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Review

Incorporating Climate Uncertainty into Conservation Planning for Wildlife Managers

Jennifer L. Wilkening [1,*], Dawn Robin Magness [2], Anita Harrington [3], Kurt Johnson [3], Scott Covington [4] and Jennie Ruth Hoffman [5]

1 U.S. Fish and Wildlife Service, National Wildlife Refuge System, Natural Resource Program Center, Fort Collins, CO 80525, USA
2 U.S. Fish and Wildlife Service, Kenai National Wildlife Refuge, Soldotna, AK 99669, USA; dawn_magness@fws.gov
3 U.S. Fish and Wildlife Service, Science Applications, 5275 Leesburg Pike, Falls Church, VA 22041, USA; anita_harrington@fws.gov (A.H.); kurt_johnson@fws.gov (K.J.)
4 U.S. Fish and Wildlife Service, National Wildlife Refuge System, 5275 Leesburg Pike, Falls Church, VA 22041, USA; scott_covington@fws.gov
5 Adaptation/Insight, Poulsbo, WA 98370, USA; jennie@adaptationinsight.com
* Correspondence: jennifer_wilkening@fws.gov

Abstract: The U.S. Fish and Wildlife Service (USFWS) is one of the oldest conservation organizations in the United States and is the only federal agency solely charged with conserving fish, wildlife, plants and their habitats. The agency leads numerous conservation initiatives, such as protecting and recovering endangered species, managing almost 600 wildlife refuges throughout all states and territories, enforcing federal wildlife laws, and regulating international wildlife trade. In the past, these activities have not accounted for climate change. The accelerating biodiversity crisis, in combination with climate uncertainty, adds to the existing complexity associated with responding to multiple anthropogenic stressors. Here we describe current practice and thinking related to climate uncertainty and management of USFWS resources. We focus on three agency domains which represent various conservation planning responsibilities: evaluating species to be listed as threatened or endangered, Habitat Conservation Plans for listed species, and land management techniques on wildlife refuges. Integrating climate considerations into agency planning documents is complex and we highlight effective current applications and suggest future improvements. Additionally, we identify outstanding research needs or management applications, and updates to existing policy that will aid in developing improved conservation strategies. Our synthesis contributes to ongoing efforts to incorporate climate uncertainty into conservation planning, natural resource management, and related policy revisions.

Keywords: climate change; wildlife conservation; protected areas; habitat conservation plans; species status assessments; nature-based solutions; scenario planning; climate refugia; natural resource policy; ecological uncertainty; Endangered Species Act

Citation: Wilkening, J.L.; Magness, D.R.; Harrington, A.; Johnson, K.; Covington, S.; Hoffman, J.R. Incorporating Climate Uncertainty into Conservation Planning for Wildlife Managers. *Earth* **2022**, *3*, 93–114. https://doi.org/10.3390/earth3010007

Academic Editors: Terri Schulz and Timothy Kittel

Received: 7 December 2021
Accepted: 10 January 2022
Published: 17 January 2022

1. Introduction

Rich in wildlife and other natural resources, exploration of North America by Europeans was motivated in large part by opportunities to capitalize on the vast natural wealth. Early explorers in 1497 found a land that "is full of white bears, and stags far greater than ours. It yields plenty of fish, and those very great, as seals" [1]. Although Native Americans had been living sustainably on the landscape for generations, European colonization across the continent was fueled by resource exploitation which unsurprisingly resulted in the disappearance of many wildlife species. As early as 1650, North American beavers (*Castor canadensis*) had been largely eliminated from the entire east coast of the modern United States due to excessive trapping [2]. Species extinctions followed as evidenced by the well-known example of the Passenger Pigeon (*Ectopistes migratorius*), which was reduced from a population size of billions to a single individual that died in the Cincinnati Zoo in 1914 [3]. Likewise, herds of American bison (*Bison bison*) estimated to have numbered 30 million were systematically slaughtered throughout the 1800s with only 540 individuals remaining by 1886 [4]. The demise of such previously abundant species prompted public outcry and contributed to the creation of federal legislation designed to conserve wildlife. These regulations include the Lacey Act of 1900, the Migratory Bird Treaty Act of 1918, the Migratory Bird Hunting and Conservation Stamp Act of 1934, and the Federal Aid in Wildlife Restoration Act of 1937. Increasing public awareness about unchecked exploitation also resulted in the first federal lands dedicated to wildlife preservation, when President Ulysses S. Grant set aside the Pribilof Islands in 1868 to protect the northern fur seal (*Callorhinus ursinus*) [5]. Another conservation milestone was the establishment of the Division of Economic Ornithology and Mammalogy in 1886, one of the federal agencies that would eventually become the United States Fish and Wildlife Service (USFWS).

Today, the USFWS employs approximately 8000 people comprised of diverse professions such as scientists, administrators, communication specialists, managers, policy analysts, and law enforcement officers. The agency is part of the Department of the Interior, which collectively manages more than 200 million hectares (500 million acres) of public lands, roughly one-fifth of the land in the United States. USFWS is the only federal agency dedicated solely to the conservation, protection, and restoration of fish and wildlife resources. The agency relies heavily on partnerships with other entities (e.g., other agencies, non-profit organizations, private landowners) to achieve its conservation mission. Primary responsibilities include protecting threatened and endangered species, managing migratory birds, administering the National Wildlife Refuge System (NWRS), enforcing fish and wildlife conservation laws, promoting international conservation efforts, restoring aquatic species and habitats, and disbursing funding and technical assistance to states, territories, and tribal nations.

On a global scale, conservation efforts have been successful at preventing new species extinctions for some taxonomic groups [6–8] and stabilizing threatened populations [9]. Similarly, designated protected areas currently cover 15.3% of the Earth's terrestrial surface [10], which function to reduce biodiversity loss from habitat conversion [11] and hunting [12]. Comparable legal protections have led to increased species population size(s) or other positive demographic trends [13] and invasive species eradication efforts have enabled the recovery of many island species [14]. The human footprint continues to expand, however, with an estimated 3.2 billion more people on the planet by 2060, a roughly 40% increase in human population size [15]. Accordingly, biodiversity continues to decline with species extinction rates currently tens to hundreds of times higher than the average across the past ten million years [16–19] and deterioration of natural systems is projected to accelerate [20]. Fish, wildlife, and other natural resources remain threatened by numerous anthropogenic stressors including habitat loss and degradation, invasive species, overexploitation, lack of enforcement in protected areas, nonnative disease, and pollution [21].

Additionally, climate change has emerged over the last few decades as an increasingly pernicious threat to global ecosystems and biodiversity [17,22]. Climate change has been identified as a primary driver behind range shifts and species decline or localized extirpations [23–25]. Many extant species have persisted through past climate fluctuations by migrating, but this may not be possible given the velocity of projected change and existing habitat fragmentation [26]. Addressing the effects of climate change is crucial to biodiversity conservation as extinction risk becomes magnified by synergistic effects associated with climate change and other anthropogenic stressors [27,28]. Although climate change effects are now widely recognized by USFWS practitioners, incorporation of this threat, and particularly climate uncertainty, into conservation planning efforts remains challenging.

Here we describe current methods and ongoing issues associated with inclusion of climate change considerations into USFWS conservation actions. We begin by explaining how wildlife management and conservation are challenged by uncertainties in climate projections and social and ecological system response. Then, we outline current techniques utilized to address climate uncertainty for two frequently conducted USFWS conservation efforts, Species Status Assessments (SSAs) and Habitat Conservation Plans (HCPs). Next, we discuss land management practices being implemented on USFWS National Wildlife Refuge System (NWRS) properties that can account for climate uncertainty, such as nature-based solutions (NbS) which improve overall landscape resiliency. Finally, we conclude with a review of USFWS program needs and relevant policies and identify areas where future updates may be necessary to account for accelerating climate change. Our review demonstrates a path forward for wildlife managers flummoxed by climate uncertainty and provides insight into natural-resource management planning and decision making.

2. Wildlife Management and Conservation under Climate Uncertainty

Although scientific consensus is almost unanimous that anthropogenic climate change is occurring [29], there is less certainty about the magnitude and extent of changes in climate as well as resulting ecological effects. Uncertainty has been defined differently by various disciplines [30], but generally refers to situations where information is lacking or there is disagreement about what is known. Wildlife managers are commonly grappling with epistemic uncertainty (imperfect knowledge about a system) and ontological uncertainty (inherent variability in systems) [30,31]. Both apply to future climate projections, which are inherently uncertain due to a variety of factors related to the general circulation models which simulate the planet's climate, and the societal components (e.g., emission scenarios, land use change) that provide input into these models [32]. The direction of climate change may be relatively uniform for some factors such as temperature where increases are predicted, but the projected increase in annual average global temperature ranges from 0.4–4.8 °C by the year 2100 [22]. Additionally, extreme events may present unforeseen obstacles to accurately estimating climate change effects. Incorporating such imprecise information into management actions presents a challenge, as managers are often making judgements related to both technical input (e.g., data quality) and societal values (e.g., stakeholder preference) to make consequential decisions about species at risk [33]. However, explicitly identifying the range of plausible climate futures allows for transparent communication about alternative scenarios which helps to increase preparedness in the face of uncertainty [34,35].

The uncertainties related to climate futures have often been evaluated with more rigor than uncertainties associated with species or ecosystem response. Managers consider numerous types of information to assess the ecological effects of climate change and the degree of uncertainty associated with this information may vary widely. For example, basic information about a species' biology (e.g., demographic parameters, physiological tolerance, adaptive capacity) or ecosystem characteristics (e.g., community composition, structure and function) may be lacking, which may be particularly true for rare species or systems that are difficult to study [36]. Climate uncertainty can exacerbate these and other existing unknowns that inform management actions, planning, and decision making (Figure 1). The unknowns about how species or ecosystems may respond to climate change usually contain epistemic uncertainty (e.g., incomplete knowledge about species biology or ecosystem characteristics), therefore crafting management to be nimble to surprises is recommended [37].

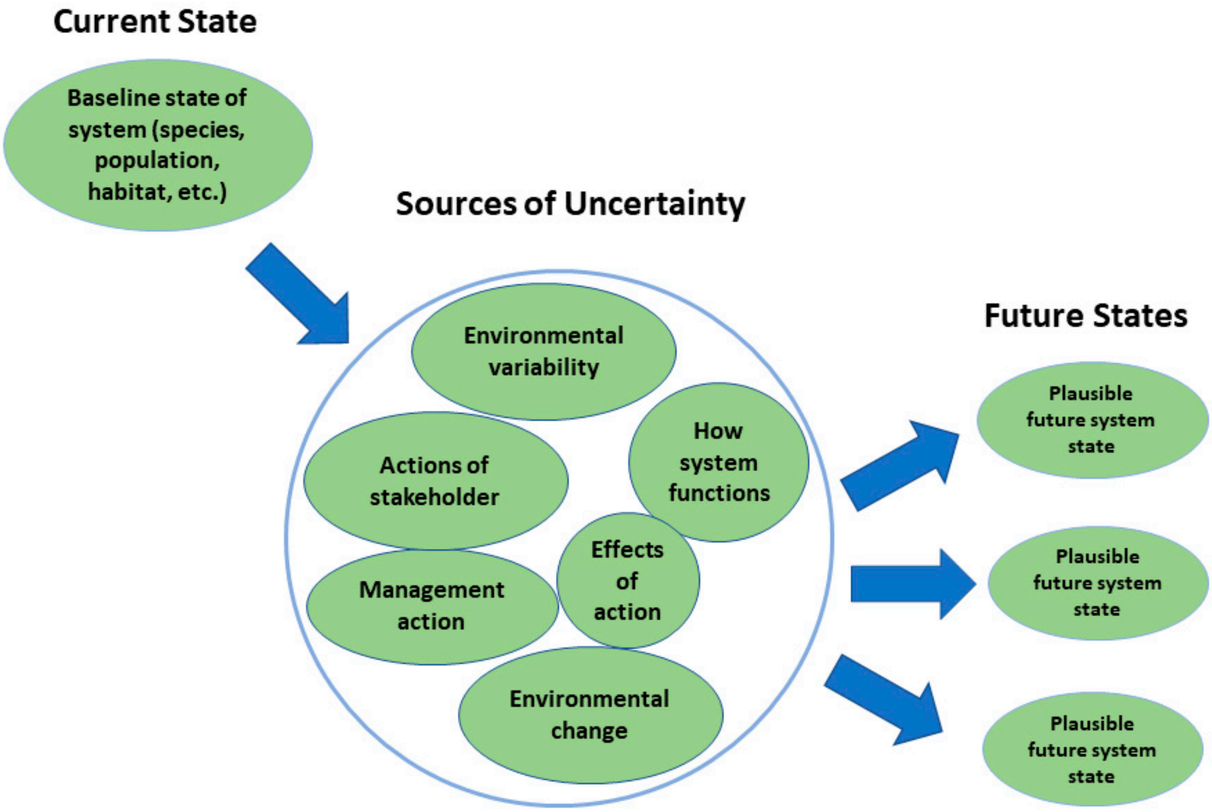

Figure 1. Conceptual diagram illustrating some of the ways uncertainty can come into projections of future system states for ecological systems. There may be initial uncertainty about the current state of a system for many wildlife managers, which may be further complicated by additional uncertainty about management or societal actions and interacting processes, as well as uncertainty about the context and function of multiple plausible future states.

The ecological models used to predict climate change effects on species or systems (e.g., Species Distribution Models, Dynamic Vegetation Models) can also contain a high degree of uncertainty. The choice of ecological response model can be a greater source of uncertainty than choice of climate projection when it comes to magnitude of effects [38]. Future ecological interactions and distributions may be different from the past for a number of reasons, including not just the changing climate but differential responses to that change by species or populations, evolutionary, epigenetic or behavioral adaptation, and introduced species [39,40]. Considering response as a range of plausible ecological trajectories allows alternatives from differing model outputs, methodological approaches, and information sources to be included in planning [41]. Table 1 summarizes sources of uncertainty commonly related to ecological systems that may interact with climate and be important considerations in environmental assessments, effects analyses, or related decision-making documents.

Table 1. Types of uncertainty related to ecological systems pertinent to wildlife managers. Uncertainty related to climate models falls primarily into the structural and parametric categories. Uncertainty related to the effects of climate change falls into all categories. From [42], building on [43,44].

Uncertainty about How the System Works (Epistemic)	
Structural uncertainty	How well we understand the basic structure of the system, i.e., links between environmental conditions and reproduction, habitat quality, etc., or the effects of particular actions. We may know what the basic elements are but remain uncertain about the details or nature of relationships among elements. Structural uncertainty can be reduced by research and monitoring, including testing model predictions, but is never completely eliminated.
Parametric uncertainty	How well we understand the strength of the relationships in our system models. Even if we know which factors are linked to which outcomes, we may be less certain about the strength of those relationships or how they will change under novel conditions. Parametric uncertainty can be reduced through research and monitoring, but is more prone to variation over time and space.
Uncertainty about what the system state is or will be (Ontological)	
Environmental variability	There’s an element of randomness in many natural phenomena. No matter how good our models get, there is an unavoidable level of uncertainty in predicting weather, climate, natural disasters, thresholds, tipping points, etc.
Observation uncertainty	Surveys of current conditions are rarely completely accurate. The amount of error and direction of bias depends on factors such as effort, conditions on the ground, and species characteristics. Monitoring design and effort can reduce observational error and in some cases can provide estimates of error, which allows for more accuracy in the resulting information.
Human behavior	Uncertainty around human behavior has tremendous implications for ecological systems at local and global levels. This may include decisions at individual, corporate, and governmental levels affecting everything from land use and invasive species introduction to greenhouse gas emissions and population growth.
Linguistic uncertainty	
	A number of terms such as “foreseeable future”, ”likely”, and “reasonable certainty”, have been interpreted different ways by different people or been the subject of legal disputes. Recognizing this uncertainty does not resolve it, but it can focus discussion on the true source of uncertainty and lead to efforts such as the IPCC’s formal definitions of verbal uncertainty terms [22].

The large geographic scale of the USFWS jurisdiction can make it challenging to incorporate climate uncertainty, since knowledge gaps may be unevenly distributed throughout states or territories. Ecological and climate uncertainties may be reduced for well-studied ecosystems with abundant data and numerous downscaled climate models, but this may not be the case for more remote regions (e.g., Hawaii, Mariana Islands) or areas with complex microclimates [45]. Wildlife managers typically require data and projections specific to their locale. Efforts can also be stymied by a mismatch in time scales between agency planning cycles (every 5–10 years) and climate projections (20–80 years into the future). Shifting government administrations and priorities may hinder inclusion of climate uncertainty into planning efforts, since the politicization of climate change has resulted in different levels of action depending on which political party has the majority [46]. Inconsistent funding, resistance to funding when scientific uncertainty is high, or the inability to acquire funding may also present barriers. Finally, communicating uncertainty to the public is not easy [47] and managers may delay making critical decisions in order to conduct research or engage in similar information gathering efforts to reduce unknowns associated with options [48].

As the complexity of managing ecosystems has increased with global change and escalating uncertainties, so has the development of tools for management response. For example, approaches to landscape-scale management such as Strategic Habitat Conservation or Landscape Conservation Design, are being utilized to address the root causes of biodiversity loss at large spatial scales and ensure the persistence of entire ecosystems and their components [49]. Strategic Habitat Conservation is an adaptive management framework adopted by the USFWS to address uncertainties associated with future landscape condition, which uses a systematic process to identify priority areas for conservation actions (https://www.fws.gov/science/doc/SHCFactSheet1008pdf.pdf, accessed on 6 January 2022). Similarly, Landscape Conservation Design is used to inform numerous USFWS conservation planning activities including the management and recovery of threatened and endangered species, identification of areas for habitat restoration, and future land acquisition. This partner driven approach integrates scientific information with diverse stakeholder input to protect biodiversity and conserve ecosystem services across large landscapes, while simultaneously promoting resilient, sustainable socio-ecological systems [50]. Landscape Conservation Design is a cornerstone of the USFWS Landscape Conservation Cooperatives, which represented the first formalized effort by a United States federal agency to promote wildlife connectivity and persistence at the continental scale [51]. Another approach frequently used by managers is a Climate Change Vulnerability Assessment, where vulnerability is evaluated based upon exposure, sensitivity, and adaptive capacity [52]. These assessments can be conducted at the species or community level and online tools are available which offer easy to use, repeatable methods that also incorporate measures of uncertainty (e.g., Nature Serve Climate Change Vulnerability Index; https://www.natureserve.org/sites/default/files/guidelines_natureserveclimatechangevulnerabilityindex_r3.02_1_jun_2016.pdf, accessed on 6 January 2022).

Although uncertainty is commonly cited as a barrier to incorporating climate change in natural resource conservation and management, the field of decision making under uncertainty goes back decades, with frameworks, tools, and techniques applied across sectors ranging from warfare to business to conservation. Several approaches to resource management planning under uncertainty with a focus on climate change are summarized in Stein et al. (2014) [53]. We describe a few of these here.

An eminently useful but underapplied approach to decision making under uncertainty is value of information analysis, which asks the question of what it would be worth to reduce a particular uncertainty prior to deciding. For example, Runting et al. (2013) [54] explore the cost-effectiveness of investing in more data or better models when making coastal land acquisition decisions in the face of sea-level rise. Likewise, Rushing et al. (2020) [55] apply a novel qualitative value of information analysis to decisions about federal land acquisition in service of migratory bird conservation. Two related approaches developed specifically to address climate-related uncertainty are decision scaling [56] and Prudhomme et al.'s scenario-neutral framework [57]. Rather than starting with large-scale climate projections and scaling them down to the decision, these approaches start with the decision and scale out to whatever level of climate information is relevant. They grow out of related frameworks including bottom-up [58,59] and robust decision making [60].

Scenario-based planning is a flexible tool that can be used to support both contingency planning and resilience-focused decision-making [34,35]. Qualitative and quantitative information about trends or changes in political, economic, social, technological, legal, or environmental systems (including climate) are used to explore a broad range of plausible futures. By understanding this spectrum of potential future conditions, managers can seek strategies that remain effective across multiple futures or develop contingency plans to react quickly to changing conditions. Additionally, by equally considering all plausible scenarios, including those that may be less likely to occur, managers and stakeholders can engage in conversations about best and worst case situations which may help to prepare for unexpected ecological outliers. Below, we provide specific examples to describe in more detail how USFWS is implementing some of these tools, frameworks, and techniques. We focus on recent examples that incorporate current understanding of climate projections and associated effects and utilize examples from different regions to represent a broad geographic area.

3. Species Status Assessments (SSAs)

One of the primary ways USFWS delivers conservation for imperiled species is through the administration of the United States Endangered Species Act (ESA), which was passed in 1973 [61]. The purpose of the ESA is to protect and recover imperiled species and it has been successful at preventing extinction to date in 99% of the species it protects [62]. The Species Status Assessment (SSA) framework was developed to improve implementation of the ESA. An SSA is an analytical approach reliant upon assessment of a species' needs under both current and future conditions. The assessment incorporates scientific and commercial information related to life history, biology, and future circumstances to determine the ability of the species to persist over time. The SSA applies the conservation biology principles of representation, resiliency, and redundancy to examine species condition and relies upon modeling and decision frameworks to predict extinction risk [63]. The process is designed to be repeatable for every species and transferable across a range of decision-making requirements; thus, a single document can serve as the scientific basis to better inform decisions related to listing, recovery, and permitting [64].

An SSA supplies the scientific information and analysis necessary for ESA determinations but it does not result in a decision directly. This separation of science and recommendation steps allows for more transparent and defensible decisions and is one of the greatest benefits of the framework. SSAs have not been conducted yet for all species currently listed as threatened or endangered, since the framework was only recently endorsed by the USFWS. SSAs have been initiated for all species being considered for future listing, however, and the evaluation process for each species adheres to the consistent standards and procedures that have been developed [64].

An essential component of the SSA framework is the use of a scenario planning analysis to assess future conditions [64]. As stated previously, scenario planning is a type of decision analysis that can be utilized when there is not a high degree of confidence in a potential outcome or the probability of an outcome. Including a broad range of plausible outcomes allows managers to understand the spectrum of potential responses to climate change, and develop strategies robust to that range while also taking note of surprises that may have severe consequences [65]. The development of scenarios engages diverse stakeholders and managers in discussions about potential futures and scenarios in SSAs typically integrate social, economic, and biophysical attributes. The SSA for the coastal marten (*Martes caurina*) exemplifies this; it was initiated to consider whether to designate the species as threatened or endangered under the ESA.

The coastal marten is a medium-size carnivore in the weasel family that inhabits coastal forests of Oregon and northern California. The species has declined historically due to fur trapping and remains threatened primarily by road mortality, rodenticides, disease, wildfire, other vegetation disturbances, and climate change. To evaluate the biological status of the coastal marten currently and into the future, a range of conditions were assessed to consider the species' resiliency, redundancy, and representation. Future viability depended upon risks related to habitat loss and associated changes in habitat quality that might favor competitor species or increase predation on coastal martens, all of which were influenced by vegetation management, wildfire, and climate change (Figure 2).

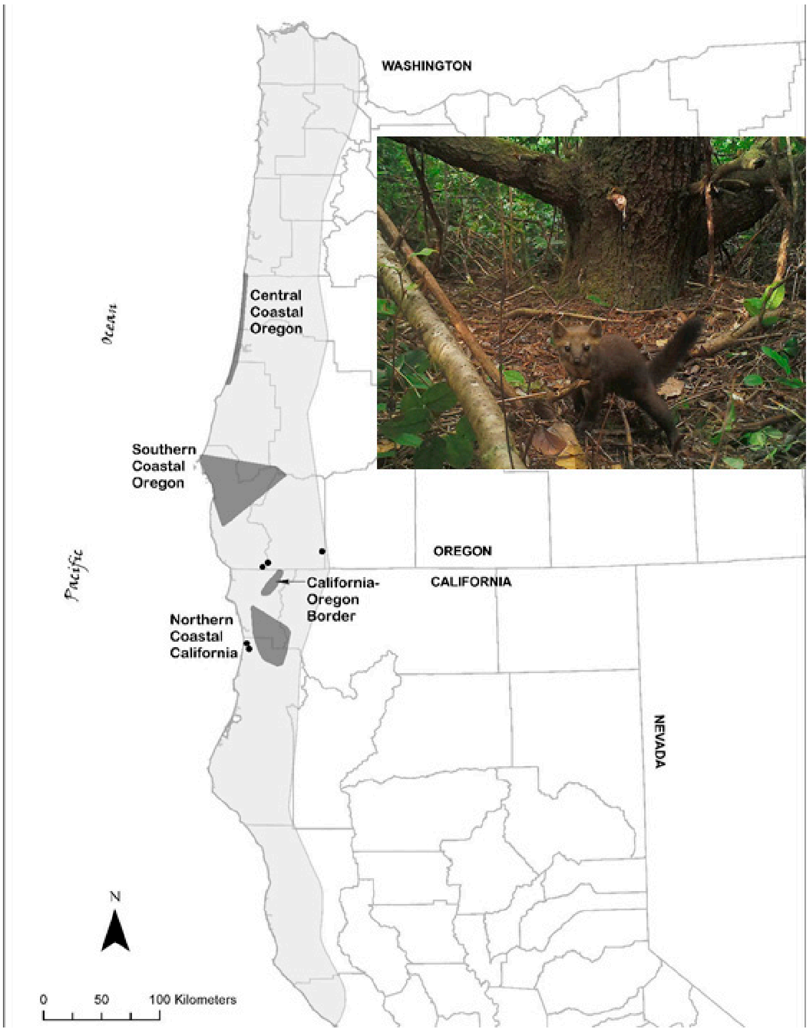

Figure 2. Historical range of the coastal marten indicated by light grey, with the 4 currently extant populations delineated by darker polygons. Black circles indicate single detections that do not constitute a population. Fires have been an important historical disturbance throughout the species' range, as fire creates structural features (e.g., snags, hollow trees, resting platforms, down logs) conducive to suitable habitat. Major fires have traditionally been infrequent [66], however, and more severe fires may eliminate structural features and increase the abundance of predators or competitors, resulting in degraded marten habitat [67,68]. Warmer and drier conditions are projected for this coastal region [69,70], which may lead to more frequent large fires and reduced habitat suitability. Future scenarios incorporated levels of altered fire cycles along with other disturbance regimes influenced by climate change. Map from [71]; photo by U.S. Forest Pacific Northwest Research Station and Oregon State University.

In order to account for climate-related and other uncertainties, three plausible scenarios were developed to assess future species condition. Each scenario incorporated different levels of components believed to influence species viability such as fur trapping, habitat connectivity, habitat loss resulting from wildfire or climate change, timber harvest, and conservation actions [71]. There was substantial uncertainty regarding the impacts of these factors on coastal marten populations; in addition, data availability and reliability varied throughout the species range. Accordingly, managers used scenario planning to determine current status in terms of species resiliency, redundancy, and representation and forecast future conditions for each coastal marten population. Scenarios examined several future time periods (15, 30, and 60 years into the future) and a ranking (high, moderate-high, moderate, moderate-low, low) indicative of population condition was assigned to each of four populations. Scenario 1 portrayed a status quo scenario where current trends related to threats and conservation efforts stayed the same, which resulted in the two Oregon populations in low condition and the two California populations in moderate-low condition (similar to current population status). Scenario 2 reflected a more optimistic scenario where trapping is banned, habitat connectivity is improved, a moderate emission scenario is utilized (RCP 4.5, [22]) and habitat loss from wildfire or climate change is minimized, timber harvest is restricted, and conservation measures are implemented; this resulted in two populations remaining in low condition, one improving to moderate condition, and one improving to moderate-high condition. Scenario 3 depicted a more pessimistic scenario where trapping remains legal, habitat connectivity is low, a high emissions scenario is utilized (RCP 8.5, [22]) leading to increased habitat loss due to fire or climate change, timber harvest is not restricted, and conservation measures are not implemented; this resulted in all populations in low condition, with one potentially extirpated.

Examining a variety of plausible scenarios under a range of future time periods allowed managers to create a risk profile related to species' future viability. Scenario 1 evaluated the species' future condition if there was no change in current threats, while the other two scenarios considered the species' response if there were increases or decreases in the factors influencing coastal marten viability. Collectively, these three scenarios represented a range of future possibilities, which allowed for discussion of multiple plausible outcomes rather than only the most likely. Although the number of scenarios and length of future time period may vary, all SSAs follow a similar approach where best and worst case scenarios are considered. This allows for managers and stakeholders to explicitly identify and discuss reasonable futures, including situations they may want to avoid, regardless of data gaps or incomplete information. Instead of being paralyzed by uncertainty associated with climate and other anthropogenic stressors, managers can move forward in their deliberations and assess how likely it is that a species may persist into the future.

4. Habitat Conservation Plans (HCPs)

Addressing climate change in documents whose purpose is primarily to provide information, such as SSAs, is quite different from addressing it in documents whose content carries the force of law, such as determining the actions a proposed project must take to limit harm to threatened or endangered species to receive the government permits necessary to proceed. These documents lay out decisions and agreements within the legal and regulatorily constraints of the ESA, whose language has been dissected in numerous court cases related to climate change and linguistic uncertainty [72]. For example, a species must be listed as threatened if it is "likely to become endangered within the foreseeable future throughout all or a significant portion of its range", but what constitutes "likely" is not defined. Habitat Conservation Plans (HCPs) must describe how the permit applicant would respond to "changes in circumstances affecting a species or geographic area covered by (an HCP) that can reasonably be anticipated" (50 CFR 17.3) [61], yet what level of certainty is needed for a change to be "reasonably" anticipated to occur is not stated. In 2019, USFWS revised ESA regulations to clarify that the "foreseeable future" extends "only so far into the future as (USFWS) can reasonably determine that both the future threats and the species' responses to those threats are likely", again using terms such as "reasonably" and "likely" that are interpreted in varying ways under different contexts.

Under the ESA, it is unlawful to "take" (defined as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct") a species listed as threatened or endangered (e.g., listed species). USFWS may, however, issue a permit to non-federal entities (e.g., individuals, corporations, state agencies) to harm listed species if it occurs incidentally as a result of otherwise lawful activities. However, to receive such a permit, the non-federal entity must complete an HCP that specifies how proposed activities might affect listed species and their critical habitat, as well as how the permittee will avoid, minimize, and mitigate any negative effects. The motivations to do an HCP are typically to minimize time spent on processes and paperwork, to be able to plan and act without too much risk of surprise roadblocks, and to limit harm to threatened and endangered species. Bringing climate change into the process is a way to decrease the likelihood of unanticipated project disruptions or of having an HCP's conservation objectives derailed by changing conditions. Including climate change in the HCP process decreases the likelihood of permitting unsustainable levels of harm and increases the likelihood that all parties to the permit will be aware of the potential for plan adjustments related to climate change.

Because of the tension among economic development, individual property rights, and limiting harm to endangered species, the development of HCPs can be time-consuming and contentious, often resulting in litigation. When it comes to climate-related uncertainty, much of the debate comes down to the meaning of one phrase or concept: "reasonably foreseeable". The FWS can only require permittees to account for "reasonably foreseeable" conditions and "reasonably certain to occur" effects. Not surprisingly, the meaning of "reasonably foreseeable" and "reasonably certain to occur" has received significant attention in the courts, in regulation, and in permit negotiations.

Because there is so much uncertainty surrounding future climate change and subsequent species' response, accounting for all "reasonably foreseeable" conditions can seem daunting. One option for limiting the potentially large analytic burden is to screen projects for the likely relevance of climate change to the project and species in question.

This focuses climate analysis on the areas of the HCP where climate change is more relevant and helps to scale the amount of effort. If a deeper dive is necessary, it can be more productive to focus on how much change it would take in climatic conditions or species' responses to alter anticipated harm or the cost or effectiveness of proposed minimization or mitigation efforts. Some minimization measures, such as monitoring for the presence of bats near a wind farm and altering wind turbine management when bats are present, can easily respond to changes in the timing or location of bat migration already being observed because of climate change. Other measures, such as locating permanent infrastructure outside of a species' current distribution, would be harder to adjust in response to climate change driven distribution shifts. Recognizing the complexity associated with incorporating climate change into HCPs, USFWS has recently begun developing guidance materials to assist with the process (e.g., Climate Informed HCP website, [73]).

Although HCPs have only recently begun to incorporate climate change in meaningful ways [74], some good precedents have been developed. For example, in southern California the Coachella Valley multispecies HCP includes conservation areas that link with other protected lands to provide an unimpeded elevational transect under the assumption that as the climate changes over time, the availability of this combined area may allow species to undergo climate-induced shifts in habitat. Their approach relied less on quantitative models and more on general trends (e.g., it's getting warmer and drier, and we know it's cooler at higher elevations). They also designed reserves to include areas that could act as climate refugia, and conserved areas covering the range of climate conditions a given species currently inhabits. The Santa Clara Valley HCP in central California included climate change in its conservation framework and strategy. Rather than focusing on detailed assessments of climatic changes and implications for covered species and activities, this HCP applies general principles of climate adaptation and resilience, such as fully representing environmental gradients in the reserve system and maintaining or enhancing landscape connectivity and permeability. By including diverse habitats with high connectivity in conservation plans, these approaches allow managers to maximize chances of conservation success under climate uncertainty.

5. Nature-Based Solutions (NbS)

In the past, the protective services that ecosystems provided (e.g., wave attenuation, flood control) in coastal environments were undervalued. People often preferred a hardened engineered approach (e.g., sea wall, breaks constructed from concrete) to protect communities from violent storms such as hurricanes or massive floods [75]. With increased knowledge of how natural systems can provide similar benefits to hardened structures, interest in natural alternatives grew. These natural alternatives can be grouped into a collection of strategies called nature-based solutions (NbS). NbS can be defined as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (https://www.iucn.org/theme/nature-based-solutions/about, accessed on 6 January 2002). Examples of NbS in coastal environments include living shorelines, oyster reefs, bioswales, and thin layer application of dredge materials; these features absorb or dissipate energy, filter nutrients and sequester carbon [76]. In this section, we focus on coastal or flood prone environments to explore what NbS are, suggest future research needed to facilitate increased use and improved implementation of NbS, discuss how NbS can improve USFWS response to climate uncertainty, and describe existing examples of NbS on lands managed by the USFWS.

NbS build climate resiliency by improving a system's response to climate perturbations using components already present, or previously available within the system such as sediment, rock, and vegetation [76]. Because these building blocks are present, NbS can often recover from disturbance without human intervention (i.e., vegetation can re-grow after a flood event, sediment is transported and re-arranged). This improves the cost-benefit of NbS projects in comparison to hardened infrastructure using artificial materials (e.g., concrete), which deteriorate over time and eventually fail. NbS can be designed to continue to recruit new sediment and biomass sources growing dynamically through time, especially when projects are engineered to leverage natural processes (e.g., using the hydrology of a system to transport sediment to a specific location).

NbS mimic natural processes and can provide many co-benefits [77]. For example, using NbS restores natural processes, which in turn can offer food (e.g., fish, shellfish, waterfowl), raw materials, and other natural resources. Additional co-benefits may include coastal protection by absorbing wave action and dissipating storm surge energy (Figure 3A), water purification and supply, and carbon sequestration through vegetative growth. Finally, NbS can also preserve unique landscapes of cultural, historical, or spiritual significance, provide nurseries for fish and wildlife (Figure 3B), and maintain habitats that many communities rely on for their economic viability (e.g., recreational activities like kayaking, wildlife observation, fishing, and hunting) [78].

While interest in NbS has grown, there remains uncertainty about the degree to which these strategies reduce impacts from environmental perturbations. Additional research is needed to better define and improve the selection of metrics and indicators to monitor the effectiveness of specific NbS strategies. For example, a hybrid approach may improve the overall performance of a project (e.g., armoring a marsh's perimeter with concrete prior to a thin layer application to "hold" the dredged soil in place), but it compromises the ability to evaluate the NbS aspect. Another issue is that engineers may be hesitant to permit NbS projects since success is not guaranteed when trying new techniques, risking professional credentials if a project was to fail. Encouraging engineers to work with ecologists, hydrologists, and other local specialists to ensure a breadth of expertise when designing projects may increase chances of success, particularly where climate uncertainty is high. Unknowns related to project cost can also be a barrier to implementation. While NbS initial project cost may be low compared to hardened structures, NbS may require periodic maintenance to ensure structures are performing as designed (e.g., may need to bolster specific areas of a project that are experiencing unexpected high erosion rates), which increases project cost and uncertainty surrounding the long-term effectiveness. Proponents of NbS need additional research on the specific applicability (e.g., what, when and where to deploy NbS), design standards (e.g., engineering, hydraulic, economic cost-benefit considerations), and duration of a project's effectiveness (i.e., compared to a hardened structure). Finally, and most importantly, determining the overall effectiveness of NbS to alleviate climate impacts remains largely unstudied. Specifically, there are substantial opportunities and needs to evaluate the ecological, economic, engineering, and social costs and benefits of NbS strategies.

Figure 3. Salt marsh systems, shown here at E.B. Forsythe NWR in New Jersey (**A**), provide important coastal habitat for wildlife such as Piping Plovers (**B**) and also offer storm protection for seaside human communities. Many NWRs along the eastern coast of the United States utilize NbS to make areas more resilient to climate change, such as this oyster reef constructed at J.H. Chafee NWR in Rhode Island (**C**) and living shoreline at Eastern Neck NWR in Maryland (**D**). NbS can also address climate uncertainty since they expand over time and are capable of responding to unanticipated changes. Photo credits: (**A**,**C**), Lia McLaughlin/USFWS; (**B**), USFWS; (**D**), Alexander Jonesi/Chesapeake Bay Program.

To illustrate how NbS are being implemented to address climate uncertainties, we highlight the efforts of the National Wildlife Refuge System (NWRS). The NWRS dates to 1903, with the establishment of the Pelican Island National Wildlife Refuge (NWR). Since its inception, the NWRS has grown to 568 individual units spanning all states and territories covering over 60 million hectares (150 million acres) [79] managed as a "network of federal lands and waters designated to sustain healthy ecosystems" [5]. Over 180 NWRs lie along United States coastal regions (Figure 3) and all are affected in some way by climate change. For example, Archie Carr NWR in Florida, whose focus is on preserving beach habitat for sea turtles, is losing habitat due to sea level rise and the associated erosional processes. While the habitat currently remains intact, there is considerable uncertainty regarding the length of time it will remain functional. Likewise, over 50% of Racoon Key at Cape Romain NWR has been lost to erosion and sea level rise in the past 50 years [80]. Volunteers are needed to uncover sea turtle nests that have been buried as erosion and sea level rise have impacted many of the islands, leaving high banks that collapse on the nests. The problem is not just found on the United States eastern coast; other NWRs are slowly being inundated by the sea [81], such as Seal Beach NWR in California. This NWR is trying to maintain marsh habitat by using NbS techniques such as thin layer deposition, where dredge materials are applied in small increments across the marsh area to add elevation [82].

Unless action is taken, the NWRS will continue to lose important coastal habitats, and the species that depend on them such as the recently listed Eastern Black Rail (*Laterallus jamaicensis jamaicensis*). This secretive marsh bird relies on high quality marsh habitat, and primary factors for its listing include "habitat loss and destruction, sea level rise and tidal flooding, incompatible land management, and increasing storm intensity and frequency" [83]. Many of the Atlantic coastal NWRs are dominated by marsh habitat, with potential use by the rail. These habitats also provide human co-benefits (Figure 3A) such as storm attenuation by absorbing the energy from these events [84]. However, if a marsh is sediment starved (i.e., cut off from the sediment source by a road or housing development) as sea level rises, the stress of frequent inundation can weaken vegetation to the point that it succumbs and dies [85]. When this occurs, erosion rapidly transforms a marsh into a mud flat and eventually open water [86]. Not only does wildlife lose habitat (Figure 3B), but the provided ecosystem services are also lost.

To address the loss of important habitat while focusing on natural solutions, many coastal NWRs are increasingly implementing NbS. There are many reasons to consider NbS over hardened infrastructure, but one of the most important considerations is cost [87]. NbS offer protection at a fraction of the cost of hardened structure. Habitat manipulations, including barrier islands, oyster reefs (Figure 3C), or living shorelines (Figure 3D), require few hardened structures (e.g., concrete) tied to foundations. Mobilizing concrete for hardened structures is expensive; in contrast, moving sediment and sand is comparably inexpensive and planting vegetation and bagging oyster shells can often be achieved with volunteer groups. NbS grow through time to restore and sustainably maintain ecosystem services. Unlike a concrete sea wall, a living shoreline's vegetation will grow and provide improved wave attenuation through time, while sequestering carbon in the sediments, root stocks, and aboveground vegetation (Figure 3D). Oyster reefs, once established, will grow wider and taller, reducing shoreline erosion impacts and providing improved nutrient filtration through time (Figure 3C).

Following the devastation of Hurricane Sandy in 2012, Prime Hook NWR applied a NbS approach by restoring a marsh and beach section on a barrier island in Delaware Bay. In 2015, the refuge broadened the beach using medium to coarse sand (with gravel) and removed high dunes to better absorb wave action, reduce erosion potential, and encourage washover (i.e., lowering the impediments to waves that can top the island). The restoration project has subsequently weathered several large storms. Since its construction, the 0.8 km wider beach now is nearing equilibrium with the regional sediment transport and maintaining its intended geometry; wave energy is attenuated, and sediment drops out by the time the wave crests the top of the beach.

Wildlife has also benefited from the restoration. Immediately following completion of the project in 2016, a pair of federally threatened Piping Plovers (*Charadrius melodusi*, Figure 3B), which had never nested on the refuge before, established a nest. This also represented the first known breeding of Piping Plovers on the Delaware Bay shoreline, as they typically nest along the Atlantic Ocean coast. Since then, the breeding population has increased each year to a peak of 18 pairs in 2021. The population has exceeded target recovery productivity almost every year. In addition, Least Terns (*Sternula antillarum*), which had also never nested on the NWR, began using the area and 70 nested pairs have been documented.

While NbS typically find wide application in natural environments, they also have broad applicability in urban settings (e.g., bioswales that intercept and filter runoff, permeable pavement that allows infiltration and slows runoff) [88]. For example, the town of Frederick, Maryland used hardened infrastructure in conjunction with NbS to address flooding of Carroll Creek that flows through its downtown. In the past, the creek was channelized, and downtown buildings were constructed in the 100-year floodplain. Due to ongoing flood issues, the city established a commission to evaluate options to remediate the flood risks. In addition to installing concrete conduits under the town, the town implemented NbS practices by restoring the creek's access to the floodplain, relocating existing structures, and creating a park in their place. Now, the creek can overtop its banks during flooding, filling the park which slowly releases floodwater into the conduits that flow out of town.

Natural resource managers around the world are utilizing NbS and these features provide co-benefits to biodiversity on a global scale [17]. NbS may contribute up to 37% of climate change mitigation needed to meet the global goal of restricting warming to 2 °C by 2030 [17]. In order to increase implementation of NbS on NWRs, more monitoring and evaluation is needed that compares the hardened and hybrid approaches in relation to cost, ecological resilience, and capacity to address community needs. NbS may make the most sense when multiple objectives can be met, such as using this approach to restore wildlife habitat on an NWR while also providing benefits to the surrounding human community. Where there is high uncertainty regarding sea level rise, erosion potential, and/or lack of natural sediment source in the system, NbS may be combined with hardened infrastructure to help hold the natural features in place as they grow. Effectiveness of NbS may be higher when long term planning considerations are included and when actions do not focus exclusively on carbon sequestration. Cost effectiveness and social desirability of NbS can vary widely across local communities and this approach is best applied when both economic benefits and societal desire outweigh costs. Finally, NbS should not be used solely to offset carbon in place of other climate change mitigation efforts such as reducing emissions.

6. Better Preparation for a Climatically Uncertain Future

Understanding of climate uncertainty and how to consider it in planning and regulatory decision-making documents varies widely across USFWS programs. For example, the Ecological Services Program (the USFWS program that administers the ESA) addresses climate uncertainty in various issues ranging from SSAs to listing rules, critical habitat designations, and HCPs. Despite familiarity with how to address climate uncertainty in some programs, USWFS still struggles with variation in climate literacy among both biologists composing documents and decision-makers approving documents. The agency could benefit from building staff capacity, creating new tools and training on current tool use, conducting research syntheses that further elucidate ecological response to climate change, and improving guidance related to assessing uncertainty and incorporating climate considerations into decision making.

Although USFWS employs scientists with climate expertise, the staffing level throughout the agency is not sufficient to meet the demand. There are currently more than 1700 species listed as threatened or endangered [62], demonstrating that the scope of the USFWS mission has grown considerably, but staffing levels and funding increases have not necessarily been commensurate. For example, NWRs often have less staff and smaller budgets than U.S. National Parks, even though NWRs encompass a much larger geographic area. The number of NWRs has increased to 568 in 2021, while the budget has decreased by almost 18% since 2010 and the number of staff has decreased 20% since 2013 [89]. Many wildlife managers are already overburdened responding to other existing anthropogenic stressors and do not always have the capacity to consider additional calamities. More scientists are needed that can provide technical assistance to biologists and managers on how to address climate change related issues in a robust and scientifically defensible way. Effectively addressing climate-related uncertainty across the wide range of USFWS activities requires a relatively large number of resource managers with diverse training and backgrounds. Additional staffing would build an appropriately-sized climate literate workforce, allowing USFWS to further explore ecological effects of climate change while also identifying and implementing effective climate adaptation actions.

Similarly, efforts aimed at increasing coordination and awareness can help to develop climate literacy in the existing USFWS work force. For example, a series of "Frequently

Asked Questions" related to utilizing climate projections has been developed, written in tandem with climate scientists from other federal agencies. This will be a valuable resource for managers considering climate change in conservation planning and decision making. To infuse consistency in the use of climate change information, the USFWS is developing general guidance on the use of climate projections and related information that various programs and regions can adapt for their planning and decision-making needs.

USFWS is exploring use of the Resist-Accept-Direct Framework (RAD) to aid conservation decision making in areas where ecological transformation associated with global change is occurring [90,91]. The RAD framework describes three potential options for management response to ecological transformation. Managers can resist change by maintaining ecosystems in their current state or restoring them to a historical state. Alternatively, when resistance is ineffective or alternative states are acceptable to society, managers can accept change. The third option is for managers to direct change toward a desirable state, by actively shaping changes in ecosystem composition, structure, processes, or function toward preferred new conditions [90,91]. Options are not necessarily mutually exclusive across a landscape and managers may utilize two or three RAD elements rather than one discrete use. For example, some NWRs have begun implementing a portfolio of RAD options to manage for wildlife, and the use of the RAD framework allows stakeholders to explicitly identify and assess economic, ecological, and sociological costs and benefits of various management strategies [92]. Models and online tools that could inform RAD and decision-making are already available, such as the Dynamic Global Vegetation Model MC2 [93–95], the Climate Toolbox (https://climatetoolbox.org/, accessed on 6 January 2022), and The Nature Conservancy's "Resilient Land Mapping Tool" (http://maps.tnc.org/resilientland/, accessed on 6 January 2022). Refinement of these online tools and development of training in tool use will be necessary to further guide effective decision making under RAD. To support this process, additional research is needed to predict how, when, and where ecological systems may be transformed and which areas may be resilient to change. Furthermore, a better understanding is needed of direct climate-related impacts to aquatic and terrestrial habitats and how indirect climate stressors such as disease or altered predator-prey dynamics will affect systems.

Prioritizing areas for conservation is critical to build climate-resilient ecological communities, provide habitats for wildlife, and sequester carbon, particularly in a changing climate that will have unequal impacts throughout nations. USFWS has a long history of partnering with other federal agencies, state and municipal governments, and non-governmental organizations (NGOs) to achieve conservation. Such partnerships will be indispensable for a successful response to climate change, particularly for landscape scale conservation efforts involving neighboring nations (e.g., Canada and Mexico). Spatial planning tools that consider climate change impacts to habitats and biodiversity are important to USFWS decision making. For example, Nature's Network (http://naturesnetwork.org/, accessed on 6 January 2022) is a collaborative effort to spatially identify important areas for the conservation of hundreds of ecosystem types and habitat connections, with consideration of future climate and development impacts. The connected networks of land, wetlands, and coastal systems provide critical habitat for threatened species and benefits for local communities. The network is a collaboration between USFWS, state partners, universities, and NGOs.

Similarly, the Southeast Conservation Adaptation Strategy Blueprint (SECAS) (https://secassoutheast.org/, accessed on 6 January 2022) is a spatial plan that informs conservation decisions by identifying critical areas for conservation and restoration across the southeastern United States and Caribbean. The blueprint is described as a 'living plan' and can be used to identify land and waters with high or medium conservation value. By combining the blueprint with local knowledge, it can inform decisions and focus conservation actions based on future changes, while maximizing chances of success. USFWS representatives serve on the SECAS steering team, providing oversight and direction. Another useful framework is the Habitat Climate Change Vulnerability Index developed by

NatureServe (https://www.natureserve.org/ccvi-ecosystems, accessed on 6 January 2022), which incorporates a series of measurements to determine the vulnerability of ecological communities to climate change.

Spatial data and tools such as these can help prioritize decisions related to land and water conservation. In addition to identifying critical areas for wildlife conservation (e.g., wildlife corridors, refugia) under a climatically uncertain future, collaborative planning efforts can enhance coastal resilience, mitigate desertification, and reduce wildfire severity or frequency [49–51]. USFWS should continue to prioritize expansion and co-production with partners of these collaborative conservation frameworks to facilitate inclusion of priority information and updates of the latest climate data or models. Regional and international partnerships for landscape conservation will be a significant mechanism to achieve global conservation of species, habitats, and wildlife corridors in an era of changing climate.

Additional training in decision-making under climate uncertainty is needed for USFWS managers and a new training model may be helpful. In addition to traditional multi-day courses, individualized, self-taught and self-paced training could be developed. Training needs to be convenient and concise, as wildlife managers often do not have a lot of time to devote to training. Self-taught courses in rapid vulnerability and risk assessments, NbS, interpretation of climate models, and translation of climate projections into plausible ecological trajectories would be beneficial. Training webinars in the use of online spatial tools, that incorporate climate and ecological trajectory data, are also desirable.

7. Policy Considerations

In order to better address the climate-related challenges outlined above, policies are needed that support fish, wildlife, and plant adaptation to a changing climate. Here we describe a suite of programs that guide and inform USFWS polices related to climate change response, as well as identify new policies or existing policy revisions that may be necessary to remove barriers to implementing climate smart conservation.

As a key mechanism to addressing climate change, USFWS has developed and is implementing the Climate Change Action Program. The Climate Change Action Program will evolve and adapt over time as USFWS gains the necessary staff capacity, knowledge, and engagement across programs and regions to guide the agency's response to climate change and inform ongoing policy revisions. Existing USFWS policy related to climate change adaptation was adopted more than eight years ago and may need updating to reflect advances in climate science [96].

Assisted migration refers to human-mediated translocations of a plant or animal species outside their historic range to combat biodiversity loss in response to climate change [97]. Policy is needed to guide USFWS in addressing assisted migration. The choice to implement assisted migration as a conservation tool is framed by a few different factors, such as confidence in ecological understanding, perceived risk of assisted migration, and perceived risk of no involvement (no assisted migration). The USFWS is considering developing an assisted migration policy to aid in consideration of the differing associated factors. The National Park Service issued a report in 2021 that describes risk assessment protocols to help park managers evaluate the ecological risks of assisted migration as part of planning and decision making [98]. The USFWS would benefit from a similar policy or protocol in order to better protect their comparable resources.

USFWS may consider revising policies that implement the ESA to broaden the section on reintroductions. The current ESA regulation (Experimental Population Reintroduction Regulations under Section 10(j) [61]) limits reintroductions to the species' historic range which can pose difficulties for reintroductions when a species' climatic niche has moved on the landscape. This USFWS restriction on reintroductions and inability to establish populations outside of their historical range when habitats have shifted may present a barrier to conserving species in our rapidly changing world.

The NWRS is reviewing possible changes to its policy providing guidance for managers to follow in maintaining the biological integrity, biological diversity, and environmental health of NWRs [99]. Importantly, the policy also provides managers with an evaluation process to recommend the best management direction to prevent further degradation of environmental conditions and restore lost or severely degraded components to 'historical condition' where appropriate [99]. Unfortunately, NWRs will be faced with many situations in which returning to a standard historical condition may be impossible. Moving away from using historical condition as a benchmark will be crucial to ensure realistic standards are set in an uncertain future.

The NWRS is also reviewing its process and policies for developing Comprehensive Conservation Plans, which describe the decision-making process used to achieve desired future conditions on the managed landscape [100]. Comprehensive Conservation Plans discuss the desired future conditions of an NWR and provide long-range guidance and management direction to achieve those objectives. USFWS must manage all national wildlife refuges according to an approved Comprehensive Conservation Plan. Updating these policies to address climate change and related uncertainty will better define future conditions and improve the ability of USFWS to protect the ecological integrity of NWRs.

Here we described a suite of policies and programs that USFWS can adopt to incorporate updated climate science guidance and remove barriers to implementing actions that facilitate species adaptation to climate change. Managers will also need flexibility to quickly respond to rapidly changing ecological conditions, as well as recognition that unknowns exist under climate uncertainty. Although it is impossible for wildlife managers to accurately forecast all potential outcomes, developing strategies to avert surprises through scenario planning is an appropriate and worthwhile approach. USFWS continues to coordinate with partners and stakeholders to identify more appropriate mechanisms to address uncertainty, and better conservation outcomes will be achieved by implementing this practice and others described.

8. Conclusions

A thorough understanding of how climate change affects biodiversity is integral to effective conservation planning and sustainable natural resource management. The USFWS has a long history of successfully conserving wildlife and habitats. As mentioned previously, many North American wildlife species have recovered from catastrophic declines in the past and this offers hope that conservation efforts can reverse biodiversity loss. The task of managing for a future increasingly characterized by rapid and uncertain change is daunting, but the capacity for response is also great. Innovative practices described here, such as scenario planning, conservation plans that maximize connectivity and other landscape scale conservation approaches, and natural climate solutions like NbS, can be useful for incorporating climate uncertainty into wildlife management. We conclude with the following list of suggestions to improve inclusion of climate uncertainty into USFWS actions and help facilitate the shift in perspective required for wildlife conservation under ongoing climate change. These recommendations may also be useful to other wildlife management agencies and conservation organizations around the world to consider when developing and implementing climate adaptation plans.

- Increase the number of staff capable of providing technical assistance on how to address climate change.
- Build staff capacity by improving coordination and awareness related to climate science and ecological effects to better develop a climate literate work force.
- Fund or conduct additional research syntheses that elucidate ecological response to climate change and identify plausible future scenarios.
- Continue to develop and co-create with partners collaborative conservation frameworks that incorporate climate science.
- Expand training opportunities to increase coverage of decision-making under climate uncertainty.

Author Contributions: Conceptualization, J.L.W., D.R.M. and J.R.H.; methodology, J.L.W.; investigation, J.L.W., D.R.M., A.H., K.J., S.C. and J.R.H.; resources, D.R.M. and J.R.H.; data curation, J.L.W., A.H., K.J., S.C. and J.R.H.; writing—original draft preparation, J.L.W., D.R.M., A.H., K.J., S.C. and J.R.H.; writing—review and editing, J.L.W., D.R.M., A.H., K.J., S.C. and J.R.H.; visualization, J.L.W., S.C. and J.R.H.; project administration, J.L.W. and D.R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We thank members of the USFWS Climate Change Community of Practice and Coordinating Group for insightful discussions that inspired this work. We also thank Jason Goldberg and Lindsey Thurman for helpful comments which improved the manuscript as well as two anonymous reviewers. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Conflicts of Interest: The authors declare no conflict of interest.

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