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Climate Change Vulnerability Assessment for the Papahānaumokuākea Marine National Monument

U.S. Department of Commerce
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Papahānaumokuākea Marine National Monument

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Cover Photo:
Coral reef off Lisianski Island inside the Papahānaumokuākea Marine National Monument that suffered high levels of bleaching in the summer of 2014. Credit: Courtney Couch/Hawaiʻi Institute of Marine Biology.

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Executive Summary

Anthropogenic emissions of greenhouse gases are changing the Earth's climate in ways that are projected to have significant and far-reaching effects on ecosystems and people. Within a global context, the coral reef and low island ecosystems of the Papahānaumokuākea Marine National Monument (PMNM) are among the places most vulnerable to climate change. The Monument's northernmost atolls may also be some of the first reef systems globally to be impacted by changing ocean chemistry, thus providing early indications of broader indications to come. Recognizing these likely impacts, the PMNM Monument's Management Board (MMB) has identified climate change as the most significant threat to this unique World Heritage site, and in collaboration with its partners has developed this Climate Change Vulnerability Assessment (CCVA). The assessment's purpose of understanding climate change impacts is consistent with a number of federal and state government initiatives and evolving international work programs. The purpose of this document is to provide guidance for PMNM's response to climate change by providing an in-depth assessment of the likely effects of climate change on the various natural and cultural resources of the Monument. The content of the CCVA was developed through a series of workshops, interviews with PMNM management partners, and a review of the literature. Through this unique process, PMNM not only sought to understand the likely impacts of climate change on Papahānaumokuākea's resources , but also outlined a research and management agenda in the form of key objectives and targeted strategies for responding to these unprecedented changes. The latter Climate Change Action Plan is in the process of final approval by the Co-Trustees of PMNM, and will be published as a separate document in the future.

The CCVA key findings are as follows:

Projected Changes in Climate Variables

- *Currently, greenhouse gas emissions are continuing to increase [high confidence][1]. As of May 2013, atmospheric CO_2 as measured at the Mauna Loa Observatory, stood at 399.73 ppm; over the past 80,000 years, atmospheric CO_2 concentrations have varied within a range of about 170 to 300 ppm [high confidence]. Future CO_2 concentrations are predicted to reach levels between 430– >1,000 parts per million (ppm) by the end of the century (IPCC, 2014), depending of the level of future anthropogenic emissions [moderate confidence]. It is very likely that the rate and scale of future greenhouse gas emissions will determine the speed and severity of climate change impacts to PMNM's resources, as well as the ability of the Monument's natural resources to adapt to these changes [high confidence].*
- *The oceans have absorbed nearly half of the CO_2 produced by human societies over the past 250 years, changing ocean chemistry through a process known as ocean acidification [high confidence].*
- *Both air and sea surface temperatures are warming and an increase in the frequency of extreme heat events is projected [moderate confidence]. Under an intermediate*

[1] Qualitative assessments of confidence in this Action Plan are based on the amount of supporting evidence, and the level of agreement between experts about the interpretation. The levels of confidence applied to assessments made in this Action Plan are: high (67% or greater), medium (33–67%) and low (33% or less).

greenhouse gas emissions scenario, available modeling estimates that air temperatures across the NWHI will rise by an average of 2.2 °C (4 °F) by 2100, with the greatest temperature increase of 2.6°C (4.7 °F) predicted for Kure, Midway, and Pearl and Hermes Atolls, and Lisianski Island [low confidence]. Average sea surface temperatures are estimated to increases from 1 - 2.8 °C (2 - 5 °F) by 2100 [moderate confidence].

- *Projected sea-level rise, combined with likely increases in storm and wave energy, indicate that there is a high likelihood of inundating low-lying islands within the NWHI and increasing coastal erosion on all islands over the next 50–100 years [high confidence].*
- *Changes in ocean circulation patterns are likely [high confidence].*
- *Tropical storms may become less frequent, more intense, or change their historical trajectories [low confidence].*
- *There may be more extreme weather events and an overall reduction in precipitation [low confidence].*

Projected Impacts to PMNM's Marine Ecosystems

- *Coral reef ecosystems in PMNM are very likely to change as a result of changing ocean chemistry and increasing ocean heat content [high confidence]. While warmer sea temperatures may benefit some of the Monument's reefs, degradation due to reduced calcification and increased frequency of bleaching and disease events is likely [moderate confidence]. If projections of more intense storms are correct, these events will also be damaging to reefs weakened by other stressors [high confidence].*
- *Changing ocean chemistry (also known as ocean acidification) is very likely to reduce the ability of some corals, calcareous algae, phytoplankton, and invertebrates to calcify their shells and skeletons [high confidence].*
- *Areas of low productivity in the open ocean are likely to expand as warmer surface water temperatures increase vertical stratification in the water column, and nutrients from cooler, deeper waters are less available in the surface, photic zone [high confidence].*
- *Changes in ecological community structure, possibly coupled with an overall loss in biological diversity, are likely as some species are unable to adapt to altered habitat structure, temperatures, and circulation patterns, while other species not currently found in PMNM may become established [high confidence].*
- *Increased stratification and changes in circulation will cause changes in ocean productivity, with cascading effects through the food web, negatively impacting predator species [moderate confidence].*
- *Endangered Hawaiian monk seals are likely to be adversely affected by climate change as their breeding sites and haul-out sites are inundated and eroded, and the abundance of their prey is reduced [moderate confidence].*
- *Endangered Hawaiian sea turtles may be negatively impacted as major nesting areas at French Frigate Shoals are inundated and eroded [low confidence].*
- *Climate change may exacerbate existing threats from invasive species, marine debris, and disease [low confidence].*

Projected Impacts to PMNM's Atoll & Island Ecosystems

- *It is very likely that PMNM's low-lying atolls will be submerged within the next 50-100 years, with some atolls being affected sooner and more extensively than others [high confidence].*

- *Beach and coastal strand habitats are very likely to be lost as a result of sea level rise, storm inundation, and erosion with significant implications for endangered species that rely on these habitats for nesting and breeding, including monk seals, sea turtles, and seabirds [high confidence].*
- *Inland waters, including both freshwater habitats and the hypersaline lake on Laysan, are likely to be degraded by changes in precipitation, compromising critical habitats for a range of endemic and protected species [moderate confidence].*
- *Papahānaumokuākea's globally important bird populations are at risk from the loss and degradation of habitat, changes in prey availability, and direct impacts from changes in environmental conditions, particularly increasing land surface temperatures [high confidence].*
- *Climate change impacts on Papahānaumokuākea's endemic plant and arthropod species are likely, however, major information gaps on these species prevent an adequate vulnerability assessment [high confidence].*

Projected Impacts to PMNM's Cultural & Heritage Resources

- *PMNM's tangible cultural and heritage resources, which include natural resources and archeological sites and artifacts, will be negatively affected by climate change [high confidence].*
- *Archaeological sites and artifacts are likely to be more resistant and resilient to climate change impacts than natural resources [high confidence].*
- *There are at least four categories of intangible cultural values associated with Papahānaumokuākea: universal values, Native Hawaiian values, heritage values, and values derived from PMNM's opportunity to serve as an exemplar site for science and management. These values are the result of human experiences or perceptions of Papahānaumokuākea, and they can contribute a sense of place and well-being for key constituencies and society at large [high confidence]. The impact of climate change on these social values is largely unknown and warrants further research [high confidence].*

Chapter 1

INTRODUCTION

Small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea-level rise, and extreme events (very high confidence).

- IPCC Working Group II, *Technical Summary*, 2007, p. 57

It is widely recognized that anthropogenic inputs of greenhouse gases into the atmosphere since the industrial revolution are changing the Earth's climate in ways that are projected to have significant and far-reaching effects on ecosystems and people (IPCC, 2007a, b, 2014). Within a global context, the coral reef and low island ecosystems of the Papahānaumokuākea Marine National Monument (PMNM) are among the places most vulnerable to climate change. Recognizing these likely impacts, the Monument's Management Board (MMB) has identified climate change as the most significant threat to this unique World Heritage site, and in collaboration with its partners has developed this Climate Change Vulnerability Assessment (CCVA).

The CCVA presents a prioritized synthesis of our current understanding about likely impacts of climate change on Papahānaumokuākea. Its content was developed by considering a broader suite of potential impacts and adaptation options, which are introduced in Section 1.1. The process used to develop the CCVA is described in Section 1.2 and the Plan's guiding principles and goals are presented in Section 1.3. A Climate Change Action Plan (CCAP) that outlines the research and management agenda for responding to climate change was also developed in tandem with this CCVA, and will be published as a separate document in the future once it is endorsed by all Co-Trustees of PMNM. Once finalized, PMNM's CCAP will guide the Monument in prioritizing its activities, effectively partnering with related initiatives, and contributing to broader scientific and policy dialogues.

1.1 Understanding and Responding to Climate Change: Dimensions of the Challenge

Many scales of climate change are in fact natural, from the slow tectonic scale, to the fast changes embedded within glacial and interglacial times, to the even more dramatic changes that characterize a switch from glacial to interglacial. So why worry about global warming, which is just one more scale of climate change? The problem is that global warming is essentially off the scale of normal in two ways: the rate at which this climate change is taking place, and how different the "new" climate is compared to what came before.

- Anthony Barnosky, *Heatstroke: Nature in an Age of Global Warming*

Incorporating climate change into the management of PMNM involves at least three broad tasks. It requires identifying and assessing the likely impacts of climate on the Monument's ecosystems and social values. Second, it calls for identifying management goals that are appropriate and achievable with the resources available. Finally, it necessitates planning meaningful adaptation actions that are able to achieve the articulated goals. The following sections review each of these tasks and the unique challenges they pose to PMNM's efforts to incorporate climate change into the Monument's management.

1.1.1 An Overview of Climate Change Impacts on Natural and Cultural Resources

Climate change is very likely to impact PMNM's ecological and social values both directly and through complex interactions. Broad categories of anticipated change are summarized here, and Section 2 identifies and prioritizes specific impacts for Papahānaumokuākea. In general terms, anthropogenic emissions of greenhouse gases since the industrial revolution are warming the planet (Figure 1.1) and changing the chemistry of the Earth's oceans and atmosphere (IPCC, 2007a, 2014). These changes in temperature and chemistry are causing sea levels to rise, ocean waters to become more acidic, shifting atmospheric circulation and associated weather patterns, increasing the intensity of storms, and are also expected to cause shifts in ocean currents. While all of these attributes have fluctuated over the history of the planet, they have never shifted at the speed currently being experienced (IPCC, 2007a, 2014), and the main variable driving these changes—greenhouse gas concentrations—has reached levels never before observed (Figure 1.2). Section 2.1 describes the best available projections of how environmental variables will change in PMNM over the next 100 years.

These far-reaching environmental changes are impacting life on the planet at multiple of levels: individual organisms, populations, species, habitats, and ecosystems. At most of these levels, impacts result from direct changes in climate variables, from interactions between biological components of the system that are changing simultaneously, and from the synergistic impacts of climate change and other anthropogenic stressors. For example, climate variables like temperature, moisture, and CO_2 concentrations can modify the metabolic rate, growth rate, time to maturity, and overall health of individual organisms. Cumulatively, these changes can reshape the characteristics of local populations, or even entire species, as individuals respond to new conditions and birth and death rates change.

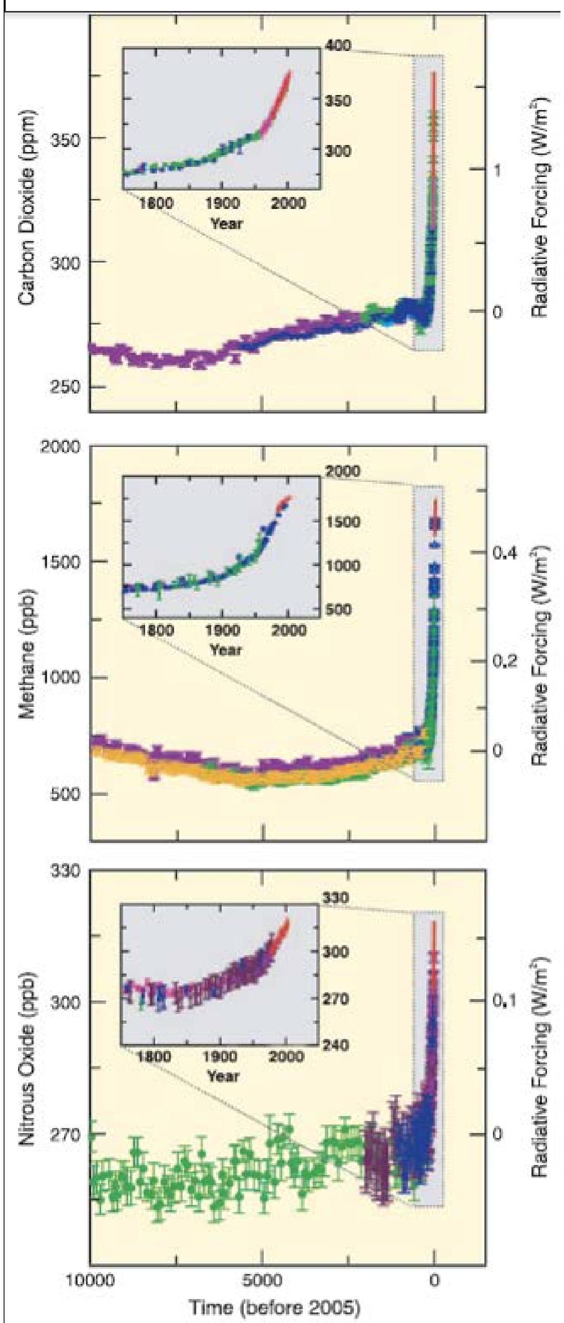


Figure 1.2 Atmospheric concentrations of CO_2, CH_4 and N_2O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colors for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. Reproduced from IPCC (2007a).

Species may be able to respond to changing environmental conditions in several ways: they can alter their physiology and behavior, they can adjust their geographic range, or they may be able to evolve to better cope with new conditions. Species' ability to adapt in these ways depends on both intrinsic and contextual characteristics. For example, species that reproduce rapidly and have larger populations sizes, greater genetic diversity, and better dispersal abilities, are more likely to evolve characteristics better suited to changing conditions. Similarly, generalist species that are able to use multiple habitats and to prey or forage on a range of species, are more likely to adapt than specialist species, whose ability to shift is constrained by the availability of other particular species or habitats. For this reason, endemic species, which are often specialists, are believed to be particularly vulnerable to climate change, and invasive species, which tend to be generalists, may become more prolific.

Because species will all be responding to changing conditions simultaneously and in different ways, their ability to adapt will also be determined by this kaleidoscope of interactions; relationships between species and their prey, predators, parasites, and symbiotic partners may all be renegotiated. Interactions are likely to change in both space and time. For example, changes in climate variables may trigger shifts in the onset and duration of seasonal events, such as leafing, breeding, migrations, and many others. As species make different behavioral adjustments to these changes in seasonality, it is likely that timing mismatches may occur, which in turn may alter the dynamics of multi-species interactions. For example, if a species' breeding season no longer coincides with the peak abundance of its prey, it may be unable to adequately provision its young, resulting in a disadvantage to the predator and a potential advantage to the prey. Similarly, species' ranges will be influenced by multi-species interactions. For example, changing temperature may increase the frequency or intensity of parasite and disease outbreaks, thereby limiting the ability of species to remain in their current ranges. Alternately, species may be unable to expand their range as climate shifts if their prey are unavailable, or if their predators are too dominant in areas of potential expansion. As species are more or less successful in their adaptation attempts, their relative abundance within habitats and ecosystems will change to reflect differences in competitive advantage.

Climate change impacts on habitats and ecosystems include the shifts in species composition described above, as well as effects on ecosystem structure, function, and geographic range. In cases where the dominant or keystone species that provide ecosystem structure are vulnerable to climate change, the ecosystem itself is likely to be susceptible to undergoing a major shift into a different state, such as transitioning from a coral reef to an algal reef. Impacts to ecosystem functions, such as herbivory, decomposition and nutrient cycling, can result from the loss of species providing these functions, or from climate change impacts more directly. For example, increased temperature may stratify water bodies, thereby disrupting nutrient cycling and productivity.

Similarly, increased temperature and changes in the amount or timing of precipitation can alter the size of an island's freshwater lens, the evapotranspiration rate, or the characteristics of water runoff, all of which could impact an ecosystem's hydrological cycle, including freshwater availability. Additionally, if there is space to enable movement, habitats or ecosystems may respond to climate change by shifting their geographic location and extent; in many cases, however, anthropogenic development has impeded this adaptive potential.

The synergistic effects of climate change and other anthropogenic impacts will determine the future conditions and characteristics for most of the world's natural resources. Human activities both influence the ability of natural systems to adapt to climate change and can exacerbate climate change impacts. For example, higher temperatures can increase the toxicity of contaminants, and past engineering of atoll lagoons may worsen stratification from warmer temperatures. Additionally, ecosystem degradation from fishing, coastal development, and introduced species can all reduce the resilience of ecosystems to climate change.

Climate change will also impact tangible cultural and heritage resources and the intangible values people hold for PMNM (see Section 2.4). Changes to natural resources, which are also cultural resources, may negatively impact World Heritage values and Native Hawaiian cultural values associated with the Monument. Additionally, climate stressors may directly impact cultural and heritage sites and artifacts, for example through destruction by more intense storms. Adaptive actions are available to enhance social resilience to these changes, including accelerating research and conservation efforts, as well as facilitating appropriate access by Native Hawaiian cultural practitioners to maintain traditional ecological knowledge.

Within the context of the extensive and inevitable changes described here (Table 1.1), managing the Monument's natural and cultural resources to maintain their current condition is an unviable proposition. The following section examines potential goals for PMNM's efforts to incorporate climate change into the Monument's management.

Table 1.1 Examples of direct and indirect climate change impacts on socio-ecological systems with examples for PMNM.

Anticipated Changes	Examples of Potential Impacts to PMNM
Physiochemical Changes	
Increase in atmospheric CO_2	Plant species benefit differentially, causing shifts in species composition within terrestrial habitats
Changing ocean chemistry (ocean acidification)	Reduced calcification by corals, calcareous algae, plankton, and other species; overall loss of biodiversity
Increased sea temperature	Increased incident and extent of coral bleaching
Increased air temperature	On high islands, terrestrial habitats may shift upward
Sea-level rise	Loss of beach habitat for monk seals, nesting sea turtles, bird species, etc.
Changes to ocean stratification and currents	Changes to productivity and the distribution of pelagic species
Changes in storm intensity and frequency	Damage to coral reef, beach, and terrestrial habitats
Changes in weather and rainfall patterns	Shifts in freshwater availability
Biological Changes	
Changes in timing of different seasonal events	Mismatch between breeding seasons and prey availability
Changes in the ranges of different species	Monk seals and sea turtles may use MHI beaches more as NWHI beaches erode and submerge
Changes in species interactions, such as competition or predation	Endemic species go extinct as they are unable to compete and run out of space to move
Changes in critical habitat availability	Loss of coral reef, beach, and freshwater areas
Changes in pest or disease outbreak, frequency, and severity	Greater incidence of coral disease
Social Changes	
Changes in tangible cultural resources	Negative impacts to natural resources, which are also cultural resources
Damage or loss to cultural and heritage sites and artifacts	Loss of knowledge and experience
Dissociation between Native Hawaiian traditional ecological knowledge and contemporary circumstances unless sufficient access and observation occur	Loss of culture
Opportunity to compare ecological resilience to climate stressors in the highly protected NWHI vs. the populated MHI	Better understanding of ecological processes and the impacts of anthropogenic stressors
Interactions with other Stressors	
Increased toxicity of contaminants	Amplified effects of PCBs in the Monument
Expansion of invasive species	Degradation of nesting habitats
Possible shifts in marine debris patterns	Possible increase in marine debris entanglements
Further stratification of altered lagoons	Amplified heat exposure to lagoon habitats

1.1.2 What are the Goals When Managing for Climate Change?

What is conservation when our goal can no longer be to protect or restore a place or species' populations to the way they were? How can we manage populations whose dynamics are shifting under our very eyes? We can no longer think in terms of safeguarding or maintaining. If the old model is spatial, static, and stuck in the status quo, it would seem that we need a temporal, kinetic, and forward-thinking model to deal with the challenges we face today.

- Hansen & Hoffman, 2011, p. 32

Climate change challenges the commonly-accepted goals of natural resource management (Hansen & Hoffman, 2011). For the last half century, natural resource management has occurred under a relatively stable climate, and it has been underpinned by an assumption that conservation and restoration actions can manage ecosystems in an equilibrium state (Kareiva et al., 2008). Past greenhouse gas emissions erode the efficacy of that basic management assumption. Even if we achieved curbs on greenhouse gas emissions today, past emissions commit us to climate change that is impacting vulnerable ecosystems—such as the coral reefs and low-lying islands of Papahānaumokuākea—and will continue to do so for at least the next several decades (IPCC, 2007a).

Within this context, what goals should Monument managers establish and what actions should they take to achieve PMNM's vision "to forever protect and perpetuate ecosystem health and diversity and Native Hawaiian cultural significance of Papahānaumokuākea"? Workshops, interviews with Monument managers and partners, and the literature were used to develop the following goals that are relevant for PMNM within the context of climate change. A concise statement of the guiding principles and goals adopted by the MMB for this CCVA is presented in Section 1.3.

Integrate Multiple Perspectives to Inform Adaptive Management

Success is having informed adaptation and awareness of the effects of climate change on the Monument. We need a common understanding … by everyone involved.

The baseline needs to include not just the western knowledge but also the indigenous, traditional knowledge that goes back 200 generations prior. It has to be a reciprocal relationship ... only in that way can we have an integrated knowledge system.

- Respondents, PMNM Climate Change Survey

While Monument managers cannot control the future climate of Papahānaumokuākea, they can develop ways of integrating different types of knowledge to foster a shared understanding of climate change impacts, management goals, and the likely effectiveness of management actions. Developing such a shared understanding enhances the ability to implement well-crafted management actions that enjoy broad support from diverse stakeholders. Furthermore, this type of integration is embedded within PMNM's Management Plan and World Heritage designation, which provide a clear mandate for harmonizing Native Hawaiian and Western scientific ways of understanding and managing Papahānaumokuākea.

In the case of PMNM, multicultural constituencies and a long history of human use provide opportunities and challenges for facilitating a shared understanding of how climate change should be integrated into the Monument's management. The NWHI has a rich legacy of observation and study by Native Hawaiians, scientists and historical users, such as the military, fishers, and other industries (Wiener & Wagner, 2013). These accounts vary in regard to time scales and methods, but taken together, they offer a unique resource for better understanding the natural variability and cycles of climatic conditions, ecosystems, and species within PMNM, as well as the way Monument resources have responded to past disturbances.

While the benefits of integrating knowledge systems to inform adaptive management are significant, there are notable challenges to realizing this potential. In particular, there are fundamental differences in the ways indigenous cultures and Western scientists generate knowledge, which create challenges for facilitating a shared understanding (Bohensky & Maru, 2011). This document takes an initial step toward establishing such a shared understanding for managing PMNM within the context of climate change. However, it is only the first step in a journey that requires ongoing commitment, trust, and open-mindedness to achieve a truly integrated approach for navigating Papahānaumokuākea through an uncertain future.

Manage for Future Scenarios rather than the Present

You need scenario planning to understand where things are headed; based on the scenario plan, you need alternative analyses for managers so that they can indicate their preferred responses to various futures that might arise. You're not going to stop the ocean from rising, you're not going to stop it from being more acidic, and you're not going to cool it off, so you have to realize that you may have a new normal every year and you have to be prepared for that.

- Respondent, PMNM Climate Change Survey

Uncertainty is not the same thing as ignorance or lack of information—it simply means that there is more than one outcome as a result of climate change.

- Kareiva et al., 2008, p. 329

Effectively managing for climate change begins with a recognition that fundamental changes are occurring and takes account of likely future conditions. In the past, management actions have usually been aimed at restoring historical baseline conditions; however, since the climates associated with these previous conditions are unlikely to persist into the future, plans aiming to maintain status quo condition may fail or impede more appropriate adaptation responses. In contrast, Hansen and Hoffman (2011) describe a "climate savvy" adaptation response consisting of restoration implemented with an understanding of future conditions. For example, a project in North Carolina is implementing wetland restoration based on projections of future sea levels (Hansen & Hoffman, 2011).

Managing for future conditions introduces greater uncertainty into decision-making. The rate of future greenhouse gas emissions, the resulting changes in climatic conditions, as well as the ecological and human responses to these new conditions, all introduce uncertainty into projections of future conditions. In response, managers are advised to move away from “optimum-based decision-making—trying to maximize benefits and minimize losses for a single expected future” (Hansen & Hoffman, 2011, p. 209) and move toward scenario-based approaches. Scenarios are developed to more fully explore a range of plausible future conditions and to identify management actions that can effectively achieve their goals across most or all of the likely scenarios (Kareiva et al., 2008).

Manage for Function and Structure rather than a Static Condition

Two general concepts provide a simple framework for thinking about and managing for resilience. One is to ensure that ecosystems have all the components they need in order to recover from disturbances…The other is to support the species composing the structural foundation of the ecosystem, such as corals or large trees as habitat.

- Kareiva et al., 2009, p. 333

As much as we may cherish our surviving architectural and archaeological heritage, its destiny, like ours, is dust….

- Adams, 2007, p. 194

My relationship to my place—knowing what’s your function in relation to the function of the place.

- Hiʻilei Kawelo, workshop presentation on Native Hawaiian perspectives of climate change, 12 June 2012

Many of the people interested in Papahānaumokuākea have traditions of navigating change by identifying and maintaining the key functions of a specific place. For example, Native Hawaiians and heritage professionals, such as archaeologists, often do not have a goal of maintaining resources in a static, equilibrium condition. Rather, their actions are based on understanding the function of cultural and heritage resources. PMNM’s maritime archaeologist, Kelly Keogh, describes her management goal this way: “Heritage resources are nonrenewable. So I am not managing to restore the resource to a particular state, or even to establish an equilibrium. Instead, the challenge is to capture this fleeting opportunity to take a glimpse at the past.” From this perspective, the function of heritage resources as windows to the past can be realized through research, documentation, and education, even if the condition of these resources cannot be maintained.

Native Hawaiian approaches to management are also influenced by an understanding of function. People and ecosystems are viewed as an interconnected whole that has interrelated functions. In some cases, ecosystems are managed to provide a particular function, such as managing fish ponds to provide food. Hawaiians themselves also have roles and *kuleana* (responsibilities) for the environment of which they are a part. From a Hawaiian perspective, incorporating climate change into the Monument's management requires asking the questions: "What is the function of PMNM?" and "What is our function in relation to Papahānaumokuākea?" (Kawelo, workshop presentation). These questions are explored in Section 2.4.

For natural resource managers and ecologists, a focus on ecosystem function and structure stems from theories about how to support ecological resilience and from practical experience with restoration. Ecological resilience refers to an ecosystem's ability to withstand disturbances, such as climate change, without shifting to an alternate state. For example, if coral reef ecosystems are resilient, they will recover after a coral bleaching event; if not, they may permanently shift from coral reefs to algal beds with an accompanying change in species composition.

Managing for ecosystem function and structure requires identifying these attributes. Ecosystem functions include providing habitat for a range of species and cycling nutrients throughout the food web. Maintaining ecosystem function is sometimes conceptualized as maintaining the functional groups within the ecosystem that carry out various roles, such as herbivory or decomposition. Maintaining biological diversity can be viewed as a proxy for maintaining ecosystem function based on the idea that greater diversity provides insurance that some organisms from each functional group will survive disturbances, enabling key functions to continue. Ecosystem structure is defined as the patterns of interactions between organisms in time and space (Odum, 1971), or more simply as the species that provide the dominant physical structure, such as corals on reefs or trees in forests (Kareiva et al., 2008). Sections 2.2 and 2.3 identify key ecosystem functions and structures for PMNM's marine and terrestrial ecosystems.

Within the context of climate change, focusing management on maintaining key functions and structures may provide a more targeted, flexible, and realistic way of adapting to new conditions; although, climate change impacts on these functions and structures themselves will remain a challenge.

Integrate Science & Management with the Main Hawaiian Islands

"I think the value in PMNM is what it can tell us about management in the Main Hawaiian Islands. For some issues, like monk seals, management across the archipelago may be the best way forward."

- Respondent, PMNM Climate Change Survey

Flora and fauna will naturally migrate in response to new conditions and facilitating these natural migrations is a widely recommended management response to climate change (Glick et al., 2011). Within the Hawaiian context, the scope for such movement is limited by the remoteness of the archipelago; therefore, intra-archipelago migration may be the only option for many species seeking to maintain the conditions they need to survive. Currently, the ability of these species to migrate from the NWHI to the Main Hawaiian Islands (MHI) is sometimes constrained by human development in the MHI that limits safe access to beaches or exposes potential nesting sites to invasive species. By integrating climate change into natural and cultural resource management across the archipelago, managers will be better able to understand the potential for these migrations and to implement restoration actions that can help facilitate successful relocations.

Additionally, differences in human use between the remote NWHI and the populated MHI provide a natural focal point for scientific and cultural learning aimed at untangling the direct impacts of climate change from the synergistic impacts of climate change and other human stressors. In essence, this inquiry can answer key questions about whether and how managing local stressors will enable coral reef and island ecosystems to adapt to climate change. Understanding the extent to which local management can support ecosystem resilience to climate change, will clarify the benefits of various management options in the MHI, presumably creating greater confidence and support for management initiatives.

Advance Cultural and Scientific Understanding

Because the ecology [of PMNM] is relatively intact, particularly when compared to the Main Hawaiian Islands, it's an amazing opportunity for a lot of re-engagement and re-understanding of a lot of traditional knowledge. We worry this knowledge could potentially be lost quite quickly through climate change.

Climate change is a scientific opportunity; it's not necessarily something we would have wanted, but there's certainly a lot of options there to learn things.

- Respondents, PMNM Climate Change Survey

If there is a silver lining to climate change, perhaps it is the opportunity and catalyst provided to cultural and scientific learning. Inspired by the need to understand the impacts of climate change on cultural and natural resources, communities are offered the chance to answer important and long-held questions about natural systems—the ways they function, their natural variation, and their inherent adaptive capacity. For Native Hawaiians these questions come at a time of cultural renaissance, as chants, songs, and cultural practices are resumed and reexamined, thereby offering a longitudinal context for understanding climate change that extends back countless generations. To the extent that climate change enhances motivation, opportunities, and resources for reconnecting with Hawaiian's deep cultural understanding of Papahānaumokuākea, it is an opportunity to enhance the well-being of this community.

Similarly, researchers have identified an outstanding opportunity to answer questions of global significance to the scientific community. The unique learning opportunity offered by comparing the uninhabited NWHI and the highly altered MHI has been described above, and is further outlined in the Hawaiian Archipelago Marine Ecosystem Research (HAMER) Plan (PIFSC, 2008), and is also the premise for the NOAA Hawaiian Islands Sentinel Site Cooperative. Additionally, PMNM's northernmost atolls may be some of the first tropical reefs in the world to be exposed to significantly altered ocean chemistry, offering the potential to serve as a sentinel site for other areas if adequate monitoring and research are in place. While the emphasis of this CCVA is on research that informs management, the potential to advance more fundamental science and theory is likely to be of interest to global scientific community and warrants further consideration.

Inspire Climate-Friendly Behaviors and Environmental Stewardship

We really need to define success as an ultimate recognition of the problem of climate change, and an ultimate recognition of a sense and responsibility that we are the problem and that we need to be taking grand steps to fix the problem, maybe not for ourselves but for future generations.

Success is a change in behavior, because most of these things are going to keep happening regardless of what adaptation we do; we're treating the symptoms until we treat the root cause of changing behavior, of the way people act towards the earth, and the atmosphere, and water.

- Respondents, PMNM Climate Change Survey

The projected and actual impacts of climate change on PMNM's fauna, flora, endemic species, Native Hawaiian culture, coral reef ecosystems, and low-lying islands offer a compelling illustration of the need for climate-friendly behaviors and environmental stewardship. Realizing this potential requires interpreting evolving science and cultural insights in a way that is understandable and personal for targeted constituencies, as well as the general public. Developing partnerships to amplify the Monument's own expertise in communications, outreach, and education can raise awareness and ultimately change behavior to lower greenhouse gas emissions.

Serve as an International Example

The Monument has been put on a pedestal as being a uniquely pristine environment, so it offers us a glimpse into what change can do and an opportunity to create more awareness within the community; the impacts of climate change are easier to see in a place like the Monument.

Understanding and being able to document change clearly and qualitatively would have some value outside the Monument. Whether it's in policy circles or elsewhere, clearly showing the linkage between climate change and its impacts on the ecosystem, the decline of species or population growth of invasive species would be a compelling success in itself.

- Respondents, PMNM Climate Change Survey

In addition to fostering stewardship at an individual level (see above), effectively demonstrating the impacts of climate change on Papahānaumokuākea's social and ecological values has the potential to inform national, regional, and international policies related to climate change adaptation and mitigation. Combining PMNM's global profile as a World Heritage Site with strong scientific and cultural understandings about the implications of climate change, offers a unique opportunity to give voice to these issues within influential policy forums. The research priorities identified in this CCVA are intended to help provide the evidence needed to effectively contribute to relevant learning opportunities and policy dialogues.

1.1.3 Adaptation Options

Achieving the goals articulated above requires combination of research, education, outreach, and management actions. Three broad types of management actions are advocated in response to climate change: eliminating other stressors, facilitating adaptation, and strengthening institutions. A widely accepted rule of thumb is that reducing or eliminating other anthropogenic stressors will enable ecosystems and species to have greater adaptive capacity for responding to climate change. Within the Monument, these other stressors might include marine debris and introduced species. Similarly, conducting actions that enhance adaptive capacity may be helpful, such as restoring lagoon circulation patterns altered by past dredging. In selecting targets for these kinds of actions, one strategy is to prioritize areas likely to be naturally resilient to climate change impacts, so they can serve as refugia and a source of replenishment for more vulnerable areas.

Facilitating adaptation can take a number of forms. It may involve implementing actions to maintain key ecosystem functions and structures in light of future conditions; for example, restoring coral reefs after bleaching events. Similarly, it could involve implementing actions to facilitate the adaptation of managed species, such as creating new nesting areas or relocating species that are unable to migrate to new areas as existing habitats are lost. In planning climate change adaptation, the concept of connectivity is important, which means considering the connections and movements of species and ecosystems now and in the future. In Hawai‘i, monk seals and sea turtles may increasingly move to the MHI as beach habitat is lost in the NWHI; thus, adaptation for these species could include protecting beach habitat in more populated areas of the MHI. .

Well-functioning social institutions can facilitate learning and responsive actions to complex and unpredictable situations, such as climate change. For example, by leading and participating in local, regional and global learning networks, PMNM’s managers will be better prepared to assess changing conditions and implement appropriate management responses. Similarly, the extent to which Native Hawaiians can observe, interpret, and share experiences about changing conditions in Papahānaumokuākea will influence the ways these changes impact Hawaiian culture. Within the context of climate change, it is particularly important that PMNM’s social institutions are able to monitor change; respond rapidly to acute events, such as coral bleaching and storms; and to facilitate agreement on management actions despite higher levels of uncertainty.

1.2 Purpose and Development of this Document

The Monument’s work to understand and respond to climate change is consistent with a number of federal and state government initiatives and evolving international work programs. For example, NOAA’s Office of National Marine Sanctuaries has developed a Climate Smart Program that aims to certify Sanctuaries as they complete situation analyses of potential climate change impacts and begin implementing actions that support adaptation and reduce the carbon footprint of Sanctuary facilities. Concurrently, the Department of the Interior has developed regional Landscape Conservation Cooperatives (LCCs), such as the Pacific Islands Climate Change Cooperative (PICCC), and supported these initiatives through the development of regional Climate Science Centers. Additional scientific support is being facilitated by NOAA’s Climate Program, implemented in Hawai‘i through the Pacific Climate Information Service (PaCIS), which operates in close collaboration with a range of regional initiatives, particularly the NOAA-funded Regional Integrated Science and Assessment (RISA) Program, NOAA’s Office for Coastal Management, and other initiatives. Through these and other partnerships, NOAA and the Department of the Interior led an enhanced assessment of climate change impacts in the U.S. Pacific as part of the National Climate Assessment (Marra et al., 2012). At a state level, Hawaiʻi has developed a Local Action Strategy for responding to coral bleaching and disease events in collaboration with the University of Hawaiʻi (Hawaiʻi DLNR, 2007).

The purpose of this document is to provide guidance for PMNM's response to climate change by providing a thorough assessment of the likely impacts of climate change on PMNM's resources. The CCVA was developed through a series of workshops, interviews with PMNM management partners, and a review of the literature. An early workshop with Monument managers established guiding principles and key goals for PMNM's response to climate change, and created a 13-member Steering Committee (Appendix A) to plan a larger Expert's Workshop. The Steering Committee met approximately twice a month for five months. A key resource developed to support the Expert's Workshop was an options paper (Schuttenberg & Polhemus, 2012), which identified the key impacts to Monument resources and potential responsive actions. This technical paper was collaboratively developed and reviewed by technical and management experts.

The Expert's Workshop was held in June 2012, bringing together managers, cultural practitioners, and scientists for three days to develop a shared understanding of the most significant climate-related issues facing the Monument and to prioritize appropriate research, monitoring, and management actions (see Appendix B). Following the Expert's Workshop, a second workshop was held in September 2013 with the objective of developing the final content for the CCVA and recommending priorities and mechanisms for responding to climate change (Appendix C). The CCVA is based on the recommendations and conclusions from these two workshops. Additionally, through the process outlined above, a series of strategies and specific activities for responding to climate change were developed. These specific activities and strategies form the basis of a forthcoming Climate Change Action Plan, which is currently in the process of approval by the Co-Trustee agencies of PMNM, and will be published subsequently.

1.3 Relationship to the Monument Management Plan and Other Step-Down Plans

The CCVA intersects with the Monument Management Plan and four associated step-down plans that expand upon specific management needs of the Monument. Each of these management plans is briefly described below, and linkages among the different plans are illustrated in Figure 1.3.

Monument Management Plan (MMP)

The MMP is the main document guiding the work of the Monument Management Board and its individual agencies (PMNM, 2008b). The Plan consists of a total of 22 action plans, which are organized under the following six priority management areas: (1) understanding and interpreting the Northwestern Hawaiian Islands, (2) conserving wildlife and habitats, (3) reducing threats to the ecosystem, (4) managing human activities, (5) coordinating conservation and management efforts, and (6) achieving effective Monument operations. Each action plan of the MMP is guided by a desired outcome in a specific management area, and describes strategies and activities to achieve that outcome.

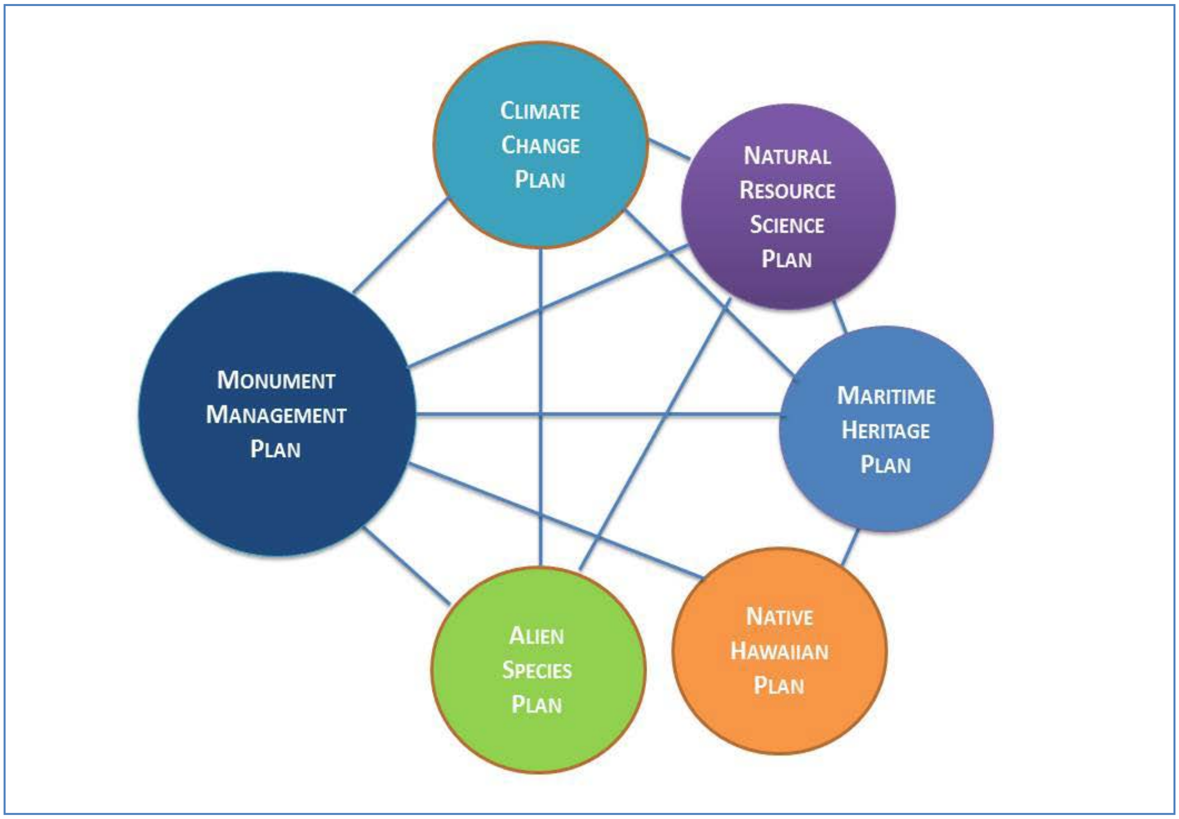


Figure 1.1 Links of the CCVA to other management plans of PMNM.

Natural Resource Science Plan

The PMNM Natural Resource Science Plan aims to provide the information required to effectively implement research and monitoring strategies in PMNM (PMNM, 2011a). It identifies priority activities in five areas of science needs, including (1) habitats and biodiversity, (2) ecological processes and connectivity, (3) human impacts, (4) indicators and monitoring of ecosystem change, and (5) modeling and forecasting of ecosystem change. The need to understand climate change impacts and adaptation options in the NWHI is reflected throughout the Natural Resource Science Plan. Further, this plan also recognizes the potential contribution of climate change research in the NWHI to informing management efforts in other parts of the globe.

Maritime Heritage Research, Education and Management Plan

The PMNM Maritime Heritage Research, Education and Management Plan aims to facilitate an interdisciplinary understanding of historical resource use within PMNM (PMNM, 2011b). Through a focus on maritime archaeology, history, ecology and Native Hawaiian heritage, the Plan aims to guide research that informs understanding of how past resource use has influenced the ecosystems being managed today. The Plan also contains guidance for education, outreach management and protection activities in the NWHI.

Native Hawaiian Cultural plan (forthcoming)

The forthcoming PMNM Native Hawaiian Cultural Plan will address priorities for Native Hawaiian cultural research and practice within and about the Northwestern Hawaiian Islands. The management of PMNM operates under the premise that cultural and natural resources are integrally linked, and are considered holistically in management strategies. Native Hawaiians have traditionally managed all natural resources as cultural resources, and the forthcoming PMNM Native Hawaiian Cultural Plan will apply this same principle.

Alien Species Plan (forthcoming)

The forthcoming PMNM Alien Species Plan will expand upon alien species research, prevention and education goals set forth in the MMP. Strategy 1 of the MMP identifies the need to conduct planning to prioritize by threat level, impacts from invasive species and feasibility of controlling non-native organisms in the Monument (PMNM, 2008b). The Plan will be developed based on the effectiveness of existing protocols and a comprehensive risk assessment of alien species introductions.

1.4 Goals and Guiding Principles for Managing Papahānaumokuākea in the Context of Climate Change

PMNM's Monument Management Board has adopted the following guiding principles and goals for integrating climate change into the Monument's management. In adopting this guidance, Monument managers considered the best available information about climate change impacts and response options, within the context of PMNM's legal mandates and guiding documents. The remainder of this plan presents the evidence on which this guidance is based (Section 2).

Guiding Principles

A. Strong scientific evidence indicates that the global climate is changing in ways that will profoundly impact the ecosystems across the Hawaiian Archipelago including the NWHI, requiring the Monument's management to be both proactive and adaptive in order to remain effective under these new and rapidly evolving conditions.

B. Papahānaumokuākea's cultural and heritage resources are integral to understanding climate change and essential to making decisions about how to manage the Monument within this new paradigm.

C. Given the high vulnerability of Papahānaumokuākea's ecology to climate change, reducing the rate and severity of change is one of the most effective ways of protecting the Monument's resources. The Monument's managers will contribute toward efforts to reduce greenhouse gas emissions by strategically engaging in policy and stakeholder forums, raising awareness through education and outreach, as well as identifying ways of minimizing PMNM's overall climate footprint.

D. Within the context of climate change and ocean acidification, the Monument will seek to maintain ecological integrity by aiming to sustain essential ecosystem structure and function in the NWHI, recognizing that the biological diversity, abundance, and distributions of flora and fauna will inevitably change in response to changing climate conditions, and may require critical integration of natural resource management throughout the Hawaiian Archipelago.

Goals

Goal 1: Implement trans-disciplinary research and monitoring efforts to understand variation in resilience and climate change impacts across the Hawaiian Archipelago under differing climate change scenarios.

Goal 2: Implement appropriate adaptive actions before ecosystem integrity and social values are compromised.

Goal 3: Contribute toward regional and national efforts to raise awareness about climate change and change behavior through strategic partnering and engagement in policy, education, and outreach.

Goal 4: Serve as an international example in the context of climate change for collaborative management of natural, cultural and historic resources that hold universal and indigenous significance.

Goal 5: Account for climate change in the Monument’s operations and logistics plans.

Chapter 2

VULNERABILITY ASSESSMENT

This section summarizes the available scientific evidence about how climate variables will change over the next 100 years in the NWHI (Section 2.1), and what these changes mean for PMNM's marine (Section 2.2), terrestrial (Section 2.3), and cultural and heritage (Section 2.4) resources. These resources are further described in Sections 2.2 through 2.4, as are their key vulnerabilities to climate change. This vulnerability assessment forms the basis for future research and management strategies.

2.1 Climate Variables

Climate change is driven by emissions of greenhouse gases, particularly CO_2. As of March 2016, atmospheric CO_2 stood at 405 ppm, an increase of over 85 ppm from when standardized measurements first began to be collected in the late 1950s at the Mauna Loa Observatory (Figure 2.1.1). Over the past 80,000 years, atmospheric CO_2 concentrations

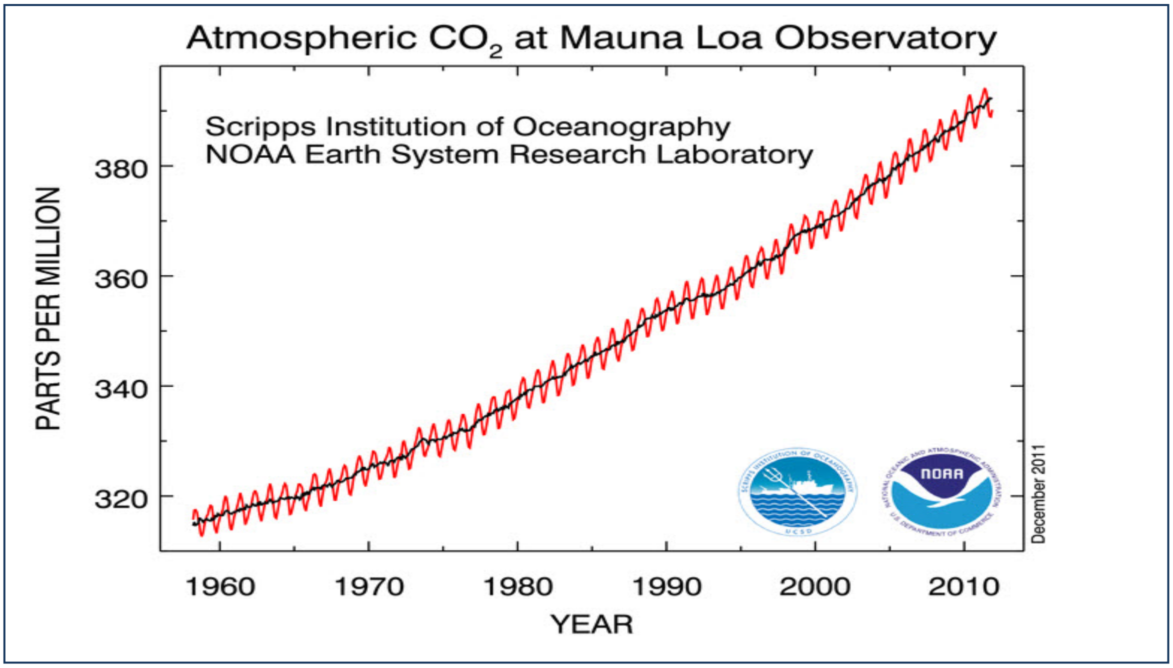


Figure 2.1.1 Trend in atmospheric concentration of CO_2 at the Mauna Loa Observatory.

have varied within a range of about 170–300 ppm. Depending on the particular Representative Concentration Pathway (RCP) scenario employed, CO_2 concentrations are predicted to reach levels between approximately 420–930 ppm by the end of the century (IPCC, 2014). It is important to note, however, that while past assessments of future climate scenarios are based on the Special Report on Emissions Scenarios (SRES), this has been superseded by an approach that predicts future greenhouse gas concentrations in the atmosphere using four RCPs designated numerically as RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 respectively, each of which represents a progressively higher concentration trend of atmospheric CO_2 by 2100. Based on current trends, RCP 6.0 or RCP 8.5 should be considered as the most likely future outcomes at this time, and it is therefore recommended that Monument management decisions be made in the context of these projected concentrations, and the associated values of other stressors and outcomes linked to them.

Table 2.1.1 Estimated future states for climate change variables under lowest and highest RCP concentration scenarios, based on data contained in the IPCC Assessment Report 5 (2014). It should be noted that the projections for air temperature in particular hold significant uncertainty due to the influence of the surrounding ocean in the maritime sector containing the Monument. It should be further noted that based on current carbon emission trends, RCP 8.5 outcomes are far more likely than RCP 2.6 outcomes.

Variable	2035 Predicted Value RCP 2.6–RCP 8.5	2100 Predicted Value RCP 2.6 (420 ppm)	2100 Predicted Value RCP 8.5 (930 ppm)
Sea Surface Temperature (SST)	+0.5–0.9 °F +0.3–0.5 °C	+1.8–3.1 °F +1.0–1.7 °C	+4.0–4.9 °F +2.2–2.7 °C
Ocean surface pH[1]	8.05–8.00	8.05	7.75
Sea-level rise	+2–8 inches +5–20 cm	+1.0 feet +0.28 m	+3.2 feet +0.98 m
Crossover Point Reached[2]	No	No	Yes
Tropical Storms	Fewer, Stronger	Fewer, Stronger	Fewer, Stronger
Air Temperature[3] (Land)	+0.7–2.0 °F +0.4–1.1 °C	+2.3–3.4 °F +1.3–1.9 °C	+7.2–11.0 °F +4.0–6.1 °C
Air Temperature (Ocean)	+0.5–0.9 °F +0.3–0.5 °C	+1.4–2.1 °F +0.8–1.2 °C	+4.7–7.2 °F +2.6–4.0 °C

[1]Current open ocean pH at the sea surface is approximately 8.1.
[2] The "cross-over point" is a threshold at which sea-level rises above the level of the carbonate platform on which an atoll is formed, allowing waves to directly attack the overlying alluvial cap, which is structurally weaker and more vulnerable.
[3]These values are based on calculations including continental land masses, and are likely to be excessive in the context of the small islands in the Monument, except perhaps in particularly sheltered locations.

PMNM is very likely to be affected by changes in climate variables over the next century (Table 2.1.1). Ocean pH is very likely to decline as more carbon dioxide is absorbed into the ocean (Section 2.1.1); air and sea temperatures are very likely to continue to warm (Section 2.1.2); sea level is very likely to rise due to thermal expansion of water and melting of land-based glaciers (Section 2.1.3); and ocean circulation patterns are likely to change at local to global scales (Section 2.1.4). Storm intensity may also increase, and extreme flood and drought events may become more frequent (Section 2.1.5). The general patterns and directions of these trends are predicted through global scale models; however, projecting how these variables will change locally at the scale of the Monument is difficult based on the coarse spatial resolution of current climate models. Additionally, validation is further hindered by inadequate local instrumentation networks. The various manifestations of climate change listed above will drive impacts to the natural, cultural, and heritage resources of the Monument. The sections below summarize findings of a critical review conducted by PMNM's Climate Change Working Group of what is currently known about climate change variables, and which ones are likely to be the most significant drivers of change in the Monument.

2.1.1 Ocean Acidification

The oceans absorb CO_2 from the atmosphere, and nearly half of the CO_2 produced by human societies over the past 250 years is estimated to have been taken up by the oceans (Royal Society, 2005). This additional dissolved CO_2 changes the chemistry of the oceans (Figure 2.1.2) and is projected to decrease the average ocean pH by 0.4–0.5 compared with pre-industrial levels (Caldeira & Wickett, 2003). If this hypothesis is correct, the oceans will by 2100 attain a lower pH than at any time in the past 400,000 years (Feely et al., 2004).

When CO_2 is absorbed by seawater, chemical reactions occur that reduce seawater pH values, carbonate ion (CO_3^{2-}) concentrations, and saturation states of the biologically important $CaCO_3$ minerals calcite (Ωca) and aragonite (Ωar) in a process commonly referred to as ocean acidification (Feely et al., 2009). For many organisms, including corals, crustose coralline algae, mollusks, and plankton, the reduced availability of these calcium carbonate minerals is very likely to make it more difficult to incorporate calcium carbonate into their shells and skeletons (Wootton et al., 2008, also see Section 2.2). Evidence from the geologic record, principles of thermodynamics, and the evolutionary pathways of $CaCO_3$ secreting organisms, also indicates that as the aragonite saturation point decreases, not only will calcification rates decrease, but carbonate dissolution rates will increase, meaning that coral skeletons may dissolve more easily (Crook et al., 2013). In addition to impairing calcification, ocean acidification may also negatively impact other aspects of development and reproduction in marine organisms (Wittman & Portner, 2013), discussed further in Section 2.2.

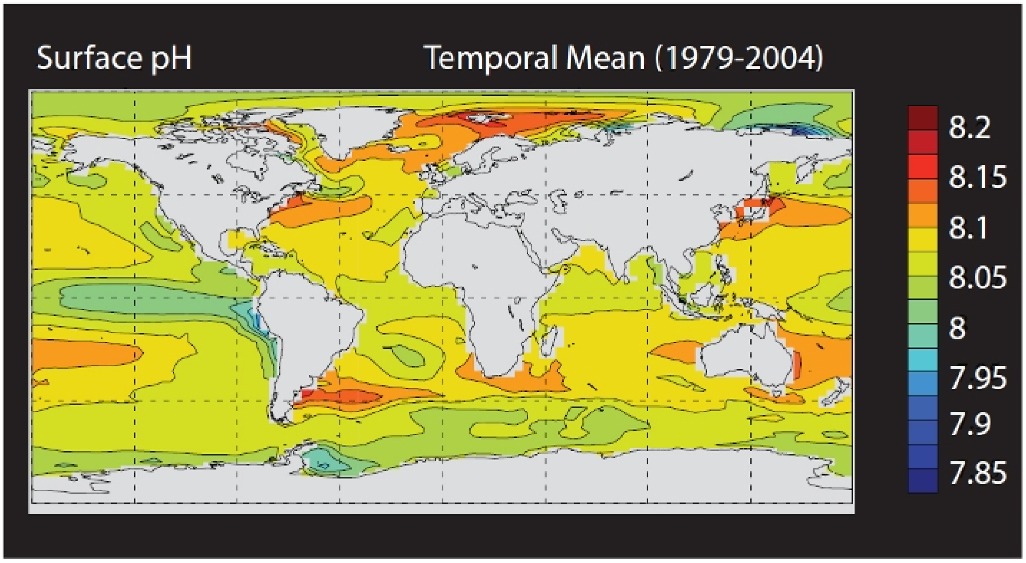


Figure 2.1.2 Sea surface pH trends from 1979–2004.

Current models and observations indicate that ocean acidification proceeds more rapidly at depth and in colder waters, however, its effects will eventually work their way into the upper ocean layers inhabited by shallow-water reef-building corals, a trend that already appears evident in the northern Pacific (Byrne et al., 2010). For example, data from Station Aloha, an oceanographic monitoring site northeast of O‘ahu (Karl & Lukas, 1996), indicate that pH at the ocean surface is decreasing as colder more acidic waters are increasingly being mixed into the surface waters; this mixing appears to be driven by changes in water density at the surface and at depth that are thickening the upper ocean mixed layer at a rate of about 4 m/decade.

2.1.2 Air and Ocean Temperatures

Both the atmosphere and the oceans are warming due to the enhanced greenhouse effect caused by the accumulation of CO_2 and other greenhouse gases in the atmosphere (IPCC, 2014), and Hawai‘i is no exception to this trend (Giambelluca et al. 2008). Global average land surface temperature is projected to increase 1.3–6.1 °C by 2100, with best estimates placing the range between 1.8 and 4.0 °C (IPCC, 2014). To better understand changes in air temperature across the NWHI, Krause et al. (2012) downscaled six general circulation models using the delta change method and emissions scenario A1B, an intermediate emissions scenario in which CO_2 concentrations stabilize at 750 ppm. Their results project an increase in average maximum temperature by approximately 2.2°C (SD 0.2) across the NWHI by 2100 (Table 2.1.2), with the greatest temperature increase of 2.6°C (SD 1.7) predicted for Kure, Midway, Pearl and Hermes and Lisianski. These values have not been recalculated in the context of the newer RCP concentration scenarios, and should therefore be considered provisional, but are included herein as one peer-reviewed projection of possible future values.

The ocean is an enormous reservoir of heat, with the top few meters storing an amount of heat equivalent to that in the entire atmosphere (Houghton, 2004). The increase in average tropical sea surface temperature (SST) is expected to run between 50–80% of the change seen in average atmospheric temperature (Lough, 2007). Therefore, average sea temperatures in the vicinity of coral reefs will probably increase by several degrees Celsius over the course of this century (Figure 2.1.3; Guinotte et al., 2003). The implications of warmer temperatures and the frequency of extreme temperature events on coral reef ecosystems are discussed further in Section 2.2.

Table 2.1.2 Projections of change in average maximum temperature for the NWHI based on downscaling six general circulation models using the A1B emissions scenario (reproduced from Krause et al. 2012).

	WorldClim (1960–1990)		Predicted Change (2100)											
	Annual	± SD	CCCMA CGCM3.1.T63	± SD	GFDL CM2.0	± SD	GFDL CM2.1	± SD	MPI ECHAM5	± SD	MRI CGCM2.3.2A	± SD	UKMO HADCM3	± SD
Average maximum temperature (°C)														
Kure Atoll	23.4	0.0	1.8	1.2	2.2	1.4	2.5	1.6	2.3	1.5	2.6	1.7	1.9	1.2
Midway Atoll	23.6	0.0	1.8	1.2	2.1	1.4	2.5	1.7	2.3	1.5	2.6	1.7	1.9	1.2
Pearl and Hermes Atoll	23.5	0.0	1.8	1.2	2.1	1.4	2.6	1.7	2.3	1.5	2.6	1.7	1.9	1.3
Lisianski Island	23.5	0.0	1.8	1.2	2.1	1.4	2.6	1.7	2.3	1.5	2.6	1.7	2.0	1.3
Laysan Island	24.5	0.1	1.9	1.3	2.5	1.6	2.0	1.3	2.3	1.5	2.5	1.6	2.0	1.3
French Frigate Shoals	25.3	0.1	2.0	1.3	1.9	1.2	2.4	1.5	2.3	1.5	2.2	1.4	2.2	1.4

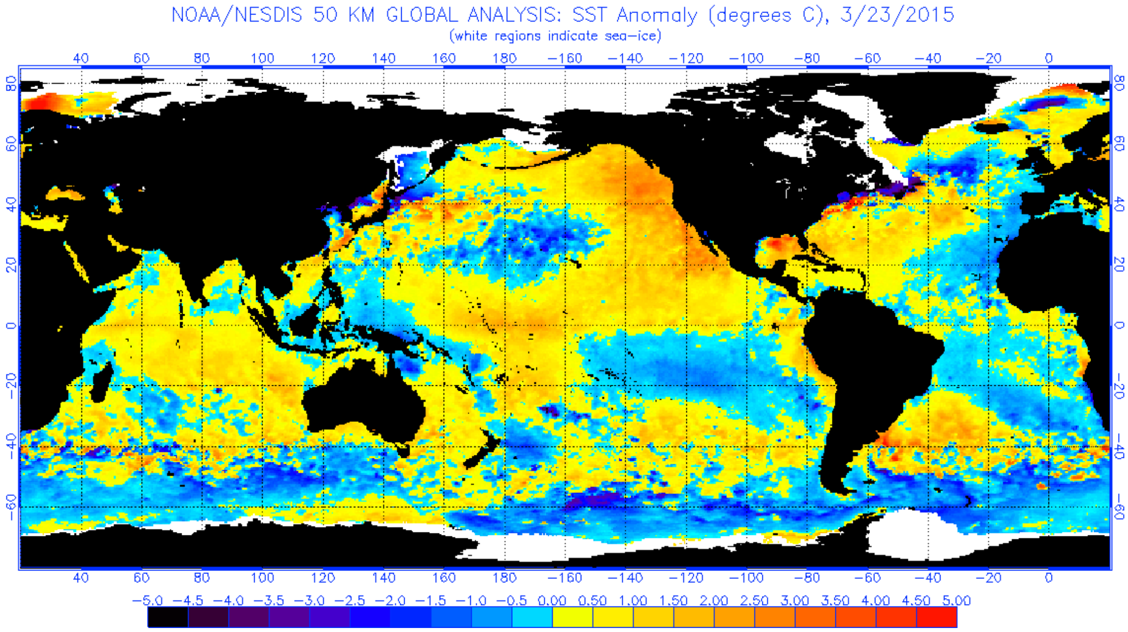


Figure 2.1.3 Current global trends in sea surface temperature deviation from long-term means based on satellite data.

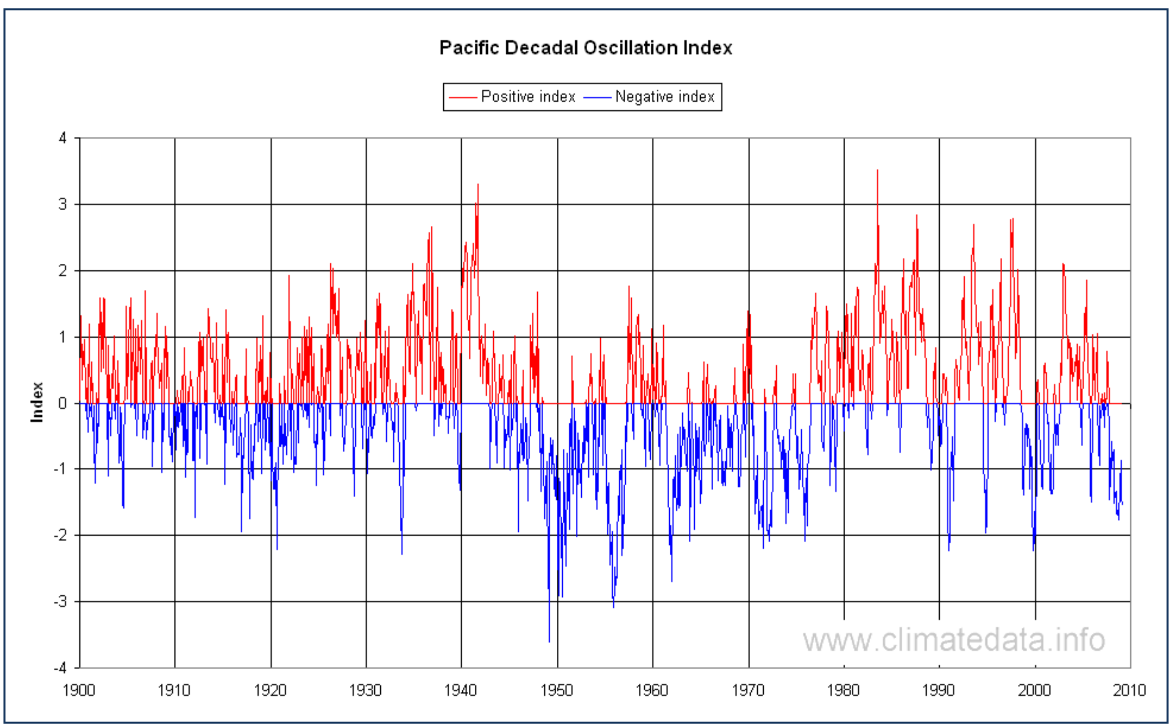


Figure 2.1.4 Trends in Pacific Decadal Oscillation from 1900–2010, showing recent transition from positive to negative.

Short to medium-term climate oscillations, such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), are also likely to introduce variability into the overall warming trend. There is no scientific consensus on whether ENSO events will change in relative duration or intensity, but there is agreement that these events will continue to be a significant source of inter-annual variability in SST across the Pacific region (Lough, 2007). Current global circulation models predict warming of SSTs in an equatorial strip, stronger evaporative cooling outside the equator, a weakening of Hadley Cells and associated atmospheric circulation (Vecchi et al., 2006), and more persistent El Niño conditions in the Eastern Pacific (Xie et al., 2010). These model predictions, however, are based primarily on data collected prior to 1995, and are not supported by more recent observations. Instead, climate in the Eastern Pacific during the past 15 years has been characterized by increasing trade wind speeds, cooler SSTs, and more persistent La Niña conditions. This inconsistency between global model predictions and current reality may possibly be linked to the PDO, a climate cycle that operates on a much longer scale than the ENSO cycle that drives El Niño and La Niña events (Figure 2.1.4). The current 15 year prediction (2009-2024) for the PDO indicates that SSTs in the Hawai‘i sector will remain cooler than long term averages during this period (Meehl et al., 2009), before the PDO cycle shifts to a warm phase around 2025.

2.1.3 Sea-Level Rise

Globally, average sea level is projected to rise 30–40 cm by 2100, based on the expansion of warming water (Church & White, 2006; IPCC, 2014), and up to 1 m if current rates of carbon emission continue on their sharp upward trend and the melting of ice sheets and glaciers accelerates dramatically (Nicholls et al., 2011; Rignot et al., 2011; Velicogna & Wahr, 2006). Rahmstorf et al. (2011) estimate a general relationship of 1 m of sea-level rise for each 1.8 °C of warming. Sea-level rise may not be a slow, gradual and linear process; recent isotopic dating of coral samples from Tahiti taken by the Ocean Drilling Program indicates that past continental ice-sheet collapse in the Pleistocene led to rises in sea level on the order of 20 m in less than 500 years, which would be 4 times the rate currently predicted (Deschamps et al., 2012). Additionally, a recent study of terrestrial ice melt from Greenland, Antarctica and other places found that resulting sea-level rises may disproportionately affect Hawaii as gravity redistributes this melt water around the globe (Spada et al., 2013). These projections, combined with likely increases in storm and wave energy, mean that there is a high likelihood of inundating low-lying islands within the NWHI and increasing coastal erosion on all islands over the next 50–100 years (Nicholls et al., 2011).

Observations since the 1870 indicate an average sea-level rise of nearly 20 cm, with average rises of 3.2 mm/year since 1993 (Nicholls & Cazenave, 2010; IPCC, 2014); however, this rate is not uniform around the globe (Figure 2.1.5). In Hawai‘i, the average rate of sea-level rise has been 1.46 mm/year since 1900, which is only half the global rate. Even within the Hawaiian Archipelago this rate is variable, ranging from 0.7 mm/yr at Midway to 3.27 mm/yr at Hilo (Parker 2013). These trends have been largely deduced from tide gauge records, which have recently been cross-validated with satellite altimetry; the data from both tide gauges and satellites correlate well, indicating that the tide gauge records are accurate for the pre-satellite time series, which extends back for 90 years in the Monument.

The currently slow sea-level rise in much of the Hawaiian Archipelago is probably an interim anomaly linked to the current phase of the PDO. The current phase of the PDO is associated with stronger winds (Firing et al., 2004) that move surface waters toward the Western Tropical Pacific, which has experienced rapid sea-level rise since 1995 (Merrifield, 2011; Merrifield et al., 2009). During the next phase of the PDO, trade winds are expected to weaken, thus potentially leading to more rapid, non-linear rises in sea level across the NWHI. The U.S. Army Corps of Engineers (USACE) has developed a sea-level change calculator, which has subsequently been modified by NOAA (http://www.corpsclimate.us/ccaceslcurves.cfm), to help assess how future sea-levels could look like. While this tool currently does not have any active gauges in the NWHI, the calculator predicts future sea levels exceeding today's values by 0.17-1.98 m in 2100, at the active tide gauge closest to PMNM in Nawiliwili, Kaua'i.

Even before physically overtopping PMNM's atolls, rising sea levels will impact the Monument's islands, atolls, ecosystems, and infrastructure in a number of ways, discussed in more detail in Section 2.3. Initially, it will change the size, shape, and possibly the location of atolls (Webb & Kench, 2010). Over time, wave action will attack the alluvial cap that covers the carbonate platform on which atolls are formed, leading to accelerated erosion even prior to overtopping as this cross-over point is reached (Dickinson, 2009; also see Table 2.1.1 and Section 2.1.5). Additionally, more frequent seawater over-wash during storms and high tides will alter habitats and may threaten some nesting areas and certain endemic plants. Sea-level rise will also reduce the amount of water that is held in the freshwater lens of atolls and small islands, a resource that is vital to many atoll plants and animals; thin lenses not only contain less water, but are also more susceptible to degradation in quality due to saltwater intrusion (Presley, 2005; Bridges & McClatchey, 2009).

2.1.4 Ocean Circulation

Changes in temperature and freshwater input at the poles are expected to change the intensity and direction of thermohaline circulation patterns (Rahmstorf, 1997; Steinberg, 2007; Stocker & Schmittner, 1997). In the tropical Pacific, several changes have already been observed. In particular, there has been a steady expansion in the extent of subtropical oligotrophic gyres over the past decade (Polovina et al., 2008), primarily during the winter months. These are waters with low surface chlorophyll and correspondingly low primary productivity. The area encompassed by expanding gyre in the North Pacific includes the Monument and the implications of these changes for PMNM's marine environments are discussed in Section 2.2.

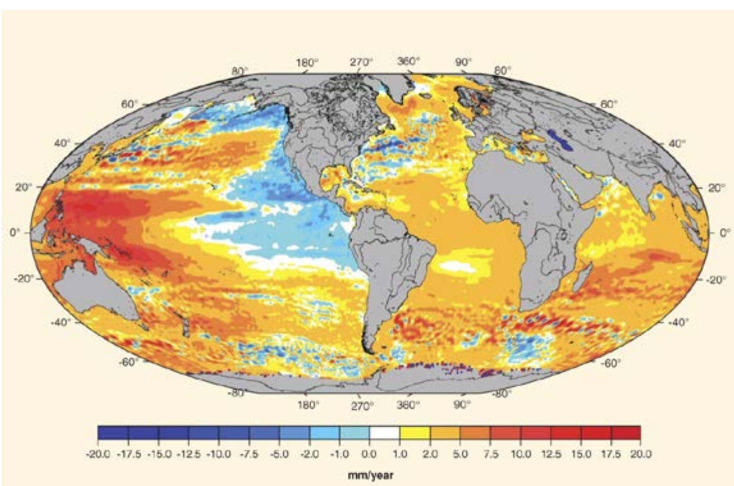


Figure 2.1.5 Current trends in sea-level rise based on satellite altimetry.

2.1.5 Storms and Weather

While there is no clear consensus on how climate change may affect tropical storms, there is some evidence that storms may become more intense (Yu et al., 2010) or change their historical trajectories (Li et al., 2010). Some global circulation models predict that climate change will result in fewer tropical storms, due to an increased propensity for wind shear in high SST environments (Nolan & Rappin, 2008), but that those storms which do form will be more intense (Bengtsson et al., 2007). Climate change may result in approximately a 25% increase in atmospheric water vapor in the tropics over the next 100 years, and a longer residence time of water in the atmosphere; this moister atmosphere is capable of retaining greater heat content, and thereby spawning stronger storms (Bengtsson et al., 2007). Global circulation models therefore predict an increase in the proportion of extreme weather events in the most severe categories (IPCC, 2007a; Webster et al., 2005), which may cause significant shoreline loss or damage due to erosion by waves. There is already some evidence of increased storm events in the Pacific Ocean and in the Monument. For example, tide gauge observations at Midway suggest that the number of storm events originating outside the tropics has increased significantly over the past 50 years (Aucan et al., 2012), and deep-water significant wave heights in the Pacific Northwest are estimated to have increased by nearly 2 m over the last 30 years (Ruggiero et al., 2010).

Storm events can cause severe damage to PMNM’s natural and cultural resources, including the islands and atolls themselves. As noted previously, atolls may be lost to wave action long before sea-level rise physically overtops them, because once sea-level rises above the level of the carbonate platform on which the atoll is formed, waves are able to directly attack the overlying alluvial cap, which is structurally weaker and more vulnerable (Dickinson, 2009). The “crossover point” at which this transition occurs may be reached in the Monument and many other archipelagoes in the Pacific as early as 2050. Additionally, storm waves are known to cause significant damage to coral reef ecosystems (Fabricus et al., 2008), and storm overwash has caused significant damage to near-shore ecosystems, nesting areas, and infrastructure (See Section 2.3).

Table 2.1.3 Projections of change in total annual precipitation for the NWHI based on downscaling six general circulation models using the A1B emissions scenario (reproduced from Krause et al. 2012).

	WorldClim (1960–1990)		Predicted Change (2100)												
	Annual	± SD	CCCMA CGCM3.1.T63	± SD	GFDL CM2.0	± SD	GFDL CM2.1	± SD	MPI ECHAM5	± SD	MRI CGCM2.3.2A	± SD	UKMO HADCM3	± SD
Total precipitation (mm)														
Kure Atoll	818.7	1.3	-85.6	55.7	-99.8	65.0	-84.8	55.3	-56.0	36.5	-27.9	18.2	-103.5	67.4
Midway Atoll	801.6	1.3	-89.3	58.2	-107.0	69.7	-87.6	57.1	-64.6	42.1	-28.9	18.9	-87.0	56.7
Pearl and Hermes Atoll	812.1	1.5	-90.3	58.8	-121.3	79.0	-91.6	59.6	-91.5	59.6	-44.0	28.7	-67.7	44.1
Lisianski Island	846.6	1.7	-91.9	59.9	-138.7	90.3	-95.5	62.2	-117.2	76.3	-51.4	33.5	-54.2	35.3
Laysan Island	778.8	5.6	-97.8	63.7	-158.1	103.0	-120.7	78.6	-126.6	82.5	-81.5	53.1	-4.3	2.8
French Frigate Shoals	577.2	3.5	-89.0	58.0	-51.4	33.5	-26.7	17.4	-34.8	22.7	-66.0	43.0	119.5	77.8

The impacts of climate change on weather patterns across the Hawaiian Archipelago is also not well understood, however, some evidence suggests an increase in extreme events and an overall reduction in precipitation. Overall, precipitation trends are likely to remain significantly influenced by regional ENSO and PDO events, therefore trend prediction is difficult. In the MHI, studies have shown a shift toward more light rainfall events, and fewer heavy rain events, resulting in increased drought (Chu et al., 2010) and reduced stream flow (Oki, 2004). To better understand changes in annual precipitation across the NWHI, Krause et al. (2012) downscaled six general circulation models using the delta change method and emissions scenario A1B, an intermediate emissions scenario in which CO_2 concentrations stabilize at 750 ppm. Their results project decreases in precipitation across PMNM by 2100 (Table 2.1.3). As noted previously in regard to air temperature projections by these same authors, this analysis has not been revised in the context of more recent RCP scenarios, so its projections should be viewed as provisional.

2.1.6 Key Implications

Expert analysis of existing evidence suggests the following changes in key climate variables for PMNM:

- It is very likely that the rate and extent of atmospheric greenhouse gas concentrations will determine the speed and severity of other climate change impacts, and the ability of natural systems to adapt to these changes. As of March 2015, atmospheric CO_2 stood at 400 ppm; over the past 80,000 years, by contrast, atmospheric CO_2 concentrations have varied within a range of about 170-300 ppm.
- The oceans have absorbed nearly half of the CO_2 produced by human societies over the past 250 years, changing ocean chemistry through a process known as ocean acidification; one of the major implications of ocean acidification is the reduced availability of calcium carbonate minerals which are the building blocks that many marine organisms use to build their shells and skeletons.
- Both air and SST are warming and an increase in the frequency of extreme heat events is projected. Under an intermediate greenhouse gas emissions scenario, available modeling estimates that air temperatures across the NWHI will rise by an average of 2.2 °C (4 °F) by 2100, with the greatest temperature increase of 2.6°C (4.7 °F) predicted for Kure, Midway, and Pearl and Hermes and Lisianski. Average SST are estimated to increases from 1.0–2.8 °C (2–5 °F) by 2100.
- Projected sea-level rise, combined with likely increases in storm and wave energy, indicate that there is a high likelihood of periodic inundation for the low-lying islands within the NWHI, and steadily increasing potential for coastal erosion on all islands over the next 50–100 years.
- Changes in ocean circulation patterns are likely. There is already evidence that areas with low surface chlorophyll and correspondingly low primary productivity, known as oligotrophic gyres, are expanding. Changing circulation may also influence the connectivity between islands, atolls, and the broader Pacific.
- Tropical storms are projected to become less frequent but more intense, and may change their historical trajectories.
- There may be more extreme weather events and an overall reduction in precipitation.

2.2 Marine Ecosystems

> *Critical areas to me would be the effects of climate change on corals, those foundational species that support entire ecosystems.*
>
> - Respondent, PMNM Climate Change Survey

Papahānaumokuākea’s marine ecosystems are considered some of the geologically oldest, most remote, and pristine in the world (Grigg et al. 2008). This section describes the Monument’s marine ecosystems (Section 2.2.1), identifies and prioritizes projected vulnerabilities to climate change (Section 2.2.2), and summarizes the issues anticipated to be of greatest concern to these ecosystems and associated species (Section 2.2.3).

*2.2.1 **Marine Ecosystems in Papahānaumokuākea***

Consisting of ten major island, atoll, and reef areas, the Monument provides a refuge for marine life within an otherwise expansive open-ocean environment. There are also numerous submerged banks and seamounts within the PMNM’s boundaries. These ecosystems are an essential spiritual and cultural foundation for Native Hawaiians (Figure 2.2.1), and they provide critical habitat for a range of unique and protected species, including the Hawaiian monk seal, green and hawksbill sea turtles, and more than 20 species of cetaceans. Overall, it is estimated that the NWHI are home to over 8,400 marine species, one quarter of which are found only in the Hawaiian Archipelago.

The Monument’s marine ecosystems are strongly influenced by the area’s environmental conditions and remoteness. Large-scale climate events, like the PDO and El Niño, influence the location of major oceanic currents, with significant impacts on nutrient availability and productivity throughout the NWHI, particularly in the northern part of the archipelago (Polovina, 1984; Polovina & Haight, 1999). Within the Monument’s coastal waters, temperature and movement patterns of strong winter waves have shaped the distribution of coral reefs. Summarizing several decades of research, Grigg et al. (2008) concluded that large winter swells are responsible for the best developed reefs occurring in lagoons or along southwest exposures throughout the archipelago, and that temperature and winter waves are the main drivers behind the peak in coral abundance and diversity found in the middle of the NWHI, around FFS and Maro Reef. They argue that cool winter temperatures, and to a lesser extent lower solar radiation, suppress coral growth in the Monument’s northern atolls, around Kure and Midway; whereas, exposure to severe winter waves around the southern islands of Mokumanamana and Nihoa prevent any substantial reef development. Coral reef biodiversity peaks at FFS, and is possibly influenced by wind and water circulation patterns that create a corridor of connectivity with Johnston Atoll (Friedlander et al., 2009; Kobayashi, 2006; Toonen et al., 2011). Throughout the Hawaiian chain, the general east-to-west direction of winds, currents, and therefore larval movement, mean that the recovery of NWHI reefs after mortality events may be influenced by the condition of reefs at Johnston Atoll and the MHI (Friedlander et al., 2009; Grigg et al., 2008). However, larval retention around individual islands is high, and connectivity studies suggest that to achieve recovery from a neighboring island after a major mortality event would take many generations (Toonen pers. comm.)

The Monument’s coral reefs have low diversity and coral cover by global standards, but exceptionally high endemism (Grigg et al., 2008; Maragos et al., 2009; Kane et al., 2014). Approximately 60 species of zooxanthellate stony corals have been identified (Maragos et al., 2009; Maragos et al., 2004) and roughly 30% of PMNM’s corals are endemic (Grigg et al. 2008). Average coral cover on NWHI reefs ranges from 5-20% (Maragos et al., 2009). These patterns are likely due to the NWHI’s cooler, subtropical waters and the extreme remoteness of the Monument.

Reefs within PMNM are dominated by macroalgae species. Calcareous algae play a critical role in binding the reef together and contributing to sand production on beaches; turf algae and seaweeds are major contributions to the base of the foodweb (Friedlander et al., 2009; Polovina, 1984). Overall, 355 species of algae have been identified within Papahānaumokuākea (Vroom & Page, 2006).

The marine food web of the NWHI has been studied extensively and an influential model of the trophic structure at FFS (Box 2.2.1) was developed and published in the 1980s (Polovina, 1984), which has been subsequently updated (Friedlander et al., 2009). These and other studies of the trophic relationships at FFS identify that benthic algae make the greatest contribution to higher trophic levels, followed by phytoplankton. The system is generally conceived as having a relatively short food chain of roughly four trophic layers (Friedlander et al., 2009; Polovina, 1984). Benthic algae and phytoplankton support a primarily herbivorous 2nd tropic layer of zooplankton, which are mainly fish larvae, and benthic invertebrates. The 3rd trophic layer of carnivorous and omnivorous organisms includes small pelagic fishes, lobsters, crabs, reef fish, bottom fish, as well as herbivorous green sea turtles (see also Grigg et al., 2008, Friedlander et al., 2009 and Kane et al. 2014 for further discussion about these fish communities, their high levels of endemism, and their history of harvest within the NWHI). The food chain culminates in a dominant layer of apex predators that include sharks, jacks, scombrids, monk seals, and seabirds. These predators provide a strong top-down forcing on the NWHI food web and their vulnerability to climate change can be expected to influence the future structure of this unique system. It is often noted that this predator-dominated structure differentiates the NWHI and MHI; apex predators account for more than 50% of the total fish biomass in the NWHI, while this same group accounts for less than 3% in the MHI (Friedlander & DeMartini, 2002).

Box 2.2.1 In Native Hawaiian genealogy, the coral polyp is the first created life form:

Birth—creation—is a central pillar of traditional cultures across the globe. In Native Hawaiian culture, human life comes not only from two biological parents, but from a complex spiritual and literal genealogy that ties humans with a bond of kinship to everything else, both living and non-living, in the natural world. Pō, the primordial female darkness from which all life springs and to which it returns after death, is seen as giving birth to the world, its natural components, all of the Hawaiian gods, and humans. The union of her progeny, Kumulipo and Pōʻele, gives rise to all the creatures of the world, beginning in the oceans with the coral polyp—a genealogy that, like current theories of evolution, starts with the simplest known life form and moves to the more complex.

- PMNM World Heritage Application, p. 27

This genealogy is described in the Kumulipo, a Hawaiian Creation Chant, quoted here with Beckwith's (1951) translation:

O ke au i kahuli wela ka honua
At the time when the earth became hot
O ke au i kahuli lole ka lani
At the time when the heavens turned about
O ke au i kukaiaka ka la
At the time when the sun was darkened
E hoomalamalama i ka malama
To cause the moon to shine
O ke au o Makalii ka po
The time of the rise of the Pleiades
O ka walewale hookumu honua ia
The slime, this was the source of the earth
O ke kumu o ka lipo, i lipo ai
The source of the darkness that made darkness
O ke kumu o ka Po, i po ai
The source of the night that made night
O ka lipolipo, o ka lipolipo
The intense darkness, the deep darkness
O ka lipo o ka la, o ka lipo o ka po
Darkness of the sun, darkness of the night
Po wale ho--i
Nothing but night
Hanau ka po
The night gave birth
Hanau Kumulipo i ka po, he kane
Born was Kumulipo in the night, a male
Hanau Poele i ka po, he wahine
Born was Poʻele in the night, a female
Hanau ka Uku-koakoa, hanau kana, he Akoakoa, puka…
Born was the coral polyp, born was the coral, came forth…

Parrish and Boland (2004) report that the Monument's moderately deep terraces and banks (30-40 m) are similarly dominated by apex predators, but with an overall mean biomass that is one fifth of that reported for shallow reefs in the region. These areas make up more than 4500 km^2 of the region's reef area, and are dominated by algal meadows (65% cover) and relief features that aggregate fish populations (Parrish & Boland 2004).

More recently, a series of NOAA expeditions have been launched to survey PMNM's coral reef ecosystems found at depths below conventional SCUBA diving (>30 m; see Wiener & Wagner, 2013). These coral reef ecosystems, commonly known as mesophotic coral ecosystems (MCEs), host distinct communities that differ from their shallow-water reef counterparts. Multiple significant discoveries have resulted from these expeditions, including the collection of several previously undescribed species and the geographic range expansions of many known species (Wagner et al., 2011; Kane et al., 2014). Perhaps the most significant finding is that the reef fish assemblages of NWHI MCEs are dominated by Hawaiian endemic species, which comprise >90% of the numerical abundance and >70% of the total number of fish species on some mesophotic reefs (Kane et al., 2014). These findings indicate that MCEs in the NWHI represent important reservoirs of biodiversity, and further support the protection of the PMNM through the highest conservation standards available (Wagner et al., 2011; Kane et al., 2014).

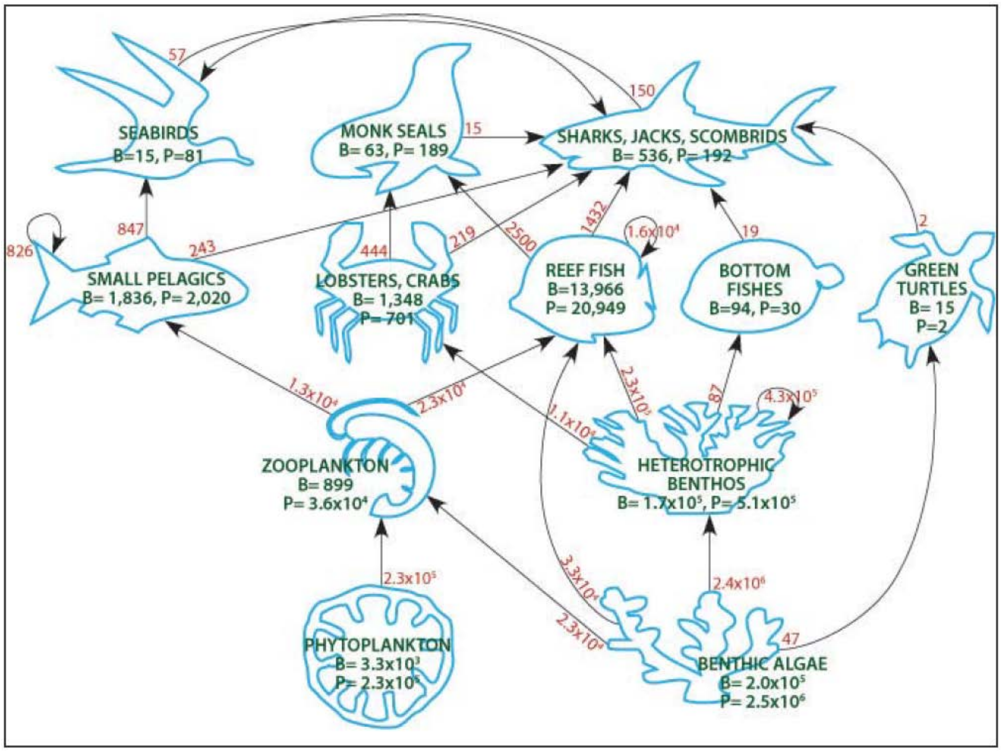


Figure 2.2.1 Ecopath model of French Frigate Shoals showing the biomass and productivity of the area's four trophic-level food web. Data from Polovina 1984; figure from Friedlander et al., 2009.

2.2.2 Projected Vulnerability to Climate Change

Climate change has significant implications for PMNM's marine ecosystems, summarized in Table 2.2.1. The following sections identify what is known about likely impacts to the Monument's pelagic ecosystems (Section 2.2.2.1), coral reef ecosystems (Section 2.2.2.2), and the endangered species associated with these systems (Section 2.2.2.3).

Table 2.2.1 Relative vulnerability of PMNM's marine ecosystems to different climate change variables in the near term (by 2035) based on assessment by climate change experts gathered for a PMNM workshop in 2012.

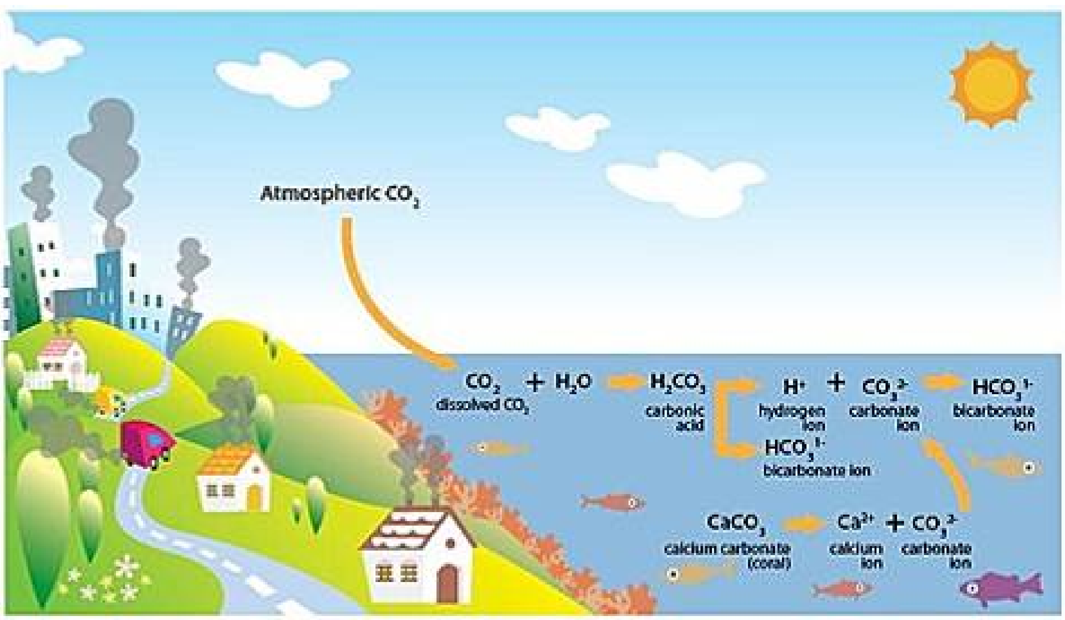
Ecosystem	Increased sea temperature	Sea-level rise	Ocean acidification	Change in currents	Change in storm tracks or intensity	Change in precipitation or weather	Key Vulnerabilities
Pelagic (open-ocean)	Moderate	Low	High	Low	Low	Moderate	❖ The abundance, distribution, and diversity of pelagic organisms is likely to shift with climate change ❖ Ocean acidification is likely to impact pelagic organisms, particularly plankton and larval life forms; effects are likely to vary among species ❖ Changes in temperature and a possible decrease in wind are very likely to increase vertical stratification patterns and decrease oceanic productivity ❖ Overall biodiversity is likely to decline ❖ Specialist species with narrow environmental ranges are likely to be more vulnerable than generalist species.
Coral reefs	Very high	Low	Very high	High	Moderate	Low	❖ Overall loss in biodiversity is very likely as climate change and habitat loss impact algal, invertebrate, and fish communities ❖ The frequency of acute damaging events from bleaching, disease, and storms are very likely to increase ❖ Ocean acidification is likely to impair corals' ability to recover from acute events
Submerged banks and seamounts	Low	Low	High	High	Low	Low	❖ Acidification may change the composition of submerged banks and seamount communities

Confidence: ❖ Low ❖ Medium ❖ High

2.2.2.1 Pelagic Ecosystems

The Monument's pelagic ecosystems are likely to experience significant shifts due to climate change as a result of ocean acidification (Figure 2.2.2), and changes in temperature and winds that shift convergent zones, currents, and areas of upwelling. Ocean acidification has the potential to impact the growth and development of all pelagic organisms; although research so far suggests high variation in impacts between species. One of the most significant impacts from climate changes is likely to be in phytoplankton development, abundance, and distribution, with repercussions throughout the pelagic food web. Additionally, shifts in the distribution of a range of species creates the potential for mismatches between predators and the availability of prey, which may result in significant ecosystem impacts (Kingsford & Welch, 2007).

Analysis of past and current climatic changes around the NWHI provides further evidence of likely impacts, both positive and negative. For example, a North Pacific climate event between 1977-88 increased the depths at which deeper, nutrient-rich waters mixed with surface waters by 30-80%, as winter storm paths shifted south and wind speeds increased; this greater mixing increased nutrient availability and productivity in the NWHI during that time (Polovina & Haight, 1999; Polovina et al., 1994). More recently, Polovina et al. (2008) have demonstrated that oligotrophic waters (the least productive ocean waters containing less than 0.07 mg of chlorophyll/m^3) are expanding in area throughout the North Pacific, a finding that is consistent with predictions that warming surface waters will increase vertical stratification, thereby decreasing nutrient availability at the surface, photic zone.



A

Figure 2.2.2 How ocean acidification impacts biological calcification. As CO_2 is absorbed by the atmosphere it bonds with sea water forming carbonic acid. This acid then releases a bicarbonate ion and a hydrogen ion. The hydrogen ion bonds with free carbonate ions in the water forming another bicarbonate ion. This free carbonate would otherwise be available to marine animals for making calcium carbonate shells and skeletons (reproduced from Ocean.org).

great deal is unknown about the adaptive capacity of pelagic ecosystems to climate change. The high generational turn-over of phytoplankton and zooplankton species at the base of the food web may provide hope for evolutionary adaptation. Larger organisms may be able to adapt to increased sea temperatures by moving to new locations, but will still be vulnerable to changes in prey-predator relationships. Overall decreases in biodiversity are likely as some species are unable to adapt to new conditions. The vulnerability of species that inhabit both pelagic and reef ecosystems, such as sharks, marine mammals, and larval organisms, is discussed below.

2.2.2.2 Coral Reef Ecosystems

> *"For me, the corals and the algae are the critical foundation. I think the native species are important, too, in terms of connecting with the people."*
>
> \- Respondent, PMNM Climate Change Survey

This section summarizes the vulnerability of coral reef ecosystems by considering the impacts of climate variables on key ecosystem components: coral reefs, macroalgae, marine invertebrates, reef fishes, sharks, and marine mammals; Table 2.2.2 presents the section's key findings.

Coral Reefs

While the Monument's coral reef area is relatively small, it contributes disproportionately to the productivity of the NWHI's marine ecosystems by providing habitat and food. The likely and severe impacts of climate change on coral reefs is well established in the scientific literature. In essence, degradation from bleaching, disease, and storm events is very likely to increase, while reefs' ability to recover from these acute events and to keep up with rising sea-level will be compromised by ocean acidification (Hoegh-Guldberg, 2011; Hoegh-Guldberg et al., 2007; Hughes et al., 2003; Marshall & Schuttenberg, 2006; Pandolfi et al., 2011; Veron et al., 2009). Ocean acidification reduces the ability of corals to calcify their skeletons, making them more brittle and slower-growing. For example, De'ath et al. (2009) have reported a 14.2% decline of calcification in massive *Porites* since 1990 on the Great Barrier Reef (GBR), and hypothesize that, increasing temperature stress and a declining saturation state of seawater aragonite may be diminishing the ability of the GBR corals to deposit calcium carbonate. However, recent studies have provided hope that some corals may be able to adapt to bleaching events and acidification (Guest et al., 2012; McCulloch et al., 2012)

While calcification rates for NWHI corals have not been measured yet, anticipated climate-related impacts from coral bleaching and disease have been documented. A severe mass bleaching event was documented in 2002 at the three most northern atolls (Aeby et al., 2003; Kenyon & Brainard, 2006), followed by another significant event in the same area in 2004 (Kenyon & Brainard, 2006). In 2010, a significant event was documented at Kure and Pearl and Hermes (Schuttenberg et al., 2011), catalyzing the development of a formal Bleaching & Disease Response Plan for PMNM (Maynard et al., 2012). In 2014, another mass bleaching event was recorded at in the NWHI, with ~90% of coral colonies being bleached on the east side of Lisianski Island (Couch pers. comm.). Disease surveys conducted over the same time period found that coral disease is widespread but is occurring at low levels. The exception is an outbreak of *Acropora* white syndrome (AWS), which is causing massive mortality of the table corals (*Acropora cytherea*) at French Frigate Shoals (FFS) (Aeby, 2006a, 2006b). AWS is

Table 2.2.2 Vulnerabilities of PMNM's marine major taxonomic groups components to climate change variables.

Ecosystem Components	Confidence	Key Vulnerabilities
Cross-cutting	Medium	An overall loss in biodiversity is very likely as some species are unable to adapt
	Medium	Acidification is likely to impair calcification, reproduction and recruitment, thus impacting fishes, phytoplankton, corals, invertebrates, and calcareous algae
	Medium	Reef-dependent fish, invertebrates, monk seals, and sea turtles are likely to be particularly vulnerable as reef structure is lost to climate change
	Medium	Increased sea temperatures are likely to change abundances and distributions of species, including the increase of invasions by non-native species
	Medium	Warmer sea temperatures and changing circulation patterns are likely to produce mis-matches between linked events, such as breeding seasons and prey availability
	Medium	Changes in ocean circulation may transport larvae to unsuitable habitats.
	Medium	Endemic species may have lower adaptive capacity than widely distributed species and are more likely to go extinct
	Medium	Species may maintain their preferred thermal range by moving deeper or poleward
	High	Climate change is likely to impact species of significance to Native Hawaiians, such as ‘opihi and culturally significant food fish that prey on crustaceans
Phytoplankton	High	Climate change is likely to reduce overall phytoplankton biomass and change the composition & distribution of species, with cascading effects to other ecosystems
	High	Warmer sea temperatures are likely to increase stratification, reducing nutrient availability in the photic zone and reducing phytoplankton biomass
	High	An overall loss in phytoplankton biodiversity is likely as some species are unable to adapt to new conditions
Macroalgae	Medium	Climate change is likely to modify the species composition of algal communities, creating nonlinear cascading effects through the system
	Low	Climate change may favor weedier turf algae, which may benefit herbivorous species and influence a shift in the species composition at higher trophic levels
	High	Ocean acidification is likely to impair the growth of calcareous algae; these algae are a major source of sand production and are important for providing cues during coral settlement, consolidating reefs, and food sources for many species including culturally significant ones. Their loss will ultimately affect the availability of sand for NHWI beaches thus changing important nesting, breeding and basking habitats.
Marine invertebrates	High	Climate change is very likely to lead to shifts in the composition of invertebrates with substantial functional roles, as species respond differently to stress from temperature, acidification and changing circulation patterns.
	High	Climate change is likely to impact species of significance to Native Hawaiians, such as ‘opihi and food fish
Reef fishes	High	Changes in ocean temperature, acidification, circulation and habitat loss are likely to alter reef fish life histories, community structures and range distributions.
	Medium	Climate change is likely to favor generalist planktivores, small herbivores and rubble dwellers; reef-dependent fish will be most negatively impacted
	Medium	Reef fish recruitment will become more unpredictable, occurring as extreme pulse events of success or failure
Sharks & Cetaceans	High	Sharks and cetaceans are primarily vulnerable to climate change through impacts on prey availability.
	High	Temperature and ocean circulation changes change is likely to alter overall range and migratory patterns
	Low	Temperature may affect growth rates or physiological processes
	High	Species with more specialized diets and smaller ranges are very likely to have less adaptive capacity than generalist, far-ranging species

Confidence: Low Medium High

spreading across FFS with one affected site found in 2003, but by 2006 that number had increased to seven acroporid reefs. At one of the FFS outbreak sites, the *Acropora* cover dropped from 53% in 2004 to 27% in 2011 (Aeby et al., 2011; Aeby, 2006a). The differential susceptibility of NWHI corals to bleaching and disease will likely result in shifts in species composition as bleaching and disease become more common.

Hoeke et al. (2011) modeled the impacts of predicted ocean temperatures and chemistry on NWHI coral reefs. Their results suggest that if corals can increase their threshold for heat stress by 0.1° C/decade, the area of shallow-water reefs will decline by 25-75% by 2100, and that reefs in the center to northern end of the Hawaiian chain may fare better, as more optimal temperatures promote their ability to recover relative to reefs toward the south of the chain. However, in the absence of adaptation (e18038 pg. 9):

model output suggests it is extremely unlikely that viable coral populations will exist in the shallow waters of the Hawaiian Archipelago in 2100. Ensemble averages of individual outcomes suggest precipitous declines in coral cover will likely begin in the northern region sometime between 2030 and 2050, while individual bleaching events are likely to be less severe in the south, leading to more steady decline over the entire century in this region.

A number of factors have been identified that may confer resilience to coral reefs from climate change impacts (West & Salm, 2003), some of which are present in PMNM. The Monument's reefs can be expected to benefit substantially by the absence of fishing, coastal development, agriculture and other anthropogenic stressors (Schuttenberg & Marshall, 2008). Conversely, the Monument's relatively low biodiversity and isolation from other reef areas that could supply larval replenishment would be expected to reduce the resilience of the PMNM's reefs to climate change.

Reefs across Papahānaumokuākea will experience climate change impacts differently, and several factors point toward French Frigate Shoals (FFS) as a particularly resilient area, which would benefit the atoll's unique population of monk seals and sea turtle nesting and basking sites by providing coastal protection. FFS and Maro Reef harbor the greatest marine biodiversity of the NWHI chain, benefitting from larval input from Johnston Atoll (Grigg et al., 2008; Kobayashi, 2006; Maragos et al., 2009); this greater diversity increases the possibility of various types of adaptation, which could include selection of thermally tolerant algal symbionts or taxonomic succession of more resistant or resilient genera (Baker et al. 2004; Grottoli et al., 2006). Additionally, Hoeke et al. (2011) hypothesize that FFS may find itself in the "sweet spot" of PMNM's future temperature regime, enjoying warmer temperatures that enhance reef growth, while avoiding temperature extremes that result in mortality from mass bleaching. Kenyon et al. (2006) concur that overall FFS may be better able to cope with climate change based on the current species composition of corals: "the predominance of massive and encrusting *Porites* …renders the reefs of FFS moderately resistant to the effects of bleaching with respect to structural architecture" (pg. 170). However, FFS resilience to coral bleaching may not extend to coral disease. Within the NWHI, *Porites* is the genus that harbors the greatest number of diseases (Vargas-Angel, pers. comm.), and the acroporid corals that contribute to FFS's greater biodiversity are also particularly vulnerable to disease outbreaks and impacts (Aeby, pers. comm.).

The Monument's mesophotic reefs are another area that may possibly benefit from future warmer temperatures. Rooney et al. (2010) hypothesize that the colder temperatures in the NWHI prevent the more substantial growth of scleractinian corals and coralline algae that is seen in the MHI. New temperature regimes may enable better growth of these species, although their current cooler temperature habitats may leave them more exposed to acidification, resulting in negative impacts on their calcification rates. Additionally, there is a possibility these deeper reefs may provide a larval source for the recovery of adjacent shallow-reef areas in the future, although many questions remain about the 'deep reef refugia hypothesis' (Bongaerts et al., 2010), such as whether it could operate over ecologically relevant time scales or how it might influence areas that are currently dominated by genera that are restricted to shallow waters.

Macroalgae

NWHI reefs are largely algal-dominated and climate change is likely to alter the composition of algal species. Extrapolating analyses from the Great Barrier Reef, we can hypothesize that climate change will favor weedier turf algal species and most negatively impact calcareous algae, although the synergistic impacts of changes in temperature, UV, ocean circulation, storms, and acidification are difficult to untangle (Diaz-Pulido et al., 2007; Jokiel et al., 2008; Kuffner et al., 2008). Changes in species composition could significantly alter the ecological functions provided by dominant species with cascading effects throughout ecosystems. For example, increases in turf algae would increase the overall biomass available at the base of the food web, creating a benefit for some herbivorous species and potentially influencing an overall shift in the relative species composition at higher trophic levels.

Perhaps one of PMNM's greatest vulnerabilities to climate change is from the impact of ocean acidification on crustose coralline algae (CCA). CCA are more vulnerable to increased acidity than corals, which means that their percent cover and survival will be reduced more quickly than most coral species. However, because CCA are the main settlement platforms for coral larvae, their demise may have larger impacts on coral survival than the increased acidification itself (Vroom, 2011). Additionally, calcareous algae are known to contribute to reef consolidation and sand production; these functions will be lost if calcareous algae are significantly reduced by ocean acidification, accelerating the loss of low-lying sandy atolls.

The adaptive capacity of the algal communities that dominate the Monument's coral reefs is expected to vary between species, with resulting shifts in community composition. More research is needed to understand how differential adaptive capacity will influence the future composition of PMNM's algal reefs.

Marine Invertebrates

The greatest climate change threats to marine invertebrates are likely from changes in sea temperature, ocean circulation, and ocean acidification (Hutchings et al., 2007). Sea temperature influences the reproductive cycles of many marine invertebrates and changes in temperature combined with changes in ocean circulation can result in mismatches between reproductive cycles and prey availability. Additionally, increased sea temperatures are expected to facilitate exotic species invasions, while changes in ocean circulation can result in transport of larvae to unsuitable habitats. The effects of ocean acidification are uncertain and species specific, but appear to pose a considerable threat to the ability of marine invertebrates to secrete a protective skeleton; Hutchings et al. (2007) hypothesize that (pg. 327):

Impaired skeletogenesis is expected to compromise survivorship of both planktonic and benthic life stages of coral reef invertebrates. The larval skeleton of gastropods, sea urchins and other benthic invertebrates *are particularly fragile and may not be produced under acidic conditions. This may result in complete recruitment failure of whole suites of benthic invertebrates.*

These changes are likely to impact species of special significance to Native Hawaiians, such as ‘opihi and culturally significant food fishes that feed on crustaceans, but further research is needed to examine the specific responses of these species. Overall, differential responses by marine invertebrates are likely to lead to shifts in current community compositions at the species level, and Hutchings et al. (2007) note that species dependent on coral reefs will be particularly vulnerable as reef structure is lost to climate change. Given the significant ecological roles marine invertebrates play within the Monument’s ecosystems, further research is warranted to better understand and predict the impact of climate change on these organisms and processes.

The ability of marine invertebrates to adapt to climate change is largely unknown. Some invertebrate species may be able to adapt to short-term temperature fluctuations by behavioral changes, such as burrowing deeper into sediments or moving deeper down the reef slope into colder waters. The short generational times and large population sizes of many invertebrate species may help facilitate evolutionary adaptation, and evidence from the fossil record suggests that some invertebrate species have been able to successfully respond to significant climate change in the past, while others did not (Hutchings et al., 2007). Whether marine invertebrates within the Monument are able to expand or change their ranges in response to rising sea temperatures is unknown, and will likely depend on how ocean circulation patterns and larval connectivity throughout the archipelago are altered.

Reef Fishes

Changes in temperature, ocean circulation, and climate change-related habitat loss, for example through coral bleaching, are the greatest drivers of change in reef fish populations (Munday et al., 2008). Anticipated changes in the species composition of reef fish might be expected to have a significant impact on reef ecosystem processes, such as predation, competition, and herbivory. Cumulatively, climate change may alter reef fish population life histories, community structure, and range distributions, and is likely to result in an overall loss in biodiversity (Munday et al., 2008).

As with many other species, the larval and reproductive stages of reef fish are expected to be more vulnerable to changes in climate than adult populations. Munday et al. (2008) identify how climate variables offer both benefits and risks to fish recruitment, hypothesizing that recruitment will become more unpredictable, occurring as extreme pulse events of success or failure. Small increases in temperature may accelerate larval growth and development, if food is available to sustain enhanced metabolic rates. This faster growth is expected to reduce time in the pelagic larval stage, increasing the chance larval fish survive this stage and recruit onto reefs. However, the availability of planktonic prey will also be influenced by climate variables, such as acidification and changes in ocean circulation, which may alter plankton distribution and biomass; as a result of these changes, it is unclear if the prey of larval fish will be available to adequately support faster larval development. Another factor that adds uncertainty to the impact of climate change on recruitment is temperature; changes may shift fish breeding timing and intervals, and large temperature increases could increase larval mortality. Additionally, acidification may affect larval development.

Based largely on predictions of increased sea temperatures, Munday et al. (2008) hypothesize a shift in reef fish toward smaller size, reduced longevity, and earlier maturation. Expectations of habitat degradation and the differential impacts of increased temperature and acidification on fish species are likely to result in shifts in community composition with generalist planktivores, small herbivores and rubble dwellers being the most likely to benefit from changing conditions; the flow-on effects of these changes to the ecological roles provided by current reef fish communities will in turn impact the composition of future coral and algal communities.

Finally, Munday et al. (2008) hypothesize that species may exhibit opportunistic range changes to maintain preferred thermal environments. Such changes could result in an increase in the rate of invasion and settlement for species not currently present the NWHI as cool-water temperature barriers are removed. Additionally, the isolation of endemic species within the Monument creates a risk of extinction given limited options for range expansion. Munday et al. highlight this risk (2008, pg. 273):

species that already have small ranges near the limits of coral reef growth will experience further range contractions that would ultimately increase their risk of extinction from other impacts. Areas of high endemism associated with isolated island groups, such as the Hawaiian Islands, are likely to experience multiple extinctions as isolation restricts the potential for range shifts

Fishes with greater temperature tolerances, shorter generational cycles, and larger ranges or greater ability to expand their ranges are more likely to adapt to changing climatic conditions (Munday et al., 2008). Interbreeding among populations as range expansion occurs, and temperature-driven decreases in age to reproductive maturity may provide some assistance in this evolution. However, more isolated populations, such as those in the NWHI, have lower levels of genetic connectivity to other populations, which greatly reduces the potential for local adaptation to increasing ocean temperature by transfer of favorable genotypes (Munday et al., 2008).

Sharks

Chondrichthyan fishes, such as sharks, are primarily vulnerable to climate change through impacts on prey availability. A review by Chin et al. (2010) notes that climate change impacts to coral reef and pelagic habitats may change or limit the availability of prey, such as teleost fishes, crustaceans, marine turtles, and marine mammals. Temperature change may also have some direct impacts on sharks, for example by increasing growth rates or physiological processes, which may be beneficial, or by altering the migratory patterns of some species.

The mobility of many shark species is identified as a source of inherent adaptive capacity, although Chin et al. (2010, pg. 1948-9) caveat this hypothesis:

Mobility assumes that individuals will be able to locate, move to and establish viable populations in new areas and this assumption should be treated with caution. Alternative habitats may not be available…even if suitable refugia can be reached, they may be unavailable if competition or predation prevents the species from establishing a viable population.

Sharks with more specialized diets and smaller ranges are considered to have less adaptive capacity than generalist, far-ranging species. Supporting the adaptive capacity of sharks will be achieved most effectively by supporting the ecological processes that will sustain their prey as the climate changes, particularly working to maintain the ecosystems upon which prey species depend.

Marine Mammals

A review of climate change impacts on marine mammals suggests that the greatest impacts will result from changes in prey availability—as a result of changing temperature, ocean circulation patterns, and acidification (Lawler et al., 2007; Learmonth et al., 2006)—and loss of seal haul-out sites due to sea-level rise (Learmonth et al., 2006). Globally, the range of many cetaceans is likely to change as species migrate to maintain their preferred thermal habitat or follow the distribution of prey species with particular thermal requirements. Additionally, species with high dependence on coastal habitats could be negatively impacted by sea-level rise (Simmonds & Elliot, 2009).

A recent modeling study of climate change impacts on marine mammals globally suggests that impacts will be greatest for tropical species and identified "possible declines in marine mammal species richness at lower latitudes and increases at higher latitudes, assuming an intermediate IPCC climate change scenario" (Kaschner et al., 2011pg. e19653-7). In particular, the study's authors found that pinniped biodiversity in tropical and temperate waters will decrease substantially, and they identified the Hawaiian monk seal as one of the species that will be most affected. Because of their heightened vulnerability to climate change, monk seals are discussed further in Section 2.2.2.3

Cetaceans found in the Monument are expected to benefit from the inherent adaptive capacity conferred by their high mobility, expansive range, and ability to learn about their environment (Harwood, 2001; Lawler et al., 2007). Globally, most management recommendations for supporting the adaptive capacity of marine mammals are not relevant to PMNM, although they may be for the MHI; these actions include: improving the management of terrestrial run-off to improve water quality and reduce toxic algal blooms, carefully managing tourism, and minimizing impacts from marine debris, fishing, and hunting (Lawler et al., 2007; Learmonth et al., 2006).

2.2.2.3 ESA Species of Particular Concern in the Context of Climate Change

> *The things people talk about are what they see up there. They talk about big fish and lots of sharks; those guys, I think, will do alright. They talk about sea birds, turtles, and monk seals; I think those guys are going to have a tougher time, so I think that will be a challenge for people.*
>
> \- Respondent, PMNM Climate Change Survey

Complementing Papahānaumokuākea's ecosystem-based approach to governance are additional species-specific mandates, such as the Endangered Species Act and Marine Mammal Protection Act, which are described in the Monument's Management Plan (PMNM, 2008b). Here Hawaiian monk seal and sea turtles are highlighted as species which are particularly vulnerable to climate change and strongly associated with Papahānaumokuākea. Key vulnerabilities to these species are summarized in Table 2.2.3.

Hawaiian Monk Seals

Hawaiian monk seal populations in the NWHI appear to be doing more poorly than those in the MHI (Baker & Johanos, 2004). In this regard, the Hawaiian monk seal is somewhat unique, because PMNM represents a refuge for a myriad of species, but not for the Hawaiian monk seal. In particular, Hawaiian monk seals are believed to be highly sensitive to climate change impacts on the availability of their prey and haul-out sites. Currently, Hawaiian monk seal populations in the NWHI are believed to be constrained by prey availability, shark predation, marine debris, occasional male aggression, and possibly limited genetic diversity (Lowry et al., 2011). Climate change may further exacerbate prey limitations, as evidenced by similar declines in prey availability during past climate events (Baker et al. , 2007; Polovina et al., 1994; Baker et al., 2012) and known negative impacts to monk seal prey from climate-related coral reef degradation. Loss of coastal habitats, particularly by inundation due to sea-level rise, are also likely to impact monk seals by reducing the quantity and quality of haul-out sites; past work on Kure found that shark predation on juvenile monk seals increased when preferred haul-out sites were unavailable (Lowry et al., 2011). Additionally, preliminary modeling suggests that climate change-related shifts in patterns of marine debris deposition may increase entanglement risks to monk seals (Donohue & Foley, 2007).

Based on current population declines, the inherent adaptive capacity of Hawaiian monk seals to climate change impacts is expected to be low; however, the recent growth in MHI seal numbers can be viewed as an increase in the species' overall resilience to climate change, and should be supported through management measures that minimize disturbance to the seals in MHI haul-out areas. Broader actions that aim to understand and support the maintenance of ecosystem integrity in the face of climate change should benefit monk seals by addressing prey limitations, while specific actions, such as coral reef restoration may also help address this vulnerability. Further analysis of climate change impacts to monk seal haul-out sites and options for addressing the loss of these sites is needed (Strategy 2.3.3).

<u>Sea Turtles</u>

Reviews of climate change impacts on sea turtles consider the greatest threat to come from loss of nesting beaches, with potential impacts also resulting from more extreme weather events, changes in ocean circulation patterns, increased UV light, and ocean acidification (Hamann et al., 2007; Hawkes et al., 2009; Poloczanska et al., 2009).

A significant focus of current research is the direct and indirect impact of these expected changes on turtle reproduction, notably changes in available nesting beaches, nest temperatures, and breeding intervals. The most abundant marine turtle species in the NWHI is the Hawaiian green turtle. Historical research has revealed that over 80% of major nesting populations of this species have been extirpated since the arrival of humans in Hawaii (Kittinger et al., 2013). Additionally, nesting areas for the Hawaiian green sea turtle were historically distributed throughout the Hawaiian Archipelago (Kittinger et al., 2013), but today over 90% of adult female green turtles in Hawai'i migrate to French Frigate Shoals from throughout the archipelago between May and September to breed and nest (Balazs et al., 1992). This current concentration of nesting sites in a relatively small area may leave the population particularly vulnerable to extreme events that could damage or eliminate these sites (Kittinger et al., 2013). There is some evidence, however, that green turtles may be expanding their nesting range by starting new nesting colonies in the MHI (Dutton et al., 2008; Frey et al., 2013).

Research by Tiwari et al. (2010) suggests that the current Hawaiian turtle population size is well below the carrying capacity of nesting beaches at FFS; for example, their modeling suggests that the mean 390 females nesting annually at East Island over the past decade represents 1.3-2% of the females that could nest at carrying capacity, and that a projected 30% loss in East Island beach habitat due to sea-level rise (see Baker et al., 2006) would still result in excess nesting capacity. However, turtle nesting habitat loss at FFS is likely to exceed 30% (see Section 2.3.2.1), and other scientists have questioned the assumption that all East Island habitat is suitable for nesting (Kyle Van Houtan, pers. comm.) with the implication that real losses in future available nesting area may be much greater.

Globally, nest temperature is known to impact hatchling sex, size, health, and fitness, and nests that are too warm result in hatchlings that are smaller, have decreased swimming ability, and have higher rates of scale and morphological abnormalities (Hamann et al., 2007; Poloczanska et al., 2009). Additionally, nests with temperatures that exceed a threshold, called the pivotal incubation temperature, produce more females; as a result, there is a concern that a warming climate may feminize turtle populations causing unknown impacts on overall population numbers (Poloczanska et al., 2009). However, Hawaiian green turtle nesting beaches on FFS are relatively cooler than most green turtle nesting beaches globally, and recent experimental studies at FFS have shown that these cooler temperatures produce unbiased or male-biased sex ratios (Layton, 2012). Additional work is needed to predict how sand temperatures at FFS may change in the future, and whether there is reason for concern about the impacts of future warmer temperatures on green turtle hatchling fitness and sex-ratios.

Table 2.2.3 Vulnerabilities of PMNM's marine ESA species of concern to climate change variables.

Ecosystem Components	Key Vulnerabilities
Monk Seals	❖ (High) Sea-level rise, compounded by loss of reef habitat, is very likely to reduce the quantity and quality of monk seal haul-out sites, negatively impacting the population ❖ (High) Projected changes in climate, combined with loss of reef habitat, are very likely to limit monk seal prey, exacerbating a known cause of decline in the NWHI population
Green Sea Turtles	❖ (Medium) Sea-level rise, storm surge, increased storm frequency and intensity are likely to reduce sea turtle nesting areas on FFS; however, it is unclear when or if reduced habitat area will constrain the overall population ❖ (Low) Increased sand temperature may feminize Hawai'i's green sea turtle population and may reduce hatchling size and fitness ❖ (Low) Climate change impacts on green sea turtle foraging are unknown, but could potentially have significant positive or negative effects on breeding intervals and the overall turtle population ❖ (Low) Warmer temperatures may exacerbate threats from fibropapillomatosis tumors

Confidence: ❖ Low ❖ Medium ❖ High

The impact of climate change on green turtle foraging at different life stages is uncertain. Adult green sea turtles are herbivorous, and it is unclear whether their diets of macroalgae and seagrass will benefit or suffer from climate change. Post-hatchling and juvenile sea turtles are believed to have an omnivorous and opportunistic diet as they are transported by large-scale oceanic currents for nearly a decade. How changes in ocean currents, chemistry, and temperature may impact this early life stage in terms of diet and transport are unknown. If the impact of climate change on food availability and quality is positive, then combined with increased temperatures, turtles may grow faster, reach maturity sooner, and breed earlier and more often. If the impact of climate change on turtle foraging is negative, the green turtle population would be reduced and breeding frequency would be also be negatively affected.

New information indicates that hawksbill sea turtles, while rare, also occur within the NWHI (Van Houtan et al., 2012), although nesting has not been documented there recently. Hawksbills utilize a diverse diet that includes sponges (King, pers. comm.). Impacts to forage species are not well known, although climate change related impacts to coral reefs, the hawksbill's primary foraging and resting habitat, are more well-studied, as described in Section 2.2.2.2.

Within the Hawaiian context, another consideration is the impact of climate change on turtle diseases, particularly fibropapillomatosis tumors, which are currently identified as a significant threat to green turtles in the Recovery Plan for Pacific populations (NMFS & US F&W, 1998). In general, increased temperature can result in increased disease, but whether this is true for fibropapillomatosis is unknown.

Researchers have suggested a number of ways sea turtles may be able to adapt to climate change, but most remain speculative. The most likely strategy would be for turtles to change the timing of their nesting to cooler times of the year. There is evidence that turtles in Florida are breeding an average of ten days earlier in response to warmer temperatures (Weishampel et al., 2004); however, turtles traveling long distances across a latitudinal gradient, such as those in Hawai‘i, may experience temperature increases differently at varying locations, complicating the mechanisms by which reproductive migrations might be shifted based on thermal cues (Hamann et al., 2007). Another temporal change may be an extension of the breeding season. Turtles may also be able to select new nesting beaches, a practice which has been documented, although it appears to be uncommon (Hawkes et al., 2009). A further uncertainty is the extent to which turtles may be able to shift their diet in response to climate change impacts on their habitat and food sources. Adult green turtles have high site fidelity, seldom shifting to new areas, and there is evidence that their intestinal micro flora are specialized, thereby reducing their ability to adapt foraging strategies (Hawkes et al., 2009).

With greater understanding, managers may be able to help maintain the quality of Hawaiian green turtle nesting beaches by planting native vegetation to provide shade and reduce nest temperatures, a strategy which has been implemented in the Galapagos (Hansen & Hoffman, 2011). Such a strategy should be based on an understanding of how sand temperatures are changing, and whether temperature thresholds that cause the negative impacts or feminization are being reached. Maintaining key sand characteristics for turtle nesting in FFS should also be considered in any decisions to stabilize beaches for monk seals or shore birds.

2.2.3 Key Implications

Expert analysis of existing evidence suggests that the key implications of climate change for PMNM's marine ecosystems include:

- Coral reef ecosystems in PMNM are very likely to change as a result of acidification and warmer temperatures [high confidence]. While warmer sea temperatures may benefit some of the Monument's reefs, degradation due to reduced calcification and increased frequency of bleaching and disease events is likely [moderate confidence].

- Areas of low productivity in the open ocean are likely to expand as warmer surface water temperatures increase vertical stratification in the water column, and nutrients from cooler, deeper waters are less available in the surface, photic zone [high confidence].
- Ocean acidification is very likely to reduce the ability of some corals, calcareous algae, phytoplankton, and invertebrates to calcify their shells and skeletons [high confidence]. Similarly, acidification may have profound impacts on native macroalgal species [low confidence].
- An overall loss in biological diversity is likely as some species are unable to adapt to altered habitat structure, temperatures, and circulation patterns [high confidence].
- Changes in ocean productivity due to increased stratification may cascade through the food web, negatively impacting predator species [moderate confidence].
- Endangered Hawaiian monk seals are likely to be adversely affected by climate change as their breeding sites and haul-out sites are inundated [high confidence] and the abundance of their prey is reduced [moderate confidence].
- Threatened Hawaiian sea turtle populations may be reduced as major nesting areas at FFS are inundated [moderate confidence].
- Climate change may exacerbate existing threats from invasive species, marine debris, and disease [low confidence].

Overall, existing evidence suggests that climate change is very likely to significantly alter PMNM's marine ecosystems over the coming century through ocean acidification and increased sea surface temperatures. These environmental changes are likely to disrupt key ecological processes, such as calcification and nutrient cycling, resulting in reduced oceanic productivity and significant changes to the Monument's coral reef ecosystems. The Monument's endemic species are particularly vulnerable to these changes with little prospect of moving to other suitable areas given the area's remoteness. The rate and extent of these changes is will be influenced by the level of future CO_2 emissions, as well as the degree to which local management actions are implemented to facilitate adaptation. Figure 2.2.2 illustrates expert opinion that higher rates of future CO_2 emissions will significantly reduce the condition and spatial extent of coral reefs compared to the situation if CO_2 emissions are reduced. Higher CO_2 emissions will also accelerate losses in productivity and rises in sea levels that will negatively impact PMNM's threatened and endangered marine species. Section 3 presents the local management strategies needed to help facilitate climate change adaptation.

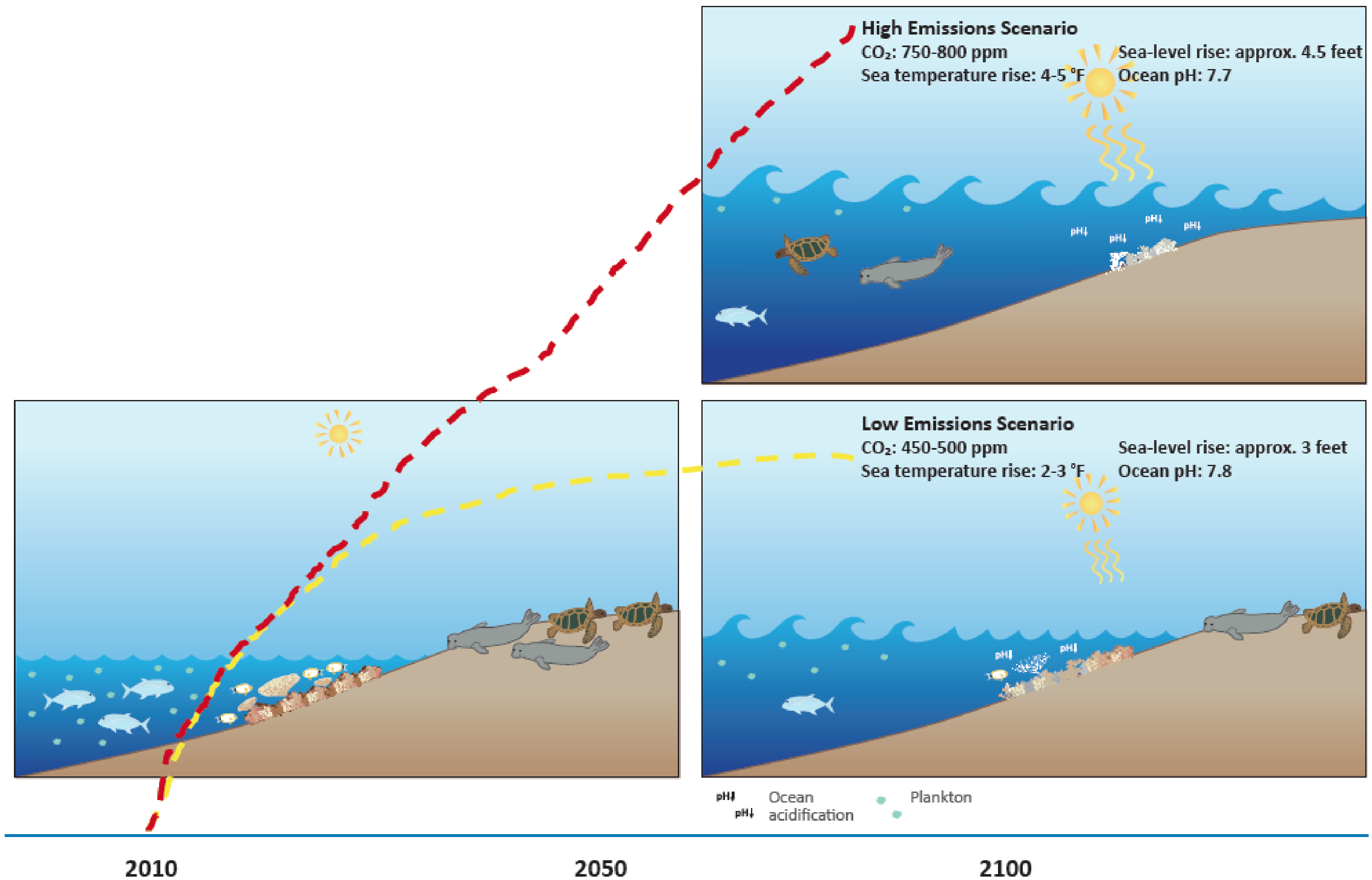


Figure 2.2.2 Projected changes in PMNM's marine ecosystems between today (left) and 2100 under high RCP 8.5 (top, right) and low RCP 2.6 (bottom, right) greenhouse gas emission scenarios.

2.3 Island and Atoll Ecosystems

> *I'm especially concerned about the fact that we do not know how fast sea level rise is actually going to happen because other things caused by climate change are actually happening faster than predicted.*
>
> - Respondent, PMNM Climate Change Survey

While PMNM's land area is small in contrast to its vast ocean spaces, both ecosystems share high endemism and exceptional biodiversity. This section introduces the Monument's island and atoll ecosystems (Section 2.3.1), identifies their projected vulnerabilities to climate change (Section 2.3.2), and summarizes the issues anticipated to be of greatest concern to these ecosystems and associated species (Section 2.3.3).

2.3.1 Papahānaumokuākea's Island and Atoll Ecosystems

PMNM's land area consists of ten island and atoll groups (Figure 2.3.1). The easternmost and youngest islands, Nihoa and Mokumanamana, are small, steep rocky islands, and the Gardner Pinnacles are rocky outcroppings. The remaining six areas are highly eroded, low sand islands and atolls with extensive sandy beaches and coastal strands; two of these latter islands, Laysan and Lisianski, are secondarily elevated. The islands support a low diversity of plants, mostly herbaceous species and small shrubs and trees. PMNM's four true atolls—Kure, Midway, Pearl and Hermes, FFS—have fringing coral reefs and interior lagoons that are open to the ocean. Laysan Island has a closed lagoon, which contains a hypersaline lake, the largest natural lake in the Hawaiian Islands. Historically, Midway, Kure, and French Frigate Shoals were operated as military installations and consequently have been highly altered. All have current or former runways and buildings. Midway, with the longest history of human occupation, also supports a non-native ironwood forest (*Casuarina equisetifolia*). Midway Naval Air Station closed in 1996, and the Coast Guard Loran Stations on Kure and French Frigate Shoals were closed in 1991 and 1979, respectively.

Within these habitats, Papahānaumokuākea hosts significant levels of biodiversity and high levels of endemism. The Monument is the largest tropical seabird rookery in the world, hosting over 5.5 million breeding adult seabirds (Keller et al., 2009). It provides nesting habitat for 25 species that are protected under the Migratory Bird Treaty Act, including the Short Tailed Albatross, which is also listed under the Endangered Species Act (Table 2.3.1). Ninety five percent of the world's Laysan and Black-footed Albatrosses nest in the NWHI, as do globally significant colonies of Bonin Petrels and Tristam's Storm-petrels. Some of the largest colonies of White Terns and Red-tailed Tropicbirds in the Central Pacific are found in PMNM, and numerous shorebird species overwinter or transit through PMNM during their migrations to the north and south. Endemic birds found in PMNM include remarkably isolated species such as the Nihoa Finch, Nihoa Millerbird, Laysan Finch, and Laysan Duck, one of the world's rarest ducks; of these four species, the Laysan Finch is listed as vulnerable by IUCN and the other three are listed as critically endangered.

Important examples of endemism extend beyond the Monument's birds and include 145 species of endemic arthropods and six species of endemic plants, with all six plant species listed under the U.S. Endangered Species Act. As a general rule, endemic species are considered more vulnerable to climate change than generalist species, a concern enhanced on small islands and atolls by the limited options for relocation with changing conditions.

Figure 2.3.1 Ranging from steep, rocky islands in the east to low-lying sandy islands and atolls, PMNM's ten island and atoll groups host the largest assemblage of tropical seabirds in the world (photos courtesy of the USFWS).

Table 2.3.1 Breeding bird species found within Papahānaumokuākea (reproduced from Krause et al. in Reynolds et al. (2012), USGS Open-File Report 2012–1182).

Common name	Status: IUCN	Status: Nature Serve	Status: U.S. Federal	Status: State of Hawai`i	Population: NWHI breeding pairs reported	Population: Proportion of global breeding population restricted to NWHI
Black-footed Albatross	Endangered	G3 - Vulnerable	BCC	Threatened	64,000 (2011)[a]	> 0.95[a]
Laysan Albatross	Near Threatened	G3 - Vulnerable	BCC		590,179 (2011)[a]	> 0.95[a]
Short-tailed Albatross	Vulnerable	G1 - Critically Imperiled	Endangered	Endangered	2 (2012)[b, c]	< 0.05[g]
Bonin Petrel	Least Concern	Not evaluated			396,150	0.5–0.95[g]
Bulwer's Petrel	Least Concern	G4 - Apparently Secure			92,370	0.05–0.5[g]
Wedge-tailed Shearwater	Least Concern	G4 - Apparently Secure			228,800	0.05–0.5[h]
Christmas Shearwater	Least Concern	G3 - Vulnerable	BCC		2,815	0.05–0.5[h]
Tristram's Storm-petrel	Near Threatened	G3 - Vulnerable	BCC		6,030	0.05–0.5[h]
Red-tailed Tropicbird	Least Concern	G4 - Apparently Secure			12,800	0.05–0.5[h]
White-tailed Tropicbird	Least Concern	G5 - Secure			5	< 0.05[h]
Masked Booby	Least Concern	G5 - Secure			2,215	Data needed
Brown Booby	Least Concern	G5 - Secure			425	< 0.05[h]
Red-footed Booby	Least Concern	G5 - Secure			7,450	0.05–0.5[h]
Great Frigatebird	Least Concern	G4 - Apparently Secure			10,345	0.05–0.5[h]
Little Tern	Least Concern	Not evaluated			20[d]	< 0.05[g]
Gray-backed Tern	Least Concern	G3 - Vulnerable			43,225	0.5–0.95[h]
Sooty Tern	Least Concern	G5 - Secure			1,190,400	0.05–0.5[h]
Blue Noddy	Least Concern	G4 - Apparently Secure			3,780	Data needed
Brown Noddy	Least Concern	G5 - Secure			76,250	0.05–0.5[h]
Black Noddy	Least Concern	G5 - Secure			15,050	0.05–0.5[h]
White Tern	Least Concern	G4 - Apparently Secure		Threatened	25,215	0.05–0.5[g]
Laysan Teal	Critically Endangered	G1 - Critically Imperiled	Endangered	Endangered	500–800 (2011)[e]	1
Laysan Finch	Vulnerable	G1 - Critically Imperiled	Endangered	Endangered	5,000–20,000[f]	1
Nihoa Finch	Critically Endangered	G1 - Critically Imperiled	Endangered	Endangered	2,100–3,550[f]	1
Nihoa Millerbird	Critically Endangered	G1 - Critically Imperiled	Endangered	Endangered	250–999[f]	1

2.3.2 Projected Vulnerabilities to Climate Change

Climate change has significant implications for the area, functions, and structure of PMNM's island and atoll ecosystems. The following sections identify what is known about habitat loss to sea-level rise (Section 2.3.2.1), likely impacts to coastal and terrestrial ecosystems (Section 2.3.2.2), and likely impacts to managed species associated with these systems (Section 2.3.2.3). The concluding section (2.3.3) recaps the issues experts assessed to be of greatest concern.

2.3.2.1 Estimates of Habitat Loss to Sea-Level Rise

One of the greatest climate-related threats to Papahānaumokuākea is the loss of island and atoll area to sea-level rise and interacting processes. This section relies on the most recent studies, which provide preliminary estimates of the likely extent of these losses, the timescales under which they may occur, and the types of habitats most likely to be impacted.

Globally, sea-level is projected to rise by 1-1.5 m by 2100 (IPCC, 2007b). Recent modeling (Baker et al., 2006; Krause et al., 2012) efforts have estimated the impacts of sea-level rise ranging from 0.5-2.0 m across habitats on many of PMNM's islands using passive inundation modeling. Although passive inundation or "bathtub" models consider the impacts of sea-level rise without including other compounding factors, such as associated changes in wave behavior, erosion, or accretion, in the absence of bathymetric and other data, these models provide a useful first-order assessment of the implications of different sea-level rise scenarios. However, it is important to note that lack of consideration of erosion and wave behavior is a major gap in the ability of such models to accurately predict future sea-level rise scenarios, given that shoreline morphologies are likely to change dramatically due to erosion.

Reynolds et al. (2012) emphasize that passive inundation models underestimate the extent of habitat losses from inundation, and note the need for additional data and modeling studies to more realistically project habitat loss under different climate change scenarios. One component of this same project was the development inundation projections by habitat type on Laysan Island using five different models and sea-level rise scenarios (Berkowitz et al., 2012); Table 2.3.2). This comparison confirmed that passive inundation models systematically underestimate areas of inundation compared to models that incorporate wave forcing and rise in groundwater, and that the underestimation by passive models is greater for higher sea- level rise scenarios because increased water levels reduce bottom friction and increase wave run-up.

From their study on Laysan Island, one of the higher-standing low islands, the authors note (p. 114): *that for a given SLR value, wave-driven water levels generally added approximately 1 m of inundation depth … to passive inundation surfaces during large-wave events. Thus, our wave-driven inundation models essentially forecasted comparable levels of inundation nearly a century earlier than passive models.*

Interpreting Krause et al.'s (2012) estimates of passive inundation (Table 2.3.3) in light of Berkowitz et al.'s (2012) comparative studies identifies several patterns. First, the difference between 1 and 2 m of sea-level rise substantially increases the total percent of land inundated from 4% to 26% (Krause et al., 2012). In their dynamic wave-driven models, Berkowitz et al. (2012) found a similar tipping point at 1 m. Krause et al.'s results project that six of the eleven islands modeled will lose 85 to 100% of their total area under 2 m of sea-level rise; as expected, islands with higher maximum elevations were more resilient to passive inundation by sea-level rise. For all 11 islands modeled, Krause et al. (2012) report that most of the area lost comes from

Table 2.3.2. Projections of habitat inundation at Laysan Island under 1.0 and 2.0 m sea-level rise based on three different inundation models (from Berkowitz et al. (2012).

Laysan Island Mean elevation: 4.3 m Max elevation: 10.7 m	**Area**	**Passive Inundation**				**Dynamic Wave-driven Inundation**				**Dynamic Wave-driven Inundation with Rising Groundwater Levels**			
	2010/11	+1.00 m SLR		+2.00 m SLR		+1.00 m SLR		+2.00 m SLR		+1.00 m SLR		+2.00 m SLR	
	ha	ha	% change	ha	% change	ha	% change	ha	% change	ha	% change	ha	% change
Tree/shrub	12.3							0.1	-1.0	3.5	-28.7	5.7	-46.6
Mixed Shrub	18.0							1.0	-5.6	5.8	-32.5	11.2	-62.1
Grass/herbaceaous cover	74.8							6.9	-9.3	7.6	-10.1	28.5	-38.2
Vine/ground cover	58.0							3.7	-6.3	0.7	-1.3	7.8	-13.4
Wetland vegetation	13.8							1.2	-8.4	9.9	-71.4	12.6	-90.9
Bare ground	129.3	0.4	-0.3	1.6	-1.3	1.5	-1.1	25.2	-19.5	1.5	-1.2	26.4	-20.4
Hard pan	3.1											2.8	-91.3
Beach	19.4	6.3	-32.3	13.8	-71.3	14.0	-72.2	18.8	-96.6	14.0	-72.2	18.8	-96.6
Wetland (unvegetated)	34.2												
Wetland (standing water)	40.0												
Partially vegetated runway													
Human structures													
Total island area	**412.0**	**6.7**	**-1.6**	**15.5**	**-3.8**	**15.5**	**-3.8**	**57.9**	**-14.1**	**49.6**	**-12.0**	**122.1**	**-29.6**

Table 2.3.3. Projections of habitat inundation under 1.0 and 2.0 m sea-level rise based on passive inundation models (from Krause et al. (2012).

Passive Inundation Models of Sea-level Rise	**Sand Island, Midway Atoll** Mean elevation:2.5 m; Max elevation: 11.0 m					**Spit Island, Midway Atoll** Mean elevation:0.8 m; Max elevation: 1.8 m					**Eastern Island, Midway Atoll** Mean elevation:2.1 m; Max elevation: 7.5 m				
	2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR		+2.00 m SLR	
	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change
Tree/shrub	36.6	36.5	-0.3	26.0	-29.0						16.1			11.1	-31.1
Mixed Shrub	16.6			11.9	-28.3	0.8	0.4	-50.0	0.0	-100.0					
Grass/herbaceaous cover	133.8	133.6	-0.1	89.5	-33.1	1.1	0.3	-72.7	0.0	-100.0	74.4	74.2	-0.3	46.1	-38.0
Vine/ground cover	29.5	29.2	-1.0	19.0	-35.6	0.2	0.1	-50.0	0.0	-100.0					
Wetland vegetation															
Bare ground	16.7	16.3	-2.4	12.1	-27.5	2.3	0.6	-73.9	0.0	-100.0	1.3	1.1	-15.4	0.3	-76.9
Hard pan															
Beach	22.3	15.3	-31.4	6.4	-71.3	0.8	0.0	-100.0	0.0	-100.0	10.2	5.6	-45.1	0.7	-93.1
Wetland (unvegetated)															
Wetland (standing water)	2.2			0.9	-59.1	0.1	0.0	-100.0	0.0	-100.0					
Partially vegetated runway											31.6	31.5	-0.3	23	-27.2
Human structures	129.3			65.7	-49.2										
Total island area	**456.8**	**448.7**	**-1.8**	**276.8**	**-39.4**	**5.3**	**1.4**	**-73.6**	**0.0**	**-100.0**	**133.6**	**128.5**	**-3.8**	**81.2**	**-39.2**

Table 2.3.3. continued

Passive Inundation Models of Sea-level Rise	Southeast Island, Pearl & Hermes Atoll Mean elevation:1.0 m; Max elevation: 2.5 m					Seal-Kittery Island, Pearl & Hermes Atoll Mean elevation:1.3 m; Max elevation: 2.6 m					North Island, Pearl & Hermes Atoll Mean elevation:1.4 m; Max elevation: 2.5 m				
	2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR			
	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change
Tree/shrub															
Mixed Shrub															
Grass/herbaceaous cover	6.6	5.1	-22.7	0.4	-93.9	0.3			0.1	-67.7	0.2			0.0	-100.0
Vine/ground cover	2.0	1.5	-25.0	0.1	-95.0	0.2			0.1	-52.4	0.6			0.1	-83.3
Wetland vegetation	1.9	0.0	-100.0	0.0	-100.0										
Bare ground	0.5	0.3	-40.0	0.0	-100.0	7.1			1.9	-73.2	1.9			0.3	-84.2
Hard pan															
Beach	7.2	0.8	-88.9	0.0	-100.0	6.1	1.9	-68.9	0.0	-100.0	5.7	3.7	-35.1	0.5	-91.2
Wetland (unvegetated)															
Wetland (standing water)	0.2	0.0	-100.0	0.0	-100.0										
Partially vegetated runway															
Human structures															
Total island area	**18.4**	**7.7**	**-58.2**	**0.5**	**-97.3**	**13.7**	**9.5**	**-30.7**	**2.1**	**-84.7**	**8.4**	**6.4**	**-23.8**	**0.9**	**-89.3**

Passive Inundation Models of Sea-level Rise	Little North Island, Pearl & Hermes Atoll Mean elevation:0.9 m; Max elevation: 2.3 m					Grass Island, Pearl & Hermes Atoll Mean elevation:1.3 m; Max elevation: 2.3 m				
	2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR		+2.00 m SLR	
	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change
Tree/shrub										
Mixed Shrub										
Grass/herbaceaous cover						0.5			0.2	-60.0
Vine/ground cover										
Wetland vegetation										
Bare ground	0.3			0.0	-100.0	0.7			0.1	-87.5
Hard pan										
Beach	2.9	0.8	-72.4	0.0	-100.0	2.0	1.0	-50.0	0.0	-100.0
Wetland (unvegetated)										
Wetland (standing water)										
Partially vegetated runway										
Human structures										
Total island area	**3.2**	**1.1**	**-65.6**	**0.0**	**-100.0**	**3.2**	**2.2**	**-31.3**	**0.3**	**-90.6**

Table 2.3.3. continued

Passive Inundation Models of Sea-level Rise	Green Island, Kure Atoll Mean elevation:2.8 m; Max elevation: 7.3 m					Lisianski Island Mean elevation:3.8 m; Max elevation: 7.6 m				
	2010/11	+1.00 m SLR		+2.00 m SLR		2010/11	+1.00 m SLR		+2.00 m SLR	
	ha	ha	% change	ha	% change	ha	ha	% change	ha	% change
Tree/shrub	19.2			19.1	-0.5	10.6				
Mixed Shrub										
Grass/herbaceaous cover	42.1			42.0	-0.2	96.2	96.1	-0.1	95.9	-0.3
Vine/ground cover	3.3					17.2	17.1	-0.6	17.1	-0.6
Wetland vegetation										
Bare ground	4.1	4.0	-2.4	3.8	-7.3	11.9			11.6	-2.5
Hard pan										
Beach	15.4	7.7	-50.0	3.1	-79.9	11.2	7.9	-29.5	5.2	-53.6
Wetland (unvegetated)										
Wetland (standing water)										
Partially vegetated runway	6.0									
Human structures										
Total island area	**90.1**	**82.3**	**-8.6**	**77.3**	**-14.2**	**147.1**	**143.7**	**-2.3**	**140.4**	**-4.6**

areas that are currently beach and coastal strand habitats. Additionally, they project significant losses to avian habitats that are currently limited within the NWHI, particularly shrub and trees. A more recent study included Midway, and the models were supported by data from two inundation events in 2011 (Storlazzi et al. 2013).

The modeling efforts presented here represent an important step forward in monitoring the elevation and habitat types of low-lying islands in PMNM. Building on this work with further data on bathymetry (Strategy 1.1.4), substrate characteristics, and water currents will allow more comprehensive modeling that can improve planning for beach stabilization and restoration efforts (Strategy 2.2.1). Additionally, a baseline study of historical shoreline erosion trends is needed in order to improve modeling of sea-level rise impacts due to erosion and wave processes.

2.3.2.2 Vulnerabilities of Island Habitats to Climate Change

Terrestrial habitats throughout the Monument are likely to be altered by increased temperature and CO_2 concentrations, an increased incidence of severe storms, and changes in precipitation patterns, winds, cloud cover, and humidity (Table 2.3.4). Changes in these environmental variables are very likely to alter the physical and chemical environments for PMNM's terrestrial flora. For example, reduced precipitation is likely to change the moisture content of soil, and sea-level rise combined with reduced rainfall is likely to shrink the freshwater lenses that provide the atolls and islands with critical sources of freshwater. Because species vary individually in the way they tolerate drought, derive benefit from greater CO_2 concentrations, and respond to other physical and environmental changes, projected shifts in climate are likely to alter the species composition of PMNM's plant communities. Such changes in flora are in turn likely to lead to shifts in the composition of invertebrate and avifaunal assemblages that rely on the existing plant communities.

On low-lying islands and atolls, rising sea level and storms may also drive changes in land cover patterns. For example, higher sea level is expected to result in more frequent wave overwash, which. can cause die-offs of salt intolerant vegetation leading to the encroachment of beach into areas that are currently vegetated avian breeding habitats. Such plant die-offs can also lead to soil instability that further accelerates erosion (Davidson-Arnott, 2005; Krause et al., 2012; LaFever et al., 2007).

Generally, it is believed that shifts associated with climate change may be an advantage to generalist invasive species (Turner & Batianoff, 2007), which can degrade habitat features that are important to PMNM's managed species. However, the remoteness of the NWHI may limit the introduction of such invasive species, conferring PMNM with resilience to this risk compared to other places with greater exposure to tourism and global commerce. Even so, this potential risk, warrants heighted monitoring of invasive species, and as appropriate, eradication (Strategy 2.1.2).

The likely impacts of climate change on key ecosystem functions and structures are described here for the major habitat types found within Papahānaumokuākea:

Beaches and Coastal Strands

Sea-level rise, warmer air temperatures, and changes in currents and storm patterns all pose risks to the spatial extent and qualities of PMNM's beach and coastal strand habitats. In the short-term, the climate-related degradation of coral reefs may contribute additional sand to the Monument's beaches, potentially increasing their size (Smithers et al., 2007). The availability of nearby offshore sand could also potentially continue to replenish beach habitats in the Monument's highly dynamic nearshore environment. However, over a longer time span Papahānaumokuākea is likely to lose substantial beach area as sea-level rise and storm surge inundate beaches, while the loss of coral reef and calcareous algae (see Section 2.2) also reduce beach replenishment. Additionally, warmer air temperatures are likely to change beach characteristics, potentially leaving them less hospitable for nesting sea turtles (see Section 2.2.2).

Mudflats and Wetlands

Compared to beaches, PMNM's wetlands and mudflats are likely to be more resilient to inundation from sea-level rise and storm surge, at least under shorter-term, moderate sea-level rise scenarios. Whether these ecosystems shift in location in response to new conditions will be related to the coastal areas adjacent to them, and to broader coastal dynamics that are poorly understood. Changes in species composition are likely.

Shrublands and Woodlands

Shrublands are an important and limited avifauna habitat in the NWHI (Reynolds et al., 2012). These ecosystems are likely to experience community shifts in response to increased salt-water overwash; changing weather patterns, such as more drought and extreme weather events; reductions in the size of the freshwater lens; and increased CO2. An increased establishment of invasive species is also a possibility. It is likely that habitat features important to key species will be compromised or lost due to such changes.

Freshwater habitats and the Hypersaline Lake on Laysan

The Monument's few freshwater habitats and the hypersaline lake on Laysan are both vulnerable to changes in rainfall and increased air temperatures and evaporation, although increased rainfall could benefit freshwater habitats. Past storm surge events have inundated the hypersaline lake, altering its chemistry and disrupting prey for Laysan ducks (Born pers. comm.; Athens et al. 2007). Interventions may be possible to facilitate some adaptation of the Monument's freshwater and lake habitats, and monitoring will be required to diagnose and plan appropriate actions, such as removal of invasive species.

Table 2.3.4 Relative vulnerability of PMNM's island & atoll ecosystems to different climate change variables.

Ecosystem	Increased air temperature	Sea-level rise	Increased atmospheric CO_2	Change in ocean circulation	Change in storm tracks or intensity	Change in precipitation or weather	Key Vulnerabilities
Beaches throughout	High	Very high	Low	Moderate	High	Low	❖ (High confidence) In the short-term reef degradation may increase sand, increasing beach area ❖ (High confidence) Ultimately, sea-level rise and storm surge will inundate beaches, while loss of reefs and calcareous algae will reduce sand replenishment; combined these impacts are very likely to significantly reduce the area of beach habitat ❖ (High confidence) Sand temperatures are very likely to rise with warmer sea & air temperatures
Coastal Strand Laysan, Midway, Lisianski, Kure, Pearl & Hermes	High	High	High	Moderate	High	High	
Wetlands & Mudflats Laysan, Midway & Kure	High	High	Moderate	Low	Moderate	High	❖ (High confidence) Changes in species composition are very likely due to increases in temperature and CO_2, along with changes in precipitation ❖ (Medium confidence) Inundation of low-lying habitats is likely
Shrublands & Woodlands	High	Low	High	Low	Moderate	High	❖ (Medium confidence) Changes in species community composition are very likely due to rises in temperature and CO2, and changes in precipitation ❖ (Low confidence) Invasive species may increase
Freshwater Habitats Mokumanamana, Nihoa, & Laysan, natural; Midway & Kure, created	High	High	Moderate	Low	High	Very high	❖ (Medium confidence) Sea-level rise and changes in precipitation, temperature, and storms are likely to have significant impacts, particularly on smaller, atolls that have smaller freshwater lenses
Hypersaline Lake Laysan	High	High	Low	Low	High	High	❖ (Medium confidence) Storm surge is likely to inundate the lake, changing its salinity and affecting the food sources of Laysan ducks ❖ (Low confidence) Changes in weather and air temperature may change salinity and temperature

Confidence: ❖ Low ❖ Medium ❖ High

Some of the climate-driven changes to these habitats can be reduced through targeted management actions (Strategies 2.2.1 and 2.2.4). Others changes will negatively impact managed species that rely on them, discussed in the next section.

2.3.2.3 Vulnerabilities of Managed Species to Climate Change

Climate change will have severe ramifications for managed species on PMNM's islands and atolls, both directly and indirectly (Table 2.3.5). Potential direct impacts include increased storm frequency and intensity, increased temperatures, and reduced availability of freshwater. Species may be indirectly affected through climate-driven changes in the quality and availability of preferred habitats and prey, as well as increased incidence of disease. Currently, almost nothing is known about how these projected changes will impact the Monument's 145 endemic arthropod species or its six plant species that are listed under the Endangered Species Act, and filling these knowledge gaps is a priority research activity (Strategies 1.4.1 and 1.4.4). Experts have greater confidence about the general impacts to PMNM's bird populations based on studies conducted within the Monument and other areas; however, more specific species and area-based assessments are needed to inform management (Strategy 2.3.1).

Papahānaumokuākea's bird populations are most likely to be impacted by climate change through effects on their nesting habitats, prey, storm events, and through changes in weather. As an island ecosystem, PMNM's land area is limited, and climate change is very likely to further reduce habitat availability, particularly of beaches, coastal scrub, and shrubland habitats (Section 2.3.2.1). For this reason, Krause et al. (2012) hypothesize that avifauna species which nest in a broad range of habitat types, do not nest within coastal strand habitat, and have broad global distributions will be the most resilient to climate change, Sooty Terns and Brown Noddies being examples of such species. Conversely, species with specialized habitat requirements and limited ranges will be most vulnerable. Krause et al. (2012) cite as examples burrow-nesting species that are limited to specific soil types and nesting depths (e.g., Bonin Petrel, Tristram's Storm-petrel, and Wedge-tailed Shearwater), and the Laysan Finch, which is restricted to specific habitats on Laysan Island and Pearl and Hermes Atoll and incapable of unaided inter-atoll dispersal. Another example is specialized shrub-nesting species, such as the Red-footed Booby, that may be vulnerable to further loss of already limited shrub habitat in the Monument (Krause et al. 2012). Habitat loss may also increase the density of nests within remaining areas, potentially leading to crowding problems or disease. Among the islands most likely to lose significant areas of nesting habitat Baker et al. (2006) highlight the particular risk to populations on French Frigate Shoals and Pearl and Hermes, where virtually all land is less than 2 m above sea level. Additionally, Krause et al. (2012) project substantial habitat loss at Midway Atoll and risks to Laysan Island from extreme events. In addition, migratory shorebirds that overwinter in the NWHI, or use the islands to rest and feed during their migrations, are also vulnerable to climate-induced changes in habitat area and food resources.

Climate change may also significantly impact Papahānaumokuākea's avifauna through impacts to their prey species. On the Great Barrier Reef, which has more land area than PMNM, Congdon et al. (2007) concluded that seabirds' greatest vulnerability to climate change was from impacts to their food resources. Changes in sea surface temperature, circulation, and upwelling can directly change the abundance and distribution of prey, thereby reducing seabird foraging opportunities and increasing foraging distances. These changes can be combined or exacerbated by climate-induced changes in the behavior of pelagic predatory fish species, particularly tuna and mackerel, which seabirds rely on to drive smaller fish species to the surface. Additionally, to the extent that these seabird species prey on reef fish, they may be impacted by the expected degradation of reef ecosystems due to climate change, as described previously.

Table 2.3.5 Vulnerabilities of PMNM's island & atoll ESA species of concern to climate change variables.

Ecosystem Components	Key Vulnerabilities
Seabirds	❖ (High) Habitat loss due to sea-level rise and storm surge is very likely to reduce the size of PMNM's breeding bird populations; impacts will vary among species. ❖ (Medium) The quantity and quality of nesting habitat is likely to be reduced as climate change impacts PMNM's island ecosystems (e.g., nests may become hotter, freshwater may become more scare, invasive species may increase, and plant species composition is likely to change); reduced quantity and quality of nests is likely to increase chick mortality ❖ (Medium) Warmer temperatures may increase the incidence of disease in chicks and adults ❖ (Low) Climate change impacts on seabird prey are very likely to negatively impact multiple seabird species, particularly through chick provisioning failure; impacts will vary between species and geographic areas ❖ (Medium) Changes in sea surface temperature, circulation, and upwelling may change the abundance and distribution of seabird prey species, reducing foraging opportunities ❖ (Low) Climate-induced changes in the abundance, distribution, or behavior of pelagic predatory fish species may negatively impact seabird foraging opportunities, because they rely on these fish species, particularly tuna and other large predators, to drive seabird prey into the surface waters ❖ (Low) Seabird species that occasionally prey on reef-associated fish, such as Black Noddies, White Terns, and Brown Boobies, may be negatively impacted by the expected climate-related degradation of PMNM's coral reef ecosystems
Endangered Land Birds	❖ (Medium) Habitat loss due to sea-level rise and storm surge is likely to reduce populations of PMNM's endangered land bird populations; impacts will vary among species ❖ (Medium) The quantity and quality of nesting habitat is likely to be reduced as climate change impacts PMNM's island ecosystems; e.g., nests may become hotter, freshwater may become more scarce, vegetation stature may change, and invasive species may increase ❖ (Low) Warmer temperatures may increase incidence of parasites and disease in chicks and adults ❖ (Medium) The availability of land bird prey species, particularly arthropods, may change with shifts in habitat types and extent, and vegetative community species composition

Confidence: ❖ Low ❖ Medium ❖ High

Based on field observations and a review of the impacts of past climatic events on reproductive success, Condon et al. (2007) propose that the impacts of climate change on prey will be seen a series of catastrophic declines in seabirds rather than in a gradual drop in population numbers. They argue that there are age-related thresholds that determine how long chicks can go without parental provisioning, and that as these thresholds are surpassed, nesting success drops steeply. Evidence for albatross in the NWHI may suggest a more graduated approach to declines, but supports the idea that increased foraging effort can have reproductive costs. A tagging study of Laysan and Black-footed Albatrosses from Tern Island by Kappes et al. (2010) found that while albatrosses demonstrate flexibility in foraging strategies, this ability to adapt to climatic variability came with reproductive consequences. In particular, for the Laysan Albatross, average annual body mass changes during foraging were positively correlated with annual reproductive success and negatively related to maximum distance traveled. During the same period, this relationship was not seen in the Black-footed Albatross, whose different foraging strategy seems to benefit from a more stable food source and whose overall reproductive success was higher than that of its Laysan counterpart.

Within Papahānaumokuākea, the type of tipping-point changes that Condon et al. (2007) hypothesize have resulted primarily from acute storm and wave events. Past events have caused inundation of nesting areas, as well as contamination of fresh-water and lake resources, and have resulted in significant loss of adults or reproductive failures; these include the loss of over 30,000 Black-footed Albatross chicks and eggs—or over 56% of the total nests at Kure, Midway, and Laysan—and over 254,000 Laysan Albatross chicks and eggs—or approximately 41% of the nests at the same sites--in 2011/2012 (Flint, pers. comm.); the loss of Laysan Teal nests in 2011; and nesting failure of Laysan Finches in 1986 (Morin, 1992). With climate projections indicating the potential for more intense, and possibly more frequent, future storms, the incidence of this type of reproductive failure may increase. For this reason, Berkowitz et al. (2012) suggested that avifauna species whose incubation and chick-rearing periods coincide with seasonal peaks in wave height are more vulnerable to climate change-related inundation, in particular the albatross species, Bonin Petrels, and Tristam's Storm-petrels.

Management actions have been successful in ameliorating habitat limitations on Hawaiian bird populations (Duffy, 2010), and offer a response to some climate-related impacts to avifauna habitats (Strategy 2.3.1). However, the scope for a rapid response to acute storm and wave events is more limited due to the remote location of the breeding sites PMNM, and management responses to climate impacts on avifauna prey species are limited and indirect at best (Strategy 2.3.5).

2.3.3 Key Implications

Expert analysis of existing evidence suggests that the key implications of climate change for PMNM's island ecosystems include:

- It is very likely that PMNM's low-lying atolls will be increasingly subjected to wave overwash and inundation within the next 50-100 years [high confidence]
- Beach and coastal strand habitats are very likely to be lost as a result of sea-level rise, storm inundation, and erosion, with significant implications for endangered species that rely on these habitats for breeding sites, including monk seals, sea turtles, and seabirds [high confidence].
- Inland waters, including both freshwater seeps and the hypersaline lake on Laysan, are likely to be degraded by changes in timing and amount of precipitation, compromising critical habitats for a range of endemic and protected species [moderate confidence].
- Papahānaumokuākea's globally important bird populations are at risk from the loss and degradation of habitat, changes in prey availability, and direct impacts from changes in environmental conditions [moderate confidence].
- Climate change impacts on Papahānaumokuākea's endemic plant and arthropod species are likely, but major information gaps on these species prevent an adequate vulnerability assessment at this time [moderate confidence].

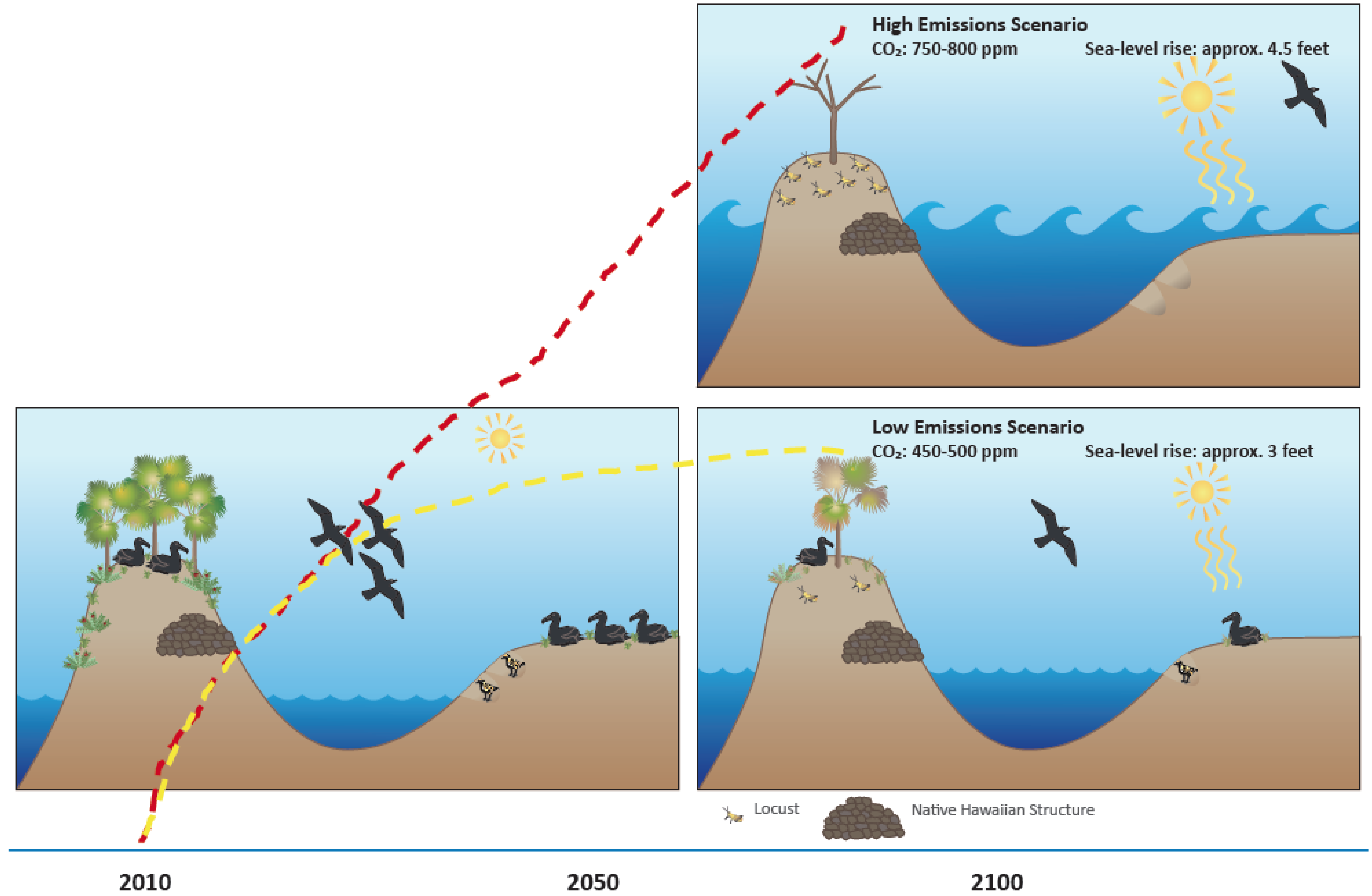


Figure 2.3.1 Projected changes in PMNM's island ecosystems between today (left) and 2100 under high RCP 8.5 (top, right) and low RCP 2.6 (bottom, right) greenhouse gas emission scenarios. In comparison to today, in the future invasive species may increase, native species and habitats will be reduced, low atolls will be inundated, and freshwater habitats may be lost.

Overall, existing evidence suggests that climate change may dramatically alter PMNM's island and atoll terrestrial ecosystems over the coming century by substantially shrinking available land area. Inundation of currently emergent land areas, changes in ecosystem composition, alteration of environmental conditions, and reductions in the availability of freshwater are likely to impact the managed species that have evolved to rely on existing habitats. The Monument's endemic species are particularly vulnerable to these changes with little prospect of moving to other suitable areas, given the islands' small size and remoteness. The rate and extent of these changes will be influenced by the level of future CO_2 emissions, as well as the degree to which local management actions are implemented to facilitate adaptation. Figure 2.3.1 illustrates expert opinion that under future scenarios with higher rates of CO_2 emission (RCP 8.5), in the result will be greater losses of land area and managed species, as well as increases in invasive species, in comparison to the situation under lower emission CO_2 scenarios (RCP 2.6). Section 3 presents the local management strategies needed to facilitate adaptation to climate change.

2.4 Cultural, Historical, and Heritage Resources

If we're talking about relative values, as climate change starts impacting more and more places, then from a relative perspective, the value of the Monument will go up compared to less protected areas; it will become more sacred. At the same time, in an absolute sense, values will be lost.

- Respondent, PMNM Climate Change Survey

While Papahānaumokuākea is formally recognized as a place of cultural and heritage significance, little work has been done to investigate the means and extent to which these resources may be affected by climate change. The situation in Papahānaumokuākea reflects discussions globally, in which cultural and non-material impacts from climate change are less considered than those with material economic costs (Adger et al., 2011). This section describes the Monument's cultural and heritage resources and values (Section 2.4.1), and considers how these resources may be impacted by climate change and the capacity of stakeholder groups to adapt to these changes (Section 2.4.2). The section concludes by summarizing the key implications of these anticipated impacts (Section 2.4.3).

2.4.1 Cultural and Heritage Resources Associated with Papahānaumokuākea

Tangible culture is the counterpart of culture which is tangible or touchable, whereas intangible culture includes songs, music, drama, skills, crafts, and the other parts of culture that can be recorded but cannot be touched and interacted with, without a vehicle for the culture.

- Wikipedia entry for "Intangible Cultural Resources"

Papahānaumokuākea is a sacred and ancestral home for Native Hawaiians; a unique historical seascape with sites of archeological significance; a remote area offering outstanding opportunities as an exemplar site for science and management; and a legacy, and responsibility, for all people as reflected in its designation as a World Heritage site. In developing this vulnerability assessment, workshop participants found it useful to distinguish between tangible cultural and heritage resources, and the intangible social values that are associated with them. Tangible resources have a physical presence or a particular tangible characteristic that is valued by a group within society. Intangible cultural and heritage resources are spiritual, religious, intellectual, or emotional experiences or perceptions associated with PMNM that contribute to human well-being. The following sections explore in greater depth the meaning of PMNM's tangible and intangible resources.

2.4.1.1 Tangible Resources

Papahānaumokuākea's tangible resources include natural resources as well as archaeological and historical sites. Many of these physical resources are vulnerable to climate change and they are the foundation for most of the intangible cultural resources described in Section 2.4.1.2.

Natural Resources Are Cultural Resources

*We hope Papahānaumokuākea's [World Heritage] inscription will help …
underscore that for so many indigenous peoples, nature and culture are one.*

– ʻAulani Wilhelm, former PMNM Superintendent

The natural resources described in Sections 2.2 and 2.3 are also cultural resources for Native Hawaiians. Like other indigenous and Pacific cultures, Native Hawaiians understand they are interconnected with their environment. As such, the plants, animals, and islands of Papahānaumokuākea are part of Native Hawaiians themselves, and impacts to these resources simultaneously impact them. More broadly, the weather, wind, and oceanic currents around PMNM are integral to Native Hawaiian traditional ecological knowledge and wayfinding, and in this regard might also be considered tangible cultural resources.

Archeological & Historical Sites

*The archaeological sites and artifacts exist nowhere else
in the world, so if we lose them they're gone.*

- Respondent, PMNM Climate Change Survey

The NWHI have a rich history of human exploration and use dating back many centuries (Figure 2.4.1). The Monument contains the material legacy of this historical use, and with it, the opportunity to more fully understand human experiences of the past, and the way these human interactions with Papahānaumokuākea have influenced the Monument's physical and ecological condition today (PMNM, 2008a, 2011a, 2011b). Nihoa and Mokumanamana contain 89 and 52 identified Native Hawaiian archaeological sites respectively; sites that are recognized as being unique both in their prehistoric content and in the extent to which they are undisturbed. Both islands are listed on the National Register of Historic Places. The legacy of the region's military history is centered on Midway Atoll, which is designated as a National Memorial and contains six structures designated as National Historic Landmarks. The military and seafaring history of the Monument is further evidenced by its 127 marine archaeological sites, 60 of which are known shipwrecks, with the remaining 67 consisting of aircraft losses (PMNM, 2011b; Speulda-Drews, 2010).

2.4.1.2 Intangible Resources

Intangible Cultural Heritage means the practices, representations, expressions, knowledge, skills – as well as the instruments, objects, artifacts and cultural spaces associated therewith – that communities, groups and, in some cases, individuals recognize as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature and their history, and provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity.

- 2003 Convention for the Safeguarding of the Intangible Cultural Heritage

A workshop involving representation from specialists in PMNM management, conservation science, social science and Native Hawaiian culture identified four categories of intangible resources associated with Papahānaumokuākea: universal values, Native Hawaiian cultural heritage, Western heritage, and knowledge derived from PMNM's opportunity to serve as an exemplar site for science and management. It is key to note that Native Hawaiian cultural heritage is a broad category, and this plan highlights those aspects that are most relevant to supporting people's connection to the place. These intangible resources are the result of human experiences or perceptions of Papahānaumokuākea, and they can contribute a sense of place and well-being for key constituencies and society at large.

Universal Values

Covering a vast area in one of the world's most isolated archipelagos, PMNM encompasses a significant expanse of low-lying islands and atolls, predator-dominated coral reef ecosystems, and marine and terrestrial flora and fauna that show significant patterns of enhanced speciation with numerous endemic and endangered species. It is a unique seascape, rich in ecological, geological and cultural heritage.

- PMNM World Heritage Application

The NWHI's designations as a National Monument and World Heritage Site recognize that this region is valued far beyond its boundaries, and is part of a legacy for all humanity. As a unique, remote area that has abundant and well-managed resources, the existence of PMNM ensures that a greater range of the world's natural and cultural diversity is protected. In turn, this offers humanity an increased sense of well-being through the knowledge that PMNM's resources remain intact. The universal values that are recognized as contributing to this global heritage are further described in the Monument's World Heritage Application.

Native Hawaiian Cultural Heritage

This place offers an amazing opportunity to Native Hawaiians to, in a sense, go back in time and see something their ancestors saw as closely as possible to what it was on the Main Hawaiian Islands.

- Respondent, PMNM Climate Change Survey

The islands that stretch across Papahānaumokuākea are important to the culture and identity of Native Hawaiians through a variety of rich and complex relationships. For every tangible cultural resource, there are links to a wide variety of intangible resources that include values and experiences (Table 2.4.1). For example, the uprights on Mokumanamana are a physical expression of a cultural practice in which chiefs secured the spiritual power (mana) to rule properly. These relationships are highly interconnected, and it is difficult—perhaps artificial—to identify them separately. Papahānaumokuākea is a sacred landscape for Native Hawaiians that provides a genealogical connection to their ancestral environment, which can foster self-understanding. This connection is supported by Hawaiian cosmology, traditional knowledge, and a long history of navigational, spiritual, and other uses that continue today. Further work is needed to understand how different groups within the Hawaiian community value Papahānaumokuākea, and how these values may be impacted by climate change.

Table 2.4.1 Guiding principles for considering Native Hawaiian Cultural Resources in the management of PMNM, quoted from The Native Hawaiian Plan for PMNM (in prep.).

1. *All natural resources are cultural resources.*
2. *Reciprocity is fundamental to the sustainability of human relationships with the world around us.*
3. *Hawaiian language is fundamental to Hawaiian knowledge; and Hawaiian knowledge is fundamental to understanding, utilizing, and protecting Hawaiian cultural resources.*
4. *Diversity in Hawaiian cultural perspective, knowledge, and tradition is important and should be nurtured.*
5. *Hawaiian inquiry methods utilize all senses and are often interpreted through a mix of intellectual, emotional, and spiritual functions.*
6. *Important factors that support rigor in Hawaiian inquiry and cultural practice are time (both specific time and the long-term duration of time), place (specific place that aligns with broader purpose), and observer (his/her familial and knowledge genealogies, the levels of skill and knowledge s/he has attained, and his/her intentions) are important factors in Hawaiian inquiry and cultural practice.*
7. *Mastery in a cultural practice is indicative of one's suitability to access PMNM for the purposes of perpetuating said practice.*
8. *Human resources directly impact capacity to manage cultural resources.*
9. *The cultural skills and knowledge of a resource manager (and the proficiency with which he/she applies them) directly impacts the natural/cultural resources for which he/she is responsible.*

Maritime Heritage and Historic Resources

The fascinating history of recent human activity in the NWHI including scientific exploitation, military operations and conservation initiatives (Wiener & Wagner, 2013) creates an opportunity for people from a range of backgrounds to reconnect with aspects of their own history and with this unique place. The sailors, soldiers, scientists, entrepreneurs, and laborers who worked in the NWHI over the last several centuries came from a broad range of geographic, cultural, and intellectual backgrounds. PMNM's heritage values flow from the ability to reconstruct and share these histories. The historical sites and artifacts left behind from these activities (see Section 2.4.1.1) offer one window for linking people to these aspects of the region's history, as do oral and written accounts of past activities.

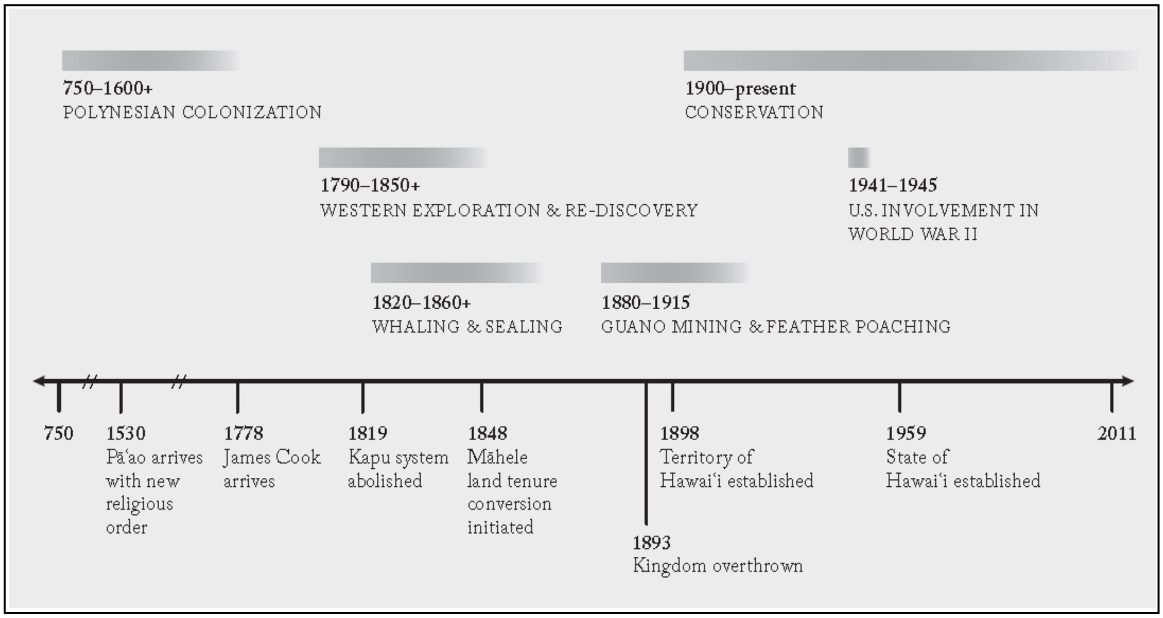


Figure 2.4.1.2 Timeline of human interactions with the NWHI. Different eras of interaction are shown above a timeline with significant events in Hawaiian history (developed by Gleason and Kittinger based on M. W. Beckwith (2007) & Kittinger et al. (2011); reproduced with permission from PMNM 2011).

An Exemplar Site for Science and Management

The Monument is part of the broader Hawaiian Archipelago that stretches from Hawaii Island in the MHI past Kure Atoll. The inherent scientific opportunity offered by this system was investigated and described through the collaboratively-developed Hawaiian Archipelago Marine Ecosystem Research (HAMER) plan (PIFSC, 2008, p. 1):

The entire archipelago thus reflects a combination of geologic processes coupled with an associated marine ecosystem succession, including substantial speciation in isolation of neighboring ecosystems. Add to this the comparatively recent occupation of the Main Hawaiian Islands (MHI) by human beings and you have in effect a natural laboratory where one portion is subject to anthropogenic influences and the rest is relatively pristine. This affords a unique opportunity to discern the human influence in the marine ecosystem across the archipelago. Few regions on the planet have the isolation, spatial structure, endemism, and research history that are needed to evaluate ecosystem dynamics and function at this scale.

As the most northern and pristine part of this system, the Monument is uniquely placed to provide answers to key science and management questions of great value. For example, comparative research and modeling will be able to suggest the extent to which human use in the MHI has altered ecosystem function and structure, and thereby help inform MHI management that aims to support ecosystem recovery and resilience. Similar research should be able to suggest the extent to which reducing the impacts from local resource use may confer ecological resilience to climate change. Notably, the high latitude of the Monument's northernmost atolls may mean they are some of the first reef systems globally to experience changing ocean chemistry, providing early indications of broader changes to come. In this regard, climate chance science and management conducted in PMNM has an essential role both in a regional and global context.

2.4.2 Projected Vulnerability to Climate Change

While there is a body of evidence to draw from in hypothesizing climate change impacts to PMNM's natural resources (Sections 2.2 and 2.3), research about climate change impacts on its cultural and heritage resources and values (Section 2.4.1) is sparse. The following sections consider the impacts of climate change on the Monument's tangible cultural and heritage resources (Section 2.4.2.1), and evaluate the available evidence regarding climate change impacts to PMNM's intangible values and the adaptive capacity of people likely to be affected.

2.4.2.1 Projected Climate Change Impacts to Tangible Cultural and Heritage Resources

> *The opportunity for cultural practices or cultural learning of those areas hasn't been that extensive, or not as extensive as it could be. Climate change could potentially remove, damage, or destroy many of those sites before they have the chance to be better understood. Looking at it from the archaeological or cultural standpoint, it may move up in priority for research, or for practitioners to access those islands and resources and learn from them what they can, before climate change has an adverse impact on them.*
>
> - Respondent, PMNM Climate Change Survey

PMNM's tangible cultural and heritage resources include the natural resources discussed in the previous sections, and sites and artifacts of importance to Native Hawaiian culture, military history, and Western exploration and exploitation, which are considered next. Many of the known Native Hawaiian archeological sites are located on elevated grounds on Nihoa and Mokumanamana. This position will protect these sites from sea-level rise and storm surge, but they may be vulnerable to more frequent or intense storms and rains; as a precaution, monitoring could be implemented to detect if they are suffering increased structural erosion. Some Native Hawaiians have expressed concern that sea-level rise may uncover or submerge undiscovered archaeological sites, for example ancestral bones (iwi kupuna). Degradation of these artifacts and sacred sites would constitute a loss of cultural knowledge and connection with Hawaiian ancestors, and therefore negatively impacts Hawaiian well-being. Given this risk, it would be preferable to accelerate work that could identify such sites (Strategies 1.5.1 and 2.4.1).

The vulnerability of historic structures and maritime heritage sites to climate change has largely not been assessed. Historic structures on Midway, particularly World War II era fortifications along the shoreline, may be vulnerable to sea-level rise or storms, and shipwrecks may be vulnerable to storms or, potentially, ocean acidification. In other contexts, environmental degradation, such as acid rain, is known to have impacted archaeological sites (Nord et al., 2005). Further work is needed to evaluate potential impacts and prioritize conservation efforts (Strategies 1.5.1 and 2.4.1).

2.4.2.2 Projected Climate Change Impacts to Intangible Cultural and Heritage Values

The impacts of climate change to the specific types of cultural and heritage values associated with Papahānaumokuākea have not been studied within the Monument, and have received limited attention globally (Adger et al., 2011). Generally speaking, the legitimacy of cultural, scientific, and existence values for healthy ecosystems, such as those described in Section 2.4.1.2, are widely recognized, but often difficult to describe or quantify (MEA, 2003). A number of studies have evaluated methods for estimating potential monetary losses in order to better understand the types of economic damages that might result from varying climate change scenarios (e.g., Balmford et al., 2011; Tol, 2002; Turner & Daily, 2008). For example, the existence value of a remote area, like Papahānaumokuākea, can be inferred from peoples' willingness to make payments that maintain varied ecosystem characteristics.

Perhaps more relevant are studies from medicine, law, and policy that analyze physical and emotional dislocation in terms of their implications for health, human rights, and damage assessment tribunals (e.g., Adger et al., 2011; Barnett, 2005; Hess et al., 2008; Kirsch, 2001; UN, 2009). For example, in their review of climate change and place in the *American Journal of Preventative Medicine,* Hess et al. assert that, "events that fundamentally alter the ecology of a given place disrupt people's attachment to place and identity, precipitating culture loss, even if inhabitants are not physically displaced" (2008, p. 475). The relationship between environmental degradation and culture loss is examined in legal and anthropological terms by Kirsch (2001), who observes that culture loss may occur through impacts to traditional knowledge, subsistence production, and attachment to place, but that counter-arguments exist which assert that indigenous cultures, specifically those in the Pacific Islands, are highly adapted to respond to environmental change, and that while cultures may change, they will not be lost.

There is broad acceptance that people form attachments to special places, and feel loss when those attachments are broken. Some experts agree that place attachment is stronger for indigenous communities (Kirsch, 2001). Work examining the impacts of climate change on indigenous communities takes its starting point, almost exclusively, from impacts to environmental conditions that affect access to food, water, and shelter; in these studies, impacts to traditional knowledge and culture flow from changes to subsistence resource use (e.g., Barnett, 2005; Berkes et al., 2000; Bridges & McClatchey, 2009; Turner & Clifton, 2009; UN, 2009). In contrast, Native Hawaiian cultural values for Papahānaumokuākea are not based on subsistence use.

Thus while there are useful parallels between existing research and the key social values that are relevant to the Monument, important differences exist that leave significant gaps in our understanding of how, and to what extent, climate change may impact the Monument's cultural and heritage values for different stakeholder groups. Because the current state of knowledge is inconclusive, a series of working hypotheses about how social values associated with Papahānaumokuākea may be vulnerable to climate change (Tables 2.4.2) are discussed below.

<u>Universal Values</u>

Because it is a remote, unique, and beautiful place, people apply a natural value to it, regardless of their culture. This value would be negatively affected by climate change, as people tend to give up on things if they think they're going to disappear.

If we're talking about relative values, as climate change starts impacting more and more places then, from a relative perspective, the value of the Monument will go up compared to less protected areas; it will become more sacred. At the same time, in an absolute sense, values will be lost.

- Respondents, PMNM Climate Change Survey

The universal value for PMNM's unique ecological and cultural environment may be perceived in either an absolute or relative sense. From an absolute perspective, we anticipate PMNM will lose species and low-lying atolls and that these losses will constitute a loss in well-being for all people who value their existence. Additionally, changes may result in detachment from Papahānaumokuākea as people protect themselves from these losses (Agyeman et al., 2009).

The relative perspective on change in PMNM is more complicated. In comparison to other places, PMNM's uninhabited and highly managed context means it will continue to be protected from direct anthropogenic impacts, and that its ecosystems will have the best chance of adapting to new conditions. At the same time, however, PMNM's ecosystems and species are more vulnerable to climate change than those found in many other places. For example, the Monument's high levels of endemism and remoteness leave it particularly vulnerable to climate change. Additionally, the NWHI still provide habitat for species that have disappeared from other areas, so the Monument has more to lose.

Overall, PMNM's strong management will remain among the most protective within a global context; therefore, to the extent that PMNM's management eliminates direct anthropogenic stress, people's value for knowing that there are remote places left to be wild and untouched may be protected. However, if climate change results in high levels of extinctions that reduce the uniqueness of the NWHI, the Monument's universal values may be similarly reduced. Thus, while the ways in which climate change may impact universal values are unknown, our overall hypothesis is that this value will be negatively impacted by climate change. The best way to protect these values is to reduce greenhouse gas emissions, thereby reducing the rate and extent of climate change impacts going forward.

Native Hawaiian Cultural Heritage

Access to the NWHI allows Hawaiians to make connections with the land, the ocean, the fish, the sharks, the monk seals – and the spirits and our ancestors that are still there. The Monument region is not strictly a scientific laboratory; it's a place that has its own life force.

– William Aila, PMNM (2008a), pg. 23

As noted earlier, intangible resources constitute a very broad category that includes values, which in the context of this plan are one of the most relevant ways to understanding the connections between natural and cultural resources, as well as between people and the place. Specific to the Native Hawaiian community, Table 2.4.1 describes the ways in which they value Papahānaumokuākea. These values can be grouped under three headings: 1) the area's cosmological significance, 2) its role in facilitating a sense of continuity with ancestors and all life; and, 3) its role in Native Hawaiian traditional ecological knowledge. These values vary in the extent to which they rely on a direct physical experience of PMNM versus a grounding in cultural perceptions and beliefs that do not require first-hand experience with the Monument. They also vary in the ways they may be impacted by climate change and the extent to which Native Hawaiians can adapt to these potential impacts without a loss to their well-being. These three types of values are explored below.

Cosmological Significance

We hypothesize that the importance of Papahānaumokuākea as a sacred place in Hawaiian spiritual cosmology will be unaffected by climate change because this status comes from the importance of the Monument's atolls and islands in Hawaiian oral traditions and geological

Table 2.4.1 Inter-related Native Hawaiian values for Papahānaumokuākea illustrated by quotes from the Monument's World Heritage Application (2008).

Value	Illustrative Quote	page
Cosmological Significance	*Papahānaumokuākea, as an associative cultural landscape, represents core elements of Native Hawaiian cosmology and tradition. The islands northwest of the Tropic of Cancer are believed to lie within the region of primordial darkness from which life originates and to which it returns.*	6
Continuity	**Pristine:** *Papahānaumokuākea is an expansive Hawaiian natural and cultural seascape, encompassing both land and sea, in which these relationships are vibrant and largely unfettered by human development. It is an immense associative cultural seascape – a Hawaiian place where man is, as in the Kumulipo, the little brother of the land and sea. And it is a place where Hawaiians can go to immerse themselves in this foundational understanding, ensuring the continuity of the generational bond and commitment to this sacred place.*	22
	Archaeological Sites: *Papahānaumokuākea's remarkable archaeology and significant ritual sites (heiau) bear exceptional testimony to the shared historical origins of all Polynesian societies, and to the growth and expression of a culture that evolved from the last and most difficult wave of cross-Pacific Polynesian migration.*	6
	Genealogy: *Many oral traditions say that Native Hawaiians are genealogically related not only to the living creatures that make up the land and ocean ecosystems, but to the islands and atolls themselves.*	21
	Continuity: *Biologists speak of Papahānaumokuākea's ecosystem, dominated by apex predators, as a rare benchmark for an intact marine system. Native Hawaiians experience this as a natural environment that hews to ancestral behaviors, rhythms, and proportions, where the ecological and spiritual links have not been frayed.*	22
	Platform for Spiritual Learning & Empowerment: *natural encounters can often be considered hōʻailona, natural signs communicated by ancestors and gods who manifest themselves in nature. These signs occur most clearly in a place like Papahānaumokuākea, where nature has not been subjugated.*	22
Traditional Knowledge	**Wayfinding:** *As in generations past, the contemporary apprentice Hawaiian wayfinder's first open-ocean training ground takes them from the MHI into Papahānaumokuākea, the Kūpuna Islands. A Native Hawaiian saying, "Nānā i ke kumu," means "Look to the source." It contains a subtle double meaning: while kumu means source, it also means teacher. This saying offers insight into the important role that kūpuna, who are also teachers, play in traditional Hawaiian society. Hawaiians are exhorted to turn to their kūpuna for knowledge, and to in turn respect and care for those kūpuna, as we must all learn from Papahānaumokuākea and respect and care for this unique place.*	23
	Cultural Learning: *The foundation of this culture* is *a nuanced awareness of, and responsive intimacy with, the patterns and processes of their specific natural environment.*	20
	Path to Meaning: *Today, we praise Papahānaumokuākea's high rates of marine endemism in a world where ecological diversity is imperiled. For Native Hawaiians, each endemic species occupies an induplicable place in the spiritual as well as physical universe. It is not only a member of the family of nature, but a path to meaning and understanding. When a species is lost, that understanding is lost forever.*	22

Table 2.4.2 Impacts and opportunities of climate change on PMNM's cultural, historical and heritage resources.

Resources	Key Impacts & Opportunities
Native Hawaiian Cultural Resources	❖ More frequent or intense storms could damage archeological and sacred sites on Nihoa and Mokumanamana; intensified rainfall and sea-level rise could uncover or submerge ancestral bones (iwi kupuna) ❖ Ecological extinctions and degradation resulting from climate change may increasingly impact Native Hawaiians in their ability to care for their ancestors ❖ Ecological extinctions and degradation resulting from climate change are likely to reduce the opportunities for Native Hawaiians to experience kinship with all things ❖ Ocean acidification and other changes in climate variables and marine ecosystems are likely to impact species of significance to Native Hawaiians ❖ Changes in weather, currents, ecosystems, and species may reduce the ability of Native Hawaiians to experience their ancestors or to experience the NWHI as their ancestors did ❖ Changes in weather, currents, ecosystems, and species, may erode the accuracy and meaningfulness of centuries of accumulated traditional knowledge ❖ Warmer temperatures may create strain in outdoor ceremonies and protocols ❖ The importance of Papahānaumokuākea as a sacred place in Hawaiian cosmology is unlikely to be affected by climate change, because this status comes from Hawaiian oral traditions and geological history, which will not be altered by changing environmental conditions
Archaeological Sites & Artifacts	❖ Heritage sites, particularly on Midway, may be vulnerable to increased storm intensity and storm surge ❖ Underwater sites may be at risk from ocean acidification, changing current patterns, and more intense storms ❖ More frequent or intense storms could damage Native Hawaiian archeological sites on Nihoa and Mokumanamana; intensified rainfall and sea-level rise could uncover or submerge ancestral bones (iwi kupuna)
Exemplar Site for Science & Management	❖ Climate change confers an important research opportunity to better understand coral reef and island ecosystems, as well as the effectiveness of local management actions in conferring ecological resilience to climate change impacts ❖ PMNM has the potential to be an international exemplar for island and protected area management, within the context of climate change, by drawing on both Native Hawaiian and Western scientific traditions in an integrated way
World Heritage Values	❖ Species extinctions and the inundation of low-lying atolls due to climate change are likely to diminish the well-being of people who value their existence ❖ PMNM's uninhabited context and strong management protections may continue to protect people's value for knowing that there are remote places left to be wild and untouched in spite of climate-driven degradation ❖ Climate-driven extinctions that reduce the uniqueness of the NWHI will also reduce the Monument's World Heritage values for nature

Confidence: ❖ Low ❖ Medium ❖ High

history, which will not be affected by future environmental conditions. We believe that this value will be highly resistant to climate change.

Continuity

I think for many Native Hawaiians, maybe 99.5% have never been up there. But for those that have, they've had a tremendous experience in connecting with their cultural past, spiritually, physically etc. and there is tremendous potential. But how do you convey that to the remainder of the population who, more than likely, will never have the chance to go up there in their lifetime? It's the stories and the understanding of the place that's captured. I think if you relayed or memorialized it somewhere, then if climate change ends up taking away a lot of that, then at least there is some record of the understanding of the places that are lost. I think the more that we understand about the place—the stories of those places—and that they're recorded, even though the place may be gone at some point in time, the legacy will remain and that can be of value.

- Respondent, PMNM Climate Change Survey

The attachment Native Hawaiians' have for Papahānaumokuākea, in part, results from the connection or continuity this place provides to Hawaiian ancestors and to all life. The ways in which this value of continuity may be vulnerable to climate change is uncertain and requires further research (Strategy 1.5.2); several scenarios are plausible.

Native Hawaiian culture understands all life to be interconnected, and PMNM's pristine environment facilitates the opportunity for Hawaiians' to experience kinship with all living things and the atolls that stretch across Papahānaumokuākea. The anticipated impacts of climate change on ecosystems and species potentially impair Hawaiians' ability to experience kinship, as the number of species available for interaction is reduced, and thus some opportunities to learn from species are also lost.

Papahānaumokuākea is also valued by Native Hawaiians as a way to connect with their ancestors. This continuity occurs through Hawaiians' ability to experience the area as their ancestors did, as well as by being able to perceive their ancestors as manifestations of nature. To the extent that climate change-induced shifts in ecology, weather, winds, and currents disrupt this continuity, Hawaiian well-being may be negatively impacted. Alternatively, this sense of ancestral continuity may remain intact.
Papahānaumokuākea has experienced many shifts in the absence of climate change over the past 1,000 years during which Hawaiians have voyaged, worshiped, observed, and accessed these islands.

Native Hawaiian continuity with their ancestors also involves a sense of *kuleana* (responsibility) to care for Papahānaumokuākea as a sacred place. It is unknown if the strong management protections operating in PMNM would enable Hawaiians to feel they were meeting this responsibility, or if the loss of species and land area would create a sense of disempowerment for Hawaiians.

Traditional Ecological Knowledge

> *The positive aspects would be that Native Hawaiians could potentially provide input into how we manage this new fluctuation in relation to how they managed previous fluctuations, maybe not of this caliber, but nonetheless they've had to deal with a much greater range of generational change than Hawaiians from the mainland.*
>
> - Respondent, PMNM Climate Change Survey

Like other indigenous cultures, Hawaiian's direct and intimate understanding of the Hawaiian Islands exists as a body of traditional ecological knowledge that is a highly valued element of Hawaiian culture. It is unknown if climate change impacts on PMNM's environment and ecology will erode the efficacy of Hawaiian traditional knowledge, creating a concurrent loss of Hawaiian culture, or whether Hawaiians will have the opportunity to adequately engage with changing conditions in PMNM, thus being able to maintain their ecological knowledge accordingly. While both of these scenarios are explored here, we believe it is more likely that Hawaiians will be able to adapt their traditional ecological knowledge, assuming their ability to access PMNM is facilitated as part of ongoing management efforts.

It is well recognized that traditional ecological knowledge is a living part of indigenous cultures, typically tied in to day-to-day experience of local environments for subsistence and spiritual use. The risk climate change poses to Hawaiian traditional knowledge is that changing conditions could possibly create a disconnect between tangible conditions and a more long-standing understanding of them. For example, as climate change alters weather patterns, ocean currents, ecosystems, and species community composition, traditional knowledge and weather forecasting may become less meaningful, or even misleading. Changing weather conditions may also prove disruptive to long-held cultural practices; for example, warmer temperatures may increase the strain of ceremonies and protocols performed outdoors, particularly those held at the auspicious time when the sun is directly overhead.

While this disconnection is a possibility, we believe it is more likely that Native Hawaiians will adapt to changing conditions, integrating new observations into traditional knowledge, and further reconnecting with important cultural insights as they seek to make sense of evolving circumstances. We hypothesize that voyaging, as one of the primary cultural training activities in the Monument, may be affected by potential changes in weather, currents and storm patterns, but will not be displaced by these changes. Additionally, climate change may stimulate further reconnection with Native Hawaiian traditional knowledge, as a context for understanding the range of natural variability observed by Hawaiians over centuries (see Turner & Clifton, 2009). Ellemor (2003) documented a cultural reconnection in response to degradation of the Barmah-Millewa Forest and floodplain in southeast Australia, finding that a need to understand the system's requirements fostered an interest in the area's ecological, genealogical, and cultural significance. We hypothesize that climate change may serve as a similar catalyst for expanding engagement with Native Hawaiian traditional ecological knowledge if institutional arrangements and opportunities for access to the Monument are appropriately expanded (Strategy 2.4.2).

Heritage Values

Section 2.4.1.2 describes how the use of the NWHI for exploration, exploitation, military operations, and conservation has left a material legacy of these activities within the Monument that offers the opportunity for a wide range of people to gain an insight into their past. To the extent that climate change degrades or eliminates these material links through storms, sea-level rise or changing ocean chemistry, access to that direct connection of the past will be lost. The risk of this loss can be mitigated by inventorying, documenting, and, as appropriate, conserving key sites and artifacts to best retain the insights they offer (Strategy 2.4.1)

An Exemplar Site for Science & Management

> *Climate change is a scientific opportunity; it's not necessarily something we would have wanted, but there's certainly a lot of options there to learn things.*
> - Respondent, PMNM Climate Change Survey

We hypothesize that from a research perspective, climate change confers an important opportunity to better understand coral reef and island ecosystems, as well as the effectiveness of local management actions in conferring ecological resilience. Thus we hypothesize that if well-designed, comparative studies are implemented, our understanding of globally important ecosystems and management strategies will be enhanced by climate change (Strategy 2.4.4).

Additionally, PMNM has the potential to be an international exemplar for protected area management within the context of climate change. By drawing on both Native Hawaiian and Western scientific traditions in an integrated way, we believe the Monument is well-positioned to demonstrate wise local action in responding to this overarching global change (Goal 4).

2.4.3 Key Implications

Expert analysis of existing evidence suggests that the key implications of climate change for PMNM’s cultural and heritage resources include:

- PMNM’s tangible cultural and heritage resources, which include natural resources and archeological sites and artifacts, will be negatively affected by climate change [high confidence].
- Archaeological sites and artifacts on the high islands of Nihoa and Mokumanamana are likely to be more resistant and resilient to climate change impacts than natural resources [high confidence].
- There are at least four categories of intangible values associated with Papahānaumokuākea: universal values, Native Hawaiian cultural values, heritage values, and those derived from PMNM’s opportunity to serve as an exemplar site for science and management. These values are the result of human experiences or perceptions of Papahānaumokuākea, and they can contribute a sense of place and well-being for key constituencies and society at large [high confidence].
- The impact of climate change on both Native Hawaiian cultural and overarching social values is largely unknown and warrants further research [high confidence].
- Actions to identify, document, and conserve vulnerable cultural and heritage sites can help ameliorate potential climate change impacts [moderate confidence].
- Actions to help facilitate appropriate Native Hawaiian access and to share these experiences with the broader Native Hawaiian community can help ameliorate potential climate change impacts [moderate confidence].

Chapter 3

REFERENCES AND APPENDICES

3.1 Glossary

- ***Confidence***: a quantitative or qualitative evaluation of the level of scientific understanding in support of a conclusion. In this action plan, qualitative assessments of confidence have been made based on the amount of supporting evidence, and the level of agreement between experts about the interpretation. The levels of confidence applied to assessments made in this Action Plan are:

High 67% or greater
Medium 33–67%
Low 33% or less

- ***Ecosystem***: The biotic community and its abiotic environment within a specified location in space and time. The interacting system of a biological community and its non-living environmental surroundings.

- ***Ecosystem functions***: Energy circuits, food chains, diversity patterns in time and space, nutrient cycles, development and evolution, and control within an ecosystem (Odum, 1971).

- ***Ecosystem structure***: Pattern of the interrelations of organisms in time and in spatial arrangements (Odum, 1971).

- ***Likelihood***: the probability that a future projection or prediction will occur based on expert judgment. The categories of likelihood used in this action plan are:

Very likely	90–99% chance
Likely	66–90% chance
May	30–66% chance
Unlikely	29% chance or less

- ***Managed species***: Species that are legally designated as threatened or endangered, are otherwise legally protected, or are an important native species.

- ***Trans-disciplinary research***: Research efforts conducted by investigators from different disciplines that work together to create new conceptual, theoretical or methodological innovations that move beyond discipline-specific approaches to address a common topic. Given PMNM's management goals of protecting nature and perpetuating Native Hawaiian culture, a key focus for the trans-disciplinary research identified in this document, is developing knowledge that integrates both Native Hawaiian and Western scientific understandings of key climate change-related issues.

3.2 References

Adams, J. (2007). Global Climate Change: every cultural site at risk? In M. Petzet & J. Ziesemer (Eds.), *ICOMOS World Report 2006-2007 on Monuments and Sites in Danger*. http://www.international.icomos.org/risk/world_report/2006-2007/pdf/H@R_2006-2007_50_Special_Focus_GCC_Every_Site_Risk.pdf.

Adger, W. N., Barnett, J., Chapin, F. S., & Ellemor, H. (2011). This Must Be the Place: Underrepresentation of Identity and Meaning in Climate Change Decision-Making. *Global Environmental Politics, 11*(2), 1-25.

Aeby, G., Bourne, D., Wilson, B., & Work, T. (2011). Coral diversity and the severity of disease outbreaks: a cross-regional comparison of Acropora white syndrome in a species-rich region (American Samoa) with a species-poor region (Northwestern Hawaiian Islands). *Journal of Marine Biology*.

Aeby, G. S. (2006a). Baseline levels of coral disease in the Northwestern Hawaiian Islands. *Atoll Research Bulletin, 543*, 471-488.

Aeby, G. S. (2006b). Outbreak of coral disease in the Northwestern Hawaiian Islands. *Coral Reefs, 24*(3), 481.

Aeby, G. S., Kenyon, J. C., Maragos, J. E., & Potts, D. C. (2003). First record of mass coral bleaching in the Northwestern Hawaiian Islands. *Coral Reefs, 22*, 256.

Agyeman, J., Devine-Wright, P., & Prange, J. (2009). Close to the Edge, Down by the River? Joining Up Managed Retreat and Attachment to Place in a Climate Changed World. *Environment and Planning A, 41*(3), 509-513.

Anderson, T. R., Fletcher, C. H., Barbee, M. M., Frazer, L. N, & Romine, B. M. (2015). Doublisng of coastal erosion under rising sea level by mid-century in Hawaii. *Natural Hazards, 78*(1), 75-103.

Athens, J. S., Ward, J.V, & Blinn, D. W. (2007). Vegetation history of Laysan Island, Northwestern Hawaiian Islands. *Pacific Science, 61,* 17-37.

Aucan, J., Hoeke, R., & Merrifield, M. A. (2012). Wave-driven sea level anomalies at the Midway tide gauge as an indicator of North Pacific storminess over the past 60 years. *Geophysical Research Letters, 39*(L17603).

Baker, A. C., Starger, C. J., McClanahan, T. R., & Glynn, P. W. (2004). Coral reefs: Corals' adaptive response to climate change. *Nature, 430*(7001), 741.

Baker, J. D., & Johanos, T. C. (2004). Abundance of the Hawaiian monk seal in the main Hawaiian Islands. *Biological Conservation, 116*, 103-110.

Baker, J. D., Littnan, C. L., & Johnston, D. W. (2006). Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands. *Endangered Species Research, 4,* 1-10.

Baker, J. D., Polovina, J. J., & Howell, E. A. (2007). Effect of variable oceanic productivity on the survival of an upper trophic predator, the Hawaiian monk seal *Monachus schauinslandi*. *Marine Ecological Progress Series, 346*, 277-283.

Baker, J. D., Howell, E. A., & Polovina, J. J. (2012). Relative influence of climate variability and direct anthropogenic impact on a sub-tropical Pacific top predator, the Hawaiian monk seal. *Marine Ecology Progress Series, 469*, 175-189.

Balazs, G. H., Hirth, H. F., Kawamoto, P. Y., Nitta, E. T., Ogren, L. H., Wass, R. C., & Wetherall, J. A. (1992). Interim Recovery Plan for Hawaiian Sea Turtles (pp. 33): Southwest Fisheries Science Center, NMFS, NOAA.

Balmford, A., Fisher, B., Green, R., Naidoo, R., Strassburg, B., Kerry Turner, R., & Rodrigues, A. (2011). Bringing Ecosystem Services into the Real World: An Operational Framework for Assessing the Economic Consequences of Losing Wild Nature. *Environmental and Resource Economics, 48*(2), 161-175.

Barnett, J. (2005). Titanic States? Impacts and Responses to Climate Change in the Pacific Islands. *Journal of International Affairs, 59*(1), 203-219.

Beckwith, M., ed. & trans. (1951). *Kumulipo: A Hawaiian Creation Chant*. Honolulu: University of Hawai‘i Press.

Beckwith, M. W. (Ed.). (2007). *Kepelino's Traditions of Hawai‘i*. Honolulu, HI: Bernice P. Bishop Museum.

Bengtsson, L., Hodges, K. I., Esch, M., Kennlyside, N., Kronblueh, L., Lua, J.-j., & Yamagata, T. (2007). How may tropical cyclones change in warmer climate? *Tellus, 59A*, 539-561.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications, 10*(5), 1251-1262.

Berkowitz, P., Storlazzi, C. D., Courtot, K. N., Krause, C. M., & Reynolds, M. H. (2012). Sea-level rise and wave-driven inundation models for Laysan Island. In M. H. Reynolds, P. Berkowitz, K. N. Courtot & C. M. Krause (Eds.), *Predicting sea-level rise vulnerability of terrestrial habitat and wildlife of the Northwestern Hawaiian Islands* (pp. 72-126): U.S. Geological Survey Open-File Report 2012-1182.

Bohensky, E. L., & Maru, Y. (2011). Indigenous Knowledge, Science, and Resilience: What Have We Learned from a Decade of International Literature on "Integration"? *Ecology and Society, 16*(4), 6.

Bongaerts, P., Ridgway, T., Sampayo, E. M., & Hoegh-Guldberg, O. (2010). Assesing the 'deep reef refugia' hypothesis: focus on Caribbean reefs. *Coral Reefs, 29*, 309-327.

Bridges, K. W., & McClatchey, W. C. (2009). Living on the margin: Ethnoecological insights from Marshall Islanders at Rongelap atoll. *Global Environmental Change, 19*, 140-146.

Byrne, R. H., Mecking, S., Feely, R. A., & Liu, X. (2010). Direct observations of basin-wide acidification of the North Pacific Ocean. *Geophysical Research Letters, 37*(L02601), 5.

Caldeira, K., & Wickett. (2003). Anthropogenic carbon and ocean pH. *Science, 425*, 365.

Chin, A., Kyne, P. M., Walker, T. I., & McAuley, R. B. (2010). An Integrated Risk Assessment for Cliamte Change: Analysing the Vulnerability of Sharks and Rays on Australia's Great Barrier Reef. *Global Change Biology, 16*, 1936-1953.

Chu, P.-S., Chen, Y. R., & Schroeder, T. A. (2010). Changes in precipitation extremes in the Hawaiian Islands in a warming climate. *Journal of Climate, 23*(18), 4881-4900.

Church, J. A., & White, N. J. (2006). A 20th century acceleration in glbal sea level rise. *Geophysical Research Letters, 33*(L01602).

Congdon, B. C., Erwin, C. A., Peck, D. R., Baker, G. B., Double, M. C., & O'Neill, P. (2007). Vulnerability of seabirds on the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: a vulnerability assessment* (pp. 427-464): Great Barrier Reef Marine Park Authority.

Crook, E. D., Cohen, A. L., Rebolledo-Vieyra, M., Hernandez, L. & Paytan, A. (2013). Reduced calcification and lack of acclimatization by coral colonies growing in areas of persistent natural acidification. *Proceedings of the National Academy of Sciences, 110* (27): 11044-11049.Davidson-Arnott, R. G. D. (2005). Conceptual model of the effects of sea level rise on sandy coasts. *Journal of Coastal Research, 21*(6), 1166-1172.

Davidson-Arnott, R. G. D. (2005). Conceptual model of the effects of sea level rise on sandy coasts. *Journal of Coastal Research, 21*, 1166-1172.

De'ath, G., Lough, J. M., & Fabricius, K. E. (2009). Declining Coral Calcification on the Great Barrier Reef. *Science, 32*, 116-119.

Deschamps, P., Durand, N., Bard, E., Hamelin, B., Camoin, G., Thomas, A. L., . . . Yokoyama, Y. (2012). Ice-sheet collapse and sea-level rise at the Bolling warming 14,600 years ago. *Nature, 483*, 559-564.

Diaz-Pulido, G., McCook, L., Larkum, A. W. D., Lotze, H. K., Raven, J. A., Schaffelke, B., . . . Steneck, R. (2007). Vulnerability of macroalgae on the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: A Vulnerability Assessment* (pp. 153-192): Great Barrier Reef Marine Park Authority.

Dickinson, W. R. (2009). Pacific atoll living: how long already and until when? *GSA Today, 19*(3), 1-10.

Donohue, M. J., & Foley, D. G. (2007). Remote Sensing Reveals Links Among the Endangered Hawaiian Monk Seal, Marine Debris, and El Nino. *Marine Mammal Science, 23*(2), 468-473.

Duffy, D. C. (2010). Changing Seabird Management in Hawai'i: From Exploitation through Management to Restoration. *Waterbirds, 33*(2), 193-207.

Dutton, P., Balazs, G., LeRoux, R., Murakawa, S., Zarate, P., & Martine, L. (2008). Composition of Hawaiian green turtle foraging aggregations: mtDNA evidence for a distinct regional population. *Endangered Species Research, 5*, 37-44.

Ellemor, H. (2003). White Skin, Black Heart? The Politics of Beloning and Native Title in Australia. *Social and Cultural Geography, 4*(2), 233-252.

Fabricus, K. E., De'ath, G., Puotinen, M., Done, T. J., Cooper, T. F., & Burgess, S. C. (2008). Disturbance gradients on inshore and offshore coral reefs caused by a severe tropical cyclone. *Limnology and Oceanography, 53*, 690-704.

Feely, R. A., Doney, S. C., & Cooley, S. R. (2009). Ocean acidification: present conditions and future changes in a high-CO2 world. *Oceanography, 22*(4), 36-47.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kelypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science, 305*, 362-366.

Finklestein, M. (2006). Midway Atoll National Wildlife Refuge lead poisoning of Laysan Albatross chicks: Summary Report. California: University of California, Santa Cruz.

Firing, Y. L., Merrifield, M. A., Schroeder, T. A., & Qiu, B. (2004). Interdecadal sea level fluctuations at Hawai‘i. *Journal of Physcial Oceanography, 34*, 2514-2524.

Frey, A., Dutton, P. H., & Balazs, G. H. (2013). Insights on the demography of cryptic nesting by green turtles (Chelonia mydas) in the main Hawaiian Islands from genetic relatedness analysis. *Journal of Experimental Marine Biology and Ecology, 442*, 80-87.

Friedlander, A. M., & DeMartini, E. E. (2002). Contrasts in density, size, and biomass of reef fishes between the northwestern and main Hawaiian islands: the effects of fishing down apex predators. *Marine Ecology Progress Series, 230*, 253-264.

Friedlander, A. M., Kobayashi, D. R., Bowen, B., Meyer, C., Papastamatiou, Y., DeMartini, E. E., . . . Wedding, L. (2009). Connectivity and Integrated Ecosystem Studies. In A. M. Friedlander, K. Keller, L. Wedding, A. Clarke & M. Monaco (Eds.), *A Marine Biogeographic Assessment of the Northwestern Hawaiian Islands* (pp. 291-330). Silver Spring, MD: NOAA.

Giambelluca, T. W., Diaz, H. F., & Luke, M. S. A. (2008). Secular temperature changes in Hawai‘i. *Geophysical Research Letters, 35*, L12702.

Glick, P., Stein, B. A., & Edelson, N. A. (Eds.). (2011). *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. Washington, D.C.: National Wildlife Federation.

Grigg, R. W., Polovina, J. J., Friedlander, A. M., & Rohmann, S. O. (2008). Biology of Coral Reefs in the Northwestern Hawaiian Islands. In B. M. Riegl & R. E. Dodge (Eds.), *Coral Reefs of the USA* (pp. 573-594): Springer Science and Business Media.

Grottoli, A. G., Rodrigues, L. J., & Palardy, J. E. (2006). Heterotrophic plasticity and resilience inn bleached corals. *Nature, 440*, 1186-1189.

Guest, J., Baird, A., Maynard, J., Muttaqin, E., Edwards, A., Campbell, S., . . . Loke Ming, C. (2012). Contrasting Patterns of Coral Bleaching Susceptibility in 2010 Suggest an Adaptive Response to Thermal Stress. *PLoS ONE, 7*(3), e33353.

Guinotte, J. M., Buddemeier, R. W., & Kleypas, J. A. (2003). Future coral reef habitat marginality: temporal and spatial trends of climate change in the Pacific basin. *Coral Reefs, 22*, 551-558.

Hamann, M., Limpus, C. J., & Read, M. A. (2007). Vulnerability of marine reptiles in the Great Barrier Reef to climate change. In J. Johnson & P. Marshall (Eds.), *Climate change and the Great Barrier Reef: a vulnerability assessment*. Townsville, Australia: Great Barrier Reef Marine Park Authority.

Hansen, L., & Hoffman, J. (2011). *Climate Savvy: Adapting Conservation & Resource Management to a Changing World*. London: Island Press.

Hartzell, P. (2012). *Brief on the Current Status of the Seawall and Stabilization Needs Tern Island, French Frigate Shoals.* Unpublished report.

Harwood, J. (2001). Marine mammals and their environment in the twenty-first century. *Journal of Mammology, 82*(3), 630-640.

Hawai‘i DLNR. (2007). *Hawai‘i's Climate Change and Marine Disease Local Action Strategy*. http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/wgroups/resources/climate/resources/hi_cc_las.pdf: Hawai‘i Department of Land and Natural Resources - Division of Aquatic Resources.

Hawkes, L. A., Broderick, A. C., Godfrey, M. H., & Godley, B. J. (2009). Climate change and marine turtles. *Endangered Species Research, 7*, 137–154.

Hess, J. J., Malilay, J. N., & Parkinson, A. J. (2008). Climate Change: The Importance of Place. *American Journal of Preventative Medicine, 35*(5), 468-478.

Hoegh-Guldberg, O. (2011). The Impact of Climate Change on Coral Reef Ecosystems. In Z. Dubinsky & N. Stambler (Eds.), *Coral Reefs: An Ecosystem in Transition*: Springer Science & Business Media.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., . . . Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science, 318*(5857), 1737-1742. doi: 10.1126/science.1152509

Hoeke, R. K., Jokiel, P. L., Buddemeier, R. W., & Brainard, R. (2011). Projected Changes to Growth and Mortaity of Hawaiian Corals over the Next 100 Years. *Plos ONE, 6*(3), e18038 18031-18013.

Houghton, J. (2004). *Global Warming: The Complete Briefing 3rd edition*. Cambridge: Cambridge University Press.

Hughes, T., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., . . . Roughgarden, J. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science, 301*(5635), 929.

Hutchings, P., Ahyong, S., Byrne, M., Przeslawski, R., & Worheide, G. (2007). Vulnerability of benthic invertebrates of the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: A Vulnerability Assessment* (pp. 309-356): Great Barrier Reef Marine Park Authority.

IPCC. (2007a). Climate Change 2007: Synthesis Report. In Core Writing Team, R. K. Pachauri & A. Reisinger (Eds.), *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 104). Geneva, Switzerland: IPCC.

IPCC. (2007b). Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report (AR4) of the Intergovernmetal Panel on Climate Change. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (Eds.). Cambridge UK and New York USA: Cambridge University Press.

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In C. B. Field, V.R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandea, & L. L. White (Eds.). Cambridge, UK and New York, USA: Cambridge University Press.

Jokiel, P. L., Rodgers, K. S., Kuffner, I. B., Andersson, A. J., Cox, E. F., & Mackenzie, F. T. (2008). Ocean acidification and calcifying reef organisms: a mesocosm investigation. *Coral Reefs, 27*, 473-483.

Kane, C., Kosaki, R. K., & Wagner, D. (2014). High levels of mesophotic reef fish endemism in the Northwestern Hawaiian Islands. *Bulletin of Marine Science, 90*(2), 693-703.

Kappes, M. A., Shaffer, S. A., Tremblay, Y., Foley, D. G., Palacios, D. M., Robinson, P. W., . . . Costa, D. P. (2010). Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. *Progress in Oceanography, 86*, 246-260.

Kareiva, P., Enquist, C., Johnson, A., Julius, S. H., Lawler, J., Petersen, B., . . . West, J. M. (2008). Synthesis and Conclusions. In S. H. Julius & J. M. West (Eds.), *Preliminary review of adaptation options for climate-sensitive ecosystems and resources* (pp. 319-359). Washington, D.C.: U.S. Climate Change Science Program.

Karl, D. M., & Lukas, R. (1996). The Hawaii ocean time-series (HOT) program: background, rationale and field implementation. *Deep Sea Research II, 43*, 129-156.

Kaschner, K., Tittensor, D. P., Ready, J., Gerrodette, T., & Worm, B. (2011). Current and Future Patterns of Global Marine Mammal Biodiversity. *PLoS ONE, 6*(5), e19653 19651-19613.

Keller, K., Anders, A. D., Shaffer, S. A., Kappes, M. A., Flint, E. N., & Friedlander, A. M. (2009). Seabirds. In A. M. Friedlander, K. Keller, L. Wedding, A. Clarke & M. Monaco (Eds.), *A Marine Biogeographic Assessment of the Northwestern Hawaiian Islands* (pp. 235-274). Silver Spring, MD: NOAA.

Kenyon, J., & Brainard, R. (2006). Second recorded episode of mass coral bleaching in the Northwestern Hawaiian Islands. *Atoll Research Bulletin, 543*, 505-523.

Kenyon, J. C., Vroom, P. S., Page, K. N., Dunlap, M. J., Wilkinson, C. B., & Aeby, G. S. (2006). Community Structure of Hermatypic Corals at French Frigate Shoals, Northwestern Hawaiian Islands: Capacity for Resistance and Resilience to Selective Stressors. *Pacific Science, 60*(2), 153-175.

Kingsford, M. J., & Welch, D. (2007). Vulnerability of pelagic systems in the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the*

Great Barrier Reef: A Vulnerability Assessment (pp. 555-592): Great Barrier Reef Marine Park Authority.

Kirsch, S. (2001). Environmental Disaster, "Culture Loss," and the Law. *Current Anthropology, 42*(2), 167-198.

Kittinger, J. N., Pandolfi, J. M., Blodgett, J. H., Hunt, T. L., Jiang, H., Maly, K., . . . Wilcox, B. A. (2011). Historical reconstruction reveals recovery in Hawaiian coral reefs. *PLoS ONE, 6*, e25460.

Kittinger, J. N., Van Houtan, K. S., McClenachan, L. E., & Lawrence, A. L. (2013). Using historical data to assess the biogeography of population recovery. *Ecography, 38*, 868-872.

Kobayashi, D. R. (2006). Colonizaiton of the Hawaiian Archipelago via Johnston Atoll: a characterization of oceanographic transport corridors for pelagic larvae using computer simulation. *Coral Reefs, 25*, 407-417.

Krause, C. M., Courtot, K. N., Berkowitz, P., Carter, J., & Reynolds, M. H. (2012). *Climate change vulnerability assessment of low-lying Northwestern Hawaiian Islands*. Honolulu, HI: USGS, Open-File Report 2012-1182.

Kuffner, I. B., Andersson, A. J., Jokiel, P. L., Rodgers, K. S., & Mackenzie, F. T. (2008). Decreased abundance of crustose coralline algae due to ocean acidification. *Nature, 1*, 114-117.

LaFever, D. H., Lopez, R. R., Feagin, R. A., & Silvy, N. J. (2007). Predicting the impacts of future sea-level rise on an endangered lagomorph. *Environmental Management, 40*, 430-437.

Lawler, I. R., Parra, G., & Noad, M. (2007). Vulnerability of marine mammals in the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: A Vulnerability Assessment* (pp. 497-514): Great Barrier Reef Marine Park Authority.

Layton, J. (2012). *Biological, ecological and conservation implications of temperature-dependent sex determination in sea turtle populations.* (PhD), University of Alabama at Birmingham.

Learmonth, J. A., MacLeod, C. D., Santos, M. B., Pierce, G. J., Crick, H. Q. P., & Robinson, R. A. (2006). Potential Effects of Climate Change on Marine Mammals. *Oceanography and Marine Biology: An Annual Review, 44*, 431-464.

Li, T., Kwon, M., Zhao, M., Kug, J.-S., Luo, J.-J., & Yu, W. (2010). Global warming shifts Pacific tropical cyclone location. *Geophysical Research Letters, 37*(L21804).

Lowry, L. F., Laist, D. W., Gilmartin, W. G., & Antonelis, G. A. (2011). Recovery of the Hawaiian Monk Seal (*Monachus schauinslandi*): A Review of Conservation Efforts, 1972 to 2010, and Thoughts for the Future. *Aquatic Mammals, 37*, 397-419.

Lough, J. (2007). Climate and climate change on the Great Barrier Reef. In J. E. Johnson & P. A. Marshall (Eds.), *Climate change and the Great Barrier Reef: a vulnerability assessment* (pp. 15-50). Townsville, Australia: Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office.

Maragos, J. E., Kenyon, J., Aeby, G., Vroom, P., Vargas-Angel, B., Brainard, R., . . . Siciliano, D. (2009). Benthic Communities. In A. M. Friedlander, K. Keller, L. Wedding, A. Clarke & M. Monaco (Eds.), *A Marine Biogeographic Assessment of the Northwestern Hawaiian Islands* (pp. 105-154). Silver Spring, MD: NOAA.

Maragos, J. E., Potts, D. C., Aeby, G., Gulko, D., Kenyon, J., Siciliano, D., & Van Ravensway, D. (2004). 2000-02 rapid ecological assessment of corals (Anthozoa) on shallow reefs of the NWHI: Part 1-species and distribution. *Pacific Science, 58*, 211-230.

Marra, J. J., Keener, V. W., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). (2012). *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA)*. Honolulu, HI.

Marshall, P., & Schuttenberg, H. Z. (2006). Adapting Coral Reef Management in the Face of Climate Change. In J. T. Phinney, O. Hoegh-Guldberg, J. Kleypas, W. Skirving & A. Strong (Eds.), *Coral Reefs and Climate Change: Science and Management* (Vol. 61, pp. 223-241). Washington, D.C.: American Geophysical Union.

Maynard, J. A., Schuttenberg, H. Z., Kosaki, R., Polhemus, D., Kenyon, J., Vargas-Angel, B., . . . Martinez, J. (2012). PMNM Bleaching & Disease Response Plan: PMNM.

McCulloch, M., Falter, J., Trotter, J., & Montagna, P. (2012). Coral resilience to ocean acidification and global warming through pH up-regulation. *Nature Climate Change*, advanced on-line publication 1 April www.nature.com/natureclimatechange.

MEA. (2003). *Millennium Ecosystem Assessment - Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press.

Meehl, G. A., Hu, A., & Santer, B. D. (2009). The mid-1970s climate shift in the Pacific and the relative roles of forced versus inherent decadal variability. *Journal of Climate, 22*(780-792).

Merrifield, M. A. (2011). A shift in Western Tropical Pacific sea level trends during the 1990s. *Journal of Climate, 24*(4126-4138).

Merrifield, M. A., Merrifield, S. T., & Mitchum, G. T. (2009). An anomalous recent acceleration of global sea level rise. *Journal of Climate, 22*, 5772-5781.

Morin, M. P. (1992). Laysan finch nest characteristics, nest spacing, and reproductive success in two vegetation types. *Condor, 94*, 344-357.

Munday, P. L., Jones, G. P., Pratchett, M. S., & Williams, A. J. (2008). Climate change and the future for coral reef fishes. *Fish and Fisheries, 9*, 261-285.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*, 1517-1520.

Nicholls, R. J., Marinova, N., Lowe, J. A., Brown, P., Vellinga, P., de Gusmao, D., & Tol, R. S. J. (2011). Sea-level rise and its possible impacts given a 'beyond 40 C world' in the twenty-first century. *Philosophical Transactions of the Royal Society, A, 369*, 161-181.

NMFS & US F&W. (1998). Recovery Plan for U.S. Pacific Populations of the Green Turtle (*Chelonia mydas*). Silver Spring, MD: National Marine Fisheries Service, NOAA.

Nolan, D. S., & Rappin, E. D. (2008). Increased sensitivity to tropical cyclogenesis to wind shear in higher SST environments. *Geophysical Research Letters, 35*.

Nord, A. G., Tronner, K., Mattsson, E., Borg, G. C., & Ullen, I. (2005). Environmental threats to buried archaeological remains. *Ambio, 34*(3), 256-262.

Odum, H. T. (1971). *Environment, Power, and Society*. New York: Wiley-Interscience.

Oki, D. (2004). Trends in streamflow characteristics at long-term gauging stations, Hawai‘i (pp. 116). Reston, VA: U.S. Geological Survey.

Palmer, H. S. (1972). Geology of Kaula, Nihoa, Mokumanamana, and Gardner Islands, and French Frigate Shoals. *BP Bishop Museum Bulletin, 35*, 1-35.

Pandolfi, J. M., Connolly, S. R., Marshall, D. J., & Cohen, A. L. (2011). Projected Coral Reef Futures Under Global Warming & Ocean Acidification. *Science, 333*, 418-422.

Parker, A. (2013). Oscillations of sea level rise along the Atlantic coast of North America north of Cape Hatteras. *Natural Hazards, 65*, 991-997.

Parrish, F. A., & Boland, R. C. (2004). Habitat and reef-fish assemblages of banks in the Northwestern Hawaiian Islands. *Marine Biology, 144*, 1065-1073.

PIFSC. (2008). Hawaiian Archipelago Marine Ecosystem Research Plan: U.S. Department of Commerce, NOAA Technical Memorandum NMFS-PIFSC-14.

PMNM. (2008a). *Nomination of Papahānaumokuākea Marine National Monument for Inscription on the World Heritage List*. [on-line] http://www.papahanaumokuakea.gov/management/worldheritage.html.

PMNM. (2008b). *Papahānaumokuākea Marine National Monument Management Plan*. Honolulu, HI: NOAA, FWS, State of Hawai'i.

PMNM. (2011a). *Papahānaumokuākea Marine National Monument Natural Resources Science Plan*. Honolulu, Hawai'i.

PMNM. (2011b). *Papahānaumokuākea Maritime Heritage Research, Education, and Management Plan*. Honolulu, Hawai'i.

Poloczanska, E. S., Limpus, C. J., & Hays, G. C. (2009). Vulnerability of marine turtles to climate change. *Advances in Marine Biology, 56*, 151-211.

Polovina, J. J. (1984). Model of a coral reef ecosystem: Ecopath and its application to French Frigate Shoals. *Coral Reefs, 3*, 1-11.

Polovina, J. J., & Haight, W. R. (1999). Climate variation, ecosystem dynamics, and fisheries management in the Northwestern Hawaiian Islands *Ecosystem approaches for fisheries management* (pp. 23-32): Alaska Sea Grant College Program.

Polovina, J. J., Howell, E. A., & Abecassis, M. (2008). Ocean's least productive waters are expanding. *Geophysical Research Letters, 35*, L03618 03611-03615.

Polovina, J. J., Mitchum, G. T., Graham, N. E., Craig, M. P., DeMartini, E. E., & Fint, E. N. (1994). Physical and biological consequences of a climate event in the central North Pacific. *Fisheries Oceanography, 3*, 5-21.

Presley, T. K. (2005). Effects of the 1998 drought on the freshwater lens in the Laura area, Majuro Atoll, Republic of the Marshall Islands. *US Geological Survey Scientific Report 2005-5098*.

Rahmstof, S. (1997). Risk of sea-change in the Atlantic. *Nature, 388*, 825-826.

Rahmstorf, S., Perrette, M., & Vermeer, M. (2011). Testing the robustness of semi-empirical sea level projections. *Climate Dynamics*.

Reynolds, M. H., Berkowitz, P., Courtot, K. N., Krause, C. M., Carter, J., Hatfield, J. S., & Storlazzi, C. D. (2012). Predicting sea-level rise vulnerability of terrestrial habitats and wildlife in the Northwestern Hawaiian Islands (pp. 139). Honolulu, HI: USGS; Available at http://pubs.usgs.gov/of/2012/1182/.

Rignot, E., Velicongna, I., van den Broeke, M. R., Monaghan, A., & Lenaerts, J. T. M. (2011). Acceleration of the contribution of Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters, 38*(L05503), 5.

Rooney, J., Donham, E., Montgomery, A., Spalding, H., Parrish, F., Boland, R., . . . Vetter, O. (2010). Mesophotic coral ecosystems in the Hawaiian Archipelago. *Coral Reefs, 29*, 361-367.

Royal Society. (2005). Ocean acidification due to increasing atmospheric carbon dioxide. *The Royal Society, London*.

Ruggiero, P., Komar, P. D., Allan, J. C. (2010). Increasing wave heights and extreme value projections: the wave climate of the U.S. Pacific Northwest. *Coastal Engineering*, 57, 539-552.

Schuttenberg, H. Z., & Marshall, P. (2008). Managing for mass coral bleaching: Strategies for supporting socio-ecological resilience. In C. Wilkinson & D. Souter (Eds.), *Status of Caribbean Coral Reefs after Bleaching and Hurricanes in 2005* (pp. 130). Townsville: Reef and Rainforest Research Centre.

Schuttenberg, H. Z., & Polhemus, D. (2012). *Papahānaumokuākea's Climate Change Situation Analysis & Options Paper*. Honolulu, HI.

Schuttenberg, H. Z., Vargas-Angel, B., Looney, E., Coccagna, E., Dennison, D., Helyer, J., . . . Brainard, R. (2011). *Challenges in Predicting & Interpreting Coral Bleaching in the NWHI: The Experience of 2010*. Paper presented at the NWHI Research Symposium 2011, East-West Center, University of Hawaiʻi.

Simmonds, M. P., & Elliot, W. J. (2009). Climate change and cetaceans: concerns and recent developments. *Journal of the Marine Biological Association of the United Kingdom, 89*(1), 203-210.

Smithers, S. G., Harvey, N., Hopley, D., & Woodroffe, C. D. (2007). Vulnerability of geomorphological features in the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: a vulnerability assessment* (pp. 667-716): Great Barrier Reef Marine Park Authority.

Spada, G., Bamber, J. L., & Hurkmans, R. T. W. L. (2013). The gravitationally consistent sea-level fingerprint of future terrestrial ice loss. *Geophysical Research Letters*, *40*, 482-486..

Speulda-Drews, L. (2010). Midway Atoll National Wildlife Refuge Historic Preservation Plan 2010. Honolulu, HI: USDI Fish and Wildlife Service, Region 1.

Steinberg, C. (2007). Impacts of climate change on the physical oceanography of the Great Barrier Reef. In J. E. Johnson & P. A. Marshall (Eds.), *Climate change and the Great Barrier Reef: a vulnerability assessment* (pp. 51-74). Townsville, Australia: Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office.

Stocker, T. F., & Schhmittner, A. (1997). Influence of CO_2 emission rates on the stability of the thermohaline circulation. *Nature*, *388*, 862-865.

Storlazzi, C. D., Berkowitz, P., Reynolds, M. H., & Logan, J. B. (2013). Forecasting the impact of storm waves and sea-level rise on Midway Atoll and Laysan Island within the Papahānaumokuākea Marine National Monument--A comparison of passive versus dynamic inundation models. *U.S. Geological Survey Open-file Report 2013-1069*, 78pp.

Tiwari, M., Balazs, G. H., & Hargrove, S. (2010). Estimating carrying capacity at the green turtle nesting beach of East Island, French Frigate Shoals. *Marine Ecology Progress Series, 419*, 289-294.

Tol, R. S. J. (2002). Estimates of the Damage Costs of Climate Change. Part 1: Benchmark Estimates. *Environmental and Resource Economics, 21*, 47-73.

Toonen, R. J., Andrews, K. R., I.A., B., Bird, C. E., Concepcion, G. T., Daly-Engel, T. S., Bowen, B. W. (2011). Defining Boundaries for Ecosystem-Based Management: A Multispecies Case Study of Marine Connectivity across the Hawaiian Archipelago. *Journal of Marine Biology*, 13.

Turner, M., & Batianoff, G. N. (2007). Vulnerability of island flora and fauna in the Great Barrier Reef to Climate Change. In J. E. Johnson & P. A. Marshall (Eds.), *Climate Change and the Great Barrier Reef: a vulnerability assessment* (pp. 620-666): Great Barrier Reef Marine Park Authority.

Turner, N. J., & Clifton, H. (2009). "It's so different today": Climate change and indigenous lifeways in British Columbia, Canada. *Global Environmental Change, 19*, 180-190.

Turner, R., & Daily, G. (2008). The Ecosystem Services Framework and Natural Capital Conservation. *Environmental and Resource Economics, 39*(1), 25-35.

UN. (2009). *Report of the Indigenous Peoples' Global Summit on Climate Change*. Retrieved from http://www.un.org/ga/president/63/letters/globalsummitoncc.pdf.

UNESCO. (1998). Transdisciplinarity 'Stimulating Synergies, Integrating Knowledge'. *retrieved from: http://unesdoc.unesco.org/images/0011/001146/114694eo.pdf*.

Van Houtan, K. S., Kittinger, J. N., Lawrence, A. L., Yoshinaga, C., Born, R., & Fox, A. (2012). Hawksbill sea turtles in the Northwestern Hawaiian Islands. *Chelonian Conservation & Biology, 11*(1), 117-121.

Vecchi, G. A., Soden, B. J., Wittenberg, A. T., Leeetmaa, A., & Harrison, M. J. (2006). Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing. *Nature*, *441*, 73-76.

Velicogna, I., & Wahr, R. (2006). Acceleration of Greenland ice mass loss in spring 2004. *Nature*, *443*, 329-331.

Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Obura, D., Pearce-Kelly, P., . . . Rogers, A. D. (2009). The coral reef crisis: The critical importance of <350 ppm CO2. *Marine Pollution Bulletin*, *58*, 1428-1436.

Vroom, P. (2011). “Coral dominance”: a dangerous ecosystem misnomer? *Journal of Marine Biology, Article ID 164127*, 8.

Vroom, P., & Page, K. N. (2006). Relative abundance of macroalgae (RAM) on Northestern Hawaiian Island reefs. *Atoll Research Bulletin*, *543*, 533-548.

Wagner, D, Papastamatiou, Y. P., Kosaki, R. K., Gleason, K. A., McFall, G. B., Boland, R. C., Pyle, R. L., & Toonen, R. J. (2011). New records of commercailly valuable black corals (Cnidaria: Antipatharia) from the Northwestern Hawaiian Islands at mesophotic depths. *Pacific Science*, *65*(2), 249-255.

Webb, A. P., & Kench, P. S. (2010). The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific. *Global and Planetary Change, 72*(3), 234-246.

Webster, P. J., Holland, G. J., Curry, J. A., & Change, H.-R. (2005). Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. *Science*, *309*, 1844-1846.

Weishampel, J. F., Bagley, D. A., & Ehrhart., L. M. (2004). Earlier nesting by loggerhead sea turtles following sea surface warming. *Global Change Biology, 10*, 1424-1427.

West, J. M., & Salm, R. V. (2003). Resistance and resilience to coral bleaching: Implications for coral reef conservation and management. *Conservation Biology*, *17*(4), 956-967.

Wiener, C. S., & Wagner, D. (2013). Sailing through time: a historical examination of the explorations and investigations of the Papahanuamokuakea Marine National Monumnet. *Atoll Research Bulletin*, *594*, 23pp.

Wittmann, A. C. and Portner, H.-O. (2013). Sensitivities of extant animal taxa to ocean acidification. *Nature Climate Change*, DOI: 10.1038/NCLIMATE1982.

Wootton, J. T., Pfiester, C. A., & Forester, J. D. (2008). Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. *Proceedings of the National Academy of Sciences*, *105*(48), 18848-18853.

Xie, S. P., Deser, G. A., Vecchi, G. A., Ma, J., Teng, H., & Wittenberg, A. T. (2010). Global warming pattern formation: sea surface temperature and rainfall. *Journal of Climate, 23*, 966-986.

Yu, J., Wang, Y., & Hamilton, K. (2010). Response of tropical cyclone potential intensity to a global warming scenario in the IPCC AR4 CGCMs. *Journal of Climate*, *23*(6), 1354–1373.

3.3 Appendix A. Members of the Steering Committee Formed November 2011 to Oversee Development of PMNM's Climate Change Workshop and Climate Change Action Plan

Rusty Brainard
Maria Carnevale
Heidi Guth
Randy Kosaki
Keoni Kuoha
Samantha Brooke
Bob Nishimoto
Michelle Phillips
Dan Polhemus
Heidi Schuttenberg, Facilitator
Nori Shoji
Deanna Spooner
'Aulani Wilhelm

3.3 Appendix B. Agenda for the Expert's Workshop held in June 2012

A Workshop on Managing Papahānaumokuākea in the Context of Climate Change

Workshop Goals:

Develop recommendations for the content of PMNM's Climate Change Action Plan by:

1. Identifying our current understanding of the potential impacts and adaptive capacity of Papahānaumokuākea's social and ecological values to climate change
2. Identifying potential responses to these changes in terms of their effectiveness and feasibility
3. Developing a prioritized agenda of research, monitoring, and instrumentation needs to inform management
4. Identifying key goals, audiences, and opportunities to engage in strategic policy and outreach efforts

Day 1 – 12 June 2012

9:00 Welcome – Randy Kosaki

9:10 Day 1 Keynote Address – Guy Kaulukukui
A Hawaiian Perspective on Climate Change

9:40 Introductions & Workshop Overview – Heidi Schuttenberg & Heidi Guth

Session 1 – Papahānaumokuākea's Climate Change Action Plan – Chaired by Randy Kosaki

10:00 Vision, Goals, & Key Information Needs for Management – Randy Kosaki
10:15 What Does it Mean to Manage for Ecosystem Function & Structure? – Gerry Davis
10:30 What Does it Mean to Serve as an Exemplar Site for Management & Science? – Heidi Guth
10:45 Questions and Discussion with Monument Management Board

11:00 Coffee/Tea Break

Session 2 – Climate Variables – Chaired by Dan Polhemus

11:15 Regional Climate Change Projections for Hawaiʻi – Kevin Hamilton
11:30 Sea-level Rise and Implications for Inundation – Chip Fletcher
11:45 Changes in Ocean Temperature, Chemistry, and Currents – Rusty Brainard
12:00 Questions & Discussion

12:20 Lunch (provided)
**** Ad hoc lunch working group on Projected Climate Variables for PMNM***

Session 3 – Impacts & Adaptive Capacity of PMNM's Social & Ecological Values to Climate Change

Marine Ecosystems – Chaired by Mike Seki

1:30 A Cultural Perspective on Papahānaumokuākea's Marine Ecosystems in the Context of Climate Change – Hi'ilei Kawelo
1:50 Projections for PMNM's Marine Ecosystems – Jeff Polovina
2:10 Projections for ESA Species of Concern – Frank Parrish
2:30 Managing for Resilience – Rod Salm
2:50 Questions & Discussion

3:05 Coffee/Tea Break

Terrestrial Ecosystems – Chaired by Stephen Miller

3:20 Projections for PMNM's Terrestrial Ecosystems & Species of Concern – Beth Flint
3:40 Projecting the Impacts of Sea-level Rise on PMNM's Terrestrial Habitats & Wildlife – Michelle Reynolds
4:00 A Cultural Perspective on Papahānaumokuākea's Terrestrial Ecosystems in the Context of Climate Change – Benton Pang
4:20 Ecosystem Restoration – David Duffy
4:40 Questions & Discussion

4:55 Introduction to Day 2's Group Work
5-6:30 Off-site nibbles – Cha Cha Cha Salsaria, Hawai'i Kai Town Center, 377 Keahole Street

Day 2 – 13 June 2012
Session 3 continued – Potential Impacts & Adaptive Capacity continued

9:00 Welcome & Overview – Heidi Schuttenberg

9:05 Coral Reef Restoration Options – Alasdair Edwards (remotely)

9:30 Day 2 Keynote Address – Roger Griffis (remotely)
A National Perspective on Ecosystem Adaptation

Social Values – Chaired by Keola Lindsey

10:00 Climate Change Impacts on Native Hawaiian Values for Papahānaumokuākea – Ulalia Woodside
10:15 The Vulnerability of Papahānaumokuākea's Heritage Resources to Climate Change – Kelly Gleason
10:30 Climate Change Impacts on Papahānaumokuākea's World Heritage Values – Chuck Burrows
10:45 Questions & Discussion

11:00 Review work to be completed in groups

3 groups of 10 people each

Group 1 – Marine Ecosystems; Facilitated by Randy Kosaki & Michelle Phillips
Group 2 – Island & Atoll Ecosystems; Facilitated by Beth Flint & Sam Gon
Group 3 – Social Values; Facilitated by Heidi Guth & 'Aulani Wilhelm

11:10 Coffee/Tea Break

Session 4 – Work in Groups

Discussion Area 1 – State of Knowledge about Potential Impacts & Adaptive Capacity

Suggested time: 11:15am to 12:45pm

1. **Identifying Key Vulnerabilities –** Would you change anything about the assessment of potential impacts & adaptive capacity presented in the Options Paper tables, or do you agree with this synthesis? Please consider:
    - Do you agree with the assessments of confidence and likelihood presented in the Options Paper?
    - Are the most significant vulnerabilities identified in the tables, and are they accurately presented?
      Note: vulnerabilities may be significant because they are likely to lead to the loss of key functions or structures, are particularly likely to occur, are likely to happen the soonest, or are irreversible.
    - Are there key thresholds at which significant impacts would be expected?

12:30 – Working Lunch (provided)

Discussion Area 2 – Management Responses

Suggested time: 12:45 to 2:15pm

1. **Identifying Management Options –** What responsive actions would you recommend for supporting social or ecological resilience to the vulnerabilities you have described? Add any new actions to the Options Paper tables.
    - What would be the specific goal of each recommended action?

2. **Assessing Effectiveness –** For each management action identified, please describe how effective you think the action would be at achieving its specific goal: High, Medium, or Low.

3. **Assessing Feasibility –** (If time) For each management action identified, please describe how technically feasible you think the action would be to implement: High, Medium, or Low.

2:15 Coffee/Tea break

Discussion Area 3 – Research, Monitoring, and Instrumentation Needs

Suggested time for Marine & Social Values WGs: 2:30 to 3:30
Suggested time for Terrestrial WG: 3:00 to 4:00

1. **Prioritizing Research Needs –** What key questions and/or information gaps should PMNM's Climate Change Action Plan focus on? Why? Please prioritize your key questions/information gaps: High, Medium, or Low.

2. **Identifying Instrumentation Needs –** For any of these research/monitoring priorities, are there specific research/data collection approaches that should be pursued? Do they require specific instrumentation needs or other infrastructure support?

3. **Identifying Partnerships –** For any of these research/monitoring priorities, are there likely partners and funding opportunities?

Discussion Area 4 – Identifying the Influence of GHG Emissions

Suggested time for Marine & Social Values WGs: 3:30 to 4:00
Suggested time for Terrestrial WG: 2:30 to 3:00

1. **Describing Scenarios –** For the impacts of greatest concern, what outcomes do you expect in 2035 and 2100 for low vs. high greenhouse gas scenarios?

2. **Illustrating Change –** How would you visualize these differences?

Session 5 – Group Reports – Facilitated by Don Palawski

4:15 Group 1 Report out
4:30 Group 2 Report out
4:45 Group 3 Report out

5:00 Adjourn for day **1 representative from each group to remain until 5:45 to work with Heidi Schuttenberg*

<u>Day 3 – 14 June 2012</u>

9:00 Welcome & Overview – Heidi Schuttenberg

Session 6 – Synthesis – Facilitated by Heidi Schuttenberg

9:05 Draft Action Plan Recommendations – Heidi Schuttenberg
9:20 Identifying and exploring cross-cutting issues by geography and theme – full group discussion

10:15 Coffee/Tea

10:30 Day 3 Keynote Address – 'Aulani Wilhelm

Global to Regional Dialogues about Climate Change – What Role for Papahānaumokuākea?

Session 7 – Implications for Policy, Education, & Outreach – Chaired by Deanna Spooner & Heidi Guth

11:00 Lessons learned from communicating climate change: an overview – Deanna Spooner

11:10 Engaging audiences in climate change as a World Heritage Site – the example of the Great Barrier Reef – Katie Munkres (remotely)
11:20 Drawing from Workshop Days 1 & 2: What issues have we raised? – Deanna Spooner and Heidi Guth

11:30 Working Group Sessions

1. What do we want to accomplish with PMNM's Climate Change Action Strategy Goals 4 & 5?
2. Who are the key audiences we need to reach to achieve these aims?
3. Are there key mechanisms or partnerships that provide strategic opportunities for achieving these aims?

12:10 Reconvene full groups to identify priority "what's," "who's," and "how's"

12:45 Lunch (provided)
**** Ad hoc lunch working group on identifying geographic areas of interest: Are there geographical areas that are key refugia or, conversely, where vulnerabilities are the greatest?***

1:30 Finalization and preparation of technical workshop presentations

2:30 Afternoon coffee/tea and snacks; Co-Manager agency staff and working group chairs arrive

Invitations for the 3rd afternoon extended to Co-Manager agency staff and the Chairs of PMNM working groups

Session 8 – Workshop Conclusions Reported to Monument Staff & Working Group Chairs

3:00 Introduction – Randy/Heidi S.
3:10 Climate Drivers – TBD during the workshop
3:25 Marine & Coastal Ecosystems – TBD during the workshop
3:40 Terrestrial & Coastal Ecosystems – TBD during the workshop
3:55 Social Values – TBD during the workshop
4:10 Policy, Outreach, and Education – TBD during the workshop
4:25 Questions & Discussion

5pm Adjourn

3.5 Appendix C. Agenda for the PMNM Climate Change Action Plan Workshop held in September 2013

AGENDA

A Workshop on Papahānaumokuākea's Climate Change Action Plan (C_2AP)

Thursday, 26 September 2013

NOAA ONMS Conference Room • 6600 Kalaniana'ole Hwy, Suite 300

Workshop Goals:

1. Develop recommendations on the final content for the C_2AP, and to
2. Recommend priorities and mechanisms for the C_2AP's implementation

The current draft of PMNM's Climate Change Action Plan (C_2AP) and comments received on the previous draft of the Plan are available at the following links:
https://www.dropbox.com/sh/i65t008nh2btybo/eSclpEWa4f
or
https://drive.google.com/folderview?id=0B1u808y2ElBkSDlHMmRRSTZYZU0&usp=sharing

9:00 Welcome and Workshop Goals – Randy Kosaki

9:15 Climate Change Overview & Working Group Tasks – Heidi Schuttenberg

9:30 Coffee break and re-arrange main conference room

9:45 Morning Work Session

12:15 Lunch (provided)
12:45 Briefing for afternoon-only participants in main conference room

1pm Afternoon Work Session

3:30 Coffee break and re-arrange main conference room

3:45 Report-backs for discussion between groups

Morning Working Groups
2.5 hours, 9:45 – 12:15

Group 1 – Climate Variables
Facilitator: Dan Polhemus
Meet in the mauka conference room in the satellite building across the road
Situation Analysis to review:
Section 2.1
Objectives to review:
Objective 1.1 (7 strategies)
Group members:

Abby Frazier
Andrea Kealoha
Chris Winn
Charles Young
John Marra
Kalei Nu'uhiwa
Kevin Hamilton
Lauren Kaiser
Mark Merrifield
Tiffany Anderson

Group 2 – Marine Ecosystems - Function, Structure, & Resilience
Facilitator: Rusty Brainard
Meet in main conference room
Situation Analysis to review:
Section 2.2
Objectives to review:
Objective 1.2 (4 strategies)
Objective 1.3 (4 strategies)
Objective 2.2 (4 strategies)
Group members:

Anne Rosinski	Jean Kenyon	Mike Nahoopii
Bernardo Vargas-Angel	Jeff Polovina	Nadiera McCarthy
Celia Smith	Kehau Springer	Nori Shoji
Courtney Couch	Kim Maison	Rob Toonen
Dan Wagner	Kyle Van Houtan	Rod Salm
Frazer McGilvray	Malia Akutagawa	Richard Hall

Group 3 – Island & Atoll Ecosystems - Function, Structure, & Resilience
Facilitators: Beth Flint & Sam Gon
Meet in main conference room
Situation Analysis to review:
Section 2.3
Objectives to review:
Objective 1.2 (4 strategies)
Objective 1.3 (4 strategies)
Objective 2.2 (4 strategies)
Group members:

Jeff Burgett	Michelle Reynolds (by phone)	Steve Miller
Lucus Fortini	Scott Shaffer (by phone)	

Group 4 – Cultural, Historical, & Heritage Resources
Facilitators: Keola Lindsey and Naia Lewis
Meet in the lower office common area of PMNM-ONMS
Situation Analysis to review:
Section 2.4
Objectives to review:
Objective 1.5 (2 strategies)
Objective 2.4 (3 strategies)
Group members:

Blane Benevedes	Healoha Johnston	Kekuewa Kikiloi
Brad Wong	Heather McMillen	Kelly Gleason
Chuck Burrows	Keali'i Sagum	Koa Kukea-Schultz

Group 5 – Communications
Facilitators: Deanna Spooner & Toni Parras
Meet in the makai conference room in the satellite building across the road

Situation Analysis to review:

Sections 1.2 & 2.4

Objectives to review:

Objective 3.1 (1 strategies)
Objective 3.2 (1 strategies)
Objective 3.3 (1 strategies)

Group members:

Andy Collins
Ann Bell
Garett Kamemoto
Deborah Ward
Emma Anders
Katie Munkres
Ken Foote
Maria Carnevale
Laura Stevens
Randy Kosaki
Wende Goo

Afternoon Working Groups

2.5 hours, 1:00 – 3:30

Group 6 – Managed Species – Marine
Facilitator: Kyle Van Houtan
Meet in main conference room

Situation Analysis to review:

Section 2.2

Objectives to review:

Objective 1.2 (4 strategies)
Objective 1.3 (4 strategies)
Objective 1.4 (4 strategies)
Objective 2.2 (4 strategies)
Objective 2.3 (5 strategies)

Group members:

Bernardo Vargas-Angel
Celia Smith
Courtney Couch
Jean Kenyon
Jeff Polovina
Keali'i Sagum
Kim Maison
Malia Akutagawa
Maria Carnevale
Rob Toonen
Rusty Brainard
Siri Hakala
Richard Hall

Group 7 – Protected Species – Terrestrial
Facilitators: Beth Flint, Sam Gon
Meet in main conference room

Situation Analysis to review:

Section 2.3

Objectives to review:

Objective 1.4 (4 strategies)
Objective 2.3 (5 strategies)

Group members:

Healoha Johnston
Jeff Burgett
Lucus Fortini
Michelle Reynolds (by phone)
Scott Shaffer (by phone)
Steve Miller

Group 8 – Sentinel Site & Collaborative Learning
Facilitators: Randy Kosaki & Kelly Gleason
Meet in the mauka conference room in the satellite building across the road

Situation Analysis to review:

Section 1.2

Objectives to review:

Objective 4.1 (1 strategies)
Objective 4.2 (1 strategies)
Objective 4.3 (1 strategies)

Group members:

Chuck Burrows	Heather McMillen	Richard Hall
Dan Wagner	Kekuewa Kikiloi	
Emma Anders	Koa Kukea-Schultz	
Frazer McGilvray	Keola Lindsey	

Group 9 – Communications
Facilitators: Deanna Spooner & Toni Parras
Meet in the makai conference room in the satellite building across the road

Situation Analysis to review:

Sections 1.2 & 2.4

Objectives to review:

Objective 3.1 (1 strategies)
Objective 3.2 (1 strategies)
Objective 3.3 (1 strategies)

Group members:

Andy Collins	Garett Kamemoto	Naia Lewis
Ann Bell	Deborah Ward	Laura Stevens
Blane Benevedes	Katie Munkres	Wende Goo
Brad Wong	Ken Foote	

Group 10 – Facilities & Operations
Facilitators: Dan Polhemus & Jason Leonard
Meet in the lower office common area of PMNM-ONMS

Objectives to review:

Objective 5.1 (2 strategies)
Objective 5.2 (6 strategies)
Objective 5.3 (3 strategies)
Objective 5.4 (6 strategies)

Group members:

David Swatland	Nadiera McCarthy	Ty Benally
Jason Misaki	Nori Shoji	
Mike Nahoopii	Scott Godwin	

NATIONAL MARINE SANCTUARIES

AMERICA'S UNDERWATER TREASURES