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Predicting species and community responses to global change using structured expert judgement: An Australian mountain ecosystems case study

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Abstract

Conservation managers are under increasing pressure to make decisions about the allocation of finite resources to protect biodiversity under a changing climate. However, the impacts of climate and global change drivers on species are outpacing our capacity to collect the empirical data necessary to inform these decisions. This is particularly the case in the Australian Alps which have already undergone recent changes in climate and experienced more frequent large-scale bushfires. In lieu of empirical data, we use a structured expert elicitation method (the IDEA protocol) to estimate the change in abundance and distribution of nine vegetation groups and 89 Australian alpine and subalpine species by the year 2050. Experts predicted that most alpine vegetation communities would decline in extent by 2050; only woodlands and heathlands are predicted to increase in extent. Predicted species-level responses for alpine plants and animals were highly variable and uncertain. In general, alpine plants spanned the range of possible responses, with some expected to increase, decrease or not change in cover. By contrast, almost all animal species are predicted to decline or not change in abundance or elevation range; more species with water-centric life-cycles are expected to decline in abundance than other species. While long-term ecological data will always be the gold standard for informing the future of biodiversity, the method

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and outcomes outlined here provide a pragmatic and coherent basis upon which to start informing conservation policy and management in the face of rapid change and a paucity of data.

KEYWORDS
adaptive capacity, alpine, biodiversity conservation, climate change, expert elicitation, exposure risk

1 | INTRODUCTION

Alpine, subalpine and montane species are predicted to be negatively impacted by climate change. For the most part, this is because the climate envelope of many mountain species is expected to shrink and, in some regions, disappear entirely as a consequence of increased global temperatures (Freeman et al., 2018; Halloy & Mark, 2003; La Sorte & Jetz, 2010). While range contractions have already been observed in some mountain plants (Grabherr et al., 1994; Lenoir et al., 2008; Steinbauer et al., 2020) and animals (Freeman et al., 2018; Wilson et al., 2005), not all species are responding to climate change in the same way (Gibson-Reinemer & Rahel, 2015; Lenoir et al., 2010; Tingley et al., 2012). What remains unclear is the capacity of mountain species to adapt (Hargreaves et al., 2014; Louthan et al., 2015; Michalet et al., 2014; Normand et al., 2014), and the characteristics that allow species to persist in the face of a changing climate (Foden et al., 2018; Fordham et al., 2012).

To understand the complexities and uncertainties of species responses to climate change, there have been several attempts to quantify adaptive capacity (Foden et al., 2013; Gallagher et al., 2019; Ofori et al., 2017). Adaptive capacity describes the ability of systems and organisms to persist and adjust to threats, to take advantage of opportunities, and/or to respond to change (IPCC, 2014; Millenium Ecosystem Assessment, 2005). Adaptive capacity confers resilience to perturbation, allowing ecological systems to reconfigure themselves with change (Holling, 1973). In the context of alpine biota in Australia, adaptive capacity is the ability of species to maintain their often limited geographical distributions and population abundance when the climate and other factors are altered. While the underlying factors determining adaptive capacity encompass genetic and epigenetic variation, life-history traits and phenotypic plasticity (Dawson et al., 2011; Ofori et al., 2017), little is known about which taxa have high adaptive capacity, how to quantify it, how it varies within and across related species, or how to manage populations in order to maximize it. As a consequence, data required to advise on the adaptive capacity of species are often lacking.

Nonetheless, conservation practitioners and land managers are under increasing pressure to make decisions about the allocation of finite resources used to conserve biodiversity under climate change. Decisions are typically based on vulnerability assessments that incorporate exposure risk, species sensitivity and adaptive capacity (Foden et al., 2013, 2018; Ofori et al., 2017). Until now, assessments of potential climate change impacts on species that cover multiple taxonomic groups have been based primarily on species correlative distribution models (e.g. La Sorte & Jetz, 2010; Lawler et al., 2009; Thomas et al., 2004). More sophisticated models incorporating species' physiological, ecological and evolutionary characteristics will likely facilitate better identification of the species most at risk from climate change (Briscoe et al., 2019). However, multiple challenges exist when attempting to build and use such process-based models (Briscoe et al., 2019). First, the data necessary to parameterize these models are rarely available for most species. Second, such models rarely incorporate indirect climate change impacts on other abiotic (e.g. disturbance regimes) and biotic (e.g. interspecific competition, predation) stresses known to affect population ecology, physiology and ultimately species' persistence (Fordham et al., 2012; Geyer et al., 2011; Guisan & Thuiller, 2005). Lastly, the technical skill and time required to build and interpret these models restrict their use to specialists (Briscoe et al., 2019). Given that the rate of climate change impacts has already outpaced our capacity to collect the required data and build necessary models to assess species empirically, it is important to utilize alternative methods that make use of existing expertise across taxa to estimate adaptive capacity and identify conservation priorities (Granger Morgan et al., 2001).

The need to predict how species will respond to climate change is particularly pertinent to the Australian alpine ecosystem which has a high level of endemism and a restricted geographical range (Venn et al., 2017). Since 1979, mean spring temperatures in the Australian Alps have risen by approximately 0.4°C and annual precipitation has fallen by 6% (Wahren et al., 2013), with a consequent decline in snow pack depth (Sanchez-Bayo & Green, 2013). Snow cover in Australia is now at its lowest in the past 2000 years (McGowan et al., 2018). These climatic changes correlate with changes in floristic structure, abundance and diversity (Camac et al., 2015; Wahren et al., 2013) and increases in fire frequency and severity (Camac et al., 2017; Zylstra, 2018). Changes are expected to threaten the many locally adapted and endemic species, with cascading effects on biodiversity and ecosystem services such as carbon storage and water yield (Williams et al., 2014).

Here, we quantify the future abundance of Australian alpine species using the IDEA protocol (Investigate, Discuss, Estimate and Aggregate; Hemming et al., 2018). This structured elicitation protocol provides a robust framework to estimate risk when data are either inadequate or lacking entirely (Hemming et al., 2018). Many of the elements essential to mitigating against common cognitive group and individual biases are prescribed in the IDEA protocol (Hemming et al., 2018). For example, eliciting estimates from a diverse group of experts avoids the

availability bias of a single expert (whose judgements are influenced more heavily by the experiences or evidence that most easily come to their mind), but may introduce group think. Within the IDEA protocol's framework, group think is avoided by first asking experts to provide initial and independent estimates. In this way, we sample a diverse set of knowledge pools, preconceptions and world views. These diverse sets of views can then be refined during the discussion phase, where experts have the opportunity to discuss the reasons behind their initial estimates, and thus allow experts the opportunity to adjust their own estimates when they come across convincing arguments or discover new information provided by their peers. Because of these strengths, the IDEA protocol is now routinely used to inform policy and management in a variety of contexts where data are either incomplete or lacking entirely, for example, forecasting changes in biosecurity risk (Wittmann et al., 2015), estimating attrition rates in defence vehicles (Hemming et al., 2020) and informing environmental impact assessment (Adams-Hosking et al., 2016) or threat management (Firn et al., 2015). Structured expert elicitation has even been used to inform data-poor processes in some of the most influential global environmental policies such as the IUCN Red List (IUCN, 2012) and IPCC Assessments (Mastrandrea et al., 2010). As yet, few examples of its use exist in the ecological and conservation literature (e.g. Geyle et al., 2020), despite it providing significant and scientifically robust opportunity to quantitatively harness the local knowledge of biologists, conservation scientists and natural resource managers. That knowledge, once harnessed, can be used to identify key species attributes and external factors governing species adaptative capacity, and to make quantitative forecasts and predictions about critical, but often data-poor, processes.

In this study, 37 experts (Table S1) estimated changes in the future abundance and/or distribution of nine Australian alpine plant communities, 60 alpine plant species and 29 mountain animal species. Expert knowledge provided insights into the species' attributes and the biotic and abiotic factors that were expected to influence a species' adaptive capacity. Using these expert elicited data, we:

1. Quantified the direction and magnitude of change in cover/abundance/elevation range of Australian mountain plant communities as well as individual plant and animal species to climatic changes expected by 2050;
2. Examined what were the most commonly invoked species attributes and biotic and abiotic; factors that experts used when predicting changes in community and species abundances, and;
3. Examined how various measurable species attributes correlated with expert predicted changes in plant species abundance.

2 | METHODS

2.1 | Study system

Australian high mountain ecosystems are restricted to south-eastern Australia, occupying an area ~11,700 km^2, or 0.15% of the continent. They are comparatively low in elevation, barely exceeding 2000 m a.s.l, and most mountain tops contain a well-developed soil mantle. There is no nival zone or areas of permanent snow and some alpine areas of Tasmania even remain snow-free during the winter (Venn et al., 2017).

Australian mainland alpine ecosystems encompass several plant communities characterized by different species and growth forms (Kirkpatrick & Bridle, 1999; Venn et al., 2017; Williams et al., 2006). Heathland predominates on relatively steep sheltered slopes where alpine humus soils are shallow (<0.3 m deep). The shrubs are 1–2 m tall, with a canopy cover typically exceeding 70%. Grassland/herbfield complexes occupy the more level ground on slopes and hollows, some of which may be subject to severe winds and frost, and where the alpine humus soils are deepest (generally up to 1 m). Short herbfields (i.e. snowpatch vegetation) occur on steep, leeward, south- to east-facing slopes where snow persists well into the spring or summer (Venn et al., 2017). Feldmark are an extremely rare ecosystem, existing only on exposed rocky ridges consisting of prostrate, hardy shrubs of the family Ericaceae. Wetland complexes consist of wet tussock grasslands, bogs and fens and occupy valley bottoms, drainage lines and some stream banks and are typically waterlogged for at least 1 month per year. Woodlands are dominated by multi-stemmed, slow-growing trees (*Eucalyptus pauciflora*) and are typically snow-covered for at least 1 month each year.

The abundance and activity of the animals are regulated by the seasons (Green & Osborne, 1994; Green & Stein, 2015). The fauna consists of seasonal migrants and alpine specialists and is dominated by insects and other invertebrates (Green & Osborne, 1994; Green & Slatyer, 2020). Many species appear to be semelparous and require the snow pack to protect their overwintering eggs (e.g. *Kosciuscola* grasshoppers). Others, such as the *Monistria* grasshoppers, can overwinter as adults in the subnivial space by supercooling and thus, have overlapping generations. Many Australian alpine insects exhibit iconic behaviour such as the long-distance migration of bogong moths (*Agrotis infusa*) (Warrant et al., 2016) or the striking startle display of the mountain katydid (*Acripeza reticulata*) (Umbers & Mappes, 2015). The streams and wetlands support large alpine crayfish (*Euastacus* spp.), endemic earthworms (e.g. *Notoscolex montiskosciuskoi*), galaxiid fish and several terrestrial-breeding frogs. The reptile diversity includes elapid snakes and many skink species. Most birds leave the alps in winter, returning to forage each summer. The only alpine endemic marsupial, the mountain pygmy possum (*Burramys parvus*), hibernates in boulder fields under the snow (Geiser & Broome, 1991) while other mammals, such as wombats and echidnas, remain active throughout winter.

2.2 | Applying the idea protocol for structured expert elicitation

We utilized the IDEA protocol for structured elicitation of expert judgement (Hemming et al., 2018; Figure S1). This protocol involved: (1) recruiting a diverse group of experts to answer questions with probabilistic or quantitative responses; (2) discussing the questions (Table S2) and clarifying their meaning, and then providing private, individual best estimates

and associated credible intervals, often using either a three-point (i.e. best estimate, lower and upper limit; animal workshop) or four-point (i.e. best estimate, lower and upper limit and confidence that the true value falls within those limits; plant workshop) elicitation method (Spiers-Bridge et al., 2010); (3) providing feedback on the experts' estimates in relation to other experts; (4) discussing the results as a group, resolving different interpretations of the questions, sharing reasoning and evidence, and then providing a second and final private estimate; and (5) aggregating experts' final estimates mathematically, including exploration of performance-based weighting schemes of aggregation (see Supporting Information for details).

The plant and animal expert elicitation projects were undertaken in July 2017 and November 2018, respectively. Because there is no accepted method to quantify or compare adaptive capacity across plants and animals, we developed questions based on estimates of percent cover for plants or abundance/elevation range for animals for the present day and in 2050. Experts (n = 22 for plants, n = 17 for animals, n = 2 shared between workshops; Table S1) were selected to represent a breadth of expertise in alpine botany, zoology and ecology in Australia. Experts included (a) academic researchers and postgraduate students actively involved in botanical, zoological and ecological research in the alps, (b) management agency staff involved in field ecology, surveys and management of the alps and (c) staff from botanical gardens, zoos and museums with extensive experience in the alps. In the plant workshop, experts estimated the current (2017) and the 2050 cover of 60 plant species (Table S4), with 10–15 representative species in each of five dominant alpine vegetation communities. Furthermore, experts estimated the future landscape cover of nine alpine/subalpine vegetation community complexes based on an agreed 2017 baseline cover: feldmark (0.1%), snowpatch (1%), grassland/herbfield (25%), woodland (24%), heathland (35%), wetland complex (15%), bog (5%), fen (4%) and wet tussock grassland (6%). Note: bogs, fens and wet tussock grasslands are treated as non-overlapping sub-communities within 'Wetland complex' (i.e. their combined cover = wetland complex). For the plant elicitation, we assumed increases in temperature, decreases in precipitation (and less of that falling as snow, and fewer days of snow cover) and increased chance of fire. For the animal elicitation, we provided a specific climate scenario for the year 2050 (Table S3).

Expert-derived data are often aggregated in one of the two ways, weighted or equally weighted (i.e. unweighted; Hemming et al., (2021)). Our analysis focused on using equally weighted *best* estimates from experts. While expert uncertainty defined by their bounds and estimated confidence was collected in both workshops, it was not used in this analysis due to considerable variability in how experts interpreted, and thus, estimated their bounds (see Supporting Information).

2.3 | Data analysis

2.3.1 | Calculation of summary statistics

We calculated the mean and 95% confidence intervals under both current and future scenarios for each species or plant community type. Various data transformations were required to estimate the mean and confidence limits because estimates were bounded (e.g. percent cover and abundance). For the plant percent cover data, individual expert best estimates were first logit transformed and then both mean and 95% confidence limits were estimated. Inverse logit transformations were then applied to each summary statistic to convert these estimates back to a proportional scale. As the animal abundance estimates were based on species-specific spatial scales, we first re-scaled expert estimates to a standard spatial scale (i.e. 100 m^2). As some experts included zeros in their best estimates of abundance and elevation estimates, we applied a small constant (0.1) prior to log transforming the data. Means and 95% confidence limits were then calculated and back transformed to their original scale. Means and confidence limits for expert estimates of elevation range (maximum elevation minus minimum elevation) were calculated on the raw scale (i.e. not transformed prior to estimation). Comparison between 'present' and 'future' estimates was done using "inference by eye" (Cumming & Finch, 2005) by examining whether the 95% confidence intervals crossed the 1:1 line in plots of current vs future estimates. Finally, we used individual expert current and future best estimates to calculate the proportion of experts that indicated increase, decrease or no change.

To determine whether the change projected by the experts for alpine plants correlated with available data on species traits or environmental attributes, we calculated a proportional change in cover estimated by each expert (See Supporting Information). Means and confidence intervals across experts were then estimated and used to calculate the Spearman rank correlations between this proxy of adaptive capacity and (1) a set of environmental measures derived from records in the Australian Virtual Herbarium and (2) plant functional trait data obtained from the experts' published and unpublished data, as well as other published and online sources and, for a few species, field specimens were collected to supplement available data.

De-identified data and code used to produce Figures 1–4 and Figures S2–S4 can be found at: https://github.com/jscamac/Alpine_Elicitation_Project.

3 | RESULTS

3.1 | Predicted change in cover of Australian mountain vegetation types

The majority of experts predicted that most alpine vegetation communities would decline in extent (i.e. total cover in the landscape) with global change by 2050 (i.e. snowpatch, bog, fen, wetland complex, grassland/herbfield). All experts predicted that snowpatch and bog communities will decrease by 2050, whereas most experts predicted heathlands and woodlands would increase in extent (Figure 1a). There was more uncertainty among experts about the future of wet tussock grasslands and feldmark communities (Figure 1a). Communities that are currently restricted in extent across the Australian alpine landscape (<5% extent) were predicted to be the ones most likely to decline (Figure 1b), but some of the more extensive communities (i.e. wetland complex, grassland/herbfield, which currently occupy ~25% of the landscape) were also predicted to decline in extent (Figure 1b).

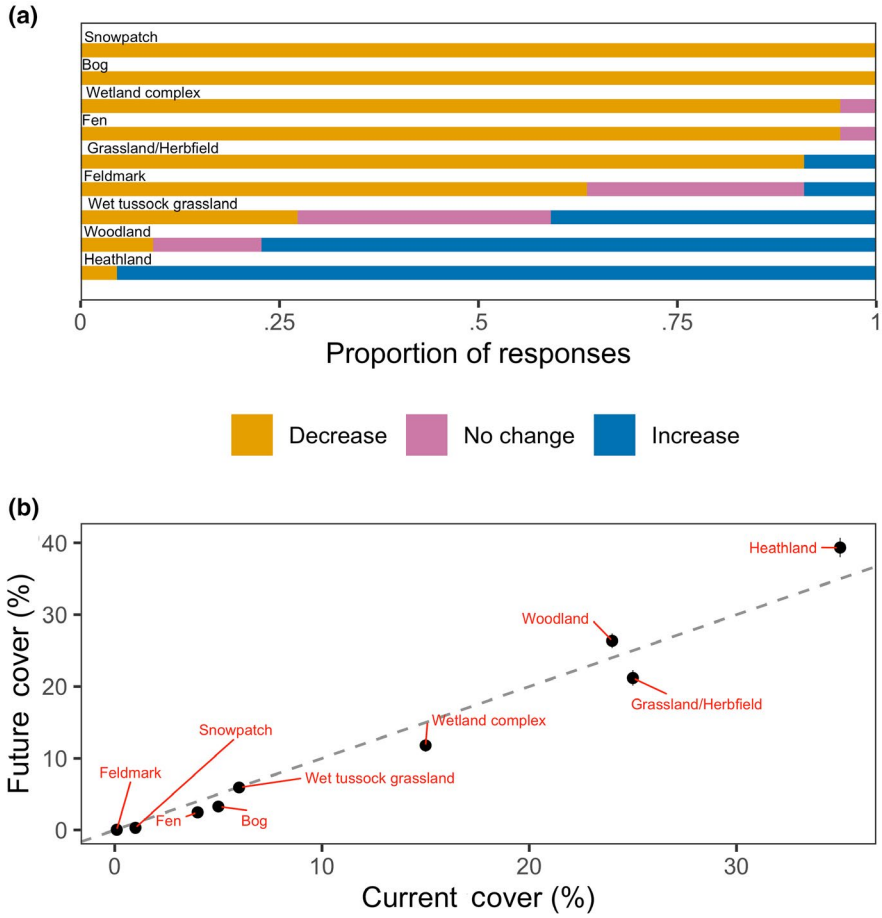

FIGURE 1 Nine Australian alpine plant community landscape cover predictions for 2050. (a) The proportion of experts (n = 22) best estimates indicating a decline (orange), no change (pink) or increase (blue) in landscape cover between 2017 and 2050. (b) Mean (±95% confidence intervals) of expert best estimates of community landscape cover for 2050. Records below the dashed 1:1 line signify a decrease in cover while those above the line signify an increase in cover. Assumed current landscape covers were agreed upon by experts: Feldmark (0.1%), Snowpatch (1%), Grassland/Herbfield (25%), Woodland (24%), Heathland (35%) and Wetland complex (15%). As wetland complexes consisted of a diverse set of sub-communities, we also included current landscape cover estimates for the components thereof: Bogs (5%), Fens (4%) and Wet tussock grasslands (6%)

3.2 | Direction and magnitude of change in cover for individual plant species

Within each plant community, experts predicted that the individual species' responses to global change would vary (Figure 2). Some species, such as the snowpatch forb *Montia australasica* (#50 in Figure 2) and the wetland moss *Sphagnum cristatum* (#38), were almost unanimously predicted to decline in cover over time (Figure 2a). For other species, such as the subalpine heathland shrub *Hovea montana* (#22), experts predicted increases in cover (Figure 2a), although the magnitude of increase was small (Figure 2b). For most alpine plant species, there was much uncertainty about their future cover relative to current cover. The snowpatch graminoid *Rytidosperma nudiflorum* (#60), the wetland shrub *Baeckea gunniana* (#49), the grassland forb *Oreomyrrhis eriopoda* (#32), the heathland shrub *Acrothamnus montanus* (#17), the woodland forb *Stylidium montanum* (#1) and even the grassland structural dominant *Poa hiemata* (#27) were, according to experts, equally likely to show increases, decreases or no change in cover (Figure 2b). This is reflected in the high uncertainty seen in future cover estimates (i.e. vertical error bars) for these species (Figure 2b).

Across all plant species, growth form was found to be relatively important in explaining expert judgements of species' adaptive capacity (Figure 2a). Woody plants (shrubs and one tree) were typically predicted to have higher adaptive capacity (i.e. show increases or no change in cover) relative to forbs and graminoids (Figure 2).

In general, plant species with current high cover in herbaceous communities (e.g. snow patches, grasslands and wetlands) were not predicted to become more dominant with climate change. Experts were uncertain about the future cover of many of these current high-cover herbaceous species (Figure 2). For example, the graminoids *Poa costiniana* (#31, grasslands), *Poa fawcettiae* (#57, snowpatches) and the forb *Celmisia costiniana* (#56, snowpatches) were predicted by experts to either increase or decrease in cover in roughly equal numbers (Figure 2a). By contrast, in communities dominated by woody plants (heathlands, woodland), species with current high cover were predicted to increase their cover into the future (Figure 2b, e.g. *Hovea montana #22*, *Oxylobium ellipticum #8*).

3.3 | Direction and magnitude of change in abundance and elevation range for individual animal species

Animal expert predictions showed considerable variability in responses to global change (Figure 3). For nearly half the species (n = 13), the majority of experts predicted a decline in abundance (Figure 3a). The majority of experts suggested the Northern Corroboree Frog (*Pseudophryne pengellyi*, #18), the Baw Baw Frog (*Philoria frosti*, #20), the Kosciuszko Galaxis fish (*Galaxias*

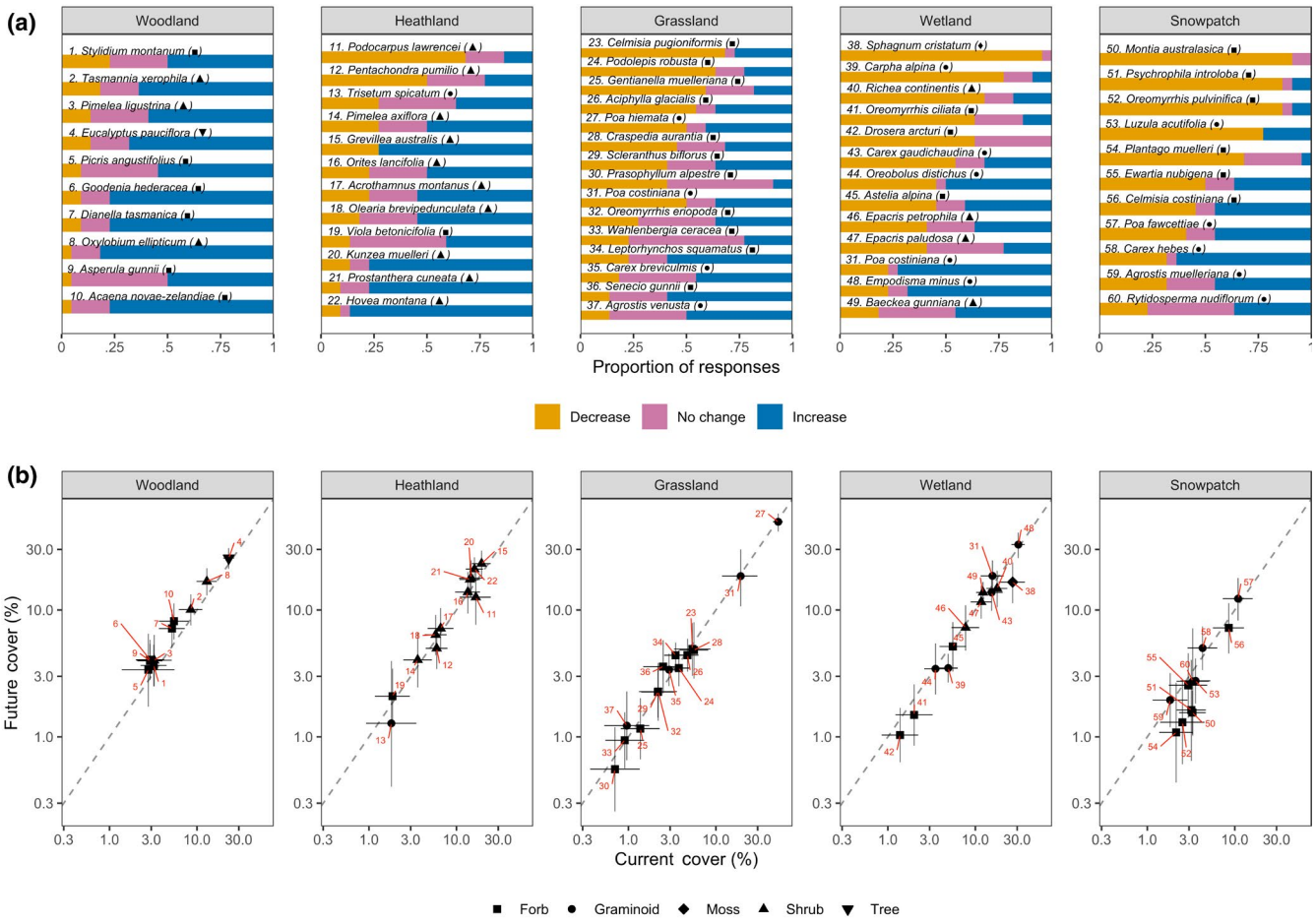

FIGURE 2 Sixty Australian alpine plants species cover predictions for 2017 and 2050. (a) The proportion of experts' (n = 22) best estimates indicating a decline (orange), no change (pink) or increase (blue) in cover between 2017 and 2050. (b) Mean (±95% confidence intervals) of expert best estimates of species cover for 2017 and 2050. Records below the dashed 1:1 line signify a decrease in cover, while those above the line signify an increase in cover. Species have been grouped by the community type they most commonly occur in. Numbers signify species ID presented in panel (a)

supremus, #19) and the Bogong Moth (*Agrotis infusa*, #1) would decline by 2050 (Figure 3a). For most of the remaining species, the majority of experts predicted no change in abundance. For example, a large proportion of experts suggested that the abundance of the Mountain Katydid (*Acripeza reticulata*, #16) and the Mountain Shrimp (*Anaspides tasmaniae*, #29) will not change by 2050 (Figure 3a). There was no species for which the majority of experts predicted an increase in abundance, but a notable proportion of experts predicted an increase in the abundance of the Thermocolour Grasshopper (*Kosciuscola tristis* #8). Experts were split equally between 'increase' and 'no change' for the Mountain Dragon (*Rankinia diemensis*, #17) and split equally between 'decrease' and 'no change' for the Alpine Darner (*Austroaeschna flavomaculata*, #28) (Figure 3a).

Examining the magnitude of change in abundance (Figure 3b), many species were predicted to decline by 2050, although in almost all cases these changes were small and uncertain (i.e. confidence limits cross the 1:1 line). The exceptions to this were the Mountain Dragon (*Rankinia diemensis*, *#17*) which is predicted to marginally increase—although this is uncertain—and both the Northern Corroboree Frog (*Psuedophryne pengellyi*, *#18*) and the Baw Baw Frog (*Philoria frosti*, *#20*), which are predicted to likely decrease in abundance. Examining species responses across water-centric and non-water-centric life histories revealed that, on average, non-water-centric species were expected not to change in abundance while water-centric species were more likely to decline.

With uncertainty, the minimum elevation limits of fauna distributions were predicted to shift upslope in 24 of 29 species (Figure 4; right panels). The Mountain Pygmy Possum (*Burramys parvus*, #4) had the largest predicted change in minimum elevation range limit, expected to move up more than 150 m. The Alpine Cool Skink (*Carinascincus microlepidotus* #3), Alpine Bog Skink (*Pseudemoia cryodroma*, #2) and Alpine Plaster Bee (*Leioproctus obscurus*, #6) also show substantial departures from no change. No change in minimum elevation was predicted for the two species whose distributions, while predominantly contained within mountain regions, extend to sea level—the Blue Planarian (*Caenoplana coerulea*, #26) and the Mountain Katydid (*Acripeza reticulata*, #16). The maximum elevation limits were predicted to increase for 16 species (range: 8–80 m) and decrease for 11 species (range: 1–80 m). Uncertainty encapsulated

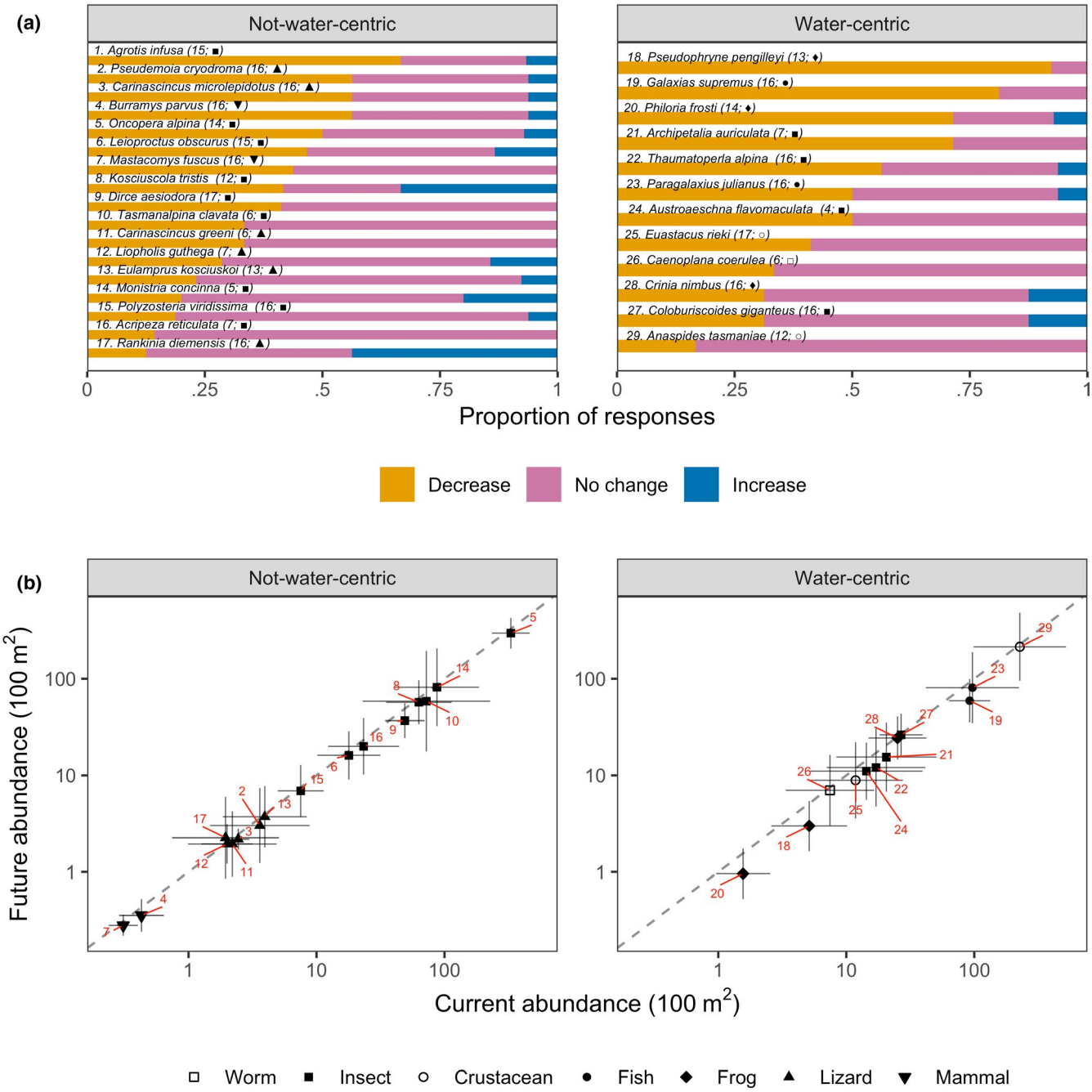

FIGURE 3 Twenty-nine Australian alpine animal species' abundance predictions for 2018 and 2050. (a) The proportion of experts best estimate indicating a decline (orange), no change (pink) or increase (blue) in cover in 2018 and 2050. (b) Mean (±95% confidence intervals) of expert best estimates of species abundance for 2018 and 2050. Records below the dashed 1:1 line signify a decrease in abundance, while those above the line signify an increase in abundance. Species are grouped by degree of dependency on water to complete their life-cycle as water-centric and non-water-centric. Numbers signify species ID presented in panel (a). Numbers in parentheses in panel (a) represent the number of experts who provided estimates (Maximum = 17). Symbols represent higher taxon. Note: the bogong moth (*A. infusa*) has been omitted from panel (b) as its abundance estimates were multiple orders of magnitude higher than other species

the 1:1 line for most species, but distinct increases in maximum elevation were predicted for the Mountain Dragon (*Rankinia diemensis*, #17). A conspicuous, but uncertain, reduction in maximum elevation was estimated for the alpine crayfish (*Euastacus reiki*, #25). For most species (n = 23), the total elevation range occupied was predicted to shrink as a result of upward shifts at low elevation limits. Increases in elevational range were predicted for four species and only one species—the Blue Planarian (*Caenoplana coerulea*, #26)—was predicted to show no change in elevational range by 2050. The largest declines in species elevational range were predicted for the Mountain Pygmy Possum (*Burramys parvus*, #4, ~250 m reduction), the Northern Corroboree Frog (*Pseudophryne pengilleyi*, #18, ~110 m

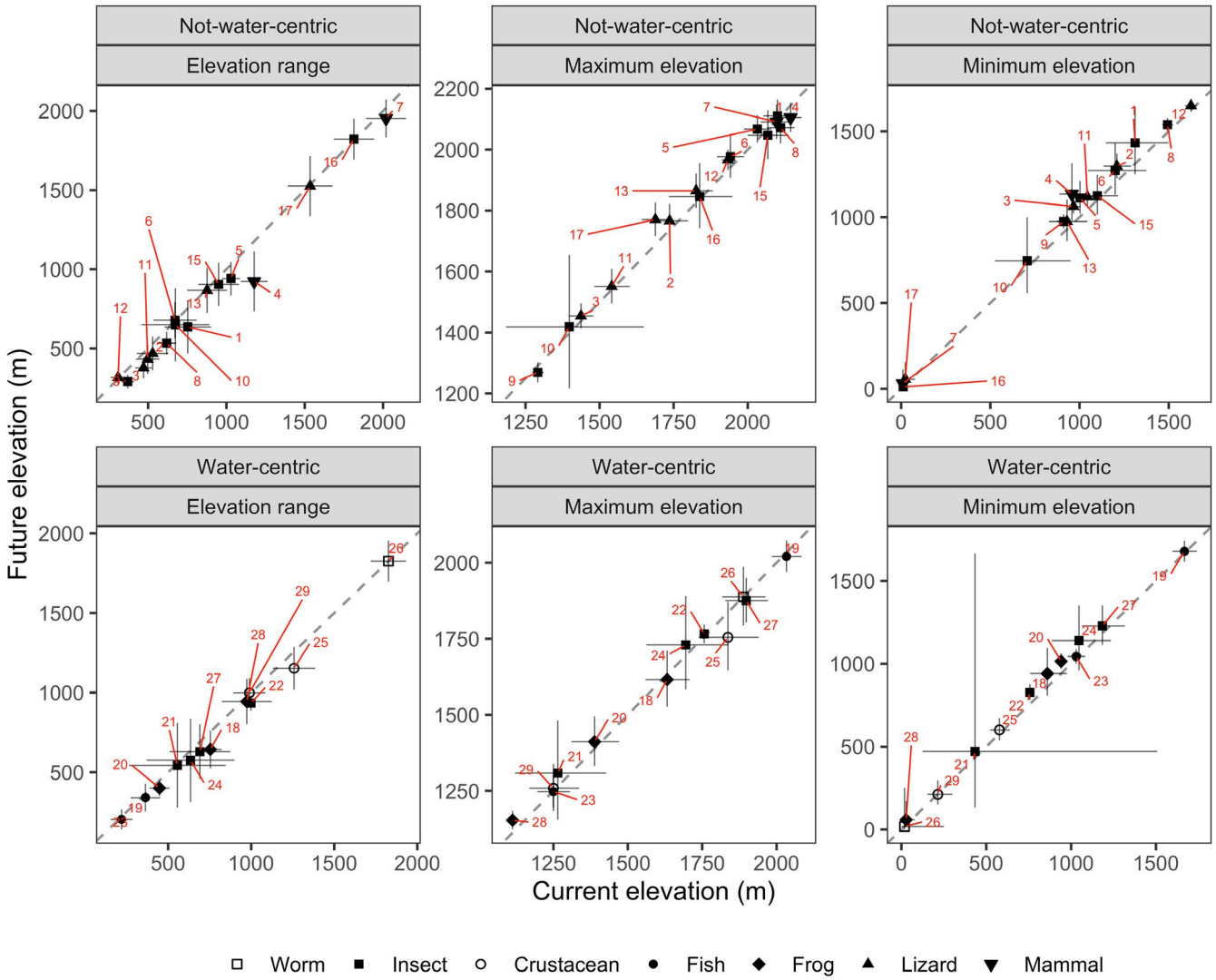

FIGURE 4 Australian alpine fauna species mean (±95% confidence intervals) elevation range (left panels); maximum elevation (centre panels) and minimum elevation (right panels) predictions for 2018 and 2050. Records below the dashed 1:1 line signify a decrease, while those above the line signify an increase. Species are grouped by degree of dependency on water to complete their life-cycle, as water-centric and non-water-centric Numbers signify species ID (see Figure 3a). Symbols represent taxon class. Note: *Monistria concinna* (#14) was not included in plot due large uncertainty bounds obscuring data trends

reduction) and the Alpine Crayfish (*Euastacus rieki*, #25, ~105 m reduction).

3.4 | Expert opinion on drivers of adaptive capacity

In the initial surveys, prior to the workshops, both plant and animal experts nominated genetic variability and phenotypic plasticity as key determinants of adaptive capacity, with fecundity, lifespan and dispersal also considered important. However, notes and comments compiled during the elicitation process suggested that experts referred more often to environmental and biotic attributes when considering drivers of change in cover/abundance for specific organisms. Climate niche breadth, disturbance regimes (e.g. fire, frost events) and species interactions, including competitive ability in the face of native (e.g. shrubs and trees) or exotic species encroachment (e.g. horses, deer, weeds), vulnerability to diseases (e.g. *Phytophthora cinnamoni*) and a dependence on other species (e.g. grazers, pollinators), dominated discussions about potential drivers of future change in alpine species abundance and/or distribution.

3.5 | Correlations of plant species attributes with expert predictions

The projected magnitude of change in cover of plant species was correlated with environmental (Figure S2) and species range attributes (Figures S3 and S4). Adaptive capacity was most negatively correlated with species' minimum elevation ($r = -.569$) and most positively correlated with mean annual temperature range ($r = .466$), elevation range ($r = .561$) and area of occupancy ($r = .43$), noting that these three variables are themselves highly correlated with each other.

We found that our measure of adaptive capacity was not strongly correlated with the continuous species traits such as mean height (r = .286), leaf area (r = −.061), specific leaf area (r = −.05), diaspore mass (r = .202) or dispersal distance (r = .342).

4 | DISCUSSION

Conservation managers are increasingly required to make decisions about the allocation of finite resources to protect biodiversity under changing climate and disturbance regimes. Climate change impacts, however, are outpacing our capacity to collect data to assess individual risk empirically to inform resource allocation. A pragmatic alternative approach is to utilize expertise across taxa to produce timely estimates of conservation risk (Burgman, Carr, et al., 2011; Granger Morgan et al., 2001; Martin et al., 2012). Experts' acquired experience allows them to provide valuable, nuanced insight into predictions about the future given a particular scenario. Our study has demonstrated the feasibility of a structured expert elicitation process for identifying the potential for adaptive capacity in Australian alpine plant communities, and individual animal and plant species. We identified that some alpine species and communities are likely to be more vulnerable to global change by 2050 than others. Our exercise also identified species for which experts are equivocal and thus, targets for further investigation.

Expert judgement identified that the adaptive capacity of Australian alpine biota in the face of global change is, not surprisingly, likely to be species-specific. Here, the adaptive capacity estimates encompassed more than just species' responses to climate change; they also included structured consideration of all issues identified by experts such as a species' response to fire, invasive species, predation and interspecific competition. While this may seem self-evident, it is the first time that multiple species and communities in alpine Australia have been simultaneously assessed for their adaptive capacity and it provides a defendable basis for targeting monitoring of vulnerable species and communities, as well as the development of potential mitigation strategies for at-risk species. When given a plausible 2050 climate change scenario, incorporating the assumption that an extensive bushfire would occur during this period (which subsequently happened in early 2020; Nolan et al., 2020), adaptive capacity was predicted to be lower in herbaceous plants relative to woody plants, and lower in water-centric animals relative to non-water-centric species. Our findings are broadly consistent with predicted forecasts based on empirical data derived from both long-term monitoring (e.g. Good, 2008; Hoffmann et al., 2019; Wahren et al., 2013; Williams et al., 2014, 2015) and field warming/burning/snow experiments (e.g. Camac et al., 2015, 2017; Slatyer et al., 2021; Wahren et al., 2013).

We found that expert estimates of adaptive capacity were not strongly correlated to quantitative plant traits such as specific leaf area or diaspore mass. This is perhaps unsurprising as such traits are thought to act on individual demographic rates (e.g. mortality, growth, fecundity), which themselves trade-off against one another (Camac et al., 2018). By contrast, adaptive capacity (i.e. proportional cover change) is the outcome of the amalgamation of multiple such trade-offs—thus diminishing possible correlations with individual traits. Moreover, the amount of interspecific variation explained by traits typically assumed to be strongly linked to demographic rates (e.g. wood density and tree mortality) have been shown to be small (e.g. Camac et al., 2018). Unlike correlative species distribution models which rely only on climate data and species occurrence data, experts undertaking structured judgements inherently consider physiological, ecological and evolutionary characteristics of species, as well as how those species might interact (or re-assemble) in novel assemblages, and how disturbance (from fire in our case) may affect their responses.

We found that experts came into the elicitation process with perceptions of key environmental and biotic drivers of species responses to global change but, after discussion with other experts, they refined these drivers. Prior to the elicitation process, experts emphasized characteristics of the focal species as being the most important predictors of their response to global change (e.g. genetic variability, phenotypic plasticity, fecundity, lifespan, dispersal). During discussion, experts shifted their thinking to include both biotic and environmental drivers as being of importance to predicting alpine biota response to global change (e.g. competitive ability, mutualisms, niche breadth). This shows the value of using a structured elicitation method relative to informal elicitation approaches (Krueger et al., 2012).

As might be expected, 'rare' species—defined by animal abundance (or elevational range) or plant cover—were typically predicted to become rarer with global change. Small population size and restricted habitat breadth are likely key reasons for such thinking among experts (Cotto et al., 2017; Kobiv, 2017; Williams et al., 2015). Terrestrial ectotherms (insects, reptiles, frogs), for example, are likely to face increased periods of heat stress (Hoffmann et al., 2013), while drought and declining snow cover duration make many plants and water-centric animals vulnerable (Griffin & Hoffmann, 2012; Williams et al., 2015; Wipf et al., 2009). For many animals, experts predicted that species with the narrowest elevational range on mountains (such as the Mountain Pygmy Possum) are most likely to further contract. Such processes are already occurring in mountain landscapes, with lower limit upward shifts in species having already been reported (Freeman et al., 2018; Pauli et al., 2007; Rumpf et al., 2019).

Unexpectedly, experts were uncertain about the future abundance/cover of some 'common' species. While some structural dominants in plant communities are forecast to be either likely 'winners' (e.g. shrubs such as *Hovea montana*, *Grevillea australis* and *Prostanthera cuneata)* or 'losers' under global change (e.g. the moss *Sphagnum cristatum* in alpine wetland bogs), which is in broad agreement with other published studies (e.g. snow patch herbfield declines: Williams et al., 2015; Heathland expansion: Camac et al., 2017), there was less agreement about others. *Poa hiemata*, a dominant and potentially long-lived tussock grass of alpine grasslands and herbfields, had uncertain adaptive capacity according to experts. We suspect that experts varied in the emphasis they placed on a

long adult lifespan in limiting the adaptive capacity of local populations, with longevity buffering individual persistence in unsuitable sites at least in the short term (Cotto et al., 2017) but slowing evolutionary rates. Alternatively, experts were potentially weighting disturbance impacts, interspecific competition and climate sensitivity very differently (Granger Morgan et al., 2001). For example, some experts may have considered *Poa hiemata* to be relatively tolerant of frequent and severe droughts (Griffin & Hoffmann, 2012), and thus able to capitalize in a warmer, drier environment by encroaching into wetlands. Other experts, however, may have considered the possibility that warmer and drier climate would increase fire frequency and severity (Zylstra, 2018) which, in turn, would provide shrub species opportunities to encroach into grasslands (Camac et al., 2017). Given such species are functionally important, provide most of the community biomass (both aboveground and belowground), structure habitat for fauna, and provide ecosystem services such as erosion control (i.e. they act as 'foundation species', Ellison & Degrassi, 2017), understanding the autecology and dynamics of dominant species in response to global change drivers appears to be a key research need. Indeed, the uncertainty around common species responses highlights that long-term cover/abundance trends need to be quantified if future ecosystem stability is to be understood, a call that has been made repeatedly in the literature (Gaston, 2011; Gaston & Fuller, 2007; Smith & Knapp, 2003; Smith et al., 2020). Monitoring species' local abundance may therefore better inform species' extinction risks in alpine areas under global change than monitoring their range (Cotto et al., 2017).

Overall, the change in cover of plant species, or elevational range and abundance change for animals, was estimated to be modest despite some climatic effects already becoming evident in Australia's alpine biota (e.g. Camac et al., 2017; Hoffmann et al., 2019); estimates for cover change in plant communities were more pronounced. This may reflect that scientific experts are typically conservative when estimating the future (Oppenheimer et al., 2019). Experts also likely view biotic response to global change as a time-lagged process (i.e. 'disequilibrium dynamics', Svenning & Sandel, 2013). Lags occur because of the limited ability of species to disperse to new areas (Alexander et al., 2018; Morgan & Venn, 2017), establishment limitations following their arrival (Camac et al., 2017; Graae et al., 2011; HilleRisLambers et al., 2013) and the extinction debt of resident species (Dullinger et al., 2012). By forecasting only to 2050, experts have indicated that many longer-lived species will potentially persist through the initial ongoing change, but their capacity to do so beyond this is not assured. Lastly, biologists may find it difficult to estimate the rate of change. Most models of global change impacts are based on short-term experiments and have typically focused on differences or ratios of state variables (e.g. control vs manipulated groups; Camac et al., 2015). While these models are useful for inferring the direction of impacts (which implicitly inform expert views), they often do not provide information on the rate of change, which is the fundamental process needed to accurately forecast the magnitude of change at some given snapshot in time (Camac et al., 2015; Morgan et al., 2016).

4.1 | Applicability of idea methodology to ecological problems

The IDEA protocol has been tested in a variety of application areas (Burgman, Carr, et al., 2011; Hanea et al., 2016; McBride et al., 2012; Speirs-Bridge et al., 2010; Wintle et al., 2012) and these tests consistently confirm the value of using a diverse group of experts, of giving experts the opportunity to cross examine the estimates of their peers, and of reducing ambiguity through discussion. In our elicitations, we speculate that experts revised their initial estimates if they (i) had no direct knowledge of the species themselves but were guided by the discussion, (ii) aligned responses to those of a taxon specialist or (iii) adjusted their values based upon a particular line of reasoning they found convincing during the discussion. Most validation studies found that when experts revise their estimates, they do so in the direction of the 'truth' (Burgman, McBride, et al., 2011; Hanea et al., 2018).

One difficulty in using this methodology was revealed at both workshops—the capacity of the participants to undertake this particular kind of statistical estimation. Gigerenzer and Edwards (2003) and many others (e.g. Low Choy et al., 2009) have previously documented the difficulties experts have when communicating knowledge in numbers and probabilities. We attempted a four-point elicitation with the plant experts for each species (1. lowest plausible value, 2. highest plausible value, 3. best estimate and 4. confidence that the truth falls between their lower and upper limits), and revised this down to a three-point elicitation for the animal experts (by omitting the confidence estimate, and fixing the upper and lower limits to correspond to a central 90% credible interval). While experts were comfortable in providing best estimates, there was inconsistency (indeed confusion) about interpreting and estimating bounds and confidence—even after conducting a brief workshop outlining how to do it. The two major discrepancies identified among experts included: (1) a variable understanding as to what confidence meant and how it should be use it to infer uncertainty bounds, and (2) a fundamental difficulty among some experts to conceptualize a distribution from which to infer bounds. As such, some experts estimated bounds that did not correspond with the confidence they had specified (i.e. in the plant group) or were asked to use (i.e. 90% in the animal group) and instead defined their bounds based on absolute maxima and minima as opposed to plausible confidence intervals around the mean. For these reasons, our analysis focused on using each expert's best estimates and not their estimated uncertainty defined by bounds and estimated confidence. Potentially valuable information about the confidence in estimates was therefore lost during the elicitation process. However, the IDEA protocol strives to elicit improved best estimates by eliciting bounds first. Even if the bounds are not used as a measure of the expert's uncertainty, the counterfactual thinking needed prior to eliciting the best estimates improves the latter. We feel that the 'best estimate' of cover or abundance is useful for forecasting the direction and magnitude of change expected by experts under a given global change scenario. Moreover, we believe that involving a mechanism for discussing and

revising estimates (through the IDEA protocol) provides robust insights into these potential changes.

4.2 | Management implications

The adaptive capacity framework we used to elicit expert opinions about how alpine species and communities may respond to global change currently exists as a framework of 'exposure risk' to change based on current state and predicted future state (i.e. our species prediction biplots). Our experts, through their judgement, implicitly accounted for multiple drivers of change in mountain ecosystems (e.g. rising temperatures, biotic interactions, feral animals and fire) but did so assuming no mitigation by management occurred. Using this approach, experts predicted that several plant (e.g. *Sphagnum cristatum*) and animal species (e.g. Baw Baw Frog *Philoria frosti*, Northern Corroboree Frog *Pseudophryne pengellyi* and Mountain Pygmy Possum *Burrymus parvus*) appear very vulnerable to the changes in alpine areas that are predicted to occur by 2050.

We believe that structured expert elicitation is a useful tool that land managers and conservationists can use to quickly identify species most vulnerable to global change (i.e. the species with limited adaptive capacity). However, for managers to operationalize these findings, they must ask: how might we buffer an identified vulnerable species against climate change? Or, improve its resilience? There are many management actions that can reduce threats and these are already part of a land manager's current arsenal such as removing feral animals and weeds, protecting vulnerable communities from fire and assisted migration. Data or additional expert elicitation could provide critical insights into the efficacy of different management options for improving the adaptive capacity of species identified as being vulnerable to global change. Managers may then use this information to rank interventions based on their efficacy to achieve such aims. In other words, not only can we use a species' adaptive capacity to identify vulnerable species but we could also identify the species most likely to respond to management interventions. Indeed, such an approach may even identify that, for some species, there is nothing that we can practically do to change their adaptive capacity. In such cases, it may be that options such as *ex situ* conservation strategies (such as seed banking and captive breeding) need to be implemented.

In an era of rapid change, conservation practitioners and land managers do not have the privilege of time to wait for additional data and knowledge to be accrued to inform their decisions. They must utilize information currently at hand to prioritize conservation efforts so that species losses may be mitigated. We believe the method and outcomes outlined here provide a pragmatic and coherent basis for integrating available expert knowledge to quantify adaptive capacity and perhaps help mitigate the overwhelming risk posed by global change to the long-term persistence of Australian alpine species.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

James Camac: Conceptualization, Investigation, Methodology, Formal Analysis, Software, Data curation, Writing—Original draft, Writing—Review & Edit, Visualization. **Kate Umbers:** Conceptualization, Investigation, Writing—Original Draft, Writing—Review and Edit, Project administration, Funding acquisition. **John Morgan**: Conceptualization, Investigation, Writing—Original Draft, Writing—Review and Edit, Project administration, Funding acquisition. **Sonya Geange:** Investigation, Data curation, Writing—Original Draft, Writing—Review and Edit. **Anca Hanea:** Investigation, Methodology, Data curation, Writing—Review and Edit. **Rachel Slatyer:** Conceptualization, Investigation, Methodology, Data curation, Writing—Review and Edit, Project administration, Funding acquisition. **Keith McDougall:** Conceptualization, Investigation, Data curation, Writing—Review and Edit. **Susanna Venn:** Investigation, Data curation, Writing—Review and Edit. **Peter Vesk:** Conceptualization, Writing—Review and Edit. **Ary Hoffmann**: Conceptualization, Writing—Review and Edit. **Adrienne Nicotra:** Conceptualization, Investigation, Writing—Original Draft, Writing—Review & Edit, Project administration, Funding acquisition.

ARTICLE IMPACT STATEMENT

Expert knowledge is used to quantify the adaptive capacity and thus, the risk posed by global change to Australian mountain flora and fauna.

DATA AVAILABILITY STATEMENT

De-identified data and code used to produce Figures 1–4 and Figures S2–S4 can be found at: https://github.com/jscamac/Alpine_Elicitation_Project.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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