Issues and Perspectives

The Importance of Assessing Climate Change Vulnerability to Address Species Conservation

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Abstract

Species conservation often prioritizes attention on a small subset of ''special status'' species at high risk of extinction, but actions based on current lists of special status species may not effectively moderate biodiversity loss if climate change alters threats. Assessments of climate change vulnerability may provide a method to enhance identification of species at risk of extinction. We compared climate change vulnerability and lists of special status species to examine the adequacy of current lists to represent species at risk of extinction in the coming decades. The comparison was made for terrestrial vertebrates in a regionally important management area of the southwestern United States. Many species not listed as special status were vulnerable to increased extinction risk with climate change. Overall, 74% of vulnerable species were not included in lists of special status and omissions were greatest for birds and reptiles. Most special status species were identified as additionally vulnerable to climate change impacts and there was little evidence to indicate the outlook for these species might improve with climate change, which suggests that existing conservation efforts will need to be intensified. Current special status lists encompassed climate change vulnerability best if climate change was expected to exacerbate current threats, such as the loss of wetlands, but often overlooked climate-driven threats, such as exceeding physiological thresholds.

Keywords: California and Southwest U.S.; conservation; vertebrates; vulnerability assessment

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Introduction

Climate change is already altering ecosystems and presents a substantial threat to the conservation of biodiversity (Hughes 2000; Peñuelas and Filella 2001; Root et al. 2003). By adding to or altering impacts already affecting species, climate change modifies extinction risk and creates a complex challenge for conservation practitioners (McCarty 2001; MacNally et al. 2009). The Intergovernmental Panel on Climate Change projected that global extinction risk would increase by 20–30% as average temperature increases exceed 3.5°C (Solomon et al. 2007). In other cases, species extinction risk may be reduced if conditions related to climate become more favorable (Peterson et al. 2001; Erasmus et al. 2002; Reino et al. 2009). Change in extinction risk will vary by species, taxonomic group, region, and time elapsed leading to questions about where to focus conservation efforts (McDonald and Brown 1992; Peterson et al. 2002; Thomas et al. 2004; MacLean and Wilson 2011).

There are large numbers of species affected by a multitude of threats and limited resources for managing them; thus, conservation practitioners select a subset of species to actively manage (Mace and Lande 1991; Hannah et al. 2002; Millar et al. 2007). Although management priorities are influenced by a wide range of factors, such as cultural values, legal protection, and economics, the identification of species for conservation (often designated as ''special status species'') generally focuses on those species most likely to go extinct (Master 1991; Mace et al. 2008). Estimating extinction risk for a species may be based on a set of quantitative criteria

such as geographic range, population size and trends, and number of threats (Terborgh and Winter 1980; Gilpin and Soulé 1986).

Threats to species from climate change can be, but are not necessarily, distinct from other threats associated with extinction risk; nor are they independent (Hughes 2000; Fordham et al. 2012). For example, habitat loss is a major threat to many populations, but could be driven by climate (e.g., extended drought) or nonclimate (e.g., mining) forces. We have relatively little data on how populations will respond to changing climate over time or how other threats associated with extinction risk could be altered (Hughes 2000). Climate change threats also comprise many uncertainties because manifestations we currently observe will not match future impacts (Thomas et al. 2004; MacNally et al. 2009). Existing methodologies to identify species vulnerable to extinction, such as the International Union for Conservation of Nature Red List criteria, can accommodate climate change threats, but are not explicitly designed to do so (Mace and Lande 1991; Akçakaya et al. 2006). Effects of climate change fall within the criteria used to identify species at risk of extinction under the US Endangered Species Act (ESA 1973, as amended), but climate change has only recently been considered and for relatively few species (Scott et al. 2005; Ruhl 2008). Because integration of climate change as a threat is relatively new, it is unclear to what extent our current designations of special status species address extinction risk inclusive of climate change response. Climate change vulnerability assessments are a potentially valuable tool because they are designed to examine the potential response of species, or other targets, to relevant climate projections.

To examine the adequacy of current lists of species at high extinction risk to accommodate the added threat of projected climate change, we compared species identified as having special status from widely available lists with those vulnerable to climate change. By special status, we refer to species selected from a given suite of species in need of active management or attention to achieve conservation goals (e.g., persistence for 100 y) by various government and nongovernment entities. We compiled data on extinction risk from climate change for terrestrial vertebrate species from an assessment for the Middle Río Grande, New Mexico, United States (Finch et al. 2011; Friggens et al. 2013b). The Río Grande region makes a good example for examining species priorities because, not only are data for an entire suite of species available, but climate projections of hotter, drier conditions along with a rapidly expanding human populations portends high susceptibility to climate change impacts (Seager et al. 2007). Species that have already been identified as special status might be expected to remain at risk in the future, because climate change can exacerbate current threats that are often implicated in population decline, such as habitat fragmentation or small population size (Laurance and Williamson 2001). Furthermore, high extinction risk is commonly indicated for species that are specialized and restricted in range because they are sensitive to fluctuating or changing conditions, including climate. Alternatively, climate change presents new threats not traditionally considered in extinction risk, such as timing mismatches and exceeding physiological thresholds (Hughes 2000). Amelioration of threats by climate change and increasing populations are also possible through reduced predator populations, milder winters, or lower disease transmission (Harvell et al. 2002).

A similar comparison for birds, amphibians, and warm-water corals was conducted using climate change susceptibility (an index based on traits associated with greater vulnerability to extinction) as compared against threatened species from the International Union for Conservation of Nature Red List (Foden et al. 2008). That study found the majority of threatened species were susceptible to negative impacts of climate change and found that large numbers of nonthreatened species were also susceptible, highlighting the need for conservation action (Foden et al. 2008). Because of the consensus that more species will be at risk of extinction in the future, we expected to find vulnerable species missing from lists of special status for the terrestrial species of the Middle Rio Grande. We compared special status designation with climate change vulnerability to investigate 1) how well designation of special status aligned with climate change vulnerability, 2) whether results varied among taxonomic groups, 3) opportunities for improved species conservation under climate change, and 4) implications for future species conservation efforts.

Methods

To obtain predictions of extinction risk with climate change, we used a vulnerability assessment of terrestrial vertebrates to climate change for the Middle Río Grande, New Mexico, United States (Friggens et al. 2013b). This report focused on the "bosque" or riparian forest that is characterized by remnant gallery cottonwood (*Populus* sp.) forests that border the stretch of river between Elephant Butte Reservoir (33°20′58.10″N, 107°10′40.12″W, elevation 1,345 m) and Cochiti Dam (35°37′13.46″N, 106°19′21.03″W, elevation 1,610 m) that bisects the city of Albuquerque (Figure 1). The assessment report lists climate-change vulnerability scores for 117 regularly occurring species under projected climate changes up to 2050. Importantly for this comparison, assessed species were not selected based on special status or other criteria related to extinction risk, making it possible to examine climate change vulnerability of species considered not at risk for the region. Our analysis excluded one species (hoary bat, *Lasiurus cinereus*) included in the assessment that occurs only as a migrant in the region.

The extracted vulnerability scores were calculated from a pilot version of the System for Assessing Vulnerability of Species (Bagne et al. 2011), a scoring system based on a series of criteria or questions related to changes in survival or reproduction from projected climate change and climate-related factors (Table 1). This system included all three elements of species vulnerability; exposure, sensitivity, and adaptive capacity (Glick et al. 2011). Vulnerability of species to climate change was equated with extinction risk and estimated from a

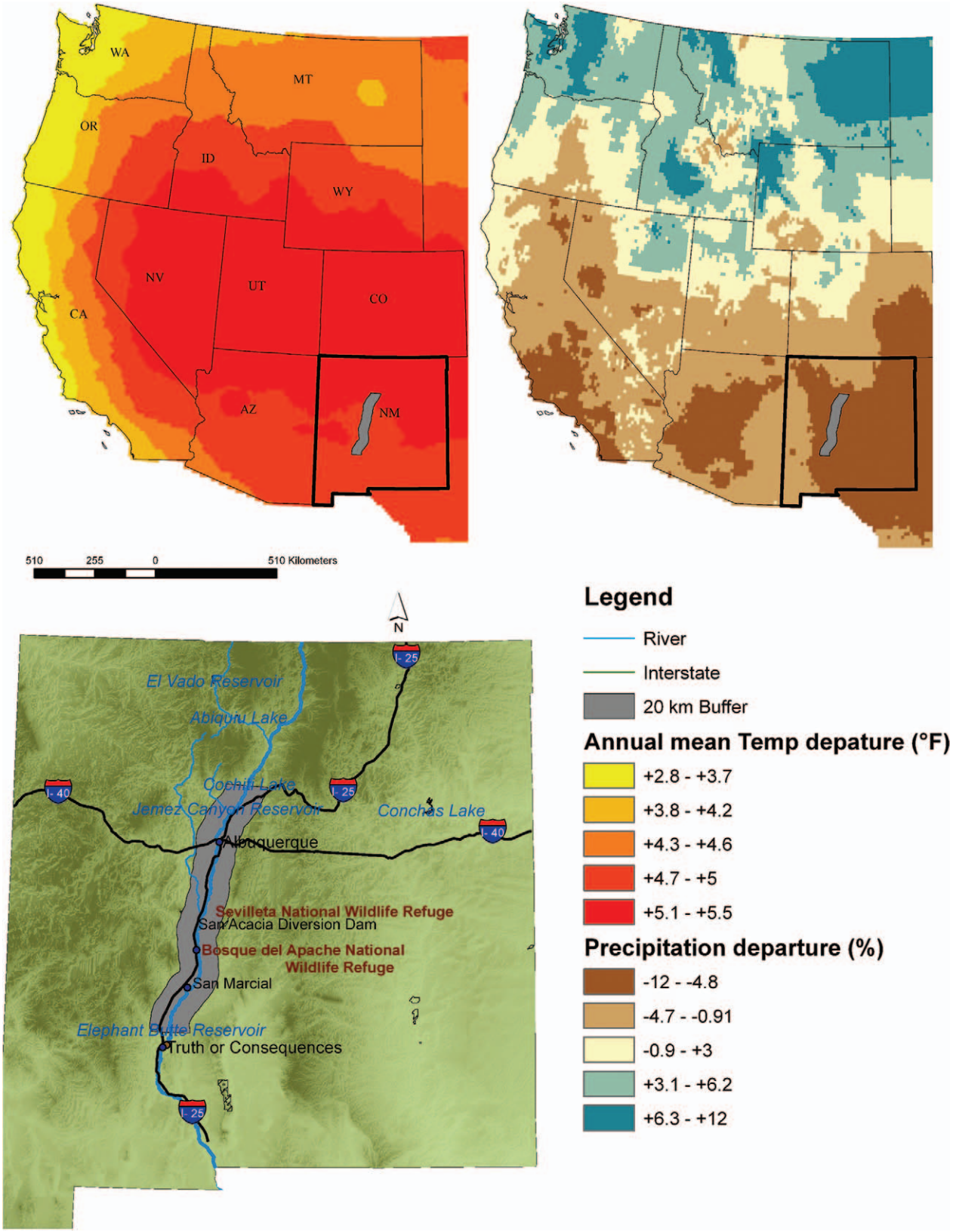

Figure 1. Location of the Middle Río Grande, New Mexico, United States with 20-km buffer used to estimate future extinction risk of species by the climate change vulnerability assessment (Friggens et al. 2013b). Future departures in temperature and precipitation for 2050 as compared with baseline averages from the period 1961–1990 are shown and were generated from Climate Wizard using the A2 emission scenario, ensemble of climate models (Maurer et al. 2007).

Table 1. Categories and criteria used to score climate change vulnerability for terrestrial vertebrates of the Middle Río Grande bosque, New Mexico, United States (Bagne et al. 2011). Vulnerability scores are based on predicted effects of climate change on survival or reproduction related to each of 25 criteria (Friggens et al. 2013b).

Categories	Scoring criteria
Habitat	Habitat area (breeding & nonbreeding)
	Habitat components (breeding & nonbreeding)
	Habitat quality (breeding & nonbreeding)
	Dispersal ability
	Migration habitats
Physiology	Physiological thresholds
	Temperature-determined sex ratios
	Extreme events
	Daily activity
	Metabolic inhibition
	Resource limitation adaptive capacity
	Variable life history
	Life span
Phenology	Use of climate cues
	Timing of resources
	Cue and resource separation
	Breeding mismatches
Interactions	Food resources
	Predators
	Symbionts
	Disease
	Competitors

set of criteria representing species traits; this strategy has been shown to be predictive of population response (Allendorf et al. 1997; Broennimann et al. 2006; Jiguet et al. 2007; Young et al. 2011; Gardali et al. 2012). Traits associated with sensitivity may respond similarly to nonclimate threats; thus, factors influencing extinction risk in System for Assessing Vulnerability of Species are not necessarily unique to climate change assessment. Additionally, it is one of few assessment methods that consider migration and nonbreeding habitats (Small-Lorenz et al. 2013). The vulnerability score for a species is related to extinction risk through the number of criteria expected to result in population declines balanced by those resulting in population increases for factors related to climate change only. To facilitate comparison with conservation priorities, we converted vulnerability scores into categories of highly vulnerable (overall score >5), vulnerable (overall score >2), neutral ($2 \geq$overall score ≥ -2), resilient (overall score <-2), and highly resilient (overall score <-5). Resilient categories under the scoring system indicate more criteria for a species are associated with population increase than decline and, therefore, extinction risk is reduced.

To capture a broad range of approaches to identifying species at risk of extinction, we extracted special status from three sources plus an additional two sources addressing only birds. Climate change effects were not necessarily excluded from any of these approaches, but all consider other threats. The three sources covering all taxonomic groups were U.S. Fish and Wildlife Service, NatureServe, and State of New Mexico, with special status defined as follows. Special status species at the national level were compiled from Federal endangered and threatened species listed by U.S. Fish and Wildlife Service under the U.S. Endangered Species Act (ESA 1973, as amended) as well as designated candidate species (www.fws.gov/endangered/; data accessed April 2011). We obtained subnational conservation status for New Mexico for each of our targeted species from the NatureServe website (version 7.1, http://explorer.natureserve.org/; data accessed March 2012) and included any species listed as "vulnerable," "imperiled," or "critically imperiled" (status = S1, S2, S3) as a special status species (Faber-Langendoen et al. 2012). We included a species as special status if designated as threatened, sensitive, and endangered under the New Mexico Wildlife Conservation Act or as the Species of Greatest Conservation Need by the New Mexico Comprehensive Wildlife Conservation Strategy (NMDGF 2006; data accessed March 2012). Note that information on distribution and population trend in New Mexico was taken from NatureServe and used, in part, to determine species of greatest conservation need (NMDGF 2006).

More estimates for extinction risk were available for birds from the Partners in Flight species assessment database and State of the Birds report on climate change (NABCI 2010, Panjabi et al. 2012). From Partners in Flight, we extracted threats to breeding scores, which evaluated current and future threats over the next 30 y for species in North America (Panjabi et al. 2012; http://rmbo.org/pifassessment/Database.aspx; data accessed February 2014). We included both scores where future conditions were expected to improve (score = 1), which could be equated with resilience from the climate change assessment, and three categories of deteriorating conditions (score $\geq$ 3), which we equated with at risk of extinction. State of the Birds highlighted climate change by evaluating two climate factors (sensitivity and exposure) in addition to three factors unrelated to climate (NABCI 2010). Species were evaluated by broad habitat relationships and we extracted scores from western forest or aridlands habitats categorizing those species with medium to high vulnerability (score $\geq$ 2) as special status (http://www.stateofthebirds.org/2010/results-for-species; data accessed February 2014).

We compared the status of each species compiled from the special status species lists with those identified as vulnerable or highly vulnerable from the climate change assessment report. We used two categories of climate change vulnerability for the comparison because the selected threshold of vulnerability would affect the results. The Federal, New Mexico, and NatureServe lists enabled us to compare taxonomic groups, but given the additional information available for birds, we did a second comparison adding the two bird assessments to see how more information might alter the results. We evaluated the adequacy of current special status designation to capture climate change vulnerability by examining how often species overlapped or were

missing between the compiled lists. A species was categorized as "overlapping" if it was vulnerable or highly vulnerable in the climate change assessment and had special status from any of the current special status lists. A species was categorized as "missing" if it was identified as climate-change vulnerable or highly vulnerable, but was not identified as special status on any of the lists. Introduced species were omitted from calculations of "overlapping" and "missing" for all but the birds-only comparison, because they were not evaluated in the other lists of special status. This only affected the number "missing" from climate-change vulnerable (score >2) for reptiles. We summed the number of overlapping and missing species across all species and for four taxonomic groups: birds, reptiles, amphibians, and mammals. We calculated the proportion of special status species that overlapped with the two categories of climate change vulnerability and the proportion of climate-change vulnerable species for both categories that were missing from current lists of special status. We also noted cases where special status overlapped with climate change resilience, climate-change vulnerable species were expected to experience improved conditions, or an introduced species was expected to be negatively affected by climate change; because, in these cases, climate change could create an opportunity (as opposed to a challenge) for more effective conservation management.

Results and Discussion

Of the 116 species we evaluated, 22 species were special status based on three current lists, 71 were identified as vulnerable to negative impacts of climate change, 30 of those were categorized as highly vulnerable, and 7 had a reduced extinction risk by 2050 for the Middle Río Grande (Tables 2 and 3). Although the climate change assessment was conducted specifically for the Middle Río Grande, we can expect species vulnerability scores to be comparable across a broader region with similar projections for climate and climate-related phenomena (Figure 1; Bagne et al. 2011). Current species conservation efforts will best accommodate changing climate when the overlap between species with special status and climate change vulnerability is high and the number of vulnerable species missing from priority lists is low. We found that climate change vulnerability often overlapped with special status (≥75% for all groups except reptiles). This is similar to results found for bird species of special concern in California, where 72% of those listed as at risk of extinction by the U.S. Fish and Wildlife Service were vulnerable to climate change (Gardali et al. 2012). When we focused on highly vulnerable species, overlap between special status and climate change vulnerability was reduced, particularly for mammals, indicating that inclusion of species on special status lists was not more likely with increasing impact of climate change (Table 3). Overlap implies that special status captures continuing extinction risk, although conservation measures may need to be intensified with additional or exacerbating threats (NABCI 2010). Conversely, many species vulnerable to climate change were missing from current special status lists and will potentially need intervention or monitoring (Table 3).

The need to reassess species conservation status to address climate change was not equal among taxonomic groups. Special status for amphibians best encompassed climate change vulnerability with the most overlap and the fewest missing, partly due to the fact that amphibians had the highest proportion of special status species, but only nine species were assessed. The International Union for Conservation of Nature comparison of the Red List and climate change susceptibility found that 75% of climate-change susceptible amphibian species overlapped those currently threatened with extinction and 53% of climate-change susceptible amphibian species were not listed as currently threatened, which closely matches our estimates for the other taxonomic groups (Foden et al. 2008). Reptiles fared worst in the comparison, with few reptile species identified as special status across three lists and poor agreement between current status and climate change vulnerability. Of potential benefit to reptiles was the finding that two introduced turtle species were vulnerable to declines, which could increase effectiveness of control measures and ultimately benefit some native species. Our findings add to the concern many have voiced about the rising threat of extinction for amphibians and reptiles due to climate change threats (Araujo et al. 2006; Sinervo et al. 2010).

Bird species, although exhibiting a large degree of overlap between special status and climate change vulnerability, had more than half of species vulnerable to climate change missing from special status lists (Table 3). Adding two special status lists for birds reduced the high number of vulnerable species missing from special status, but the proportion of overlap remained relatively unchanged (Tables 3 and 4). Although overlap between climate change vulnerability and special status did not improve, it is noteworthy that at-risk species from the State of the Birds (which had a climate change focus) were all identified as climate-change vulnerable in the Middle Río Grande assessment (Table 2). The majority of special status bird species only appeared on one list; thus, efforts adopting a single method of estimating extinction risk may overlook a large number of potentially declining species (Table 2).

We found no instances where special status species were predicted to be at lower extinction risk and few where introduced species would decline with climate change for the Middle Río Grande (Tables 3 and 4). This suggests that species subject to positive effects of climate change are not likely to be those at risk of extinction. Although opportunities may be few, they present a potentially cost-effective route to improved conservation and should garner greater recognition from those evaluating climate change impacts (Bradley et al. 2009).

Examination of individual species showed a tendency toward overlap between special status and climate change vulnerability when climate change exacerbated a current threat to a species, such as decline in riparian

Table 2. Climate change vulnerability and current special status for terrestrial vertebrates of the Middle Río Grande bosque, New Mexico, United States up to 2050. Partners in Flight and State of the Birds refer to bird species only. (I) follows the common name of introduced species, but these species were only included in the climate change vulnerability assessment and the Partners in Flight list. Order is based on ascending overall vulnerability score (not shown).

Common name	Scientific name	Climate change vulnerability[a]	Current status[b]
Amphibians			
Plains spadefoot	*Spea bombifrons*	R	—
American bullfrog (I)	*Lithobates catesbeianus*	—	—
Couch's spadefoot	*Scaphiopus couchii*	—	—
Mexican spadefoot	*Spea multiplicata*	—	—
Great plains toad	*Anaxyrus cognatus*	—	—
Woodhouse's Toad	*Anaxyrus woodhousii*	HV	
Barred tiger salamander	*Ambystoma mavortium mavortium*	HV	NM
Western chorus frog	*Pseudacris triseriata*	HV	NM
Northern leopard frog	*Lithobates pipiens*	HV	NS, NM
Reptiles			
Desert grassland whiptail	*Aspidoscelis uniparens*	R	—
Common kingsnake	*Lampropeltis getula*	—	—
Western diamond-backed rattlesnake	*Crotalus atrox*	—	—
Prairie rattlesnake	*Crotalus viridis*	—	—
Ornate box turtle	*Terrapene ornata*	—	—
Western hog-nosed snake	*Heterodon nasicus*	—	—
Gophersnake	*Pituophis catenifer*	—	—
Common gartersnake	*Thamnophis sirtalis*	—	
North American racer	*Coluber constrictor*	—	NS
Southwestern fence lizard	*Sceloporus cowlesi*	—	—
Tiger whiptail	*Aspidoscelis tigris*	—	NS
Glossy snake	*Arizona elegans*	V	—
Terrestrial gartersnake	*Thamnophis elegans*	V	—
New Mexico whiptail	*Aspidoscelis neomexicana*	V	—
Plains black-headed snake	*Tantilla nigriceps*	V	—
Red-eared slider (I)	*Trachemys scripta elegans*	V	—
Coachwhip	*Coluber flagellum*	V	—
Common side-blotched lizard	*Uta stansburiana*	V	—
Snapping turtle (I)	*Chelydra serpentina*	V	—
Chihuahuan spotted whiptail	*Aspidoscelis exsanguis*	V	—
Common checkered whiptail	*Aspidoscelis tesselata*	V	—
Many-lined skink	*Plestiodon multivirgatus*	V	—
Painted turtle	*Chrysemys picta*	V	NM
Mexican plateau slider	*Trachemys gaigeae*	V	NS, NM
Spiny softshell	*Apalone spinifera*	V	—
Checkered gartersnake	*Thamnophis marcianus*	V	—
Desert spiny lizard	*Sceloporus magister*	V	—
Black-necked gartersnake	*Thamnophis cyrtopsis*	HV	—
Great Plains skink	*Plestiodon obsoletus*	HV	—
Birds			
Greater roadrunner	*Geococcyx californianus*	R	—
Brown-headed cowbird	*Molothrus ater*	R	—
House finch	*Carpodacus mexicanus*	R	—
Mourning dove	*Zenaida macroura*	—	NM, Pi
European starling (I)	*Sturnus vulgaris*	—	Pi
American kestrel	*Falco sparverius*	—	Pd
Blue grosbeak	*Passerina caerulea*	—	—

Table 2. Continued.

Common name	Scientific name	Climate change vulnerability[a]	Current status[b]
Indigo bunting	*Passerina cyanea*	—	—
Spotted towhee	*Pipilo maculatus*	—	—
Northern rough-winged swallow	*Stelgidopteryx serripennis*	—	—
Eastern bluebird	*Sialia sialis*	—	NS
Lesser goldfinch	*Carduelis psaltria*	—	—
Black phoebe	*Sayornis nigricans*	—	Pd
Ash-throated flycatcher	*Myiarchus cinerascens*	V	—
Western kingbird	*Tyrannus verticalis*	V	SB
Bewick's wren	*Thryomanes bewickii*	V	Pd
Phainopepla	*Phainopepla nitens*	V	Pd, SB
Great horned owl	*Bubo virginianus*	V	Pi
Ladder-backed woodpecker	*Picoides scalaris*	V	—
Bushtit	*Psaltriparus minimus*	V	—
Black-chinned hummingbird	*Archilochus alexandri*	V	SB
Black-capped chickadee	*Poecile atricapillus*	HV	NS
Hairy woodpecker	*Picoides villosus*	HV	—
Barn swallow	*Hirundo rustica*	HV	—
Red-winged blackbird	*Agelaius phoeniceus*	HV	—
Yellow-breasted chat	*Icteria virens*	HV	NS, Pd
Western meadowlark	*Sturnella neglecta*	HV	Pd
Bank swallow	*Riparia riparia*	HV	NS, NM
Black-headed grosbeak	*Pheucticus melanocephalus*	HV	SB
Lucy's warbler	*Vermivora luciae*	HV	NS, NM, Pd, SB
Bullock's oriole	*Icterus bullockii*	HV	Pd
Cooper's hawk	*Accipiter cooperii*	HV	—
Northern flicker	*Colaptes auratus*	HV	—
Western screech-owl	*Megascops kennicottii*	HV	Pd
White-breasted nuthatch	*Sitta carolinensis*	HV	—
Downy woodpecker	*Picoides pubescens*	HV	—
Summer tanager	*Piranga rubra*	HV	Pd
Western wood-pewee	*Contopus sordidulus*	HV	Pd
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	HV	F, NS, NM, Pd
Cliff swallow	*Petrochelidon pyrrhonota*	HV	Pi
Common yellowthroat	*Geothlypis trichas*	HV	—
Southwestern willow flycatcher	*Empidonax traillii extimus*	HV	F, NS, NM, Pd
Mammals			
Crawford's gray shrew	*Notiosorex crawfordi*	R	—
Black-tailed jackrabbit	*Lepus californicus*	R	—
Big brown bat	*Eptesicus fuscus*	—	—
Rock squirrel	*Spermophilus variegatus*	—	—
North American deermouse	*Peromyscus maniculatus*	—	—
Fringed bat	*Myotis thysanodes*	—	—
Raccoon	*Procyon lotor*	—	—
Ord's kangaroo rat	*Dipodomys ordii*	—	—
Silky pocket mouse	*Perognathus flavus*	—	—
Botta's pocket gopher	*Thomomys bottae*	—	—
Bobcat	*Lynx rufus*	—	—
Coyote	*Canis latrans*	—	—
Arizona myotis	*Myotis occultus*	—	—
Striped skunk	*Mephitis mephitis*	—	—
Pallid bat	*Antrozous pallidus*	—	—

Table 2. Continued.

Common name	Scientific name	Climate change vulnerability[a]	Current status[b]
White-footed deermouse	*Peromyscus leucopus*	—	—
Long-legged myotis	*Myotis volans*	V	—
Desert cottontail	*Sylvilagus audubonii*	V	—
Elk	*Cervus elaphus canadensis*	V	NS
North American porcupine	*Erethizon dorsatus*	V	—
Long-tailed weasel	*Mustela frenata*	V	—
Yuma myotis	*Myotis yumanensis*	V	—
Cougar	*Puma concolor*	V	NS
Western harvest mouse	*Reithrodontomys megalotis*	V	—
Tawny-bellied cotton rat	*Sigmodon fulviventer*	V	—
Common muskrat	*Ondatra zibethicus*	V	—
Hispid cotton rat	*Sigmodon hispidus*	V	—
Mexican free-tailed bat	*Tadarida brasiliensis*	V	NS
Piñon deermouse	*Peromyscus truei*	V	—
White-throated woodrat	*Neotoma albigula*	V	—
Mule deer	*Odocoileus hemionus*	V	NM
Gray fox	*Urocyon cinereoargenteus*	V	—
Mexican woodrat	*Neotoma mexicana*	V	—
American beaver	*Castor canadensis*	HV	NM
American black bear	*Ursus americanus*	HV	NM
New Mexico meadow jumping mouse	*Zapus hudsonius luteus*	HV	NS, NM

[a] From Friggens et al. (2013b): score >2 = vulnerable (V), score >5 = highly vulnerable (HV), and score <−2 = resilient (R). All others considered neutral.
[b] Status from U.S. Fish and Wildlife Service, Endangered Species Act 1973 (F = endangered or candidate; data accessed April 2011), NatureServe (NS = vulnerable, imperiled, or critically imperiled; data accessed March 2012), State of New Mexico (NM = species of greatest conservation need, sensitive, endangered, or threatened; data accessed March 2012), and (for birds) Partners in Flight (Pi = populations improving, Pd = slight to moderate decline; data accessed February 2014), State of the Birds (NABCI 2010; SB = high or medium vulnerability; data accessed February 2014).

Table 3. Comparison from three lists of special status to two categories of climate change vulnerability for 116 terrestrial vertebrates by taxonomic group for the Middle Río Grande, New Mexico, United States. Comparison includes number and proportion of species overlapping (species on any priority list that were also considered vulnerable or highly vulnerable to climate change), missing (species considered vulnerable or highly vulnerable but not on any priority lists), or that presented an opportunity for improved management with climate change (improved conditions for special status species or declines for introduced species). Introduced species were not evaluated under special status, thus were omitted to calculate overlapping or missing species. Special status was taken from U.S. Fish and Wildlife Service, NatureServe, and State of New Mexico. Climate change vulnerability scores were taken from Friggens et al. (2013b).

Taxonomic group	No. of species	No. special status	No. climate-change vulnerable	No. overlapping (% of status)	No. missing (% of vulnerable)	No. of opportunities
Highly vulnerable only (score >5)						
Amphibians	9	3	4	3 (100%)	1 (25%)	0
Reptiles	29	4	2	0 (0%)	2 (100%)	0
Birds	42	8	21	6 (75%)	15 (71%)	0
Mammals	36	7	3	3 (43%)	0 (0%)	0
Subtotal	116	22	30	12 (55%)	18 (60%)	0
Vulnerable (score >2)						
Amphibians	9	3	4	3 (100%)	1 (25%)	0
Reptiles	29	4	18	2 (50%)	14 (88%)	2
Birds	42	8	29	6 (75%)	23 (79%)	0
Mammals	36	7	20	7 (100%)	13 (65%)	0
Total	116	22	71	18 (82%)	51 (74%)	2

Table 4. Comparison of special status from five lists to two categories of climate change vulnerability for bird species of the Middle Río Grande, New Mexico, United States. Comparison includes number and proportion of species overlapping (species on any priority list that were also considered vulnerable or highly vulnerable to climate change), missing (species considered vulnerable or highly vulnerable but not on any priority lists), or that presented an opportunity for improved management with climate change (improved conditions for special status species or declines for introduced species). Special status was taken from U.S. Fish and Wildlife Service, NatureServe, State of New Mexico, Partners in Flight, and State of the Birds (NABCI 2010). Climate change vulnerability scores were taken from Friggens et al. (2013b) and project to 2050.

No. of species	No. special status	No. climate-change vulnerable	No. overlapping (% of status)	No. missing (% of vulnerable)	No. of opportunities
Highly vulnerable only (score >5)					
42	17	21	12 (71%)	8 (38%)	1
Vulnerable (score >2)					
42	17	29	13 (76%)	16 (55%)	2

forests and drying of wetlands. For example, population declines leading to listing of the southwestern willow flycatcher *Empidonax traillii extimus* as an endangered species were attributed to the loss of dense riparian habitats, which is expected to continue under climate change and contributed to the species' vulnerability (McAda and Barroll 2002; U.S. Fish and Wildlife Service 2002; Hurd and Coonrod 2008; Finch et al. 2011; Friggens et al. 2013b). Similarly threatened by continued wetland loss, amphibian species overlapped well in our comparison as well as the one conducted by International Union for Conservation of Nature (Foden et al. 2008). Overlap under exacerbated threats was supported by an analysis of vulnerability for birds of conservation concern in California that found wetland birds to be the most vulnerable as climate change threatens already diminished habitats (Gardali et al. 2012). A species tended to be missing from special status lists when climate change introduced a new threat, such as exceeding thermal tolerances and altered timing of temporary pools. The checkered gartersnake *Thamnophis marcianus,* a species currently considered not at risk, was found highly vulnerable where changes to timing and quantity of rainfall were expected to impact onset and success of reproduction, dispersal opportunity, and prey availability (Friggens et al. 2013b). The appearance of new climate-related threats may have been responsible for the poor alignment we found for reptiles in general.

Current methods of determining special status primarily focus on rare or range-restricted species; thus, not surprisingly, several of the climate vulnerable species missing from priorities could be currently classified as common or abundant. Common or abundant species, however, are not immune to extinction nor are they necessarily resilient to climate change. History has shown that common species can decline rapidly under certain circumstances (Gaston and Fuller 2007a). Importantly, abundant species represent a large proportion of the individuals in a community and play a fundamental role in ecosystem structure and function (Gaston and Fuller 2007b). Their ecological contribution is particularly significant in light of frequently advocated climate change adaptation strategies that seek to enhance resilience of ecological communities and maintain critical ecosystem services.

Climate change vulnerability assessments of species are meant to supplement and not replace current species conservation priorities, but the lack of agreement among lists in our comparison demonstrates the importance of reexamining our reliance on special status lists within the context of a rapidly changing climate (Bagne and Finch 2012; Coe et al. 2012). To add just the species categorized as highly vulnerable to climate change to current special status lists would require a >80% increase. An almost 50% increase would be needed to include all highly vulnerable birds species even with the addition of two lists of at-risk species (Table 4). The solution is not necessarily to add all species that are climate-change vulnerable to special status lists, but we need to be more aware of what threats these lists are missing and find ways to respond to the growing challenge ahead. Methodology used to estimate extinction risk clearly affects special status designation and this should be recognized when applying the results of any assessment (Friggens et al. 2013a; Lankford et al. 2014). A critique of methods used to determine special status is outside the scope of this paper, but inadequacies of current lists to address climate change can be partly attributed to the retrospective approach taken where designation as special status often occurs after a species' numbers have declined to critical levels (Taylor et al. 2005).

Many advocate taking proactive steps to address the large magnitude and rapid pace of climate change threats, which will require conservation advocates to take a more prospective approach that uses projections in addition to observed population measures (Harris et al. 2006; Glick et al. 2011). Species conservation efforts need to consider the unique effects of climate change and anticipate rapidly increasing numbers of at-risk species. Many new methods are available or in development to predict species climate change response, including vulnerability indices (Czúcz et al. 2011; Bagne et al. 2011; Young et al. 2011), species distribution models (Schwartz et al. 2006; Keith et al. 2008; Thuiller et al. 2009), landscape connectivity (Cushman and Landuth 2012), and bioenergetic models (Buckley 2008; Sinervo et al. 2010). Work remains to be done to determine how to best balance traditional and climate-related threats in evaluating extinction risk given that threats will vary in

time, space, and by species. Climate change vulnerability assessments can contribute by identifying species that may need further evaluation and by revealing mechanisms of species response that can be targeted by management actions. Other strategies to select conservation targets focus not on vulnerability, but on uncertainty, cost, public perception, or potential effectiveness of various management options (Regan et al. 2005; McDonald-Madden et al. 2008; Dawson et al. 2011). We are left with many questions: which species should receive management as threats to persistence increase, how can we incorporate disparate and interacting threats in estimating extinction risk, and should prioritization for management action be directed toward ecological function over rarity? However imperfect our knowledge, adding climate change vulnerability to the identification of at-risk species is a step that can be taken now and that will encourage proactive solutions.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Reference S1. Friggens MM, Finch DM, Bagne KE, Coe SJ, Hawksworth DL. 2013b. Vulnerability of species to climate change in the Southwest: vertebrate species of the Middle Rio Grande. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-306.

Found at DOI: http://dx.doi.org/10.3996/052013-JFWM-039.S1 (12.3 MB PDF).

Reference S2. Table 3.1, climate change vulnerability scores from Friggens et al. 2013b; Reference S1.

Found at DOI: http://dx.doi.org/10.3996/052013-JFWM-039.S2 (168 KB PDF).

Reference S3. Bagne KE, Friggens MM, Finch DM. 2011. A System for Assessing Vulnerability of Species (SAVS) to climate change. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-257.

Found at DOI: http://dx.doi.org/10.3996/052013-JFWM-039.S3 (2 MB PDF).

Reference S4. Bagne KE, Finch DM. 2012. Vulnerability of species to climate change in the Southwest: threatened, endangered, and at-risk species at the Barry M. Goldwater Range, Arizona. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-284.

Found at DOI: http://dx.doi.org/10.3996/052013-JFWM-039.S4 (4.5 MB PDF).

Reference S5. Coe SJ, Finch DM, Friggens MM. 2012. An assessment of climate change and the vulnerability of wildlife in the sky islands of the Southwest. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-273.

Found at DOI: http://dx.doi.org/10.3996/052013-JFWM-039.S5 (4.5 MB PDF).

Reference S6. Friggens MM, Bagne KE, Finch DM, Falk D, Triepke J, Lynch A. 2013a. Review and recommendations for climate change vulnerability assessment approaches with examples from the Southwest. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-309.

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References

Akçakaya HR, Cutchart SHM, Mace GM, Stuart SN, Hilton-Taylor C. 2006. Use and misuse of the IUCN Red List Criteria in projecting climate change impacts on biodiversity. Global Change Biology 12:2037–2043.

Allendorf FW, Bayles D, Bottom DL, Currens KP, Frissell CA, Hankin D, Lichatowich JA, Nehlson W, Trotter PC, Williams TH. 1997. Prioritizing Pacific salmon stocks for conservation. Conservation Biology 11:140–152.

Araujo MB, Thuiller W, Pearson RG. 2006. Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33:1712–1728.

Bagne KE, Finch DM. 2012. Vulnerability of species to climate change in the Southwest: threatened, endangered, and at-risk species at the Barry M. Goldwater Range, Arizona. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-284. (see *Supplemental Material,* Reference S4, http://dx.doi.org/10.3996/052013-JFWM-039.S4); also available: http://www.treesearch.fs.fed.us/pubs/41079 (February 2014).

Bagne KE, Friggens MM, Finch DM. 2011. A System for Assessing Vulnerability of Species (SAVS) to climate change. Fort Collins, Colorado: U.S. Department of

Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-257. (see *Supplemental Material,* Reference S3, http://dx.doi.org/10.3996/052013-JFWM-039.S3); also available: http://www.treesearch.fs.fed.us/pubs/37850 (February 2014).

Bradley BA, Oppenheimer M, Wilcove DS. 2009. Climate change and plant invasions: restoration opportunities ahead? Global Change Biology 15:1511–1521.

Broennimann O, Thuiller W, Hughes G, Midgley GF, Alkemade JR, Guisan A. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12:1079–1093.

Buckley LB. 2008. Linking traits to energetics and population dynamics to predict lizard ranges in changing environments. American Naturalist 171:E1–E19.

Coe SJ, Finch DM, Friggens MM. 2012. An assessment of climate change and the vulnerability of wildlife in the sky islands of the Southwest. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-273. (See *Supplemental Material,* Reference S5, http://dx.doi.org/10.3996/052013-JFWM-039.S5); also available: http://www.treesearch.fs.fed.us/pubs/40418 (February 2014).

Cushman SA, Landguth EL. 2012. Ecological associations, dispersal ability, and landscape connectivity in the northern Rocky Mountains. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-90. Available: http://www.treesearch.fs.fed.us/pubs/40438 (February 2014).

Czúcz B, Csecserits A, Botta-Dukát Z, Kröel-Dulay G, Szabó R, Horváth F, Molnár Z. 2011. An indicator framework for the climatic adaptive capacity of natural ecosystems. Journal of Vegetation Science 22:711–725.

Dawson TP, Jackson ST, House JI, Prentice IC, Mace GM. 2011. Beyond predictions: biodiversity conservation in a changing climate. Science 332:53–58.

Erasmus BF, Van Jaarsveld AS, Chown SL, Kshatriya M, Wessels KJ. 2002. Vulnerability of South African animal taxa to climate change. Global Change Biology 8:679–693.

Faber-Langendoen D, Nichols J, Master L, Snow K, Tomaino A, Bittman R, Hammerson G, Heidel B, Ramsay L, Teucher A, Young B. 2012. NatureServe conservation status assessments: methodology for assigning ranks. Arlington, Virginia: NatureServe.

Finch DM, Friggens MM, Bagne KE. 2011. Case study 3: species vulnerability assessment for the Middle Rio Grande, New Mexico. Pages 96–103 in Glick P, Stein BA, Edelson NA, editors. Scanning the conservation horizon: a guide to climate change vulnerability assessment. Washington, D.C.: National Wildlife Federation. Available: http://www.treesearch.fs.fed.us/pubs/37408 (February 2014).

Foden W, Mace G, Vie J, Angulo A, Butchart SH, DeVantier L, Dublin H, Gutsche A, Stuart S, Turak E. 2008. Species susceptibility to climate change impacts. Gland, Switzerland: [IUCN] International Union for Conservation of Nature. Available: http://training.fws.gov/ec/resources/shc/species_susceptibility_to_climate_change_impacts.pdf (February 2014).

Fordham DA, Akçakaya HR, Araújo MB, Elith J, Keith DA, Pearson R, Auld TD, Mellin C, Morgan JW, Regan TJ, Tozer M, Watts MJ, White M, Wintle BA, Yates C, Brook BW. 2012. Plant extinction risk under climate change: are forecast range shifts alone a good indicator of species vulnerability to global warming? Global Change Biology 18:1357–1371.

Friggens MM, Bagne KE, Finch DM, Falk D, Triepke J, Lynch A. 2013a. Review and recommendations for climate change vulnerability assessment approaches with examples from the Southwest. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-309. (see *Supplemental Material,* Reference S6, http://dx.doi.org/10.3996/052013-JFWM-039.S6); also available: http://www.treesearch.fs.fed.us/pubs/44184 (February 2014).

Friggens MM, Finch DM, Bagne KE, Coe SJ, Hawksworth DL. 2013b. Vulnerability of species to climate change in the Southwest: vertebrate species of the Middle Rio Grande. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-306. (see *Supplemental Material,* Reference S1, http://dx.doi.org/10.3996/052013-JFWM-039.S1; also available: http://www.treesearch.fs.fed.us/pubs/43922 (February 2014).

Gardali T, Seavy NE, DiGaudio RT, Comrack LA. 2012. A climate change vulnerability assessment of California's at-risk birds. PloS One 7(3): e29507.

Gaston KJ, Fuller RA. 2007a. Biodiversity and extinction: losing the common and the widespread. Progress in Physical Geography 31:213–225.

Gaston KJ, Fuller RA. 2007b. Commonness, population depletion and conservation biology. Trends in Ecology and Evolution 23:14–19.

Gilpin ME, Soulé ME. 1986. Minimum viable populations: processes of species extinction. Pages 19–34 in Soulé, ME, editor. Conservation biology: the science of scarcity and diversity. Sunderland, Massachusetts: Sinauer.

Glick P, Stein BA, Edelson NA, editors. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. Washington, D.C.: National Wildlife Federation.

Hannah L, Midgley GF, Millar D. 2002. Climate change-integrated conservation strategies. Global Ecology and Biogeography 11:485–495.

Harris JA, Hobbs RJ, Higgs E, Aronson J. 2006. Ecological restoration and global climate change. Restoration Ecology 14:170–176.

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD. 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162.

Hughes L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution 15:56–61.

Hurd BH, Coonrod J. 2008. Climate change risks New Mexico's waterways: its byways and its flyways. Water Resources Impact 10(4):5–9.

Jiguet F, Gadot AS, Julliard R, Newson SE, Couvet D. 2007. Climate envelope, life history traits and the resilience of birds facing global change. Global Change Biology 13:1672–1684.

Keith DA, Akcakaya HR, Thuiller W, Midgley GF, Pearson RG, Phillips SJ, Regan HM, Araujo MB, Rebelo TG. 2008. Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. Biology Letters-United Kingdom 4:560–563.

Lankford AJ, Svancara LK, Lawler JJ, Vierling K. 2014. Comparison of climate change vulnerability assessments for wildlife. Wildlife Society Bulletin. doi: 10.1002/wsb.399

Laurance WF, Williamson GB. 2001. Positive feedbacks among forest fragmentation, drought, and climate change in the Amazon. Conservation Biology 15: 1529–1535.

Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akçakaya HR, Leader-Williams N, Milner-Gulland EJ, Stuart SN. 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. Conservation Biology 22:1424–1442.

Mace GM, Lande R. 1991. Assessing extinction threats: toward a reevaluation of IUCN threatened species categories. Conservation Biology 5:148–157.

MacLean IM, Wilson RJ. 2011. Recent ecological responses to climate change support predictions of high extinction risk. Proceedings of the National Academy of Sciences 108:12337–12342.

MacNally R, Bennett AF, Thomson JR, Radford JQ, Unmack G, Horrocks G, Vesk PA. 2009. Collapse of an avifauna: climate change appears to exacerbate habitat loss and degradation. Diversity and Distributions 15:720–730.

Master LL. 1991. Assessing threats and setting priorities for conservation. Conservation Biology 5:559–563.

Maurer EP, Brekke L, Pruitt T, Duffy PB. 2007. Fine-resolution climate projections enhance regional climate change impact studies. Eos, Transactions American Geophysical Union 88:504.

McAda DP, Barroll P. 2002. Simulation of ground-water flow in the middle Río Grande basin between Cochiti and San Acacia, New Mexico. Albuquerque, New Mexico: U.S. Geological Survey. Water-Resources Investigations Report 02-4200.

McCarty J. 2001. Ecological consequences of recent climate change. Conservation Biology 15:320–331.

McDonald KA, Brown JH. 1992. Using montane mammals to model extinctions due to global change. Conservation Biology 6:409–415.

McDonald-Madden E, Baxter PWJ, Possingham H. 2008. Making robust decisions for conservation with restricted money and knowledge. Journal of Applied Ecology 45:1630–1638.

Millar C, Stephenson N, Stephens S. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145–2151.

[NMDGF] New Mexico Department of Game & Fish. 2006. Comprehensive wildlife conservation strategy for New Mexico. Santa Fe, New Mexico: New Mexico Department of Game and Fish. Available: http://www.wildlife.state.nm.us/conservation/comp_wildlife_cons_strategy/cwcs.htm (February 2014).

[NABCI] North American Bird Conservation Initiative. 2010. The state of the birds 2010 report on climate change, United States of America. Washington, D.C.: U.S. Department of the Interior. Available: http://www.stateofthebirds.org/2010/pdf_files/State%20of%20the%20Birds_FINAL.pdf (February 2014).

Panjabi AO, Blancher PJ, Dettmers R, Rosenberg KV. 2012. Partners in Flight technical series No. 3. Brighton, Colorado: Rocky Mountain Bird Observatory. Available: http://www.rmbo.org/pubs/downloads/Handbook2012.pdf. (February 2014).

Peñuelas J, Filella I. 2001. Responses to a warming world. Science 294:793–795.

Peterson AT, Ortega-Huerta MA, Bartley J, Sanchez-Cordero V, Soberon J, Buddemeier RH, Stockwell DRB. 2002. Future projections for Mexican faunas under global climate change scenarios. Nature 416: 626–629.

Peterson AT, Sánchez-Cordero V, Soberón J, Bartley J, Buddemeier RW, Navarro-Sigüenza AG. 2001. Effects of global climate change on geographic distributions of Mexican Cracidae. Ecological Modelling 144:21–30.

Regan HM, Ben-Haim Y, Langford B, Wilson WG, Lundberg P, Andelman SJ, Burgman MA. 2005. Robust decision-making under severe uncertainty for conservation management. Ecological Applications 15:1471–1477.

Reino L, Moya-Laraño J, Heitor AC. 2009. Using survival regression to study patterns of expansion of invasive species: will the common waxbill expand with global warming? Ecography 32:237–246.

Root T, 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.

Schwartz MW, Iverson LR, Prasad AM, Matthews SN, O'Connor RJ. 2006. Predicting extinctions as a result of climate change. Ecology 87:1611–1615.

Scott JM, Goble DD, Svancara LK, Pigorna A. 2005. By the numbers. Pages 16–35 in Goble DD, Scott JM, Davis

FW, editors. The Endangered Species Act at thirty: volume 1. Washington, D.C.: Island Press.

Seager, R, Ting M, Held I, Kushnir Y, Lu J, Vecchi G, Huang H, Harnik N, Leetmaa A, Lau N, Li C, Velez J, Naik N. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181–1184.

Sinervo B, Mendez-de-la-Cruz F, Miles DB, Heulin B, Bastiaans E, Villagrán-Santa Cruz M, Lara-Resendiz R, Martínez-Méndez N, Calderón-Espinosa ML, Meza-Lázaro RN, Gadsden H, Avila LJ, Morando M, De la Riva IJ, Sepulveda PV, Rocha CF, Ibargüengoytía N, Puntriano CA, Massot M, Lepetz V, Oksanen TA, Chapple DG, Bauer AM, Branch WR, Clobert J, Sites JW Jr. 2010. Erosion of lizard diversity by climate change and altered thermal niches. Science 328:894–899.

Small-Lorenz SL, Culp LA, Ryder TB, Will TC, Marra PP. 2013. A blind spot in climate change vulnerability assessments. Nature Climate Change 3:91–93.

Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. 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, England, United Kingdom; and New York: Cambridge University Press.

Taylor MFJ, Suckling KF, Rachlinski JJ. 2005. The effectiveness of the Endangered Species Act: a quantitative analysis. BioScience 55:360–367.

Terborgh J, Winter B. 1980. Some causes of extinction. Pages 119–134 in Soulé ME, Wilcox BA, editors. Conservation biology: an ecological-evolutionary perspective. Sunderland, Massachusetts: Sinauer.

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, de Siqueira MF, 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.

Thuiller W, Lafourcade B, Engler R, Araújo MB. 2009. BIOMOD—a platform for ensemble forecasting of species distributions. Ecography 32:369–373.

[ESA] U.S. Endangered Species Act of 1973, as amended, Pub. L. No. 93-205, 87 Stat. 884 (Dec. 28, 1973). Available: http://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf (February 2014).

U.S. Fish and Wildlife Service. 2002. Southwestern willow flycatcher recovery plan. Albuquerque, New Mexico: U.S. Fish and Wildlife Service.

Young B, Byers E, Gravuer K, Hall K, Hammerson G, Redder A. 2011. Guidelines for using the NatureServe climate change vulnerability index (release 2.1). Arlington, Virginia: NatureServe. Available: http://www.natureserve.org/sites/default/files/publications/files/guidelines_natureserveclimatechangevulnerabilityindex_r2.1_apr2011.pdf. (February 2014).