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CAUSES AND CONSEQUENCES OF BIRD EXTINCTIONS

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August 2003

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ABSTRACT

Increased human domination of the planet has caused the declines and extinctions of countless species. Each species has not only intrinsic value, but ecological functions of organisms are also essential for the integrity of ecosystems that allow people to benefit from essential free ecosystem services, such as carcass disposal, pest control, pollination and seed dispersal. In order to retain global biodiversity and ecosystem services, we must study the factors behind species' declines, understand their consequences, improve capacity of human-dominated landscapes to maintain biodiversity, and persuade local human communities to preserve their natural heritage. With birds as my focal group, I take various approaches to addressing these issues, including an analysis of the world's bird species, modeling bird extinctions in the 21st century, field research on effects of habitat degradation on tropical forest bird communities, a radio telemetry study of forest birds that persist in deforested landscapes, and a review of birdwatching tourism. My research sheds light on the ecological consequences of species' declines, the long-term impacts of tropical forest degradation, the role of mobility for persistence of birds in deforested tropical landscapes, the conservation significance of integrating human-dominated and native habitats, and the importance of local human communities for biodiversity preservation. Analyzing a database of all the world's bird species, I found that certain functional groups, such as frugivores, herbivores, piscivores and scavengers, are more extinction-prone than average, and some areas, such as oceanic islands and forested landscapes, have significantly more species that are at risk. These patterns are likely to deteriorate in the 21st century, signaling the potential loss of crucial ecosystem services such as pest control, pollination, and seed dispersal. In Uganda, I found that

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beyond a certain intensity, one-time forestry practices can have long-term negative impacts on forest birds through changes in vegetation structure, whereas low intensity forestry can be compatible with the preservation of local biodiversity. The largest simultaneous study of forest understory insectivorous birds, their diets and prey base in the premontane forest fragments of southern Costa Rica showed that these area-sensitive species disappear from small forest fragments not due to lack of food, but because their limited mobility prevents movements between small habitat patches, making them vulnerable to stochastic, local extinctions. On the other hand, three forest bird species that were able to persist in agricultural countryside dominated by coffee plantations were able to do so either by being pre-adapted to disturbed habitats (*Catharus aurantiirostris*) or by being highly mobile and making efficient use of 11% of the landscape still covered by trees (*Tangara icterocephala* and *Turdus assimilis*). Results from radio telemetry also underlined the importance of remnant trees, riparian strips, and small forest patches for native forest species. An analysis of birdwatching tourism revealed that, just as human-dominated landscapes are often excluded from conservation initiatives, most local people in less-developed areas are also excluded from the income generated by birdwatching that is overwhelmingly conducted by wealthy citizens of developed countries. If the combination of large scale habitat clearance, exclusion of human-dominated landscapes from conservation policies, and alienation of local communities from ecotourism initiatives continues, consequent disappearance of species is likely to cause collapses in ecosystems and their services that are crucial for humanity.

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INTRODUCTION

Global biodiversity is under assault from habitat loss and modification, direct exploitation, species introductions, climate change, pollution and a host of other factors related to the scale of the human enterprise. The disappearance of irreplaceable species is not only morally wrong and the aesthetic equivalent of destroying all the world's art, but it also has grave consequences for ecosystems and for human beings, all of whom benefit from ecosystem services. To stop the ongoing sixth extinction crisis and the concomitant collapse of life-support systems, conservation biologists and ecologists need answers to the following questions:

1-What are the mechanisms behind species loss?

2-What are the consequences for ecosystems and for people?

3-How can we persuade people to preserve biodiversity?

Since birds are the best known major group of organisms, I chose them as my focal group, and used a range of methods (database construction, fieldwork, modeling and review of published work) to attempt to answer these questions.

In the first chapter, I provide an overview of extinct and threatened bird species, predict actual and functional bird extinctions in the 21st century and summarize the ecological consequences of bird declines. For this study, I directed the creation of a database of the world's 10,000+ bird species. This chapter was co-authored by Gretchen Daily and Paul Ehrlich, and has been submitted.

In the next two chapters I investigate the effects of habitat degradation on tropical forest bird communities in two continents. In Chapter 2, I examine the long-term effects of forestry practices on the vegetation structure and bird community of

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Kibale National Park in Uganda. I am the sole author of this chapter which was published in *Biological Conservation*. In Chapter 3, I look into the role of reduced invertebrate prey base as a factor causing the decline of understory insectivorous birds from fragments of Pacific premontane forest in southern Costa Rica. This chapter was co-authored by Paul Ehrlich, Gretchen Daily, Deniz Aygen, David Goehring and Randy Sandi and was published in the *Proceedings of the National Academy of Sciences*.

In Chapter 4, I look at the opposite side of the coin, focusing on three Costa Rican forest bird species that are also common in agricultural countryside dominated by coffee plantations. Using radio telemetry, I investigated the factors behind these species' persistence in human-dominated habitats and the most important components of these landscapes for supporting native biodiversity. This chapter was co-authored by Gretchen Daily, Paul Ehrlich, Scott Loaria and Viviana Ruiz-Gutierrez.

In Chapter 5, I focus on an important mechanism for promoting the conservation of bird diversity--ecotourism. I review the economic potential of birdwatching for community-based conservation, outline the potential benefits and problems, and provide suggestions for improving the conservation value of this activity. I am the sole author for this chapter which was published in *Environmental Conservation.*

CHAPTER I

Ecological consequences of bird extinctions

Abstract

To investigate the ecological impacts of avian extinctions, we developed comprehensive databases of the status and functional roles of birds, and simple models for forecasting change. Currently, 21% of bird species are extinction-prone and 14% are functionally extinct, contributing negligibly to ecosystem processes. One quarter of frugivorous species, and over a third of herbivorous, piscivorous and scavenging species are extinction-prone. Our models suggest that, by 2100, 6-13% of all bird species will be extinct and 13-51% (48%-83% on oceanic islands), functionally extinct. Important ecosystem processes, particularly decomposition, pest control, pollination, and seed dispersal, will likely decline as a result.

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Introduction

The accelerating extinctions of species(IUCN 2002) and populations(Hughes et al. 1997), threaten to disrupt important ecosystem processes and services(Luck et al. 2003; Myers 1996; Redford 1992). Many species already have such small populations that they contribute negligibly to ecosystem processes, and can be considered ecologically or functionally extinct(Luck et al. 2003; Redford 1992). Although patterns of biodiversity loss have been explored extensively(Sala et al. 2000), few studies have investigated the ecological implications thereof and, in general, these have been limited to temperate plants, microbes and invertebrates(Loreau et al. 2001). Yet on-going reductions in vertebrate abundance and species richness are likely to have far-reaching consequences, with diverse societal impacts ranging from the spread of disease to loss of agricultural pest control and landscape destabilization.

Since there are more detailed data on the ecology of bird species than on any other major group, we compiled and analyzed a database of the conservation status, distribution, and ecology of all extant (9876) and historically extinct (131) bird species. We synthesized, in a second database, studies of the ecological roles of birds, and specified their impacts on the functioning of diverse natural and human-dominated ecosystems (Table 1). In order to estimate the potential effects on ecosystem processes and services of bird population declines and extinctions, we compared the current distribution of threatened birds across various functional groups, habitats and regions, to the distributions predicted for 2100 based on three scenarios. The scenarios are projections based on the past and present distribution of

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threatened and non-threatened birds, and the likelihood of becoming threatened and going extinct was weighted by restricted range status, a good predictor of threat class.

Methods

Global bird database

Basic conservation, distribution and ecological data on all the extant (9876) and historically extinct (131) bird species of the world from 245 sources were entered into a database with over 700,000 entries. Data entry error rate was 0.8% and each species was entered twice to reduce errors. We used the list of 10,052 world bird species currently being evaluated by BirdLife International/IUCN, with the exception of 45 taxa that we deemed to be of controversial taxonomic status.

For the location of each species, we included biogeographical realm, latitudinal distribution, hemisphere, and whether the species' breeding is limited to islands or not. For altitudinal distribution, we included upper and lower elevational limits of each species' center of abundance, as well as extreme values we came across in the literature.

We entered as many as four body mass values (to allow for male and female minimum and maximum values) for each species and used the average of these values for analyses. There were 12 main habitat types: coastal, desert, forest, grassland, human-modified, riparian, rocky, savanna, sea (pelagic), shrubland/scrubland, wetland and woodland. We ranked the habitat preferences of each species, and calculated habitat breadth as the number of different habitats each species uses. We had nine main diet categories: fish, fruit, invertebrates, nectar, omnivore, plant parts

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(non-reproductive), scavenger (carcass/garbage/offal), seeds and vertebrates. For 8716 species, we had sufficient dietary information to rank diet preferences and to calculate diet breadth as the number of different food types consumed. We assigned all species to one of nine primary diet categories and one of 37 feeding guilds, extrapolating diet and guild based on the diets of congeners when there was no diet information. For 6053 species, we had information on clutch size and included normal minimum and maximum values, ignoring extreme clutch sizes. We also noted if the species has long-distance migration, altitudinal migration, long-distance dispersal or irregular/nomadic movements.

Each species was assigned a threat category based on formal assessments by BirdLife International(BirdLifeInternational 2000) and IUCN(IUCN 2002). The main categories are extinct since 1500 (131 species); critically endangered (50% chance of extinction in the next 10 years, 186 species), endangered (20% chance of extinction in the next 20 years, 327 species), vulnerable (10% chance of extinction in the next 100 years, 685 species), data-deficient (78), and near-threatened (733 species which almost meet the criteria for vulnerable status). For 1193 of these species, including all those that are critical, endangered and vulnerable, we had data on types of threat, population size (or an educated guess by IUCN), population trend and range size. For an additional 3689 species, we had data on range size class(Manne et al. 1999; Stattersfield et al. 1998), going logarithmically from 10^0-10^2 km^2 to 10^7-10^8 km^2. We also noted if a species was range-restricted (global range less than 50,000 km^2; 2632 extant and 103 extinct species).

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Scenarios

Our scenarios were based on IUCN criteria (see above) used for assessing extinction likelihood of bird species(BirdLifeInternational 2000)(Figure 1). We report the averages of 10,000 simulations run for each decade from 2010 to 2100. For Scenario 1 (best case), we assumed that conservation measures would be sufficient to prevent any more bird species from becoming threatened, while being unable to reduce the average extinction likelihood of threatened species during this century. In this scenario, a vulnerable species had a 1.048%, endangered species a 10.56%, and critical species a 50.00% chance of going extinct every decade. This resulted, on average, in 10% of the vulnerable species, 67% of the endangered species, and 99.9% of the critical species going extinct by 2100. All species were treated equally.

For Scenario 2 (intermediate case), we compared the threatened bird lists of the past 14 years(BirdLifeInternational 2000; Collar et al. 1988; IUCN 2002) to calculate the probability (0.0136) that a non-threatened bird species (including near-threatened and data deficient species) would become threatened after a decade. We assumed that non-threatened species would continue to become threatened at this rate and the newly threatened species were randomly distributed among three threat categories based on the current percentage of threatened species in each threat category. Once again, we used IUCN probabilities of extinction to calculate likelihood of extinction for every decade.

For Scenario 3 (worst case), we assumed that the probability of a non-threatened species becoming threatened would increase by a conservative 1% per decade (1.36% in 2010, 2.36% in 2020 and so on), and that threatened species would go extinct at the current IUCN rate. These assumptions are conservative since it is estimated that every *year*, natural habitats and dependent vertebrate populations decrease by an average of 1.1%(Jenkins et al. 2003).

Since some species are more likely to become threatened and go extinct than others in the same threat category, for scenarios 2 and 3, we investigated various criteria and indices for weighing the probabilities of becoming threatened and going extinct. In agreement with IUCN's most important criteria, estimated population size class ($r^2 = 0.504$, $p < 0.0001$) and global range size class ($r^2 = 0.520$, $p < 0.0001$) had the strongest correlations with conservation status. However, we had to choose a variable that was available for all the species in our database. Restricted-range status (global range less than 50,000 km^2) had the next highest correlation ($r^2 = 0.156$, $p < 0.0001$), and had the added advantage of being straightforward to incorporate into our models. Primary diet did not have a high correlation with threat status ($r^2 = 0.05$, $p < 0.01$), and was not used in weighing the model. This also prevented our reasoning from becoming circular, since we used extinction likelihoods based on population and range sizes to predict the distribution of species across functional groups. Therefore, in scenarios 2 and 3, species with restricted ranges had higher probabilities of becoming threatened and going extinct, and these probabilities were calculated using the ratio of restricted range species to other species in their respective categories during the previous time step.

Since it is impossible to estimate the population sizes of species a century from now, and since presently 289 near-threatened species with global populations of <10,000 individuals more than balance 232 threatened species with populations

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>10,000, for our scenarios, we conservatively assumed only extinct and threatened species to be functionally extinct.

Results

Current patterns of extinction

Based on criteria used by the International Union for Conservation of Nature and Natural Resources (IUCN) (IUCN 2002), over one fifth of the 10,007 historic bird species (all species that survived past 1500 A.D.) are "extinction-prone", a category that includes species that are extinct (1.3%), threatened with extinction in the next 10-100 years (12%) or meeting all but one criteria of being threatened (7.4%, "near-threatened"). Four-fifths of threatened bird species (961) have fewer than 10,000 individuals, a threshold frequently used in bird conservation(BirdLifeInternational 2000), and which we accepted as the upper limit for functional extinction. We estimated that each of an additional 287 near-threatened species also has a global population of <10,000 individuals(BirdLifeInternational 2000). The combined populations of these species (<6.6 million individuals) make up less than 1/1000th of the projected world bird population (of 86.7 billion individuals(Gaston et al. 2003)), and contribute little to ecosystem processes compared to rest of the avifauna. Therefore, 14% of all historic bird species or 67% of extinction-prone bird species can be considered functionally extinct.

Primary diet is not a good predictor of threat status ($r^2 = 0.05$, $p < 0.0001$); nevertheless, extinction-prone birds are not randomly distributed across different functional groups (based on primary diet; Figure 2) and guilds (based on order of dietary preferences; Figure 3). Some functional groups have significantly more extinction-prone species than average: frugivores (χ^2 = 45.24; p<0.0001), herbivores (consumers of non-reproductive plant parts; χ^2 = 37.78; p<0.0001), omnivores (χ^2 = 20.92; p<0.025), piscivores (χ^2 = 59.76; p<0.0001), and scavengers (χ^2 = 32.27; p<0.001). Invertebrate (χ^2 = 32.96; p<0.005) and seed (χ^2 = 19.57; p<0.025) eaters have fewer extinction-prone species than average. Increased specialization is highly correlated with increased likelihood of extinction (Figure 4), and 41% of bird species limited to one habitat type are extinction-prone.

In agreement with previous research, we also found significant differences in the distribution of extinction-prone species among categories other than diet (Table 2): habitat(BirdLifeInternational 2000) (Figure 5), region(BirdLifeInternational 2000)(Figure 6), altitudinal distribution(Renjifo et al. 1997), global range(BirdLifeInternational 2000), taxonomy(Bennett & Owens 1997), clutch size(Bennett & Owens 1997), and body mass(Bennett & Owens 1997). Up to 100% of the species are extinction-prone in some groups combining diet and other attributes. Island birds (Malagasy, New Zealand, Oceanic, South Polar and parts of Indomalayan and Palearctic regions) are particularly at risk (Table 2). Forest, sea, and wetland birds, restricted-range species, sedentary birds (no migration or nomadism), lowland and highland species, and large and slow-reproducing species are also significantly more extinction-prone (Table 2).

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Future patterns of extinction

The results of our scenarios for 2100 reinforce previous estimates(Crosby et al. 1994). By 2100, 6%-13% of all historic bird species are expected to be extinct (including those that are currently extinct), and 13%-51% to be functionally extinct (Figure 7). The models predicted greater-than-average extinction rates for frugivores, herbivores, nectarivores, piscivores, and scavengers (Figure 7). Some guilds may lose up to 47% of their species (Figure 8). Specialists are predicted to have more extinctions than average (Figure 9). Forest and marine habitats (Figure 10), and regions with large numbers of island birds are projected to experience the highest proportion of real and functional extinctions, with Malagasy, New Zealand, and Oceanic regions expected to lose 26-45% of their species (Figure 11). This is particularly serious considering that about 2000 bird species may already have disappeared from Pacific Islands before 1600 as a consequence of human colonization(Steadman 1995).

Discussion

Ecological consequences

As it has been the case with other taxa(Chapin et al. 2000), we expect that bird extinctions and population reductions(Gaston et al. 2003) in the 21^{st} century will disrupt important ecosystem processes and services(Luck et al. 2003). Of the bird functional groups that are expected to have more extinctions than average, frugivores are important seed dispersers, nectarivores pollinate many plant species, and scavengers provide crucial decomposition services (Table 1). Declines in seed

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dispersal and pollination as a result of bird extinctions have been documented, particularly in Austral, New Zealand and Oceanic regions, where the proportion of bird-pollinated plants is higher than other parts of the world(Ford), and, in the case of the latter two regions, most of the pre-settlement avifauna is already extinct(Steadman 1995).

Though slightly less threatened than average, insectivorous birds include more extinction-prone species than any other, and many tropical forest insectivores are highly sensitive to habitat loss and fragmentation(Sekercioglu et al. 2002). Exclusion of insectivorous birds from apple trees, coffee shrubs, oak trees, and other plants resulted in significant increases in insect pests and consequent plant damage (Table 1). The fact that 11%-50% of insectivorous birds are expected to be functionally extinct by 2100, and that their declines will not likely be compensated by increases in similar species, is clearly cause for concern. So is the predicted functional extinction of 14%-43% of avian top predators, which may lead to trophic cascades and outbreaks of vertebrate pests (Table 1).

Little is known about the potential consequences of widespread disappearance of fish-eating and scavenging bird species. The disappearance of sea birds may have unanticipated top-down or bottom-up consequences as a result of trophic cascades or significant reductions in nutrient deposition on rookery islands (Table 1). Since most scavenging birds are highly specialized to rapidly dispose of the bodies of large animals, they are important in the recycling of nutrients, leading other scavengers to dead animals, and limiting the spread of diseases to human communities as a result of slowly decomposing carcasses. In South Asia, the combination of extremely rapid–

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and so far unexplained–crash of vulture populations(Pain et al. 2003), highly virulent diseases, and soaring human population density is particularly worrisome. This may result in an increase in incidences of anthrax and rabies(Pain et al. 2003), and it may be no coincidence that the 1994 outbreak of bubonic plague in western India occurred soon after the start of the crash of vulture populations. The outbreak was initiated by an unusually hot summer killing many animals, the carcasses of which caused an explosion in rat numbers(Kaplan 1997; Pain et al. 2003). In addition to actual and functional extinctions, large scale reductions in bird numbers(Gaston et al. 2003) and distinct populations(Hughes et al. 1997) will also disrupt ecological services(Luck et al. 2003) and evolutionary processes(Thompson 1996). Not only do 78% of threatened bird species have continuously declining populations(IUCN 2002), but also a quarter of all European(Heath et al. 2000) and North American(Sauer et al. 2003) bird species have significantly declined in the past 3 decades. Changes in the proportions of species in different functional groups may also result in destabilizing effects(Gonzalez & Chaneton 2002). Later, the expected extinctions of proportionately more avian specialists may cause additional losses of dependent species(Daily et al. 1993).

Equivalence

Declines in bird species that are important for a particular ecosystem process/service may not necessarily mean a decline in that process/service if the populations of other functionally equivalent species increase in response(Walker 1992). On the other hand, many bird species, such as Southern Cassowary *Casuarius*

casuarius(Stocker & Irvine 1983) or Three-wattled Bellbird *Procnias tricarunculata*(Wenny & Levey 1998), have irreplaceable roles in ecosystems despite initial impressions to the contrary(Wenny & Levey 1998). Since highly specialized species are more likely to go extinct, this also reduces the probability of other bird species (or members of non-avian taxa) taking their place. Furthermore, avian dispersers and pollinators for some plant communities, including Cape *fynbos* and tropical lowland humid forest, have low equivalence, and there is a high risk of plant extinction from lost mutualisms(Bond 1994). Ecological replacement itself may be undesirable. In parts of India, the ecological extinction of vultures has resulted in an increased availability of carcasses, driving a population explosion of their "replacements", feral dogs and rats, which are the main carriers of rabies and bubonic plague, respectively(Pain et al. 2003). Given the reality of rapid ecological change around the world, more populations and species preserved means increased ecosystem resilience(Naeem & Li 1997), and better ecological insurance against global change(Ehrlich & Walker 1998).

Economic consequences

The ecological consequences of the reductions in bird species, populations and numbers are hard enough to estimate, let alone to put a price on. However, it is almost certain that there will be financial losses as a result of the reductions in ecosystem services provided by birds. Our synthesis of the literature (Table 1) reveals that birds are important in reducing the cost of restoring degraded lands by facilitating tree seed dispersal. Morever, bird pollination and dispersal of a number of economically important species has been demonstrated in Indomalayan, Neotropical, and Palearctic regions. In various agricultural systems, insectivorous birds have been documented to significantly reduce insect pest damage, and are likely to rise in importance as pesticide use is curbed by environmental regulations and consumer trends. No one has estimated the potential cost of the loss of decomposition services provided by vultures, but increased disease transmission and a consequent rise in health spending is likely. The 1994 plague outbreak in India, for example, was estimated to cost over $2 billion(Kaplan 1997), most of it a result of the ensuing quarantine. Birds also generate income by appealing to birdwatchers who make significant economic contributions to many communities around the world(Sekercioglu 2002). In areas that suffer heavy avian losses, birdwatching tourism income will also decline considerably. Even putting ecological and economical consequences aside, one does not have to be a birdwatcher to feel a profound sense of loss from the extinction of hundreds, if not thousands, of bird species.

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Table 1: Ecological functions and ecosystem services provided by avian functional groups.

Functional group	Ecological process	Ecosystem service & economical benefits	Negative consequences of the loss of functional group
Frugivores	Seed dispersal(Howe & Miriti 2000; Howe & Smallwood 1982; Snow 1981; Stiles 1985)	Removal of seeds from parent tree(Avila-H et al. 1996; Greenberg et al. 1995; Sun et al. 1997; Wenny & Levey 1998); escape from seed predators(Janzen 1972); improved germination(Meyer & Witmer 1998; Murphy et al. 1993); increased economical yield(Hammond et al. 1996; Hutchins et al. 1996; Narang et al. 2000; Yumoto 2000); increased gene flow(Gibson & Wheelwright 1995; Hamrick et al. 1993; Howe et al. 1985); recolonization and restoration of disturbed ecosystems (Galindo-Gonzalez et al. 2000; Hjerpe et al. 2001; Robinson & Handel 1993; Tucker & Murphy 1997; Wilkinson 1997)	Disruption of dispersal mutualisms(Clark et al. 2001; Meehan et al. 2002; Stocker & Irvine 1983); clumping of seeds under parent tree(Bleher & Bohning-Gaese 2001); increased seed predation(Howe 1993); reduced gene flow(Pacheco & Simonetti 2000; Shapcott 1999) and germination(Compton et al. 1996; Meyer & Witmer 1998; Peres & Van Roosmalen 1996); reduction(Santos & Telleria 1994; Santos et al. 1999) or extinction(Bond 1994; Hamann & Curio 1999; Loiselle & Blake 1999) of dependent species
Nectarivores	Pollination(Proctor et al. 1996; Stiles 1985; Stiles 1978)	Outbreeding of dependent (Ford 1985; Keighery 1980; Proctor et al. 1996) and/or economically important species(Nabhan & Buchmann 1997; Narang et al. 2000)	Pollinator limitation(Murphy & Kelly 2001; Nabhan & Buchmann 1997); extinction(Bond 1994; Sakai et al. 2002); inbreeding and reduced fruit yield(Cox & Elmqvist 2000; Feinsinger et al. 1982; Montgomery et al. 2001; Paton 2000; Rathcke 2000; Robertson et al. 1999); evolutionary consequences (Nabhan & Buchmann 1997; Stiles 1978; Thompson 1996)
Scavengers	Consumption of carrion(Houston 1994)	Removal of carcasses(Pain et al. 2003; Prakash et al. 2003); leading other scavengers to carcasses(Houston 1994); nutrient recycling; sanitation(Pain et al. 2003; Prakash et al. 2003)	Slower decomposition(Houston 1994); increases in carcasses(Pain et al. 2003; Prakash et al. 2003); increases in undesirable species (Pain et al. 2003; Prakash et al. 2003); disease outbreaks(Pain et al. 2003; Prakash et al. 2003); changes in cultural practices(Pain et al. 2003; Parry-Jones 2001)

Table 1 (cont.): Ecological functions and ecosystem services provided by avian functional groups.

Functional group	**Ecological process**	**Ecosystem service & economical benefits**	**Negative consequences of the loss of functional group**
Insectivores	Predation on invertebrates	Control of insect populations (Crawford & Jennings 1989; Greenberg et al. 2000; Jantti et al. 2001; Kirk et al. 1996; Marquis & Whelan 1994; Mols & Visser 2002); reduced plant damage(Greenberg et al. 2000; Sanz 2001; Sipura 1999); alternative to pesticides (Dolbeer 1990; Mourato et al. 2000; Naylor & Ehrlich 1997)	Loss of natural pest control(Dolbeer 1990; Naylor & Ehrlich 1997); pest outbreaks (Crawford & Jennings 1989; Kirk et al. 1996; Quammen 1997); crop losses(Greenberg et al. 2000); trophic cascades (Terborgh et al. 2001)
Piscivores	Predation on fishes and invertebrates Production of guano	Controlling unwanted species(Wootton 1995); nutrient deposition around rookeries(Anderson & Polis 1999; Palomo et al. 1999; Powell et al. 1991; Sanchez-Pinero & Polis 2000); soil formation in polar environments(Heine & Speir 1989); indicators of fish stocks(Crawford & Shelton 1978); environmental monitors(Gilbertson et al. 1987)	Loss of guano and associated nutrients(Oliver & Legovic 1988); impoverisment of associated communities (Oliver & Schoenberg 1989); loss of socio-economic resources (Haynes-Sutton 1987) and environmental monitors (Gilbertson et al. 1987); trophic cascades(Wootton 1995)
Raptors	Predation on vertebrates	Regulation of rodent populations(Ims & Andreassen 2000; Korpimaki & Norrdahl 1991); secondary dispersal(Nogales et al. 2002)	Rodent pest outbreaks (Korpimaki & Norrdahl 1998); trophic cascades(Crooks & Soule 1999; Terborgh et al. 2001); unpredictable consequences
Other groups	Miscellaneous	Environmental monitoring (Bryce et al. 2002; Eriksson 1987); indirect effects(Dean et al. 1990; Izhaki & Safriel 1989; Loiselle 1990; Milton et al. 1998; Murakami & Nakano 2002; Nogales et al. 2002; Paine et al. 1990; Wootton 1994); birdwatching tourism (Bouton & Frederick 2003; Jacquemot & Filion 1987; Sekercioglu 2002); reduction of agricultural residue(Bird et al. 2000); cultural and economic uses(Diamond 1987)	Losses of socio-economic resources(Filion 1987; Sekercioglu 2002) and environmental monitors(Peakall & Boyd 1987); unexpected consequences

Table 2: Bird groups that are significantly more extinction-prone than average (20.6%). Threatened (vulnerable, endangered or critical) and extinct species are considered extinction-prone.

Category	**% extinction-prone**	χ^2	**p**
Indomalayan region	32.6	219.6	<0.0001
Malagasy region	46.4	325.5	<0.0001
New Zealand region	81.5	483.2	<0.0001
Oceanic region	66.7	648.9	<0.0001
Palearctic region	25.1	102.2	<0.0001
South Polar region	51.9	35.65	<0.005
Forest	25.0	72.64	<0.0001
Sea	46.5	155.1	<0.0001
Wetland	22.1	39.45	<0.0001
Species with restricted-ranges	52.0	1927	<0.0001
Sedentary species (non-migrating)	25.0	102.7	<0.0001
Species living below 500 m	30.2	193.5	<0.0001
Species living above 3000 m	26.2	24.3	<0.01
Species with an altitudinal range < 500 m	34.1	397.4	<0.0001
Species weighing >1000 g	36.2	118.8	<0.0001
Species with one-egg clutches	30.7	68.54	<0.0001

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Figure 1: A flowchart of the model the scenarios were based on. $P_{r,n}$ and $P_{t,n}$ are the respective rates at which restricted range (global extent of occurrence <50,000 km^2) and other species become threatened respectively. For scenarios 2 and 3 these values were recalculated for each decade, based on the ratios of threatened and non-threatened species in the previous decade. P_1, P_2 and P_3 (calculated separately for restricted-range species and remaining species) are the respective probabilities of vulnerable, endangered and critical species going extinct. For scenarios 2 and 3 these values were recalculated for each decade, based on the ratios of threatened and extinct species in the previous decade. An example of the probabilities for the time step 2020-2030 are provided. For scenario 1, all species had equal probabilities of becoming threatened and going extinct.

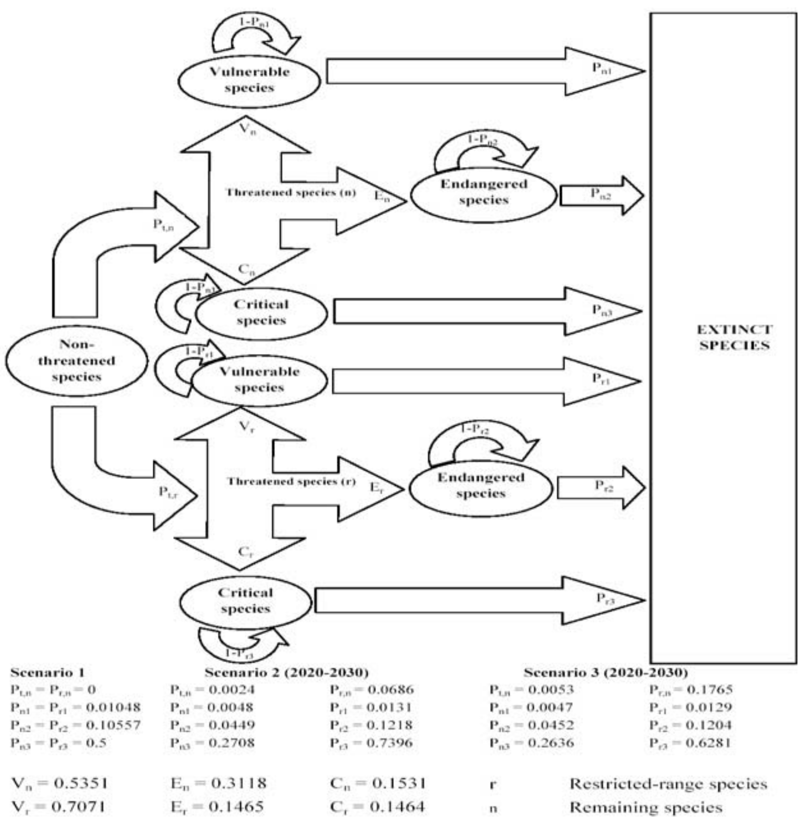

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Figure 2: Distribution of extinction-prone species among functional categories based on primary diet. On the x-axis, numbers in parentheses refer to the number of species in that group. If omnivores are distributed among various categories according to their first diet choice, percentages for extinction-proneness do not change except for scavengers where it drops to 33%.

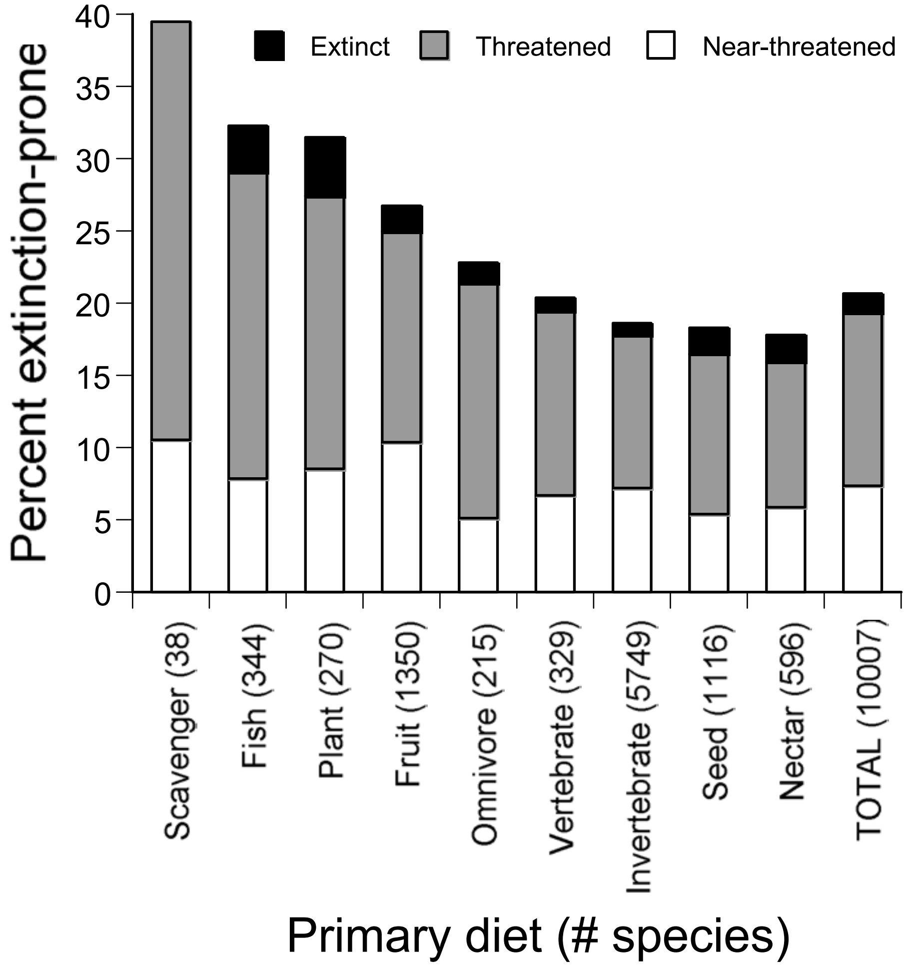

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Figure 3: Current distribution of near-threatened, threatened and extinct species among various guilds. Guilds were assigned based on types and order of preference of food items. “Vertebrates” do not include fish. “Plant Matter” is non-reproductive plant parts. Numbers in parentheses refer to the number of species in that guild.

1-Plant matter, seeds (14)
2-Fish (57)
3-Nectar (19)
4-Fruit, seeds (130)
5-Invertebrates, fish (127)
6-Aquatic invertebrates (82)
7-Carcasses, refuse (26)
8-Seeds, fruit (109)
9-Plant matter (148)
10-Fish, invertebrates (201)
11-Nectar, fruit (56)
12-Fruit (388)
13-Plant matter, invertebrates (271)
14-Invertebrates, plant matter (109)
15-Fruit, invertebrates, vertebrates (79)
16-Nectar, fruit (26)
17-Fruit, plant matter (45)
18-Omnivore (215)
19-Vertebrates (176)
20-Vertebrates, invertebrates (128)
21-Fruit, invertebrates (611)
22-Seeds, fruits, invertebrates (80)
23-Invertebrates, nectar, fruit (182)
24-Fish, other vertebrates, invertebrates (93)
25-Invertebrates (3210)
26-Seeds (342)
27-Invertebrates, vertebrates (636)
28-Invertebrates, nectar (76)
29-Invertebrates, seeds (342)
30-Nectar, invertebrates (467)
31-Vertebrate, carcasses, refuse (49)
32-Seeds, invertebrates (362)
33-Invertebrates, fruit (806)
34-Invertebrates, seeds, fruit (121)
35-Nectar, fruit, invertebrates (101)
36-Seeds, plant matter (111)
37-Vertebrate, invertebrate, fruit (11)
TOTAL-All species (10007)

Figure 3 (cont.)

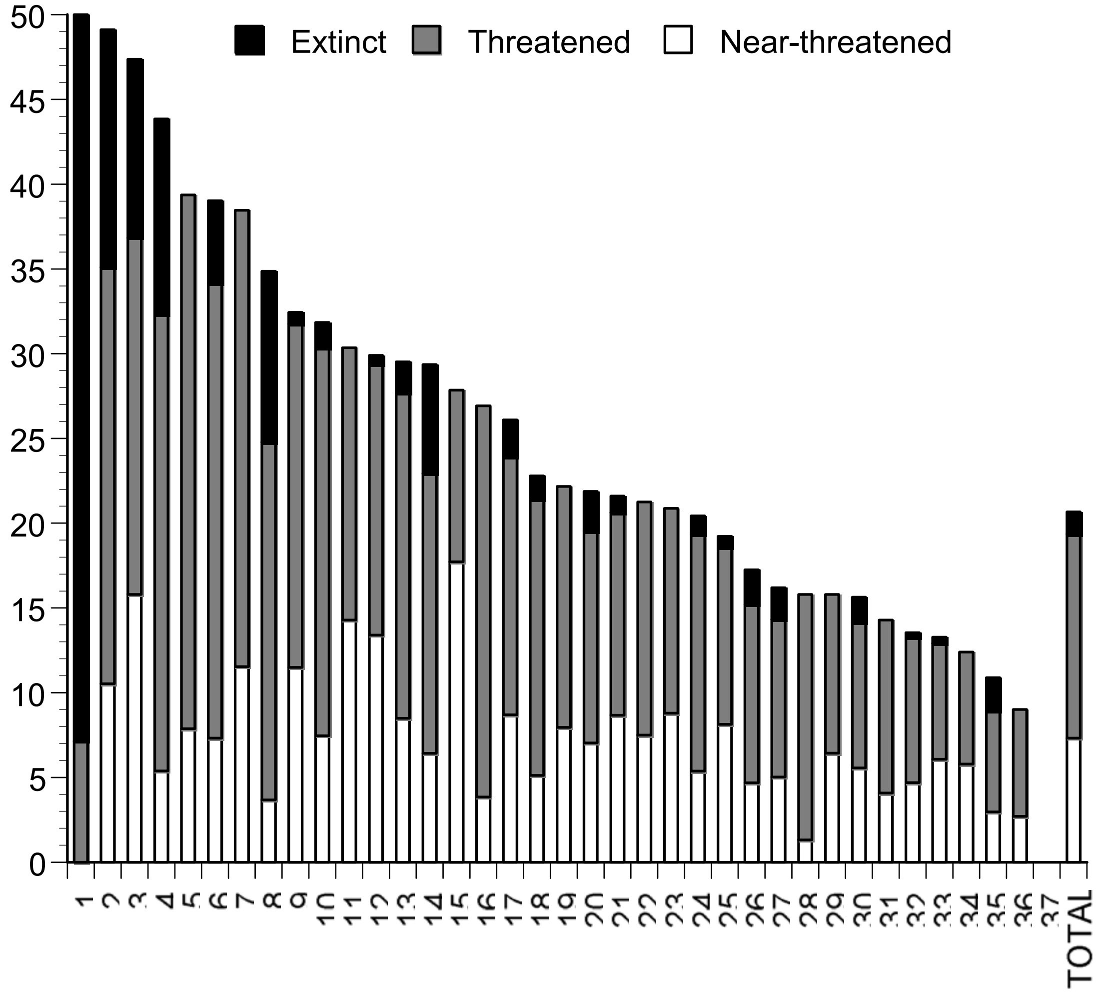

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Figure 4: Increased specialization increases extinction risk; $r^2 = 0.851$. Specialization index was calculated by multiplying number of habitats used and number of food types consumed by a species. Therefore, a specialization index of 1 (corresponding to 0 on the x-axis) would include species that are limited to one habitat type and feed on only one type of food. *Higher* numbers indicate *less* specialization.

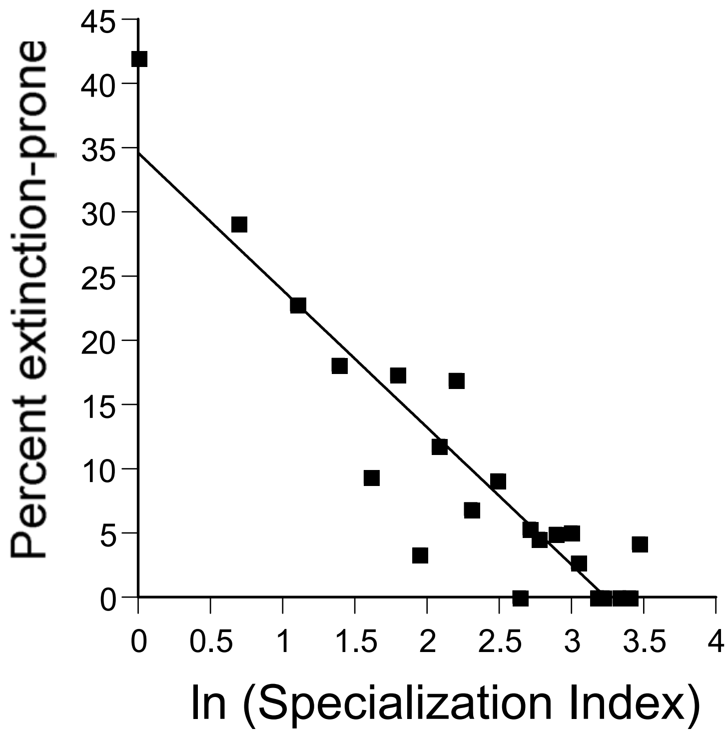

Figure 5: Extinction-proneness based on primary habitat. On the x-axis, numbers in parentheses refer to the number of species in that group. "Human" means human-dominated habitats such as artificial ponds, farms, plantations, towns, etc. If forest birds are taken out, the global average of extinction-prone birds drops to 15%

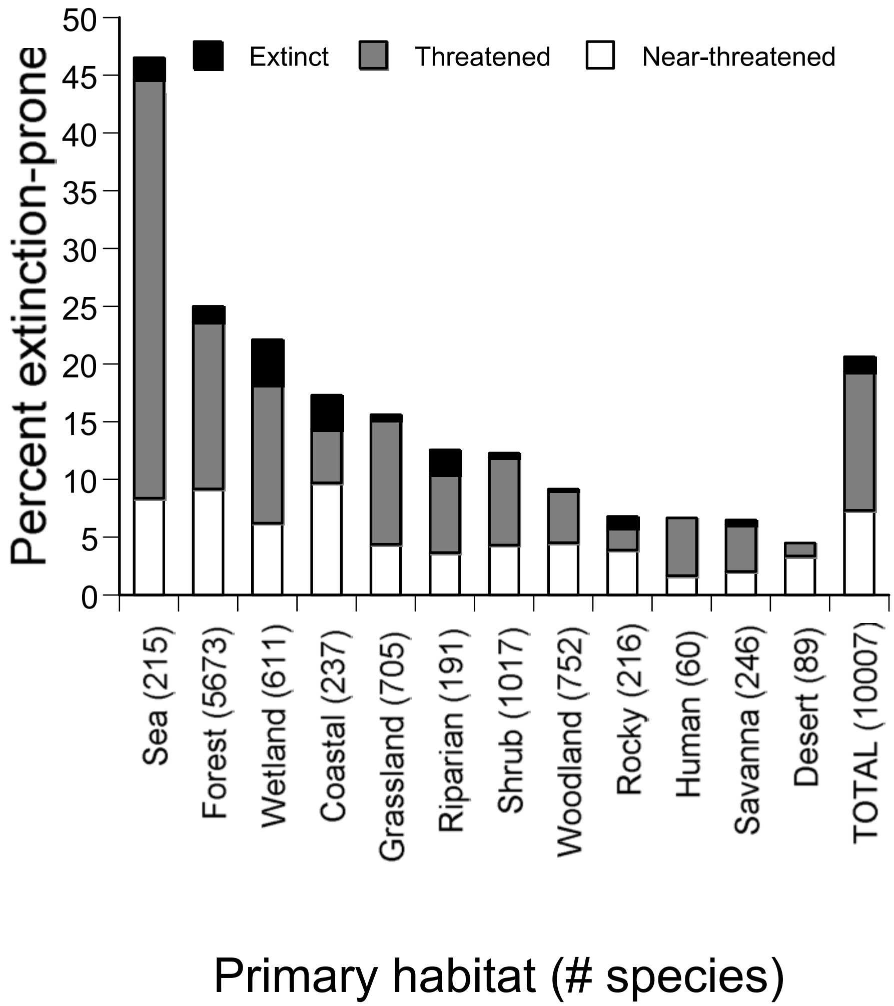

Figure 6: Distribution of extinction-prone species among world regions. On the x-axis, numbers in parentheses refer to the number of species in that group. Major regions are: Austral (A), Cosmopolitan (C), Eastern Hemisphere (E), Afrotropical (F), Indomalayan (I), Malagasy (M), Neotropical (N), Oceania (O), Palearctic (P), South Polar (S) and New Zealand (Z). Each bird was placed in only one region. Two letters indicate combination regions (e.g. NP includes all bird species found both in Nearctic and Palearctic regions).

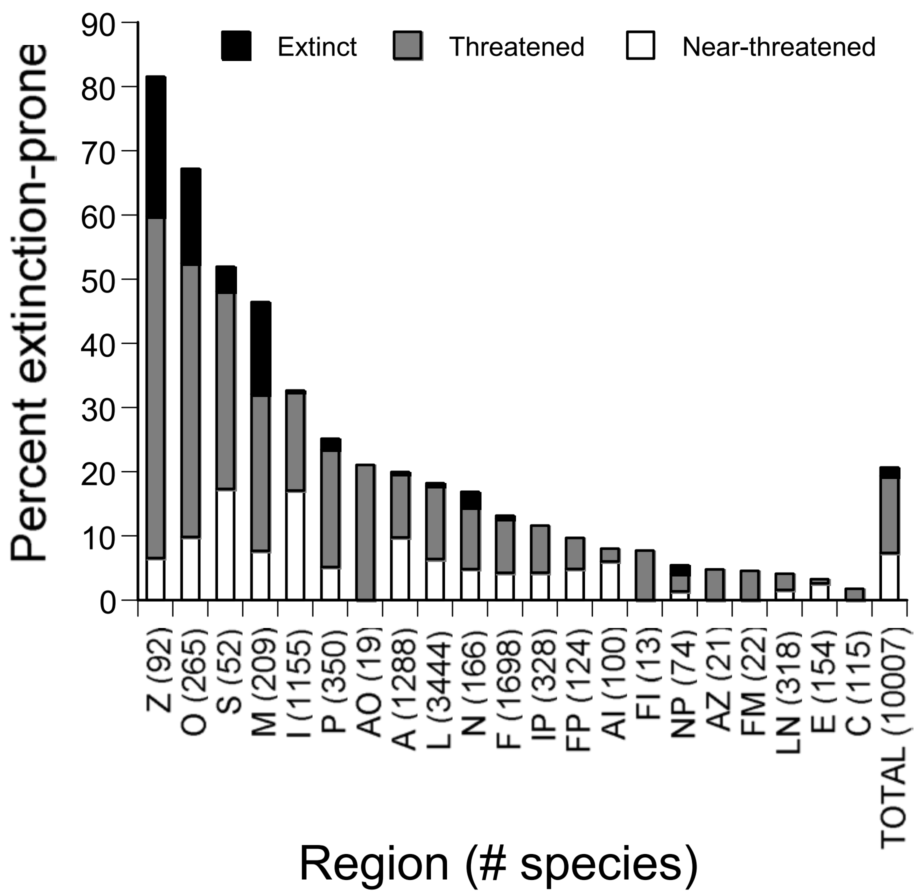

Figure 7: Expected distribution of functionally extinct species in 2100 based on various scenarios. Threatened and extinct species are considered functionally extinct. On the x-axis, numbers in parentheses refer to the number of species in that group. The main bars are the estimates of scenario 2 (intermediate) and error bars indicate the estimates of scenarios 1 (best case) and 3 (worst case).

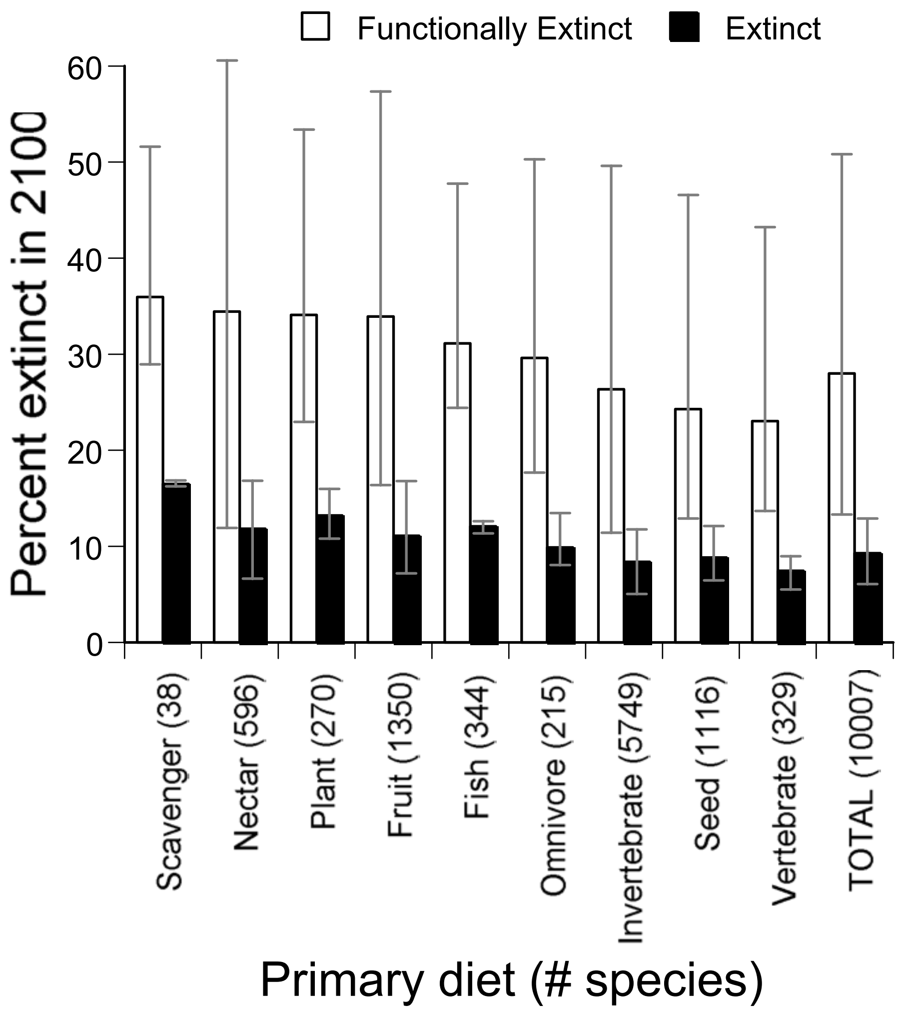

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Figure 8: Distribution of functionally extinct species among various guilds in 2100 based on scenario 2 (intermediate). For a description of guilds, see Figure 3. Estimates of best and worst case scenarios were not included for the purpose of clarity.

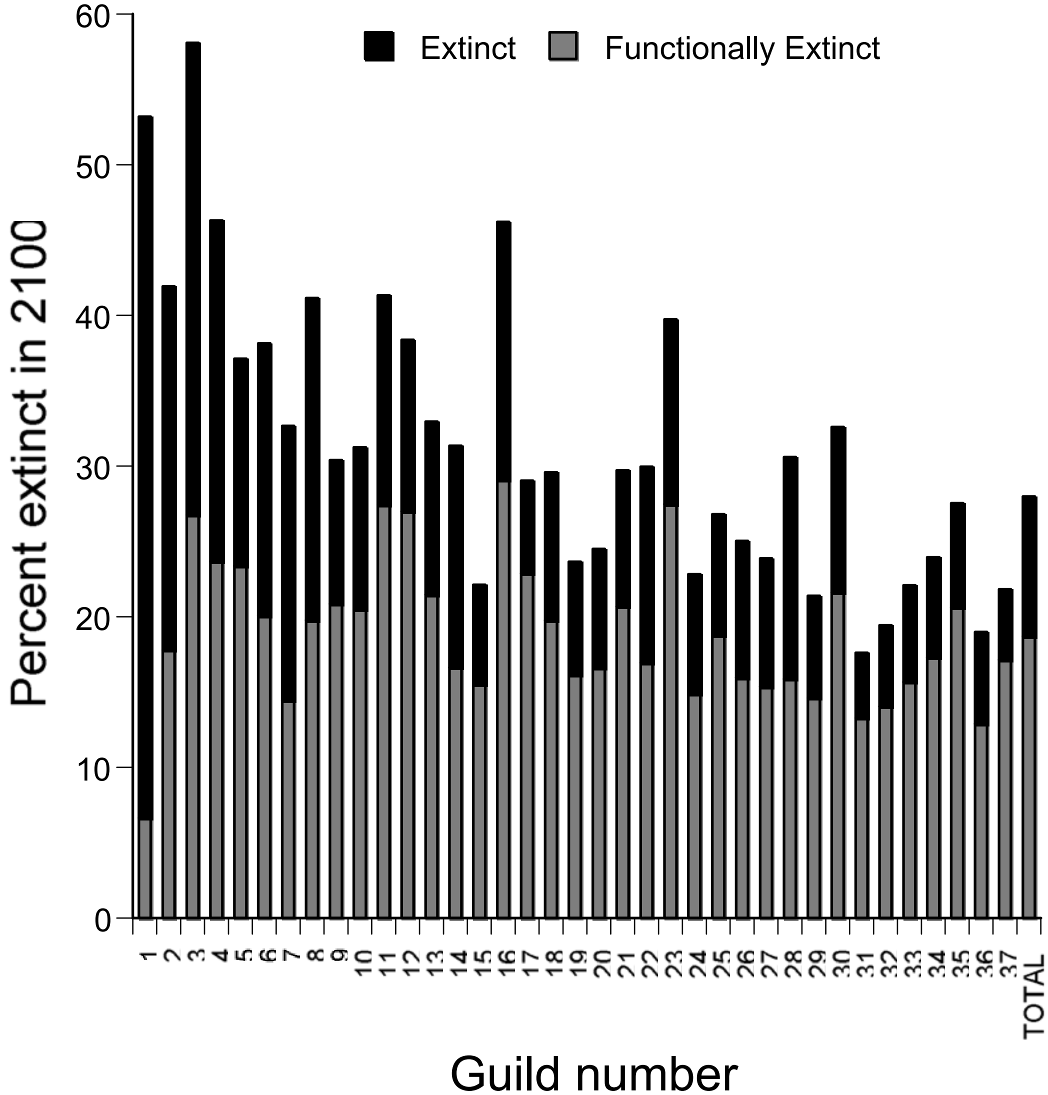

Figure 9: Specialized species are more likely to be functionally extinct; $r^2 = 0.845$. For the description of specialization index, see Figure 4. Threatened and extinct species are considered functionally extinct. The main bars are the estimates of scenario 2 (intermediate) and error bars indicate the estimates of scenarios 1 (best case) and 3 (worst case).

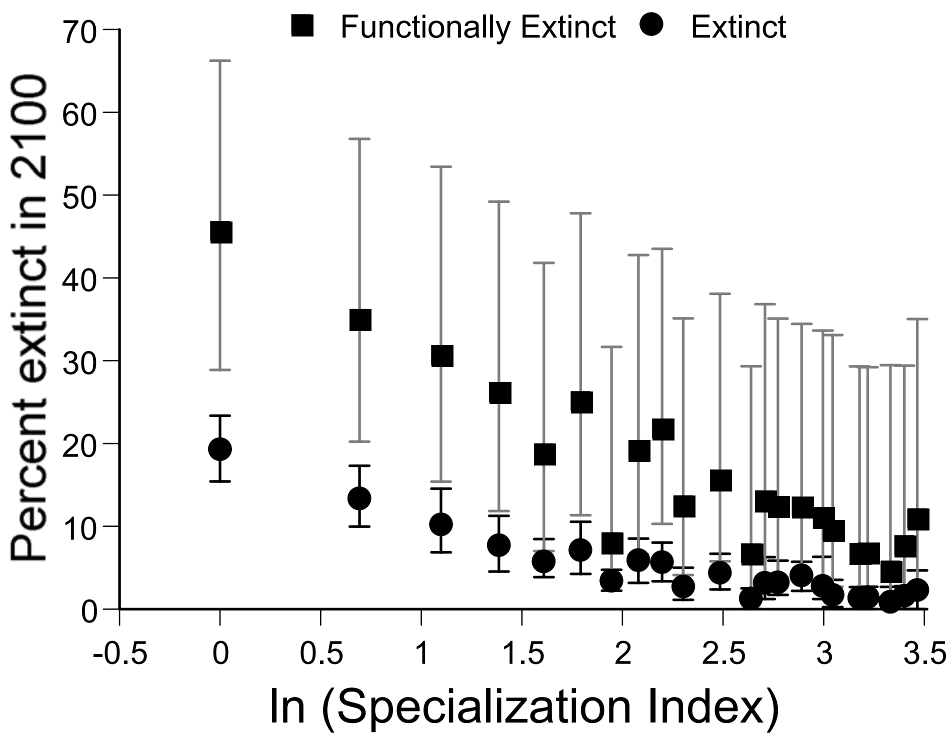

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Figure 10: Expected distribution of functionally extinct species among habitats in 2100 based on various scenarios. Threatened and extinct species are considered functionally extinct. On the x-axis, numbers in parentheses refer to the number of species in that group. The main bars are the estimates of scenario 2 (intermediate) and error bars indicate the estimates of scenarios 1 (best case) and 3 (worst case).

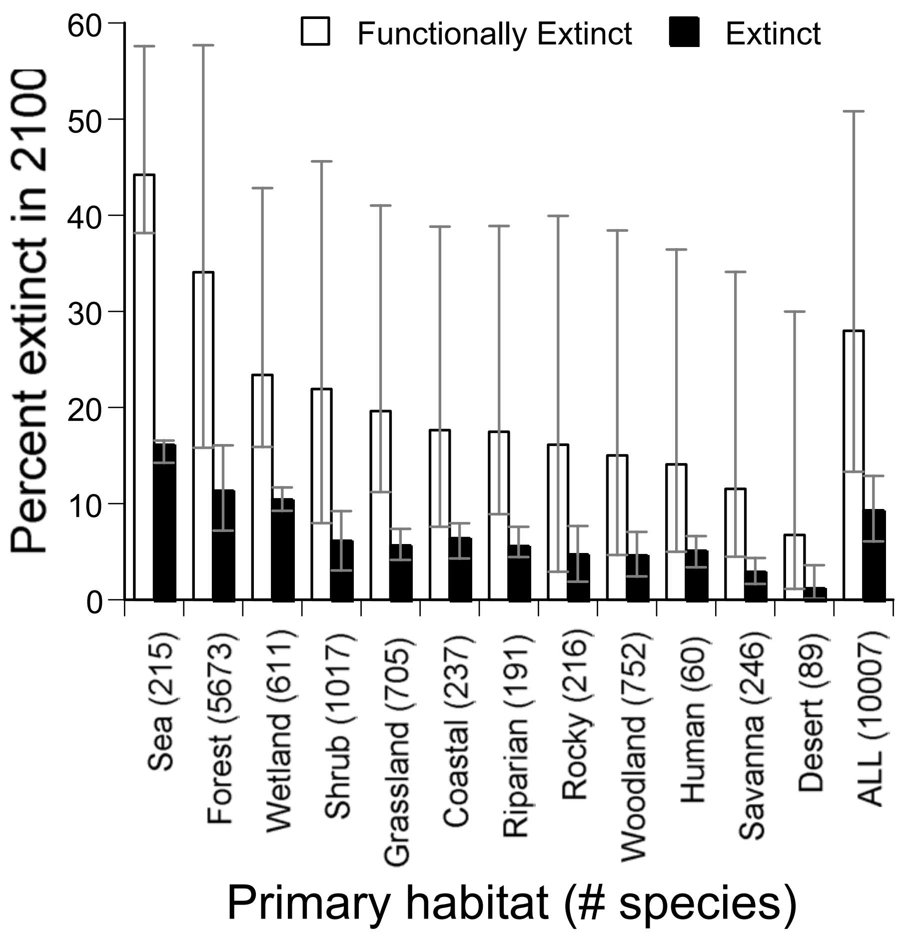
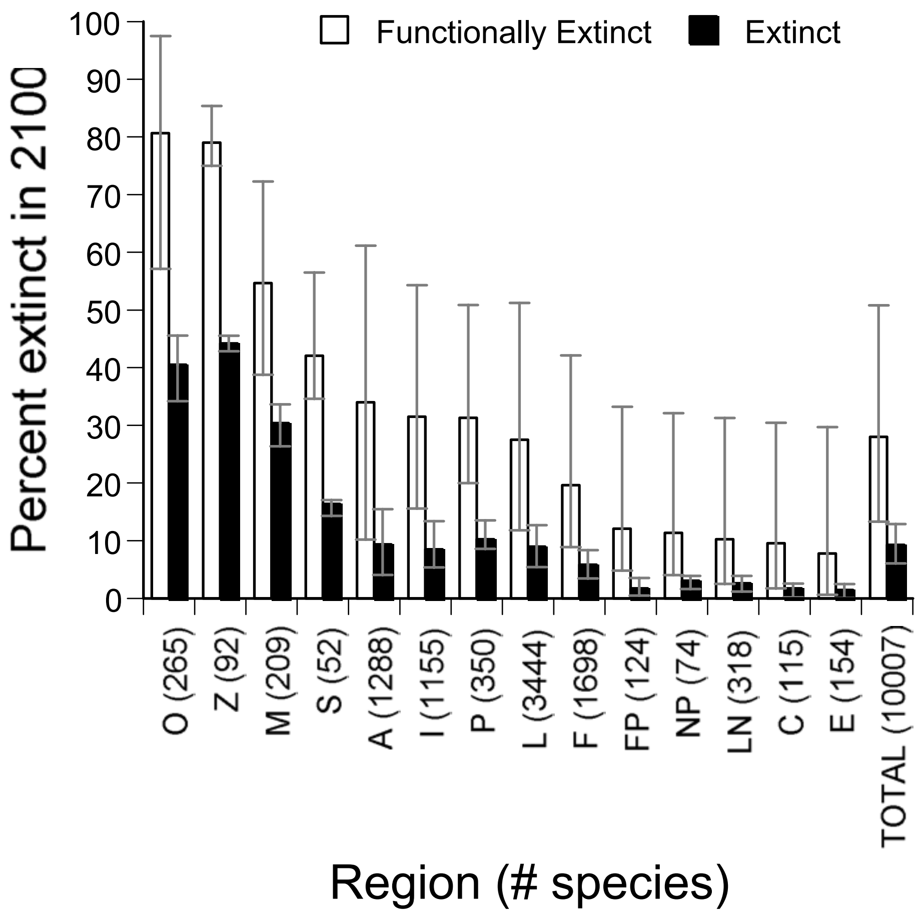


Figure 11: Expected distribution of functionally extinct species among world regions in 2100 based on various scenarios. For an explanation of regional codes, see Figure 6. Some combination regions were excluded for the sake of clarity. Threatened and extinct species are considered functionally extinct. On the x-axis, numbers in parentheses refer to the number of species in that group. The main bars are the estimates of scenario 2 (intermediate) and error bars indicate the estimates of scenarios 1 (best case) and 3 (worst case).



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CHAPTER II

Effects of forestry practices on vegetation structure and bird community of Kibale National Park, Uganda

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