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# CLIMATE CHANGE EFFECTS ON WILDLIFE RANGE: AN EMPIRICAL STUDY

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**Abstract**
*The rapidity of anthropogenic climate change is having profound impacts on the distribution, life-cycle, and density of wildlife across all biomes. This research has been presents an empirical study of the observed and projected impacts of climate change on wildlife distribution, synthesizing quantitative evidence from global species-range datasets, long-term ecological monitoring programmes, and Species Distribution Modelling (SDM) outputs. The study synthesises evidence from peer-reviewed journals in ecology, conservation biology and biogeography, as well as data from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report to quantify consistent poleward and elevational range contractions across groups, disruptions to trophic synchrony, and the creation of new community compositions in ecosystems undergoing rapid climate change. This article also evaluates the differential vulnerability of taxonomic groups, analyzes the ecological tools driving distributional change, and critically assesses conservation strategies designed to maintain habitat connectivity and population viability under future warming scenarios. So the central empirical finding is that the pace of observed range shifts is outstripping the capacity of conservation infrastructure designed for a climatically stable world to protect peoples that are increasingly displaced from the environments for which existing reserve networks were designed.*

## 1. Introduction

Species distributions are not constants of nature; they are dynamic balances between the physiological tolerances and ecological needs of organisms, on one hand, and the spatial distribution of appropriate habitat and climate, on the other. If the rate of climate change outstrips the ability of organisms to adjust via dispersal or evolution, then distributional disequilibrium is generated, where populations are left behind in environments that no longer match their tolerances, or where new environments are colonised where new competitors, predators or pathogens may create new threats. The growing body of evidence from a range of species, geographic areas and ecosystem types now leaves no reasonable doubt that anthropogenic climate change is causing distributional disequilibrium on a global scale.

The IPCC sixth assessment report of 2022 concluded with very high confidence that climate change has already caused widespread and significant shifts in the distribution of terrestrial and marine species and that the projected warming under all but the most aggressive mitigation pathways will result in distributional changes that are larger and faster than the natural dispersal and adaptive capacities for many species.

No longer is the empirical question, whether climate change is driving changes in wildlife distributions this is now beyond reasonable doubt - but how fast, how far, by what mechanisms, and with what ecological consequences, and what conservation measures are able to sustain viable wildlife populations as changes accelerate.

In a landmark meta-analysis, Chen and colleagues analysed 764 species from a broad range of taxonomic groups, and found that average poleward range contractions and upward elevational shifts were 16.9 kilometers and 11.0 meters per decade respectively - two to three times faster than previous meta-analyses, and in line with the observed acceleration in regional warming. Root and colleagues previously showed, in a study of 143 species, that 80 percent of species exhibited changes in distribution, behaviour or physiology in the direction expected from regional temperature trends, proving that the biological responses are systematic.

This paper is structured to present the empirical and analytical aspects in turn. Section 2 outlines the methods of analysis of distributional change. Section 3 presents empirical evidence of distributional changes, shifts in abundance, and shifts in phenology. Section 4 explores the underlying mechanisms of response. Section 5 explores ecosystem- and community-level impacts. Section 6 examines future shifts with warming. Section 7 evaluates conservation strategies. Section 8 provides conclusions and recommendations.

## *2. 2. Approaches to Studying Distributional Change*

### *2.1 Long-Term Ecological Monitoring*

The evidence base for climate-driven distributional change is largely founded on long-term ecological monitoring studies of species occurrences, abundances and life events. The Breeding Bird Survey (North America), the Common Bird Census (UK), the Butterfly Monitoring Scheme (Europe) and the Global Biodiversity Information Facility (GBIF) are the databases of observations that allow the detection of systematic, directional trends (against the backdrop of natural year-to-year variation). Parmesan's initial study on the Edith's Checkerspot butterfly (Euphydryas editha) across North America showed a contraction of the range in a northward and upward direction consistent with regional warming trends - one of the first empirical examples of single-species climate-driven range contraction.

The main issue with using observational monitoring data for attributing distributional change to climate is that multiple factors can influence species distributions: land-use change, habitat destruction, invasive species, pollution, and human exploitation are all independent of climate, and in reality, these factors interact and are confounded. Sound attribution studies have overcome this problem through the use of spatial controls, lengthy time-frames and multiple-species analyses that exploit the shared climatic response of multiple species while ameliorating the idiosyncratic effects of non-climatic drivers

### *2.2 Species Distribution Modelling*

Bioclimatic envelope models, also known as species distribution models (SDMs), are the most widely used computational approach to projecting future climate change impacts on species distributions. SDMs link species occurrence data with climate data (usually from interpolated gridded climate data sets such as WorldClim) to model the current climatic envelope of a species, and project that envelope into spatial predictions of General Circulation Models (GCMs) driven by greenhouse gas emissions scenarios to determine where suitable climactic habitat might be found in the future.

SDM techniques have evolved from their early incarnations in tools such as BIOCLIM to a range of more sophisticated methods. Araújo and New called for ensemble SDM approaches, involving multiple algorithms (MaxEnt, GLM, BRT, Random Forest, etc.) and their results, to be used to describe and communicate the uncertainty of model predictions, which can be high and varies among species and regions. The choice of predictor variables, resolution of predictor data, treatment of dispersal barriers, and the assumption of climatic-niche stability all represent uncertainties, the relative importance of which is not always clear to the non-specialist user of SDM models.

In their review of SDM methodology, Guisan and Zimmermann provided a detailed examination of the main sources of uncertainty in SDM projections, which are: (1) sampling bias in species occurrence data; (2) resolution and selection of predictor variables; (3) choice and parameterisation of algorithms; (4) assumptions of dispersal constraints; and (5) the modelling of biotic interactions, which are rarely accounted for in models of species' fundamental (as opposed to realised) niches. Despite the limitations, ensemble SDM projections are the most effective means for predicting future distributional shifts at the resolution needed for conservation.

## *3. Empirical Evidence of Distributional Responses*

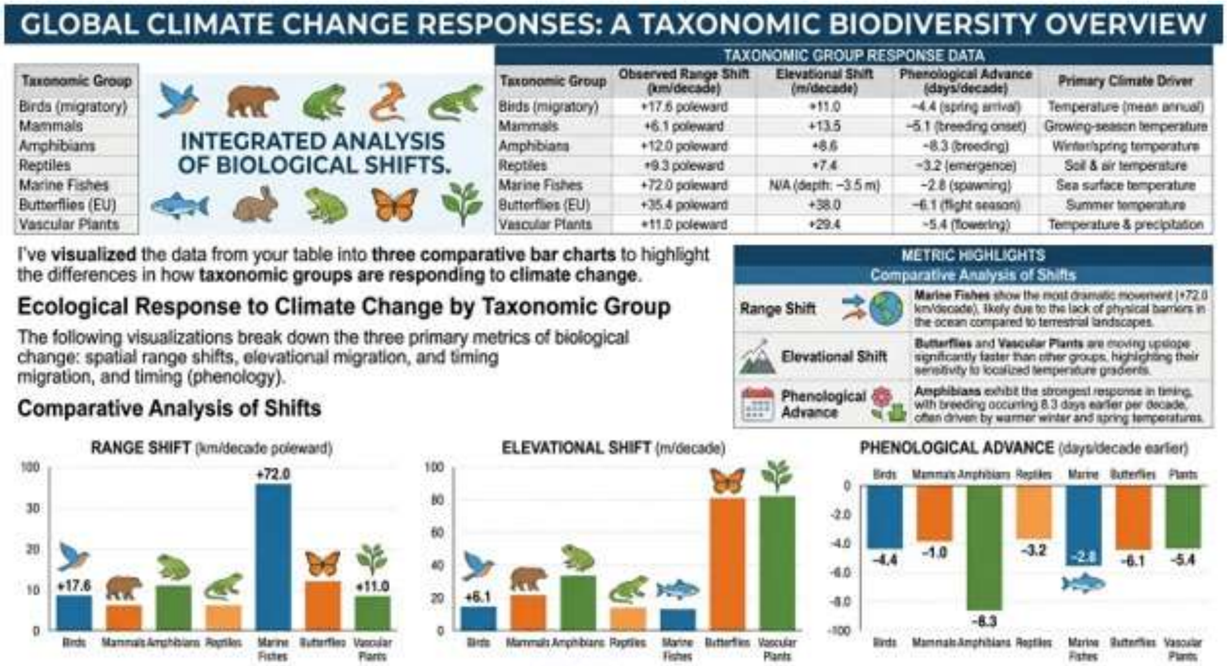
### *3.1 Poleward and Up-Slope Range Shifts*

Perhaps the best-studied type of climate-induced distributional shift is the consistent poleward and upward movement of species' distributions in response to the shifting geographic distribution of suitable climate conditions as global average temperature increases. Stenseth and co-authors showed that climate variability, such as the North Atlantic Oscillation (NAO), has a demonstrable effect on the distribution and abundance of species ranging from plankton to mammals, and established the link between climate variability and species distribution at different spatial scales.

Root and colleagues conducted a meta-analysis of 143 species, and detected that 81 percent of these displayed distributional or phenotypic changes consistent with regional warming, with the likelihood of detecting a climate-consistent shift positively related to the rate of local warming. The meta-analysis of Chen et al, which expanded the empirical data set to include 764 species with sufficient temporal data, found mean poleward shifts of 16.9 km/decade and mean elevational shifts of 11.0 m/decade across all species, with marine species shifting four times faster (72 km/decade) than land species, consistent with the greater coherence and magnitude of warming trends in ocean surface temperatures than on land

Vertical changes have been extensively studied in mountains, where high spatial gradients in climate regimes create especially strong vulnerabilities for montane specialists. In a meta-analysis, Walther and colleagues showed that plant communities in the European Alps moved their range limits upward by 1 to 4 metres per decade during the 20th century, with rapidly growing forerunner and warm-adapted species shifting faster than slowly growing alpine specialists. There is evidence of such shifts in the Rocky Mountains, the Andes, the Himalaya, and the equatorial African mountains, suggesting that the trend is not idiosyncratic.

*Table #01: Summary of observed climate-driven range and phrenological changes across major Taxonomic Groups*



GLOBAL CLIMATE CHANGE RESPONSES: A TAXONOMIC BIODIVERSITY OVERVIEW

| Taxonomic Group |
|---|
| Birds (migratory) |
| Mammals |
| Amphibians |
| Reptiles |
| Marine Fishes |
| Butterflies (EU) |
| Vascular Plants |

INTEGRATED ANALYSIS OF BIOLOGICAL SHIFTS.

TAXONOMIC GROUP RESPONSE DATA

| Taxonomic Group | Observed Range Shift (km/decade) | Elevational Shift (m/decade) | Phenological Advance (days/decade) | Primary Climate Driver |
|---|---|---|---|---|
| Birds (migratory) | +17.6 poleward | +11.0 | −4.4 (spring arrival) | Temperature (mean annual) |
| Mammals | +6.1 poleward | +13.5 | −5.1 (breeding onset) | Growing-season temperature |
| Amphibians | +12.0 poleward | +8.6 | −8.3 (breeding) | Winter/spring temperature |
| Reptiles | +9.3 poleward | +7.4 | −3.2 (emergence) | Soil & air temperature |
| Marine Fishes | +72.0 poleward | N/A (depth: −3.5 m) | −2.8 (spawning) | Sea surface temperature |
| Butterflies (EU) | +35.4 poleward | +38.0 | −6.1 (flight season) | Summer temperature |
| Vascular Plants | +11.0 poleward | +29.4 | −5.4 (flowering) | Temperature & precipitation |

I've **visualized** the data from your table into **three comparative bar charts** to highlight the differences in how **taxonomic groups** are responding to climate change.

**Ecological Response to Climate Change by Taxonomic Group**

The following visualizations break down the three primary metrics of biological change: spatial range shifts, elevational migration, and timing migration, and timing (phenology).

**Comparative Analysis of Shifts**

METRIC HIGHLIGHTS
Comparative Analysis of Shifts

| | |
|---|---|
| Range Shift | **Marine Fishes** show the most dramatic movement (+72.0 km/decade), likely due to the lack of physical barriers in the ocean compared to terrestrial landscapes. |
| Elevational Shift | **Butterflies** and **Vascular Plants** are moving upslope significantly faster than other groups, highlighting their sensitivity to localized temperature gradients. |
| Phenological Advance | **Amphibians** exhibit the strongest response in timing, with breeding occuring 8.3 days earlier per decade, often driven by warmer winter and spring temperatures. |

*Source: data is taken from all combine compiled from Chen et al. (2011), Parmesan and Yohe (2003), Root et al. (2003), Walther et al. (2002), and IPCC (2022). Values represent meta-analytic means; individual species responses vary substantially.*

### *3.2 Phonological disruption and trophic discrepancy*

Phonological events (the timing of biological processes, such as flowering, breeding, migration, and hibernation) are strongly influenced by temperature and photoperiod. Increasing temperatures have caused many species to advance the timing of their spring biological events, altering the synchrony of ecological interactions that rely on the coincidental timing of complementary events: emergence of insect prey and hatching of chicks in migratory birds, flowering and the flight times of pollinators, availability of prey and breeding success of predators.

Parmesan's meta-analysis showed advances in spring events of 5.1 days per decade for 879 species, with a positive correlation between the rate of advance and local warming. Trophic mismatch occurs where the phenology of two (or more) species in an ecological interaction advance at different rates in response to the same climatic cue. The misalignment of the peak supply of caterpillars (tracking the start of oak bud burst, which is highly sensitive to temperature) and the hatching of great tit (Parus major) chicks (which are more sensitive to photoperiod, an independent cue) in temperate European forests is one of the best documented examples, with populations unable to sufficiently advance their breeding date suffering a decline in reproductive success as the peak caterpillar supply moves beyond the period of maximum chick food demand.

Inouye and colleagues documented that climate warming in the Colorado Rocky Mountains has advanced the snowmelt date—the trigger for emergence from hibernation in ground squirrels and for the arrival of altitudinal migrants—but has simultaneously increased the risk of late-season frost events that can destroy early-season foraging resources. This combination of phenological advance and increased climatic variability creates a double exposure that elevates extinction risk beyond what either factor in isolation would imply.

### *3.3 Freshwater and Marine Shifts*

Marine species have responded to warming sea outsides with distributional expansions that are greater than those seen in terrestrial ecosystems. The rapid northward shift of warm-water fish in the North Sea, North Pacific and Southern Ocean is a consequence of the creation of new thermal habitat at higher latitudes that was previously inaccessible. The impact of this shift for marine food webs is complex and not always predictable from single-species studies: the invasion of warm-water predators can suppress local prey populations, alter the relative abundance of local prey species, and propagate through the food web to affect species that have not been directly affected by the invasion in ways that are compounded by existing human impacts of commercial fishing and eutrophication.

The situation is especially dire for coral reefs. Hoegh-Guldberg's pioneering analysis of the link between sea surface temperature anomalies and mass bleaching events found that temperatures above the climatological maximum by 1°C for an extended period induce disruption of the coral-zooxanthellae symbiosis, mass bleaching, and increased coral mortality. At current warming trajectories, virtually all tropical coral reefs will experience annual severe bleaching before 2050, representing not merely a distributional shift but a functional elimination of the ecosystem type from much of its current geographic range.

## 4. *Ecological mechanisms of climate-driven distributional change*

### *4.1 The Physiology of Temperature and the Climate Envelope*

The main mechanistic pathway by which climate change affects wildlife distributions involves thermal physiology: survival, growth, reproduction and behavior of both ectothermic and endothermic organisms are constrained by thermal tolerances that establish a fundamental niche envelope along a temperature gradient. In the case of ectotherms - all reptiles, amphibians, insects and fish - body temperature is directly influenced by environmental temperature, and distributional limits are highly dependent on temperature. For the endotherms, the energy demands of thermoregulation rise at thermal extremes, thereby imposing indirect thermal constraints on foraging and reproductive concert.

Pearson and Dawson reviewed the evidence that bioclimatic envelope models, which correlate observed distributions with contemporary climate, capture the realized climatic tolerance of species, and can predict distributional impacts of climate change with reasonable precision where dispersal is not a strong constraint. But they also highlighted the most important unknown in SDM projections as the assumption of biotic niche conservatism: that the climatic niche of a species will not change over the time frame of the projection. If species can quickly adapt to new climatic conditions through plastic or evolutionary responses, SDMs will overestimate future declines; if species lack the physiological flexibility to adapt to new conditions, SDMs may underestimate declines.

### *4.2 Habitat Connectivity and Dispersal Control*

Species' ability to keep pace with changing climatic envelopes relies on their ability to disperse across the landscape matrix between existing habitat and newly suitable habitat. In highly fragmented agricultural and urban landscapes, the spatial continuity of habitat needed for dispersal is compromised: populations are fragmented into habitat islands embedded in an unsuitable matrix (the surrounding landscape), and the climate velocity (speed of movement of climatically suitable conditions) may outpace the dispersal ability of slow-dispersing or habitat-specialist spec.

Possingham and Wilson stressed that the transformation of species-range monitoring into maintenance aptitude entails not only detecting distributional change, but also detecting connectivity deficits that block range adjustment. In extreme cases of dispersal limitation, species may accumulate "climate debt" populations - in suitable habitat today but which will become unsuitable before natural dispersal processes can relocate the population to new suitable habitat. Climate debt is accrued most in species with low dispersal ability (soil-dwelling invertebrates, many reptiles, slow-growing trees), in highly fragmented landscapes (much of the European and South Asian farmlands) and at the trailing edges of species ranges where the rate of habitat loss exceeds local population adaptation.

### 4.3 Biotic exchanges and community disassembly

The impact of climate change on species is not isolated; it acts to modify the consequences of biotic interactions (competition, predation, mutualism, parasitism), by changing the timing, abundance, and geographic ranges of interacting species. Gilman and colleagues developed a model for the restructuring of community interactions under climate change, and the key parameters, interaction strength, phenological sensitivity, and overlap in spatial distributions of interacting species, that dictate whether climate change will enhance, weaken or dissolve biotic interactions.

Stenseth and colleagues found that climate variability, via the El Niño-Southern Oscillation (ENSO), creates coherent shifts in food web structure from marine phytoplankton to large mammalian predators across the Pacific Ocean, demonstrating the widespread effects of climate variability on food webs. When the responses of interacting species differ in their magnitude or mode of action, the resulting mismatches can dissolve mutualistic partnerships (such as pollination), increase competition between species with previously non-overlapping phenologies and affect predator-prey interactions in ways that can ripple through food webs.

### *4.4 Pathological Effects: Parasites and Disease*

Among the most alarming mechanisms connecting climate change to wildlife distribution is the expansion of infectious disease and parasite prevalence driven by warming temperatures that expand the geographic ranges of pathogen vectors and increase the year-round transmission potential of diseases previously confined by cold-season thermal barriers. Pounds and colleagues presented compelling evidence that the catastrophic wave of extinction among montane harlequin frog (*Atelopus*) species in Central and South America—with at least 70 species disappearing since the 1980s—was driven by the expansion of the chytrid fungus *Batrachochytrium dendrobatidis* into montane refugia under warming conditions that had previously been thermally inhospitable to the pathogen.

Such epidemiological effects have also been observed in tick-borne diseases of temperate mammals, high-elevation malaria in birds, and a variety of parasitic diseases in marine mammals. The mismatch between climate-induced range contractions and expansions of vectors and pathogens, and distributional responses of wildlife hosts, results in new encounters of hosts and pathogens in wildlife communities with no evolutionary experience with the pathogen in question, a situation that is expected to result in high pathogen-induced mortality and potential population collapse.

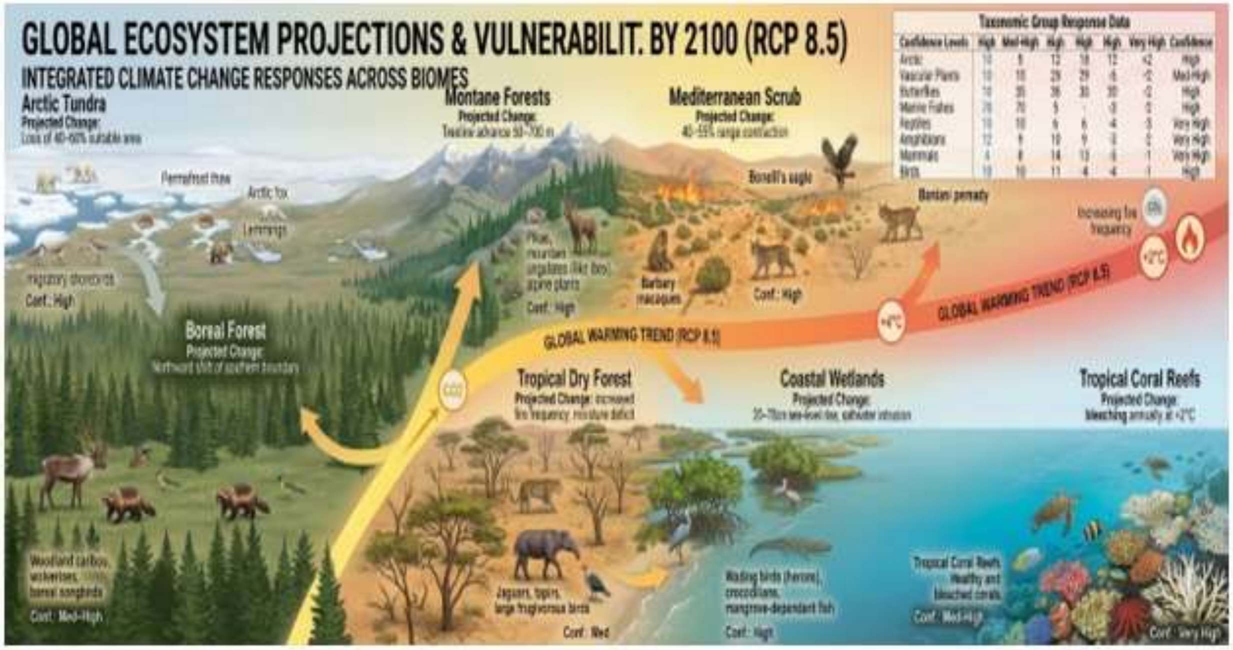
## 5. Ramifications for Ecosystems and Communities

The collective distributional responses of individual species to climate change underpin community-level and ecosystem-scale responses that cannot simply be scaled up from individual species' responses. As individual species within a community respond to climate change at different rates and via different dispersal pathways, the composition of ecological communities shifts: some species interactions that previously governed community structure and dynamics disappear, new interactions emerge among species that were previously geographically isolated, and the functional diversity of ecological communities is altered, potentially with consequences for key ecosystem services.

Thuiller and colleagues predicted that climate change could lead to the extinction or contraction of 58 percent of European vascular plant species under the highest emission scenarios by 2080, with the removal of functionally significant species (nitrogen fixers, large-seeded trees, specialist pollinators) potentially having ramifications for community structure and ecosystem function that are greater than simply the sum of the species' contributions. The notion of novel ecosystems - communities with no modern or historical precedents, comprising species with mismatched dispersal histories under new climatic regimes - is emerging as a likely outcome of many regional climate futures, with serious implications for conservation management and ecosystem restoration.

The IPCC AR6 reported with high confidence that climate change is changing the timing, intensity and distribution of primary productivity in terrestrial and marine ecosystems, with flow-on effects on the consumer assemblages that exploit this productivity. The northward shift of the boreal treeline, the greening of the Arctic tundra, the brownification of Mediterranean scrublands with intensifying drought, and the spread of hypoxic dead zones in coastal seas represent ecosystem-scale changes in response to climate change that alter wildlife habitat structure and the distributional possibilities available to wildlife populations..

**Table #02: Climate-based Habitat Change Projections by Major Ecosystem Type (RCP 8.5/2100)**



Source: data is taken from IPCC AR6 (2022), Thomas et al. (2004), Hoegh-Guldberg (1999), Thuiller et al. (2011), and Urban (2015). Projections assume high-emission scenario (RCP 8.5) with no significant emissions mitigation.

## *6. Future Wildlife Distributions under Warming*

The projected future distribution of wildlife under climate change is determined by the scenario of future emissions that will determine the rate of change, the ability of species to shift their ranges via dispersal or adapt via evolutionary change to remain in their climatic niches, and the efficacy of conservation measures that aim to preserve population viability during the transition. Thomas and colleagues' influential analysis of projected future distributions for 1,103 plant, animal and insect species concluded that between 15 and 37 percent of species are likely to be "committed" to extinction by 2050 under mid-range climate change scenarios, a result that highlighted climate change as a major threat to biodiversity.

Urban's meta-analysis of 131 SDM studies projected that the global extinction rate from climate change will accelerate to 5.2 percent of species under current commitments, 8.5 percent at 3°C, and 16 percent at 4.3°C of warming - with extinction risks much higher for species in South America, Australia and New Zealand, where biogeographic isolation has resulted in high endemism and low connectivity for tracking shifts. These estimates are probably conservative, as they do not address the potentially amplifying role of habitat fragmentation, biotic interactions and the acceleration of warming under high-emissions scenarios with positive carbon cycle feedbacks.

Vollesen and colleagues applied the climate velocity framework, which quantifies the pace of movement of the boundary between climate zones, to predict that 3°C to 4°C of warming would cause the temperate zone boundary to shift 500-700 kilometers poleward from the pre-industrial physiological zone, suggesting that species currently living in the temperate zone of the Northern Hemisphere will need to track climate change by dispersing at 5-7 kilometers per year, which radically exceeds the dispersal ability of most terrestrial vertebrates without landscape-scale habitat connectivity.

Scheiner and Willig's theoretical model for predicting species distributional responses to non-stationary climates highlights the importance of evolutionary potential - the ability of populations to adapt in situ to changing climatic conditions - as a factor affecting extinction risk that is commonly underweighted in predictions based on SDMs. If populations have sufficient genetic diversity, short generation times relative to the rate of climatic change, and intense, directional selection, evolutionary adaptation may alleviate the range contractions forecast by SDMs Where these conditions are not met, as in large, long-lived species with low genetic diversity and slow generation times, such as many of conservation's iconic species, evolutionary rescue is unlikely to keep pace with projections of global warming.

## 7. Responses to Climate-Driven Distributional Change

### *7.1 expanding and connecting protected areas*

The primary conservation response to climate-driven distributional change is the expansion and re-design of protected area networks to include climate refugia (areas of relative climatic stability or lower rates of warming) and to create connectivity between areas of current occupancy and areas likely to be suitable in the future, allowing wildlife to keep pace with shifting climate envelopes. The "30×30" target for the fortification of at least 30 percent of global land and ocean area by 2030, approved under the CBD at the Kunming-Montreal Global Biodiversity in December 2022, explicitly incorporates climate connectivity as a design criterion for expanding protected area networks.

Dudley's guidelines for protected area management recognise the value of particular protected areas for wildlife conservation under climate change is critically dependent on their connectivity to surrounding areas, and to the matrix of adjacent landscapes, rather than on their area or biodiversity richness. The development of climate-smart conservation planning frameworks that consider projected shifts in species' distributions, dispersal corridors and climate refugia in prioritising conservation investment to land areas, constitute a major step forward in the design of protected areas, whose design was previously based on distributional stability. But the technical requirements of these frameworks are beyond the capacity of many developing country conservation agencies.

### *7.2 Assisted Migration and Translocation*

For species whose natural dispersal ability is limited and therefore unable to keep pace with climate velocity across a fragmented landscape, active human translocation (moving individuals or propagules in anticipation of the leading edge of the climatically unsuitable habitat) is a proposed conservation strategy. The scientific principles for assisted migration were outlined by Hoegh-Guldberg and colleagues so if dispersal limitation is a constraint on distributional tracking, and if the new habitat is appropriately climate-matched and ecologically suitable, then translocation can avoid extinction without necessitating the eradication of the original cause of extinction.

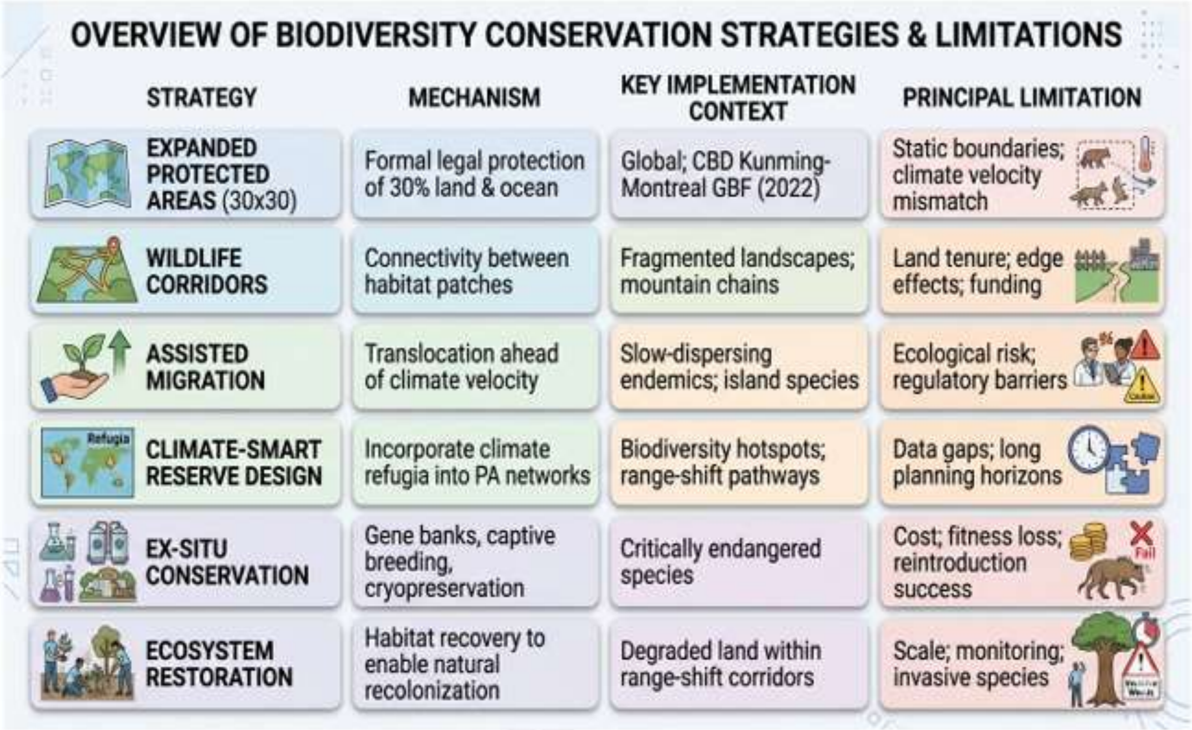
The operational and moral challenges of assisted migration are, nevertheless, discussed. Dispersals across natural range boundaries can introduce competitive and (for predators) predatory interactions with naive communities, and not all effects of novel introductions can be predicted from knowledge of species' natural range ecology. The governance processes to manage these risks - which involve cooperation between political jurisdictions, regulatory bodies and conservation groups - are not as well-developed as the conservation crisis that motivated the development of assisted migration.

### *7.3 Restoration and Management of Novel Ecosystems*

Where current environment is so degraded that it cannot provision wildlife connectivity under present or future climatic conditions, restoration of functional ecological access strip is a priority. Hobbs, Higgs and Harris suggested that the emergence of "novel ecosystems" that are ecologically unprecedented and assembled under the multiple impacts of climate change, land use, and invasive species require a pragmatic shift in focus for conservation practice, because the restoration of pre-disturbance species compositions may not be technically or economically feasible across much of the landscape as the climate changes beyond historic bounds.

Parmesan's synthesis highlighted that conservation science needs to develop normative frameworks for managing novel ecosystems which place value on ecological function (provision of ecosystem processes such as water cycling, nutrient cycling and biomass production) rather than compositional fidelity to pre-disturbance states, because the latter may be impossible without the former.

**Table #03: conservation strategies for climate-Driven wildlife distributional change: mechanisms, contexts, and limitations**



OVERVIEW OF BIODIVERSITY CONSERVATION STRATEGIES & LIMITATIONS

| STRATEGY | MECHANISM | KEY IMPLEMENTATION CONTEXT | PRINCIPAL LIMITATION |
|---|---|---|---|
| EXPANDED PROTECTED AREAS (30x30) | Formal legal protection of 30% land & ocean | Global; CBD Kunming-Montreal GBF (2022) | Static boundaries; climate velocity mismatch |
| WILDLIFE CORRIDORS | Connectivity between habitat patches | Fragmented landscapes; mountain chains | Land tenure; edge effects; funding |
| ASSISTED MIGRATION | Translocation ahead of climate velocity | Slow-dispersing endemics; island species | Ecological risk; regulatory barriers |
| CLIMATE-SMART RESERVE DESIGN | Incorporate climate refugia into PA networks | Biodiversity hotspots; range-shift pathways | Data gaps; long planning horizons |
| EX-SITU CONSERVATION | Gene banks, captive breeding, cryopreservation | Critically endangered species | Cost; fitness loss; reintroduction success |
| ECOSYSTEM RESTORATION | Habitat recovery to enable natural recolonization | Degraded land within range-shift corridors | Scale; monitoring; invasive species |

*Source: data is taken from Hoegh-Guldberg et al/ CBD (2022), IUCN Hobbs et al. and primary conservation literature.*

## 8. *Conclusions*

The evidence reviewed in the sections above leads to a number of analytically robust conclusions concerning the impact of climate change on wildlife distributions, the processes underlying observed and projected distributional shifts, and the conservation implications of the ongoing distributional transformations.

First, the directionality of observed distributional shifts (poleward and upward range contractions and expansions, phenological shifts, and abundance changes consistent with the direction of regional trends in temperature) across a wide range of butterflies, birds, mammals, marine fishes, and vascular plants is strong evidence for a systematic biological response to climate forcing that is unlikely to have been confounded by sampling bias, land-use changes, and other non-climatic factors operating at continental scales. The consistency documented by Parmesan and Yohe for 1,700 species in 279 studies, remains the most compelling single line of evidence for this conclusion.

Second, the rate of distributional change is more rapid than previously projected and is increasing. The doubling of shift estimates between previous meta-analyses (6-7 km/decade) and the Chen et al. analysis (16.9 km/decade for terrestrial species, 72 km/decade for marine species) is due to the acceleration in observed warming, to the existence of longer biological time series that allow stronger inferences on the trends, and to the improved representation of monitoring data across both species and geography.

Third, the impacts of distributional change do not end with types but ripple through ecological communities through the erosion of trophic interactions, the breakage of long-evolved mutualistic associations, and the development of unprecedented public assemblages. These community-level effects compound the extinction risk implied by species-level distributional projections, and introduce non-linearity (tipping points, cascades, multiple stable states) that the additive approach of species-level conservation assessment fails to capture.

Fourth, the legacy of 20th century conservation planning reserve networks developed for a climatically stable world, the boundaries of threatened areas established around current species distributions, restoration penalty area referenced to pre-disturbance compositional baselines - is awry with the distributional dynamics that are in performance out. Urban's prediction that 16 percent of species will be extinct at 4.3°C of warming, and that this risk is already locked in (5.2 percent) even if global warming is halted at present levels, suggests that conservation biology is already on the nose.

Fifth, the most effective conservation response to a distributional change driven by climate is the incorporation of dynamic distributional projections in spatial conservation planning: planning a network of protected areas with clear focus on climate corridors and refugia, managing the landscape matrix to allow dispersal, building governance systems around assisted migration, and accepting that the conservation of ecological functioning may necessitate the abandonment of compositional restoration objectives under the harshest conditions of climate All these answers do not negate the underlying necessity to lower the pace of greenhouse gas emissions of the more quickly warming occurs, the quicker conservation infrastructure becomes outdated, and the fewer options to adapt to any of these changes wildlife or conservation practitioners have.

The empirical record is now in depth enough to be used in planning at spatial scales ranging over individual protected areas to continental biogeographic regions. Availability of scientific evidence is no longer the major limiting factor on conservation effectiveness but rather the political will and institutional capability to act on the evidence as fast as it needs to be accomplished and at the rate needed by the accelerating rate of distributional change.

## References

Camille Parmesan and Gary Yohe, "A Globally Coherent Fingerprint of Climate Change Impacts across Natural Systems," Nature 421 (2003): 37.

IPCC, climate change 2022: Impactr adaptation and vulnerability. contribution of Working Group II to the Sixth Assessment Report (Cambridge: Cambridge University Press, 2022), 13.

I-Ching Chen, Jane K. Hill, Ralf Ohlemüller, David B. Roy, and Chris D. Thomas, "Rapid Range Shifts of Species associated with High Levels of Climate Warming," Science 333, no. 6045 (2011): 1024.

Terry L. Root, Jeff T. Price, Kimberly R. Hall, Stephen H. Schneider, Cynthia Rosenzweig, and J. Alan Pounds, "Fingerprints of global warming on wild Animals and Plants," Nature 421 (2003): 57.

Camille Parmesan, "Ecological and Evolutionary Responses to Recent Climate Change," Annual Review of Ecology, Evolution, and Systematics 37 (2006): 638.

Richard G. Pearson and Terence P. Dawson, "Predicting the Impacts of Climate Change on the Distribution of Species: Are Bioclimate Envelope Models Useful?" Global Ecology and Biogeography 12, no. 5 (2003): 361.

Miguel B. Araújo and Mark New, "Ensemble Forecasting of Species Distributions," Trends in Ecology and Evolution 22, no. 1 (2007): 42.

Antoine Guisan and Niklaus E. Zimmermann, "Predictive Habitat Distribution Models in Ecology," Ecological Modelling 135, nos. 2–3 (2000): 147.

Nils C. Stenseth, Atle Mysterud, Geir Ottersen, James W. Hurrell, Kung-Sik Chan, and Mauricio Lima, "Ecological Effects of Climate Fluctuations," Science 297, no. 5585 (2002): 1292.

Root et al., "Fingerprints of Global Warming," 57–60.

Gian-Reto Walther, Eric Post, Peter Convey, Annette Menzel, Camille Parmesan, Trevor J. C. Beebee, Jean-Marc Fromentin, Ove Hoegh-Guldberg, and Franz Bairlein, "Ecological Responses to Recent Climate Change," Nature 416 (2002): 389.

David W. Inouye, Barb Barr, Kenneth B. Armitage, and Brian D. Inouye, "Climate Change Is Affecting Altitudinal Migrants and Hibernating Species," Proceedings of the National Academy of Sciences 97, no. 4 (2000): 1630.

Parmesan, "Ecological and Evolutionary Responses," 641.

Ove Hoegh-Guldberg, "Coral Reefs, Climate Change, and Mass Bleaching," Science 283 (1999): 1844.

Hugh P. Possingham and Kerrie A. Wilson, "Turning Wildlife Monitoring into Conservation Action," Science 312 (2006): 1390.

Sarah E. Gilman, Mark C. Urban, Joshua Tewksbury, George W. Gilchrist, and Raymond B. Huey, "A Framework for Community Interactions under Climate Change," Trends in Ecology and Evolution 25, no. 6 (2010): 325.

Pounds et al., "Widespread Amphibian Extinctions," 161–165.

Wilfried Thuiller, Sébastien Lavergne, Cristina Roquet, Isabelle Boulangeat, Bruno Lafourcade, and Miguel B. Araújo, "Consequences of Climate Change on the Tree of Life in Europe," Nature 470 (2011): 531.

Richard J. Hobbs, Eric Higgs, and James A. Harris, "Novel Ecosystems: Implications for Conservation and Restoration," Trends in Ecology and Evolution 24, no. 11 (2009): 599.

IPCC, Climate Change 2022, 388.

Thomas et al., "Extinction Risk from Climate Change," 145–148.

Mark C. Urban, "Accelerating Extinction Risk from Climate Change," Science 348, no. 6234 (2015): 571.

Ane Vollesen, Jens-Christian Svenning, and Alejandro Ordonez, "Future Climate Change Is Expected to Drive a Significant Poleward Shift of the Temperate Zone," Nature Climate Change 12 (2022): 647.

Hoegh-Guldberg et al., "Assisted Colonization," 345–347.

Convention on Biological Diversity, Kunming-Montreal Global Biodiversity Framework (Montreal: CBD Secretariat, 2022), 8.

Nigel Dudley, ed., Guidelines for Applying Protected Area Management Categories (Gland: IUCN, 2008), 10.

Ove Hoegh-Guldberg, Lesley Hughes, Scott McIntyre, David B. Lindenmayer, Camille Parmesan, Hugh P. Possingham, and Chris D. Thomas, "Assisted Colonization and Rapid Climate Change," Science 321, no. 5887 (2008): 345.

Parmesan, "Ecological and Evolutionary Responses," 650.

Parmesan and Yohe, "Globally Coherent Fingerprint," 37-42.

Chen et al., "Rapid Range Shifts," 1024-1026.

Urban, "Accelerating Extinction Risk," 571-573.