RED LIST

SPECIES SUSCEPTIBILITY TO CLIMATE CHANGE IMPACTS

Wendy Foden, Georgina Mace, Jean-Christophe Vié, Ariadne Angulo, Stuart Butchart, Lyndon DeVantier, Holly Dublin, Alexander Gutsche, Simon Stuart and Emre Turak

The IUCN Red List of Threatened Species™

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Species Survival Commission

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Species susceptibility to climate change impacts

Wendy Foden, Georgina Mace, Jean-Christophe Vié, Ariadne Angulo, Stuart Butchart, Lyndon DeVantier, Holly Dublin, Alexander Gutsche, Simon Stuart and Emre Turak

Background

There is growing evidence that climate change will become one of the major drivers of species extinctions in the 21st Century. An increasing number of published studies have documented a variety of changes attributable to climate change (IPCC 2007), for example changes in species breeding times and shifts in distributions (Figure 1). One study suggests that 15-37% of terrestrial species may be 'committed to extinction' by 2050 due to climate change (Thomas *et al*. 2004). How can we predict which species will become most threatened by climate change and how best can we mitigate the impacts?

To date, most assessments of species extinctions under climate change have been based on either isolated case studies or large-scale modelling of species' distributions. These methods depend on broad and possibly inaccurate assumptions, and generally do not take account of the biological differences between species. As a result, meaningful information that could contribute to conservation planning at both fine and broad spatial scales is limited. Conservation decision-makers, planners and practitioners currently have few tools and little technical guidance on how to incorporate the differential impacts of climate change into their plans and actions.

IUCN is developing assessment tools to identify the potential effects of climate change on species. The IUCN Red List

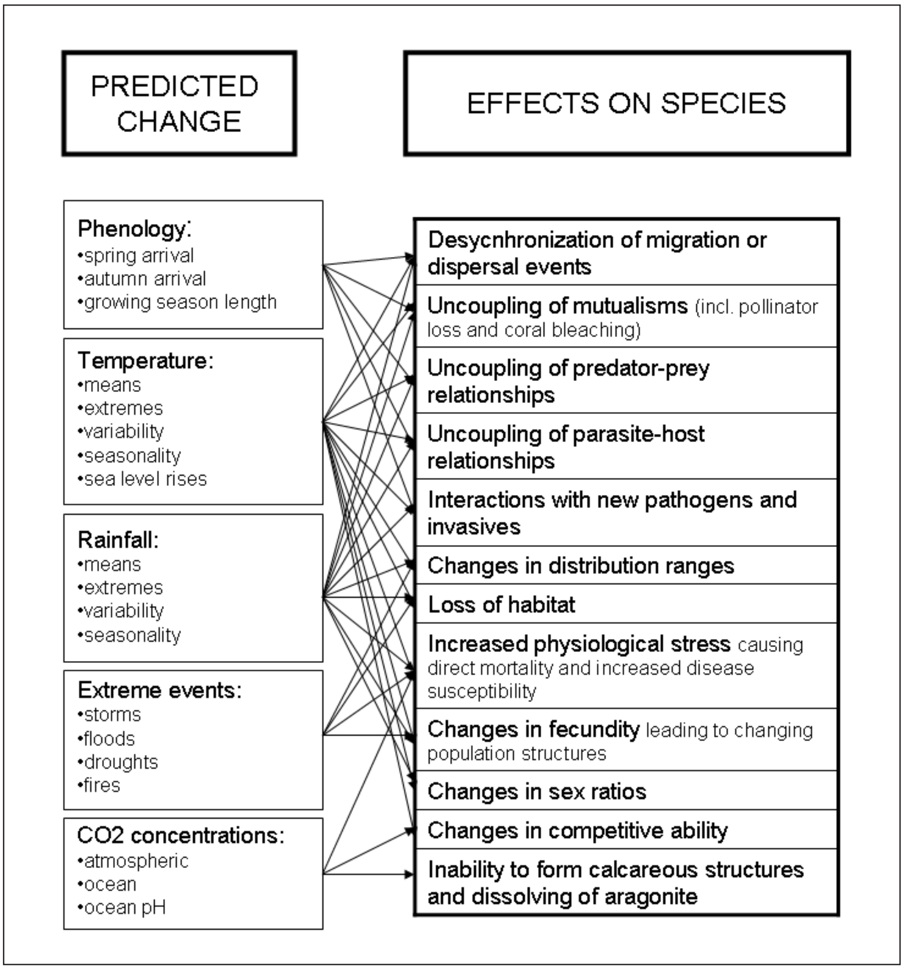


Figure 1. *A summary of some of the predicted aspects of climate change and examples of the effects that these are likely to have on species.*

Categories and Criteria were developed before climate change impacts on species were widely recognized, and although they remain effective for identifying species that are undergoing declines in range or population sizes, they may need further refinement in order to identify the full suite of species at risk from climate change. A new initiative aimed at examining how the IUCN Red List Criteria can be used for

Climate change is causing population declines of the Quiver Tree Aloe dichotoma*, a long-lived giant tree aloe from the Namib Desert region. Growing evidence suggests that desert ecosystems may be more sensitive to climate change than previously suspected. © Wendy Foden*

identifying the species most at risk from climate change is underway. This study, although it forms part of the overall project looking at the impacts of climate change on species, is not discussed further here.

Methodological approach

General Circulation Models (GCMs) predict that climate change will affect different areas of the world to different degrees. But it is also widely recognized that not all species will respond in the same way, even to similar levels of climatic change. A species' individual susceptibility to climate change depends on a variety of biological traits, including its life history, ecology, behaviour, physiology and genetic makeup. Species exposed to large climatic changes in combination with intrinsic susceptibility to climate change face the greatest risk of extinction due to climate change (Figure 2).

We assessed susceptibility to climate change according to taxon-specific biological traits and present an analysis of the potential impacts of climate change on species based on an analysis of these traits. Using expert assessments for birds (9,856 species), amphibians (6,222 species) and warm-water reef-building corals (799 species), we examined the taxonomic and geographical distributions of the species most susceptible to climate change and compared these to the existing assessments of threatened species in The 2008 IUCN Red List of Threatened Species™ (herein The IUCN Red List; IUCN 2008). Specifically we address the following questions:

- What are the biological traits that make species potentially susceptible to climate change?
- How common are these traits in birds, amphibians and warm-water reef-building corals?

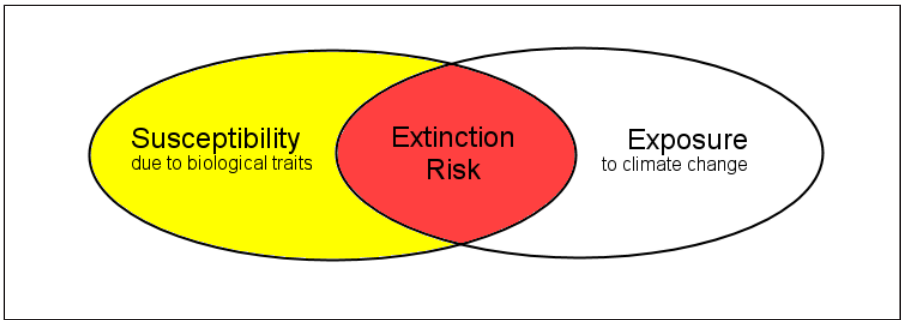


Figure 2. *Increased risk of extinction due to climate change occurs where species possess biological traits or characteristics that make them particularly susceptible to change, and simultaneously occur in areas where climatic changes are most extreme.*

- Are the species that are potentially susceptible to climate change the same as those already identified as threatened on The IUCN Red List?

- How do taxonomic and geographic concentrations of species that are potentially susceptible to climate change compare to those of threatened species?

What are the biological traits that make species most susceptible to climate change?

Through detailed consultations with a wide range of experts, we identified over 90 biological traits that may be associated with enhanced susceptibility to climate change. These were consolidated into five groups of traits (Table 1 and Box), and each trait within these groups, was assessed using a range of biological information. Specific trait combinations were developed for each of the three taxonomic groups covered in this study. Table 1 shows the groups, traits and the number of bird, amphibian and coral species that met each of them either singly or in combination.

There were a number of challenges in selecting traits. These included the scarcity of key species-level data (e.g., population sizes, temperature-tolerance thresholds, prey species), as well as defining traits in quantifiable, objective and replicable ways. Although not always possible, we aimed to represent each of the trait groups with at least one specific trait for each taxonomic group. Even though many species possess multiple susceptible traits, for this analysis we defined "susceptible species" to be those that were recorded as having any one or more susceptible traits. While this method allows for very broad comparability between taxonomic groups, accurate quantification of the contribution of each trait to extinction risk is necessary before cross-taxonomic group comparisons can be made with confidence. Our approach to assessing species' susceptibility to climate change assesses relative susceptibility within each taxonomic group only.

The IUCN Red List and BirdLife International's World Bird Database provided

Which traits or characteristics make species susceptible to climate change?

In October 2007, Imperial College London, IUCN and the Zoological Society of London hosted a four-day workshop to identify the traits associated with elevated extinction risk, particularly due to climate change. Thirty-one biologists, whose expertise spanned a broad range of taxonomic groups and geographic regions, identified, discussed and eventually reached consensus on a list of over 90 traits that are generally indicative of species' vulnerability to extinction across most taxonomic groups. These traits were subsequently refined and form the basis of IUCN's ongoing assessment of species susceptibility to climate change. The traits fall into the following five trait groups:

A. Specialized habitat and/or microhabitat requirements. Species with generalized and unspecialized habitat requirements are likely to be able to tolerate a greater level of climatic and ecosystem change than specialized species. Where such species are able to disperse to new climatically suitable areas, the chances of fulfillment of all their habitat requirements are low (e.g., plants confined to limestone outcrops; cave-roosting bats). Susceptibility is exacerbated where a species has several life stages, each with different habitat or microhabitat requirements (e.g., water-dependent larval-developing amphibians), or when the habitat, microhabitat to which the species is specialized is particularly vulnerable to climate change impacts (e.g., mangroves, cloud forests or polar habitats). In some cases (e.g., deep sea fish), extreme specialization may allow species to escape the full impacts of competition from native or invading species so the interaction of such traits climate change must be considered carefully for each species group assessed.

B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle. The physiology and ecology of many species is tightly coupled to very specific ranges of climatic variables such as temperature, precipitation, pH and carbon dioxide levels, and those with narrow tolerance ranges are particularly vulnerable to climate change. Even species with broad environmental tolerances and unspecialized habitat requirements may already be close to thresholds beyond which ecological or physiological function quickly breaks down (e.g., photosynthesis in plants, protein and enzyme function in animals).

C. Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change. Many species rely on environmental triggers or cues for migration, breeding, egg laying, seed germination, hibernation, spring emergence and a range of other essential processes. While some cues such as day length and lunar cycles will be unaffected by climate change, others such as rainfall and temperature (including their interacting and cumulative effects) will be heavily impacted upon by climate change. Species become vulnerable to changes in the magnitude and timing of these cues when they lead to an uncoupling with resources or other essential ecological processes e.g., early spring warming causes the emergence of a species before their food sources are available. Climate change susceptibility is compounded when different stages of a species' life history or different sexes rely on different cues.

D. Dependence on interspecific interactions that are likely to be disrupted by climate change. Many species' interactions with prey, hosts, symbionts, pathogens and competitors will be affected by climate change either due to the decline or loss of these resource species from the dependent species' ranges or loss of synchronization in phenology. Species dependent on interactions that are susceptible to disruption by climate change are at risk of extinction, particularly where they have high degree of specialization for the particular resource species and are unlikely to be able to switch to or substitute other species.

E. Poor ability to disperse to or colonise a new or more suitable range. In general, the particular set of environmental conditions to which each species is adapted (its 'bioclimatic envelope') will shift polewards and to increasing altitudes in response to climate change. Species with low rates or short distances of dispersal (e.g., land snails, ant and rain drop splash dispersed plants) are unlikely to migrate fast enough to keep up with these shifting climatic envelopes and will face increasing extinction risk as their habitats become exposed to progressively greater climatic changes.
Even when species are able to disperse to newly suitable bioclimatic areas, several other factors affect colonization success. Species' phenotypic plasticity and genetic diversity determine the likelihood of adaptation over different time scales. Where it exists, direct measures of genetic variability can be supplemented with information on naturalization outside species' native ranges and on the success of any past translocation efforts. Extrinsic factors decreasing dispersal success include the presence of any geographic barriers such as mountain ranges, oceans, rivers, and for marine species, ocean currents and temperature gradients. Anthropogenic transformation of migration routes or destination habitats increases a species' susceptibility to negative impacts from climate change.

Trait Group	Biological Trait	No. of species qualifying		
		Birds	Amphibians	Corals
A. Specialized habitat and/or microhabitat requirements	Altitudinal range narrow and at high elevation	224		
	Restricted to habitats susceptible to climate change	820	757	15
	High degree of habitat specialization	693		28
	Dependence on a particular microhabitat	438	889	
	Contribution of trait group	46%	42%	5%
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Global temperature tolerances likely to be exceeded			61
	Larvae particularly susceptible to heat stress			108
	Sensitive to increased sedimentation			143
	Vulnerable to physical damage from storms and cyclones			183
	Contribution of trait group	0%	0%	68%
C. Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change	Environmental trigger/cue disruption observed or likely	316	315	
	Contribution of trait group	9%	10%	0%
D. Dependence on interspecific interactions which are likely to be disrupted by climate change	Dependent on very few prey or host species	27		
	Dependent on an interspecific interaction that is likely to be impacted by climate change	44		
	Susceptible to chytridiomycosis and/or enigmatic decline		1,034	
	Susceptible to breakdown of coral-zooxanthellae interaction			144
	Contribution of trait group	2%	32%	25%
E. Poor ability or limited opportunity to disperse to or colonize a new or more suitable range	Low maximum dispersal distances	1,500		73
	Geographic barriers limit dispersal opportunity	709	744	117
	Limited opportunity to establish at new locations	769	602	55
	Low genetic diversity or known genetic bottleneck	63		
	Contribution of trait group	69%	40%	40%
Number of climate change susceptible species		**3,438**	**3,217**	**566**
Number of species assessed		**9,856**	**6,222**	**799**
Climate change susceptible species (%)		**35%**	**52%**	**71%**

Table 1. A summary of the trait groups, biological traits and numbers of bird, amphibian and warm-water reef-building coral species that qualify as having the trait in question. Trait group summary rows (grey) show the relative contribution of each trait group to the total number of climate change susceptible species for each taxonomic group. The sum of these values is >100% because many qualifying species have multiple traits. Detailed descriptions of trait groups are given in the Box.

essential information such as taxonomy, distribution maps, habitats and threats, and additional information was gathered from published and unpublished data, online resources, literature and expert knowledge. While we attempted to address data gaps with experts' inferences and assumptions, numerous uncertainties remain. In summary, our results are based on the following assumptions: that species' susceptibility to climate change is associated with the possession of specific biological traits that we have identified; that the possession of any one of these traits increases the susceptibility of a species to climate change; and that our classification of each species according to these traits is accurate.

How common are these traits in the amphibians, birds and warm-water reef-building corals?

Birds

Eleven traits were selected for this relatively information-rich group. 3,438 of the world's 9,856 extant bird species (35%) possess traits that make them potentially susceptible to climate change. Of these, 1,288 species have between two and seven such traits with the majority of species qualifying due to specialized habitat and microhabitat requirements, and poor or limited opportunity to establish at new locations, particularly due to low maximum dispersal distances. We also examined any evidence of impacts of changing seasonal cues, confinement to narrow altitudinal ranges at high elevations, and dependence on five or fewer prey or host species.

Susceptibility to climate change in birds shows strong taxonomic and geographic patterns with all species considered susceptible within the Diomedeidae (albatross), Spheniscidae (penguin), Procellariidae, Pelecanoididae and Hydrobatidae (petrel and shearwater) families. Large families with particularly high levels of susceptibility include Turdidae (thrushes, 60%), Thamnophilidae (antbirds, 69%), Scolopacidae (sandpipers and allies, 70%), Formicariidae (antthrushes and antpittas, 78%) and Pipridae (manakins, 81%). In contrast, large families showing low levels of climate change susceptibility include Ardeidae (herons and egrets, 3%), Accipitridae (osprey, kites, hawks and eagles, 10%), Estrildidae (waxbills, grass finches and munias, 12%), Cuculidae (cuckoos, 15%), Picidae (woodpeckers, 21%) and Columbidae (doves and pigeons, 27%).

Amphibians

We found that 3,217 of the 6,222 global amphibian species (52%) are potentially susceptible to climate change, and 962 species possess two to four climate change susceptibility traits. Within three small families in order Caudata (salamanders), namely the Amphiumidae (amphiumas, three species), Sirenidae (sirens, four species) and Proteidae (mudpuppies and waterdogs, six species), all species are "climate-change-susceptible". The low numbers of susceptible species in the order Gymnophiona (caecilians) (18%), might be due to the scarcity of global knowledge of the group. The Sooglossidae (Seychelles frogs and Indian Burrowing Frog), Myobatrachidae and Limnodynastidae (Australian ground frogs), Ceratophryidae (horned toads), and Centrolenidae (glassfrogs) families have 80-100% of species assessed as "climate-change-susceptible". Large families with more than 50% "climate-change-susceptible" species include Strabomantidae, Bufonidae (toads and true toads), Hylidae (treefrogs) and Plethodontidae (lungless salamanders).

Of the six traits used to assess amphibian susceptibility to climate change, those relating to specialized habitat requirements, poor dispersal and colonization ability, and disruption of interspecific interactions identified the majority of susceptible species. These included species occurring exclusively in habitats vulnerable to climate change; those with water-dependant larvae occurring exclusively in unbuffered habitats; those unable to disperse due to barriers such as large water bodies or unsuitable habitat; and those with small ranges in combination with very low population densities.

Emerging infectious diseases, such as chytridiomycosis, caused by the chytrid fungus (*Batrachochytrium dendrobatidis*), and 'enigmatic' or unexplained declines play an increasingly large role in driving amphibians towards extinction (Bosch and Rincon 2008; Corey and Waite 2008; Lips *et al.* 2003; Navas and Otani 2007; Pounds *et al.* 2006; Stuart *et al.* 2004). While the direct contribution of climate change to these threats remains disputed, at best, species particularly susceptible to or already experiencing such declines are more likely to fare poorly in the face of increasing climate change.

Under the trait group covering 'dependence on interspecific interactions which are likely to be disrupted by climate change', amphibians were regarded as "climate-change-susceptible" where chytrid infection has been recorded in wild populations, or where experts have deemed infection highly likely, or where enigmatic declines have been recorded but not directly linked to chytridiomycosis. In many cases, susceptibility to chytrid infection shows a taxonomic and ecological bias (Corey and Waite 2008; Stuart *et al.* 2004), so we have provisionally included in this trait group all species in genera containing infected members (e.g., members of genus *Atelopus*) that also occur exclusively in subtropical or tropical montane environments and are dependent on water bodies. Species with chytrid presence but no symptoms of clinical disease (e.g., members of genus *Xenopus*) did not qualify as susceptible under this trait.

Corals

To date, most climate change studies have focussed on reef-level impacts and few have attempted to distinguish individual species' responses to climate change impacts. Here we assess only the warm-water reef-building corals, including 789 species (those either *zooxanthellate or hermatypic*) of order Scleractinia (stony corals), eight Milleporina species (fire or stinging corals), one Helioporaceae (blue coral) and one Stolonifera species (organ pipe coral). Due to insufficient information and taxonomic uncertainties, we were unable to assess the 46 other species in the group.

Restricted to a very small range in north-west Ecuador, the Black-breasted Puffleg Eriocnemis nigrivestis *has been assessed as both Critically Endangered according to The IUCN Red List and "climate-change-susceptible" based on its biological traits. These "climate-change-susceptibility" traits include its habitat specialization, restriction to a climate change susceptible habitat, a narrow and high altitude range, very short typical dispersal distances and an extremely small population size. The species is suffering ongoing declines from deforestation. © Francisco Enriquez*

We found that 566 of 799 global warm-water reef-forming coral species (71%) are potentially susceptible to the impacts of climate change, while 253 species possess between two and six susceptibility traits. Families Acroporidae (including staghorn corals), Agariciidae and Dendrophylliidae had particularly high numbers of susceptible species, while Fungiidae (including mushroom corals), Mussidae (including some brain corals) and Pocilloporidae (including cauliflower corals) possess relatively few.

Coral susceptibility assessments were based on 10 traits and most species qualified due to their sensitivity to increases in temperature both by adult polyps as well as free-living larvae; sedimentation; and physical damage from storms and cyclones. Poor dispersal ability and colonization potential proved a further important trait group and included larval longevity (as a proxy for maximum dispersal distance) and the presence of currents or temperatures as barriers to dispersal. Although climate change related ocean acidification is likely to become a serious threat to coral survival in the future (Kleypas *et al.* 1999; Royal Society 2005), we did not include it in our assessment due to the uncertainty surrounding time frames of effects, low anticipated differentiation in species' aragonite decalcification rates, and the relatively small depth range of warm-water reef-building corals.

Are the "climate-change-susceptible" species the same as those already identified as threatened on The IUCN Red List, or are they different?

For each taxonomic group, we assigned all species into the following four categories: (i) threatened (according to The IUCN Red List) and "climate-change-susceptible"; (ii) threatened but not "climate-change-susceptible"; (iii) not threatened but "climate-change-susceptible"; and (iv) neither threatened nor "climate-change susceptible". A summary of the results is shown in Table 2.

The summaries in Table 2 show that each taxonomic group faces different challenges in response to climate change. At 32%, the amphibians already have a very high number of threatened species. Seventy-five percent of these are also susceptible to climate change, greatly exacerbating their extinction risk. In addition, 41% of currently non-threatened species are "climate-change-susceptible".

The overall percentage of threatened birds is lower than those of the other groups assessed (12%), but most threatened birds (80%) are also susceptible to the impacts of climate change. In addition, a quarter of all bird species and nearly 30% of all non-threatened species are susceptible to climate change.

At 51%, corals have the greatest proportion of not threatened but "climate-change-susceptible" species of the groups assessed, while a further 19% of species are both susceptible and threatened. Corals are the only group in which non-threatened but susceptible species outnumber those that are neither threatened nor susceptible (21%), and they do so by more than two-fold. This suggests that if climate change becomes extreme globally, more than three quarters of all warm-water reef-building coral species could be at risk of extinction.

The large overlap between threatened and "climate-change-susceptible" amphibian and bird species means that, ideally, they may already be included in conservation prioritization strategies. However, the question above has more complex implications. Species that already face a high risk of extinction, irrespective of the threat type, are far less likely to be resilient to environmental and climatic changes. A large overlap between threatened and "climate-change-susceptible" species may therefore mean that climate change may cause a sharp rise in both the extinction risk and extinction rate of currently threatened species. It is also important to identify susceptible species which, while currently not threatened, are likely to become so in the future as climate change impacts intensify. By highlighting such species before they decline, we hope to promote preemptive and more effective conservation actions.

Data Deficient Species

While Data Deficient species (i.e., those with insufficient information to conduct Red List assessments) represent only one per cent of bird species, 25% and 14% of amphibians and corals respectively fall into this Red List Category. Because a trait-based assessment of

Birds		Threatened		
		YES	NO	TOTAL
Climate Change Susceptible	YES	976 10%	2,462 25%	35%
	NO	246 2%	6,172 63%	65%
	TOTAL	**12%**	**88%**	**9,856**

Amphibians		Threatened		
		YES	NO	TOTAL
Climate Change Susceptible	YES	1,488 24%	1,729 28%	52%
	NO	503 8%	2,502 40%	48%
	TOTAL	**32%**	**68%**	**6,222**

Corals		Threatened		
		YES	NO	TOTAL
Climate Change Susceptible	YES	155 19%	411 51%	71%
	NO	68 9%	165 21%	29%
	TOTAL	**28%**	**72%**	**799**

Table 2. *The numbers and percentages of species assessed for "climate-change-susceptibility" and in the 2008 IUCN Red List for birds (a), amphibians (b) and warm-water reef-building corals (c). These values fall into categories: (i) threatened and "climate-change-susceptible" (red); (ii) threatened but not "climate-change-susceptible" (orange); (iii) not threatened but "climate-change-susceptible" (yellow); and (iv) neither threatened nor "climate-change susceptible" (green).*

Cochranella antisthenesi (known in Spanish as Ranita de cristal de Rancho Grande*) lives only in cloud and gallery forest within a restricted area of Venezuela. It is currently considered to be Vulnerable due to human-caused habitat loss, but is also likely to be susceptible to climate change impacts because of the likelihood of infection by chytrid fungus, and because any future dispersal to remain in climatically suitable areas is blocked by ocean and human-transformed habitat. © Ariadne Angulo*

species susceptibility to climate change requires different information to Red List assessments, we were able to infer that 38 (58%), 679 (44%) and 94 (81%) of Data Deficient bird, amphibian and coral species respectively are potentially susceptible to climate change (Figure 2). For corals these susceptibility assessments were based on traits inferred from knowledge of close taxonomic relatives (e.g., similar reproductive modes), while inferences were made based largely on habitats (e.g., disease susceptibility) for amphibians. Due to particularly poor distribution information for most Data Deficient species, they were not included in the geographic analyses.

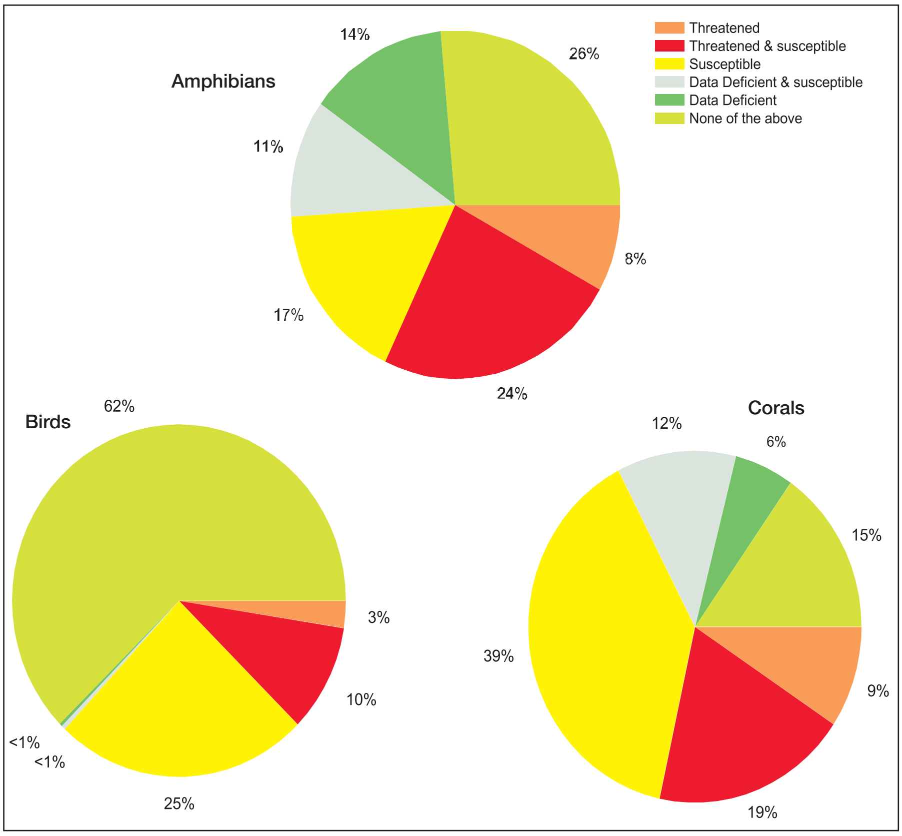


***Figure 3.** The proportion of bird, amphibian and coral species falling in one of the 6 following categories: (i) threatened (according to The 2008 IUCN Red List) (orange); (ii) threatened and "climate-change-susceptible" (red); (iii) not threatened but "climate-change-susceptible" (yellow); (iv) Data Deficient and "climate-change-susceptible" (brown); (v) Data Deficient and not "climate-change-susceptible" (dark green); and (vi) neither threatened, Data Deficient nor "climate-change-susceptible" (light green).*

Where are the areas of highest concentrations of "climate-change-susceptible" species?

Although birds are generally a data rich group, range maps are not currently available for many of the non-threatened species, making meaningful analysis of global geographic trends in "climate-change–susceptible" species impossible. For this reason we are only able to present global geographical trends for amphibians and corals.

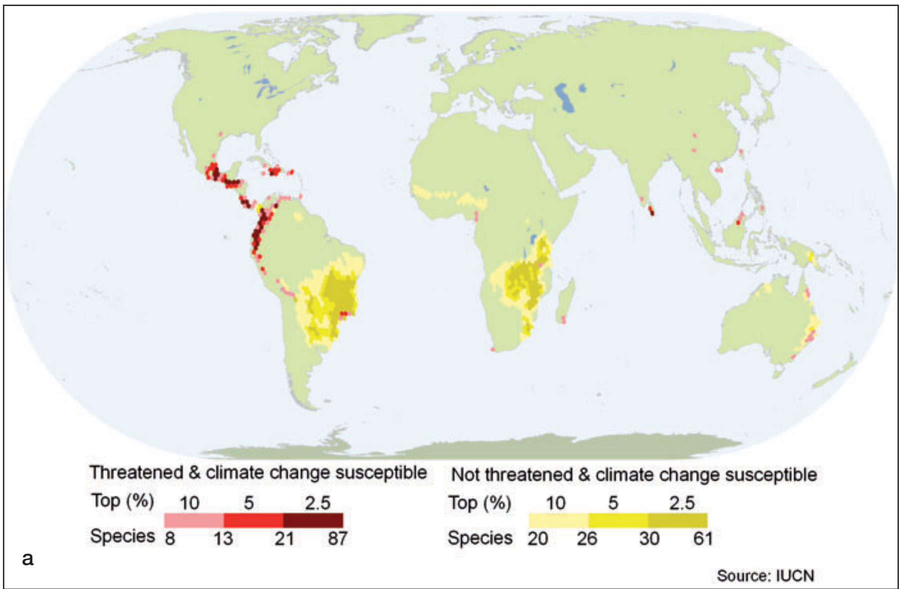
Amphibians

We identified high concentration areas by selecting areas with the top 10%, 5% and 2.5% of species richness (or nearest appropriate percentages when these were not distinguishable). For amphibians assessed as threatened and "climate-change-susceptible" (Figure 4a), the areas of greatest richness span Mesoamerica and northwestern South America. Smaller areas of high richness include various Caribbean Islands; south-eastern Brazil; Sri Lanka, the Western Ghats of India; northern Borneo (Malaysia); and the eastern coast of Australia. As expected, this shows strong correspondence with areas of both overall and threatened species richness (Stuart *et al.* 2004), although interesting exceptions are the lower levels of susceptibility in the Amazon Basin; central to southern Africa; and the southeastern USA. While each of these areas has moderate to high species richness and many threatened species, they did not meet the thresholds for inclusion as high concentration areas.

High concentration areas for amphibians assessed as not threatened but "climate-change-susceptible" complement the threatened and "climate-change-susceptible" species' coverage of the regions of overall species richness. The largest and most dominant high concentration areas are southern Brazil and its neighbouring countries, and a large region from east to central and southern Africa. We also identified smaller high concentration areas in West Africa, New Guinea and eastern and northern Australia. High concentration areas of not threatened and susceptible species co-occur with those of threatened and susceptible species in Mesoamerica, northwestern South America and western Australia.

High concentration areas for threatened and "climate-change-susceptible" amphibians cover a relatively small geographic extent. This is due to the typically extremely small ranges of most threatened amphibians, particularly in Mesoamerica, the northern Andes and the Caribbean, where threatened species richness is greatest. That relatively small areas contain such high amphibian richness, particularly of priority species, further highlights their extreme importance for amphibian conservation. In contrast with threatened and "climate-change-susceptible" species, several that are not threatened but susceptible have much larger ranges. In combination with the larger number of these species, this results in much larger high concentration areas for this group.

In order to identify areas of disproportionately high threat or susceptibility, we compared the number of threatened and susceptible species relative to the total number of species in any one area (expressed as the percentage of species of interest relative to the total species number).



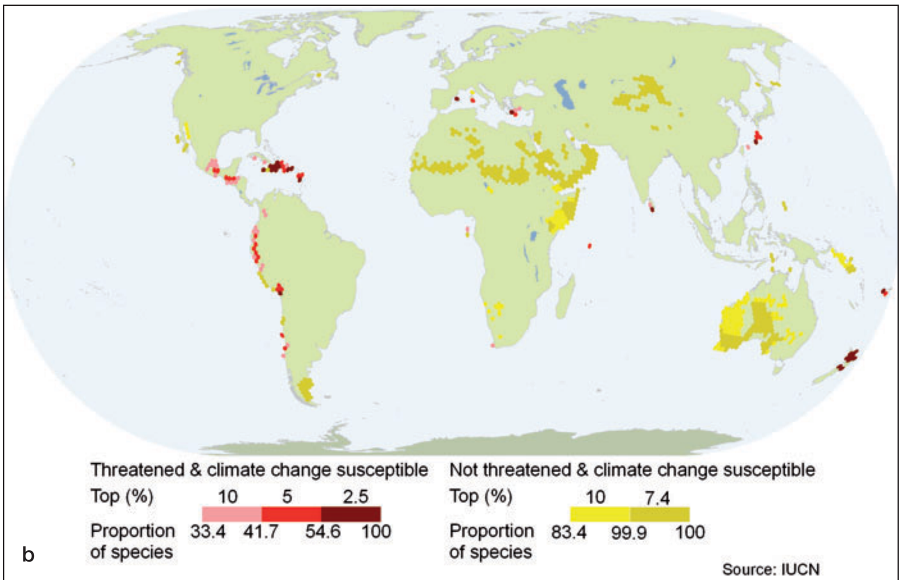


Figure 4. *Areas of high concentration of amphibian species assessed as* ***(a)*** *threatened and "climate-change-susceptible" (reds), and not threatened but "climate-change-susceptible" (yellows).* ***(b)*** *Shows areas containing high proportions of threatened and "climate-change-susceptible" (reds), and not threatened and "climate-change-susceptible" amphibian species (yellows) (expressed as the percentage of species in these categories relative to the total number of species occurring there). High concentration areas indicate those with the top 10%, 5% and 2.5% of values, and when these were not distinguishable, the nearest appropriate percentages were used.*

This information complements high concentration areas of overall species richness and is particularly important for conservation planning at regional and global scales.

For amphibians, mapping the relative richness of threatened and "climate-change-susceptible" species (Figure 4b) once again highlights Mesoamerica, the northern Andes and the Caribbean, but for this group, the area of high concentration continues intermittently through southwestern North America and the Andes as far south as central Chile. Additional areas of high concentration include several Mediterranean islands and south-western Turkey; Seychelles; the southern Japanese islands; New Zealand's North Island; and Fiji. Areas of high concentration of relative numbers of species assessed as not threatened but "climate-change-susceptible" include western and central Australia; the Solomon Islands; south eastern South America; north-western Mexico; the arid region extending from the Western Sahara through the Red Sea basin, south to the Horn of Africa and along the coastal regions of the Arabian Peninsula; and the foothills surrounding the northern Himalayan Plateau.

Corals

Based on high concentration area analysis, a single high concentration area is identified for warm-water reef-building corals based on all assessment categories and their combinations, namely the 'Coral Triangle' bordered by the Philippines, Malaysia and Indonesia (Figure 5a). This is the high concentration area of threatened and "climate-change-susceptible", not threatened but "climate-change-susceptible", as well as for overall coral species richness and threatened coral species richness (Carpenter *et al.* 2008). The 'Coral Triangle' is already being negatively impacted by climate change (Carpenter *et al.* 2008) and our results reinforce the extreme importance of effective conservation in this region.

Mapping areas with high proportions of threatened and "climate-change-susceptible" coral species (Figure 5b) also highlights the 'Coral Triangle', though additional high concentration areas include the northern parts of the Great Barrier Reef; the south-western coast of Australia; the Yellow Sea, East China Sea and Sea of Japan; and various areas along the coastlines of Pakistan, India and Bangladesh. Although not particularly species rich on a global scale and therefore not appearing as high concentration areas in Figure 5a, these regions clearly face an extremely high level of threat.

Areas with high concentrations of non-threatened but "climate-change-susceptible" corals show a markedly different pattern to those of other coral groups (Figure 5b). The species-rich 'Coral Triangle' is not highlighted, but in several areas of generally low species richness, more than 90% of all species are not threatened but "climate-change-susceptible". High concentration areas of these species include the Mediterranean and extending to north-west Africa; the east coast of the United States; the

Paper mill in Mpumalanga, South Africa. © Wendy Foden

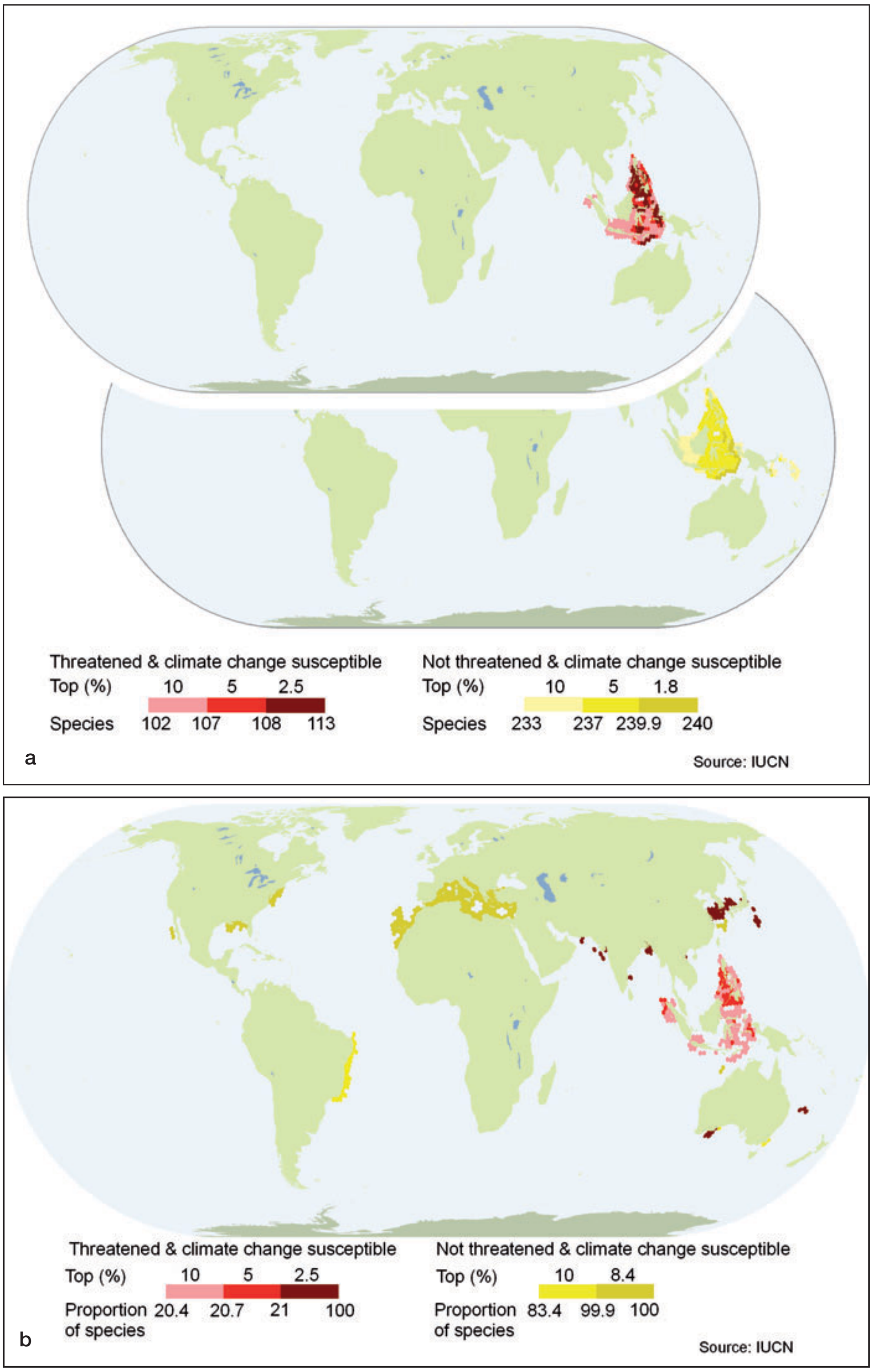


Figure 5. *Areas of high concentration of warm-water reef-building coral species assessed as* ***(a)*** *threatened and "climate-change-susceptible" (reds), and not threatened but "climate-change-susceptible" (yellows).* ***(b)*** *Shows areas containing high proportions of threatened and "climate-change-susceptible", and not threatened and "climate-change-susceptible" coral species (yellows) (expressed as the percentage of species in these categories relative to the total number of species occurring there). High concentration areas indicate those with the top 10%, 5% and 2.5% of values, and when these were not distinguishable, the nearest appropriate percentages were used.*

southern United States coast; north-western Mexico; the east and south-east of Brazil; the East China Sea; and smaller areas around Australia. These areas are likely to be subject to rapid coral declines if they are exposed to large climatic changes.

In the long term we shall compare the distribution of "climate-change-susceptible" species with areas of large climatic change, based on General Circulation Model projections, which will allow us to identify species, taxonomic groups and areas where species potentially face the highest risk of extinction due to climate change. However, first we propose to examine the traits and their distribution across species in order to evaluate the extent to which they can be shown to be predictive of climate change impacts, as well as to examine the inter-relationships and possible redundancies in the trait set. This process will contribute to the validation and testing of our methods in order to provide reassurance that the traits used are reliable predictors within and across species groups.

Key messages

- Some species are much more susceptible to climate change impacts than others due to inherent biological traits related to their life history, ecology, behaviour, physiology and genetics.
- High risks of extinction occur when species experience both high susceptibility to climate change and large climatic changes.
- IUCN has conducted assessments of susceptibility to climate change for the world's birds, amphibians and warm-water reef-building coral species. Based on a range of taxon-specific traits, we found that 35%, 52% and 71% of these groups respectively have traits that render them particularly susceptible to climate change impacts.
- 70-80% of birds, amphibians and corals that are already threatened are also "climate-change-susceptible". Given exposure to large climatic changes, these species which also have least resilience to further threat, face the greatest risk of extinction. Of species that are not considered threatened, 28-71% are "climate-change-susceptible". We identify the taxonomic groups and geographic regions harbouring the greatest concentrations of the above species and recommend that they are given high conservation priority.
- Assessments of "climate-change-susceptibility" complement IUCN Red List assessments of extinction risk and serve as a 'warning flag' highlighting the need for intensive monitoring and

These corals of the Solomon Islands are healthy and none is currently threatened, yet 4 of the 5 species photographed have traits that are likely to make them susceptible to climate change impacts. These susceptible corals include Acropora digitifera *(Near Threatened),* A. gemmifera *(Least Concern),* A. robusta *(Least Concern) and* Pocillopora eydouxi *(Near Threatened), which are more vulnerable to bleaching because their symbionts algae have low temperature tolerance, while those of the pink coral shown (Pocillopora verrucosa – Least Concern) may be more robust. © Emre Turak*

potentially conservation action for affected species.

References

Bosch, J. and Rincon, P.A. 2008. Chytridiomycosis-mediated expansion of *Bufo bufo* in a montane area of Central Spain: an indirect effect of the disease. *Diversity and Distributions* 14(4): 637-643.

Carpenter, K.E., Abrar, M., Aeby, G., Aronson, R.B., Banks, S., Bruckner, A., Chiriboga, A., Cortes, J., Delbeek, J.C., DeVantier, L., Edgar, G.J., Edwards, A.J., Fenner, D., Guzman, H.M., Hoeksema, B.W., Hodgson, G., Johan, O, Licuanan, W.Y., Livingstone, S.R., Lovell, E.R., Moore, J.A., Obura, D.O., Ochavillo, D., Polidoro, B.A, Precht, W.F., Quibilan, M.C., Reboton, C., Richards, Z.T., Rogers, A.D., Sanciangco, J., Sheppard, A., Sheppard, C., Smith, J., Stuart, S.N., Turak, E., Veron, J.E.N., Wallace, C., Weil, E. and Wood, E. 2008. One-Third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science* 321(5888): 560-563.

Corey, S.J. and Waite, T.A. 2008. Phylogenetic autocorrelation of extinction threat in globally imperilled amphibians. *Diversity and Distributions* 14: 614-629.

IPCC 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

IUCN 2008. *2008 Red List of Threatened Species.* Available at: http://www.iucnredlist.org.

Kleypas, J.A., Buddemeier, R.W., Archer, D., Gattuso, J.P., Langdon, C. and Opdyke, B.N. 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. *Science* 284(5411): 118-120.

Lips, K.R., Reeve, J.D. and Witters L.R. 2003. Ecological traits predicting amphibian population declines in Central America. *Conservation Biology* 17(4): 1078-1088.

Navas, C.A. and Otani, L. 2007. Physiology, environmental change, and anuran conservation. *Phyllomedusa* 6(2): 83-103.

Pounds, J.A., Bustamante, M.R., Coloma, L.A., Consuegra, J.A., Fogden, M.P.L., Foster, P.N., La Marca, E., Masters, K.L., Merino-Viteri, A., Puschendorf, R., Ron, S.R., Sanchez-Azofeifa, G.A., Still, C.J. and Young B.E. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* 439(7073): 161-167.

Royal Society 2005. Ocean acidification due to increasing atmospheric carbon dioxide. Report nr 12/05.

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. and Waller, R.W. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306(5702): 1783-1786.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson A., Phillips, O.L. and Williams, S.E. 2004. Extinction risk from climate change. *Nature* 427(6970): 145-148.

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