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Planning for Species Conservation in a Time of Climate Change

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1. Introduction

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007) presented clear evidence that the global climate is changing because of human activities (Box 1). There is little doubt that this human-forced climate change event will become one of the main contributors to the global loss of biological diversity and has already caused accelerated rates of species' extinctions and changes to ecosystems across Earth (Sala et al., 2000; Thomas et al., 2004; Pimm, 2008). However, despite grim, almost doomsday-like, warnings in both the scientific literature and the general media for the best part of the last two decades (Peters & Darling 1985; Hannah et al., 2002), there has been little headway in the development of appropriate methodologies for integrating climate adaptation into conservation planning (Hannah et al., 2010; Poinani et al., 2011).

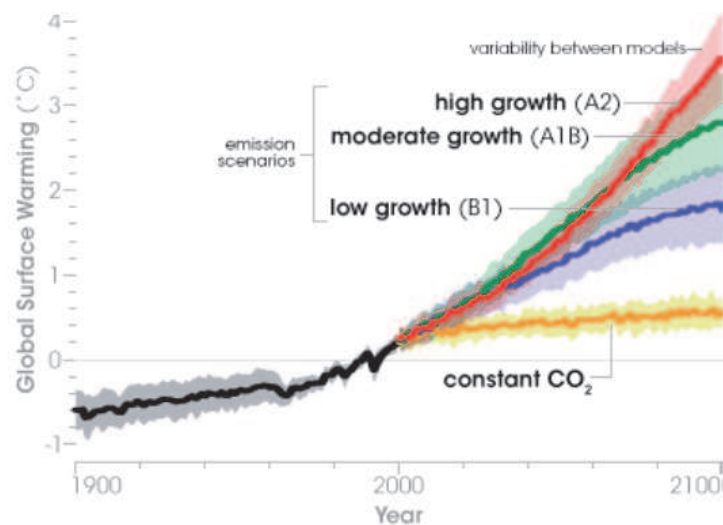
The purpose of this book chapter is to describe and classify some of the different methodologies governments and non-government organisations are using to integrate climate adaptation into conservation planning. By writing this book chapter, we hope to describe some of the benefits and limitations of the different adaptation planning approaches that are currently being espoused in the conservation arena. We conclude by describing some of the major hurdles human-forced climate change presents to conservation planners and some ways to overcome these. By no means is this an exhaustive review; rather, it builds on the work of others (e.g. Mawdsley et al., 2009; Dawson et al., 2011) by categorising some of the different adaptation planning activities being conducted within the conservation realm, so as to provide some clarity to national and international policy makers, private and public funding agencies, and practitioners, on what the best options are for conservation planning when climate change is considered.

Here, we focus on species-oriented conservation planning because it will ultimately be the reaction of species that define how ecosystems (and the services they provide) change because of human-forced climate change; species, as the basic evolutionary unit always need to be a focus of conservation planning. Although this chapter is species focused, many of the

conclusions are also applicable to ecosystems, habitats, ecological communities, and genetic diversity, whether terrestrial, marine, or fresh water.

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as statistically significant changes in the mean or variability of climate properties that persist for long periods of time (decades or longer, IPCC 2007). Over the past few centuries, human activities, such as the burning of fossil fuels and agricultural practices, have increasingly contributed to climate change. Since the beginning of the Industrial revolution, the burning of fossil fuels has contributed to the increase in carbon dioxide in the atmosphere from 280ppm to 390ppm, despite the uptake of a large portion of the emissions through various natural "sinks" involved in the carbon cycle. Although climate has changed repeatedly over past millennia, for a variety of reasons, anticipated human-driven changes are likely to be unusually fast and large (Houghton et al., 2001). Global mean annual temperatures have already increased by 0.75 °C (1.3 °F) between 1901 and 2002, and are projected to increase by another 2 to 4°C (3.6 to 7.2°F) before 2100 with considerable changes in the timing and distribution of precipitation (IPCC 2007a). However, these changes in temperature and precipitation are occurring at different rates around the world (Girvetz et al., 2009).

While 0.75 °C rise in the global mean temperature may seem a small change, this increase has already had a demonstrable impact on natural resources as maximum high temperatures and droughts have become more pronounced and acute over the last 100 years. This trend is projected to continue over the next 100 years (Christensen et al., 2007). While the public generally appreciates that a world of rapidly changing climate is not desirable for nature or for people, most do not understand the gravity of the situation and the need to act now to mitigate emissions and adapt our conservation actions to a changing climate. If we remain on the current greenhouse gas emission trajectory, we are committed to no less than a global mean temperature increase of 3 °C (5.4 °F) by the end of the 21st century (see the figure below).



Source: <http://www.epa.gov/climatechange/science/futuretc.html>

Fig. Projected increases in global surface temperature as predicted by different models of the Intergovernmental Panel on Climate Change (IPCC).

Box 1. A summary of human-forced climate change.

2. What is being done to integrate climate adaptation into conservation planning?

A quick review of the conservation literature when searching on terms such as 'climate change', 'climate adaptation' and 'conservation planning and climate change' highlights two things. First, the vast majority of research conducted to date has focused on documenting the effects of climate change on species and ecosystems. Relatively few studies go into much detail about what should be done when planning for conservation in a time of rapid climate change. This is not unsurprising considering ecologists and conservation biologists have only just started to grapple with the threat climate change poses to biodiversity and it normally takes conservation scientists time to move from understanding a threat to planning to overcome it. Second, when strategies for conservation in light of climate change are developed, a myriad of approaches are raised, all under the guise of 'climate adaptation'. An soon to be published survey of all activities being undertaken by the African Biodiversity Collaborative Group (ABCG) in response to the impacts of climate highlights a number of distinctly different planning activities conducted by seven NGO partners over the past five years – for example, identifying where corridors needed to be restored, undertaking species vulnerability analyses, assessing agricultural production against different climate forecasts, and holding stakeholders conferences—all of which were labelled 'climate adaptation planning'.

It is our contention that despite some excellent work on describing different adaptation-relevant activities (see, for example, Mawdsley et al., 2009) there has been little critical review of what distinguishes some of the very familiar conservation approaches and actions (e.g. protecting corridors) touted as adaptation strategies as truly addressing the new or enhanced challenges faced by species in the context of rapidly changing climate conditions and their impacts. It is unclear which activities are appropriate and which are not. As the literature increasingly addresses climate change and conservation, we believe it is important to go beyond calling everything we do 'climate adaptation'. Without critically evaluating the different approaches identified as climate adaptation by planners and practitioners, the confusion around which actions are effective responses will only get greater.

To date, we argue that most conservation planning activities that have been labelled in some form 'climate adaptation' can be placed into three broad strategies:

1. Continuing 'best practice';
2. Extending on 'best practice' principles in consideration of species response to past climate change; and
3. Integrating assessments on species vulnerability to climate change into a conservation planning framework.

The following sections summarize these categories in more detail.

3. Continuing 'best practice'

The start of the 1980s marked a new era for spatial conservation planning. Since Kirkpatrick et al.'s (1983) groundbreaking work of using detailed biogeographic information and selection algorithms in the design of protected area networks, the days of ad hoc placement of protected areas and the focus on saving a few flagship species are (hopefully) in the past. Over the past thirty years we have seen an extraordinary growth in systematic conservation planning, and related tools are now used by all the major environmental organizations and

many governments. From the publications of hundreds of peer-reviewed papers (see Moilanen et al., 2009; Watson et al., 2011 for summaries), a series of key principles have been identified as 'best practice':

- Identify and protect representative habitats (e.g. all habitats in a region are represented in conservation areas);
- Identify a persistence (adequacy) target of protection;
- Avert risk through replication (i.e. protection of multiple examples of each target);
- Protect critical habitats for threatened species; and
- Ensure the design is efficient, and aiming to reduce current threats to natural systems.

Until relatively recently, one of the most common beliefs held by governments and NGOs has been that continued planning using these principles will remain appropriate in a changed climate (Hannah et al., 2002). For example, the Australian government has stated that the first thing they need to accomplish when considering the long term impacts of climate change, is to ensure that a comprehensive, adequate and representative reserve system is achieved (Steffen et al., 2009).

While achieving these best practices principles are important aspects of an overall conservation agenda aimed at overcoming existing stressors that are creating the current extinction crisis, they should not be the sole basis of a climate adaptation strategy. The reason for this is the strategies that come from these 'best practice' principles are based on two problematic assumptions: (1) a relatively stable climate, and (2) that biological attributes are inextricably linked to place. We are not living in a period of a stable climate (see Box 1) and there is increasing evidence to show that the paradigm of 'place' (i.e. each site or region has its own suite of species, ecosystems, and genetic attributes that can be conserved without thinking of wider spatial or long-term temporal considerations) is very rare, regardless of climate change (Whittaker et al., 2005, Anderson and Ferree, 2010). When the problematic logic to these assumptions is ignored, the 'best practice' conservation paradigm is largely predicated on static spatial planning, and focused almost entirely on the establishment of protected areas and the identification of 'gaps' of important habitat. This type of planning does not consider the long-term implications of climate change and is not, as Game et al., (2010) observe, "approaches to climate change adaptation, despite commonly being cited as such in conservation literature; they are all things that we should be doing anyway."

4. Extending on 'best practice' principles

A goal of simply trying to achieve an adequate and representative system of reserves based on current species and ecosystem distributions and conditions has been rejected by most planners as insufficient to overcome the climate change challenge, and its use is in decline (Mackey et al., 2008). It has been replaced by the identification of a series of extensions of these principles, all of which are based on the fact that climate change is a natural phenomenon. Research over the past two decades has shown that there have been severe climatic oscillations for at least the last 500,000 years (Petit et al., 1999). Importantly, the ice core record shows that the transition out of glacial troughs may have been extremely rapid; arguably involving as much as 5°C warming in 20 years in some localities (Taylor, 1999). Almost all the species that persist today have gone through at least one of these glacial-interglacial cycles (Dawson et al., 2011), and a key question is – how did they survive past (often rapid) climate change events?

Five adaptation strategies have been derived based on past climate and biological response (see Box 2), and Mackey et al., (2008) argue that these strategies distil into a set of 'common sense' general, inter-related principles for conserving species and ecosystem viability in light of future climate changes (Heller & Zavaleta, 2009; Mackey et al., 2010; Watson et al., 2009). These principles are:

- Significantly expand the current protected area estate to maintain viable populations of species and maximize adaptive capacity;
- Significantly expand the current protected area estate so as to capture refugia;
- Assign priority to protecting large, intact landscapes; and
- Ensure functional connectivity is maintained beyond protected areas.

These 'extending on best practices' principles are summarized below.

Evidence from marine sediments and polar ice cores has revealed the severe climatic oscillations that have occurred over the last 500,000 years (Petit et al., 1999). About every 120,000 years, average planetary conditions have oscillated between long glacial periods with low levels of atmospheric CO₂, low temperatures and dryness to shorter inter-glacial 'highs' that experienced high levels of atmospheric CO₂, higher temperatures and wetness. These glacial-interglacial oscillations revealed in the marine and ice core records are considered to be driven by long term periodic 'wobbles' in the Earth's orbit which changes the balance of solar energy reaching each hemisphere (Muller et al., 1997). The transition from glacial to interglacial is accelerated by positive feedbacks from ice melt and oceanic discharge of greenhouse gases (Hansen et al., 2007). Importantly, it is not a linear transgression with the ice core record showing that the transition out of glacial troughs may have been extremely rapid; arguably involving as much as 5°C warming in 20 years (though not all species have been confronted with changes of this magnitude) (Taylor, 1999). Almost all the species that persist today have gone through at least one of these glacial-interglacial cycles.

Five adaptive strategies have been identified, all of which help guide generic planning (Mackey et al., 2008):

(1) Micro-evolution. Evolution is heritable genetic change within populations. It is commonly understood to refer to only long term directional genetic change leading to speciation, that is, the evolution of new species. However, also evident is the evolution of new, fitter traits that represent local adaptations to changing conditions, including climate change, that are not necessarily directional and lead to speciation. There is increasing evidence that micro-evolution is far more rapid, common and widespread than previously recognized (Thompson, 2005) and is now occurring in response to rapid climate change (Bradshaw & Holzapfel, 2006).

(2) Phenotypic plasticity. The phenotype is the physical expression in an organism of its genome. Phenotypic plasticity refers to the range of genetically controlled permissible responses with respect to a species' morphological, physiological, behavioural or life history strategies and traits (Nussey et al., 2005). An example of phenotypic plasticity is the ability of a plant to change its growth form from a 'tree' to a 'shrub' in response to reduced water availability. Phenotypic plasticity differs from micro-evolution in that the adaptive response is found within the existing genome and is not the result of new, heritable genetic

change in the population.

(3) Dispersal. The dispersal of juveniles and seasonal migrations are common ecological activities. However, dispersal – in the sense of long distance movement – to locations that meet a species physiological niche and habitat resource requirements is a common adaptive life history strategy in many species, especially birds (Gilmore et al., 2007). In Australia, this is a necessary adaptive response for many species given the great variability in year-to-year rainfall and associated fluctuations in plant growth and the supply of food resources (Berry et al., 2007).

(4) Refugia and range reductions. Species can also persist by range reduction to micro-habitats that retain the necessary niche and habitat requirements; so called refugia (Mayr, 2001; Lovejoy & Hannah, 2004). Locations can function as refugia as a result of species responses to long term or short term environmental change. In Australia, refugia have been documented in the arid zone (long-term climate change related refugia; Morton et al., 1995), in temperate forests (fire refugia with respect to fire intervals of decades to centuries; Mackey et al., 2002), and monsoonal Northern Australia (annual seasonal refugia; Woinarski et al., 2007). The recognition of locations or networks of locations as refugia also invokes issues of spatial scale. For example, Soderquist and MacNally (2000) identified the role of mesic gullies embedded within dominantly drier forested landscapes. Remnant patches in a fragmented landscape can also function as refugia from which organisms can disperse to re-populate habitat as it regenerates following broad scale ecological restoration efforts.

(5) Wide fundamental niche. It is also possible for species to persist simply because they have evolved very wide fundamental (that is, physiological) niche requirements (*sensu* Hutchinson, 1957) and are able to survive, compete and reproduce under a broad range of climatic conditions. For example, many of Australia's forest and woodland birds occur in temperate, subtropical and tropical climatic zones, with the common determinant being vegetation-related habitat resources rather than fundamental niche response to temperate regimes.

Box 2. Five different adaptive strategies that species may have employed to overcome past climate change events (adapted from Mackey et al., 2008).

4.1 Principle 1: significantly expanding the current protected area estate to maintain viable populations of species and maximize adaptive capacity

A primary principle for conservation in a time of climate change is to maintain viable populations of all extant species across natural ranges in order to maximize intra-species genetic diversity and thus options for local adaptation and phenotypic plasticity (adaptation responses (1) and (2) in Box 2). A fundamental focus is thus replicating habitats in the reserve system so as to protect multiple source-populations across the environmental gradients occupied by the species (Watson et al., 2011).

4.2 Principle 2: significantly expanding the current protected area estate so as to capture refugia

A related goal is the identification and protection of refugia, or macro- and micro-habitats that supported relict species during past episodes of climatic warming (e.g., during

interglacial periods) (Morton et al., 1995; Pressey et al., 2007; Ashcroft, 2010). Past climate change has resulted in some species experiencing dramatic range shifts and/or in-situ reductions; many species now only occur in networks of scattered locations that retain suitable conditions at a micro-scale because of this. It is thought that protection of refugia may prove critical in assisting certain species to persist through future rapid climate change (Mackey et al., 2002). If information on the specific locations of refugia that supported cooler-climate species during past times of warming is lacking, then a logical extension of the idea presented in section 4.1 is to significantly expand the protected area estate in the hope that this will increase the likelihood of capturing important refugia.

4.3 Principle 3: assign priority to protecting large, intact landscapes

As discussed in the 'Continuing best practices' section (3), conservation biologists and planners have reacted to the biodiversity crisis that is currently caused by, among others, rampant vegetation clearance and the introduction of invasive species by identifying priority areas to manage for conservation (Margules & Pressey, 2000; Fuller et al., 2010). Many of these approaches prioritize areas using criteria such as maximizing the number of threatened species and/or ecosystems (Myers et al., 2000; Dietz & Czech, 2005). While this threat-based approach to spatial prioritisation, targeting a snapshot of vulnerable biodiversity and landscapes, is logical in the short term given accelerating anthropogenic threats and past impacts (Brooks et al., 2002; Spring et al., 2007), it is not likely to be sufficient to ensure the long term persistence of biodiversity in the face of climate change. A reactive, threat-based approach does not take into consideration the impacts of climate change on the degree of threat and vulnerability of species.

Therefore a key principle is to proactively conserve large intact areas, often termed 'wilderness', alongside hotspots of threatened biodiversity (Mackey et al., 2008; Watson et al., 2009), as these landscapes sustain key ecological and evolutionary processes outlined in Box 2 (Soulé et al., 2006; Mackey et al., 2008). The high level of natural connectedness and climatic gradients driven by variability in elevation and aspect in intact landscapes improves the likelihood of survivorship of species by supporting large populations and a range of microhabitats. The ecosystems of extensive and intact lands will play a vital role in facilitating natural adaptation responses by species to human-forced climate change (Soulé & Terborgh, 1999). In particular, mobile species will have more habitat options as they disperse to find suitable locations in response to rapidly changing climate.

4.4 Principle 4: ensure functional connectivity is maintained beyond protected areas

A strategy based solely on the first three principles (e.g. expanding the protected area estate to increase species' adaptive capacity and protect past climate refugia, and ensuring large intact landscapes remain large and intact), is not likely to be sufficient to protect all biodiversity in a time of climate change (Rodrigues et al., 2004a; 2004b). This is because many of the most biologically productive landscapes around the world have been converted to agricultural uses, are privately owned or are in demand for more lucrative land uses (Mittermeier et al., 2003; Recher, 2004). As such, there is a general shortage of large intact areas to preserve in many landscapes (Lindenmayer, 2007). For these reasons, it is also important to undertake conservation management in the lands around formal protected areas to buffer them from threatening processes originating off-reserve and ensure 'connectivity' between protected areas.

Until recently, ensuring 'connectivity' in fragmented landscapes was focused entirely on the spatial arrangement of different types of habitat patches in the landscape and assessing

ways to connect them (Tischendorf & Fahrig, 2000). Landscape connectivity was measured by analysing landscape patterns (McGarigal et al., 2002). In recent years, 'increasing ecological connectivity' has moved away from assessing the best design for vegetation corridors between protected areas, and towards achieving 'functional connectivity', which refers to protecting the spatially dependent biological, ecological and evolutionary processes within a landscape that will ensure long term persistence of biodiversity (Crooks & Sanjayan, 2006; Mackey et al., 2010). Examples of 'functional connectivity' processes include: maintaining ecologically functional populations of highly interactive species in the landscape (i.e. trophic regulators), understanding the habitat requirements of dispersive fauna, and maintaining natural disturbance (e.g. fire) and hydro-ecological regimes (Soulé et al., 2004; Mackey et al., 2007). The move towards ensuring functional connectivity does not preclude the creation of corridors, but rather it ensures a more holistic set of considerations that will be critical when considering the more dynamic connectivity needs of species during times of rapid climate change.

As noted above, the habitat loss, fragmentation and degradation now present in many productive landscapes presents significant impediments and barriers to species that may need to disperse and find new habitats (Bennett et al., 1992; Mansergh & Cheal, 2007). Therefore, an important component of ensuring functional connectivity is the protection and/or restoration of large-scale migration corridors that operate at regional and continent scales (Mackey et al., 2008). Where habitat connectivity has already been largely disrupted through broad scale land clearing, it is imperative that large scale rehabilitation of land cover conditions and land use between existing nature reserves becomes an integral part of the conservation framework. These intervening lands need to become more conducive to biological permeability and associated ecological and evolutionary processes. In this context, restoration will include development of regional networks of habitat patches, habitat corridors and habitat 'stepping stones'.

Some off-reserve 'connectivity conservation' actions that have been identified in the literature include:

- halting and reversing land clearing as this will help prevent further loss and fragmentation of core habitats and migration corridors (Soulé et al., 2004);
- developing policies that lead to removal of unsustainable extractive land use activities (primarily livestock grazing and logging (Woinarski et al., 2007; Lindenmayer, 2007) thereby preventing further habitat degradation;
- halting further large scale impoundment and diversion of water (Mackey et al., 2007);
- restoring migration corridors and stepping stones between intact protected areas (Donlon et al., 2006);
- re-vegetating riparian systems so as to provide corridors and at the same time ensure waterways remain cool (Seavy et al., 2009);
- restoring (or protecting) altitudinal and latitudinal gradients (Hodgson et al., 2009);
- controlling invasive weeds and animal pests (Woinarski et al., 2007); and
- restoring ecologically appropriate fire regimes (Soulé et al., 2004).

5. Integrating assessments on species vulnerability to climate change into a conservation planning framework

While it is widely accepted that the principles based on past climate responses outlined in the previous section are useful as they provide a 'rule of thumb' set of activities to guide

conservation planning, it must be remembered that this the current anthropogenically-driven climate change event is different. All extant species are going to be exposed to climate changes of a rate and magnitude that they have most previously experienced, or that they have not experienced for thousands of years. Paleoecological data suggests the majority of the last 800,000 years was considerably cooler than today and the lowest or near-lowest global temperatures were reached at the last glacial maximum, 20,000 years ago. It is therefore thought that there has been much stronger selection for cold tolerance than heat-tolerance for nearly a million years (and possibly much longer), with the implication that the most heat-tolerant genes and species will already have been eliminated (Corlett et al., 2011). Moreover, the rate of change is going to be extremely rapid when compared to much of the warming that has taken place in the past (Box 1), and species are already coping with landscapes that have been significantly altered by human activities. As a consequence, simply adhering to the principles outlined above is unlikely to capture a coherent conservation adaptation agenda and it is therefore necessary that conservation planning and action explicitly account for this unique human-forced climate change event, and the vulnerabilities and impacts it will cause.

5.1 Assessing species vulnerability

To develop a plan that identifies strategies that will help species overcome this human-forced, and unnatural, climate change event, it is first necessary to understand how species differ in their vulnerability to projected future climate (Foden et al., 2009). As elaborated in Box 3, the vulnerability of species to climate change is generally assessed as a product of its: (i) susceptibility/sensitivity (defined by its intrinsic biological traits), (ii) exposure (does the species occur in a region of high climatic change?) and (iii) adaptive capacity (Box 3; Foden et al., 2009; Hole et al., 2011).

Vulnerability is the extent to which a species or population is threatened with decline, reduced fitness, genetic loss, or extinction owing to climate change. Vulnerability has three components: exposure (which is positively related to vulnerability), sensitivity (positively related), and adaptive capacity (negatively related).

Exposure refers to the extent of climate change likely to be experienced by a species or locale. Exposure depends on the rate and magnitude of climate change (temperature, precipitation, sea level rise, flood frequency, and other hazards) in habitats and regions occupied by the species. Most assessments of future exposure to climate change are based on scenario projections from GCMs often downscaled with regional models and applied in niche models.

Sensitivity is the degree to which the survival, persistence, fitness, performance, or regeneration of a species or population is dependent on the prevailing climate, particularly on climate variables that are likely to undergo change in the near future. More sensitive species are likely to show greater reductions in survival or fecundity with smaller changes to climate variables. Sensitivity depends on a variety of factors, including ecophysiology, life history, and microhabitat preferences. These can be assessed by empirical, observational, and modeling studies.

Adaptive capacity refers to the capacity of a species or constituent populations to cope with climate change by persisting in situ, by shifting to more suitable local microhabitats, or by migrating to more suitable regions. Adaptive capacity depends on a variety of intrinsic factors, including phenotypic plasticity, genetic diversity, evolutionary rates, life history traits, and dispersal and colonization ability. Like sensitivity, these can be assessed by empirical, observational, and modeling studies.

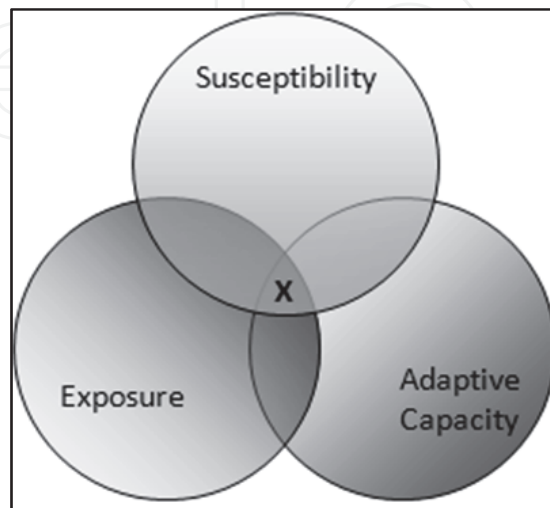


Fig. A schematic representation of a species vulnerability to climate change, where each component varies from 'low' to 'high' according to the shading gradient, such that 'X' represents greatest vulnerability (i.e., the intersection of the three components – high susceptibility, high exposure and low adaptive capacity; see also Box 3) (Source: Hole et al., 2011).

Box 3. Species vulnerability in the context of climate change (Source: Dawson et al., 2011).

There are a number of methods that assess species vulnerability and integrate this into conservation planning (Hole et al., 2011). Arguably the most commonly used methods utilize some variation of climate-envelope (or empirical niche) models (Guisan and Thuiller, 2005). Climate-envelope models use current distributions of species to articulate the range of climatic conditions that suit them. Climate model projections for the future are then examined to determine where on the landscape the optimal 'envelope' of climate conditions may be located in the future. For many species, these models have shown that large geographic displacements and widespread extinctions will take place (e.g Araújo et al., 2006).

Despite their frequent use, climate envelope models are contentious, not least because they omit a number of factors that may be as or more important than climate in controlling species distributions. For example, these models generally exclude consideration of human activities, interactions with other species and random events. They are also not comprehensive, since they focus almost exclusively on exposure to climate change and do not incorporate other aspects of vulnerability such as acclimation, interspecific interactions, dispersal limitations and adaptive capacity (Corlett in press, Dawson et al., 2011, Rowland et al., 2011).

A recent paper by Dawson et al., 2011 outlined a new framework for assessing how vulnerable a species is to climate change, based on the integration of mechanistic, empirical

and observational methodologies (See Figure 2). While this framework has not yet been utilized (as far as we are aware), it is likely to be useful because it overcomes the shortfalls of climate envelope models.

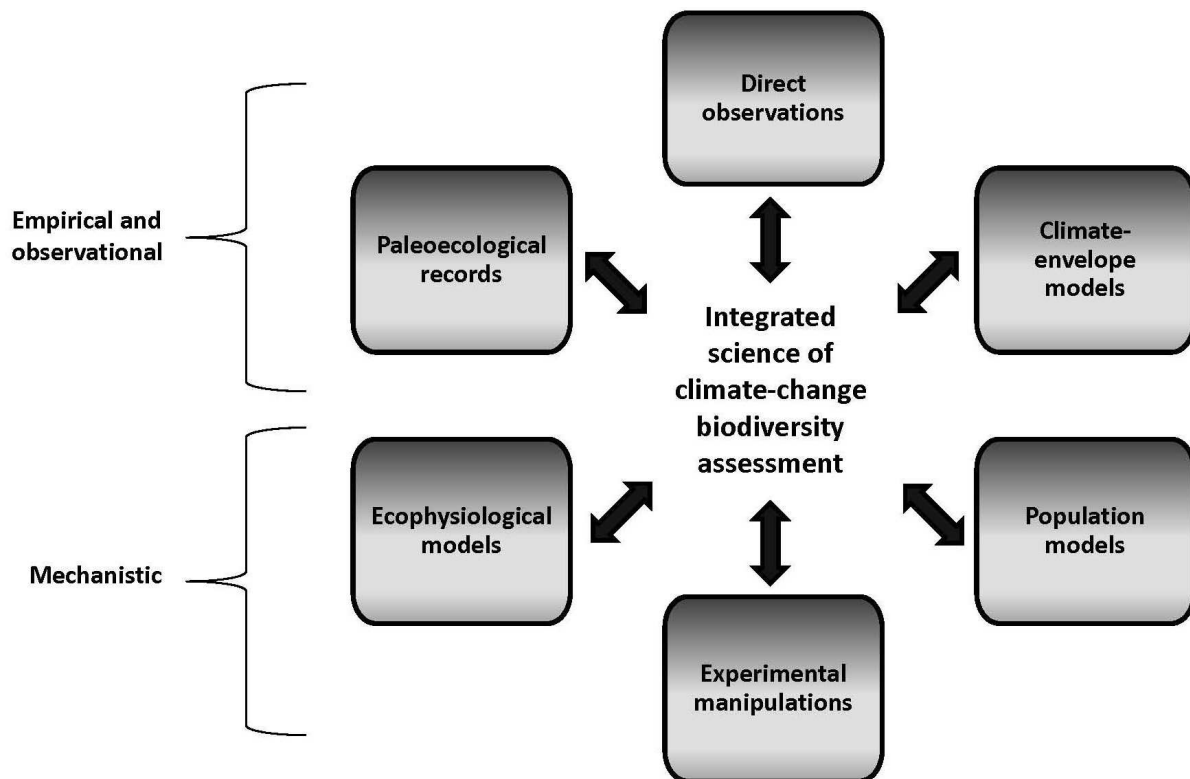


Fig. 2. Dawson et al., (2011) argue that an ‘integrated’ climate-change biodiversity assessment will overcome the shortfalls of climate-envelope modeling by drawing from multiple sources and approaches. Each provides useful information on exposure, sensitivity, and adaptive capacity, and integration of these approaches will provide a more robust basis for vulnerability assessment and allocation of resources for conservation and adaptation.

While the integrated methodology outlined by Dawson et al., (2011) has never been used, there exist expert opinion driven methodologies that capture all the aspects of vulnerability (exposure, sensitivity, adaptive capacity). For example, NatureServe has developed a *Climate Change Vulnerability Index* (see <http://www.natureserve.org/>) that uses a scoring system that integrates a species’ predicted exposure to climate change within an assessment area and three sets of factors associated with climate change sensitivity: 1) indirect exposure to climate change, 2) species-specific factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors), and 3) documented response to climate change. NatureServe argues that assessing species with this Index facilitates grouping taxa by their relative vulnerability to climate change, and by sensitivity factors, which NatureServe expects will help users to identify adaptation options that could benefit multiple species. Further, while it is still new, they hope that this tool will help land managers develop and prioritize strategies for climate change adaptation that lead to actions that reduce the vulnerability of species to climate change. A limitation to the NatureServe methodology is that it is not spatially explicit; however, vulnerability results associated with species distributions have potential to be used in large scale planning exercises.

5.2 Integrating species vulnerability into a conservation planning framework

Adaptation, as defined by the IPCC (Schneider et al., 2007), is an *adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*. Accordingly, a key aspect of integrating adaptation into conservation is to ascertain what the future will look like (and accepting the uncertainties around this), and then integrating this knowledge into all activities (and not just conservation-oriented planning) that are currently in place. Therefore while undertaking species' vulnerability assessments is an important first step in developing an adaptation plan, it can only be considered a first step, and there needs to be a process of integrating this data into a holistic planning framework.

While still in its infancy, there are now a number of tools aimed at overcoming the considerable uncertainty and complexity of climate change by tailoring adaptation strategies to particular species, human communities and geographies (e.g. Groves et al., 2010; Cross et al., in review). Common to many of these tools are the following steps:

1. Identify features targeted for conservation (e.g., species, ecological processes, or ecosystems) and specify explicit, measurable management objectives for each feature.
2. Build a conceptual model that illustrates the climatic, ecological, social, and economic drivers of each feature.
3. Examine how the feature may be affected by multiple plausible climate change scenarios. This can be a threats-based analysis of current and future states, and often takes the form of a vulnerability assessment (see section 5.1).
4. Identify intervention points and potential actions required to achieve objectives for each feature under each scenario.
5. Prioritize potential actions based on feasibility and tradeoffs.
6. Implement priority actions, monitor the efficacy of actions and progress toward objectives, and re-evaluate to address system changes or ineffective actions.

The Adaptation for Conservation Targets (ACT) Framework is one such tool that was developed by a team of conservation planners and practitioners (affiliated with the National Center for Ecological Analysis and Synthesis in Santa Barbara, California, and including NGO, government agency and university participants) (Cross et al, in review; Figure 3). The ACT Framework is a participatory and iterative process for generating adaptation strategies that is practical, proactive, place-based, and helps to overcome the reluctance to take actions due to uncertainties inherent in future projections. Working with multiple stakeholders and partners, the Wildlife Conservation Society is using the ACT Framework to identify and implement priority climate change-informed wildlife conservation and management strategies across a number of landscapes in the United States (see Table 1). The framework draws on collective knowledge to translate climate change projections into a portfolio of adaptation actions. These actions can then be evaluated in the social, political, regulatory, and economic contexts that motivate and constrain management goals and policies.

While planning processes such as the ACT Framework may end up recommending some of the same actions outlined in section 4 (e.g create and/or restore corridors, increase the size of protected areas etc), the key difference is the process by which those actions are identified. Rather than simply relying on 'rules of thumb', structured adaptation planning explicitly considers the long term impacts of climate change when determining appropriate and necessary conservation actions. Targeted climate change planning also attempts to strategically direct where adaptation actions are needed most.

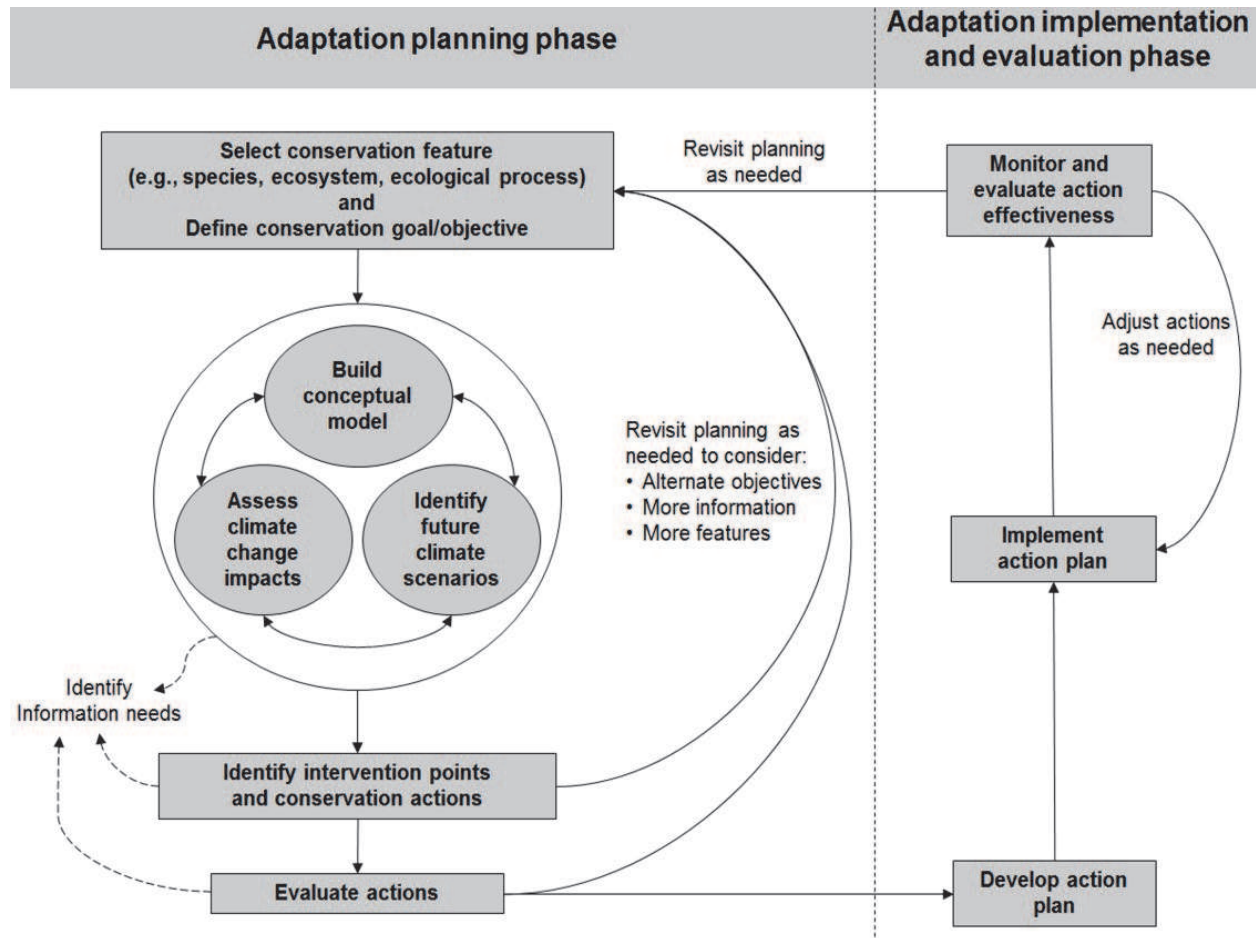


Fig. 3. The Adaptation for Conservation Targets (ACT) framework (adapted from Cross et al., in review). An online description of this framework is available at the Climate Adaptation Knowledge Exchange (CAKE; <http://www.cakex.org/virtual-library/2285>)

7. Several challenges for effective climate change planning

This review provides a first attempt to classify some of the different climate adaptation approaches being undertaken around the world. While all the approaches are important for conservation, we argue that we need to move from a conservation paradigm dominated largely by static spatial assumptions (i.e. the *Continue 'best practices'* approach described in section 3) to one that incorporates spatial and temporal dynamics of climate change and their attendant uncertainties. Given the absence of precedent for this multifaceted (and globally distributed) threat, the conservation community has largely been caught off balance in determining what the best courses of action are to address it (Moser & Ekstrom 2010). While there has been some movement away from generic principles towards explicit species impact assessments and planning frameworks that integrate climate change (such as the approaches outlined in section 5), a few remaining challenges to effective climate change planning are outlined below. These challenges are the focus of a burgeoning area of research that deserves much attention in the near future if these challenges are to be overcome.

Project Location	Conservation Features Addressed	Project Leads
Jemez Mountains, New Mexico	Wildfire regime; Jemez River flows	Southwest Climate Change Initiative ¹
Gunnison River Basin, Colorado	Alpine wetlands; Gunnison River headwater flows; Gunnison sage-grouse	Southwest Climate Change Initiative
Four Forest Restoration Initiative area, Arizona	Ponderosa pine wildfire regime; Ponderosa pine watershed function; Mexican spotted owl	Southwest Climate Change Initiative
Bear River Watershed, Utah	Abandoned oxbow wetlands; Bonneville cutthroat trout	Southwest Climate Change Initiative
Adirondack State Park, New York	Lowland boreal wetlands	Wildlife Conservation Society
Northern U.S. and Transboundary U.S.-Canada Rocky Mountains	Grizzly bears; Wolverines	Wildlife Conservation Society and U.S. Fish and Wildlife Service
Great Plains Landscape Conservation Cooperative region (parts of Colorado, Nebraska, Kansas, Oklahoma, Texas and New Mexico)	Grassland structural and compositional diversity (to support sustainable bird populations)	Wildlife Conservation Society

¹The Southwest Climate Change Initiative is led by The Nature Conservancy in partnership with the Climate Assessment for the Southwest, Wildlife Conservation Society, National Center for Atmospheric Research, Western Water Assessment, USDA Forest Service, and the University of Washington.

Table 1. On-going efforts to test and refine the Adaptation for Conservation Targets (ACT) Framework in landscapes across the United States.

7.1 Forecasting the impacts of climate change at scales that are relevant to planners

While the general physics of global warming can be easily explained and understood (e.g. more greenhouse gases in the atmosphere will lead to radiative forcing that will, in turn, lead to the Earth warming; see Box 1), the science of how climate change will affect landscapes and seascapes at the spatial scales at which conservation is normally planned for and conducted is far more complex. Current limitations in the different global circulation models (GCMs) and downscaling techniques, and the variability of forecasts that are derived from these exercises has resulted in considerable uncertainty (and sometimes scepticism) in how to best plan for climate change in different landscapes and seascapes (Wiens & Bachelet, 2010). For example, while most GCMs show consistent rainfall and temperature trends in east Africa over the next century, they are vastly inconsistent in their predictions throughout Southeast Asia (IPCC, 2007). Integrating future climate scenarios in conservation plans will mean very different things to conservation planners in Southeast Asia, as the degree of uncertainty is immense. A lack of information on what future climates

are possible in different regions has hampered climate change adaptation planning to an extent that most conservation action undertaken across the globe is completely blind to the challenge that climate change presents. This challenge can only be overcome with increased efforts in understanding how the current climate system works. However, it is important to recognise that some of these problems outlined above may not be overcome for many years or decades. Therefore, while improving climate-change projections and downscaling techniques is important, planners must recognize that there will continue to be unknowns – we need to become comfortable planning for conservation within realms of uncertainty (Watson et al., 2011).

7.2 Addressing climate variability in addition to climate change

There is considerable confusion over what can be attributed to climate variability (at inter-annual and multi-decadal time scales) and what can be attributed to long-term climate change. This confusion can hamper the process of conservation planning. Regional variation in temperature and precipitation is sensitive to fine-scale topographic features that affect weather patterns (e.g. mountain ranges) as well as other larger-scale climate features (e.g. the El Niño-Southern Oscillation), some of which are not well understood and therefore not captured by the GCMs on which current projections are based (CSIRO, 2007, Sheridan & Lee, 2010). For example, for the continent of Australia, Prowse and Brook (2011) identify four modes of climate variability that are particularly important for the Australian climate: the El Niño Southern Oscillation (ENSO), the inter-decadal Pacific Oscillation (IPO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM), none of which are accurately captured in the current generation of climate models, but all of which have significant impacts on biodiversity.

When assessing the effects of climate change, we need to move away from simply taking into account the long-term changes in mean climate variables (e.g. temperature increases or decreases in seasonal rainfall occurring over many years or decades). A thorough planning exercise needs to consider discrete impacts, principally extreme weather events (e.g., storms, droughts, fires, extreme temperature or rainfall events) that can have dramatic implications for the persistence of many species. Conservation planners need to formulate vulnerability assessments that integrate the impacts of both climate variability and climate change (and how climate change may impact climate variability), and integrate this knowledge into spatially explicit planning tools. This may only be achieved with a more thorough understanding of species thresholds to climate events, which is relatively unexplored in the climate – biodiversity literature at the moment (Corlett, 2011).

7.3 Incorporating the myriad of threats climate change presents into planning

Although most planners are likely to be aware of frequently discussed changes such as sea-level rise, melting of sea-ice and permafrost, or the impacts of severe droughts or storms, there are many less obvious impacts to ecosystems around the globe that are more difficult to predict and plan for. As the climate changes, so will key abiotic characteristics that are the basic building blocks of a species' fundamental niche (e.g. temperature, rainfall, cloud formation, rates of evaporation, evapotranspiration etc). The distribution and abundance of many species are likely to be affected by climate change induced alterations of the length of the growing season, the timing of seasonal events (e.g. phenology), and the length of the stratification period in lakes, to name but a few examples (see Figure 4; Parmeson & Yohe,

2003; Root et al., 2006). These impacts of climate change are relatively hard to predict and require a depth of knowledge of a species' ecology, which is rare for 99.9% of species (Whittaker et al., 2005). A recent paper by Geyer et al., (2011) highlight the issue that climate change impacts are complex: in their analyses of 20 conservation sites they classified and grouped climate change induced stresses on biodiversity and found that there were at least 90 different specific stresses could be attributed to climate change.

A related challenge is ascertaining how processes that currently effect species persistence will be indirectly affected (and often exacerbated) by climate change. When considering the impacts of climate change, it should not be forgotten that we are in the midst of an extinction crisis. Global species extinctions currently exceed the background rate by several orders of magnitude (Pimm et al., 1995; Woodruff, 2001) and the most recent International Union for Conservation of Nature (IUCN) Red List describes an ever worse situation for the world's biodiversity, with at least 38% of all known species facing extinction in the near term (Vie et al., 2009). Habitat loss is the most pressing threat to species persistence globally (Baillie et al., 2004); however, a range of other threats also drive species endangerment, including spread of disease, increase in frequency and intensity of fire and the relative importance of particular types of threat varies across taxonomic groups (Ceballos & Ehrlich, 2002; Davies et al., 2006; Ehrlich & Pringle, 2008). For certain species overexploitation and loss of habitat are immediate threats- so actions such as enforcement need to be undertaken regardless of the predicted impacts of climate change on the species. Most of these other threats will ultimately be dictated by how humans respond to climate change, which leads to a further complexity. To overcome this challenge, more research needs to be focussed on both developing methods that assess (quickly) what the impacts of climate change will be for particular species and how current drivers of extinction will change as a consequence of climate change.

7.4 Mainstreaming adaptation

One of the main obstacles with conservation planning is that many of the products of planning, while well thought through, are never implemented because they do not consider how humans will be affected by the plan. To be successfully implemented, systematic conservation plans must be complemented with social, political, and institutional tools and processes (Knight et al., 2009). Planned adaptation involves societal intervention to manage systems based on the knowledge that conditions will change, and actions must be undertaken in order to reduce any risks that may arise from that change, and particularly within vulnerable systems. While often talked about, this is rarely achieved when conservation planning is conducted.

The linkages between the impacts and responses of people and biodiversity to climate change are very strong and in recent years a concept known as 'ecosystem based adaptation' (EBA) has been developed which aims to use biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change (Secretariat of the CBD, 2009). Such an approach aims to take into account the role that ecosystem services can play in human adaptation, while at the same time helping people to adapt in equitable and participatory ways that avoid bringing short-term benefits but in the longer term place additional pressures on natural systems, threatening the very systems that people depend on. We believe that this while in its infancy, the tenets of EBA can be integrated into the framework outlined in Figure 3 and be used to find optimum solutions to balance the needs of both humans and biodiversity.

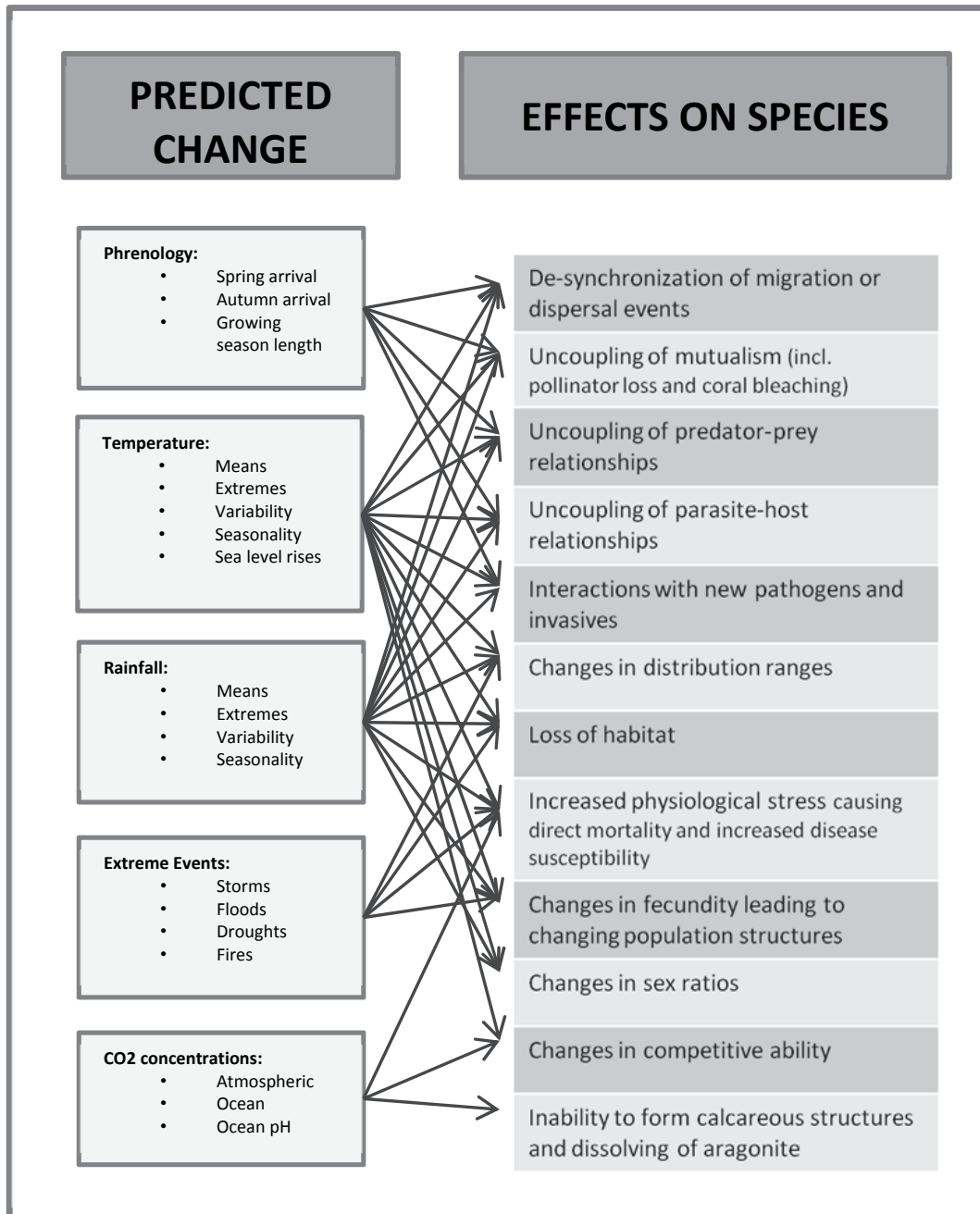


Fig. 4. Climate change impacts and their predicted effects on species (from Foden et al., 2008).

8. Conclusion

Climate change is a fact of our times. It is already altering species from the poles to the tropics (Root et al., 2005; Parmesan, 2006) and because greenhouse gas emissions to date commit the Earth to substantial climate change, will do so for decades or centuries to come regardless of the mitigation efforts we undertake. This change is happening faster than

originally expected and faster than most managed systems have experienced previously. The potential for the loss of biodiversity, termination of evolutionary potential, and disruption of ecological services must be taken seriously. Averting deleterious consequences for biodiversity will require immediate action, as well as strategic conservation planning for the coming years and decades.

In this chapter, we have identified a number of broad strategies being used by conservation planners to overcome the challenge presented by climate change. We are critical of an approach that blindly relies on status quo and *Continue 'best practices'* as we think it is inappropriate and in the long-term, could lead to conservation activities that are maladaptive. Planners must adapt to deal with the new reality that climate change presents, and abandon the current focus on the preservation and restoration of 20th century reference conditions, as they will no longer be relevant in a changing world. We believe that a refocus on *Extending 'best practice' principles* is a more appropriate response as the set of 'common sense' general principles outlined in section 4 for conserving species and ecosystem viability that are based on adaptive responses to past climate changes are important and should always be considered and enacted, especially if there is limited access to data on future climate changes and associated impacts (Heller & Zavaleta, 2009; Mackey et al., 2010; Watson et al., 2009). However, integrating future climate change forecasts and scenarios into conservation strategies is going to be vital for long-term biodiversity protection as this human-induced climate change event is different from past climate changes (Heller & Zavaleta, 2009). This is especially true in the context of the many other current threats to natural systems that will also be affected by changes in local climate (Sala et al., 2000; Orr et al., 2008). Structured climate change planning needs to consider not just how species will be affected by climate, but also how humans are going to be affected. Many species are likely to go extinct because of the direct and indirect consequences of climate change unless we develop pro-active planning frameworks within a new, more dynamic conservation paradigm.

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This book provides an interdisciplinary view of how to prepare the ecological and socio-economic systems to the reality of climate change. Scientifically sound tools are needed to predict its effects on regional, rather than global, scales, as it is the level at which socio-economic plans are designed and natural ecosystem reacts. The first section of this book describes a series of methods and models to downscale the global predictions of climate change, estimate its effects on biophysical systems and monitor the changes as they occur. To reduce the magnitude of these changes, new ways of economic activity must be implemented. The second section of this book explores different options to reduce greenhouse emissions from activities such as forestry, industry and urban development. However, it is becoming increasingly clear that climate change can be minimized, but not avoided, and therefore the socio-economic systems around the world will have to adapt to the new conditions to reduce the adverse impacts to the minimum. The last section of this book explores some options for adaptation.

How to reference

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