Environmental Management (2012) 49:1103–1114
DOI 10.1007/s00267-012-9853-2

FORUM

Integrating Climate Change into Habitat Conservation Plans Under the U.S. Endangered Species Act

Paola Bernazzani · Bethany A. Bradley · Jeffrey J. Opperman

Received: 27 July 2011 / Accepted: 19 March 2012 / Published online: 26 April 2012

Abstract Habitat Conservation Plans (HCPs) under the Endangered Species Act (ESA) are an important mechanism for the acquisition of land and the management of terrestrial and aquatic ecosystems. HCPs have become a vital means of protecting endangered and threatened species and their habitats throughout the United States, particularly on private land. The scientific consensus that climate is changing and that these changes will impact the viability of species has not been incorporated into the conservation strategies of recent HCPs, rendering plans vulnerable biologically. In this paper we review the regulatory context for incorporating climate change into HCPs and analyze the extent to which climate change is linked to management actions in a subset of large HCPs. We conclude that most current plans do not incorporate climate change into conservation actions, and so we provide recommendations for integrating climate change into the process of HCP development and implementation. These recommendations are distilled from the published literature as well as the practice of conservation planning and are structured to the specific needs of HCP development and implementation. We offer nine recommendations for integrating climate change into the HCP process: (1) identify species at-risk from climate change, (2) explore new strategies for reserve design, (3) increase emphasis on corridors, linkages, and connectivity, (4) develop anticipatory adaptation measures, (5) manage for diversity, (6) consider assisted migration, (7) include climate change in scenarios of water management, (8) develop future-oriented management actions, and (9) increase linkages between the conservation strategy and adaptive management/monitoring programs.

Keywords Biological conservation · Climate change · Habitat conservation plans · Ecosystem management · Endangered species act · Reserve design · Adaptation strategy · Conservation planning

Introduction

Habitat Conservation Plans (HCPs) developed under the Endangered Species Act (ESA) are an important mechanism for protecting wildlife and plants on non-federal lands. Large or regional HCPs often acquire and manage land and water and typically fund active conservation over long time horizons—often 50 years or more. Effective HCPs must anticipate and mitigate a wide range of current and potential threats to species. A growing body of research describes the potential effects of climate change on species and ecosystems and proposes strategies for acquiring and managing habitats to effectively address the associated uncertainty (e.g., Hannah and others 2007; Millar and others 2007; Heller and Zavaleta 2009; West and others 2009; Lawler and others 2010). This paper synthesizes the key insights from the literature to inform the specific practices and requirements of those who develop, review, implement and otherwise interact with HCPs. We provide nine recommendations for integrating

P. Bernazzani (✉)
ICF International, 91 Carriage Stone Drive, Chagrin Falls, OH 44022, USA
e-mail: pbernazzani@icfi.com

B. A. Bradley
Department of Environmental Conservation, University of Massachusetts, Amherst, MA 01003, USA

J. J. Opperman
The Nature Conservancy, Chagrin Falls, OH 44022, USA

climate change into HCP development and increasing plans' durability in the context of climate change.

Regulatory Context

The earth's climate is changing rapidly and affecting species and natural communities (MEA 2003). A large percentage of plants and animals are likely to face extinction risk due to forecasted temperature rise (2–3 degrees above pre-industrial levels) (Thomas and others 2004) and associated perturbations to precipitation and disturbance regimes (IPCC 2007). Because HCPs are tasked with the conservation of U.S. endangered species over significant time horizons (often in perpetuity), the effectiveness of HCP's may be reduced if plans do not account for climate change. The U.S. government did not officially acknowledge that global climate change was a significant issue until 2008 (National Science and Technology Council 2008), resulting in an overall lack of emphasis on climate change in federally regulated conservation planning. Furthermore, the ESA was signed prior to broad scientific understanding of climate change, but the long permit term of HCPs, as well as the No Surprises clause that precludes the retroactive adjustment of management commitments, makes the consideration of climate change in HCP development critical.

Case law (e.g., Massachusetts v. Environmental Protection Agency (USEPA) (2007) and Natural Resources Defense Council v. Kempthorne (2007)) suggests that inclusion of climate change in federally regulated processes is gaining importance (Ruhl 2008) (Box 1). Also, recent guidance from the U.S. Fish and Wildlife Service (USFWS) recommends incorporating "climate change in service activities and decisions, *including conservation plans*" (emphasis added) (USFWS 2011). In addition, a draft national strategy on climate change adaptation was released in January 2012 (CEQ (White House Council on Environmental Quality) and DOI (U.S. Department of the Interior) 2012) that identifies critical actions that federal agencies should implement over the next five to ten years. Failure to consider climate change may result in plans that lack biological and legal defensibility or meet regulatory criteria. This paper provides suggestions for incorporating climate change into HCPs.

Overview of Habitat Conservation Planning

The ESA prohibits take of listed species.[1] The original Act (1973) did not include an exemption to the prohibition of take for non-federal entities, leading to widespread resistance within the regulated community (e.g., developers, landowners, utility companies, public agencies). In 1982, the U.S. Congress created Section 10 of the ESA to provide non-federal entities a process for receiving an incidental take permit, or an exemption to the prohibition against take. Section 10 requires that project proponents submit a "habitat conservation plan" that mitigates for impacts on listed species (Cylinder and others 2004). The HCP program is administered by the USFWS and the National Marine Fisheries Service ('the Services').

Only 14 HCPs were developed in the 10 years following the 1982 amendments. However, in 1994, the Department of the Interior and the Department of Commerce jointly issued a policy titled "No Surprises: Assuring Certainty for Private Landowners in Endangered Species Act Habitat Conservation Planning" (the "No Surprises" policy). These assurances greatly increased the popularity of HCPs within the regulated community (Kostyack 1997). No Surprises provided applicants with the certainty that no additional mitigation, in terms of land or money, would be required beyond what was specified in the HCP. Between 1992 and 2008, almost 600 plans were approved covering more than 18 million hectares (ha), with typical management time horizons for the larger plans of 30-50 years (http://ecos.fws.gov/conserv_plans/public.jsp).

Since 1982, HCPs have evolved considerably—from 0.5 ha, single-landowner plans to regional, multi-jurisdiction plans on hundreds of thousands of hectares. Large HCPs that permit regional land use typically acquire land and, as such, have become significant vehicles for the creation of new reserves. HCPs undertaken by single permitees with large land holdings (e.g., utilities, timber companies) typically mitigate impacts on their own land through ongoing management activities. Here, we focus on strategies that link climate-change planning into large HCPs (>6,000 has) that have the potential to impact and preserve significant areas of land and water resources.

History of Climate Change in HCPs

To understand the extent to which climate change has been incorporated into HCPs, we reviewed the USFWS website, which lists all plans developed since 1982 (http://ecos.fws.gov/conserv_plans/public.jsp), and we identified 58 geographically large plans (>6000 ha). Of these plans, 31 were publicly

[1] Take is defined as any action that would "harass, harm, pursue, hunt, shoot, wound kill, trap, capture, or collect, or to attempt to engage in any such conduct" of listed species (16.USC § 1532 (19)). Harm is further defined as any significant habitat modification or degradation that results in death or injury of an endangered species (50 CFR § 17.3). Take is allowed for threatened species as determined by the Secretary of the Interior.

Box 1 Legal precedent regarding a consideration of climate change

Massachusetts v. EPA: Massachusetts and eleven other states and several cities sued the Environmental Protection Agency (EPA) regarding their failure to regulate CO_2 under the Clean Air Act as a potentially harmful airborne pollutant. The EPA argued that the relationship between CO_2 emissions and global warming was not clearly established and that the Act did not specifically address the regulation of greenhouse gases as they related to climate change. The case was eventually heard before the Supreme Court, and in a 5-4 decision, the Court sided with the petitioners, upholding that scientific uncertainty is not sufficient reason to fail to regulate and that the threats posed by CO_2 are sufficiently understood as to be subject to the broad provisions of the Act.

Natural Resources Defense Council v. Kempthorne: A citizen's action group sued the FWS regarding the failure of a Biological Opinion (BO) under section 7 of the ESA to adequately address climate change in their assessment of water operations in the Bay Delta and potential impacts to endangered delta smelt. The courts sided with the plaintiffs attesting (as in *Massachusetts v. EPA*) that the inconclusiveness of the impacts of climate change was not a reason to fail to address within the context of the BO.

Both cases point to the importance of, at a minimum, addressing the potential impacts of climate change with regards to their respective Acts.

available, and we reviewed all of these. The purpose of this analysis was only to provide a general understanding of the mechanisms and degree to which climate change is being incorporated into HCPs, not a definitive review of all recently developed plans. We assigned each plan to one of four categories: (1) climate change not referenced; (2) climate change mentioned in species accounts or other background sections only; (3) climate change loosely associated with conservation (in monitoring, adaptive management, conservation strategy, or changed circumstances sections) but lacking specific linkages between climate-change scenarios and management actions; (4) climate change integrated into the conservation strategy with direct linkages between climate-change scenarios and management actions (Table 1).

Before 2005, only one of the sixteen plans reviewed mentioned climate change, whereas, on or after 2005, seven of fifteen scored a "3." None of the reviewed plans analyzed the implications of climate change or developed specific linkages between climate-change scenarios and conservation actions (Table 1). Most plans simply noted that the potential for climate change was an important reason for conducting adaptive management. The Montana Department of Natural Resources and Conservation HCP (2009) is typical of plans that were scored with a "3":

> Land and water resources are vulnerable to a wide range of effects from climate change… While these potential effects are known, there is not sufficient site-specific information to plan for and manage the effects of climate change at this time… New research and guidance materials related to the future management of state forests in light of climate changes and potential effects of climate change on the HCP species will be a topic of discussion as necessary between DNRC and the USFWS at scheduled annual update meetings (pp. 6–11).

Because HCPs—and large, regional HCPs in particular—take years to develop, they have been understandably slow to incorporate current scientific understanding. With that in mind, our analysis indicates that, while some recently completed plans acknowledge that climate change could affect future conditions, specific linkages between probable effects and management responses are not articulated.

Recommendations for Integrating Climate Change into HCPs

Despite uncertainties associated with climate change, several strategies have been proposed and refined through the scientific literature that identify and minimize risk to species (e.g., Heller and Zavaleta 2009). Recommendations for biological conservation in the context of climate change have been reviewed for natural resources generally (Baron and others 2008a; West and others 2009; Lawler and others 2010), montane ecosystems (Baron and others 2008b), forests (Millar and others 2007; Evans and Perschel 2009), and freshwater ecosystems (Palmer and others 2009; WWF 2010). However, these recommendations have not been adapted to the particular demands of HCP development and implementation, which combine scientific analyses and conservation actions within a specific regulatory framework. Here we offer nine recommendations focused on informing the work of those who develop, review, and implement HCPs. These recommendations are aimed at future HCPs, as well as HCPs that are now being implemented, because climate change will affect the ability of these plans to meet their permit requirements.

Identify Species At-Risk From Climate Change

One of the first steps in HCP development is the identification of species covered by the plan's incidental take permit. Typically, listed species that could be affected by applicant activities are covered. However, HCPs often also cover unlisted species that are likely to become listed over the permit term. By covering unlisted species, applicants are, in essence, hedging bets against future ESA regulation for these species. A list of factors used to determine listing

Table 1 Level of integration of climate change into HCPs larger than 6,000 hectares (ha)

Plan	Climate Change	Year	Area (ha)	Listed Species	Total Species
Balcones Canyonlands Preserve[a]	(1) Not referenced	1996	256166	9	23
Bastrop Utilities Houston Toad	(1) Not referenced	2005	57678	1	1
Benton County Prairie Species	(1) Not referenced	2010 (Draft) 2011 (permit)	7652	5	7
Broughton Land Company	(1) Not referenced	2008	15,200	3	3
City of Carlsbad	(1) Not referenced	2004	9,828	18	54
City of Chula Vista (Subarea)	(1) Not referenced	2003 (document) 2005 (permit)	23410	26	81
City of Palm Bay	(1) Not referenced	2007	18516	2	3
City of San Diego Sub-area Plan	(1) Not referenced	1997	82,450	25	80
Clark County Multispecies	(2) Background only	2001	2,000,000	2	76
Coachella	(3) Loosely associated	2008	482,631	10	27
Comal County	(3) Loosely associated	2009	26,400	2	2
East Bay MUD	(3) Loosely associated	2008 (Draft)	11,200	5	6
East Contra Costa County	(3) Loosely associated	2007	70,174	8	26
Elliot State Forest	(1) Not referenced	1995	37636	2	2
Florida Scrub Jay Umbrella	(1) Not referenced	2007	6000	1	1
Iron County (Utah Prairie Dog)	(1) Not referenced	1998	112,384	1	1
Kern Water Bank[a]	(1) Not referenced	1997	8053	21	50
Lost Pines[a]	(1) Not referenced				
Malpai Borderlands (Submitted)	(1) Not referenced	2007 (Draft)	320,000	9	19
Metropolitan Bakersfield[a]	(1) Not referenced	1994	106028	9	9
Montana DNR	(3) Loosely associated	2009 (Draft)	224,000	3	5
Natomas	(1) Not referenced	2003	21337	8	20
PGE San Joaquin Valley O&M	(1) Not referenced	2007	111835	24	24
Poway Subarea[a]	(1) Not referenced	1996	10133	25	80
Riverside County, Stephens' Kangaroo Rat (Long-Term)	(1) Not referenced	1996	216,000	1	1
San Joaquin County	(1) Not referenced	2001	358,400	13	43
Southeastern Lincoln County	(1) Not referenced	2010	680,000	2	2
State-Wide Karner Blue/WI DNR	(1) Not referenced	1999	2,800,000	1	1
WA DNR Forest Practices	(3) Loosely associated	2006	3,720,000	9	16
WA DNR Geoduck Fishery	(3) Loosely associated	2008	12141	2	6
Washington County, Utah	(1) Not referenced	1996	54633	1	1
Western Riverside	(1) Not referenced	2004	520,000	25	165

[a] Not available as searchable pdf

under the ESA can be found in Easter-Pilcher (1996). Once a species is covered by the plan, no commitment of additional resources is required, even if that species' legal status changes from unlisted to listed. However, if, during plan implementation, a species that was not covered becomes listed, any activities that take the species are prohibited, and the applicant must amend the plan to address impacts to that species (an expensive and time-consuming process).

Because it is impractical to cover all unlisted species (often hundreds), the likelihood of listing over the permit term is an important consideration. One approach to help identify the probability of listing over the permit term would be to consider how climate change interacts with the criteria identified for listing under the ESA (see EasterPilcher 1996) and, in turn, how these specific criteria apply to species under consideration for coverage. In general, species that are most vulnerable to climate change effects have restricted distributions and/or small populations sizes, are undergoing population reductions, are habitat specialists, and/or are located in habitats likely to be affected by climate change (USEPA 2009). Consideration of climate change as a factor affecting probability of species persistence, and thus potential listing status, will improve the species-selection process and increase protections for these species by addressing their needs up front. The USEPA (2009) proposed a framework for categorizing

Table 2 Criteria to determine vulnerability from climate change

Criteria	Climate change might increase risk if	Example species
Species has a restricted range or habitat is highly fragmented	Movement is restricted by edaphic factors, topography, or land use	American pika *(Ochotona princeps)* Unlisted
	Range is restricted due to unique climatic conditions	
Species or habitat is vulnerable to non-native invasion or pathogens	Non-native species become more abundant or more competitive with rising CO_2	Indiana bat *(Myotis sodalis)* Endangered
	Pests and pathogens expand or become more problematic as their life cycle is affected by rising temperatures	California red-legged frog *(Rana draytonii)* Threatened
Species or habitat is directly vulnerable to climate change effects	Life cycle or physiology is directly sensitive to temperature	Fish in the family Salmonidae Numerous listed runs
	Life cycle or physiology is directly sensitive to precipitation or hydrology (less certain than temperature)	
	Species is sensitive to changes in disturbance regime (less certain than precipitation change)	
Species is a specialist dependent on another organism	Phenology, distribution or abundance of mutualist species is compromised	Callippe silverspot butterfly (*Speyeria callippe callippe)* Endangered
Species or habitat lacks phenological or genetic diversity	Species have inflexible phenologies (e.g., growth linked to daylight rather than temperature/moisture conditions) (Willis and others 2008)	Cushenbury buckwheat *(Eriogonum ovalifolium* var. *vineum)* Endangered
	Species have poor genetic diversity/ability to adapt	San Joaquin Kit Fox (*Vulpes macrotis*) Endangered

vulnerability of threatened and endangered species to climate change and evaluated six species as case studies and numerous vulnerability analyses have been developed since then (e.g., NatureServe 2010). The PRBO also analyzes vulnerability by ecoregion based on critical factors such as temperature, precipitation, streamflow and water availability, fire and vegetation change (2011). In the future, if such an analysis were developed for all rare and sensitive species, it could be used to inform the covered-species list. Absent this in-depth analysis, which links current vulnerability to climate-change stressors, we identified five drivers that increase species' vulnerability to climate change and summarized them in Table 2. These factors, in conjunction with existing criteria, could be used to screen species for inclusion in the covered-species lists developed for HCPs. As an example, we re-assessed the covered-wildlife evaluation table for the East Contra Costa County, California Conservation Plan to identify wildlife species with increased vulnerability from climate change (Table 3). These are species that might merit coverage, in a climate-change context, given the length of the planning permit. Other vulnerability assessment tools are available (e.g., NatureServe 2010; Bagne and others 2011) that can be used to inform the covered-species list and/or long-term monitoring.

Explore New Strategies for Reserve Design

Climate change is predicted to cause shifts in land cover (Scholze and others 2006) and temperature patterns within protected areas (Ackerly and others 2010), which may no longer encompass the habitats that existed when they were established. For example, Ackerly and others (2010) examined the implications of climate change for 500 protected areas within the Bay Area of California and found that, under one climate-change scenario, nearly all (98 %) will shift to entirely novel patterns of summer temperature. Because distributions of both plants (Loarie and others 2008) and animals (Winchell and Doherty 2008) can be strongly influenced by climate variables, such as temperature, the ability of protected areas to provide suitable conditions for covered species may be compromised.

To address the potential effects of temperature and habitat shifts, guidance in the scientific literature for reserve design frequently recommends the inclusion of habitat/climate gradients or a diverse range of climates and habitat types. The Natural Community Conservation Planning Act, which provides a means for endangered-species compliance in the state of California, already requires plans to "incorporate a range of environmental gradients (such as slope, elevation, aspect, and coastal or inland characteristics) and high habitat diversity to provide for shifting species distributions due to changed circumstances" [California Fish and Game Code Section 2820(a)(4)(D)].

Beyond simply striving to incorporate gradients and/or habitat diversity in reserves, HCPs can improve long-term protection for covered species by determining areas of future habitat for covered species or of underlying diversity, such as geology. One approach involves specifically forecasting the location and quality of future vegetation

Table 3 Additional wildlife species that merit consideration for coverage based on climate-change threats in the East Contra Costa County HCP/NCCP, CA

Species Name	Extremely restricted or fragmented range	Vulnerable to direct change in temperature	Sensitive to phonological shift	Sensitive to nonnative invasives or pathogens	Vulnerable to changes in rainfall/water
Molestan blister beetle	X		X		X
Western spadefoot toad	X	X		X	X
Small-footed myotis				X	X
Long-eared myotis				X	X
Fringed myotis				X	X
Long-legged myotis				X	X
Yuma myotis				X	X

Based on East Contra Costa County HCP/NCCP covered species evaluation table (See supplemental materials)

(and wildlife habitat) and integrating these areas into the land-acquisition strategy (e.g., Loarie and others 2008). Model-based projections that relate species distribution to vegetation and climate provide insight as to where and how habitat might shift (Guisan and Zimmermann 2000; Morin and Lechowicz 2008; Wiens and others 2009). Statistical-based models, such as Maxent, that use occurrence data to predict species distribution can incorporate climate variables to create robust, predictive models under various climate-change scenarios (see NatureServe 2011). However, projections based on habitat suitability models are uncertain due to assumptions of unchanged species interactions and lack of evolutionary or phenotypic adaptation (Dormann 2007). We caution that climate-based models are only predictions and cannot be validatated. Ideally, reserve acquisition would be designed with sufficient flexibility to allow changes in response to new information. In addition to habitat suitability modeling (which can be costly), expert opinion or decision rules can guide the identification and acquisition of future habitat.

Another tool to guide reserve design within the context of climate change uses the underlying geology of a plan area (Beier and Brost 2010, Anderson and Ferree 2010). This framework is premised on the fact that geology and topographic variables (e.g., elevation, insolation, slope) affect the distribution of vegetation and ecological communities and determine location of key habitats and is based on the physical patterns underlying current heterogeneity and diversity. These same underlying physical patterns are likely to continue to influence biological distribution when climate changes (Beier and Brost 2010, Anderson and Feree 2010) and thus may provide information on future habitat distributions without relying on a sequence of linked forecast models (climate to vegetation to species distributions), which can propagate error. This methodology also has the benefit of using accessible geologic data, unlike vegetation data which may not be readily available and which changes through time. In some regions, patterns of geologic diversity may capture much of the biotic diversity and thus may provide an effective proxy for maintaining regional biodiversity (Anderson and Feree 2010). However, because HCPs need to fulfill regulatory requirements that are species-specific, and not just based on overall regional diversity, geologic approaches should be used to complement and not replace focal-species approaches.

Increase Emphasis on Corridors, Linkages, and Connectivity

Shifts in species distribution in response to climate change will be constrained without connectivity between conservation areas. For terrestrial species, habitat corridors promote the movement of species (Gilbert-Norton and others 2010), although they can potentially facilitate undesirable outcomes such as spreading disease and invasive species (Heller and Zavaleta 2009). Connectivity can be particularly important for conservation of aquatic organisms to allow aquatic species to migrate within a channel network in response to changing climatic conditions (Lawler and others 2010). Connectivity studies should be required during regional HCP development or during early implementation to guide future acquisition, including an assessment of species that may become increasingly fragmented under climate-change-driven shifts in distribution. As described above, there are numerous approaches that should be considered when designing reserves, and many of these apply to corridors or linkages as well, including use by focal species and representation of physical units.

Develop Anticipatory Adaptation Measures (Increase Resistance)

Most approaches to conservation planning involve maintaining or re-creating a desired existing or historical condition in the HCP planning area. This means increasing resistance by anticipating effects of climate change and addressing them proactively in the planning process (USFWS 2011) (Box 2). The IPCC defines anticipatory adaptation as "adaptation that takes place before impacts of climate change are observed" (IPCC 2007).

Box 2 Resistance and resilience

Ecological resistance refers to the capacity of an ecosystem to persist in its current state through changing climate conditions. Increasing resistance is often a temporary measure designed to preserve ecological communities over the short-term while other steps are taken (Millar et al. 2007). Building resistance typically takes the form of reducing threats from other sources (e.g., invasive species, anthropogenic land use) that affect existing ecological processes and increase stress to native organisms.

Ecological resilience refers to the ability of an ecosystem to adapt to climate change. Promoting resilience involves changing ecological communities (e.g., facilitating species-distributions shifts, the creation of novel species assemblages). Management for ecological resilience does not focus on a "baseline" because attempts to maintain static conditions will impede necessary ecological shifts and may lead to catastrophic changes. Strategies for increasing resilience often involve increasing diversity within a system.

To increase the resistance of HCP reserves to the adverse impacts of climate change, HCPs can identify those ecosystem-level threats likely to be exacerbated by climate change and deploy management actions to reduce those threats. Many climate-change models predict major disruptions in disturbance regimes such as increased frequency or intensity of fire or flash floods (Westerling and others 2006, Sponseller and others 2010). Plans can proactively minimize such impacts through actions that improve the resistance of important ecosystems (Table 4). For example, fire frequency may increase by 55 % in California (Luers and others 2006). The impacts of altered fire regimes can be reduced by increasing fuel breaks within a reserve system. Management actions that reduce surface runoff from roads (Weaver and Hadans 1994) could also counteract increased erosion rates from altered hydrology (Table 4).

Climate change is also likely to alter the distribution and abundance of invasive plants & animals (Dukes and Mooney 1999; Bradley and others 2010), which directly threaten many rare and endangered species (Wilcove and others 1998). Increasing ecological resistance to invasives is facilitated by early detection and long-term control efforts, both of which require ongoing funding (Myers and others 2000). The allocation of additional resources for invasive-species management to support early detection and, if needed, control actions is another example of anticipatory adaptation that should be incorporated into HCPs.

Manage for Diversity (Increase Resilience)

Resilience is the ability of an ecosystem or natural community to return to a desired condition after a disturbance event or other change (Box 2). The resilience of an ecosystem can be influenced by its diversity, defined at various levels, including species, structural, phenological, and demographic. For example, the resilience of a grassland ecosystem to drought can be positively correlated to the diversity of native species (Tilman and Downing 1994). The age-structure of a plant community, an example of demographic diversity, can also influence resilience. In forested ecosystems, older, established trees might be less susceptible to drought but more susceptible to pests, while the opposite may be true of younger trees (Millar and others 2007). Because climate change is likely to increase the number of disturbance events and other changes, considering resilience is an important component for conservation planning in the context of climate change.

Managing for a range of ages in forested ecosystems would reduce the likelihood of substantial loss due to either drought or infestation. Another means of increasing resilience to climate change is by promoting species with diverse phenologies (Millar and others 2007; West and others 2009). A community consisting of species that germinate, bloom, nest, migrate, etc. at different times will respond to different climatic stressors and may be more resilient to change (Schwartz 1999). Promoting resilience to climate change would require broadening the sources of seeds and seedlings used for habitat management (Millar and others 2007; West and others 2009). Most species survive along a range of climatic gradients, and genotypes in southern- or lower-elevation areas might be better adapted to warmer conditions. Expanding the gene pool beyond the local reserve could support the persistence of covered species (Millar and others 2007).

Consider Assisted Migration

Assisted migration, assisted colonization, or managed relocation (McLachlan and others 2007, Hoegh-Guldberg and others 2008, Richardson and others 2009) is a last resort for conserving many species but should nonetheless be considered as an option for HCPs, particularly for species highly vulnerable to climate-related shifts in habitat. Assisted migration might include moving covered species to new reserves or importing new species that would provide necessary habitat functions for covered species. In both cases, the species being moved is presumed to be adapted to conditions at the recipient site. For species that can provide habitat functions, those with traits that make them more resilient to change, such as plants with high

Table 4 Potential threats and example resistance actions for HCPs

Increased threat from Climate change	Resistance action
Drought	Plan for supplemental watering at restoration sites
	Implement water-conservation measures
Wildfire	Increase firebreaks
	Manage vegetation or prescribe burning to reduce the risk of high-intensity fires
Warming water	Retrofit dam infrastructure to release cold water into streams
	Additional riparian restoration
Increased stream flashiness	Emphasize sediment reduction in watersheds (improved road construction and maintenance)
Invasive plant species	Develop list of potentially invasive plants that will increase with climate change
	Implement early detection and reduction programs to manage these species

phenological plasticity (Willis and others 2008), might be the most successful long-term colonizers of recipient ecosystems. Other species that are closely linked to resources that cannot move in response to climate change (e.g., edaphic endemics) may require translocation when populations are extirpated due to changes in habitat or host-plant phenology.

Assisted migration should be undertaken with extreme caution and only as a last resort. Because HCPs are implemented over long time periods, climate-induced changes may compel novel management strategies, such as assisted migration, to maintain the viability of covered species. However, the Services may be reluctant to approve novel strategies without a formal plan amendment, unless they have been agreed upon beforehand, underscoring the value of vetting management responses to climate change during initial plan development.

Include Climate Change in Scenarios of Water Management

Aquatic ecosystems have higher rates of species endangerment than do terrestrial (Ricciardi and Rasmussen 1999), and, in addition to acquiring or managing land, many large HCPs that cover aquatic species also encompass water management. For example, some plans incorporate guidelines for the management of a reservoir that influences habitat for endangered fish downstream (Ricciardi and Rasmussen 1999). Aquatic ecosystems will be affected by climate change as alterations in precipitation, runoff, and temperature—interacting with ongoing flow regulation, extraction, and changes in land cover—result in altered flow regimes, hydroperiod, and water quality, including water temperature (Bates and others 2008). Because climate change has the potential to alter precipitation patterns in multiple ways (e.g., quantity, timing, and type of precipitation [e.g., rain vs. snow]), and due to the uncertainty of hydrological forecasts (Palmer and others 2009), HCPs should adopt a risk-based approach that emphasizes management flexibility across a range of potential hydrological conditions (WWF 2010; Wenger and others 2011).

Such an approach can be an extension of scenario-based planning commonly used for water management actions, such as reservoir releases. For example, water managers often develop indicators that define a water year type (e.g., "wet," "normal" or "dry") and then develop management actions that correspond to each. To incorporate climate change into a flexible, scenario-based management structure, HCP developers can create additional hydrological scenarios based on climate models (if available) (e.g., Maurer and others 2009) or expert judgment (e.g., flood flows increase by 20 %, low flows reduced by 20 %). Plan developers can then assess likely impacts from the various scenarios, including climate-influence scenarios on covered species using quantitative or conceptual models of habitat or species responses to the scenarios' hydrology. For example, the Ecosystem Diagnosis and Treatment (EDT) tool can model the relative abundance and habitat capacity for anadramous fish in response to various scenarios, including those that specifically incorporate climate change, and predict effects on covered fish species (Lestelle and others 2004). Finally, the plan should include a set of hydrological and ecological metrics that can be monitored and serve as indicators to trigger specific management responses. Through this process, plan developers can assess, propose, and vet solutions for potentially challenging hydrological conditions prior to those conditions arising.

Potential management responses to altered hydrology include both direct water management, as well as management of river channels, riparian vegetation, and watershed land cover (Wenger and others 2011). The release of water from dams can be managed so as to provide appropriate flow, habitat, and temperature conditions (e.g., "environmental flows;" Richter and others 2006; Tharme 2003). Dams with the physical capacity to provide a range of flow characteristics (e.g., magnitude and temperature), should integrate these management responses into the conservation strategy. For dams lacking this capacity, plans could include provisions that would trigger retrofits, if needed, to respond to altered hydrological conditions.

Develop Future-oriented Management Actions

A challenge for HCP implementers, with respect to climate change, is the balance between a preservation-oriented approach (resistance and resilience actions described above) versus future-oriented actions that anticipate and manage to expected future conditions. To date, plans have focused on preserving or recreating existing or historical conditions. As the effect of climate change manifests in natural communities, these approaches may become increasingly difficult and require more intensive management through time. Future-oriented management action focuses on creating habitat for covered species that is sustainable in the future and not necessarily limited to historical vegetation composition. It also should develop success criteria for habitat restoration projects that account for multiple endpoints or various goals (Choi 2007).

Increase Connection between the Conservation Strategy and Adaptive Management and Monitoring Programs

Our final recommendation focuses on the organization of the HCP document itself. Our review of recent plans indicates that, if discussed, climate change is generally included in the adaptive-management or changed-circumstances sections and not within the conservation strategy. Therefore plans generally do not develop specific management actions in anticipation of or in response to potential climate scenarios. Although adaptive management is a challenging component of HCP implementation, plans can improve the likelihood of effectively implementing adaptive management by explicitly linking potential climate-related threats to specific management actions, their hypothesized outcomes, and monitoring. Better linkages between the scientific foundation of the plan and its management actions will lead to better designed and better implemented plans, in general (Kareiva and others 1999), and with specific reference to climate change.

To illustrate these linkages, we developed an example of a management-oriented conceptual model for California tiger salamander—a state-listed species that occurs in central California. Climate change is anticipated to exacerbate existing threats, such as habitat loss, through increased fragmentation of metapopulations, separation of breeding and movement/aestivation habitat, and altering interspecies dynamics, such as predation and disease. The proposed model provides a conceptual management and monitoring framework (Fig. 1) to respond to climate-related threats. The model anticipates a set of climate-related threats, proposes specific management actions to address those threats, and hypothesizes anticipated outcomes and a monitoring regime.

Overall, HCPs should incorporate climate change in a specific and comprehensive manner within key components of the plan. We suggest that plans move beyond broad recognition that climate change may affect covered species toward greater specificity anticipating climate-related threats and proposing solutions. Choosing climate-change variables (i.e., temperature, precipitation, snowpack, streamflow, water availability, sea-level rise, fire and vegetation change) and linking conservation actions to expected outcomes will help make adaptive management more explicit within a context of future climate change (PRBO Conservation Science 2011).

Summary

We suggest that HCPs address climate change in a comprehensive manner and demonstrate that, to date, this has not been done. Our recommendations describe approaches that would improve the ability of HCP processes to conserve and protect species over the long time horizons that these plans cover. We emphasize the importance of identifying potential climate-related changes, linked to specific management responses, rather than deferring generally to adaptive management. By identifying potential changes and responses during plan development, plan developers can identify solutions when a fuller set of options remain, rather than seeking solutions only after changes have become apparent and some options may have become precluded.

While permittees should provide the information necessary to develop HCPs, many of our recommendations—such as scenario-based modeling—can be expensive and beyond the capability of all applicants. Funding such studies through the HCP program, through other state or federal mechanisms, or in conjunction with academic research is an important component of creating HCPs that effectively promote resistance and resilience to climate change. Recent grant awards (2010 Section-6 Cooperative Endangered Species Fund) are funding HCPs in regions that previously had few, such as the Midwest. As the geographic reach of HCPs expands, the importance of improving conservation planning for protected species expands as well. Integrating climate change is an important step in improving HCPs so they can fulfill both their regulatory and conservation objectives.

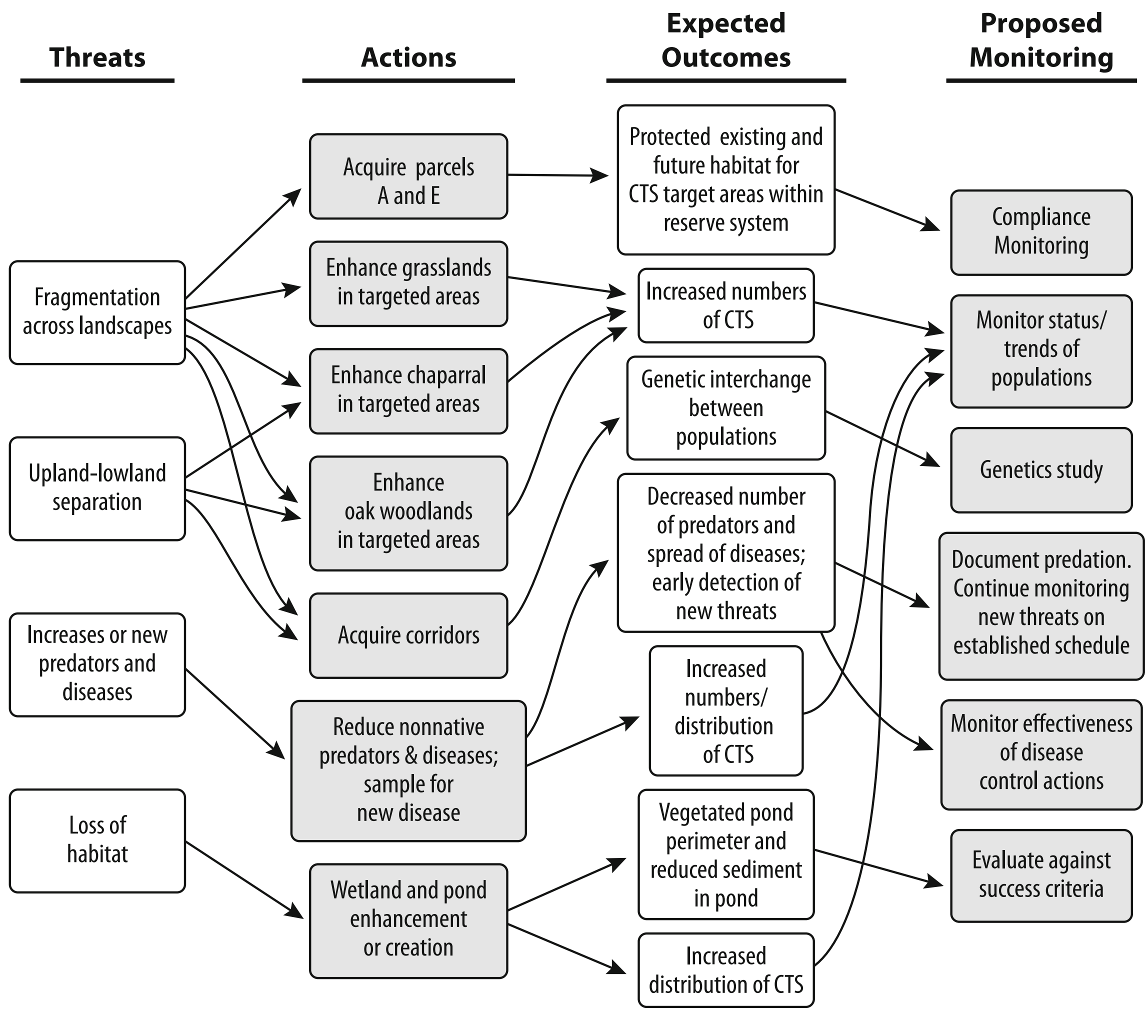

Fig. 1 Example conceptual model for climate change threats—California Tiger Salamander (CTS)

Acknowledgments We wish to acknowledge the help of Dr. David Wilcove who provided initial guidance for this effort. Dr. David Zippin, Dr. Erica Fleishman and Dr. Scott Fleury provided input on early versions of the manuscript. Tim Messick gave valuable graphical support, and two anonymous reviewers provided important insights that improved the final version of the manuscript.

References

Ackerly DD, Loarie SR, Cornwell WK, Weiss SB, Hamilton H, Branciforte R, Kraft NJB (2010) The geography of climate change: Implications for conservation biogeography. Diversity and Distributions 16:476–487

Anderson MG, Ferree CE (2010) Conserving the stage: climate change and the geophysical underpinnings of species diversity. PLos ONE 5(7):e11554. doi:10.1371/journal.phone.0011554

Bagne KE, Friggens MM, Finch DM (2011) A system for assessing vulnerability of species (SAVS) to climate change. General Technical Report RMRS-GTR-257. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Baron JS, Allen CD, Fleishman E, Gunderson L, McKenzie D, Meyerson L, Oropeza J, Stephenson N (2008a) National parks. In: Julius SH, West JM (Eds), Preliminary review of adaptation options for climate sensitive ecosystems and resources. A report by the U.S. Climate change science program and the subcommittee on global change research. U.S. Environmental Protection Agency, Washington, DC, pp 4-1–4-68

Baron JS, Julius SH, West JM, Joyce LA, Blate G, Peterson CH, Palmer M, Keller BD, Kareiva P, Scott JM, Griffith B (2008b) Some guidelines for helping natural resources adapt to climate change. IHDP Update 46–52

Bates BC, Kundzewicz ZW, Wu SH, Palutikof JP (2008) Climate change and water: Technical paper of the intergovernmental panel on climate change. In: Bates BC, Kundzewicz ZW, Wu SH, Palutikof JP (eds) IPCC Secretariat. Geneva

Beier P, Brost B (2010) Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology 24:701–710

Bradley BA, Blumenthal DM, Wilcove DS, Ziska LH (2010) Predicting plant invasions in an era of global change. Trends in Ecology & Evolution 25:310–318

CEQ (White House Council on Environmental Quality), DOI (U.S. Department of the Interior) (2012) National Fish, Wildlife and

Plants Climate Adaptation Strategy. Public Review Draft. http://www.wildlifeadaptationstrategy.gov/

Choi YD (2007) Restoration ecology to the future: a call for new paradigm. Restoration Ecology 15:351–353

Cylinder P, Bogdan K, Zippin D (2004) Understanding the habitat conservation planning process in California. Institute for Local Government, Sacramento, p 57

Dormann CF (2007) Promising the future? Global change projections of species distributions. Basic and Applied Ecology 8:387–397

Dukes JS, Mooney HA (1999) Does global change increase the success of biological invaders? Trends in Ecology & Evolution 14:135–139

EasterPilcher A (1996) Implementing the endangered species act. Bioscience 46:355–363

Evans A, Perschel R (2009) A review of forestry mitigation and adaptation strategies in the northeast U.S. Climatic Change 96:167–183

Gilbert-Norton L, Wilson R, Stevens JR, Beard KH (2010b) A meta-analytic review of corridor effectiveness. Conservation Biology 24:660–668

Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecological Modelling 135:147–186

Hannah L, Midgley G, Andelman S, Araujo M, Hughes G, Martinez-Meyer E, Pearson R, Williams P (2007) Protected area needs in a changing climate. Frontiers in Ecology and the Environment 5:131–138

Heller NE, Zavaleta ES (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14–32

Hoegh-Guldberg O, Hughes L, McIntyre S, Lindenmayer DB, Parmesan C, Possingham HP, Thomas CD (2008) Assisted colonization and rapid climate change. Science 321:345–346

IPCC (2007) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, UK and New York, USA

Kareiva P et al (1999) Using science in habitat conservation plans. Santa Barbara: national center for ecological analysis and synthesis. University of California, Santa Barbara

Kostyack J (1997) Reshaping habitat conservation plans for species recovery: an introduction of a series of articles on habitat conservation plans. Environmental Law 27:755–766

Lawler JJ, Tear TH, Pyke C, Shaw MR, Gonzalez P, Kareiva P, Hansen L, Hannah L, Klausmeyer K, Aldous A, Bienz C, Pearsall S (2010) Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment 8:35–43

Lestelle L, Mobrand L, McConnaha W (2004) Information structure of ecosystem diagnosis and treatment (EDT) and Habitat rating rules for Chinook Salmon, Coho Salmon and Steelhead Trout. Mobrand Biometrics, Inc., Vashon Island, WA. http://www.jonesandstokes.com/index.php?option=com_content&task=view&id=488&Itemid=784

Loarie SR, Carter BE, Hayhoe K, McMahon S, Moe R, Knight CA, Ackerly DD (2008) Climate change and the future of California's endemic flora. PLoS ONE 3:e2502

Luers A, Cayan D, Franco G, Hanemann M, Croes B (2006) Our changing climate: assessing the risks to California. A summary report from the California climate change center. CEC-500-2006-077

Massachusetts v. Environmental Protection Agency (2007) 549 U.S. 497

Maurer EP, Adam JC, Wood AW (2009) Climate model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America. Hydrology and Earth System Sciences 13:183–194

McLachlan JS, Hellmann JJ, Schwartz MW (2007) A framework for debate of assisted migration in an era of climate change. Conservation Biology 21:297–302

Millar CI, Stephenson NL, Stephens SL (2007) Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145–2151

Morin X, Lechowicz MJ (2008) Contemporary perspectives on the niche that can improve models of species range shifts under climate change. Biology Letters 4:573–576

Myers JH, Simberloff D, Kuris AM, Carey JR (2000) Eradication revisited: dealing with exotic species. Trends in Ecology & Evolution 15:316–320

National Science and Technology Council (2008) Scientific assessment of the effects of global climate change on the united states: a report of the committee on environment and natural resources

Natural Resources Defense Council v. Kempthorne (2007) No. 1:05-cv-1207 OWW GSA, 2007 U.S. Dist. LEXIS 91968

NatureServe (2010) Climate change vulnerability index. http://www.natureserve.org/prodServices/climatechange/ccvi.jsp

NatureServe (2011) Mojave Basin and range rapid ecoregional assessments final memorandum I-3-C: prepared for the Department of the Interior Bureau of Land Management Rapid Ecoregional Assessments, pp 1–224

Palmer MA, Lettenmaier DP, Poff NL, Postel SL, Richter B, Warner R (2009) Climate change and river ecosystems: protection and adaptation options. Environmental Management 44:1053–1068

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37–42

PRBO Conservation Science (2011) Projected effects of climate change in California ecoregional summaries emphasizing consequences for wildlife. Version 1.0

Ricciardi A, Rasmussen JB (1999) Extinction rates of North American freshwater fauna. Conservation Biology 13:1220–1222

Richardson DM, Hellmann JJ, McLachlan JS, Sax DF, Schwartz MW, Gonzalez P, Brennan EJ, Camacho A, Root TL, Sala OE, Schneider SH, Ashe DM, Clark JR, Early R, Etterson JR, Fielder ED, Gill JL, Minteer BA, Polasky S, Safford HD, Thompson AR, Vellend M (2009) Multidimensional evaluation of managed relocation. Proceedings of the National academy of Sciences of the United States of America 106:9721–9724

Richter BD, Warner AT, Meyer JL, Lutz K (2006) A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297–318

Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA (2003) Fingerprints of global warming on wild animals and plants. Nature 421:57–60

Ruhl JB (2008) Climate change and the endangered species act: building bridges to the no-analog future. Boston University Law Review 88:1–62

Scholze M, Knorr W, Arnell NW, Prentice IC (2006) A climate-change risk analysis for world ecosystems. Proceedings of the National academy of Sciences of the United States of America 103:13116–13120

Schwartz MD (1999) Advancing to full bloom: planning phenological research for the 21st century. International Journal of Biometeorology 42:113–118

Sponseller RA, Grimm NB, Boulton AJ, Sabo JL (2010) Responses of macroinvertebrate communities to long-term flow variability in a Sonoran desert stream. Global Change Biology 16:2891–2900

Tharme RE (2003) A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19:397–441

Thomas CD, Cameron A, Rhys EG, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, Ferreira de Siqueira M, Grainger

A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145–148

Tilman D, Downing JA (1994) Biodiversity and stability in grasslands. Nature 367:363–365

U.S. Environmental Protection Agency (2009) A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. National Center for Environmental Assessment, Washington, D.C.: EPA/600/R-09/011. Available from the National Technical Information Service, Springfield, VA, http://www.epa.gov/ncea

U.S. Fish and Wildlife Service (2011) Rising to the urgent challenge: strategic plan for responding to accelerating climate change, pp 1–32

Weaver WE, Hadans DK (1994) Handbook for forest and ranch roads. A guide for planning, designing, constructing, reconstructing, maintaining and closing wildland roads, Ukiah. Mendocino County Resource Conservation District, CA, p 161

Wenger SJ, Isaak DJ, Luce CH, Neville HM, Fausch KD, Dunham JB, Dauwalter DC, Young MK, Marketa ME, Rieman BE, Hamlet AF, William JE (2011) Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proceedings of the Natural Academy of Sciences of the United States of America 108(34):14175–14180

West JM, Julius SH, Kareiva P, Enquist C, Lawler JJ, Petersen B, Johnson AE, Shaw MR (2009) U.S. Natural resources and climate change: concepts and approaches for management adaptation. Environmental Management 44:1001–1021

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier spring increase western us forest wildfire activity. Science 313:940–943

Wiens JA, Stralberg D, Jongsomjit D, Howell CA, Snyder MA (2009) Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National academy of Sciences of the United States of America 106:19729–19736

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E (1998) Quantifying threats to imperiled species in the United States. BioScience 48:607–615

Willis CG, Ruhfel B, Primack RB, Miller-Rushing AJ, Davis CC (2008) Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change. Proceedings of the National academy of Sciences of the United States of America 105:17029–17033

Winchell CS, Doherty PF (2008) Using California gnatcatcher to test underlying models in habitat conservation plans. Journal of Wildlife Management 72:1322–1327

WWF (2010) Flowing forward: freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation. Prepared for the World Bank