A Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change

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ABSTRACT

This report describes an evaluative framework that may be used to categorize the relative vulnerability of species to climate change. Four modules compose this framework: Module 1 categorizes baseline vulnerability to extinction or major population reduction by scoring those elements of the species' life history, demographics, and conservation status that influence the likelihood of its survival or extinction (excluding climatic changes); Module 2 scores the likely vulnerability of a species to future climate change, including the species' potential physiological, behavioral, demographic, and ecological response to climate change; Module 3 combines the results of Modules 1 and 2 into a matrix to produce an overall score of the species' vulnerability to climate change, which maps to an adjectival category, such as "critically vulnerable", "highly vulnerable", "less vulnerable", and "least vulnerable"; Module 4 is a qualitative determination of uncertainty of overall vulnerability (high, medium, and low) based on evaluations of uncertainty done in each of the first 3 modules. To illustrate the use of this framework, it was applied to five U.S. threatened and endangered species and one species that has since been delisted. Based on the authors' evaluation, four of those species were categorized as "critically vulnerable": the golden-cheeked warbler (Dendroica chrysoparia), the salt marsh harvest mouse (Reithrodontomys raviventris), the Mount Graham red squirrel (Tamiasciurus hudsonicus grahamensis), and the Lahontan cutthroat trout (Oncorhyncus clarki henshawi). The desert tortoise (Gopherus agassizii) was characterized as "highly vulnerable" and the bald eagle (Haliaeetus leucocephalus) -- now delisted, except for the southwest population -- was categorized as "less vulnerable". Certainty scores in Module 4 ranged between medium and high and reflect the amount and quality of information available.

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PREFACE

This report was prepared by Hector Galbraith of Manomet Center for Conservation Sciences and Jeff Price of World Wildlife Fund. Review, comments and general oversight of this work were provided by the Global Change Research Program (GCRP) in the National Center for Environmental Assessment (NCEA), U.S. Environmental Protection Agency (U.S. EPA). This report presents a framework for evaluating the current and future vulnerability of threatened and endangered animal species to existing stressors and to potential future climatic changes. Results are intended to be regarded as indications of the comparative vulnerabilities of species to climate change, not estimates of a species' absolute vulnerability.

The report has undergone peer consultation and external peer review, including review of the first draft in 2002 by the U.S. Fish and Wildlife Service within the Department of Interior. Changes and edits made between the draft report and this final report posted for public comment reflect edits made to respond to expert reviewers during the peer consultation and external peer review process. When publishing the final report, EPA will consider any public comments received the public comment period.

EPA's Global Change Research is an assessment-oriented program committed to developing frameworks and tools to assist decision-makers in evaluating the impacts of climate change to air quality, water quality and ecosystems. This framework is offered as one of a number of potential approaches for determining species' relative vulnerability to climate change. It is not intended to serve as a tool for determining whether a species is endangered or threatened under the Section 4 listing process of the Endangered Species Act. It is also not intended to be used by federal or state agencies for the determination of whether specific actions cause a "taking" of any listed species of endangered fish or wildlife under the Endangered Species Act. This framework is intended to provide information to ecosystem and resource managers to support their decision making about management actions that reflect consideration of those threatened and endangered species that are most vulnerable to climate change. This framework also may be helpful in supporting management decisions related to species not listed as threatened or endangered.

EXECUTIVE SUMMARY

Organisms listed as threatened or endangered under the Endangered Species Act (ESA) of 1973 are at risk of extinction due to adverse effects of current natural or anthropogenic stressors (e.g., habitat loss, contaminants, and competition with invasive species). Climate change and variability, acting alone or exacerbating current stressors, may constitute an important new threat for many threatened and endangered (T&E) species. Evaluative tools that account for climate change impacts are being developed for use by resource managers as they become more aware of the effects of climate change. This report describes the development of an evaluative framework to categorize the vulnerability of species to climate change. The framework is then applied to six species that were listed as threatened or endangered at the time the framework was developed to illustrate its use in categorizing the vulnerability of these species to climate change.

This framework for evaluating vulnerabilities to climate change comprises four modules. Module 1, which includes 11 variables, categorizes the comparative vulnerabilities to existing stressors, not including climate change. Likely, baseline vulnerability to extinction or major population reduction is categorized by scoring those elements of the species' life history, demographics, and conservation status that influence the likelihood of its survival or extinction regardless of climate change. Module 2, consisting of 10 variables, scores the likely vulnerability of a species to future climate change. Specifically, the species' potential response to physiological (e.g., temperature, precipitation), behavioral, demographic, and ecological sensitivity to climate change are the elements of this module. Additionally, each variable in Modules 1 and 2 is assigned a "best estimate" certainty score that results in a subjective confidence statement. Module 3 combines the results of Modules 1 and 2 into a matrix to produce an overall evaluation and a score of the species' vulnerability to climate change. The numerical scores are then grouped into adjectival categories: "critically vulnerable", "highly vulnerable", "less vulnerable", and "least vulnerable". Module 4 is a qualitative scoring of uncertainty based on the evaluations from the first 3 modules resulting in an index of certainty (high, medium, and low) associated with the overall vulnerability score from Module 3.

The framework was applied to threatened and endangered species listed under the U.S. ESA. The golden-cheeked warbler (*Dendroica chrysoparia*), salt marsh harvest mouse (*Reithrodontomys raviventris*), Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*), and the Lahontan cutthroat trout (*Oncorhyncus clarki henshawi*) were categorized as "critically vulnerable." The desert tortoise *Gopherus agassizii* was ranked "highly vulnerable," and the bald eagle *Haliaeetus leucocephalus* (no longer listed as threatened or

endangered, except for the southwest population) was scored "less vulnerable." Certainty scores in Module 4 ranged between medium and high and reflect the amount and quality of information available.

Species that are most vulnerable tend to be: restricted in their distributions, small in population size, undergoing population reductions, habitat specialists, and found in habitats that are likely to be most adversely affected by future climate change. Conversely, species like the bald eagle, which are widely distributed, are flexible in their habitat preferences and are considered to be stable or increasing, scored least vulnerable. Thus, the predictions of the model are consistent with what might be expected based on the ecologies and demographics of the test species. The results also indicate that major areas of uncertainty complicate any evaluations of vulnerability. For the species tested, the greatest uncertainties are associated with our relatively poor knowledge about the potential for direct, physiological effects on animal species; relationships between changes in temperature and precipitation regimes and the physiologies and behaviors of animals are apparently only poorly understood.

1. INTRODUCTION

Organisms listed as Threatened or Endangered (T&E species) under the Endangered Species Act (ESA) of 1973 (16 U.S.C. 15631 *et seq.*) are at risk of extinction due to the adverse effects of current natural or anthropogenic stressors (e.g., habitat destruction, contaminants, interactions with invasive species, etc.). Climate change, either acting alone or by exacerbating the effects of these current stressors, may constitute an important new threat for many of these species (Peters, 1992; Tucker and Heath, 1994; Schneider and Root, 2002; Walther et al., 2002). If future conservation priorities, strategies, tactics, and resource allocations are to reflect these changing circumstances, there is a need to develop new tools. In particular, tools are needed that integrate the likely effects of both current and climate change stressors to identify those T&E species that may face the greatest increased risks of extinction or major population reductions, and the specific climatic, physiological, and/or ecological factors that contribute to these increased risks. This report describes an analytical framework that is intended to rank T&E animal species in terms of these current and future risks and potential causal factors.

The primary purpose of the ESA is to "provide for the conservation of endangered and threatened species of fish, wildlife, and plants..." (ESA of 1973, 16 U.S.C. 15631 *et seq.*). Animals typically are listed under the ESA when their population sizes or distributions become so small or limited that their continued existence may be in jeopardy (or at least approaching such a condition). Some T&E animals may always have had extremely restricted distributions or small populations (e.g., some desert fish species or cave-dwelling amphibians or arachnids), and they have been listed as a safeguard against possible future habitat destruction. Other listed species, however, that may have been more widespread and abundant in the past have been so reduced in range or numbers that their continued existence may be in jeopardy. In most such cases, the population/range reduction has been due to anthropogenic stressors, particularly habitat destruction.

Regardless of why an animal species was placed on the T&E list, its presence there implies that its future existence may be in jeopardy. Into this already tenuous situation, a new stressor, climate change, has now been introduced. This raises questions that are important in the conservation, scientific, and regulatory arenas. For example, how might climate change affect the already threatened existence of many T&E animal species; what particular aspects of climate change may be important for individual species, and how will they affect them; which species are likely to be most vulnerable; might some T&E species benefit from climate change; can we mitigate the effects of climate change for any species (e.g., through habitat manipulation,

translocation of organisms, removal of other stressors, etc.); and, lastly, do our current conservation approaches require modification in the light of the likely effects of climate change?

As a first step toward addressing these questions, it is necessary to be able to categorize each T&E animal species in the United States in terms of its likely relative vulnerability to climate change, assess what its responses might be, and identify the causal factors likely to be most important (either due to the direct effects of climate on the organisms themselves, or indirect effects acting through their environment). This report presents the results of an attempt to develop an evaluative framework that can be used to assess the relative vulnerabilities of T&E animal species to climate change and address these issues. It details the structure of the proposed framework and tests it on six species that were listed as threatened or endangered at the time the framework was developed: the bald eagle, *Haliaeetus leucocephalus* (no longer listed), golden-cheeked warbler, *Dendroica chrysoparia*, salt marsh harvest mouse, *Reithrodontomys raviventris*, Mount Graham Red Squirrel *Tamiasciurus hudsonicus grahamensis*, desert tortoise, *Gopherus agassizii*, and the Lahontan cutthroat trout, *Oncorhyncus clarki henshawi*. These species were selected because they are very different in their natural histories, demographies, status and distribution, population trends, and susceptibilities to different stressors, and, because of these differences, may provide an adequate *preliminary* test of the framework. This report does not provide a finalized framework but rather describes a proposed framework for discussion and future refinement. Therefore, as the framework is developed further, it should be tested against additional species.

At least three previous studies have attempted to categorize animal species in terms of their population vulnerabilities: the International Union for the Conservation of Nature (IUCN) developed a system for scoring the conservation status of organisms worldwide (Mace and Stuart, 1994). This was the method underpinning the development of the IUCN's Red List categorizations and was adopted by Birdlife International to assess the conservation of wild bird species in Europe (Tucker and Heath, 1994) and to identify birds at risk worldwide (Collar et al., 1994). In the United States, Partners in Flight have developed a framework to categorize the conservation status and vulnerability of landbirds (Carter et al., 2000). This system was subsequently the basis of the Watchlist of North American birds published by the National Audubon Society. Neither of these methods attempts to predict the potential incremental effects of climate change on species' future vulnerabilities and are, therefore, not suitable for projecting future risks. However, Herman and Scott (1994) attempted to do so by developing a scoring framework to evaluate the risks posed by future climate change to vertebrates in Nova Scotia, Canada. Herman and Scott (1994) did not include risks posed by existing nonclimate stressors. The framework developed in this study incorporates many of the concepts and components of

these earlier studies and extends them so as to be able to predict the future risks posed by existing stressors and climate change acting on organisms.

Section 2 identifies and discusses some overarching considerations that are relevant to the construction of any evaluative framework. Section 3 describes the general structure of the framework. Sections 4 through 8 describe in greater detail the specific components of the framework. Section 9 summarizes the results of the tests of the framework on the six test species and Section 10 presents the major conclusions of this process. Appendices A through J provide example narratives and applications of Modules 1 through 4 to six selected species.

It should be noted that while this framework will help in evaluating the likely risks of climate change to T&E species in the United States, the information generated is intended to be a guide to how the future vulnerability of organisms might change. It should not be used alone to provide a mechanism for determining whether a species is endangered or threatened under the Section 4 listing process of the Endangered Species Act. To do so would be a misuse of the framework's intended purpose.

2. OVERARCHING ISSUES

In this section, some overarching issues important in evaluating species' vulnerabilities to climate change are identified and discussed. Sections 3 through 8 demonstrate how these issues are incorporated into the proposed framework structure.

2.1. FRAMEWORK OBJECTIVES

To provide information that will be useful in addressing the questions in Section 1 of this report and assist conservationists and regulators in formulating conservation strategies and policies, an effective predictive framework will have to:

(1) characterize and rank the current (i.e., non-climate change) vulnerabilities of T&E species in a consistent fashion;

(2) characterize the potential effects of climate change on a species' vulnerability;

(3) integrate the results of (1) and (2) into an overall evaluation of potential future vulnerability;

(4) evaluate the risks and potential magnitudes of population and distributional change;

(5) identify specific climate change causal factors that may contribute to these changes and their relative importance;

(6) evaluate uncertainties associated with Steps 1 through 5; and

(7) identify data needs for species for which uncertainty is high.

Climate change may already have affected some T&E organisms in the United States (Parmesan and Galbraith, 2005). To the extent that such changes are recognized and incorporated into existing distribution, population size, and habitat estimates, they are included and evaluated in this framework as "baseline" conditions. The primary purpose of this framework, unlike current approaches, is to evaluate potential consequences of *future* climate change.

2.2. IMPORTANT FRAMEWORK ATTRIBUTES

Process Transparency. The intended result of this framework is to produce evaluations of the relative vulnerabilities of T&E species to climate change and other stressors. The focus of this framework is on evaluating vulnerabilities—not predicting risks to T&E species. T&E species were chosen to use as examples because these species generally have sufficient data to implement the framework. It is equally important that the process and reasoning through which the evaluation was arrived at be well documented and transparent. This will be essential in

modifying species evaluations if new data are gathered that cast doubt on previous assessments. Ensuring process transparency and documenting important assumptions are as important components of the framework as producing predictive scores.

Framework Precision and Accuracy. By their nature, the results of a predictive framework will involve speculation (we cannot be entirely confident about how an organism will respond to future stressors that may not be adequately understood). Thus, in the absence of *a posteriori* knowledge, this framework provides approximations of species' ranked vulnerabilities. It is not intended that results be considered completely accurate or precise estimations of a species' absolute vulnerability—the results should be regarded as indications of the comparative vulnerabilities of T&E species as represented by the species evaluated.

Also, not all species may be adversely affected by climate change; it is possible some may benefit from new climatic regimes (for example, due to their habitats being expanded, or to their competitors or predators being adversely affected). It is important, therefore, that the evaluative framework allows for this possibility in the range of species' responses.

Treatment of Certainty/Uncertainty. Uncertainty is inevitable in any predictive framework that attempts to anticipate specific effects of future stressors on organisms. Such uncertainty may have many sources, including the specifics or variability of likely future climates, the physiological sensitivity of the species, uncertainty about its demographics, population dynamics, or habitat ecology, or about the likely responses of habitats, or critical habitat components, to climate change. Any prediction regarding future vulnerability would be of limited practical value without an evaluation of the certainty/uncertainty associated with it. In this framework, the degree of certainty is assessed in two ways: first, when scoring each module variable, "best estimate" and alternate (possible but less likely) scores are assigned. These are intended to capture the range of responses that may occur, rather than focusing on a single "point estimate" of responses. Second, each individual variable score is assigned a ranked certainty evaluation (i.e., high, medium, or low level of certainty). This 3-point ranking is based on the 5-category scale developed for the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (Moss and Schneider, 2000). These rankings are then combined into an assessment of the degree of certainty that should be associated with the final assessment of the species' overall vulnerability. For most species, these certainty scores will not be based on quantitative evidence, but on the judgment of experts in the species' ecology, conservation, and/or demographics.

Sources of Information and Expert Opinion. Some of the scores determined in this framework may be based on quantitative and empirical data (e.g., abundance estimates based on actual census data) published in peer-reviewed scientific or other report literature. However, for

many less well studied species, it is likely that many of the framework scores will be based not on actual empirical data, but will comprise rankings (Siegel, 1956) based on expert opinion. In this context, expert opinion is defined as the professional judgment of one or more experts in the species or, failing that, ecologically comparable members of its taxonomic group (up to and including the Family). If expert opinion is the main source of a score, its argument, underlying assumptions, and the evidence that supports the opinion must be clearly stated in the species' narrative section.

For some species there may only be a small number of experts; for others there may be comparatively many. If expert opinion is to constitute the majority of a species' scores, and if a number of experts can participate, some version of a Delphi approach (Linstone and Turoff, 1975; Zuboy, 1980, 1981; Crance, 1985) might be used to formalize and record their opinions.

It should be noted that the main role of the experts will be in helping to evaluate species' framework scores, based on their expert knowledge, i.e., in the *application* of the finalized framework. This paper concentrates on *developing* the framework. Thus, the species evaluations provided to test this framework should not be considered definitive statements about each species but as examples of applying the framework.

2.3.   INFORMATION NEEDS AND SOURCES FOR FRAMEWORK

To meet the performance standards identified in Section 2.1 and thereby realistically evaluate the likely responses of a T&E organism to climate change, the following categories of information will be useful:

Physiological information
  ➢ its likely physiological vulnerability to potential changes in temperature
  ➢ its likely physiological vulnerability to potential changes in precipitation
  ➢ the likelihood of its physiological/behavioral adaptation to climate change

Demographic/life history information
  ➢ the organism's population/sub-population abundance relative to extinction risk
  ➢ the factors currently limiting its distribution/population status
  ➢ the degree to which the organism's geographical distribution is localized or dispersed
  ➢ its past and current population/sub-population trends
  ➢ its potential dispersive ability
  ➢ its ability to recover quickly from population reductions

> the likely vulnerabilities of populations to fluctuations in climatic variability and severe weather events

> its interactions with competitors, predators, and pathogens

Habitat information

> the habitats needed to meet all of the organism's life history requirements

> its degree of habitat specialization

> limiting habitat components and their likely sensitivities to climate change

> current trends in the availability of preferred habitats

> the likely vulnerabilities of its main habitats to climate change

> the extent to which suitable habitats may be present within the species' new range

> the abilities of its main habitats to migrate in response to climate change

> the likely rates at which the species' habitats could migrate relative to its physiological tolerances

> the likely vulnerabilities of habitats to climatic variability and severe weather events

Phenological information

> the likelihood that phenological relationships between crucial events in the species' life cycle (e.g., timing of breeding) and in its environment (e.g., snow melt) could be disrupted

Stressor information

> the direction and magnitude of likely climate change factors that may affect the organism

> other anthropogenic/natural stressors that may currently be affecting the organism and how their intensities are changing, or are likely to change in the future as humans respond to climate change

Our ability to evaluate the likely effects of climate change on T&E taxa will be a function of the quantity and quality of the data in each of the above categories. However, in addition to categorizing the likely vulnerabilities of taxa, the framework also must be able to identify crucial data needs for relatively little-known T&E organisms. Thus, missing information for any one taxon does not necessarily mean that it should not be evaluated, only that the uncertainty associated with the conclusions should be recognized and stated.

A number of sources exist for the above categories of information:

Information about the direct relationships between ambient temperature and the species' physiology, and its potential ability to persist

Specifically, what are the average, transient, or maximum long- or short-term temperatures above which the species is likely to suffer acute or chronic effects, such as impairment of reproduction or survival, physiological malfunctions, etc.? Such information could be gleaned from two main sources:

a) Ideally, such information should be derived from experimental physiological studies of the species being evaluated. However, such experimental studies have been carried out on relatively few species (especially terrestrial species), and no such studies of the six species evaluated in this report have been found. Furthermore, where thermal stress studies have been performed, the experimental endpoint is most often a gross measure of the species' vulnerability, such as the temperature that results in the death of a substantial part of the experimental population. In the field, organisms would almost certainly begin to respond well before such acute temperatures are reached. Thus, while acute mortality studies may provide information on individuals' ultimate temperature tolerances, they may only be of limited relevance regarding the temperature regimes that may govern a species' distribution or abundance in the field.

Some experimental studies have been carried out on more subtle responses to temperature change. These include studies of the behavioral responses and thermal habitat choices of organisms. Such studies might provide more relevant information for assessing the likely effects of climate change on species' distributions. However, no such studies on T&E species have been located. If available, information for surrogate species (i.e., organisms that are closely related to the species under investigation and that are morphologically and ecologically similar) could be substituted.

b) Valuable information also can be obtained by examining the current and past ranges of organisms. For example, if the southernmost edge of an organism's current or historical range stops substantially north of the southern limit of its habitat type, then it could be directly climate-limited. It might, therefore, be reasonable to assume that some climate metric at the southern edge of its range is a limiting factor. However, what should be concluded in cases where the organism's range matches that of its main habitat? In such cases, the species could either be habitat- or climate-limited (or both). One way of addressing this problem is to examine the habitats and ranges of closely-related species. For example, the ranges of some North American *Dendroica* warblers suggest that they may be climate-limited (e.g., the upland conifer forest breeding habitats of Townsend's and hermit warblers [*Dendroica townsendi* and *Dendroica occidentalis*, respectively] extend south through the western states and into Mexico, yet the two species do not breed any farther south than central California). Perhaps temperature or precipitation is limiting these two species. If the breeding habitat of the closely related golden-cheeked warbler, *Dendroica*

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chrysoparia, (a T&E species), extends south of its distribution (southern Texas), it might be reasonable to conclude that this species also may be climate-limited.

In performing such analyses, it is important to consider both current and historical distributions. For example, the current range of grizzly bears extends south from above the Arctic Circle in Alaska and northern Canada to the northern Rocky Mountain States, and east from the Alaska Peninsula to the western shore of Hudson's Bay (Craighead and Mitchell, 1982), covering over 25° of latitude and 70° of longitude. This may demonstrate a high degree of overall climatic flexibility on the part of this species. However, this flexibility and tolerance of widely different temperature and precipitation regimes becomes even more marked when the historical range of the species is considered; in pre-Colombian times, the species' range extended south into northern Mexico and from the Pacific coast, east to the Missouri River (Rausch, 1963), and from low-lying deserts to alpine tundra. Thus, up until 200 years before the present, grizzly bears could be found across over 40° of latitude and 70° of longitude, and from close to sea level to above 10,000 feet, with associated widely differing climatic conditions. From its current and historical distribution, it could be surmised that future climate change is likely to have relatively small direct effects on grizzly bears in areas where they still persist. The information from this type of historical analysis should be treated with caution, however, since species with previously wide distributions may have consisted of different genotypes each adapted to specific climatic conditions.

When determining if a species may be climate-limited in its distribution and the extent to which it may be *directly* affected by future climate change, the following procedure might be adopted:

1. Determine whether there is evidence from experimental studies that the study species (or closely-related and morphologically and ecologically similar species) is likely to be affected by future climatic factors (e.g., do likely future temperature regimes exceed those to which the species [or a surrogate] has been experimentally shown to be sensitive?).

2. If the information required for Step 1 is not available, determine if the species' habitat extends beyond its actual range, and into areas where the climatic conditions exceed those within the species' actual range. If so, the extremes of the actual range might be climatic limits on the species' distribution. In this step, care should be taken to identify the extent to which biogeographical barriers (e.g., cities or waterbodies) might be preventing a species from occupying the whole of its potential current range.

3. If information for the study species is not available to perform Steps 1 or 2, carry out Step 2 for closely-related (congeners) and morphologically and ecologically similar species.

Information about the species' distribution. For many vertebrate species listed under the ESA, there is a wealth of accurate information on current distributions. This is particularly the case where the species is terrestrial, diurnal, and restricted to relatively small areas (e.g., the Mount Graham red squirrel [*Tamiasciurus hudsonicus grahamensis*] is known to be confined to one mountain range in southern Arizona, or Kirtland's warbler [*Dendroica kirtlandii*], largely confined to a few counties in the Lower Peninsula of Michigan). Although the exact range boundaries of more widespread T&E species may be less easy to delineate, for many taxa (particularly birds and the larger mammals), approximate range boundaries (to about the closest 100 km) are relatively well known and published as maps or text descriptions in a large number of sources, ranging from national distribution maps in field guides and atlases (e.g., Root, 1988; Price et al., 1995; Kaufman, 1996; Dunn and Garrett, 1997; National Geographic Society, 1999; Sibley, 2000; individual species accounts by various authors in The Birds of North America series from the Philadelphia Academy of Natural Sciences [birds]; Burt and Grossenheider, 1964; Whitaker, 1980; Chapman and Feldhamer, 1982; Wilson and Ruff, 1999 [mammals]), to state and local atlas reports (e.g., Temple and Cary, 1987; Laughlan and Kibbe, 1985; Andrews and Righter, 1992; Bergeron et al., 1992; Veit and Petersen, 1993; Kingery, 1998 [birds]; Ingles, 1965; Baker, 1983; Merrit, 1987; Jameson and Peeters, 1988; Knox Jones and Birney, 1988; Zevelof, 1988; Caire et al., 1989; Hoffmeister, 1989; Choate et al., 1994; Fitzgerald et al., 1994; Whitaker and Hamilton, 1998 [mammals]).

Detailed information regarding the distributions of most freshwater fish species is also available, ranging from national atlases (e.g., Lee et al., 1982; Boschung et al., 1983), to state-level treatises (e.g., Trautman, 1981; Cooper, 1983; Tomelleri and Eberle, 1990; Sublette et al., 1990; Sigler and Sigler, 1996). The distributions of cold-water salmonids that are (or were) prized quarry species such as greenback cutthroat trout or bull trout are particularly well studied.

Distributional information is generally less well known for the three remaining taxa (reptiles, amphibians, and insects). However, good data do exist for certain of the more "charismatic" groups such as snakes, turtles and tortoises, and salamanders (e.g., Webb, 1970; Minton, 1972; Collins, 1982; Dixon, 1987; Lanoo, 1988; Dundee and Rossman, 1989; Ernest et al., 1994; Harding, 1997; Conant and Collins, 1998; Petranka, 1998; Hunter et al., 1999). Among the insects, the best distributional information is for butterflies (Scott, 1986; Shull, 1987; Opler and Malikul, 1998; Opler and Wright, 1999).

These data are supplemented by the distributional information within the United States (to the extent that it is known) given in the "Background" and "Distribution and Status" sections of T&E species listing packages in the Code of Federal Regulations. Additional information may also be available for T&E species in the Population and Habitat Viability Assessment Reports

produced to support Recovery Plans (e.g., Beardmore et al., 1995), and in the Recovery Plans, themselves (e.g., U.S. FWS, 1992). In general, accurate and easily obtainable data exist that describe the distributions of many T&E species (from a number of taxa) within the United States.

Information on the elevational distribution of species may also be of value in predicting the effects of climate change. For example, white-tailed ptarmigan (*Lagopus leucurus*) and grizzly bears (*Ursus arctos horribilis*) both occur in the Rocky Mountain states. However, the ptarmigan is confined to land above about 10,000 feet, whereas the grizzly bear can be found over a much greater range of elevations. Thus, it is likely that climate change may have a more pronounced effect on the ptarmigan.

Information about the species' population status. Except for a few very scarce and easily counted organisms (e.g., grizzly bear, Kirtland's warbler), T&E species population status data are sparse. However, in developing this predictive framework, it is sufficient to estimate approximate population size categories such as those used by the IUCN (Collar et al., 1994; Tucker and Heath, 1994).

Information about the species habitat preferences. General information about a T&E species' habitat preferences may be obtainable from the sources listed in the last section (field guides, monographs, listing packages, etc.). Most such sources will only provide information on the ecotypes used by the organisms (e.g., deciduous forest, conifer forest, tundra, and prairie). Nevertheless, for most cases, this level of information is sufficient for developing this predictive framework. For some species, more detailed information may be available in individual species accounts, monographs, or the supporting text from Habitat Suitability Index models from the U.S. Fish and Wildlife Service (U.S. FWS) (e.g., Peterson, 1986).

Information on non-climate stressors affecting the species. The identities of the more important stressors currently affecting T&E species are comparatively well known (e.g., habitat destruction) and described in the materials produced by the U.S. FWS as part of the listing process.

2.4. DIRECT AND INDIRECT EFFECTS OF CLIMATE CHANGE

The potential effects of climate change on any organism might be *direct* (i.e., climate change factors, such as temperature or precipitation, might exceed the physiological tolerances of the organism and affect its ability to persist in an area). Climate change may also *indirectly* affect the organism. For example, climate change might modify the organism's habitat composition or structure or the phenology of crucial events (e.g., ice melt or flowering seasons), thereby affecting the ability of the organism to persist. Such trophic mismatches due to climate

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change may already be occurring as has been indicated in recent studies of European pied flycatchers and the emergence times of arboreal caterpillars (Sanz et al., 2003). Climate change could also indirectly jeopardize a species by conferring advantages on its predators, parasites, or competitors.

3. FRAMEWORK GENERAL STRUCTURE

The proposed framework for evaluating risks to a T&E species due to climate change and other stressors comprises four connected modules and a narrative (see Figure 1). Module 1 categorizes the comparative vulnerabilities of T&E species to existing stressors (i.e., not including climate change). This "baseline" vulnerability is subsequently combined with the categorization in Module 2 (evaluating vulnerability to climate change) into an estimate of overall future vulnerability in Module 3. Module 4 combines certainty scores from Modules 1 and 2 into an evaluation of the overall degree of certainty that we can assign to the framework predictions.

The narrative that accompanies each species' evaluation details the rationales and justifications for the assigned scores in Modules 1 and 2.
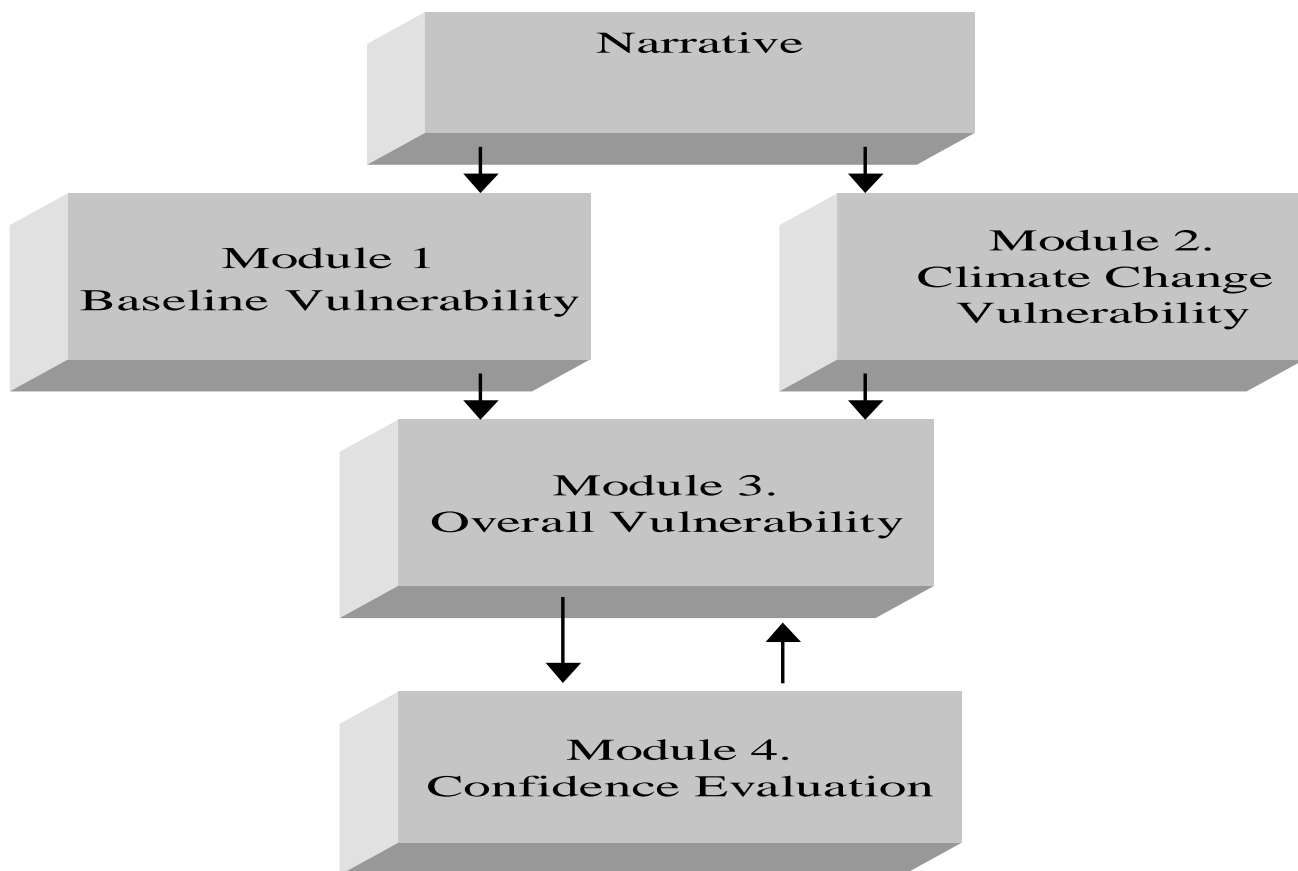
Figure 1. Framework for evaluating effects of existing stressors and climate change.

The framework modules and their scoring categories are discussed in greater detail in Sections 4 through 8, and examples of their application to the six species are given in Appendices A through J. The species evaluated were chosen because it was believed that, based on their natural histories, there is good evidence that they may cover the spectrum of potential responses of T&E organisms to climate change (e.g., from most susceptible, to least susceptible). It was not our intention to focus only on the most vulnerable species because that would not have facilitated the development of a general framework.

4. THE NARRATIVES

Most categorizations in Modules 1 through 4 will be based largely on the results of literature reviews and expert judgment for each species being evaluated. The narrative module of the framework reports the relevant results of those reviews and opinions, and the justifications for the individual categorization scores in the modules. Thus, the primary aim of the narratives is to make transparent the thought processes and assumptions that result in the scores in Modules 1 through 4.

The narratives have three additional important aims:

(1) To identify main sources of uncertainty and those areas where additional data might reduce uncertainty.

(2) To identify and describe the roles of the main stressors (climate and nonclimate) in the estimate of vulnerability of the study species.

(3) To qualitatively describe potential population responses of the study species to the addition of climate change to the already existing stressors, and any resulting change in extinction risk.

Example narratives for six species, golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout are presented in Appendices A through F, respectively.

5. MODULE 1—EVALUATING BASELINE VULNERABILITY

In this module, the likely baseline (i.e., current) vulnerability of the study species to extinction or major population reduction is categorized by scoring those elements of its ecology, demographics, and conservation status that influence the likelihood of its survival or extinction (irrespective of the potential effects of future climate change). This is based on determining ordinal rankings for 11 Module 1 variables (see Table 1). The scoring of these is described in greater detail below (see Section 5.1). Treatment of certainty/uncertainty is discussed in Section 5.2. Six examples of the application of Module 1 for golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout are presented in Appendix G.

Table 1. Variables included in Module 1.

(1) Current population size	(7) Likely current stressor future trends
(2) Population trend in last 50 years	(8) Individual replacement time
(3) Current population trend	(9) Future vulnerability to stochastic events
(4) Range trend in last 50 years	(10) Future vulnerability to policy/management changes
(5) Current range trend	(11) Future vulnerability to natural stressors
(6) Current (nonclimate) stressors	

Each variable is assigned a "best estimate" certainty score, together with an "alternate" (i.e., possible, but less likely) score(s). This will allow subjective confidence limits to be applied to the overall framework prediction in Module 3. For some species and variables, there may be enough confidence underlying the best estimate certainty score that no other score is considered necessary.

5.1. SCORING MODULE 1 VARIABLES

The variable categorizations and their scores used in Module 1 are presented in Table 2.

Table 2. Module 1 variables and scores used in categorizing the "baseline" vulnerabilities (Vb) of T&E species.

Current population size	Score	Range trend in last 50 years	Score	Individual replacement time	Score
<100	1	>80% reduction	1	>5 years	1
100–500	2	>50% reduction	2	2–5 years	2
500–1,000	3	>20% reduction	3	<2 years	3
1,000–10,000	4	Apparently stable	4	<1 year	4
10,000–50,000	5	Increasing	5	*Certainty:*	high (3)
>50,000	6	*Certainty:*	high (3)		medium (2)
Certainty:	high (3)		medium (2)		low (1)
	medium (2)		low (1)		
	low (1)			**Future vulnerability to stochastic events**	**Score**
		Current range trend	**Score**	Highly vulnerable	1
Population trend in last 50 yrs	Score	Rapid reduction	1	Vulnerable	2
>80% reduction	1	Slow reduction	2	Not vulnerable	3
>50% reduction	2	Stable	3	Likely to benefit	4
>20% reduction	3	Increasing	4	*Certainty:*	high (3)
Apparently stable	4	*Certainty:*	high (3)		medium (2)
Increasing	5		medium (2)		low (1)
Certainty:	high (3)		low (1)		
	medium (2)			**Vulnerability: policy/management change**	**Score**
	low (1)	**Current stressors (narrative)**		Highly vulnerable	1
				Vulnerable	2
Current population trend	Score	**Future non-climate stressors**	**Score**	Not vulnerable	3
Rapid decline	1	Increase	1	Benefiting	4

Table 2. (continued)

Current population size	Score	Range trend in last 50 years	Score	Individual replacement time	Score
Slow decline	2	Stable	2	*Certainty:*	high (3)
Stable	3	Reduction	3		medium (2)
Increasing	4	*Certainty:*	high (3)		low (1)
Certainty:	high (3)		medium (2)		
	medium (2)		low (1)	**Future vulnerability to natural stressors**	**Score**
	low (1)			Highly vulnerable	1
				Vulnerable	2
				Not vulnerable	3
				Certainty:	high (3)
					medium (2)
					low (1)

Current population size. The importance of this variable is that, in general, species with small populations are likely to be less resilient and more vulnerable to extinction risk than those with larger populations.

In assessing a species' baseline vulnerability to extinction, it would be valuable to know how close its current population size is to its minimum viable population size (the population level below which the species may inevitably face extinction). Ideally, these categorizations would be based on reliable long-term census data, together with estimates of minimum viable population sizes. Unfortunately, such information exists for very few organisms, particularly for rare or restricted species. Any approximations made for the purposes of this framework would likely, for most species, be so conjectural as to compound rather than eliminate uncertainty. For this reason, the population size categories in Module 1 are not intended to imply a high degree of accuracy or precision but to delineate broad "concern categories" that reflect varying degrees of extinction risk. Assigning a species to any category would typically be based on expert judgment about the species (or a surrogate).

Past and current population trends. The importance of these variables is that, in general, species with reduced and/or currently declining populations are likely to be more vulnerable to extinction risk than those with stable or increasing populations. The greater the past population reduction and the more rapid the current rate of decline, the more vulnerable the species is likely to be. Thus, in assessing a species' baseline vulnerability to extinction, it is important to know to what extent its population has been reduced in the past and its current rate of reduction. Quantitative data on many species' populations in North America have only begun to be gathered since about 1950. For this reason, the past reduction category focuses on this time period. The current rate of population reduction variable focuses on the current 10-year period. The past trend categorization scheme used (see Appendix G for examples) is similar to and based on that used in the IUCN Red List scheme (Mace and Stuart, 1994). The current trend categorization scheme assigns one of four categories: (1) rapid population decline, (2) slow population decline, (3) stable populations, or (4) increasing populations.

Ideally, these population trend categorizations would be based on quantitative census data. Unfortunately, such information exists for very few organisms, particularly for rare or restricted species. Assigning a species to any category will, therefore, typically be based on expert judgment about the species. For this reason, the population trend categories in Module 1 are not intended to imply a high degree of accuracy or precision, but to delineate broad "concern categories" that reflect varying degrees of extinction risk.

Past and current range trends. As with population trends, species that have suffered range (i.e., extent of distribution) contractions in the past, or that are currently suffering such

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contractions, are likely to be more vulnerable to extinction risk than those with stable or extending ranges, since the change in their distribution is evidence that they are already under stress. The greater the past range contraction and the more rapid the current contraction rate, the more vulnerable the species is likely to be. Thus, in assessing a species' baseline vulnerability to extinction, it is important to know to what extent its distribution has changed in the past and its current rate of change. Similar to the population trend categories, the past range change category focuses on the time period over the last 50 years. The current rate of range change should focus on the current 10-year period.

Range fragmentation is another variable that was considered for inclusion in this framework. However, without detailed information about the population viability in each of the range fragments, or the biogeographic processes of the metapopulation, it is difficult to determine *a priori* whether or how range fragmentation may affect extinction risk. A highly fragmented range could either reduce or increase extinction risk, depending on the dispersive capability of the organism, its subpopulation viability, and the spatial distribution of the stressor.

Future trends in the magnitude and/or extent of non-climate stressors that could affect the species' distribution or population status. Species that are or may be affected by nonclimate stressors that are likely to increase in the future in their intensity, frequency, or spatial extent (e.g., habitat loss due to urban sprawl), are likely to be more vulnerable than those affected by stressors that are reducing or stable (e.g., environmental dichlorodiphenylethylene [DDE] concentrations). In this module component, the likely future trends in the frequencies and/or intensities of non-climate stressors are categorized as likely to increase, remain stable, or decrease.

Individual replacement time. k-Selected species (i.e., those with deferred maturity, slow reproductive rates, postnatal care, etc.) may generally be more at risk of extinction than r-selected species (i.e., fast reproducers). k-Selected species are best adapted to stable environments with low stresses, whereas r-selected species are best able to exploit unpredictable and stressed environments. A population of a k-selected species that is reduced by a stochastic event has less opportunity than an r-selected species to quickly make good its losses before the next stochastic event. Approximate individual replacement rate is a useful index for k- or r-selection status. Thus, desert tortoises, which are k-selected, have an approximate individual replacement time of 15 years or more and may be more vulnerable to stressors than, for example, voles, with a replacement time of less than 1 year.

Vulnerability to stochastic events. Some species, because of their habitat preferences or distributions, may be more at risk to stochastic events than others. For example, organisms that

occupy habitats that are vulnerable to tropical storms, fires, tidal surges, or "red tides" may be more vulnerable than organisms that live in more predictable environments.

Vulnerability to policy/management changes. Because their fates depend to a great extent on societal values or policy objectives (either of which may change through time), species that are heavily dependent on human intervention or management, or specific policies for their continuing survival (e.g., California condors or black-footed ferrets, which are dependent on captive breeding programs) are likely to be more vulnerable than those that depend less, or not at all, on such interventions. All T&E species are dependent on policy (since all are listed under the ESA). However, some, such as the species listed above, are more dependent than others.

Vulnerability to natural stressors. Some species may be more vulnerable to currently acting natural stressors, such as disease, or invasive species than others are. Seabirds, for example, appear to be particularly susceptible to botulism, while rodents are vulnerable to outbreaks of sylvatic plague. A species' vulnerability to such events could affect its ability to persist.

Each of these variables is assigned a numerical score, reflecting their ordinal rankings. These individual scores are then combined in Module 1 into one of four baseline vulnerability rankings:

- *Critically vulnerable (Vb1)*—species that are likely to be at imminent risk of extinction (a total Module 1 score of less than 18).

- *Highly vulnerable (Vb2)*—species that may be close to such an extinction risk and are likely to be recategorized as critically vulnerable if their populations or ranges are diminished further (a total Module 1 score of 18–25).

- *Less vulnerable (Vb3)*—species that are not in imminent danger of extinction but that could be so in the future if their population and range trends continue (a total Module 1 score of 26–33).

- *Least vulnerable (Vb4)*—species that have comparatively large and stable (or increasing) populations or ranges (a total Module 1 score of greater than 33).

5.2. MODULE 1—CERTAINTY EVALUATION

Two methods for evaluating certainty/uncertainty have been incorporated into the Framework:

First, where necessary, each variable in Table 1 is assigned a "best estimate" score and an "alternate" score. The former is a professional judgment of the most likely case, whereas the latter is a less likely, but not an unreasonably unlikely, estimate. In this, we have tried to capture legitimate uncertainty about the individual scorings. In cases where there is very little uncertainty, only best estimate scores are given. Summing each of these scores provides some

indication of the accuracy or reliability of the total best estimate scores and the extent to which they may be in error. Thus, for the bald eagle, the sum of the best estimate scores in Module 1 is 32 (see Appendix G), which translates into an overall baseline vulnerability of Vb3 (less vulnerable). However, if the alternate scores are integrated, the overall score then becomes 28—34; based on this range, the species is most likely to be Vb3, but could, though this is less likely, be Vb4 (least vulnerable).

Second, each "best estimate" score in Module 1 is also assigned a numeric certainty evaluation (high [scores 3], medium [scores 2], or low [scores 1]), which is used in Module 4 to evaluate the overall degree of certainty that can be assigned to the framework predictions. These are ordinal rankings, based on expert judgment about the quantity and quality of the available data (or required but missing data) that support the "best estimate" variable scores. The three scores should be viewed as approximately equivalent to probabilities of: high—equal to or greater than about 70%; medium—greater than about 30% but less than 70%; or low—less than 30%.

Examples of Module 1 applied to the golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout are provided in Appendix G.

6. MODULE 2—EVALUATING VULNERABILITY TO CLIMATE CHANGE

In this module, the likely vulnerability of a species to future climate change is assessed and categorized by scoring those elements of its physiology, life history, and ecology that will likely be important determinants of its responses. This is based on determining ordinal rankings for 10 Module 2 variables (see Table 3). The scoring of these is described in greater detail below (see Section 6.1). Treatment of certainty/uncertainty is discussed in Section 6.2. The Module 2 variables and their scores are presented in Table 4, while six examples of the application of Module 2 are presented in Appendix H.

The scoring system used in Module 2 allows for the possibility that some species may actually benefit from climate change, for example, species that could benefit from an increased frequency of climate change-induced stochastic events (e.g., shrub or grassland species that may benefit from forests being affected by an increased incidence and severity of fires).

Each variable is assigned a "best estimate" certainty score, together with an "alternate" (i.e., possible, but less likely) score. This will allow subjective confidence limits to be applied to the overall framework prediction in Module 3. For some species and variables, there may be enough certainty underlying the best estimate certainty score that no other score is considered necessary.

Table 3. Components of species' potential physiological, behavioral, demographic, and ecological sensitivity to climate change included as variables in Module 2.

(1) Physiological vulnerability to temperature change	(6) Likely extent of habitat loss due to climate change
(2) Physiological vulnerability to precipitation change	(7) Abilities of habitats to shift at same rate as species
(3) Vulnerability to climate change-induced extreme weather events	(8) Habitat availability within new range of species
(4) Dispersive capability	(9) Dependence on temporal inter-relationships
(5) Degree of habitat specialization	(10) Dependence on other species

Table 4. Module 2 variables and scores used in categorizing the vulnerabilities of T&E species to climate change (Vc).

Physiological vulnerability to temp. increase	Score	Degree of habitat specialization	Score	Availability of habitat in new range	Score
Likely highly sensitive	1	Highly specialized	1	None	1
Likely moderately sensitive	2	Moderately specialized	2	Limited extent	2
Likely insensitive	3	Generalist	3	Large extent	3
Likely to benefit	4	*Certainty:*	high (3)	*Certainty:*	high (3)
Certainty:	high (3)		medium (2)		medium (2)
	medium (2)		low (1)		low (1)
	low (1)				
		Likely future habitat loss due to climate change	**Score**	**Dependence on temporal inter-relations**	**Score**
Physiological vulnerability to precipitation change	**Score**	All or most (>50%)	1	Highly dependent	1
Likely highly sensitive	1	Some (20–50%) trend	2	Moderately dependent	2
Likely moderately sensitive	2	No change	3	Independent	3
Likely insensitive	3	Some gain (20–50%)	4	*Certainty:*	high (3)
Likely to benefit	4	Large gain (>50%)	5		medium (2)
Certainty:	high (3)	*Certainty:*	high (3)		low (1)
	medium (2)		medium (2)		
	low (1)		low (1)	**Dependence on other species**	**Score**
				Highly dependent	1
Vulnerability to change in frequency or degree of extreme weather events	**Score**	**Ability of habitats to shift at same rate as species**	**Score**	Moderately dependent	2
Likely highly sensitive	1	Highly unlikely	1	Independent	3

Table 4. (continued)

Physiological vulnerability to temp. increase	Score	Degree of habitat specialization	Score	Availability of habitat in new range	Score
Likely moderately sensitive	2	Unlikely	2	*Certainty:*	high (3)
Likely insensitive	3	Likely	3		medium (2)
Likely to benefit	4	*Certainty:*	high (3)		low (1)
Certainty:	high (3)		medium (2)		
	medium (2)		low (1)	**Dispersive capability**	**Score**
	low (1)			Low	1
				Moderate	2
				High	3
				Certainty:	high (3)

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6.1. SCORING MODULE 2 VARIABLES

The species' likely physiological sensitivity to two main aspects of climate change, temperature, and precipitation. Some species are more likely than others to be directly affected by climate change because their physiological tolerances may be narrower (though some species could benefit). For example, cold-water fish species, such as some salmonids, may be affected more by increased water temperature. These species may be more apt to avoid affected areas than warm water fish (e.g., cyprinids or ictalurids), which are physiologically or behaviorally tolerant to increased temperatures and/or lowered oxygen levels. Thus, it will be critical in evaluating a species' likely sensitivity to climate change to be able to assess its intrinsic limits to physiological adaptation to changing temperature or precipitation regimes. Ideally, such evaluations would be based on experimental evidence for the species being evaluated, or rigorous observational data from the field. Unfortunately, however, such data are scarce for most species, and the ordinal rankings in Module 2 will likely be based on inferences about closely related species, or from current limits to the species distribution correlated with climate variables (e.g., Root, 1988), or recent range changes.

The sensitivity categories for this variable of Module 2 are not intended to imply a high degree of accuracy or precision, rather, they attempt to delineate broad "response categories" that reflect varying degrees of physiological/behavioral sensitivity. Assigning a species to any category would typically be based on expert judgment about the species (or a surrogate).

The species' likely vulnerability to an increased frequency or magnitude of climate change-induced extreme weather events. Some species (e.g., forest-nesting birds, or species confined to small low-lying islands) may be put at greater risk of extinction or population reduction if climate change results in an increased frequency or magnitude of stochastic events, such as lightning-caused fires or hurricanes or storm surges. In general, species that are dependent on habitat variables that are vulnerable to fire, wind storms, or storm surges may be most vulnerable.

Once more, the vulnerability categories for this variable of Module 2 are not intended to imply a high degree of accuracy or precision, but to identify broad "vulnerability profiles" that reflect varying degrees of potential sensitivity. Assigning a species to any category would typically be based on expert judgment about the species (or a surrogate).

Dispersive characteristics that may ameliorate or exacerbate the effects of climate change. Species with high dispersal capabilities (e.g., flying insects) may be less vulnerable to climate change than sedentary organisms (e.g., amphibians or reptiles). In this component of Module 2, species are ranked according to this characteristic and its likely modifying influence. This allocation is based on the species' *potential* ability to disperse from the localized effects of climate change. Thus, a "low" ranking is assigned to species that are unlikely to move more than a few or tens of kilometers from their natal area and, hence, may be most vulnerable to the localized effects of climate change.

Assigning a "moderate" ranking means that a species may be able to disperse as much as a few hundreds of kilometers. A "high" ranking refers to highly mobile animals that could potentially disperse as much as many hundreds or some thousands of kilometers. A reptile or amphibian species may be an example of the first category, whereas a relatively mobile mammal may fit the second, and a migratory bird the last.

The species' degree of habitat specialization. Species that have a high degree of habitat specialization (i.e., that are not flexible in their choice of habitats), may be most vulnerable to climate change because their "fates" are not only a function of their own responses to climate change, but also to those of their critical habitat components. For example, golden-cheeked warblers and salt marsh harvest mice are entirely dependent on Ashe juniper forest and salicornia flats, respectively (see Appendices A and C). These dependencies may render these species more vulnerable than others that are more flexible in their habitat preferences. In scoring this Module 2 variable, a species is assigned to one of three habitat specialization categories:

- *Highly specialized*—species that are restricted by their behaviors or physiologies to a well defined habitat (usually a vegetation community). Examples of such species include the California gnatcatcher, *Polioptila californica*, which is restricted to the remaining fragments of coastal sage scrub in southern California.

- *Moderately specialized*—species able to tolerate variability within a habitat type. Examples might include wetland organisms that can tolerate a wide variety of wetlands from bogs to marshes, to lakes and rivers (e.g., the bald eagle).

- *Generalists*—species that are able to exploit a wide variety of habitats (e.g., the European starling, *Sturnus vulgaris*, or American robin, *Turdus migratorius*, both of which can inhabit a wide range of habitats from native woodlands to farmlands to urban gardens).

The likely extent of habitat loss or gain due to climate change. In this variable, expert opinion is used to judge the likely impact of climate change on the spatial extents of the T&E species' main habitats. These classifications are necessarily speculative and should not be assumed to imply a high degree of accuracy or precision. They are intended to be reasonable approximations.

Many, if not most, species may depend on two or more habitats during their annual or lifetime cycles. For example, some marine mammals need both an offshore foraging habitat and a terrestrial breeding site; some migratory shorebirds require arctic tundra breeding habitat, migration stopover sites on mid-latitude estuaries, and southern latitude grasslands for wintering habitat. For this variable, the species should be scored according to the largest negative effect. For example, if a species has two or more critical habitats and the putative effects on these range between 20% and 80% loss, the latter should determine the score.

If the species has two or more habitats and at least one of these is a putative loss, this should determine the score, even if the other habitats are predicted to show gains. The reasoning behind this is that if the species is likely to be habitat limited, in the absence of any evidence to the contrary, we should conservatively assume that the reduced habitat is likely to be the limiting factor. For example, if, in the case of the shorebird, its southern hemisphere grassland habitat is predicted to increase in extent under climate change but its arctic tundra habitat decrease, the latter should determine the score.

The likely ability of critical habitats to shift at same rate as species in response to climate change. Some habitats may be able to shift in response to climate change. For example, the southern boundary of boreal forest in northern New England may shift north into Canada, and the corresponding northern habitat ecotone move further north in Labrador (Neilson and Drapek, 1998). Also, montane plant communities in the European Alps are shifting upslope due to the warming climate (Grabherr et al., 1994). In such cases, animal species dependent on these habitats could, potentially, shift with them. However, the success with which this may occur is dependent on synchronicity (i.e., the habitat being able to shift in approximate synchrony with the species). If a species' physiological tolerances are exceeded and it is forced to shift its range into regions where its optimal habitat does not already exist, its future prospects will be affected by how quickly its habitat can also shift into that new area. For example, if the species being assessed is a songbird that breeds in California coastal redwood forest and it is forced to move north into less optimal conifer habitat, it may take so long for its habitat to catch up that the species' existence may be jeopardized. If, however, the species' habitat was grassland or shrub, the habitat may be able to move in a relatively short time frame. For this variable, expert judgment is used to score the likelihood of the critical habitat being able to shift along with the species.

Availability of habitat within the new range. A species that is forced to track its climatic envelope and shift its range into areas where its critical habitat already exists, may suffer less from climate change than one that is forced to move into areas where no such habitat exists. In the latter case, the persistence of the organisms may depend on whether or not its habitat can shift in synchrony (see above).

The degree of dependence that the species has on other species or the temporal relationships between species. Species that are highly dependent on another for some critical life history requirement (for example the golden-cheeked warbler's dependence on Ashe juniper, or a species that depends for its food supply during an energetic bottleneck on the emergence of a specific life-stage of another species) may be more vulnerable to the effects of climate change since their likely fates are closely dependent on those of another species.

Each of the above 10 variables is assigned numerical scores. These individual scores are then combined in Module 2 into an overall evaluation of the species' potential vulnerability to climate change:

- critically vulnerable (Vc1)
- highly vulnerable (Vc2)
- less vulnerable (Vc3)
- least vulnerable (Vc4)
- likely to benefit from climate change (Vc5)

6.2. MODULE 2—CERTAINTY EVALUATION

Two methods for evaluating certainty/uncertainty are incorporated into the framework:

First, where necessary, each variable in Table 4 is assigned a "best estimate" score and an "alternate" score. The former is a professional judgment of the most likely case, whereas the latter is a less likely, but not an unreasonably unlikely, estimate. In this, we have tried to capture legitimate uncertainty about the individual scorings. In cases where there is very little uncertainty, only best estimate scores are given. Summing each of these scores provides some indication of the accuracy or reliability of the total best estimate scores and the extent to which they may be in error. Thus, for the bald eagle, the sum of the best estimate scores in Module 2 is 27 (see Appendix H), which translates into an overall climate change vulnerability of Vc3 (less vulnerable). However, if the alternate scores are integrated, the overall score then becomes 22 to 29; based on this range, the species is most likely to be Vc3, but could, though this is less likely, be Vc2 or Vc4.

Second, each "best estimate" score in Module 2 is also assigned a numeric certainty evaluation (high [scores 3], medium [scores 2], or low [scores 1]), which is used in Module 4 to evaluate the overall degree of certainty that can be assigned to the framework predictions. These are ordinal rankings, based on expert judgment about the quantity and quality of the available data (or required but missing data) that support the "best estimate" variable scores. The three scores should be viewed as approximately equivalent to probabilities of high—equal to or greater than about 70%; medium— greater than about 30% but less than 70%; or low—less than 30%.

Examples of Module 2 applied to the golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout are provided in Appendix H.

7.   MODULE 3—EVALUATING OVERALL VULNERABILITY

In this module, the "best estimate" scores from Modules 1 and 2 are combined in a matrix to produce an overall best estimate evaluation and score of the species' vulnerability to climate change and important existing stressors. In doing so, species are categorized as critically vulnerable, highly vulnerable, less vulnerable, least vulnerable, or likely to benefit from climate change. It is important to note that these are likely approximations of each species' comparative vulnerability. They are not measures or indices of absolute vulnerability.

The Module 3 evaluation matrix is presented in Table 5.

Table 5. Module 3—Overall vulnerability best estimate scoring matrix.

Climate change (Module 2) vulnerability scores	Baseline (Module 1) vulnerability scores			
	Vb1	**Vb2**	**Vb3**	**Vb4**
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	Vo1	Vo2	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

In this module, several assumptions are made (see below):

1. If a species scores Vb1 in Module 1 (i.e., it is critically endangered at the present), any Module 2 score between Vc1 and Vc4 will result in the overall rating of Vo1. A Module 2 score of Vc5 (the species may actually benefit from climate change) will result in its overall score being Vo2. Thus, the species continues to be critically endangered unless climate change may actually improve its condition.

2. A species that scores Vb2 in Module 1 but Vc1 or Vc2 in Module 2 will have an overall score of Vo1 (i.e., its likely susceptibility to climate change will exacerbate its extinction risk).

3. A species that scores Vb2 in Module 1 but that is likely to benefit from climate change (Vc5) will have an overall score of Vo3 (i.e., its likely benefits from climate change may ameliorate its extinction risk).

The rationale behind these assumptions is applied throughout the matrix structure of Module 3.

The alternate vulnerability evaluations from Modules 1 and 2 are used to develop subjective vulnerability limits on the Module 3 estimate. Thus, for the golden-cheeked warbler, a best estimate is that the species is overall Critically Vulnerable (see Appendix I), but there is also a less likely possibility that it could be "only" Highly Vulnerable.

Examples of Module 3 applied to golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout are provided in Appendix I.

8. MODULE 4—CERTAINTY EVALUATION

The approximate level of certainty for each "best estimate" score in the first two Modules is categorized as high (approximate probability of 70% or more); medium (approximate probability of between 30 and 70%); or low (less than approximately 30%). These qualitative certainty scores are recorded separately in each Module and correspond to numeric scores of 3, 2, and 1, respectively. For the most part, these categorizations will be the product of expert judgment, rather than a strictly quantitative appraisal.

In Module 4, the "best–estimate" certainty scores assigned to each of the variables in Modules 1 and 2 are combined into an index of the certainty associated with the overall vulnerability score in Module 3. The total minimum score (Modules 1 and 2 combined) is 20, while the maximum is 60. The numeric range between the two is arbitrarily and approximately equally divided into three categories: high, medium, and low certainties. A final certainty evaluation is then applied to each species. It is important to note that these categorizations are indices of the certainty associated with the overall "best estimate" score.

Examples of the individual variable certainty scores are provided for golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout in Appendix J. Examples of the overall certainty level assignations for these species are also provided in the same appendix.

9. SUMMARY OF FRAMEWORK EVALUATIONS

The results of the species evaluations are shown in Tables 6 and 7. In general, baseline vulnerabilities were either Vb2 (highly vulnerable) or Vb3 (less vulnerable). The bald eagle is scored as the least vulnerable species in this module (a score of 32 out of 42), and the salt marsh harvest mouse and golden-cheeked warbler is the most vulnerable (both scored 22). The contrasting scores for these species are largely a function of widely different population sizes and trends, and distributions, with the bald eagle being widely distributed across the United States and with a relatively large and increasing population, while the salt marsh harvest mouse and golden-cheeked warbler are relatively restricted in their distributions with relatively small populations. In terms of population size and distribution, the desert tortoise is closer to the bald eagle. However, unlike the bald eagle, it is restricted to a relatively small area and its populations are decreasing. It, therefore, scored 26.

Table 6. Modules 1 and 2, and certainty scores for the six test species.

Species	Module 1 score[a,b]	Module 2 score[b,c]	Certainty score (Module1/Module2)[d]
Bald eagle	32	27	26/23
Golden-cheeked warbler	22	15	26/25
Mount Graham red squirrel	24	17	23/24
Salt marsh harvest mouse	22	18	18/19
Desert tortoise	26	19	24/21
Lahontan cutthroat trout	23	16	17/18

[a]The total species evaluation score in Module 1.
[b]The lower the score the greater the vulnerability.
[c]The total species evaluation score in Module 2.
[d]The certainty scores for Modules 1 and 2.

Potential vulnerability to climate change also ranged widely among the test species, from Vc3 to Vc1. No species scored Vc4 or Vc5. This is possibly because either no species that really merits these scores is evaluated or because, by definition, species on the T&E list are unlikely to be successful exploiters of stressed conditions and all would be adversely affected to some degree by climate change. Perhaps if an invasive, "weed" species were evaluated, it would score Vc4 or Vc5; however, there are no such species on the T&E list.

The golden-cheeked warbler has the lowest total score (or the greatest vulnerability) in Module 2 (a score of 15 out of 35). The Lahontan cutthroat trout was a close second at 16, and the Mount Graham red squirrel third at 17. In general, species that had specialized habitat requirements that were likely to be reduced in extent by climate change and that were vulnerable to stochastic events tend to have the lowest scores. In contrast, the bald eagle, with its comparatively large population size, generalized habitat requirements, widespread distribution, and low sensitivity to stochastic events scores highest.

Table 7. Summarization of results of species evaluations.

Species	Module 1 baseline scores	Module 2 climate change scores	Module 3 best estimate scores	Module 3 alternate scores	Module 4 certainty score
Golden-cheeked warbler	Vb2 (highly vulnerable	Vc1 (critically vulnerable)	Vo1 (critically vulnerable)	Vo2 (highly)	High
Bald eagle	Vb3 (less vulnerable)	Vc3 (less vulnerable)	Vo3 (less vulnerable)	Vo2, Vo4 (highly, least)	High
Salt marsh harvest mouse	Vb2 (highly vulnerable	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	Medium
Mount Graham red squirrel	Vb2 (highly vulnerable)	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	High
Desert tortoise	Vb3 (less vulnerable)	Vc2 (highly vulnerable	Vo2 (highly vulnerable)	Vo1, Vo3 (critically, less)	Medium
Lahontan cutthroat trout	Vb2 (highly vulnerable)	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	Medium

Golden-cheeked warbler, salt marsh harvest mouse, Mount Graham red squirrel, and Lahontan cutthroat trout are categorized as critically vulnerable in the overall vulnerability module (Module 3). In contrast, with its widespread distribution, currently increasing populations, and relatively catholic habitat preferences, the bald eagle is assessed, overall, as the least vulnerable of the species evaluated.

Desert tortoise is intermediate. This is because of its large current population and the possibility that the species may benefit from climate change.

Certainty scores in Module 4 range between medium and high and reflect the amount and quality of ecological information available. The bald eagle and the golden-cheeked warbler (which are "charismatic" species, and relatively easily studied and counted) have the highest scores. None of the species evaluated have a "low" certainty score. However, all of the taxa evaluated (birds, mammals, and reptiles) are relatively well studied.

The certainty evaluation identified major uncertainties in module components common to all of the species tested. The most universal of these are the likely physiological sensitivities that organisms may show toward changes in temperatures and precipitation. Empirical data are almost entirely lacking for most terrestrial organisms (though data for aquatic organisms may be more plentiful). Even where data are available, they typically are derived from studies of acute effects, which have less relevance for most organisms (which will likely respond to changing conditions before acute levels of change are reached). This gap in knowledge points to the need for more studies of sublethal and behavioral temperature responses in organisms.

10. SUMMARY AND CONCLUSIONS

This report describes a framework for evaluating the potential sensitivities of T&E animal species in the United States to future climate change. The framework developed consists of five separate components:

(1) A module that evaluates the current vulnerability to extinction of the species.
(2) A module that evaluates the potential incremental risk of extinction due to climate change.
(3) A module that integrates the results of 1 and 2.
(4) A module that evaluates uncertainty regarding the framework predictions.
(5) Narratives that provide the justifications for the framework scores.

The framework was preliminarily tested by applying it to six species: golden-cheeked warbler, bald eagle, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and Lahontan cutthroat trout. Scores for these species varied widely. However, the species that scored most vulnerable are restricted in their distributions, have small population sizes, are currently undergoing population reductions, are habitat specialists, and/or have habitats that are likely to be most adversely affected by future climate change. Conversely, animals (for example, the bald eagle) that are widely distributed, that are flexible in their habitat preferences, and that are stable or increasing, scored least vulnerable. Thus, the predictions of the model accord with what might be expected based on the ecologies and demographics of the test species. The results of these tests also indicate that major areas of uncertainty complicate any evaluations of vulnerability. For the species tested, the greatest uncertainties are associated with a relatively poor knowledge about the potential for direct, physiological effects on animal species; relationships between changes in temperature and precipitation regimes and the physiologies and behaviors of animals are, apparently, only poorly understood.

While this framework was developed to evaluate the vulnerabilities of T&E species, there is no reason why it could not, with some minor modification, be suitable for use with all vertebrate species. The main limitation might be that while T&E species are often relatively well studied and the data necessary for the framework may be available, this might not be the case for other less well known species. However, it should still be possible to assign vulnerability scores using the framework, although the confidence scores may be lower.

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APPENDIX A
EXAMPLE NARRATIVE FOR GOLDEN-CHEEKED WARBLER

A.1. INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the golden-cheeked warbler to severe population reduction or extinction, and its potential future vulnerability under climate change. Its main objectives are to

- make transparent the rationale underlying each score in Modules 1 and 2;
- identify main sources of uncertainty;
- identify and describe the roles of the main stressors in the estimate of vulnerability for this species; and
- qualitatively describe potential population responses to climate change and other stressors.

A.2. ENDANGERED SPECIES ACT STATUS

The golden-cheeked warbler, *Dendroica chrysoparia*, was proposed for listing as Endangered under the ESA in May 1990 (U.S. FWS, 1990). The Final Rule confirming this listing was published in December 1990. The species was also listed as Endangered under State of Texas legislation in February 1991 (Texas Parks and Wildlife Department, Executive Director Order no. 91-001).

A.3. DISTRIBUTION, STATUS, AND POPULATION TRENDS

A summer visitor and breeding bird to the United States, the golden-cheeked warbler winters mainly in southern Mexico (Chiapas), Honduras, and Nicaragua (Curson et al., 1994; Kaufman, 1996; Dunn and Garrett, 1997; Ladd and Gass, 1999). Its breeding range is extremely restricted—only 30 counties in central Texas. As far as is known, it breeds nowhere else. This range extends as a strip approximately 250 miles in length and 150 miles in width from near San Antonio in the south almost to Dallas and Ft. Worth in the north (Ladd and Gass, 1999). Even within this very limited range, golden-cheeked warblers are localized (Dunn and Garrett, 1997) to highly fragmented areas where suitable habitat occurs (see below).

Based on habitat delineation from aerial photographs, the total breeding population was estimated in 1990 as somewhere between 10,000 and 30,000 individuals (Wahl et al., 1990). Wahl et al. (1990), also estimated that the breeding population of golden-cheeked warblers declined by approximately 25% between 1962 and 1981. Pulich (1976) estimated a decrease from 18,500 pairs in 1962 to approximately 14,750 pairs in 1974, a 20% reduction. Although both these sets of figures are likely to have large unresolved uncertainties, it is likely that breeding numbers (and hence the world

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population) of golden-cheeked warblers has declined markedly in the last 4−5 decades and is now less than 30,000 individuals.

A.4. HABITAT

During the breeding season, golden-cheeked warblers are habitat specialists, being confined to juniper-oak woodlands dominated by Ashe juniper, *Juniperus ashei*. The close relationship with the juniper is explained by the fact that in mature trees of this species, the bark peels in long strips, and the warbler constructs its nest largely from this material (Ladd and Gass, 1999). Ashe juniper woodland is confined to central Texas. Even within areas where Ashe juniper occurs, golden-cheeked warblers are selective, preferring sites dominated by mature or old growth trees. Mature stands of Ashe juniper-oak woodlands are extremely limited in their distribution in central Texas and are confined largely to Cretaceous upland limestone karsts and canyon sides with shallow soils along the eastern edge of the Edwards Plateau, the Balcones Escarpment, and the Lampasa Cut Plain (Kuchler, 1975). It is the availability of this specialized breeding habitat that presently defines and limits the distribution and status of golden-cheeked warblers.

In winter, golden-cheeked warblers are also dependent on conifer-oak woodlands, their main habitat in this season being high elevation (1,500–3,000 m) pine-oak woodlands in Central America (Ladd and Gass, 1999).

A.5. PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

No experimental information has been found on the physiological sensitivity of golden-cheeked warblers to changes in temperature or precipitation. However, field studies of four other species of New World warblers (Wilson's warbler, *Wilsonia pusilla*; red-faced warbler, *Cardellina rubifrons*; Virginia's warbler, *Vermivora virginiae*; and orange-crowned warbler, *Vermivora celata*) nesting in hot, arid environments in the U.S. southwest have shown that temperature and humidity can directly affect individuals, causing them to alter their micro-habitat preferences (Martin, 2001). Thus, year-to-year changes in these local climatic variables, mediated through habitat selection behavior, result in changes in distribution. It is not known whether these climate sensitivities also apply to golden-cheeked warblers, (although information from Sexton 2007, suggests that breeding success of golden-cheeked warblers may be depressed during extreme drought conditions). Nevertheless, the study describes above found direct climate effects in the only species thus far examined, and it is likely that the relationships could be more widespread within the New World warblers.

Of the 21 species in the genus *Dendroica* that breed in North America, only 9 breed as far south as the southernmost states. Of these 9, only 1 (yellow-rumped warbler, *Dendroica coronata*) breeds further south than the southernmost geographical limit of the golden-cheeked warbler, and only

by about 100 miles. The two *Dendroica* species that breed as far or further south than the golden-cheeked warbler are the yellow-rumped warbler and Grace's warbler (*Dendroica graciae*). However, they breed in high-mountain forests in northern Mexico, habitats that are likely to be generally cooler than those of the golden-cheeked warbler. Thus, the southern limit of the breeding distribution of golden-cheeked warblers may be the hottest environment in which *Dendroica* warblers breed. The absence of other congeners in this temperature zone may imply a climatic limit that follows the southern limit of golden-cheeked warblers. If this is the case, golden-cheeked warblers may be at their southernmost physiological climatic limit, and the 4−7° C temperature increase predicted for central Texas by a number of General Circulation Models (GCMs [VEMAP Members, 1995]) may in the future render currently occupied areas physiologically unsuitable.

The above considerations could mean that climate imposes a southern limit on the current breeding range of golden-cheeked warblers. However, given the lack of experimental evidence, this must be regarded as conjectural.

A.6. ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

The breeding distribution of golden-cheeked warblers is limited by the geographical distribution of their preferred habitat: mature stands of Ashe juniper—dominated woodland (Pulich, 1976; Ladd and Gass, 1999). While Ashe juniper trees occur from northern Mexico to southern Oklahoma and Arkansas, stands of woodland *dominated* or *codominated* by mature Ashe junipers are confined to areas of central Texas where solid geology, soil characteristics, precipitation, and land use are suitable (Diamond, 1997).

The current spatial distribution of suitable Ashe juniper woodland reflects surficial geology in that it is largely confined to an area of upland that once was a Cretaceous marine reef. This reef now comprises a limestone escarpment and upland area stretching north from its highest elevations at Balcones to its lowest point just south of the Dallas-Fort Worth area (AAPG/USGS, 1973). In its southern and central areas, the reef is close to the land surface, which is characterized by upland limestone karst and thin skeletal soils. This is the surficial geology that best supports the development of the Ashe juniper woodlands (Amos and Gelbach, 1988; Diamond, 1997). As the reef dips to the north, it gradually becomes covered by deeper soils supporting grasslands and oak savannas (Kuchler, 1975), less suitable habitat for golden-cheeked warblers. To the west, on the flatter parts of the Edwards Plateau uplands, the soils are deeper and the juniper woodlands are largely replaced by grasslands and savannas (Diamond, 1997). To the east of the plateau escarpment, the soils are deeper and the land is intensively cultivated. Thus, the potential breeding range of the golden-cheeked warbler is, ultimately, largely defined by solid and surficial geology acting on plant community development (although human land use has further contracted this range—see Section A.7).

A.7. EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

Since colonization of the area by Europeans, the geographical extent of Ashe juniper-dominated woodlands and, therefore, the breeding distribution of golden-cheeked warblers, has been reduced drastically. At first, the juniper forests were harvested for wood products and for fuel; later they were cleared for grazing animals and for urbanization. In some counties where juniper woodlands currently exist only in isolated patches, early maps (cited in Diamond, 1997) show the landscape formerly entirely covered by woodlands. It is not possible to quantify the entire extent of habitat loss since Europeans began manipulating the landscape (since no estimates of pre-Columbian cover exist); however, Pulich (1976) estimated that between 1962 and 1974, 20% of the habitat was destroyed. Keddy-Hector (1992) estimated that a further 30% was lost between 1974 and 1990. Thus, mature Ashe juniper woodland is the main determinant of the breeding distribution of golden-cheeked warblers, and destruction of this plant community has been a major factor responsible for the contraction of this breeding range.

Other stressors, particularly fire and drought, may have limited the range and numbers of golden-cheeked warblers. Ashe junipers are not fire tolerant, and wild fires and fires caused by humans may have been a factor in determining the current distribution of the species (Diamond et al., 1995; Diamond, 1997). The drought of the early 1950s killed many stands of junipers (Diamond et al., 1995). During this drought, older and larger Ashe junipers (the age group preferred by golden-cheeked warblers) suffered 90% mortality in some areas (Merrill and Young, 1959, cited in Diamond et al., 1995).

Another more recent stressor on golden-cheeked warblers in their nesting habitat is nest parasitism by cowbirds, *Molothrus ater* (Kaufman, 1996; Eckrich et al., 1999). Typically, cowbirds are more successful at parasitising woodland birds' nests, where the woodland is fragmented (Britingham and Temple, 1983). The current fragmentation of the golden-cheeked warblers' breeding habitat may facilitate their parasitism by cowbirds.

A.8. POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

As discussed in Section A.5, the breeding range of golden-cheeked warblers may be at or close to the southern edge of a distributional limit set by high temperatures acting directly on the physiology and/or behavior of the species. If this is the case, the temperature increases of between 4 and 7°C that are generally projected by Global Climate Models (GCMs) for central Texas (VEMAP Members, 1995) could result in physiological problems and pressure on individuals to shift their ranges north. The likely feasibility of such a range shift is discussed in Section A.9.

A.9. POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

Golden-cheeked warblers are likely to be indirectly highly vulnerable to climate change for the following reasons:

(1) They are habitat specialists dependent on a plant community that could be drastically affected by climate change. As discussed above, woodlands dominated by Ashe juniper are extremely localized in their distribution. It is unlikely that this community will be able to shift its location in response to climate change for the following reasons:

- The current distribution of the community is at least partly determined by solid geology and soil type. Immediately north of the current range of Ashe juniper forests, the soil becomes deeper and more fertile and more suitable for the establishment of grasslands and deciduous trees, rather than junipers.

- Important barriers to community migration exist. Immediately north of the current range of Ashe juniper woodlands, the land is intensively farmed for arable crops, creating habitat that junipers would be unlikely to be able to colonize. Also, the Dallas-Ft. Worth metropolis lies across the likely migration route. This is an urban barrier about 50 miles wide by 30 miles deep. Even if suitable soils and land-use patterns existed to the north, it is unlikely that Ashe juniper woodlands could cross such a barrier.

(2) Their current population is relatively small and likely to be only just maintaining itself in the face of existing stressors (U.S. FWS, 1996). Additional important stressors (such as climate change) could be enough to push the species closer to extinction.

Given the barriers to migration discussed above and the sensitivity of Ashe juniper woodlands to fire and drought, it is likely that climate change will result in the further fragmentation of the existing Ashe juniper woodlands with resulting loss of habitat for the warblers.

A.10. JUSTIFICATION FOR FRAMEWORK SCORES

The framework scores for the golden-cheeked warbler are presented in Appendices G through J.

In **Module 1** (baseline vulnerability), the species scored Vb2, indicating that it is currently in a highly vulnerable condition. This score is based on the following subcomponents:

- Current population size and trends—based on the census data that are available (see Section A.2), there are likely to be less than 30,000 individuals in existence. Moreover, there is evidence that the population may be in decline. Because of this, the species has been given best estimate scores of 5 and 2, respectively, in the population size and trends variables of Module 1 (with alternate scores of 3 in the two population trend variables).

- Range trends—golden-cheeked warblers are restricted to a relatively small breeding range that is being reduced in its extent. For these reasons, the species has been allocated best estimate scores of 3 and 2 in the historic and current range trends variables of Module 1.

- Current stressors and likely stressor trends—the main stressor that has reduced the populations of golden-cheeked warblers within their range is habitat modification (see Section A.7). Although, not being destroyed at previous rates, the habitat of golden-cheeked warblers is still under some threat from land use changes, in particular modification through grazing and burning and urbanization. It is likely that this threat will persist into at least the near future. Also, the current fragmented nature of the species breeding habitat makes it more vulnerable to nest parasitism by cowbirds. For these reasons, the species has been allocated a best estimate score of 1 (increasing stressors), with an alternate score of 2 (stable stressors).

- Individual replacement time—individual golden-cheeked warblers begin breeding in their first year and may be producing young in as little as 14 months after they, themselves, fledged. Thus potential replacement time may be less than 2 years, and the species has been allocated a best estimate score of 3.

- Vulnerability to stochastic events—drought and fire may have important adverse impacts on golden-cheeked warbler local populations. For this reason the species has been allocated a best estimate score of 1 (highly vulnerable), with an alternate score of 2 (vulnerable).

- Policy/Management change vulnerability—a large component of the existing golden-cheeked warbler population exists in protected areas (e.g., Fort Hood Military Base). Because of this, it has been assigned a best estimate conservation dependency score of 1 (highly vulnerable to change in policy or management), with an alternate score of 2.

- Vulnerability to natural stressors—the incidence of disease, parasitism, or other natural stressors on this species is not known. However, given that the population is so small and restricted in its distribution, it is feasible that such a stressor could, potentially, have important effects on population viability. Nest parasitism by cowbirds is an important and perhaps increasing natural stressor for this species. The species is allocated a best estimate score of 2 (vulnerable), with an alternate score of 3 (not vulnerable).

Certainty evaluations were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that the species is relatively well studied, high certainty scores were assigned to most of the variables. The exceptions were future vulnerability to pathogens, future stressor trends, and past and current population trends (all of which had medium certainty scores). No variable of Module 1 had a low certainty score.

In **Module 2**, the species scored Vc1, indicating that it is likely to be critically vulnerable to climate change and that its extinction risk may be increased substantially. This score is based on the following subcomponents:

- Physiological vulnerability to temperature and precipitation change and to extreme weather events—the golden-cheeked warbler may nest close to the southern limit of its physiological climate "envelope" (see Section A.5). If so, the species may be adversely affected by future increases in temperature. Therefore, it has been allocated a best estimate score of 2 (likely moderately sensitive) in the temperature variable of Module 2, with an alternate score of 1 (likely highly sensitive). The species may be less sensitive to precipitation change and has been allocated a best estimate score of 3 (likely insensitive), and an alternate score of 2 (likely moderately sensitive).

- Vulnerability to changes in the frequency/degree of extreme weather events—the species has been allocated a best estimate score of 1 (likely highly sensitive). This has been assigned because of the potential vulnerability of the species' habitat to increased frequencies of drought and consequent fires. An alternate score of 2 (likely moderately sensitive) has also been assigned.

- Dispersive capability—the dispersive capability of this mobile species is high (best estimate score of 3 in Module 2).

- Habitat specialization—golden-cheeked warblers are extremely specialized in their breeding habitat requirements (see Section A.4). Because of this acute dependence on one specific habitat type, the species has been allocated a best estimate score of 1.

- Likely extents of future habitat loss due to climate change—for this variable, golden-cheeked warblers were allocated a best estimate score of 1 (>50% likely habitat loss). This score reflects the species' degree of habitat specialization, the already limited extent of breeding habitat and its fragmentation, and the unlikely possibility of the habitat being able to move in response to climate change. A secondary effect of future habitat fragmentation may be increased rates of nest parasitism by cowbirds. An alternate score of 2 (20–50% habitat loss) was allocated.

- Ability of habitats to shift at same rate as species in response to climate change—because the current distribution of Ashe juniper woodland is largely determined by geology, soils, and land use, and suitable conditions do not exist to the north of its current range, it is highly unlikely that the breeding habitat of the species will be able to shift in response to climate change. Thus, this variable scores (best estimate) 1, with an alternate score of 2.

- Availability of habitat within new range—as discussed in Section A.4, the breeding habitat of this species is limited by surficial geology, and no habitat exists to the north of the species' current breeding range because of spatial changes in the geology. It has, therefore, been allocated a best estimate score of 1 (no habitat exists), with an alternate score of 2 (only limited habitat exists).

- Dependence on temporal inter-relations and other species—the golden-cheeked warbler is extremely dependent on at least one other species—Ashe juniper. Therefore, it has been assigned a score of 1 (highly dependent) in the second variable. Most small songbirds time their migrations and breeding to take advantage of seasonal flushes of invertebrate prey. Accordingly, a score of 2 has been assigned to the temporal variable.

Certainty evaluations were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that golden-cheeked warbler autoecology is relatively well known, most of the ecological components of Module 2 were assigned high certainty scores. However, the physiological relationships between the species and climate variables are less well understood and were generally assigned medium scores.

In **Module 3**, the scores from Modules 1 (Vb2) and 2 (Vc1) are combined in an integrative matrix to give an overall vulnerability score of Vo1 (likely to be critically vulnerable to future changes in existing stressors in conjunction with climate change). It is important to note that even using the alternate scores, the species still is allocated a score of Vo1 in this module. This implies that the species is likely to be particularly vulnerable.

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into overall evaluation of certainty of High. This implies that the vulnerability evaluation for golden-cheeked warblers performed in Modules 1 through 3 is robust.

A.11. POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

Golden-cheeked warblers are particularly vulnerable to climate change. They are already under considerable stress due to habitat loss and fragmentation. A population viability analysis performed by the U.S. FWS and the U.S. Geological Survey (U.S. GS) National Biological Service (now the U.S. GS Biological Resources Division) in 1995 (U.S. FWS, 1996) concluded that if the current population was to decline to below 3,000 breeding pairs (the lower end of current population estimates), the risk of extinction would become unacceptably high. Given the likely constraints on the ability of their breeding habitat to shift in response to climate change (plus the potential for an increased incidence of wildfire), it is likely that increased temperatures and drought in the future will lead to further fragmentation and loss of the species' habitat.

If, as seems likely, the current population is between 10,000 and 30,000 individuals, and the level at which comparatively high risk of extinction would occur is about 6,000 individuals, loss of less than 50% of the species' breeding habitat could alter its population dynamics to the extent that extinction or near extinction may become not unlikely.

A.12. UNCERTAINTIES

There are two main areas of uncertainty inherent in predicting the likely effects of climate change on golden-cheeked warblers:

- Uncertainty associated with assessing the species' physiological sensitivity to increased temperatures and changes in precipitation patterns. On the basis of the evidence presented in Section A.4 of this narrative, it is assumed that the relationship between temperature and the species' physiology is moderately sensitive. It is also assumed that the species is insensitive to changes in precipitation, though uncertainty associated with this score is high.

- Uncertainty associated with predicting future changes in the frequencies of fire and drought and the likely effects of these on the distribution and quality of the warbler's breeding habitat. While the GCMs can predict regional changes in the main climate variables, temperature, and precipitation, they are generally less useful in predicting climate-associated change in stochastic events such as droughts or fires. Drought is likely an important determinant of the extent and quality of the golden-cheeked warbler's breeding habitat (as was shown by the effects of the drought in the 1950s [see Section A.7]). If climate change in central Texas resulted in a substantially increased frequency of fire and/or drought, the implications for the future survival of golden-cheeked warblers could be serious.

- Also, the effects of climate change on human populations within the range of the species are uncertain. If it results in changes in the way that humans exploit the landscape (through, for example, changes in water availability), anthropogenic pressure on golden-cheeked warblers might be altered.

A.13. SUMMARY

Golden-cheeked warblers are currently listed as Endangered under the ESA. Their current world population is probably less than 30,000 individuals, and they are confined to a relatively small breeding range in Central Texas, where they depend on the existence of mature Ashe juniper woodlands for their nesting habitat. Because of their highly restricted habitat requirements, historical and continuing losses in their breeding habitat and its current fragmentation, and the fact that the distribution of the habitat is probably limited by surface geology (and unlikely, therefore, to shift in response to a changing climate), golden-cheeked warblers are likely to be Critically Vulnerable to future climate change.

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APPENDIX B
EXAMPLE NARRATIVE FOR BALD EAGLE

B.1.   INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the bald eagle to severe population reduction or extinction, and its potential future vulnerability under climate change. Its main objectives are to

- make transparent the rationale underlying each score in Modules 1 and 2;
- identify main sources of uncertainty;
- identify and describe the roles of the main stressors in the estimate of vulnerability for this species; and
- qualitatively describe potential population responses to climate change and other stressors.

B.2.   ENDANGERED SPECIES ACT STATUS

The bald eagle was initially listed for protection under the Bald Eagle Protection Act in 1940. Subsequently, birds in the United States were listed as Endangered in 1966 under the Endangered Species Protection Act. The population in the contiguous states (but not Alaska) was listed as Endangered under the Endangered Species Act (ESA) of 1973, but subsequently downgraded to Threatened in 1995. In 1999, because of spectacular population recovery in the previous three decades, the U.S. Fish and Wildlife Service proposed the species for de-listing from the Endangered Species Protection Act. However, at present, the species is still listed.

B.3.   DISTRIBUTION, STATUS, AND POPULATION TRENDS

At the beginning of European colonization, the bald eagle bred in Alaska and all but three (Rhode Island, Virginia, and Vermont) of the contiguous states (Buehler, 2000). At that time, densities of breeding eagles were locally very high; on Chesapeake Bay, for example, it is likely that between 3,000 and 8,000 pairs nested (Fraser et al., 1996; Buehler, 2000). Beginning after European settlement, the species was persecuted to the extent that its population in the contiguous states was greatly reduced. By the mid-1930s, only 39 nests remained in Chesapeake Bay (Tyrrel, 1936 cited in Buehler, 2000). Beginning in the mid-1940s, the effects of direct human persecution were exacerbated by the introduction of the pesticide dichlorodiphenyltrichloroethane (DDT), the metabolite of which, Dichlorodiphenyldichloroethylene (DDE), resulted in embryo mortality and further widespread population decreases (Nisbett, 1989; Weimeyer et al., 1993). By the mid-1950s and 1960s, only about 400 breeding pairs remained in the entire contiguous states.

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With the banning of DDT in 1972, the North American breeding population of bald eagles began a spectacular increase. Populations increased within areas in which the bird had persisted, while areas from which the bird had been extirpated were recolonized. Between the mid-1960s and the mid-1980s, the breeding population in the contiguous states increased from approximately 400 pairs to about 2,000 pairs, and by the late 1990s, there were almost 6,000 pairs (Buehler, 2000). At present, there are probably more than 100,000 individuals in the whole of the United States and Canada (Buehler, 2000), and this number is still increasing.

Currently, the bald eagle breeds across Canada in the boreal forest from Newfoundland to Vancouver. In the United States, it is a scattered breeder in the interior and Great Plains states, but it is well distributed within coastal states from Alaska to California and Maine to Florida and Texas. There is also a small breeding population as far south as Baja, Mexico (Buehler, 2000).

B.4. HABITAT

Within certain broad limits, the bald eagle is a habitat generalist (Kaufman, 1996). Any forested area that has a suitable body of water close by, with fish, mammalian, or bird prey available meets its two main requirements, nesting and foraging sites. Such areas range from reservoirs or coastal areas with adjacent deciduous forests in the east coast states, to coniferous boreal forest on inland lakes or rivers or on the seacoast in the west, to riparian deciduous corridors in the Great Plains and Arizona, to forested subtropical swamps in Florida. In one area in Alaska, where trees are not available, bald eagles even nest on the ground (Buehler, 2000).

The species' flexibility in choice of nest sites is matched by its selection of prey. Bald eagle diets can range from exclusively fish to a mixture of fish, mammals, and birds (Buehler, 2000). In many areas, they are largely dependent on carrion, or on prey stolen from other species (Stalmaster, 1987).

B.5. PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

No data have been found that suggest that climate imposes a physiologic limit on the distribution of bald eagles. Indeed, their wide historic and current ranges (from Sonoran deserts in the southwest to the northernmost limit of tree line in Alaska and northern Canada) suggest that the species may be tolerant of a wide range of temperature and precipitation regimes.

It is possible that the southern limit of the bald eagles' range in Mexico, Texas, New Mexico, and Arizona may be at least partly a function of direct temperature or precipitation effects on the birds. There is, however, no evidence to support this, and the range limit may equally likely be a function of habitat availability.

B.6. ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

The main ecological limitations on the distribution and status of bald eagles are the availability of nest sites and prey (Stalmaster, 1987). However, the birds are flexible in their choice of both (see Section B.3), which is why their historic and current ranges were, and are, so extensive.

B.7. EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

The species was historically limited by direct human persecution and the toxicological effects of organochlorine pesticides. However, bald eagles are no longer persecuted on any large scale, and the lingering effects of DDE are reduced to the extent that previously affected populations (such as the Great Lakes coastal birds) may now be as productive as "clean" populations.

Some breeding sites may suffer reduced productivity due to human recreational disturbance (Buehler, 2000). However, such effects are local rather than regional in their occurrence and do not greatly affect the distribution and status of the species. Currently, bald eagles do not appear to be limited by anthropogenic or natural stressors to any great extent.

B.8. POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

Given the bald eagle's presumed tolerance of a wide range of temperature and precipitation regimes (see Section B.4), it is unlikely that the range of climatic changes projected in General Circulation Models (GCMs) would exercise any great effect on bald eagles throughout most of their current range. The only area where this might not be true may be at their current southernmost range limits, where increased temperature might conceivably directly affect the birds. This, however, is largely conjectural.

B.9. POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

The majority of bald eagles breeds and winters in the temperate and boreal forest zones. The main likely climate change effect on this biome would likely be a northward shift into areas that hitherto were arctic tundra, with a corresponding northward retraction of range in the south (Neilson and Drapek, 1998; Bachelet and Neilson, 2009.). Thus, bald eagle habitat could be forced by climate change to shift northward. However, although this would certainly mean redistribution, it is not certain what, if any, effects this would have on the North American status of the species. It is unlikely, however, that such a redistribution would put the continental population at any great risk of extinction.

Bald eagle breeding distribution in the Great Plains of the United States is fragmented, probably by the sporadic distribution of suitable water-bodies in the largely arid landscape. Some GCMs for this region predict increased aridity. This could result in localized loss of aquatic habitats

and further fragmentation of the regional range of the population. However, the vast majority of bald eagles breed in the north and in Alaska, not the Great Plains. Thus, any effect of climate change on Great Plains habitat would affect only a minority of birds.

Other potential local or regional scale effects of climate change could be mediated through changes in food supply. Many eagles in the Pacific Northwest and in Alaska are dependent during the breeding season and fall on runs of salmonids (Buehler, 2000). Welch et al. (1998) predict that increasing sea temperatures in the northern Pacific Ocean could lead to population reductions and extinction of salmon species. This could have repercussions for the bald eagle populations in the area, though the extent to which they would be able to switch to an alternative food supply is not known.

B.10. JUSTIFICATIONS FOR FRAMEWORK SCORES

The framework scores for the bald eagle are presented in Appendices G through J.

In **Module 1** (baseline vulnerability), the species scored Vb3, indicating that it is among the less vulnerable of T&E species. This score is based on the following subcomponents:

- Current population size and trends—based on most recent census data (see Section B.2) there are likely to be more than 100,000 individual bald eagles in North America. Therefore, the species scores 6 in the current population size variable of Module 1. In the past, the North American bald eagle population was reduced by at least 50% so it has been allocated a best estimate score of 2 in Variable 2. More recently, the species has been and is increasing throughout its North American range, thus it has been given a best estimate score of 4 in the current population trend variable.

- Past and current range trends—prior to the recent population resurgence, the bald eagle was widely extirpated from much of its historical range. In Variable 4, a best estimate score of 3 (>20% reduction) is conservatively applied, with an alternate score of 2. More recently (the past 2–3 decades), the species has been extending its range. Consequently, it has been allocated a best estimate score of 4 (increasing) in Variable 5, with an alternate score of 3 (stable).

- Likely future stressor trends—until recently, the main stressors acting on bald eagles were habitat destruction and the toxicological effects of organochlorine pesticides. With regulatory protection and the banning of DDT, these stressors have been ameliorated. It is likely that these contaminants will continue to diminish in their effects. Thus, the species has been allocated a best estimate score of 3 (reduction in stressors) with an alternate score of 2 (stable).

- Individual replacement time—the bald eagle reproduces slowly (individuals do not breed until they are 4–5 years old, and the maximum number of young that are reared per annum is 3, with most pairs only producing 1 or 2). Thus, the potential replacement time for individuals is 4–5 years. It has, therefore, been allocated a best estimate score of 2 in Module 2.

- Likely future vulnerability to stochastic events—with a widespread distribution and relatively large population, and an adult lifespan of decades, the bald eagle is relatively non-susceptible to, and able to withstand the adverse impact of sporadic events such as temporary food

shortage, or nest site destruction. Therefore, it has been allocated a best estimate score of 3 (not vulnerable).

- Vulnerability to changes in policy/management—because of its relatively large and increasing numbers and widespread range, the bald eagle is likely to be less susceptible than other T&E species to changes in land management or future policy. It has been allocated a best estimate score of 2, with an alternate score of 3.

- Future vulnerability to natural stressors—the incidence of disease, parasitism, or other natural stressors on this species is not known. However, given that the population is large and widespread in distribution, it is unlikely that such a stressor could have more than local impacts. Therefore, the species is allocated a best estimate score of 3 (not vulnerable), with an alternate score of 2 (vulnerable).

Certainty categories were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability of information for each category, rather than rigorous evaluations. Given that bald eagles are a well studied species, a high certainty score was assigned to most variables, with medium scores allocated to the remainder.

In **Module 2**, the bald eagle scored Vc3, indicating that while it is not likely to be completely immune to climate change, it is unlikely to be fundamentally affected to the point that its extinction risk is greatly increased. This score is based on the following subcomponents:

- Physiological sensitivity to temperature and precipitation change and to extreme weather events—given its ability to thrive in areas of markedly different temperature and precipitation regimes, and the likely localized focus of extreme weather events (relative to the species' extensive range), it is unlikely that bald eagles will be sensitive to these direct weather variables. Thus, it has been allocated best estimate scores of 3 (likely insensitive), with alternate scores of 2 (only moderately sensitive).

- Dispersive capability and potential rate of increase—the dispersive capability of this mobile species is high (and scores 3 in Module 2).

- Habitat specialization—bald eagles are largely dependent on one habitat type (wooded coastal, lake, or river margins). Within these broad habitat types, they are flexible in their habitat use. For these reasons, the species scores 3 (best estimate) and 2 (alternate estimate).

- Likely extents of future habitat loss due to climate change—bald eagles score 2 (20–50% habitat loss). This score reflects the possibility of habitat change in the arid west areas of the species' range. Such changes are less likely elsewhere. Given the species' habitat flexibility, this score may be over-conservative, and an alternate score of 3 (no change) has also been applied.

- Ability of habitats to shift at same rate as the species in response to climate change—it is assumed in this scoring that the species' main habitat (conifer and deciduous forest) will be able to shift northward in response to climate change but only slowly (relative to the rate at which eagles may shift).

- Availability of habitats within new range—bald eagles currently occupy all forested habitat north to the tree line. Therefore, this entire extensive boreal forest habitat is suitable for colonization by individuals forced to move north by climate change, and the species is allocated a best estimate score of 3.

- Dependence on temporal inter-relations and other species—except in the limited case of salmon runs, bald eagles are unlikely to be dependent on such factors and, accordingly, score 3 (best estimates) in each of these variables.

Certainty categories were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability of information for each category, rather than rigorous evaluations. Given that bald eagle autoecology is relatively well known, the ecological components of Module 2 were generally assigned high or medium certainty scores. However, the physiological relationships between bald eagles and climate variables are less well understood and were generally assigned medium scores. No low certainty scores were assigned.

In **Module 3**, the scores from Module 1 (Vb3) and Module 2 (Vc3) are combined in an integrative matrix to give an overall vulnerability score of Vo3 (likely to be among those T&E species that are less vulnerable to climate change).

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into an overall evaluation of certainty of High. This implies that the vulnerability evaluation for bald eagles performed in Modules 1 through 3 is robust.

B.11. POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

Among T&E species, bald eagles are likely to be among the least vulnerable to climate change. This is due to their currently burgeoning populations and range extension (since their main anthropogenic stressors were reduced), the flexibility of their habitat preferences, and the likely ability of their main habitats to survive climate change. Except in the Great Plains, where their habitat is already limited and fragmented by surface water distribution, radical population reductions and/or extinctions due to climate change are not expected.

B.12. UNCERTAINTIES

The main areas of uncertainty in the bald eagle analysis are associated with their potential direct/physiological sensitivity to climate change. If the species is at or close to abundance and distributional limits set by temperature of precipitation patterns, then it may be more vulnerable, at least in the southern and interior components of its range, than this analysis suggests.

B.13. SUMMARY

Bald eagles are currently listed as Threatened under the ESA. Their current North American (and world) population is probably more than 100,000 individuals, and they breed and winter in a variety of habitats throughout the contiguous states and Alaska. Because of their relatively flexible habitat and diet requirements and their currently increasing populations, bald eagles have been scored as Less Vulnerable (the second-least vulnerable of the potential scores) to future climate change.

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APPENDIX C
EXAMPLE NARRATIVE FOR SALT MARSH HARVEST MOUSE

C.1.   INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the salt marsh harvest mouse, *Reithrodontomys raviventris*, to severe population reduction or extinction, and its potential future vulnerability under climate change. It is intended to provide support for the scores listed in Modules 1 through 4 with the specific objectives of

- making transparent the rationale underlying each score in Modules 1 and 2;
- identifying main sources of uncertainty;
- identifying and describing the roles of the main stressors in the estimate of vulnerability for this species; and
- qualitatively describing potential population responses to climate change and other stressors.

C.2.   ENDANGERED SPECIES ACT STATUS

The salt marsh harvest mouse was listed as Endangered under the Federal Endangered Species Preservation Act in 1970. The species was later listed as Endangered under that act's successor—the Endangered Species Act (ESA), in 1973. The State of California also extended Endangered status to the species under its ESA in 1971.

C.3.   DISTRIBUTION, STATUS, AND POPULATION TRENDS

The salt marsh harvest mouse is endemic to salt marshes in San Francisco Bay and occurs in the southern Bay, the central Bay, San Pablo Bay, and Suison Bay (U.S. FWS, 1984). Because the species is difficult to census, there have been few attempts to estimate its population size. However, based on live-trapping results, the entire population at its midsummer peak has been estimated as probably no larger than a few thousand individuals (U.S. FWS, 1984). There may be less than this once postbreeding juvenile mortality has occurred.

Historically, there have likely been large reductions in the population status of the salt marsh harvest mouse due to habitat loss (U.S. FWS, 1984). Between 1850 and the 1960s, approximately 80% of its salt marsh habitat in San Francisco Bay was converted to agricultural or urban use (see Section C.7). The rate of habitat loss has slowed but continues in some areas due to land subsidence and inundation of tidal lands.

C.4. HABITAT

Within their restricted range and throughout their life cycle, salt marsh harvest mice are largely confined to intertidal salicornia flats. This is the tidal zone that is intermediate between the lowest vegetated intertidal community (spartina beds) and the upper, intermittently flooded high marsh, a community dominated by fewer obligate halophytic plant species. They have their highest densities in salicornia flats that have minimal densities of other plant species (i.e., monocultures of salicornia). Salicornia plants and grasses comprise the greatest part of the harvest mouse diet.

During extreme high tides, salt marsh harvest mice leave the salicornia flats and take refuge from the rising water by moving up into the high marsh or, beyond that, into upland vegetation. Thus, the salt marsh harvest mouse is a habitat specialist, and its future status and population viability are largely a function of the fate of its salicornia habitat, and access to its high tide escape habitat above the salicornia zone.

C.5. PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

Salt marsh harvest mice are relatively slow moving and inactive rodents (Fisler, 1968). Perhaps because of this, and their consequent vulnerability to predators, they avoid open areas where they cannot find cover. This physiological/behavioral characteristic may limit their ability to colonize new areas and may be one of the reasons why their distribution is highly limited and patchy (U.S. FWS, 1984).

C.6. ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

The distribution of salt marsh harvest mice is confined to tidal salt marshes in the San Francisco Bay complex. The species has never been found outside of this area, despite the fact that its salicornia habitat is extensive along the Californian coast. Even within its range, the species is patchily distributed, with highest densities in salicornia marshes that are largely monocultures and that are connected to higher elevation high tide escape habitat. Areas where the salicornia marsh has been invaded by brackish or fresh water plants tend to have fewer or no mice, as do areas where access to escape habitat has been closed (e.g., by diking the salt marsh). Thus, harvest mice are indicators of comparatively pristine and functioning salt marshes.

C.7. EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

The current distribution and status of the salt marsh harvest mouse is mainly a function of its own habitat specialization and habitat destruction and modification by humans. Although there is no evidence that it has ever occurred outside of San Francisco Bay, it was once much more widely distributed and abundant within that area. Prior to post-Columbian colonization, the salt marshes of

the bay were much more extensive than they are now, covering about 730 km^2 (U.S. FWS, 1984; San Francisco Estuary Institute: http://www.sfei.org/ecoatlas/index.html). Beginning in the 1850s, much of this marshland was diked and reclaimed for agriculture or urbanization. In addition, mining in the Sierra Nevada in the second half of the 19th Century resulted in large quantities of silt being washed downstream and deposited in the Suison and San Pablo bays. Later, in the 20th Century, groundwater withdrawals for human use triggered land subsidence in the southern part of the bay, with consequent increased inundation and habitat loss. At the same time that this was happening, large areas of the southern bay were diked and used as salt pannes. The net result of this was that by the middle of the 20th Century, approximately 80% of the historical marshes had been lost or highly modified (San Francisco Estuary Project, 1992; U.S. FWS, 1984).

While the habitat destruction and modification that occurred prior to the 1960s has slowed (and even been reversed in some areas through habitat management and restoration), there continue to be anthropogenic effects on the salt marshes that are detrimental to the harvest mice: management of some areas for waterfowl populations has resulted in the replacement of salicornia flats with plant species preferred by waterfowl but unacceptable to harvest mice (U.S. FWS, 1984). Also, land subsidence in the southern bay continues. This, together with freshwater outflows from the cities that line the southern bay, have changed the salinity patterns of inshore habitats and the vegetation communities, away from the salicornia flats preferred by the harvest mice.

C.8.   POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

No data have been found on the likely physiological tolerances of salt marsh harvest mice to changes in temperature or precipitation. Therefore, it is not possible to comprehensively assess their potential direct vulnerability to changes in climate. However, perhaps because it is relatively slow moving, the species avoids crossing open spaces. This physiological trait may limit its ability to move to and colonize new areas when their present habitats are affected or modified by climate change.

C.9.   POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

The climate change component to which the salt marsh harvest mouse is likely to be most vulnerable is sea level rise, with consequent inundation of their current habitats. Titus and Narayanan (1995) have estimated that there is a 50% probability that sea level in the southern bay will rise by approximately 2 m by the year 2100. Even without factoring climate change into this calculation, Titus and Narayanan (1995) estimate that current rates of land subsidence will result in a 1.5-m rise in sea level in the southern bay by 2100. In the northern part of San Francisco Bay (where such drastic land subsidence is not occurring), Titus and Narayanan (1995) estimate a 50% probability of about 0.4-m

rise in sea level by 2100. The extensive network of dikes and salt pannes in the southern bay limits the ability of the estuary to simply move inland in response to sea level rise.

Galbraith et al. (2002) used the Titus and Narayanan (1995) projections to model changes in the extents of intertidal habitats in the southern and northern parts of the bay. They project that a 2-m rise in sea level in the southern bay will result in a 63% reduction in the current area of salt marsh (a 1.5-m sea level rise will result in a 50% loss). By the year 2200, Galbraith et al. (2002) project that salt marsh habitat loss in the southern bay will exceed 90%. In the northern bay, they project no loss of salt marsh because in that area, the salt marshes are buffered by the conversion of intertidal mud and sand flats to subtidal habitats.

These extents of habitat loss in the southern part of the San Francisco Bay could have extremely important consequences since they are in an area where a large part of the salt marsh harvest mouse population currently exists.

C.10. JUSTIFICATION FOR FRAMEWORK SCORES

The framework scores for the salt marsh harvest mouse are presented in Appendices G through J.

In **Module 1** (baseline vulnerability), the species scored Vb2, indicating that it is currently in a highly vulnerable condition. This score is based on the following subcomponents:

- Current population size and trends—based on the data that are available (see Section C.2), there are likely to be, at most, a few thousand individual harvest mice at any one time, perhaps substantially less. Much of the historical habitat of the species was lost between colonization of the area by Europeans and the mid part of the 20th Century, and there is also good evidence that the population may be reducing further as habitat continues to be lost. Because of this, the species scores 4 (best estimate) in the population size variable and 2 in the population trend variable.

- Range trends—the U.S. range of salt marsh harvest mice has always been confined to salt marshes in San Francisco Bay. The majority of this habitat was lost in the 19th and 20th centuries, and it continues to be lost, though at a slower rate. Thus, the species has been allocated best estimate scores of 2 in each of these variables.

- Likely future stressor trends—the main stressor that has reduced salt marsh harvest mice populations in the past, and that continues to do so, is anthropogenic habitat destruction or modification. Although the rate of loss is slower than in the past, it still continues. Also, land subsidence in the southern bay (caused by aquifer depletion) is likely to continue, if not increase, as the area becomes more developed. This will result in yet more marshes becoming inundated. For these reason, the species scores 1 (best estimate) in this variable.

- Individual replacement time—small rodents tend to have replacement times in the order of 1−2 years. No data were found on the population dynamics and reproductive biology of the species, but it is assumed that individual replacement time is less than 2 years (i.e., a best estimate score of 3).

- Likely future vulnerability to stochastic events—This species is likely to be particularly vulnerable to high tidal surges. While in the past, individuals could simply move upslope to avoid drowning, the diking of much of their habitat makes this less feasible. For this reason, the species scores 1.

- Likely future vulnerability to policy/management changes—many, perhaps most, salt marsh harvest mice exist on preserves owned by the Federal government (e.g., San Francisco National Wildlife Refuge) or by the State of California. They are, therefore, somewhat conservation dependent and have been assigned a score of 2.

- Likely future vulnerability to natural stressors—no information has been found on the susceptibility of this species to natural stressors. It has been assumed that it is not vulnerable and allocated a score of 3.

Certainty evaluations were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Most of the scores allocated to this species were medium, reflecting the lack of information about the species. Some variables scored low, particularly those pertaining to the extent of past and current population and range trends. This reflects the lack of information on the species' population status and trends.

In **Module 2**, the salt marsh harvest mouse scored Vc2, indicating that it is likely to be critically vulnerable to climate change and that its extinction risk may be increased substantially. This score is largely based on the extreme habitat specialization of the species, the potential scale of habitat loss due to sea level rise (>50%), and the likely inability of the species to move to and colonize new areas.

Certainty scores were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that little is known about the physiological tolerances of the species, its sensitivity to extreme weather events, or its dependencies on other species or conservation actions, many of these scores are only medium or low.

In **Module 3**, the scores from Modules 1 (Vb2) and 2 (Vc2) are combined in an integrative matrix to give an overall vulnerability score of Vo1 (likely to be critically vulnerable to future trends in stressors in conjunction with climate change). It should be noted that the alternate estimates (possible though less likely) are, at best, Vo2. This emphasizes the vulnerability of the species.

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into overall evaluation of certainty of Medium. This implies that the vulnerability evaluation for the salt marsh harvest mouse performed in Modules 1 through 3 is reasonably robust, though not entirely dependable.

C.11. POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

The projected extent of salt marsh habitat loss in southern San Francisco Bay due to sea-level rise could have extremely serious consequences for the population viability of the salt marsh harvest mouse and its likelihood of extinction. If the southern bay population is catastrophically reduced (as would be expected from a >50% habitat loss), the future viability of the species would then be solely dependent on the population in the northern part of the bay, thus reducing still further the species ability to survive future stochastic events and continued climate change.

C.12. UNCERTAINTIES

There are four main areas of uncertainty inherent in predicting the likely effects of climate change on salt marsh harvest mice:

- Uncertainty associated with assessing the species' physiological sensitivity to increased temperatures or altered precipitation patterns. There is no information on the species' physiological tolerances or sensitivity, and the evaluation of Vo1 is based largely on the projected indirect effects of climate change (i.e., acting through habitat modification). If the species is also physiologically sensitive to climate change, the population effects and risks could be more profound than assessed.

- Uncertainty associated with our understanding of current population trends. This species is extremely difficult to census, and its current population trends are not well known. The assumption for this analysis is a slow decline in population numbers. However, this is not based on rigorous evidence, and it is also possible that the species is responding to current stressors at a much faster rate. If so, the extinction risk could be higher than assumed.

- Uncertainty associated with predicting future frequencies and severities of extreme weather events. If rising sea levels are also accompanied by an increased frequency of on-shore storms and tidal surges, the risks posed to the salt marsh harvest mice could be greater than anticipated (especially those segments of the population that have little or no escape habitat. General Circulation Models do not provide reliable predictions of the likely frequency of extreme weather events.

- Future trends in human land use in the areas surrounding the bay. Much of the current risk posed to the harvest mice is due to anthropogenic depletion of the underground aquifer underlying the southern bay (with resultant land subsidence), the rate of urban development in the area, and concomitant increases in the rate at which wastewater and sewage is released into the bay (thereby affecting the floristics of the salt marshes). It is likely that the Californian human population may approximately double by the year 2100 (Landis 2006). This could result in accelerated rates of habitat loss even without factoring climate change into the equation.

C.13. SUMMARY

The salt marsh harvest mouse is currently listed as Endangered under the Federal and State of California ESAs. It is a habitat specialist confined to fragmented salt marshes surrounding San Francisco Bay, and its current population is likely to be, at most, a few thousand individuals. Its essential habitat (salicornia marshes) is likely to be at great risk to sea level rise (induced by climate change and land subsidence). Conservative estimates project that more than 50% of the mouse's habitat could be lost by 2100 (U.S. FWS 1984). Given its current restricted range, its habitat specialization, and the potential degree of habitat loss, this analysis has concluded that the future extinction risk for this species may be high.

C.14. REFERENCES

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APPENDIX D
EXAMPLE NARRATIVE FOR MOUNT GRAHAM RED SQUIRREL

D.1.   INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the Mount Graham red squirrel, *Tamiasciurus hudsonicus grahamensis*, to severe population reduction or extinction, and its potential future vulnerability under climate change. It is intended to provide support for the scores listed in Modules 1 through 4 with the specific objectives of

- making transparent the rationale underlying each score in Modules 1 and 2;
- identifying main sources of uncertainty;
- identifying and describing the roles of the main stressors in the estimate of vulnerability for this species; and
- qualitatively describing potential population responses to climate change and other stressors.

D.2.   ENDANGERED SPECIES ACT STATUS

The Mount Graham red squirrel was listed as Endangered under the Federal Endangered Species Act in 1987.

D.3.   DISTRIBUTION, STATUS, AND POPULATION TRENDS

The Mount Graham red squirrel is endemic to the Pinalenos Mountains in southern Arizona (U.S. FWS, 1993). Since the Pinalenos Mountains are the southernmost extreme of the range of *Tamiasciurus hudsonicus,* the Mount Graham red squirrel is the southernmost outlier of the species (Flyger and Gates, 1982; U.S. FWS, 1993). Within these mountains, it is confined to two successive life zones: the mixed conifer forest from about 8,500 ft in elevation to about 10,000 ft, and the spruce-fir forest from 10,000 ft to the highest peaks at 10,700 ft. They apparently do not occur in the open ponderosa pine forests below 8,500 ft. Thus, the subspecies is confined to a fairly narrow altitudinal zone of about 2,000 vertical ft. Based on fieldwork and review of aerial photographs, the U.S. Forest Service (1988) estimated that within this zone there were probably approximately 50 km^2 of habitat suitable for the squirrels. Thus, not only is the subspecies restricted elevationally, it is also restricted to a very small horizontal range.

The Mount Graham red squirrel has been censused each year since 1986. During this time, the entire population has varied from a low of about 150 individuals to about 570. U.S. FWS (1993) speculates that these fluctuations may be due to variability in the quantity and quality of the cone crop,

with the lowest populations during years of cone crop failure (perhaps tied to climatic variability). During the last decade, numbers have apparently increased, and there have typically been between 300 and 500 individuals counted (http://medusa.as.arizona.edu/graham/envir.html).

D.4. HABITAT

Within their restricted range, and throughout their life cycle, Mount Graham red squirrels are entirely confined to two main plant associations: mixed conifer and spruce-fir forests. The pine seeds are the squirrels' main food item. Prior to the 1990s, it was believed that most squirrels lived in the high elevation spruce-fir association and that the mixed conifer zone was less important for the survival of the species. This belief was the basis for the designation by the U.S. Forest Service of 1,700 acres of spruce-fir forest above 10,000 ft as critical habitat for the subspecies. More recently, however, census data indicate that the mixed forest zone may be more important for the species than hitherto believed (http://medusa.as.arizona.edu/graham/envir.html). Irrespective of the relative importance of the two associations, the squirrels are confined to a narrow zone of conifer habitat between 8,500 and about 10,000 ft.

Within their area of occurrence, Mount Graham red squirrels apparently prefer conifer forests that are relatively dense, with a closed canopy, and composed of mature or old-growth trees (U.S. FWS, 1993). This may reflect their need for relatively cool and moist food storage sites ("middens"), where their stored food will not decay and where fungal growth (another important food item) can occur. It might also indicate a physiological requirement on the part of the squirrel, itself.

Mount Graham red squirrels do not occur much below 8,500 ft in the ponderosa pine forests, although red squirrels use this habitat further to the north within their range. This avoidance may be due to the high degree of solar insolation at the low latitude of the Pinalenos (U.S. Forest Service, 1988). Insulation could act either as a direct climatic limitation on elevational range of the squirrel (i.e., acting through its physiology), or indirectly (by limiting the availability of cool, moist midden sites).

D.5. PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

The extent to which the current range of red squirrels, and Mount Graham red squirrel, in particular, is limited by relationships between physiology and climate is not known. However, they are adapted to moist, cool forests, and the Pinalenos Mountains are the southernmost outpost of the species. It is feasible that they are thermally limited from existing any further south. Also, at this southern extreme of their range, they do not inhabit the lower ponderosa pine association, though they do so further north in their range. This also could indicate a direct thermal constraint on their distribution. However, it is also feasible that their range and habitat preferences in the Pinalenos

Mountains might be an indirect effect of climate, acting through some attribute of habitat quality, such as latitudinal and elevational patterns in canopy cover, limiting the availability of cool, moist midden sites. Thus, red squirrels might not occur any further south because they cannot physiologically tolerate higher temperatures and/or because their habitat is unsuitable.

D.6.   ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

Red squirrels probably colonized southern Arizona during the last glaciation, when contiguous stretches of spruce-fir forest extended farther south. With subsequent warming temperatures, it is likely that the conifer and spruce-fir forests on individual mountain ranges retracted and became isolated by intervening tracts of either Sonoran or Chihuahuan desert (Gelbach, 1981) that the squirrels were unable to cross. It was this that led to the reproductive isolation of the Pinalenos population of red squirrels and the eventual evolution of the Mount Graham subspecies.

It is likely that the current distribution of the Mount Graham red squirrel is at least partly due to habitat limitation. They are at the southernmost limit of the spruce-fir forest vegetation complex, which is the main habitat of red squirrels in general. This habitat does not extend further south into Mexico, where it is replaced by mixed forest or drier pine forests (Barbour and Billings, 1988). The fact that Mount Graham red squirrels do not occur further to the north in other mountain ranges is explained by the isolation of the mountain ranges in the region. Within their restricted range, they are also limited elevationally by habitat: the lower slopes of the Pinalenos Mountains support much more open ponderosa pine woodland, which apparently, is unsuitable for the squirrel at these latitudes (though not further north). Thus, the Mount Graham red squirrel is confined to a relatively small area of Arizona by their strict habitat requirements, by the fragmented distribution of that habitat, and perhaps by their thermal tolerances (see Section D.5).

D.7.   EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

The main current limitations on the status and distribution of Mount Graham red squirrels are all factors that affect the spatial extent and productivity of the spruce-fir and mixed conifer forests in southern Arizona. Thus, logging (prior to the Pinalenos Mountains being declared a refuge area by the U.S. Forest Service) probably exerted a limiting effect on the squirrel's distribution. Also, fire, although not frequent in the high, cool, and damp spruce-fir forests, probably also has limited their distribution and population status. The main factor that currently affects their numbers within their small range seems to be the size of the annual cone crop. In years of cone shortage, the squirrel population is reduced (probably through reproductive failure or mortality of juvenile animals). Thus, any factors that caused their preferred conifer habitats to shrink, that increased the risk of catastrophic

fires, or that increased the frequency of poor cone crops could have detrimental effects on the population viability of the squirrel.

D.8. POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

No data have been found on the likely physiological tolerances of Mount Graham red squirrels to changes in temperature or precipitation. However, there is evidence that squirrels avoid areas of high solar insolation. Also, their distribution may suggest a thermal constraint acting on their physiology (see Section D.5). Alternatively, or in addition, these attributes could be due to increased levels of insolation further south, or in the more open ponderosa pine forests, rendering the squirrels' habitat less suitable for food storage. If the former explanation is true, increased temperatures due to global climate change could directly affect the ability of the squirrels to persist in these southernmost areas of their range (especially if precipitation patterns also change, increasing the "droughtiness" in the squirrels' habitat).

D.9. POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

As noted above (Section D.7), any factors that reduce the extent of the mixed conifer and spruce-fir habitat of Mount Graham red squirrels, or that reduce the cone crop could adversely affect the status and distribution of the subspecies.

Batchelet and Neilson (1999), using the MAPSS model and 4 different GCM outputs, showed that in all cases temperate evergreen forest (which includes mixed conifer and spruce-fir associations) was eliminated in southern Arizona and replaced by either mixed forests or shrub woodland (e.g., pinon-juniper associations). Moreover, assuming an elevational lapse rate of about 1°C for every 120 m (the measured temperature lapse rate at Niwot Ridge, Colorado), it would take only a 5°C annual average temperature increase, which is within the range expected to occur under a CO_2 doubling, to entirely eliminate the squirrel's preferred habitats in the Pinalenos Mountains. Even if the annual average temperature did not increase by as much as 5°C, increases that are more modest could still result in the extinction of the Mount Graham red squirrels, as their distribution is reduced and fragmented to the tops of the highest peaks.

Global warming could also adversely affect the habitat of the squirrel short of eliminating it entirely. Southern Arizona is an area where a number of GCMs (e.g., the Hadley, Canadian Climate Center, and Geophysical Fluid Dynamics Laboratory (GFDL) models predict warming. If, as may be likely, this warming resulted in an increased frequency, intensity, or duration of drought, increased forest fire frequency could also adversely affect the squirrels. Increased temperatures could also potentially affect the overwinter survival of insect pests and, thereby, result in more frequent

outbreaks and tree mortality. This also could reduce the amount of habitat available to Mount Graham red squirrels. The environmental mechanisms responsible for local pine cone crop failures are little understood and may vary from tree species to tree species and area to area. However, there is evidence that summer drought and low soil moisture can reduce cone productivity in some conifers (Barbour and Billings, 1988). Thus, warming in southern Arizona could also affect the cone crop and, thereby, the squirrel's food supply.

D.10. JUSTIFICATION FOR FRAMEWORK SCORES

The framework scores for the Mount Graham red squirrel are presented in Appendices G through J.

In **Module 1** (baseline vulnerability), the species scored Vb2, indicating that it is currently in a highly vulnerable condition. This score is based on the following subcomponents:

- Current population size and trends—based on the data that are available (see Section D.2), there are likely to be less than 600 Mount Graham red squirrels in existence. This small population size confers a best estimate score of 2 in the population size variable. Since some habitat loss has occurred in the past, it is assumed that the population has been reduced, but only by a relatively small amount (a best estimate score of 3).

- Range trends—the range of the Mount Graham red squirrel is confined to a few tens of km^2 of conifer forests in the Pinalenos Mountains. This range may have contracted somewhat (though probably by less than 20%) in the past few decades due to development, although it is likely stable now. Thus the species scores 4 and 3 in the past and current range trend variables.

- Likely future stressor trends—the main "stressor" that limits Mount Graham red squirrels is habitat availability, which is currently stable. Thus, the species scores 2 in this variable.

- Individual replacement time—red squirrels begin breeding when about 1-year old (Flyger and Gates, 1982). For this analysis, an individual replacement time of 2−5 years has been assumed.

- Future vulnerability to stochastic events—Mount Graham red squirrels are likely to be highly vulnerable to future stochastic events. In particular, catastrophic forest fires could potentially eradicate a large part of the population. With the increase in the human population in Arizona and the enhanced access to the squirrel's habitat, the likelihood of such fires is increased. For this reason, the species scores 1.

- Future vulnerability to policy/management change—all Mount Graham red squirrels exist within a refuge area owned by the Federal government. They are, therefore, entirely conservation dependent and have been assigned a score of 1 in this variable.

- Likely future vulnerability to natural stressors—no information has been found on the susceptibility of this species to non-climate natural stressors. It has been assumed that it is not vulnerable and allocated a score of 3.

Certainty evaluations were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Most of the certainty scores allocated for this species were medium or high.

In **Module 2**, the Mount Graham red squirrel scored Vc2, indicating that it is likely to be highly vulnerable to climate change and that its extinction risk may be increased substantially. This score is largely based on the extreme habitat specialization of the species, the potential scale of habitat loss due to warming temperatures, the increased likelihood of catastrophic fires, and the isolation of the species and its likely inability to move to and colonize new areas.

Certainty evaluations were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that little is known about the physiological tolerances of the species, its sensitivity to extreme weather events, or its dependencies on other species or conservation actions, many of these scores are only medium.

In **Module 3**, the scores from Modules 1 (Vb2) and 2 (Vc2) are combined in an integrative matrix to give an overall vulnerability score of Vo1 (likely to be critically vulnerable to climate change).

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into overall evaluation of certainty of High. This implies that the vulnerability evaluation for the Mount Graham red squirrel performed in Modules 1 through 3 is likely to be robust.

D.11. POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

The extremely limited range of Mount Graham red squirrels, together with their high degree of habitat specialization and the potential effects of global warming on their habitats, makes the species vulnerable to a high risk of extinction. Even if their habitat was not eliminated completely, the subspecies could still suffer extinction due to its fragmentation and the further fragmentation and relative isolation of subpopulations. For these reasons, the Mount Graham red squirrel should be considered one of the most highly vulnerable T&E organisms. It is conceivable that a mitigation strategy could involve animals being introduced into less threatened habitat further north. However, there they would likely interbreed with the resident red squirrels (unless they were first eradicated), and the unique genetic identity of Mount Graham red squirrels would be lost.

D.12. UNCERTAINTIES

There are two main areas of uncertainty inherent in predicting the likely effects of climate change on Mount Graham red squirrels:

- Uncertainty associated with assessing the species' physiological sensitivity to increased temperatures. There is some evidence from the species habitat use patterns that they may be directly sensitive to insolation and temperature, and we have assumed in Module 2 a moderate degree of sensitivity. However, they could be more sensitive and, therefore, more vulnerable than assessed.

- Uncertainty associated with our understanding of how climate change may affect factors that influence the extent and quality of the red squirrel's habitat. Warming temperatures and increased drought frequencies could conceivably increase the risk of catastrophic forest fires or pest attacks. This variable of Module 2 has been scored as moderately sensitive. However, the ecosystem may be more sensitive than assessed. Also, we have little information or theoretical basis for projecting how warming temperatures might affect the pinecone crop, the squirrel's main food supply.

D.13. SUMMARY

The entire population of Mount Graham red squirrels consists of a few hundred individuals confined to a small area (probably less than 50 km^2) of the Pinalenos Mountains in southern Arizona. Within their range, they are habitat specialists, being confined to higher elevation mixed conifer or spruce-fir forests. Because of their small population, their habitat requirements and the potential eradication by climate change of their main habitats, this subspecies should be considered critically endangered to the effects of current stressors and future climate change and at high risk of extinction.

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E.1.   INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the desert tortoise, *Gopherus agassizii*, to severe population reduction or extinction, and its potential future vulnerability under climate change. It is intended to provide support for the scores listed in Modules 1 through 4 with the specific objectives of

- making transparent the rationale underlying each score in Modules 1 and 2;
- identifying main sources of uncertainty;
- identifying and describing the roles of the main stressors in the estimate of vulnerability for this species; and
- qualitatively describing potential population responses to climate change and other stressors.

E.2.   ENDANGERED SPECIES ACT STATUS

The Utah population of the desert tortoise was listed as Threatened under the Endangered Species Act (ESA) in 1980. The Mohave population (the population to the north and west of the Colorado River) was listed as Endangered in 1989, but upgraded to Threatened in April 1990.

The species is also protected by legislation at the State level: it is listed as Threatened under the California ESA and is protected under the Revised Statutes of both Arizona and Nevada.

E.3.   DISTRIBUTION, STATUS, AND POPULATION TRENDS

The desert tortoise is resident in the deserts of the American southwest. Within the United States, its current range includes the Mohave and Sonoran deserts of southwest Utah, southern Nevada, southern California, and south and west Arizona. This is an area of approximately 60,000 miles^2 (extrapolated from a range map developed by the U.S. Geological Survey http://geochange.er.usgs.gov/sw/impacts/biology/tortoise1/tortmap.html), though not all of this area may be suitable habitat, or occupied by desert tortoises. South of the U.S.-Mexico border, the desert tortoise's range extends through Sonora to northern Sinaloa.

No previous attempts to estimate the total U.S. population of desert tortoises have been found. However, densities in 14 proposed Desert Wildlife Management Areas (DWMAs) range between approximately 5–10 and 100+ animals per square mile (U.S. FWS, 1994). With a total area of approximately 12,500 miles^2 (U.S. FWS, 1994), and conservatively assuming an average density of

about 7–8 animals per mile^2, the DWMAs, alone, currently support at least 100,000 desert tortoises. Consequently, the current total population throughout the entire U.S. range is likely to be at least in the low hundreds of thousands of individuals.

Beginning in the 1970s, reductions were noticed in a number of desert tortoise populations. The reduction rates varied between 3 and 59% per annum, with the highest rates among those populations most exposed to human disturbance (U.S. FWS, 1994). In some areas that previously supported healthy tortoise populations, these reductions have led to apparent local extinctions (e.g., in Antelope Valley in Kern and Los Angeles counties, California [Berry and Nicholson, 1984; Tierra Madre Consultants, 1991]). These rapid negative population trends were the main reason for the listing of the Utah and Mohave populations of the species.

E.4. HABITAT

In the wild, desert tortoises occur exclusively in deserts, particularly in scrub and cactus deserts, where the shrubs provide shelter from the summer sun. They prefer habitat where the shrubs are widely spaced, since this discontinuous canopy facilitates the growth of the desert annuals on which the tortoises feed. Preferred shrubs include creosote bush, bursage, blackbush, saguaro cactus, Joshua tree, palo verde, and yucca. Thus, they are fairly flexible in their habitat requirements within the scrub desert association (Ernst et al., 1994).

The diet of desert tortoises comprises mainly ephemeral forbs and their flowers, and the population densities of the tortoises, in some areas, may be determined by the biomass production of these species after spring rains (U.S. FWS, 1994). Therefore, ideal habitat consists of scrub deserts with relatively dense seasonal developments of ephemeral plants. Grasses are eaten but may be secondary food items (Ernst et al., 1994).

The tortoises spend much of the drier part of the year between November–March (when plant growth is limited) below the surface of the ground in burrows that they dig themselves. They, therefore, prefer areas of loose and penetrable soils.

E.5. PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

Not surprisingly for an ectothermic organism, ambient temperature plays an important role in the autecology and behavior of desert tortoises. Much of their behavior is apparently aimed at avoiding excessively low and high temperatures. Desert tortoises hibernate in burrows during the cooler months (generally October–April) and emerge only in the warmer summer months (Ernst et al., 1994). When active, their activity patterns are highly influenced by diel temperature cycles, remaining in their burrows until the ambient air temperature exceeds about 20°C (Woodbury and Hardy, 1948). There may also be a critical maximum temperature that desert tortoises can tolerate of about 43°C

(Hutchison et al., 1966). Spending most of their lives in burrows is probably an adaptation to avoiding low surface temperatures, and to conserve water and avoid desiccation (Ernst et al., 1994). In abnormally hot weather, the desert tortoise may remain in their burrows most of the day, emerging only in the cooler mornings and evenings (Ernst et al., 1994).

In a number of turtle species, sexual differentiation has been shown to be affected by egg incubation temperature (Gans, 1985). In these species, incubation at temperatures above 31°C usually results in an abnormally high proportion of phenotypic females, while incubation at temperatures below about 27°C yields mostly phenotypic males. It is not known whether a temperature-based sexual differentiation relationship exists in desert tortoises. However, if it did, it could potentially contribute to the current range limits.

Desert tortoises are k-selected species. That is, their adult survival and longevity is high (they may live for 50 or more years), but their reproductive rates are low. Individuals do not reach breeding age until they are about 15 years old, and embryonic and juvenile mortality is high, with more than 90% of juveniles dying before reaching adulthood (U.S. FWS, 1994). This, coupled with relatively low dispersal ability, means that desert tortoises have only a limited ability to compensate for population reductions caused by anthropogenic or natural factors. U.S. FWS (1994) estimates that the normal population growth rate (in favorable environmental circumstances) could not exceed 0.5% per year. Thus, if a population were halved in size by a stressor, it would require at least 140 comparatively stress-free years to return to its previous size. This highlights the fact that any increased mortality among adult tortoises could fundamentally affect population viability.

E.6.   ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

The current range of desert tortoises in the United States is confined to the Mohave and Sonoran warm scrub deserts (Barbour and Billings, 19889). This is also the likely extent of the species' range prior to European colonization of North America (U.S. FWS, 1994). There is no fossil evidence that the species ever successfully colonized the colder Great Basin deserts further to the north. The species' current and historical distribution suggests that the northern extent of its range may be limited, either directly or indirectly, by temperature. The ranges of many reptiles reach their northernmost extents at the northern extremes of the warm deserts (e.g., western banded gecko, desert night lizard, desert iguana, long-tailed brush lizard, and Gila monster [Stebbins, 1985]), suggesting a general climatic limitation on many members of the taxon.

The absence of the species from the warm Chihuahuan deserts of eastern Arizona, New Mexico, and Texas is less easily explained. However, climate may also play a role: since the Chihuahuan desert generally lies at higher elevations than the Mohave or Sonoran deserts, it is generally cooler, with an annual mean temperature of 18.6°C, compared with 20°C or higher in the

Sonoran and Mohave deserts (Bailey, 1979; Schmidt, 1986; Barbour and Billings, 1989). Furthermore, precipitation amounts and patterns differ between the Mohave/Sonoran and the Chihuahuan deserts: at most sites in the former, the majority of the precipitation falls in winter, while in the latter, precipitation is higher, and it falls mainly in summer (Barbour and Billings, 1989). The generally cooler and moister conditions of the Chihuahuan desert have resulted in marked differences in the structure and composition of its vegetation communities, when compared to the Mohave and Sonoran. The flora of the former has a much higher representation of grass species, to the extent that grasses may dominate, while the latter are mainly shrub and forb dominated. Thus, the desert tortoise might be excluded from the Chihuahuan desert either directly by climate or indirectly through its effect on habitat.

It is not likely that competition with other chelonians plays a role in excluding the desert tortoise from the Chihuahuan desert since no other species are found there, at least in the western part abutting the desert tortoise range.

E.7.   EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

Desert tortoise populations in the southwestern U.S. are currently under a high degree of anthropogenic stress. Humans are directly responsible for much of the premature mortality, either through shooting, crushing by off-road vehicles, mortality on the roads, facilitating the spread of disease (e.g., upper respiratory tract disease in pet tortoises being released into wild populations), or by collecting the animals either to eat or to keep as pets. Humans are also indirectly responsible for declining desert tortoise populations through urbanization leading to habitat loss, increased recreational disturbance and modification of habitat, the introduction of alien predators (e.g., dogs) into the tortoise habitat or increasing the density of native predators (e.g., ravens), crushing by livestock, livestock-induced habitat modification, fires, or the introduction of alien plant species into the deserts.

Since there is a common denominator to all of these effects—humans—the effects are often spatially correlated in their occurrence. For example, the development of desert subdivisions results in direct effects, in that the increased human population and traffic leads to increased mortality in tortoises. Furthermore, the subdivision itself results in habitat loss, while increased use of the desert by the new human residents and their pets leads to elevated mortality rates and further, more widespread, habitat modification. Thus, the greatest rates of population decline in desert tortoises have occurred in areas that have been developed or that are undergoing development (U.S. FWS, 1994).

Projections of future urbanization in California hold out little relief for desert tortoises. Some of the areas that are projected to encompass the greatest growth in urbanization are in the arid scrub desert in the southwest, particularly in San Bernardino County in the Twentynine Palms area. This

area is adjacent to the proposed Joshua Tree DWMA (Landis 2006). Also, rapid urbanization and sprawl in the neighborhoods of Tucson and Phoenix, Arizona are likely to affect the quantity and quality of desert tortoise habitat. The footprint of the City of Phoenix doubled in size between 1970 and 1990, and it continues to grow: the city's population increased by 22% in the years between 1990 and 1995 (http://www.sierraclub.org/sprawl/report98/phoenix.html).

Natural factors also may affect tortoise population processes. During drought conditions, their breeding success may be low, due, possibly, to the limited growth of their food plants and poorer maternal condition (U.S. FWS, 1994). Fires may also cause increased mortality among desert tortoises (U.S. FWS, 1994).

E.8. POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

It is unlikely that increases in temperature due to global climate change will have a direct physiological effect on desert tortoises, resulting in further population reduction or local extinctions. The species is already adapted to some of the hottest, most arid environments on Earth. Furthermore, its Mexican distribution extends 600 miles south of the U.S.-Mexican border into areas where annual ambient air temperature is 3−5°C higher than in its U.S. range (http://www.cdc.noaa.gov/cg). Alternatively, it is feasible that temperature increases in the northern part of the desert tortoise range may assist it to extend its distribution into the Great Basin deserts, an area from which it is currently excluded, probably by low ambient temperatures (annual ambient air temperature approximately 3−5°C lower than in Sonoran and Mohave deserts: http://www. cdc.noaa.gov/cg).

While it may be possible that desert tortoise reproductive biology may be adversely affected by increased temperature through disruption of gender differentiation, it is not certain whether the species is sensitive to this factor, and the thermal thresholds at which it this might become important are not known.

E.9. POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

Galbraith et al. (*in prep.*) have modeled the likely spatial responses of southern Californian vegetation communities to future climate change scenarios. The future climate scenarios that they

evaluated are shown below in Table E-1.

Table E-1. Climate scenarios used to model change in spatial distribution of southern California vegetation communities.

Scenario	Temp. Change	Precipitation change
Hadley	+3°C	+100%
T3P0	+3°C	0%
T5P0	+5°C	0%
T3P18	+3°C	+18%

These scenarios shown in Table E-1 bracket the likely range of changes that the current Global Circulation Models (GCMs) project for the area.

The potential future (by 2100) spatial distributions of the vegetation communities were projected using the Mapped Atmosphere–Plant–Soil system MAPPS model (VEMAP members, 1995) and the above climate scenarios. The projected future distributions of the vegetation communities were delineated after current agricultural land and land that is urban now or predicted to be urban by the year 2020 was masked out (Landis 2006). The projected changes for southern Californian subtropical arid shrubland (the scrub desert required by desert tortoises) are shown in Table E-2. Approximately 1.4% of the loss of desert acres will be due to development (from data supplied by John Landis), the remainder to climate change.

Table E-2. Acre and percent changes in the spatial extent of subtropical arid shrubland projected by the MAPPS model (to 2100) and using the climate change scenarios from Table E-1. Agricultural and developed (by 2020) land masked out.

Scenario	Current acres	2100 acres (% change)
Hadley	17,346,799	7,610,846 (−56%)
T3P0	17,346,799	14,579,218 (−16%)
T5P0	17,346,799	13,837,902 (−20%)
T3P18	17,346,799	12,379,980 (−29%)

In general, MAPPS projects that the subtropical arid shrubland will be invaded and replaced by other vegetation communities, particularly grasslands dominated by C4 species. The extent of this replacement will vary with the temperature and precipitation assumptions in the scenario but will typically range between about 20 and 50% habitat loss.

The data in Table E-2 could be viewed as "best-case estimates" of the likely extents of habitat loss since the urbanization projections only go as far as 2020. Nevertheless, all the climate change scenarios project substantial changes in the extent of desert tortoise habitat in southern California. It is likely that these losses will be matched with corresponding losses in Arizona, Utah, and Nevada.

Also, the model projections reported above focus on relatively gross measures of vegetation change (community replacement). Climate change could result in habitat change that might be more subtle but just as fundamentally important for desert tortoises. For example, facilitated invasion by nonnative plant species could result in alterations to the amount and quality of food provided by habitat. Invasive grass species are already a problem for tortoises in some parts of their range (U.S. FWS, 1994). Also, changes in vegetation or woody biomass could lead to an increased frequency of fires, which desert tortoises are not well adapted to withstand.

E.10. JUSTIFICATION FOR FRAMEWORK SCORES

The framework scores for the desert tortoise are presented in Appendices G through J. In **Module 1** (baseline vulnerability), the species scored Vb3, indicating that it is currently in a less vulnerable condition. This score is based on the following subcomponents:

- Current population size and trends—based on the distribution and density data that are available (see Section E.2), there are likely to be more than 100,000 individual desert tortoises in existence in the U.S. However, there is good evidence that the U.S. population has and is declining in many parts of its range (U.S. FWS, 1994). Because of this, the species scores 6 in the population size variable; but only 3 in the past population trend variable, and 2 in the current population trend variable.

- Range trends—the U.S. range of desert tortoises extends over a relatively large area ($>100,000$ km^2). However, its range is contracting as local populations are reduced or become extinct. For these reasons, the species scores 3 and 2, respectively, in these variables.

- Likely future stressor trends—the main stressors that have reduced desert tortoise populations in the U.S. have been anthropogenic habitat loss or modification, and human-induced mortality. Much of this is connected to increasing urbanization in the tortoises' habitat, with concomitant increases in recreational use. Growth of desert communities and the establishment of new communities are continuing and expected to continue for the foreseeable future. Thus, the resulting stressors are expected to increase in the future and to reach areas that may be currently less affected. For this reason, desert tortoise scores 1 in this variable.

- Individual replacement time—desert tortoises do not begin breeding until they have reached about 15 years of age. For this reason, the species scores 1.

- Likely future vulnerability to stochastic events—since the desert tortoise is widespread in its distribution and individuals live for many decades, the species has the potential to withstand localized and short-term stochastic events such as sporadic droughts. Therefore, it scores 3.

- Future vulnerability to policy/management change—most desert tortoise populations in the U.S. are not on protected land, and few populations are being actively managed or conserved. However, State and Federal protection is important in the viability of local populations. Because of this, it has been assigned a policy/conservation dependency score of 2.

- Likely future vulnerability to natural stressors—no information has been found on the susceptibility of this species to non-climate change natural stressors. It has been assumed that it is not vulnerable and allocated a score of 3.

Certainty evaluations were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that the species is relatively well studied, medium-to-high certainty scores were assigned to most of the variables.

In **Module 2**, the desert tortoise scored Vc2, indicating that it is likely to be highly vulnerable to climate change and that its extinction risk may be increased substantially. This score is based on the following subcomponents:

- Physiological sensitivity to temperature and precipitation change and to extreme weather events—desert tortoises are believed to be sensitive to drought, to the extent that their reproductive success is reduced during drought years. Also, the availability of their preferred food plants is dependent on seasonal precipitation. Thus, future climate scenarios in which temperature increases and the rainfall pattern changes, resulting in less soil moisture at critical times of the year, could have adverse effects on tortoises. While we are not able to predict changes in precipitation in the tortoise's range with any certainty, it is highly likely that temperature will increase by several degrees Centigrade. For this reason, it scores 2 in each of these variables.

- Dispersive capability and potential rate of increase—the dispersive capability of this species is low. Also, given that its potential reproductive replacement rate is low (see Section E.5), it scores only 1 in each variable.

- Habitat specialization—desert tortoises are only moderately specialized in their habitat requirements (see Section E.3). However, they are restricted to one major plant association—warm deserts. Because of this, the species scores 2 in the habitat specialization and diversity variables.

- Likely extent of future habitat loss due to climate change—vegetation modeling suggests that future climate change in southern California could result in the replacement of between 20 and 50% of the tortoises scrub desert habitat by C4 grasslands (this does not include additional habitat that will be lost due to urbanization). Thus, desert tortoise scores 2 in this variable.

- Ability of habitats to shift in response to climate change—It is possible that increasing temperatures could result in the northward extension of the Mohave and Sonoran deserts into what is currently the southern range of the Great Basin deserts. No apparent geological or

anthropogenic barriers oppose this migration. If this occurred, new habitat could eventually become available for colonization by the tortoise. Desert tortoise scores 3 in this variable.

- Dependence on temporal inter-relations and other species—desert tortoises are dependent to a great extent on winter and spring rains triggering the growth of the desert annual plant species on which they feed. Without this spring growth, it is unlikely that the tortoises could reproduce (in drought years when the annual plants are less abundant, tortoise breeding success is low). Accordingly a score of 1 has been assigned to this variable of Module 2. Desert tortoises are assigned a score of 2 for Variable 10 (dependence on other species) because of their reliance on the spring growth of annual plants.

Certainty evaluations were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that desert tortoise autoecology is relatively well known, the ecological components of Module 2 were assigned high or medium certainty scores. However, the physiological relationships between the species and climate variables are not as well understood and were therefore assigned low-to-medium scores.

In **Module 3**, the scores from Modules 1 (Vb3) and 2 (Vc2) are combined in an integrative matrix to produce an overall vulnerability score of Vo2 (likely to be highly vulnerable to climate change).

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into overall evaluation of certainty of Medium. This implies that the vulnerability evaluation for desert tortoises performed in Modules 1 through 3 is reasonably robust.

E.11. POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

Desert tortoises, though they are abundant in comparison to most other T&E species, are currently under considerable anthropogenic stress. This has already resulted in population reductions and local extinctions. It is likely that, since these stressors (urbanization and associated human activities) are unlikely to be ameliorated in the foreseeable future, additional population reductions and extinctions will follow. Thus, even without the added complication of climate change, there is a strong possibility that the U.S. population of desert tortoises could be reduced markedly in the relatively near future, with associated range contractions. However, the vegetation modeling that has been performed thus far indicates that most climate scenarios project losses of the warm desert scrub habitat on which the species depends. Thus, the habitat losses due to future climate change may greatly accelerate the overall rate of habitat loss for the species. Also, the vegetation models fail to capture more subtle potential effects such as the invasion of native desert communities by alien plant species. These also could have adverse impacts on tortoises as preferred forb food plants are replaced by non-native species. Conversely, although uncertain, temperature increase could open up new areas of habitat for the species to the north of its current range. The extent to which this may occur is conjectural (see below).

The likely net result of climate change and other stressors is that a considerable part of the current desert tortoise range in the U.S. may be converted to unsuitable habitat. This loss could approach or exceed 50%. The consequences for tortoises are likely to be further major population reductions and local extinctions among already fragmented populations. Thus, climate change could act to exacerbate the effects of other stressors.

E.12. UNCERTAINTIES

There are three main areas of uncertainty inherent in predicting the likely effects of climate change on desert tortoises:

- Uncertainty associated with assessing the species' physiological sensitivity to increased temperatures. While desert tortoises are adapted to extremely hot and arid climates, they do apparently have maximum temperature thresholds (during extremely hot periods, they may withdraw to their burrows). Also, like some other chelonians, their reproductive biology may be sensitive to high temperatures (acting through sexual differentiation). If these are the case, the species may be more sensitive to the direct effects of climate change than we have assumed.

- Uncertainty associated with predicting future climate-induced changes in extent and quality of desert tortoise habitat. It is possible that increased temperatures could result in the northward extension of the tortoise range. However, it is not certain that all of the habitat factors that are important to tortoises will survive this migration. For example, if the migration is accompanied

by an increasing dominance of invasive plant species and a decrease in the native forbs preferred by tortoises, they may not be able to exploit the new habitat. Also, it is possible that there may be new constants in the new landscape that may be detrimental to tortoises. For example, if the new and existing habitat has an increased fire frequency (due to higher temperatures), tortoise populations may be put at risk.

- Uncertainty associated with the ability of desert tortoise populations to withstand an altered frequency of environmental perturbation. Although long-lived, desert tortoises are slow to make good losses due to environmental stochasticity. Thus, they are adapted to extreme, but relatively predictable habitats. If the predictability of their habitat is altered (a higher frequency of unpredictable extreme events such as fires, droughts, or storms), tortoise population viability may be put at risk. While GCMs can predict regional changes in the main climate variables, temperature and precipitation, they are generally less useful in predicting climate-associated change in stochastic events such as droughts.

E.13. SUMMARY

The Mohave population of the desert tortoise is currently listed as Threatened under the ESA. The Sonoran population is listed and protected by Arizona State regulations. The current U.S. population is probably a few hundreds of thousands of individuals, distributed across about 60,000 miles^2 of scrub desert in California, Utah, Nevada, and Arizona. Over the last three or four decades, these populations have come under high degrees of stress due largely to human activity (particularly urbanization and recreational intrusion). This has resulted in population reductions and local extinctions. Climate change may be a significant new stressor, causing even more habitat loss and exacerbating an already difficult situation. Together, existing stressors and the direct and indirect effects of climate change could result in desert tortoises being put at even greater risk of population reduction and extinction in their U.S. range.

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APPENDIX F
EXAMPLE NARRATIVE FOR LAHONTAN CUTTHROAT TROUT

F.1.   INTRODUCTION

Based on a review of available information, this narrative describes the current vulnerability of the Lahontan cutthroat trout, *Oncorhynchus clarki henshawi*, to severe population reduction or extinction, and its potential future vulnerability under climate change. Its main objectives are to

- make transparent the rationale underlying each score in Modules 1 and 2;

- identify main sources of uncertainty;

- identify and describe the roles of the main stressors in the estimate of vulnerability for this species; and

- qualitatively describe potential population responses to climate change and other stressors.

F.2.   ENDANGERED SPECIES ACT STATUS

The Lahontan subspecies of the cutthroat trout was listed as Endangered by the U.S. Fish and Wildlife Service (U.S. FWS) in 1970 [35 FR 16047 16048] but was reclassified under the Endangered Species Act (ESA) in 1975 as Threatened [40 FR 29863 29864]. This status applies to all populations throughout its range in California, Nevada, and Oregon.

F.3.   DISTRIBUTION, STATUS, AND POPULATION TRENDS

Lahontan cutthroat trout originally evolved in Lake Lahontan, which until about 14,000 years b.p., covered approximately 8,500 miles^2 of present day Nevada, California, and Oregon (Benson and Thompson, 1987). With the drying up of the lake, beginning about 12,000 years ago, the trout's distribution was fragmented into a number of disconnected drainage basins. Many of these were later rendered unsuitable as trout habitat by anthropogenic modifications (water diversions, dams, pollution, or over-harvesting) or the introduction of non-native fish species (U.S. FWS, 1995), causing further fragmentation of the fish's distribution. Impacts caused by dams, water diversions, and non-native species introductions still continue.

Currently, self-sustaining populations of Lahontan cutthroat trout are restricted to about 11% of their ancestral riverine habitats and to less than 1% of lake habitats (U.S. FWS, 1995). They occur in about 160 streams and 6 lakes in three major areas: the Truckee/Carson/Walker river basins in eastern California/western Nevada; the Quinn River/Black Rock Desert/Coyote Lake basins in northern Nevada/southern Oregon; and the Humboldt River basin in north-central Nevada. Survey

data assembled by U.S. FWS (1995) indicate that within this range approximately 56% of existing trout subpopulations comprise less than 500 individual fish and only about 29% have more than 1,000 individuals. Thus, the Lahontan cutthroat trout currently is distributed in a number of isolated, relatively small, and, in some cases, declining populations.

F.4.   HABITAT

The Lahontan cutthroat trout is a cold-water fish that can inhabit a wide variety of riverine and lake habitats. They generally live in relatively small streams that provide gravel spawning areas and deep, shaded pools. Lake habitats range from small alpine lakes to large, saline basin lakes. However, if a lake is to provide suitable habitat, it must provide access to stream spawning areas.

F.5.   PHYSIOLOGICAL/CLIMATIC LIMITATIONS ON DISTRIBUTION AND STATUS

Being a fish that is adapted to existence in relatively cold waters, the distribution of Lahontan cutthroat trout, like many salmonid species, is ultimately limited by ambient water temperatures. Above maximum temperature thresholds, the physiological processes of the fish began to deteriorate: growth in juvenile fish slows, egg viability decreases, behavioral avoidance occurs, and fish may expire (Scott and Crossman, 1973; McGinnis, 1984; Crisp, 2000). The water temperature threshold that imposes these physiological limitations varies depending on the endpoint and life stage being assessed. However, exceedances of about 19°C may cause increased lethality in eggs (Crisp, 2000), while temperatures in excess of 25°C will cause excessive fry mortality (Scott and Crossman, 1973). U.S. EPA (1995) report that the upper 95th percentile of the maximum weekly average water temperatures at all stations where the species has been reported is 22.8°C. This, they postulate, is a good indicator of the upper thermal limit on the species' distribution. U.S. FWS (1995) report that Lahontan cutthroat trout can withstand short-term water temperatures exceeding 27°C and daily maxima of 20°C. Thus, it is likely that water temperatures that exceed 20–23°C on a regular basis may set physiological limits to the distribution of the species.

F.6.   ECOLOGICAL LIMITATIONS ON DISTRIBUTION AND STATUS

The main ecological limitations on the distribution of Lahontan cutthroat trout are likely to be habitat availability and contiguity, and competition with other fish species. Their distribution is confined to a relatively arid area of the Great Basin where suitable coldwater streams and lakes are few and isolated. Approximately 90% of their potential riverine habitat and more than 99% of their potential lake habitat has been rendered unsuitable by human activities including dewatering, pollution, dams, increased sediment loads, and destruction of shading riparian vegetation by livestock (U.S. FWS, 1995). Overfishing and the introduction of non-native competitors (e.g., kokanee salmon,

Oncorhynchus nerka, brook trout, *Salvelinus fontinalis*, and shiners, *Richardsonius egregious)*, have also been responsible for eliminating cutthroat trout from many areas of their ancestral habitat. During the 19th and early 20th centuries, important commercial fisheries existed at Lake Tahoe, California and Pyramid Lake, Nevada. These were wiped out by fish population crashes due to overharvesting and competition with introduced species.

F.7. EXISTING STRESSORS AND THEIR EFFECTS ON DISTRIBUTION AND STATUS

The main ancestral stressor that resulted in a large contraction of the range of the Lahontan cutthroat trout was the drying of Lake Lahontan. However, since then, the main stressors have been anthropogenic. During the mining booms of the 19th Century, much habitat was lost as a result of releases of mining-related contaminants and sediments into the streams and lakes. The increase in agriculture during the late 19th and early 20th Centuries resulted in habitat impacts as water was diverted for irrigation and streams and lakes dewatered. In the 20th Century, and continuing into this century, the main stressors have been competition with nonnative fish species and habitat destruction due to overgrazing by domestic livestock (U.S. FWS, 1995).

F.8. POTENTIAL DIRECT (PHYSIOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

Short-term maximum temperatures in water bodies inhabited by Lahontan cutthroat trout are close to the subspecies' likely physiological maximum. U.S. EPA (1995) projects that maximum weekly average water temperatures in Nevada range between about 18 and 23°C, while in California and Oregon, the corresponding data are 32 and 19°C and 24 and 15°C, respectively.

General circulation models (GCMs) such as the Hadley, the Canadian Climate Center, and the Oregon State University models project substantial warming over the next century in the areas occupied by Lahontan cutthroat trout. Assuming a doubling of atmospheric CO_2 by 2100, these GCMs project mean annual temperature increases of between 2 and 5.5°C or between 3.6 and 10°F (U.S. EPA, 1995; National Assessment Synthesis Team, 2000). Assuming that these air temperature increases are directly translated into water temperature increases (U.S. EPA, 1995), ambient water temperatures in the habitat of the cutthroat trout could rise by up to 5.5°C (10°F). Such rises in temperature could have fundamental effects on habitat suitability and distribution. In a modeling exercise, U.S. EPA (1995) predicted that similar temperature increases could result in cutthroat trout habitat loss in California and Oregon of more than 50%. Thus, global warming over the next century could result in a drastic reduction in the habitat available to Lahontan cutthroat trout.

F.9. POTENTIAL INDIRECT (ECOLOGICAL) VULNERABILITY TO CLIMATE CHANGE

In aquatic organisms, the distinction between direct physiological effects and indirect ecological effects is not as clear as it is in terrestrial organisms. Water is both the habitat for the organism and the main interface with the changing climatic parameters. Therefore, increased water temperature results in both direct and ecological effects. The main ecological vulnerability of Lahontan cutthroat trout to global temperature increases is likely to be through rising water temperatures rendering hitherto suitable habitat less so.

GCMs predict increased temperatures within the trout habitat over the next century (see Section F.8). However, there are also likely to be changes in the amount and timing of precipitation (National Assessment Synthesis Team, 2000). Both the Canadian Climate Center and the Hadley models predict increased precipitation in the trout's range (80–100% in the former and 20–40% in the latter). Not only might the amount of precipitation change, but its seasonal pattern is also likely to be affected: given the higher temperatures, much more may fall as rain rather than snow. This could mean that high spring high flows due to snow melt may be less marked. This could have important implications for the seasonal availability of trout spawning habitat: if there is less of a spring peak in flow, trout may be less able to move upriver to spawn.

F.10. JUSTIFICATION FOR FRAMEWORK SCORES

The framework scores for the Lahontan cutthroat trout are presented in Appendices G through J.

In **Module 1** (baseline vulnerability), the subspecies scored Vb2, indicating that it is currently in a highly vulnerable condition, when compared to other T&E species. This score is based on the following subcomponents:

- Current population size and trends—U.S. FWS (1995) collated population data from 92 of the approximately 160 extant river populations. These data indicate that between 68,000 and 140,000 individual fish exist at these sites, alone. The numbers of fish at the approximately 70 sites not included in this analysis are unknown, neither are the numbers in lakes inhabited by the fish. However, based on these data, it is very likely that an excess of 100,000 Lahontan cutthroat trout exist within their range. Because of this population status, the subspecies scores 6 in this variable.

  Given the alleviation of many of the historical major stressors (pollutants, etc.) and the protected status extended to the species, it is unlikely that population trends are as steeply negative as they once were. However, it is still possible, and perhaps likely, that the subspecies is in slow decline. For this reason, it has been assigned a score of 2.

- Range trends—extrapolating from a range map in U.S. FWS (1995), the current range of Lahontan cutthroat trout has three main centers extending over an approximate total area of 8,000 miles^2. U.S. FWS (1995) indicate that only about 485 miles of stream are currently

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inhabited, plus six lakes. Thus, the distribution of this species is limited to a comparatively small area. Also, some subpopulations probably are continuing to decline through interactions with invasive species and human modification of habitat. Because of these data, the subspecies has been given scores of 2 and 2, respectively.

- Current stressors and stressor trends—the main stressor that has reduced Lahontan cutthroat trout populations since post-Colombian colonization has been habitat modification and destruction. These include releases of pollutants, dewatering for agriculture, riparian vegetation destruction by livestock, overharvesting, and the introduction of exotic fish species. Some of these stressors have been reduced in the last few decades (e.g., pollution and overharvesting), however, others (e.g., livestock vegetation modification and exotic species) continue to exert deleterious effects on trout populations. The intensity and spatial pattern of these stressors is, however, probably stable. Because of this, the subspecies scores 2 in this variable.

- Individual replacement time—Lahontan cutthroat trout breed in the first few years of life and have been assigned a replacement time of 2–5 years.

- Likely future vulnerability to stochastic events—While they inhabit a comparatively stable freshwater environment, this species could be susceptible to an increased frequency, or degree, of climate change-induced droughts. For this reason, it has been assigned a score of 2 in this variable.

- Likely future vulnerability to policy/management change—Significant portions (i.e., >50%) of streams and lakes inhabited by Lahontan cutthroat trout are on lands owned by the Bureau of Land Management or the U.S. Forest Service. However, there is only sporadic active conservation occurring on these lands, and stressors, such as overgrazing, continue to affect habitat. Thus, the potential for active conservation is relatively unexploited, and the trout's current status is relatively independent of conservation. For this reason, the subspecies scores 3 in this variable.

- Likely future vulnerability to natural stressors—the species is susceptible to salmonid pathogens such as whirling disease, though the incidence is low. It has been assigned a score of 2.

Certainty evaluations were allocated to each of the scores in Module 1. These are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that uncertainties exist regarding the subspecies' current population and habitat trends, low-to-medium certainty scores were assigned to a number of the variables.

In **Module 2**, the species scored Vc2, indicating that it is likely to be highly vulnerable to climate change and that its extinction risk may be increased substantially. It should be noted that the species almost merits a score of Vc1 (in fact, the low alternate score is Vc1). These scores are based on the following subcomponents:

- Physiological sensitivity to temperature and precipitation change and to extreme weather events—the Lahontan cutthroat trout is likely to be physiologically highly sensitive to increased water temperatures (see Section F.8). It, therefore, scores 1 in this variable of Module 2. The subspecies may also be sensitive to altered precipitation patterns (see Section F.9). However, these effects are likely to be expressed in changes in the trout's ecology and habitat and dealt with in Variable 4.

- Dispersive capability—the dispersive capability of this subspecies, which lives in isolated subpopulations, is low (scores 1 in Module 2).

- Habitat specialization—coldwater species cutthroat trout are relatively specialized in their habitat requirements. However, within this cold-water regime, they are flexible in that they can inhabit streams, rivers, or lakes with a wide variability of water chemistries. Therefore, it scores 2 in this variable.

- Likely extents of future habitat loss due to climate change—in this variable, Lahontan cutthroat trout scored 2 (20−50% likely habitat loss). This score reflects the species' degree of dependency on coldwater habitats and the potential effects of ambient temperature increases. However, this score may underestimate the potential degree of habitat loss: considerable uncertainty exists regarding how altered precipitation patterns may affect habitat quality and availability. While the assigned score is 2, further information and analysis could elevate it to 1.

- Ability of habitats to shift at same rate as species in response to climate change—because the current distribution of the habitats of the cutthroat trout are severely circumscribed and limited by topography and human activities, it is highly unlikely that they will be able to shift much in response to climate change. Thus, this variable scores 1, only.

- Availability of habitats within new range—given the enclosed nature of the species' watersheds, it is likely that the only way in which it can naturally (i.e., without human intervention) colonize new habitats is by moving upstream. However, most such habitats are probably already colonized, and the potential for this shift is low. Therefore, this variable scores 2.

- Dependence on temporal inter-relations and other species—the timing of spawning in cutthroat trout is dependent on the seasonal pulse of water from spring snowmelt. Changes in the amount and seasonality of precipitation predicted by GCMs could mean that the size of this pulse may be reduced. This could adversely affect the trout, and this variable has been assigned a score of 2. The cutthroat trout is currently under considerable stress from introductions of non-native fish species. If increased climate stress were to give these invasives even more of a competitive advantage, the cutthroat trout could be harmed further. For this reason, a score of 2 has been assigned to this variable.

Certainty evaluations were allocated to each of the scores in Module 2. Again, these are largely subjective evaluations of the robustness of each of the scores and reflect the availability and quality of information for each category, rather than rigorous evaluations. Given that some aspects of Lahontan cutthroat trout autoecology are relatively well known (e.g., numbers, distribution, habitat preferences),

some of the ecological variables of Module 2 were assigned high or medium certainty scores. However, the potential relationships between climate change and physiological and ecological effects are uncertain, and in many of these categories, the subspecies scored only medium or low.

In **Module 3**, the scores from Modules 1 (Vb2) and 2 (Vc2) are combined in an integrative matrix to give an overall vulnerability score of Vo1 (likely to be critically vulnerable to climate change).

In **Module 4**, the individual variable certainty scores from Modules 1 and 2 are combined in an integrative matrix into overall evaluation of certainty of Medium. This implies that the vulnerability evaluation for Lahontan cutthroat trout performed in Modules 1 through 3 is reasonably robust.

F.11.   POTENTIAL EFFECTS OF CLIMATE CHANGE ON STATUS AND DISTRIBUTION

Climate change, particularly temperature increases and changes in precipitation patterns, could have important implications for the distribution and population status of Lahontan cutthroat trout. Like other coldwater salmonids, the subspecies is sensitive to water temperatures, and the increases projected by GCMs could result in a large portion of its current range being made unsuitable. Also, the trout is probably sensitive to the timing of river flow patterns. Precipitation changes forecast by the GCMs could potentially disrupt its spawning activities and render currently suitable habitat unsuitable. Taken together, these potential effects could result in population reductions among local subpopulations of the fish and render its overall status and stability problematic.

F.12.   UNCERTAINTIES

The greatest uncertainties associated with this analysis concern potential future changes in precipitation amount, seasonality, and the likely responses of the trout. GCMs are relatively imprecise in their predictions of future precipitation patterns. This, together with uncertainty about the resulting changes in river flow patterns complicates the projection of effects on the cutthroat trout. However, it is at least feasible that the effects of changing flow patterns could be severe, perhaps as much as temperature change. For this reason, the score allocated in Module 2 may underestimate the actual degree of risk.

F.13.   SUMMARY

Lahontan cutthroat trout are currently listed as Threatened under the ESA. Though their current world population probably exceeds 100,000 individuals, they have declined greatly since Europeans settled the Great Basin and their population is now highly fragmented into relatively small, isolated, and vulnerable subpopulations. They are also under considerable stress from invasive species and human modification of their habitats. This, and their sensitivity to temperature and precipitation

regimes, make this species one of the most vulnerable of the T&E species evaluated with regard to climate change. It is likely that climate change could result in the reduction and extinction of, at least, some of the subpopulations.

F.14.   REFERENCES

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APPENDIX G
EXAMPLE APPLICATIONS OF MODULE 1 – ESTIMATING "BASELINE"
VULNERABILITIES

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES
Species -   Golden-cheeked Warbler (bold scores represent "best estimates" others are alternate scores)

1) Current population size:

		Score
<100	1	
100-500	2	
500-1,000	3	
1,000-10,000	4	
10,000-50,000	5	**5**
>50,000	6	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

2) Population trend in last 50 years:

		Score
>80% reduction	1	
>50% reduction	2	**2**
>20% reduction	3	3
Apparently stable	4	
Increasing	5	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

3) Current population trend:

		Score
rapid decline	1	
slow decline	2	**2**
stable	3	3
increasing	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

4) Range trend in last 50 years

		Score
>80% reduction	1	
>50% reduction	2	2
>20%reduction	3	**3**
apparently stable	4	
increasing	5	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

5) Current range trend:

		Score
rapid reduction	1	
slow reduction	2	**2**
stable	3	
increasing	4	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

6) Main current stressors (narrative)

7) Likely future non-climate stressor trends:

		Score
increase	1	**1**
stable	2	2
reduction	3	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

8) Replacement time for individuals:

		Score
> 5 years	1	
2-5 years	2	
<2 years	3	**3**
<1 year	4	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

9) Likely future vulnerability to stochastic events:

		Score
Highly vulnerable	1	**1**
vulnerable	2	2
not vulnerable	3	
benefiting	4	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

10) Likely future vulnerability to policy/management changes

		Score
Highly vulnerable	1	**1**
vulnerable	2	2
not vulnerable	3	
benefiting	4	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

11) Likely future vulnerability to natural stressors:

		Score
Highly vulnerable	1	
vulnerable	2	**2**
not vulnerable	3	3

Certainty:	high (3)	
	medium (2)	2
	low (1)	

TOTAL SCORE	22 (21 - 28)		**CUMULATIVE CERTAINTY SCORE:**		26
Max. score	42		Max. score	30	
Min. score	10		Min. score	10	

Baseline vulnerability scores:

Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	less vulnerable
Vb4	>33	Least vulnerable

Species score: Vb2 (Vb3)

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES
Species -   Bald Eagle (bold scores represent "best estimates" others are alternate scores)

1) Current population size:		Score		7) Likely future non-climate stressor trends:			Score
<100	1			increase	1		
100-500	2			stable	2		2
500-1,000	3			reduction	3		**3**
1,000-10,000	4						
10,000-50,000	5			Certainty:	high (3)		
>50,000	6	**6**			medium (2)		2
					low (1)		
Certainty	high (3)	3					
	medium (2)						
	low (1)						

2) Population trend in last 50 years:		Score		8 Replacement time for individuals:			Score
>80% reduction	1			> 5 years	1		
>50% reduction	2	**2**		2-5 years	2		**2**
>20% reduction	3	3		<2 years	3		
Apparently stable	4			<1 year	4		
Increasing	5						
				Certainty:	high (3)		3
Certainty:	high (3)	3			medium (2)		
	medium (2)				low (1)		
	low (1)						

3) Current population trend:		Score		9) Likely future vulnerability to stochastic events:			Score
rapid decline	1			Highly vulnerable	1		
slow decline	2			vulnerable	2		
stable	3			not vulnerable	3		**3**
increasing	4	**4**		benefiting	4		
Certainty:	high (3)	3		Certainty:	high (3)		3
	medium (2)				medium (2)		
	low (1)				low (1)		

4) Range trend in last 50 years		Score		10) Likely future vulnerability to policy or management changes			Score
>80% reduction	1						
>50% reduction	2	2					
>20%reduction	3	**3**		Highly vulnerable	1		
apparently stable	4			vulnerable	2		**2**
increasing	5			not vulnerable	3		3
				benefiting	4		
Certainty:	high (3)						
	medium (2)	2		Certainty:	high (3)		
	low (1)				medium (2)		2
					low (1)		

5) Current range trend:		Score		11) Likely future vulnerability to natural stressors:			Score
rapid reduction	1						
slow reduction	2						
stable	3	3		Highly vulnerable	1		
increasing	4	**4**		vulnerable	2		2
				not vulnerable	3		**3**
Certainty:	high (3)	3					
	medium (2)			Certainty:	high (3)		
	low (1)				medium (2)		2
					low (1)		

6) Main current stressors (narrative)

TOTAL SCORE	32 (28 - 34)		**CUMULATIVE CERTAINTY SCORE:**		26
Max. score	42				
Min. score	10		Max. score	30	
			Min. score	10	

Baseline vulnerability scores:

Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	less vulnerable
Vb4	>33	Least vulnerable

Species score: Vb3 (Vb3, Vb4)

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES
Species - Salt marsh harvest mouse (bold scores represent "best estimates" others are alternate scores)

1) Current population size:		Score	**7) Likely future non-climate stressor trends:**			Score
<100	1		increase	1		**1**
100-500	2		stable	2		
500-1,000	3	3	reduction	3		
1,000-10,000	4	**4**				
10,000-50,000	5		Certainty:	high (3)		3
>50,000	6			medium (2)		
				low (1)		
Certainty: high (3)						
medium (2)			**8) Replacement time for individuals:**			Score
low (1)		1	> 5 years	1		

2) Population trend in last 50 years:		Score	2-5 years	2		
>80% reduction	1		<2 years	3		**3**
>50% reduction	2	**2**	<1 year	4		
>20% reduction	3	3				
Apparently stable	4		Certainty:	high (3)		
Increasing	5			medium (2)		2
				low (1)		
Certainty: high (3)						
medium (2)			**9) Likely future vulnerability to**			
low (1)		1	**stochastic events:**			Score

3) Current population trend:		Score	Highly vulnerable	1		**1**
rapid decline	1		vulnerable	2		2
slow decline	2	**2**	not vulnerable	3		
stable	3	3	benefiting	4		
increasing	4					
			Certainty:	high (3)		
Certainty: high (3)				medium (2)		2
medium (2)				low (1)		
low (1)		1				

| | | | **10) Likely future vulnerability to** | | | |
| | | | **policy or management changes** | | | Score |

4) Range trend in last 50 years		Score	Highly vulnerable	1		
>80% reduction	1		vulnerable	2		**2**
>50% reduction	2	**2**	not vulnerable	3		3
>20% reduction	3	3	benefiting	4		
apparently stable	4					
increasing	5		Certainty:	high (3)		
				medium (2)		2
Certainty: high (3)				low (1)		
medium (2)		2				
low (1)			**11) Likely future vulnerability to**			
			natural stressors:			Score

5) Current range trend:		Score	Highly vulnerable	1		
rapid reduction	1		vulnerable	2		2
slow reduction	2	**2**	not vulnerable	3		**3**
stable	3					
increasing	4		Certainty:	high (3)		
				medium (2)		2
Certainty: high (3)				low (1)		
medium (2)		2				
low (1)						

6) Main current stressors (narrative)

TOTAL SCORE		22 (20 - 27)	**CUMULATIVE CERTAINTY SCORE:**			18
Max. score		42				
Min. score		10	Max. score		30	
			Min. score		10	

Baseline vulnerability scores:
Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	less vulnerable
Vb4	>33	Least vulnerable

Species score: **Vb2 (Vb2 - Vb3)**

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES
Species -   Mount Graham red squirrel (bold scores represent "best estimates" others are alternate scores)

1) Current population size:			Score
<100	1		
100-500	2	**2**	
500-1,000	3		
1,000-10,000	4		
10,000-50,000	5		
>50,000	6		

Certainty:	high (3)	3
	medium (2)	
	low (1)	

2) Population trend in last 50 years:			Score
>80% reduction	1		
>50% reduction	2		
>20% reduction	3	**3**	
Apparently stable	4	4	
Increasing	5		

Certainty:	high (3)	
	medium (2)	2
	low (1)	

3) Current population trend:			Score
rapid decline	1		
slow decline	2	2	
stable	3	**3**	
increasing	4		

Certainty:	high (3)	
	medium (2)	2
	low (1)	

4) Range trend in last 50 years			Score
>80% reduction	1		
>50% reduction	2		
>20%reduction	3		
apparently stable	4	**4**	
increasing	5		

Certainty:	high (3)	
	medium (2)	2
	low (1)	

5) Current range trend:			Score
rapid reduction	1		
slow reduction	2		
stable	3	**3**	
increasing	4		

Certainty:	high (3)	
	medium (2)	2
	low (1)	

6) Main current stressors (narrative)

7) Likely future non-climate stressor trends:			Score
increase	1	1	
stable	2	**2**	
reduction	3	3	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

8) Replacement time for individuals:			Score
> 5 years	1		
2-5 years	2	**2**	
<2 years	3		
<1 year	4		

Certainty:	high (3)	3
	medium (2)	
	low (1)	

9) Likely future vulnerability to stochastic events:			Score
Highly vulnerable	1	**1**	
vulnerable	2	2	
not vulnerable	3		
benefiting	4		

Certainty:	high (3)	3
	medium (2)	
	low (1)	

10) Likely future vulnerability to policy or management changes			Score
Highly vulnerable	1	**1**	
vulnerable	2	2	
not vulnerable	3		
benefiting	4		

Certainty:	high (3)	3
	medium (2)	
	low (1)	

11) Likely future vulnerability to natural stressors:			Score
Highly vulnerable	1		
vulnerable	2	2	
not vulnerable	3	**3**	

Certainty:	high (3)	
	medium (2)	
	low (1)	1

	TOTAL SCORE	24 (21 - 28)
	Max. score	42
	Min. score	10

Baseline vulnerability scores:
Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	less vulnerable
Vb	>33	Least vulnerable

Species score: Vb2 (Vb2, Vb3)

CUMULATIVE CERTAINTY SCORE:		**23**
Max. score	30	
Min. score	10	

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES					
Species -	Desert tortoise (bold scores represent "best estimates" others are alternate scores)				

1) Current population size:			Score	7) Likely future non-climate stressor trends:			Score
	<100	1		increase	1	**1**
	100-500	2		stable	2	2
	500-1,000	3		reduction	3	
	1,000-10,000	4				
	10,000-50,000	5	5	Certainty:	high (3)	
	>50,000	6	**6**		medium (2)	2
					low (1)	
Certainty:	high (3)		3			
	medium (2)					
	low (1)			8) Replacement time for individuals:			Score
				> 5 years	1	**1**
2) Population trend in last 50 years:			Score	2-5 years	2	2
	>80% reduction	1		<2 years	3	
	>50% reduction	2	2	<1 year	4	
	>20% reduction	3	**3**			
	Apparently stable	4		Certainty:	high (3)	3
	Increasing	5			medium (2)	
					low (1)	
Certainty:	high (3)		3			
	medium (2)					
	low (1)			9) Likely future vulnerability to stochastic events:			Score
				Highly vulnerable	1	
				vulnerable	2	2
3) Current population trend:			Score	not vulnerable	3	**3**
	rapid decline	1	1	benefiting	4	
	slow decline	2	**2**			
	stable	3		Certainty:	high (3)	3
	increasing	4			medium (2)	
					low (1)	
Certainty:	high (3)		3			
	medium (2)					
	low (1)			10) Likely future vulnerability to policy or management changes			Score
				Highly vulnerable	1	1
4) Range trend in last 50 years			Score	vulnerable	2	**2**
	>80% reduction	1		not vulnerable	3	
	>50% reduction	2	2	benefiting	4	
	>20%reduction	3	**3**			
	apparently stable	4		Certainty:	high (3)	
	increasing	5			medium (2)	2
					low (1)	
Certainty:	high (3)					
	medium (2)		2	11) Likely future vulnerability to natural stressors:			Score
	low (1)			Highly vulnerable	1	
				vulnerable	2	2
5) Current range trend:			Score	not vulnerable	3	**3**
	rapid reduction	1	1			
	slow reduction	2	**2**	Certainty:	high (3)	
	stable	3			medium (2)	2
	increasing	4			low (1)	
Certainty:	high (3)		3			
	medium (2)					
	low (1)					

6) Main current stressors (narrative)

	TOTAL SCORE		26 (18 - 28)		CUMULATIVE CERTAINTY SCORE:		24
	Max. score		36				
	Min. score		9		Max. score	30	
					Min. score	10	
Baseline vulnerability scores:							
	Vb1	<16	Critically vulnerable				
	Vb2	17-22	Highly vulnerable				
	Vb3	23-29	less vulnerable				
	Vb	>29	Least vulnerable				

Species score: **Vb3 (Vb2, Vb3)**

MODULE 1 - CATEGORIZING THE "BASELINE" VULNERABILITIES (Vb) OF T&E SPECIES
Species - Lahontan cutthroat trout (bold scores represent "best estimates" others are alternate scores)

1) Current population size:

		Score
<100	1	
100-500	2	
500-1,000	3	
1,000-10,000	4	
10,000-50,000	5	5
>50,000	6	**6**

Certainty:	high (3)	
	medium (2)	
	low (1)	1

2) Population trend in last 50 years

		Score
>80% reduction	1	1
>50% reduction	2	**2**
>20% reduction	3	
Apparently stable	4	
Increasing	5	

Certainty:	high (3)	3
	medium (2)	
	low (1)	

3) Current population trend:

		Score
rapid decline	1	1
slow decline	2	**2**
stable	3	3
increasing	4	

Certainty:	high (3)	
	medium (2)	
	low (1)	1

4) Range trend in last 50 years

		Score
>80% reduction	1	1
>50% reduction	2	**2**
>20% reduction	3	3
Apparently stable	4	
Increasing	5	

Certainty:	high (3)	
	medium (2)	
	low (1)	1

5) Current range trend

		Score
rapid decline	1	1
slow decline	2	**2**
stable	3	
increasing	4	

Certainty:	high (3)	
	medium (2)	
	low (1)	1

6) main current stressors (narrative)

7) Likely future non-climate stressor trends:

		Score
increase	1	**1**
stable	2	
reduction	3	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

8) Replacement time for individuals:

		Score
>5 years	1	
2-5 years	2	**2**
<2 years	3	3
< 1 year	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

9) Likely future vulnerability to stochastic events:

		Score
highly vulnerable	1	
vulnerable	2	**2**
not vulnerable	3	3
benefiting	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

10) Likely future vulnerability to policy or management changes:

		Score
highly vulnerable	1	
vulnerable	2	**2**
not vulnerable	3	
benefiting	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

11) Likely future vulnerability to natural stressors:

		Score
highly vulnerable	1	
vulnerable	2	**2**
not vulnerable	3	3

Certainty:	high (3)	
	medium (2)	2
	low (1)	

TOTAL SCORE	23 (18-28)		**CUMULATIVE CERTAINTY SCORE:**		17
Max. score	42		Max. score	30	
Min. score	10		Min. score	10	

Baseline vulnerability scores:

Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	Less vulnerable
Vb4	>33	Least vulnerable

Species score: **Vb2 (Vb2, Vb3)**

APPENDIX H
EXAMPLE APPLICATIONS OF MODULE 2 – ESTIMATING VULNERABILITIES TO
CLIMATE CHANGE

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species -   Golden-cheeked warbler (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase: Score
Likely highly sensitive   1   1
Likely moderately sensitive   2   **2**
Likely insensitive   3
likely to benefit   4
Certainty: high (3)
medium (2)
low (1)   1

2) Physiological vulnerability to precipitation change: Score
Likely highly sensitive   1
Likely moderately sensitive   2   2
Likely insensitive   3   **3**
Likely to benefit   4
Certainty: high (3)
medium (2)   2
low (1)

3) Vulnerability to changes in frequency/degree of extreme weather events: Score
Likely highly sensitive   1   **1**
Likely moderately sensitive   2   2
Likely insensitive   3
likely to benefit   4
Certainty: high (3)   3
medium (2)
low (1)

4) Dispersive capability: Score
Low   1
Moderate   2
High   3   **3**
Certainty: high (3)   3
medium (2)
low (1)

5) Degree of habitat specialization: Score
Highly specialized   1   **1**
Moderately specialized   2
Generalist   3
Certainty: high (3)   3
medium (2)
low (1)

6) Likely extent of habitat loss due to climate change
all or most (>50%)   Score
some (20-50%)   1   **1**
no change   2   2
some gain (20-50%)   3
large gain (>50%)   4
          5
Certainty: high (3)
medium (2)
low (1)   2

7) Ability of habitats to shift at same rate as species:
highly unlikely   Score
unlikely   1   **1**
likely   2   2
          3
Certainty: high (3)
medium (2)   3
low (1)

8) Availability of habitat within new range:
none   Score
limited extent   1   **1**
large extent   2   2
          3
Certainty: high (3)
medium (2)   3
low (1)

9) Dependence on temporal inter-relations:
highly dependent   Score
moderately dependent   1   **1**
independent   2   2
          3
Certainty: high (3)
medium (2)
low (1)   2

10) Dependence on other species:
highly dependent   Score
moderately dependent   1   **1**
independent   2   2
          3
Certainty: high (3)
medium (2)   3
low (1)

TOTAL	15 (13 - 21)		CUMULATIVE CERTAINTY SCORE:	25
Max score	35			
Min score	10		Max. score	30
			Min. score	10

Climate change vulnerability scores:
Vc1   <16   Critically vulnerable
Vc2   17-22   Highly vulnerable
Vc3   23-27   Less vulnerable
Vc4   28-32   Least vulnerable
Vc5   >32   Likely to benefit

Species score: Vc1 (Vc1, Vc2)

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species -   Bald Eagle (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	2
Likely insensitive	3	**3**
likely to benefit	4	

Certainty: high (3)
          medium (2)   2
          low (1)

6) Likely extent of habitat loss
due to climate change   Score

all or most (>50%)	1	
some (20-50%)	2	**2**
no change	3	3
some gain (20-50%)	4	
large gain (>50%)	5	

Certainty: high (3)
          medium (2)   2
          low (1)

2) Physiological vulnerability to precipitation change: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	2
Likely insensitive	3	**3**
Likely to benefit	4	

Certainty: high (3)
          medium (2)   2
          low (1)

7) Ability of habitats to shift at same rate
as species: Score

highly unlikely	1	**1**
unlikely	2	2
likely	3	

Certainty: high (3)   3
          medium (2)
          low (1)

3) Vulnerability to change in frequency/degree
of extreme weather events: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	
Likely insensitive	3	**3**
likely to benefit	4	

Certainty: high (3)   3
          medium (2)
          low (1)

8) Availability of habitat within new range: Score

none	1	
limited extent	2	
large extent	3	**3**

Certainty: high (3)
          medium (2)   2
          low (1)

4) Dispersive capability: Score

Low	1	
Moderate	2	
High	3	**3**

Certainty: high (3)   3
          medium (2)
          low (1)

9) Dependence on temporal inter-relations: Score

highly dependent	1	
moderately dependent	2	2
independent	3	**3**

Certainty: high (3)
          medium (2)   2
          low (1)

5) Degree of habitat specialization: Score

Highly specialized	1	
Moderately specialized	2	2
Generalist	3	**3**

Certainty: high (3)
          medium (2)   2
          low (1)

10) Dependence on other species: Score

highly dependent	1	
moderately dependent	2	2
independent	3	**3**

Certainty: high (3)
          medium (2)   2
          low (1)

TOTAL	27 (22 - 29)	
Max score	35	
Min score	10	

Climate change vulnerability scores:

Vc1	<16	Critically vulnerable
Vc2	17-22	Highly vulnerable
Vc3	23-27	Less vulnerable
Vc4	28-32	Least vulnerable
Vc5	>32	Likely to benefit

Species score: Vc3 (Vc2, Vc4)

CUMULATIVE CERTAINTY SCORE:		**23**
Max. score	30	
Min. score	10	

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species -   Salt marsh harvest mouse (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase:		Score	6) Likely extent of habitat loss due to climate change			Score
Likely highly sensitive	1		all or most (>50%)	1		**1**
Likely moderately sensitive	2	2	some (20-50%)	2		2
Likely insensitive	3	**3**	no change	3		
likely to benefit	4		some gain (20-50%)	4		
			large gain (>50%)	5		
Certainty: high (3)						
medium (2)			Certainty: high (3)			
low (1)		1	medium (2)			2
			low (1)			

2) Physiological vulnerability to precipitation change:		Score				
Likely highly sensitive	1					
Likely moderately sensitive	2	**2**	7) Ability of habitats to shift at same rate			Score
Likely insensitive	3	3	as species:			
Likely to benefit	4		highly unlikely	1		**1**
			unlikely	2		2
Certainty: high (3)			likely	3		
medium (2)						
low (1)		1	Certainty: high (3)			
			medium (2)			2
			low (1)			

3) Vulnerability to change in frequency/degree of extreme weather events:		Score	8) Availability of habitat within new range:			Score
Likely highly sensitive	1	**1**	none	1		
Likely moderately sensitive	2		limited extent	2		**2**
Likely insensitive	3		large extent	3		
likely to benefit	4					
Certainty: high (3)			Certainty: high (3)			3
medium (2)		2	medium (2)			
low (1)			low (1)			

4) Dispersive capability:		Score	9) Dependence on temporal inter-relations:			Score
Low	1	**1**	highly dependent	1		
Moderate	2		moderately dependent	2		
High	3		independent	3		**3**
Certainty: high (3)		3	Certainty: high (3)			
medium (2)			medium (2)			
low (1)			low (1)			1

5) Degree of habitat specialization:		Score	10) Dependence on other species:			Score
Highly specialized	1	**1**	highly dependent	1		
Moderately specialized	2		moderately dependent	2		
Generalist	3		independent	3		**3**
Certainty: high (3)		3	Certainty: high (3)			
medium (2)			medium (2)			
low (1)			low (1)			1

	TOTAL	18 (17 - 21)		CUMULATIVE CERTAINTY SCORE:	19
	Max score	35			
	Min score	10		Max. score	30
				Min. score	10

Climate change vulnerability scores:

	Vc1	<16	Critically vulnerable
	Vc2	17-22	Highly vulnerable
	Vc3	23-27	Less vulnerable
	Vc4	28-32	Least vulnerable
	Vc5	>32	Likely to benefit

Species score: Vc2 (Vc2)

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species -   Mount Graham red squirrel (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase:		Score	6) Likely extent of habitat loss			
			due to climate change			Score
Likely highly sensitive	1		all or most (>50%)	1		1
Likely moderately sensitive	2	**2**	some (20-50%)	2		**2**
Likely insensitive	3	3	no change	3		
likely to benefit	4		some gain (20-50%)	4		
			large gain (>50%)	5		
Certainty: high (3)						
medium (2)		2	Certainty: high (3)			
low (1)			medium (2)			2
			low (1)			

2) Physiological vulnerability to precipitation change:		Score				
Likely highly sensitive	1					
Likely moderately sensitive	2	**2**	7) Ability of habitats to shift at same rate			
Likely insensitive	3	3	as species:			Score
Likely to benefit	4		highly unlikely	1		**1**
			unlikely	2		2
Certainty: high (3)			likely	3		
medium (2)		2	Certainty: high (3)			3
low (1)			medium (2)			
			low (1)			

3) Vulnerability to change in frequency/degree of extreme weather events:		Score	8) Availability of habitat within new range:			Score
Likely highly sensitive	1	**1**	none	1		**1**
Likely moderately sensitive	2	2	limited extent	2		
Likely insensitive	3		large extent	3		
likely to benefit	4					
Certainty: high (3)			Certainty: high (3)			3
medium (2)		2	medium (2)			
low (1)			low (1)			

4) Dispersive capability:		Score	9) Dependence on temporal inter-relations:			Score
Low	1	**1**	highly dependent	1		
Moderate	2		moderately dependent	2		2
High	3		independent	3		**3**
Certainty: high (3)		3	Certainty: high (3)			
medium (2)			medium (2)			2
low (1)			low (1)			

5) Degree of habitat specialization:		Score	10) Dependence on other species:			Score
Highly specialized	1	**1**	highly dependent	1		
Moderately specialized	2		moderately dependent	2		2
Generalist	3		independent	3		**3**
Certainty: high (3)		3	Certainty: high (3)			
medium (2)			medium (2)			2
low (1)			low (1)			

TOTAL	17 (14 - 21)		CUMULATIVE CERTAINTY SCORE:	24
Max score	35			
Min score	10		Max. score	30
			Min. score	10

Climate change vulnerability scores:

Vc1	<16	Critically vulnerable
Vc2	17-22	Highly vulnerable
Vc3	23-27	Less vulnerable
Vc4	28-32	Least vulnerable
Vc5	>32	Likely to benefit

Species score: Vc2 (Vc1, Vc2)

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species -   Desert tortoise (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	**2**
Likely insensitive	3	3
likely to benefit	4	

Certainty: high (3)
                 medium (2)   2
                 low (1)

2) Physiological vulnerability to precipitation change: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	**2**
Likely insensitive	3	3
Likely to benefit	4	

Certainty: high (3)
                 medium (2)
                 low (1)   1

3) Vulnerability to change in frequency/degree of extreme weather events: Score

Likely highly sensitive	1	
Likely moderately sensitive	2	**2**
Likely insensitive	3	
likely to benefit	4	

Certainty: high (3)
                 medium (2)   2
                 low (1)

4) Dispersive capability: Score

Low	1	**1**
Moderate	2	
High	3	

Certainty: high (3)   3
                 medium (2)
                 low (1)

5) Degree of habitat specialization: Score

Highly specialized	1	
Moderately specialized	2	**2**
Generalist	3	

Certainty: high (3)   3
                 medium (2)
                 low (1)

6) Likely extent of habitat loss due to climate change   Score

all or most (>50%)	1	
some (20-50%)	2	**2**
no change	3	3
some gain (20-50%)	4	
large gain (>50%)	5	

Certainty: high (3)
                 medium (2)   2
                 low (1)

7) Ability of habitats to shift at same rate as species: Score

highly unlikely	1	
unlikely	2	2
likely	3	**3**

Certainty: high (3)
                 medium (2)   2
                 low (1)

8) Availability of habitat within new range: Score

none	1	1
limited extent	2	**2**
large extent	3	

Certainty: high (3)
                 medium (2)   2
                 low (1)

9) Dependence on temporal inter-relations: Score

highly dependent	1	**1**
moderately dependent	2	2
independent	3	

Certainty: high (3)
                 medium (2)   2
                 low (1)

10) Dependence on other species: Score

highly dependent	1	
moderately dependent	2	**2**
independent	3	3

Certainty: high (3)
                 medium (2)   2
                 low (1)

TOTAL	19 (17 - 24)	
Max score	35	
Min score	10	

Climate change vulnerability scores:

Vc1	<16	Critically vulnerable
Vc2	17-22	Highly vulnerable
Vc3	23-27	Less vulnerable
Vc4	28-32	Least vulnerable
Vc5	>32	Likely to benefit

Species score: Vc2 (Vc2, Vc3)

CUMULATIVE CERTAINTY SCORE:		**21**
Max. score	30	
Min. score	10	

MODULE 2 - CATEGORIZING THE VULNERABILITIES OF T&E SPECIES TO CLIMATE CHANGE (Vc)
Species - Lahontan cutthroat trout (bold scores represent "best estimates" others are alternate scores)

1) Physiological vulnerability to temperature increase:

		Score
Likely highly sensitive	1	**1**
Likely moderately sensitive	2	2
Likely insensitive	3	
Likely to benefit	4	

Certainty: High (3)
medium (2)   2
low (1)

2) Physiological vulnerability to precipitation change:

		Score
Likely highly sensitive	1	1
Likely moderately sensitive	2	**2**
Likely insensitive	3	
Likely to benefit	4	

Certainty: High (3)
medium (2)   2
low (1)

3) Vulnerability to change in frequency/degree of extreme weather events:

		Score
Likely highly sensitive	1	
Likely moderately sensitive	2	**2**
Likely insensitive	3	3
Likely to benefit	4	

Certainty: High (3)
medium (2)
low (1)   1

4) Dispersive capability:

		Score
Low	1	**1**
Moderate	2	
High	3	

Certainty: High (3)   3
medium (2)
low (1)

5) Degree of habitat specialization:

		Score
Highly specialized	1	
Moderately specialized	2	**2**
Generalist	3	

Certainty: High (3)
medium (2)   2
low (1)

6) Likely extent of habitat loss due to climate change:

		Score
all or most (>50%)	1	**1**
some (20-50%)	2	2
no change	3	
some gain (20-50%)	4	
large gain (>50%)	5	

Certainty: High (3)
medium (2)
low (1)   1

7) Ability of habitats to shift at same rate as species:

		Score
highly unlikely	1	**1**
unlikely	2	2
likely	3	

Certainty: High (3)
medium (2)   2
low (1)

8) Availability of habitat within new range:

		Score
none	1	
limited extent	2	**2**
large extent	3	

Certainty: High (3)
medium (2)   2
low (1)

9) Dependence on temporal inter-relations:

		Score
highly dependent	1	
moderately dependent	2	**2**
independent	3	

Certainty: High (3)
medium (2)
low (1)   1

10) Dependence on other species:

		Score
highly dependent	1	
moderately dependent	2	**2**
independent	3	3

Certainty: High (3)
medium (2)   2
low (1)

TOTAL   16 (15-21)

Max score   35
Min score   10

Climate change vulnerability scores:

Vc1	<16	Critically vulnerable
Vc2	17-22	Highly vulnerable
Vc3	23-27	Less vulnerable
Vc4	28-32	Least vulnerable
Vc5	>32	Likely to benefit

Species score: Vc2 (Vc1, Vc2)

CUMULATIVE CERTAINTY SCORE: **18**

Max.score   30
Min. score   10

APPENDIX I
EXAMPLE APPLICATIONS OF MODULE 3 – ESTIMATING OVERALL VULNERABILITY SCORES

Species: Golden-cheeked Warbler (bold and italics show "best estimate" and "alternate" scores, respectively

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	**Vo1**	*Vo1*	Vo2
Vc2	Vo1	Vo1	*Vo2*	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: **Vo1 (Vo2)**

Species: Bald eagle (bold and italics show "best estimate" and "alternate" scores, respectively

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	Vo1	*Vo2*	Vo3
Vc3	Vo1	Vo2	**Vo3**	Vo4
Vc4	Vo1	Vo2	Vo3	*Vo4*
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: **Vo3 (Vo2, Vo4)**

Species: Salt marsh harvest mouse (bold and italics show "best estimate" and "alternate" scores, respectively

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	**Vo1**	*Vo2*	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: **Vo1 (Vo1, Vo2)**

Species: **Mount Graham red squirrel (bold and italics show "best estimate" and "alternate" scores, respectively**

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	*Vo1*	Vo2	Vo3
Vc2	Vo1	**Vo1**	*Vo2*	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: Vo1 (Vo1, Vo2)

Species: **Desert tortoise (bold and italics show "best estimate" and "alternate" scores, respectively**

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	*Vo1*	**Vo2**	Vo3
Vc3	Vo1	Vo2	*Vo3*	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: Vo2 (Vo1, Vo3)

Species: Lahontan cutthroat trout (bold and italics show "best estimate" and "alternate" scores, respectively

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	*Vo1*	Vo2	Vo3
Vc2	Vo1	**Vo1**	*Vo2*	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1 - Critically Vulnerable
Vo2 - Highly Vulnerable
Vo3 - Less Vulnerable
Vo4 - LeastVulnerable

Species score: Vo1 (Vo1, Vo2)

APPENDIX J
EXAMPLE APPLICATIONS OF MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: **Golden-cheeked warbler**

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	26	25	51

Certainty Score - High

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: **Bald eagle**

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	26	23	49

Certainty Score - High

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: **Salt marsh harvest mouse**

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	18	19	37

Certainty Score - Medium

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: **Mount Graham red squirrel**

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	23	24	47

Certainty Score - High

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: **Desert tortoise**

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	24	21	45

Certainty Score - Medium

MODULE 4 - CERTAINTY/UNCERTAINTY ANALYSIS
Species: Lahontan cutthroat trout

	Max. Scores	Min. Scores
Module 1	30	10
Module 2	30	10
Both Modules	60	20

Total Score	Certainty Evaluation
20-32	Low
33-45	Medium
>45	High

	Module 1	Module 2	Both
Total score	17	18	35

Certainty Score - Medium