Supplementary Material

**Appendix S1**. Trait definitions used for climate change vulnerability assessments for bats in Aotearoa New Zealand

(from Brumby et al. 2025 - Brumby A, Marshall J, Murray T, O'Donnell C, Richards R 2025. Trait-based climate change vulnerability assessments of terrestrial taxa in Aotearoa New Zealand. Science for Conservation 343, Department of Conservation, Wellington. 149 p.).

**Sensitivity – Habitat specialisation**

Generalist species that are less tightly coupled to specific habitats are likely to be more resilient to climate change because they will have a wider range of habitat options available to them. For example, a bat that uses forest, shrubland, grasslands and human-induced habitats is likely less sensitive than a forest specialist. The trait 'habitat specialisation' was based on the number of 'major' habitats listed in the IUCN Red List (IUCN 2012; n = up to 17). Major habitats are defined as (1) the habitat(s) in which the species occurs regularly or (2) any habitat that is important for the survival of the species because it has an absolute requirement for the habitat at some point in its life cycle (e.g., for breeding, overwintering or as a critical food source). Any other habitat where the species occurs irregularly or infrequently, as a vagrant, or where only a small proportion of individuals are found were considered minor habitats, not major habitats.

**Sensitivity – Dependence on a particular microhabitat or single location**

This trait addresses the risks to species that can have small or large populations but are confined to small or specific areas or microhabitat types, which put the species that are reliant on them at a higher risk of extinction. Microhabitat dependency was defined as where a species is (1) restricted to a specific limited or patchy habitat type within a more extensive major habitat (e.g. salt pan areas within wider grassland habitat), (2) is found in only a small proportion of a what may be a more extensive habitat, (3) is found at a single location even if the habitat is present in other locations or (4) is confined to the rarest and most-restricted threatened ecosystem types (<10,000 ha; Holdaway et al. 2012) (e.g., karst or ultramafic habitats). Sensitivity is increased if a species has several life stages, each with different microhabitat requirements (e.g., for breeding), or if it requires a microhabitat that is particularly vulnerable to climate change impacts. This trait could apply to (but is not restricted to) some species that have a 'One Location' qualifier in the NZ Threat Classification System (NZTCS); defined as one geographically or ecologically distinct area of less than 1000 $km^2$ (100,000 ha) (Townsend et al. 2008). Single locations are vulnerable to a single event (e.g., a predator irruption) that could easily affect all individuals of the taxon.

**Sensitivity – Narrow temperature tolerance**

Species with physiological tolerances that are tightly coupled to specific environmental conditions are likely to be particularly sensitive to climatic changes. Species with **'Narrow' tolerance** are those for which projected changes in temperature are likely to exceed physiological thresholds (e.g., species that exist within a narrow thermal range or have temperature-specific demographic traits). For example, sex in tuatara (*Sphenodon punctatus*) is determined by incubation temperature, with a male bias caused by higher temperatures (Mitchell et al. 2010). '**Medium**' tolerance species will primarily remain within physiological thresholds. They may feel some stress or become inactive during limiting conditions (e.g., species with a moderate thermal range, species that use torpor or dormancy to avoid hot/dry conditions; McNab & O'Donnell 2018). **'Broad'** tolerance species will thermoregulate when temperature thresholds are exceeded (e.g., species active in very cold climates, species with a very broad thermal range).

**Sensitivity – Narrow precipitation tolerance**

Species with **'Narrow' tolerance** are those for which projected changes in rainfall are likely to exceed physiological thresholds (e.g., species that have life history characteristics dependent on narrow precipitation gradients such as some plants; He et al. 2013). **'Medium'** tolerance species will primarily remain within physiological thresholds. Some stress may limit functions or breeding requirements. **'Broad' tolerance** species will tolerate a very broad range of precipitation.

**Sensitivity – Declining positive interactions with other species**

Species dependent on functional interspecific interactions that are likely to be disrupted by climate change are at risk. Climate change driven alterations in species' ranges, phenologies and relative abundances may affect their beneficial inter-specific and ecological interactions, for example, plant species dependent on pollinators or seed dispersers that will be affected by climate change (Foden et al. 2013). Species are likely to be particularly sensitive to climate change if, for example, they are highly dependent on one or few specific resource species and are unlikely to be able to substitute these for other species**.**

**Sensitivity – Small population size**

The inherent vulnerability of small populations to Allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will face greater impacts from climate change than more common and/or widespread species. In Aotearoa New Zealand, small populations are defined as ≤5,000 individuals or area of occupancy <100 ha (for many cryptic species population size is unknown so area of occupancy is used instead). This aligns with the NZTCS where taxa with these criteria all are ranked in the 'Threatened' umbrella category, reflecting their higher threat of extinction.

**Sensitivity – Small population size and heightened sensitivity to threatening processes**

Species with relatively small populations (<20,000 mature individuals) and sensitivity to certain threatening processes are also likely to have increased sensitivity to climate change (Foden et al. 2013). These processes include heightened sensitivity due to (a) small fragmented subpopulations that have disrupted metapopulation dynamics; (b) skewed sex ratios (male to female ratio of ≤0.4 or ≥0.6); (c) activity or breeding systems that require a high level of synchrony driven by environmental conditions (e.g., polygynous or polyandrous breeding systems); (d) cooperative, lekking or colonial breeding systems where individuals regularly or seasonally congregate at particular sites, and then disperse over a wide area (e.g., lekking in lesser short-tailed bats; Toth et al. 2015); (e) higher adult mortality due to behavioural or physiological traits making them more vulnerable to predation (e.g., use of torpor in Aotearoa New Zealand bats means they cannot retreat from introduced mammalian predators); (f) declining and extremely fluctuating populations (fluctuations >10-fold); and (f) species that congregate during migration or during the non-breeding season (e.g., staging points and wintering sites - at least 1% of the global population must be found at one or more sites to qualify).

**Exposure – Habitat types exposed to sea level inundation and increased storm surges**

*Sea level* around Aotearoa New Zealand is expected to continue to *rise* by an additional 0.2–0.3 m by 2040 and 0.4–0.9 m by 2090, depending on which greenhouse gas projection scenario is used. Thus, some habitat types exposed to sea level inundation will be lost through flooding depending on local topography. In addition, predicted increases in the frequency and magnitude of storm surges are likely to impact significantly on shoreline and low coastal-cliff breeders and their roosting and feeding habitats. Vulnerable habitats include mangroves, intertidal salt marshes, coastal freshwater, brackish or saline lakes and lagoons, marine lakes, coastal caves, intertidal shorelines, some sea cliffs, low-lying rocky offshore islands, and coastal sand dunes. Species were considered to have higher exposure if they occur exclusively in one or more vulnerable habitats that are of major importance for the species (e.g., they are dependent on the exposed habitat for critical parts of their life cycle).

**Exposure – Extent of species range exposed to changes in temperature**

The greater the amount of a species range that is exposed to substantially increased temperatures, the greater the potential vulnerability. Ranges include major at-sea foraging areas, so this trait includes areas with exposure to sea surface temperature increases (>2.5°C). Species with higher exposure are those exposed to substantial (>2.5°C) changes in mean land temperature (an arbitrary threshold, representing the mean temperature change for c.25% of species with greatest projected changes; Foden et al. 2013) and for which such an increase in temperature is predicted to have a negative impact on the species across most (>75%) of the species range.

**Exposure – Extent of a species range exposed to changes in temperature extremes**

The greatest impact of climate change is likely to be experienced first by changes in extremes rather than by changes in mean conditions. Species with higher exposure are those exposed to substantial changes in frequency, duration and intensity of extreme cold or hot events across most (>75%) of the species range, which lead to stress affecting productivity and survival, especially if they are cold-adapted species. Aotearoa New Zealand models express these as increases in the number of hot days (exceeding 25°C) or the number of frost days (0°C or colder). For example, Northland is predicted to have a considerable increase of 40-90 hot days by 2090 (RCP 8.5). Extremes are likely to influence species more during critical life history stages or seasons (e.g., summer breeding season, autumn or spring migration routes, wintering habitats).

**Exposure – Extent of a species range exposed to changes in precipitation**

Changes in precipitation and its intensity and duration in Aotearoa New Zealand are predicted to have both positive and negative trends depending on the region. Aotearoa New Zealand models express these as percentage increases (e.g., West Coast) or decreases (e.g., Northland) in annual rainfall. Species with higher exposure are those exposed to substantial changes in precipitation across most (>75%) of the species range. Predicted reductions in snow fall are likely to influence alpine species directly, and species downstream indirectly because of changes in the pattern of snowmelt.

**Exposure – Extent of a species range exposed to changes in precipitation extremes**

Substantial (extreme) increases or decreases in the duration and intensity of rainfall result in increased frequency and magnitude of flooding and associated significant erosion and slip events at one extreme, or drought at the other. Aotearoa New Zealand models express the rainfall changes as 1-in-50-year rainfall events (%) and increases in the number of heavy rain (>25 mm) days. Drought results from an interaction between temperature and precipitation extremes, so consideration needs also to be given to the number of hot days (>25°C), potential evapotranspiration deficit (mm) and frequency of annual dry days (<1 mm rainfall). Species with higher exposure are those exposed to substantial changes in precipitation extremes across most (>75%) of the species range. Extremes are likely to influence species more during critical life history stages or seasons (e.g., summer breeding season, autumn or spring migration routes, wintering habitats).

**Low adaptive capacity – Limitations to dispersal**

Factors that limit dispersal will impede the ability of species to shift to alternative habitats if their current range becomes unsuitable or they are unlikely to be able to keep up with a shifting climate envelope. Limitations include low dispersal rates (<1 km/yr) or intrinsic or extrinsic barriers. Extrinsic barriers may be geographic features such as unsuitable elevations (e.g., species confined to mountain ranges), oceans (e.g., for species on small islands), rivers, ocean currents and temperature gradients (for marine species) or other impassable habitat types (e.g., open habitats, vegetated habitats or human modified habitats such as roads/pasture/dams). Intrinsic barriers include behavioural traits such as very high site fidelity. Species with low adaptive capacity include (a) species with poor mobility limiting the ability to cross inhospitable habitats such as fragmented landscapes; (b) island endemics with an inability to move between climate-vulnerable islands because the sea is a barrier; or (c) flightless species, would not be able to move among islands, but would be able to move within them.

**Low adaptive capacity – Low genetic diversity**

Species' potential for rapid genetic change will determine whether evolutionary adaptation can occur at a rate sufficient to keep up with climate change driven changes to their environments. Species with low genetic diversity can result from recent bottlenecks in population numbers, generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such species tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions. When assigning vulnerability, we consider the extent of the species range/population that had gone through the bottleneck; if only a fraction of the population had been through a bottleneck, but if most of the population hadn't, we assign a species as lower vulnerability.

**Low adaptive capacity – Slow turnover of generations**

Evidence suggests that evolutionary adaptation is possible in relatively short timeframes (e.g., 5 to 30 years) but for most species with long generation lengths (e.g., large animals and many perennial plants), this is likely to be too slow to have any serious minimising effect on climate change impacts. Species with lower adaptive capacity (therefore higher potential vulnerability) are defined as those with slow maturation rates or a generation length ≥ 6 years (an arbitrary threshold used by Foden et al. (2013), representing the c.25% of bird species with the longest generation lengths).

**Low adaptive capacity – Low reproductive capacity**

Low productivity has consequences for adaptability because fewer young are produced, further reducing potential for opportunities for genetic adaptation for a species (e.g., reduced rate at which advantageous novel genotypes could accumulate in populations and species). Species with higher potential vulnerability are defined as those that produce low numbers of young or have low number of breeding events per season (e.g., for birds - mean clutch size ≤ 2 or number of broods/yr ≤1; an arbitrary threshold, representing the c.25% of species with the lowest productivity; Foden et al. 2013).

**References**

Foden WB, Butchart SH, Stuart SN, Vié JC, Akçakaya HR, Angulo A, DeVantier LM, Gutsche A, Turak E, Cao L, Donner SD 2013. Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals. PloS one 8: p.e65427.

He Q, Bertness MD, Altieri AH 2013. Global shifts towards positive species interactions with increasing environmental stress. Ecology Letters 16: 695–706.

Holdaway RJ, Wiser SK, Williams PA 2012. Status assessment of New Zealand's naturally uncommon ecosystems. Conservation Biology 26: 619-629.

International Union for Conservation of Nature (IUCN). 2012. Habitats classification scheme, Version 3.1. https://www.iucnredlist.org/resources/habitat-classification-scheme (Accessed: 14 September 2022).

McNab BK, O'Donnell C 2018. The behavioural energetics of New Zealand's bats: Daily torpor and hibernation, a continuum. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 223: 18–22.

Mitchell NJ, Allendorf FW, Keall SN, Daugherty CH, Nelson NJ 2010. Demographic effects of temperature-dependent sex determination: will tuatara survive global warming? Global Change Biology 16: 60–72.

Toth CA, Dennis TE, Pattemore DE, Parsons S 2015. Females as mobile resources: communal roosts promote the adoption of lek breeding in a temperate bat. Behavioral Ecology 26: 1156–1163.

Townsend AJ, de Lange PJ, Duffey CAJ, Miskelly CM, Molloy J, Norton DA. 2008. New Zealand threat classification system manual. Wellington, Department of Conservation. 35 p.