantitative model match what we expect from the amount of forest lost. We then extend these ideas to more recently deforested areas to predict the numbers of species likely

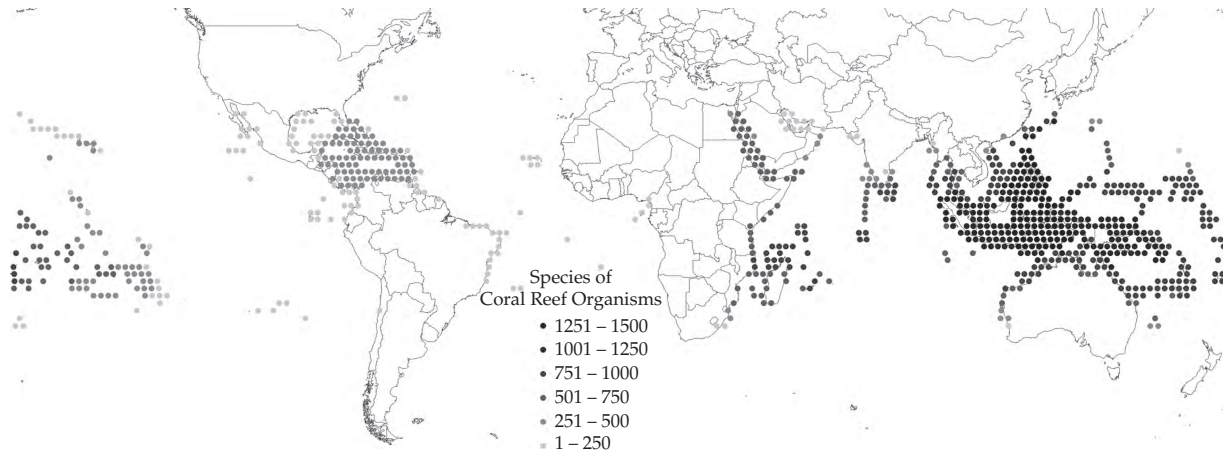


Figure 10.8 Species richness of coral reef organisms (data from Roberts *et al.* 2002).

to become extinct eventually. The observed numbers of threatened species match those predictions, suggesting that we understand the mechanisms generating the predicted increase in extinction rate.

Rarity — either through small range size or local scarcity — does not itself cause extinction. Rather, it is how human impacts collide with such susceptibilities. As Myers reminds us, extinctions will concentrate where human actions impact concentrations of small ranged species. Without such concentrations, human impacts will have relatively little effect. The eastern USA provides a case history.

10.5.2 Eastern North America: high impact, few endemics, few extinctions

Europeans settled Eastern North America in the early 1600s and moved inland from the mid-1700s, settling the prairie states in the late 1800s. Along the way, they cleared most of the deciduous forest at one time or another. Despite this massive deforestation, only four species of land birds became extinct — the Carolina parakeet (*Conuropsis carolinensis*), passenger pigeon (*Ectopistes migratorius*), ivory-billed woodpecker (*Campyphilus principalis*), and Bachman’s warbler (*Vermivora bachmanii*) — out of a total of about 160 forest species.

Pimm and Askins (1995) considered why so few species were lost, despite such extensive damage. They considered a predictive model of how many species should be lost as a function of the fraction of habitat lost. This model follows from the familiar species-area law that describes the number of species found on islands in relation to island area. There is an obvious extension to that law that posits that as area is reduced (from A_0 to A_n) then the original number of species S_0 will shrink to S_n in a characteristic way.

LAW 7. The fraction of species (S_n/S_0) remaining when human actions reduce the area of original habitat A_0 to A_n is $(A_n/A_0)^{0.25}$.

We call this a law because we now show it to hold across a variety of circumstances.

First, Pimm and Askins noticed that while few forests were uncut, the deforestation was not simultaneous. European colonists cleared forests along the eastern seaboard, then moved across the Appalachians and then into the lake states. When settlers realized they could grow crops in the prairies, the eastern forests began to recover. At the low point, perhaps half of the forest remained. Applying the formula, the region should have retained 84% of its species and so lost 16%. Now 16% of 160 species is ~26 species and that is clearly not the right answer.

Second, Pimm and Askins posed the obvious thought-experiment: how many species should

have been lost if all the forest was cleared? The answer is not 160, because most of those species have ranges outside of eastern North America — some across the forests of Canada, others in the western USA, some down into Mexico. They would survive elsewhere, even if all the forest were cut. Indeed only 30 species have sufficiently small ranges to be endemic to the region and so at risk if all the forest were lost. Applying the formulae to these one predicts that there would be 4.8 species at risk — surprisingly close to the right answer, given that another eastern species, the red-cockaded woodpecker (*Picoides borealis*), is threatened with extinction!

Simply, that there were so few extinctions — and so few species at risk — is largely a consequence of there being so few species with small ranges. So what happens when there are many species with small ranges?

10.5.3 Tropical areas with high impact, many endemics, and many species at risk

Case histories comparing how many species are threatened with extinction with how many are predicted to become extinct using Law 7 include birds in the Atlantic coast forest of Brazil (Brooks and Balmford 1996), birds and mammals in insular southeast Asia (Brooks *et al.* 1997; Brooks *et al.* 1999a), plants, invertebrates, and vertebrates of Singapore (Brook *et al.* 2003), and birds, mammals, amphibians, reptiles, and plants across the 25 biodiversity “hotspots” that we now introduce.

These studies, by choice, look at areas where there are many species with small geographical ranges, for the number of predicted extinctions depends linearly on the number of such species. But notice that Law 7 implies a highly non-linear relationship to the amount of habitat destruction. Losing the first half of eastern North America’s forests resulted in a predicted loss of 16% of its species. Losing the remaining half would have exterminated the remaining 84%! The studies the previous paragraph cites looked at areas with far more extensive habitat destruction than eastern North America.

Pimm and Raven (2000) applied this recipe to each of the 25 hotspots using the statistics on

endemic bird species, original area, and the present area of remaining natural vegetation. This provides a best-case scenario of what habitat might remain. They predicted that ~1700 species of birds should be lost eventually. Species can obviously linger in small habitat fragments for decades before they expire — as evidenced by the rediscovery of species thought extinct for up to a century. They suggest that bird extinctions among doomed species have a half-life of ~50 years (Brooks *et al.* 1999b; Ferraz *et al.* 2003). So perhaps three quarters of these species — 1250 — will likely go extinct this century — a number very similar to the number Birdlife considers to be at risk.

These estimates of extinction rates (~1000 E/MSY) come from human actions to date. Two extrapolations are possible. The worst-case scenario for the hotspots assumes that the only habitats that will remain intact will be the areas currently protected. This increases the prediction of number of extinctions to 2200 (Pimm and Raven 2000). The second adds in species from areas not already extensively deforested. If present trends continue, large remaining areas of tropical forest that house many species (such as the Amazon, the Congo, and Fly basin of New Guinea) will have extinction rates that exceed those in the hotspots by mid-century. For example, the Amazon basin is often ignored as a concentration of vulnerable species because its ~300 endemic bird species are found across ~5 million km². At current rates of deforestation, most of the Amazon will be gone by mid-century. There are plans for infrastructure development that would accelerate that rate of forest clearing (Laurance *et al.* 2001). If this were to happen, then many of the Amazon’s species will become threatened or go extinct.

10.5.4 Unexpected causes of extinction

There are various unexpected causes of extinction and they will add to the totals suggested from habitat destruction. The accidental introduction of the brown tree snake (*Boiga irregularis*) to Guam eliminated the island’s birds in a couple of decades (Savidge 1987; Wiles *et al.* 2003). In the oceans, increases in long-line fisheries (Tuck *et al.*

2003) are a relatively new and very serious threat to three-quarters of the 21 albatross species (Bird-life International 2006).

10.5.5 Global change and extinction

Finally, one of the most significant factors in the extinction of species will undoubtedly be climate change (see Chapter 8), a factor not included in any of the estimates presented above. Thomas *et al.* (2004) estimate that climate change threatens 15–37% of species within the next 50 years depending on which climate scenario unfolds. Even more species are at risk if one looks to climate changes beyond 50 years. More detailed, regional modeling exercises in Australia (Williams *et al.* 2003) and South Africa (Erasmus *et al.* 2002) have led to predictions of the extinction of many species with narrowly-restricted ranges during this or longer intervals.

The critical question is whether these extinctions, which are predominantly of small-ranged species, are the same as those predicted from habitat destruction or whether they are additional (Pimm 2008). In many cases, they are certainly the latter.

For example, the Atlantic coast humid forests of Brazil have the greatest numbers of bird species at risk of extinction within the Americas (Manne *et al.* 1999). The current threat comes from the extensive clearing of lowland forest. Upland forests have suffered less. Rio de Janeiro State has retained relatively more of its forests — 23% survives compared to <10% for the region as a whole. Less than 10% of the forest below 200 m remains though, whereas some 84% of the forest remains above 1300 m. It is precisely the species in these upper elevations that are at risk from global warming, for they have no higher elevations into which to move when the climate warms. These upland, restricted-range species will suffer the greatest risk from global warming, not the lowland species that are already at risk. Thus, the effects of direct habitat destruction and global warming are likely to be additive.

How large an additional threat is global warming? For New World passerine birds, a quarter live 1000 m above sea-level. Detailed modeling can

certainly provide predictions of which species are at most risk (Sekercioglu *et al.* 2008), but the basic concerns are clear. If that fraction of species in mountains is typical of other taxa and other places, then a quarter of those species are at risk — a very substantial addition to species already threatened with extinction (Pimm 2008).

10.6 How does all this help prevent extinctions?

Thus far, we have guided the reader to areas of roughly one million km² — many orders of magnitude larger than the tens or at best hundreds of km² at which practical conservation actions unfold. Brooks (Chapter 11) considers formal tools for setting more local conservation priorities. We have rarely used such approaches in our work, though we understand the need for them.

This chapter establishes a recipe for conservation action that transcends scales. One can quite literally zoom in on Figure 10.5 to find out exactly where the greatest concentrations of threatened species are and, moreover, plot their ranges on maps of remaining forest. Our experiences are shaped by two places where our operational arm, www.savingspecies.org, has worked to date: the Atlantic Coastal Forest of Brazil and the island of Madagascar.

We have told this story in detail elsewhere (Harris *et al.* 2005; Jenkins 2003; Pimm and Jenkins 2005; Jenkins and Pimm 2006). For the Americas, we start with the species map of Figure 10.5 (but much enlarged). This shows the very highest concentration of threatened species to be in the State of Rio de Janeiro — an area of ~40 000 km². At that point, what compels us most strongly is satellite imagery that shows what forest remains — not ever more detail about where species are found. There is not much forest — and very little indeed of the lowland forest remains. And that forest is in fragments.

Whatever conservation we do here is driven by these facts. We do not worry about the issues of capturing as many species in a given area (Pimm and Lawton 1998), and then write philosophical papers about weighting species because of their

various “values” — taxonomic distinctiveness, for example. We do not fret about whether our priorities for birds match those for orchids for which we have only crude range information (Pimm 1996) or nematodes about which we know even less. What few remaining fragments remain will be the priorities for every taxon.

The practical solution is obvious too. The land between isolated forests needs to be brought into protection and reforested. That is exactly what we have helped our Brazilian colleagues achieve (www.micoleao.org.br). Connecting isolated forest fragments by reforesting them in areas rich in small-ranged species is an effective and cheap way of preventing extinctions. We commend this solution to others.

Summary

- Extinctions are irreversible, unlike many other environmental threats that we can reverse.
- Current and recent rates of extinction are 100 times faster than the background rate, while future rates may be 1000 times faster.
- Species most likely to face extinction are rare; rare either because they have very small geographic ranges or have a low population density with a larger range.
- Small-ranged terrestrial vertebrate species tend to be concentrated in a few areas that often do not hold the greatest number of species. Similar patterns apply to plants and many marine groups.
- Extinctions occur most often when human impacts collide with the places having many rare species.
- While habitat loss is the leading cause of extinctions, global warming is expected to cause extinctions that are additive to those caused by habitat loss.

Suggested reading

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Relevant web sites

- BirdLife International, Data Zone: <http://www.birdlife.org/datazone>.
- Threatened amphibians: <http://www.globalamphibians.org>.
- The IUCN Red List: <http://www.iucnredlist.org>.
- Saving species: <http://savingspecies.org>.

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