# Assessing Impacts to Terrestrial and Marine Habitat and Identifying Adaptation Pathways at Lalo (French Frigate Shoals) in light of a Rapidly Changing Climate: State of Knowledge and Call to Action

*Photographs of Hawaiian Monks Seals, Green Sea Turtles, Coral Reef at Lalo courtesy of NOAA and White Tern USFWS.*

## NOAA Report to the NOAA Pacific Region Executive Board

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## Table of Contents

Overview ..... 4
Background ..... 7
Recent Efforts to advance our understanding of systems, stressors, and solutions ..... 10
NMFS 4th Annual Collaborative Climate Science Workshop Special Session on Lalo ..... 12
  Framing the Problem. ..... 12
  Defining the System. ..... 13
  Exploring Stressors. ..... 16
NMFS 5th Annual Collaborative Climate Science Workshop Special Session on Lalo ..... 20
  Defining the System. ..... 20
  Exploring Stressors. ..... 23
Implications and Recommendations: ..... 27
Citations and other Sources of Information ..... 36
Appendix ..... 39

## List of Tables

Table 1. Summary of critical components needed to develop a MMB Action Plan, their priority and timing ..... 6
Table 2. Critical life history activities and associated habitat types/locations for Hawaiian monk seals (top) and Hawaiian green sea turtles (bottom) ..... 15
Table 3. Critical life history activities and associated habitat types/locations for seabirds (top) and corals (bottom) ..... 23
Table 4. Top climatic or anthropogenic stressors for Hawaiian monk seals, Hawaiian green sea turtles, seabirds, coral ecosystems, and the overarching Lalo system ..... 27
Table 5. Summary of critical components needed to develop a MMB Action Plan, their priority and timing ..... 34

## List of Figures

Figure 1. Map of the Papahānaumokuākea Marine National Monument (PMNM) ..... 7
Figure 2**.** Map of Lalo (French Frigate Shoals) including 8 remaining islets, several of which are ephemeral, eroding and accreting seasonally ..... 9
Figure 3. Schematic of the Systems and Stressors-Based Assessment Protocol NMFS 4th Annual Collaborative Climate Science Workshop Special Session on French Frigate Shoals ..... 12
Figure 4. Two weaned Hawaiian monk seal pups sleeping at French Frigate Shoals in the Northwestern Hawaiian Islands ..... 14
Figure 5. Basking green sea turtles on Tern Island ..... 14
Figure 6. Aerial imagery of East Island in Lalo before (top) and after (bottom) Hurricane Walaka ..... 17

Figure 7. Aerial Imagery showing human-built infrastructure that currently exists at Tern Island and has proven to be an entrapment hazard (inset) for both monk seals and green sea turtles .......................... 18
Figure 8. A White Tern at Tern Island (left) and coral reef at Lalo (right) ................................................ 20
Figure 9. Top three stressors to the survival and population health of the key wildlife species at Lalo, identified by Lalo special session attendees ................................................................................ 39
Figure 10. System and stressor elements associated with Hawaiian green sea turtles at Lalo outlined using the system/stressor assessment framework. ................................................................... 40
Figure 11. System and stressor elements associated with Hawaiian monk seals at Lalo outlined using the system/stressor assessment framework ......................................................................................... 41
Figure 12. System and stressor elements associated with Black-footed Albatross at Lalo outlined using the system/stressor assessment framework ................................................................................ 42
Figure 13. System and stressor elements associated with corals and coral ecosystems at Lalo outlined using the system/stressor assessment framework ..................................................................... 43

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# Assessing Impacts to Terrestrial and Marine Habitat and Identifying Adaptation Pathways at Lalo (French Frigate Shoals) in light of a Rapidly Changing Climate: State of Knowledge and Call to Action

## Overview

This document assesses impacts to terrestrial and marine habitats within the Papahānaumokuākea Marine National Monument (PMNM or Monument) at Lalo (French Frigate Shoals) in light of a rapidly changing climate. It frames the existing problem(s) and proposes a path forward with respect to investigations and other actions warranted to better understand, predict, and adapt to climate-related impacts at Lalo. It lays out a plan to engage the larger inter-agency working group in this exercise, in a robust and sustainable manner necessary to protect and maintain healthy ecosystems and ecosystem services within PMNM in the coming decades.

Lalo is an open atoll consisting of a large, crescent-shaped reef surrounding numerous small, sandy islets within the larger complex of islands and atolls that make up PMNM and the Hawaiian Islands Wildlife Refuge. Lalo serves as the principal nesting site for the entire threatened Hawaiian green sea turtle (*Chelonia mydas*) distinct population segment, with more than 90% of the archipelagic population nesting there. It serves as a primary place of refuge for more than 20% of the endangered Hawaiian monk seals (*Monachus schauinslandi*) in PMNM. Lalo is one of the largest tropical seabird rookeries in the world. It also has one of the most significant reef systems in PMNM, supporting the greatest variety of coral species in PMNM.

Like the rest of the Monument, a rapidly changing climate threatens the ecosystems and associated marine and terrestrial habitats of Lalo. Increased regional sea surface temperature and ocean heat content has resulted in mass coral bleaching seven times in the last 20 years, four of which occurred in the last 10. Sea level rise, coupled with storms and high tides have resulted in flooding, inundation, and the loss of terrestrial habitat. The sudden disappearance of East Island at Lalo caused by Hurricane Walaka in early October of 2018 serves as a sobering reminder of the potential fate of habitat that is crucial to monk seal, green sea turtle, and other species' survival. Other factors that exert pressures on species that rely upon marine and terrestrial habitat at Lalo include entrapment in infrastructure or marine debris.

With the intention of invigorating on-going efforts among a broad group of stakeholders, the National Oceanic and Atmospheric Administration (NOAA) Pacific Region Executive Board (PREB) tasked a small cross-line office working group to prepare a report (this document) that:

1) frames the existing problem(s) and proposes a path forward with respect to investigations and other actions warranted to better understand, predict, and adapt to climate-related impacts at Lalo; and
2) lays out a plan to engage the larger inter-agency working group in this exercise, in the robust and sustainable manner necessary to protect and maintain healthy ecosystems and ecosystem services within PMNM over the coming decades.

As part of this cross-line office effort a special session on Lalo was held during the NMFS 4th Annual Collaborative Climate Science Workshop (October of 2020). During this half-day virtual workshop subject matter experts from across NOAA, US Fish and Wildlife Service (FWS), and the Western Pacific

Fisheries Council convened to apply a vulnerability assessment protocol to Hawaiian monk seals and Hawaiian green sea turtles to help outline the current state of knowledge and to identify information gaps. A follow up special session on Lalo Resilience was held in February 2022 and employed the same assessment protocol to seabirds and coral ecosystems. This group of experts focused on extending the current state of knowledge to a wider range of valued wildlife species at Lalo, and to identify information gaps and commonalities across a range of priority species and systems. For monk seals, green sea turtles, seabirds, and coral ecosystems, the overarching objective is to *maintain and/or enhance habitat as a means to ensure abundance and persistence*. In this regard, terrestrial habitat, surrounding nearshore coral ecosystems, and other marine ecosystems are all essential to the survival of all these species as it supports *critical life history activities* such as nesting, resting, breeding, etc.

From the suite of stressors identified as directly influencing critical life history activities and the associated characteristics of habitat that are important to the four main species mentioned, the three climate related factors that constitute the greatest threat to the survival of monk seals, green turtles, seabirds, and coral ecosystems at Lalo include:

1. Direct loss of terrestrial habitat due to flooding and inundation caused by sea level rise and storms;
2. Sea surface and subsurface temperatures; and,
3. Damaged and decaying infrastructure and marine debris that currently exist at Tern Island that presents an entrapment hazard.

**The outcomes of the special sessions on Lalo, along with a literature review and discussions among working group members suggest that without the implementation of actions intended to maintain and/or enhance the terrestrial habitat upon which these species rely, the long-term persistence of green sea turtles, monk seals, seabirds, and marine invertebrates (including corals and algae) at Lalo is at risk. Efforts to better understand these risks and identify mitigation actions at Lalo that optimize outcomes in terms of the abundance and persistence of seals and turtles, as well as other threatened and endangered species (e.g., seabirds and corals), must be undertaken with urgency.** Such efforts need to be framed within a comprehensive, collaborative plan to maintain and enhance the resilience of terrestrial and marine habitats at Lalo. Critical components of this plan have elements that require development and implementation in advance of and/or parallel with, completion of a full resilience strategy for Lalo planned to be completed by August 2023. The resilience strategy is part of a broader MMB Action Plan described below and summarized in Table 1.

*Table 1. Summary of critical components needed to develop a MMB Action Plan, their priority and timing. Red denotes activities of high priority. See text for further detail.*

| Critical Components for MMB Action Plan Development | NOW | 6 Months | 12 Months | 18 Months and Beyond |
|---|---|---|---|---|
| **A) Engaging Co-Trustees and Stakeholders** | | | | |
| 1. Partners/Stakeholders agree on next steps and formulate overall resilience strategy | X | X | X | X |
| 2. Hold webinars to include Nat'l and Int'l participation with a focus on exploration of successful management measures used elsewhere | X | X | | |
| 3. Convene large adaptations workshop to include Nat'l and Int'l participation with a focus on developing a comprehensive MMB Action Plan for Lalo. | | | X | |
| **B) Engaging Working Groups** | | | | |
| 1) Lalo MMB Working Group provides management advice, direction and support toward relevant initiatives in addition to supporting Lalo components in management planning | X | X | X | X |
| 2) Terrestrial Habitat Advisory Committee provides specialized and technical advice on terrestrial and island habitat components of developing Lalo Resilience | X | X | X | X |
| 3) Marine Habitat Advisory Committee provides specialized and technical advice on nearshore reef and pelagic habitat components of developing Lalo Resilience | X | X | X | X |
| **C) Ensuring Continuity of Projects and Programs** | X | X | X | X |
| **D) Securing Financial and Technical Resources** | X | X | X | X |

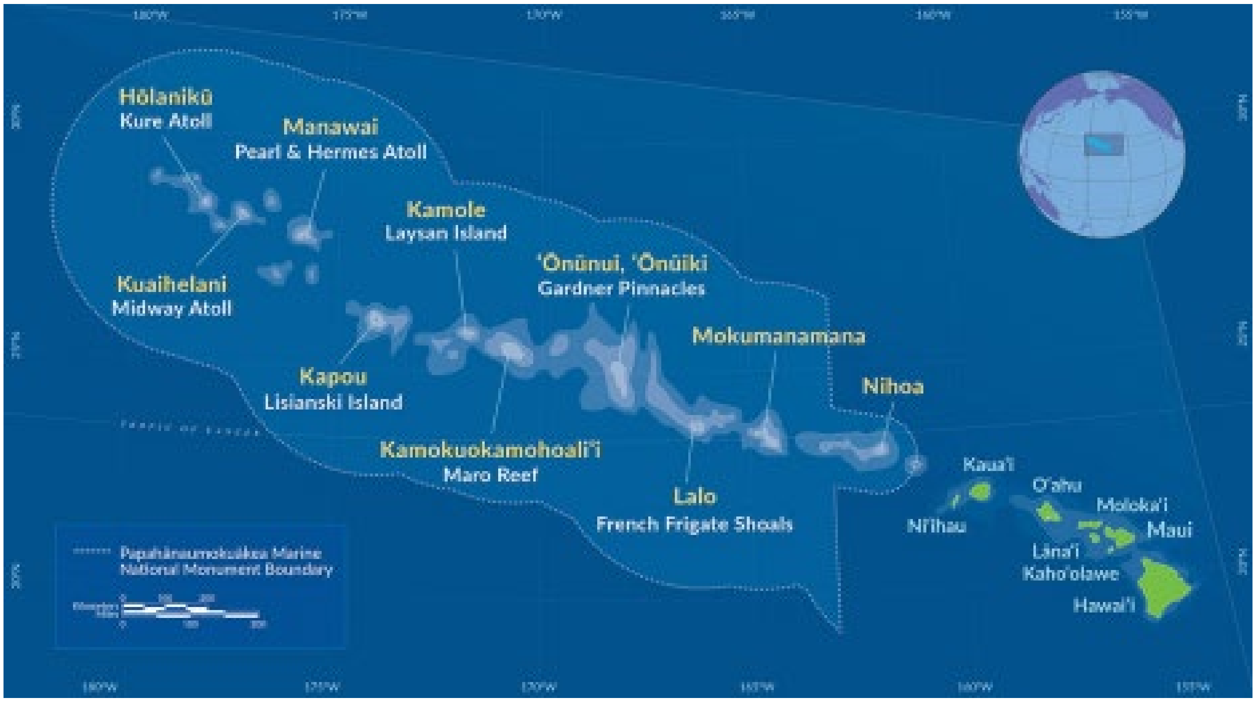



*Figure 1. Map of the Papahānaumokuākea Marine National Monument (PMNM).*

*The bounded area on the left defines PMNM per se. This area is synonymous with the Northwest Hawaiian Islands. The Main Hawaiian Islands (MHI) are shown in green in the lower right. Lalo (French Frigate Shoals) is approximately 500 nmi from O'ahu and contains important terrestrial and marine habitat for protected species (e.g., Hawaiian green sea turtles or honu, Hawaiian monk seals, and seabirds). From https://www.papahanaumokuakea.gov/.*

## Background

As noted in NOAA's Office of National Marine Sanctuaries (ONMS) *2020 State of Papahānaumokuākea Marine National Monument* report, the Monument and the Hawaiian Islands Wildlife Refuge comprise a conservation area larger than all other terrestrial US national parks combined (Figure 1). The complex marine ecosystems of PMNM are significant contributors to marine biological diversity. Pelagic and seafloor habitats are important for deep-sea coral, fish, marine mammals, and more. Shallow seamounts may be hotspots of biodiversity (Morato et al., 2010) and of special interest for management of pelagic predators. Archipelagic habitat includes coral reefs that make up 70% of the total coral reef area within the United States exclusive economic zone (EEZ) and have the highest levels of marine endemism of any large archipelago in the world (Randall, 1992; Eldredge & Miller, 1995; Miller & Eldredge, 1996). The terrestrial ecosystems of PMNM consist of islands and atolls that serve as home to the endangered Hawaiian monk seal; threatened Hawaiian green sea turtle; numerous species of sea, land and shore birds; and other animal and plant species found nowhere else on earth. In addition to its living resources, PMNM is a unique and significant historical heritage site and native Hawaiian cultural resource.

The ecosystems and associated marine and terrestrial habitats of PMNM are considered to be in relatively pristine condition, however threats are diverse and increasing (ONMS, 2020); chief among these threats is the rapidly changing climate. In 2016, the ONMS released the *Climate change vulnerability assessment for the Papahānaumokuākea Marine National Monument* based on findings collected from a series of workshops, interviews with PMNM management partners, and a literature review (Wagner and Polhemus, 2016). Providing guidance for PMNM's response to climate change by assessing the climate's effects on various living and cultural resources, the vulnerability assessment identified impacts to marine and terrestrial habitat that are expected to arise from increasing ocean temperatures, ocean acidification, rising sea levels, and increasing storm intensity, among other stressors. With a goal of supporting adaptive management, the *2020 State of Papahānaumokuākea Marine National Monument* report (ONMS, 2020) identified shallow marine and low-lying terrestrial habitats (i.e., coral reefs and atolls) as most vulnerable to climate change. These areas are already experiencing impacts. Increased regional sea surface temperature and ocean heat content has resulted in coral bleaching. Mass coral bleaching was recorded in 2002 and again in 2004, 2006, 2009, 2010, 2014, and 2019 at different locations to varying degrees (Aeby et al., 2003; Kenyon & Brainard, 2006; Kenyon et al., 2006). Sea level rise, coupled with storms and high tides have been associated with both gradual erosion and acute loss of critical terrestrial habitat. These impacts may become more severe and intense as the atmosphere and oceans warm. The rapidly changing climate will undoubtedly affect marine habitats as well. However, its impacts on prey availability, for example, are not yet well understood. Other factors also exert pressures on species that rely upon marine and terrestrial habitat at PMNM. Incidental capture by commercial and recreational fisheries outside of PMNM and entrapment in infrastructure or marine debris within PMNM can result in direct species losses. Contaminants, pollution, disease, invasive species, as well as vessel groundings may also have detrimental effects on species and habitat.

Among the islands and atolls that makeup PMNM is Lalo. This ~900 square kilometer open atoll consists of a large, crescent-shaped reef surrounding numerous small, sandy islets primarily composed of marine-derived materials such as coral rubble and sand (Figure 2: https://www.papahanaumokuakea.gov/visit/Lalo.html; https://www.fws.gov/refuge/Hawaiian_Islands/about/French_Frigate_Shoals.html). The emergent La Perouse Pinnacle is composed of volcanically originated basalt that underlies the atoll. Terrestrial habitat takes up only 1⁄4 square kilometers of the area. However, these tiny islets serve as the principal nesting site for the entire Hawaiian green sea turtle distinct population segment, with more than 90% of the archipelagic population nesting there (Balazs & Chaloupka, 2004). They also serve as a primary place of refuge for more than 20% of the Hawaiian monk seals in the Monument (Baker, et al., 2020; ONMS, 2020). Preserving this habitat is critical to these and other species' survival.

In terms of marine habitat, with nearly 1,000 square kilometers of coral reef, Lalo has one of the most significant reef systems in PMNM. It supports the greatest variety of coral species in PMNM; more than 600 species of invertebrates many of which are endemic; and more than 150 species of algae including especially diverse and lush algal communities immediately adjacent to La Perouse Pinnacle. The outer reef waters support gray reef sharks, butterfly fish, and large schools of jacks and groupers.

Lalo is also important historically. During World War II, Tern Island was formed into a runway to serve as a refueling stop for planes en route to Midway. Remnants of the original seawall and building structures remain in a greatly deteriorated state.

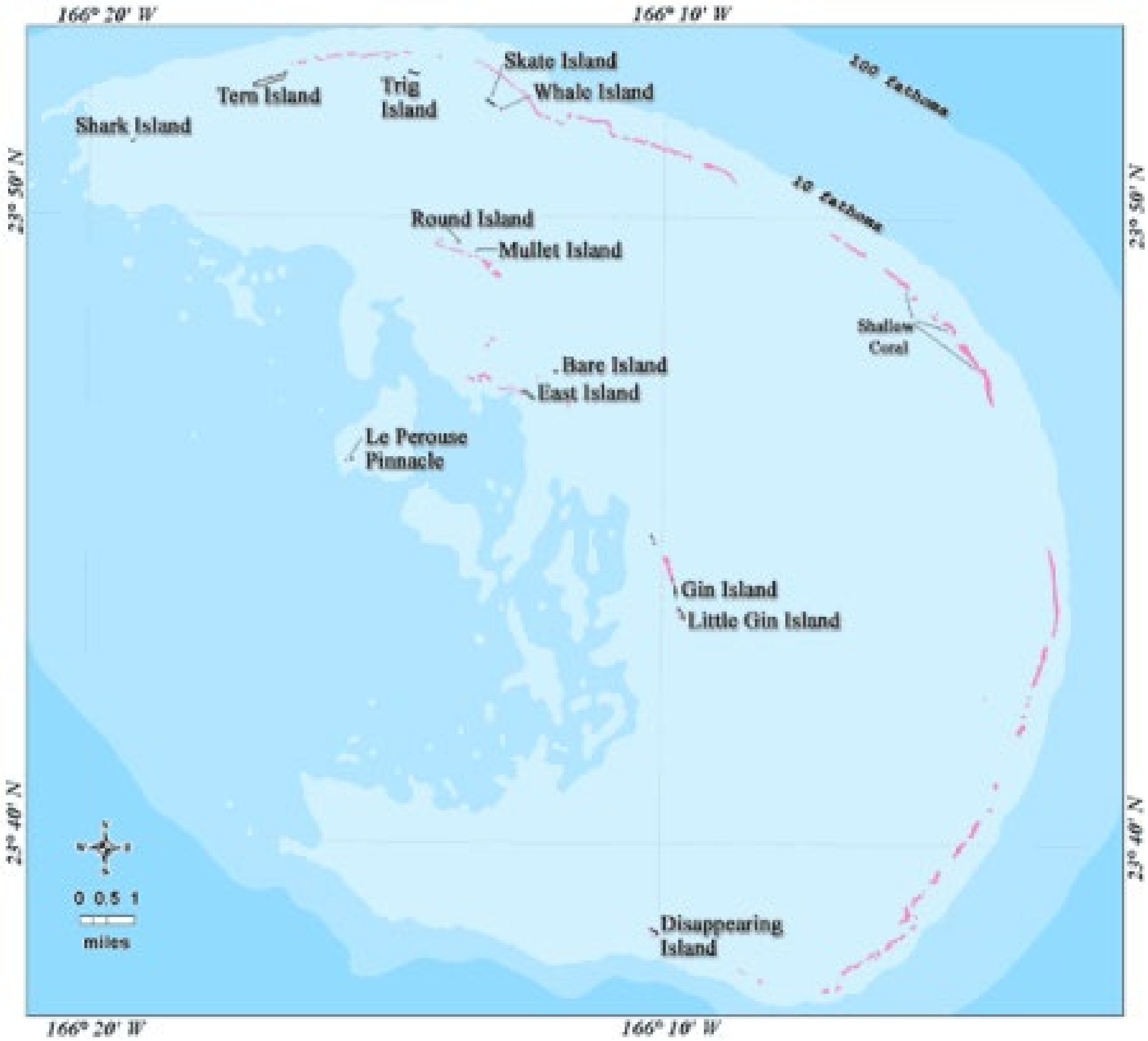



*Figure 2. Map of Lalo (French Frigate Shoals) including 8 remaining islets, several of which are ephemeral, eroding and accreting seasonally. The atoll is located towards the southeastern end of the NWHI as shown in Figure 1. From https://www.papahanaumokuakea.gov/.*

Native Hawaiian culture emphasizes the connections between place and community. The cultural and ecological significance of PMNM to native Hawaiians is well documented in the Kumulipo, one of the most well-known Hawaiian creation chants that expresses Hawaiian cosmology in relation to time, space, and place which specifies the unique identity of Hawaiian geography. According to the Kumulipo, the islands, elements, marine resources, and unique wildlife that make up PMNM are valued by native Hawaiian communities as a place of creation and origin where all life springs, where deities and spirits dwell, and where ancestors return to after death. Lalo is also home to maritime artifacts, including the recently found *Two Brothers* shipwreck, weaving in another layer of Pacific history to this site. There are also many ways that a new generation of Native Hawaiian scientists and cultural practitioners are using Lalo to weave Hawaiian cultural practice and research to strengthen native Hawaiian connection to place and culture. This cultural resurgence within PMNM includes indigenous-led scientific research in an array of disciplines, traditional voyaging, non-instrument navigation and wayfinding, Hawaiian language nomenclature subgroups, and participation in management despite the lack of a residential population. An integral part of establishing Lalo resilience is reinforcing both existing and new innovative strategies to strengthen this pilina (connection) Native Hawaiians have to this culturally valuable space.

## Recent Efforts to advance our understanding of systems, stressors, and solutions

In order to maintain and enhance the important terrestrial and marine habitats at Lalo, and the full breadth and depth of ecosystem services they provide, it is necessary to understand the scope, scale, and timing of potential impacts from a suite of climate and anthropogenic stressors. Such information provides the basis for establishing effective monitoring and management measures. Recognizing this, over the past decade or so the co-managing agencies - NOAA, USFWS, the State of Hawaii and the Office of Hawaiian Affairs - have conducted and supported numerous studies on varying aspects of this problem. Examples include:

- The *2020 State of Papahānaumokuākea Marine National Monument* report, noted above, is the most recent and comprehensive effort to monitor and report on the status of living and cultural resources (ONMS, 2020).
- *Terrestrial habitat loss and the long-term viability of the Lalo Hawaiian monk seal subpopulation* (Baker, et al., 2020)
- *Status and trends of Honu, or green sea turtles (Chelonia mydas), in the Papahānaumokuākea Marine National Monument.* A presentation at the 27th Annual Hawai'i Conservation Conference. (Staman et al. 2020)
- *Past, present, and future: nesting ecology and the resilience of the Hawaiian green sea turtle to climatic events.* A presentation at the 39th Annual Symposium on Sea Turtle Biology and Conservation. (Staman et al. 2019)
- *Spatial distribution of green sea turtle (Chelonia mydas) nests at Lalo, Hawaii: implications for carrying capacity?* A presentation at the 39th Annual Symposium on Sea Turtle Biology and Conservation. (Reininger et al. 2019)
- *Impact of climate change on green sea turtle (Chelonia mydas, Cheloniidae) hatching success on East Island, Lalo, Northwestern Hawaiian Islands.* A presentation at The 44th Annual Albert L. Tester Memorial Symposium, University of Hawai'i. (Bull et al. 2019)
- *Integrating climate projections into a population model for the Hawaiian green turtle.* A presentation at the 38th Annual Symposium on Sea Turtle Biology and Conservation. (Martin et al. 2018)
- The *Climate change vulnerability assessment for the Papahānaumokuākea Marine National Monument*, also noted above, provided an extensive assessment of climate-related factors and their impacts (Wagner and Polhemus, 2016).
- *Predicting sea-level rise vulnerability of terrestrial habitat and wildlife of the Northwestern Hawaiian Islands* (Reynolds, et al., 2012)
- *Dramatic shifts in Hawaiian monk seal distribution predicted from divergent regional trends* (Baker, et al., 2011).
- *Estimating the carrying capacity of French Frigate Shoals for the endangered Hawaiian monk seal using Ecopath with Ecosim* (Parrish, et al., 2011).
- *Trading off short-term and long-term risk: minimizing the threat of Laysan Duck extinction from catastrophes and sea-level rise. A Case Study from the Structured Decision Making Workshop, January 25–29, 2010* (Reynolds, et al., 2010)
- *Range-Wide Genetic Connectivity of the Hawaiian Monk Seal and Implications for Translocation* (Schultz et al., 2010)

• *Estimating carrying capacity at the green turtle nesting beach of East Island, French Frigate Shoals* (Tiwari et al. 2010)
• *Marine Biogeographic Assessment of the Northwestern Hawaiian Islands Management Concerns and Responsibilities* (Keller, et al., 2009).
• *A map of human impacts to a ''pristine'' coral reef ecosystem, the Papahānaumokuākea Marine National Monument Coral Reefs* (Selkoe, et al., 2009)
• *Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands* (Baker et al., 2006).

Further, management actions such as translocations, invasive species removal, and habitat restoration have also been applied at PMNM and have proved successful in improving habitat quality and species abundance and distribution (ONMS, 2020). NOAA's National Marine Fisheries Service (NMFS) Hawaiian monk seal and sea turtle field research camps are typically established at Tern Island (and previously East Island) at least during summer months and FWS monitors the island with periodic trips.

Still, gaps remain in our understanding of various aspects of both physical and biological systems and the relationships between the two. The combined impacts of rapid climate change and anthropogenic stressors add layers of complexity that confound that understanding as well. Even where systems, relationships and impacts are relatively well understood (with sufficient monitoring in place), available information typically lacks the granularity necessary to identify and prioritize mediation measures. Adding to this, the degree of communication, coordination, and collaboration between and among state and federal agencies, academic institutions, and non-governmental organizations does not always occur to the extent desirable.

Issues of this nature were discussed during the NMFS' 3rd Annual Collaborative Climate Science Workshop held at the NOAA Inouye Regional Center (IRC) in September of 2019 (Woodworth-Jeffcoats, et al., 2019). The workshop focus was to report on previously identified priority areas where climate science was needed to support resource management. The workshop was designed to bridge the gap between scientists and managers by improving information exchange among agencies, institutions and organizations with science and management responsibilities. During this meeting, the issue of terrestrial habitat loss at Lalo rose to the fore. This was due to recognition of the conservation significance of Lalo island habitat, especially for Hawaiian green sea turtles and Hawaiian monk seals. The destruction of East Island at Lalo caused by Hurricane Walaka in early October of 2018, was still fresh in everyone's mind and served as a sober reminder of the potential fate of this precious resource.

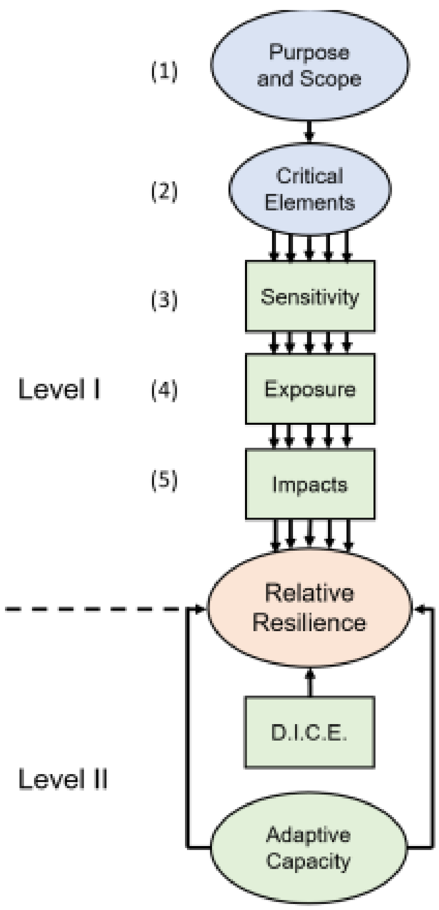
Building upon the outcomes of the NMFS workshop, in January of 2020 the NOAA PREB endorsed a cross-line office regional collaboration effort to formulate a more nuanced understanding of the impacts on various natural and cultural resources within PMNM in light of a rapidly changing climate and identify a range of measures that can be taken to mitigate these impacts. Specifically, they called for the creation of a small cross-line office working group and tasked it with:

1) framing the existing problem(s) and proposing a path forward with respect to investigations and other actions warranted to better understand, predict, and adapt to climate-related impacts at Lalo; and
2) laying out a plan to engage a larger inter-agency working group in this exercise, in the robust and sustainable manner necessary to protect and maintain healthy ecosystems and ecosystem services within PMNM over the coming decades.

To this end, a small cross-line office working group composed of subject matter experts from NOAA NMFS's Pacific Islands Regional Office (PIRO) and Pacific Island Fisheries Science Center (PIFSC); NOS's Office of National Marine Sanctuaries (ONMS) and Office of Coastal Management (OCM), NESDIS, NWS and OAR began meeting regularly to advance the PREB's charge. As part of the NMFS 4th and 5th Annual Collaborative Climate Science Workshop, in October 2020 and February 2022, respectively, this working group convened special sessions on Lalo. These half-day virtual workshops looked at the Lalo ecosystem primarily through the lens of monk seals and green sea turtles (2020), and seabirds and coral ecosystems (2022). The workshop process and its outcomes are summarized below. These, along with a literature review and discussions among working group members and other stakeholders form the basis for the concluding recommendations herein.

## NMFS 4th Annual Collaborative Climate Science Workshop Special Session on Lalo

### Framing the Problem.




The special session of Lalo assessment employed a systems and stressors-based vulnerability assessment protocol applied to monk seals and green sea turtles as a way to help outline the current state of knowledge and to identify information gaps (Figure 3). The assessment protocol follows a sequence of steps that starts by (1) framing the problem in terms of: the purpose/objectives for which the information is being collected; the decision-relevant metrics, measures that are meaningful in the context of the purpose/objectives, and the relevant spatial and temporal domains. It next calls for (2) identification of critical elements, and individual components associated with these elements that taken together define the system of interest. In this instance that would be *critical life history activities* such as nesting, breeding, etc. and the habitats that support these activities. Each activity's/habitat's potential sensitivity to harmful effects due to climate-related physical, biological, chemical, and anthropogenic forcings is then explored (3), and ideally relevant impact thresholds and/or tolerances to these stressors/pressures are identified. Then information about exposure is brought in (4); projected changes in magnitude, frequency, duration etc. of the full spectrum of climate-related forcings at the location and over the time periods of interest. Finally, (5) sensitivity and exposure information are combined to

*Figure 3. Schematic of the Systems and Stressors-Based Assessment Protocol NMFS 4th Annual Collaborative Climate Science Workshop Special Session on French Frigate Shoals.* This assessment protocol was developed by NOAA NESDIS National Centers for Information (NCEI) as part of efforts being conducted for and sponsored by the DOD Strategic Environmental Research and Development Program (SERDP). This protocol is designed to identify the "weakest links", including what impacts of significance are likely to happen first and when, at a level of granularity necessary to identify and prioritize mediation measures.

determine the expected ranges of negative impacts on the critical activities/habitats, their relative risk or vulnerability, and ultimately that of their meaning with respect to the overall purpose/objectives via the projected change in management metrics. The assessment protocol closes out with a re-examination of results to look for dependencies including cascading and cumulative effects, as well as an assessment of adaptive capacity in its broadest sense. The scope of the process was extremely broad by design, to ensure that all relevant factors were considered even though the results may be very focused. It is recognized that limiting the analysis to seals, turtles, seabirds, and coral ecosystems does not fully capture what ultimately needs to be a broad assessment of a myriad of ecosystem-wide considerations (i.e., other habitats, other species, etc.). However, it proved to be useful in addressing the predominant species who utilize Lalo and a justified focus given the immediate and significant threats of climate change to these species at Lalo.

Framing the problem. For both monk seals and green sea turtles, the overarching objective is to *maintain and/or enhance habitat as a means to ensure abundance and persistence*. Population demographics are the primary metrics used to assess status with respect to these objectives (e.g., number of individuals, in the case of sea turtles the annual number of nesting females, age/sex structure, reproduction rates, etc.) with specific values associated with respective ESA down listing and delisting criteria (e.g., NMFS and USFWS, 1998; Seminoff et al., 2015) The areal extent of key habitats is another management metric. In this case it is the value in square kilometers or acres, for example associated with habitat types that support specific services (critical life history activities) detailed below. Key among these (for monk seals, green sea turtles, and seabirds at least) is terrestrial habitat in the form of sandy beach between Mean Higher High Water (MHHW) and the vegetation line. A third category of metrics linked to threats was also identified. This includes measures such as the number of human-caused deaths due to entanglement or entrapment.

With respect to the spatial and temporal domains over which such metrics would apply, to some extent these parameters are outlined in the context of respective ESA criteria (e.g., NMFS and FWS, 1998; Seminoff et al., 2015). Domain distinctions were made between *island*, *atoll*, and *archipelago* scales and their differences with respect to critical life history activities. Activities associated with terrestrial habitats tend to occur at the island to atoll scale and those associated with marine habitat on the archipelago scale and beyond. Aspects pertaining to relevant temporal domains were discussed. This included management planning horizons and impact horizons as well as nuances such as the 4-year on average nesting cycles of turtles, the 20-50 years it takes for them to reach maturity, and how this might affect assessment of impacts due to a rapidly changing climate. Further attention to the topic of establishing relevant temporal domains is warranted.

## Defining the System.

**Terrestrial habitat** is critical to the survival of both monk seals and green sea turtles (Table 1). Monk seals use it for resting, giving birth, and nursing (Figure 4). With respect to giving birth and nursing, sandy beaches - between MHHW and the vegetation line, and adjacent to shallow and protected reef habitat - are preferred. At Lalo, Whaleskate, Trig, and East Islands have historically accounted for the vast majority of seal births at Lalo. However, those three islands are completely or nearly submerged, so that seal mothers must give birth at alternative sites, the largest of which is Tern Island. The land area needs to be of sufficient size to avoid overcrowding among mother-pup pairs and protected from wave runup and overwash that can wash away and drown pups. What such an area is, say per mother-pup pair, and requirements for such over time – the carrying capacity - is not well understood: however, the main priority is to preserve/restore as much habitat as possible. Seals of all age and sex classes require terrestrial habitat upon which to rest. The required features of resting habitat are less specific than for birthing and nursing habitat. As with birthing and nursing, ideal beach habitat also provides a refuge from predation risk (e.g., Tiger and Galapagos sharks) and is in proximity to marine feeding habitat. Green sea turtles use terrestrial habitat for nesting and resting (Figure 5).

*Figure 4. Two weaned Hawaiian monk seal pups sleeping at French Frigate Shoals in the Northwestern Hawaiian Islands. Source NOAA.*

*Figure 5. Basking green sea turtles on Tern Island. Source NOAA.*

Again, sandy beaches between MHHW and the vegetation line are preferred. In the case of green sea turtles, the beach needs to be of a sufficient depth and appropriate substrate type to enable digging of suitable nests, incubation of nests, and hatchling emergence. Ideal beach habitat also provides a refuge from predation risk. Lalo and specifically Tern Island currently meet this need, with <50% of green sea turtles nesting on Tern Island. Prior to the destruction caused by Hurricane Walaka >50% of adult females nested at East Island Lalo, while turtles (of both sexes and maturity states) also haul themselves out of the ocean to rest on the beach. How much land to support these activities, for the desired number of individuals over a given time – the carrying capacity - is not well understood (Tiwari et al., 2010; Reninger et al. 2019; Bull et al. 2019). Basking on sandy beaches adjacent to shallow and protected reef habitat is likely an important behavior for resting and thermoregulation while they are in the midst of their reproductive season or part of daily life for resident immature and adult turtles. This activity occurs throughout the Main Hawaiian Islands as well as within the Monument, a large portion of which occurs at Lalo.

*Table 2. Critical life history activities and associated habitat types/locations for Hawaiian monk seals (top) and Hawaiian green sea turtles (bottom).*

| **Terrestrial Habitat** | | | Marine Habitat | |
|---|---|---|---|---|
| **Resting** | **Birthing** | **Nursing** | Feeding | Breeding |
| Seals require island habitat upon which to rest. Required features of resting habitat are less specific than for pupping and nursing habitat. Appropriate beach habitat is required to provide a refuge from predation risk. – FFS/Tern Island | Typically, sandy beaches preferred adjacent to shallow and protected reef habitat. Sufficient space to avoid overcrowding among mother-pup pairs. – FFS/Tern Island | Same comments as for birth. Protected nearshore waters to mitigate shark predation and so that pups aren't washed away and drowned. – FFS/Tern Island | Feeding is primarily benthic up to 200m depth. Suitable terrestrial habitat is required in proximity to foraging habitat to allow seals to exploit foraging resources. – NWHI-MHI/FFS/Tern Island | Breeding occurs in the water, not relevant to terrestrial habitat. – NWHI-MHI |

| **Terrestrial Habitat** | | **Marine Habitat** | | |
|---|---|---|---|---|
| **Nesting** | **Resting** | **Breeding** | **Feeding** | **Migration** |
| Turtles require sandy beaches of sufficient depth and substrate type to dig a nest, for incubation of eggs, and hatchling emergence. Appropriate beach habitat is required to provide a refuge from predation risk. – FFS/Tern Island | Basking on sandy beaches adjacent to shallow and protected reef habitat is likely an important behavior for resting and thermoregulation while they are in the midst of their reproductive season (or any time of year for resident turtles). Appropriate beach habitat is required to provide a refuge from predation risk. – NWHI-MHI/FFS/Tern Island | Mating occurs in waters near FFS. Location or depth unknown, but likely at or near the surface. Relevant mostly for turtles that reside at FFS for their whole lives. | Feeding occurs in waters near FFS, and throughout the Hawaiian Archipelago and beyond. Relevant mostly for turtles that reside at FFS for their whole lives. | Adult turtles complete round-trip migrations to FFS from the MHI for mating and nesting. |

**Marine habitat** at Lalo is important for both species, but probably more so for monk seals, because they are central place foragers that commute between the atoll's islands and accessible foraging habitat all year round. Feeding primarily occurs in benthic areas in depths up to 200m and approximately 250 km from their terrestrial resting sites (Baker et al, 2020). Seals based at Lalo access 42% of the total Monument foraging habitat and have near exclusive access to 31% of the available foraging area in PMNM. If seals cannot land at Lalo due to loss of landing areas, most of that foraging habitat would be unreachable. Monk seals also mate at sea.

Green sea turtles use marine habitat for breeding, feeding, and migration. Breeding occurs in waters near Lalo and beyond, exactly how far offshore and at what depths (mating is generally observed at the surface) is not known. Most turtles that migrate to Lalo to mate and nest are not thought to be foraging there; instead, they forage in nearshore environments throughout the MHI within a relatively small home range for each individual (within a couple to tens of square miles rather than hundreds). However, there is a small population of turtles that are resident within PMNM and forage there. For migratory habitat, the area between the MHI and NWHI is what green sea turtles use to move back and forth, with females migrating every 4 years on average ("remigration interval") and males having an unknown remigration interval (but possibly migrating more frequently).

## Exploring Stressors.

Distinguishing between acute and chronic stressors was highlighted as an important component of developing a resilience strategy. Conservation measures needed to address these stressors may vary depending on the extent and timeline of the anticipated impact. Acute stressors can also be thought of as catastrophic events with only two possible outcomes, the persistence or the loss of an individual organism or group of organisms. Chronic stressors result in a slow decline in species fitness and long-term deleterious effect on individuals and groups of species. When identifying key stressors to terrestrial and marine habitat, it is also critical to consider scale, as some stressors will overlap habitat sections/types. One section of habitat can be different from another; considering the thresholds of change, thus understanding thresholds depends on clearly defining scale. Acute stressors may include intense storm events or bird mortality due to rat predation, versus a chronic stressor such as ocean acidification or rising ambient air temperature, which will have long drawn-out effects and impact seen gradually over time.

During the Lalo special session, considerable attention was given to this aspect of the assessment protocol. That is, given each of the critical life history activities and the characteristics of associated habitat that are important, what climate-related and/or anthropogenic factors constitute potential stressors? For identified stressors, how do they manifest in terms of impact on the given species/habitat and what thresholds and tolerances are relevant in this regard?

**Terrestrial habitat.** At the top of the list of threats to the terrestrial habitat critical to the survival of both monk seals and green sea turtles is **direct loss of terrestrial habitat due to inundation and flooding.** Here, *flooding* refers to temporary submergence from wave runup and overwash that occurs due to the combination of high waves and water levels generated during high tides, extra-tropical and tropical storms. Such events (linked to climate variability), with their destructive (and constructive) forces remove and reshape terrestrial habitat on an irregular, but recurring basis. From a conservation perspective, such flooding can drown sea turtle embryos incubating in nests and increase hatchling entrapment risks at the deteriorated Tern Island site. *Inundation* refers to permanent submergence associated with changes in the mean sea level. With the anticipated rise in global mean sea level, even without storms, loss of habitat for nesting and resting is inevitable (Reynolds, et al., 2012; ONMS, 2016).

Baker et al., 2020 report that the sand islets that make up Lalo have been decreasing in size for several decades. Whaleskate Island was once the second largest in the atoll. By 2000 it was completely inundated. Trig Island succumbed to progressive inundation in September 2018. Then in early October of 2018 Lalo suffered a direct hit from Hurricane Walaka, at its peak a Category 5 hurricane. East Island all but disappeared (Figure 6). Tern Island now accounts for about three-quarters of the remaining terrestrial habitat area at Lalo (Baker et al., 20200). Such historical observations suggest Lalo is a highly dynamic setting; changes in weather and climate are driving what is undoubtedly a complex system of nearshore circulation and sedimentation. How patterns and trends of nearshore circulation and sedimentation might change, in particular their scope and timing are not well understood. For that matter, how do current levels of change compare to those observed historically and how have species adapted previously to large changes?

As terrestrial habitat is lost due to storms and sea level rise, **competition for space increases, both within and among species (i.e., seals, turtles, seabirds)**. With respect to seals, Baker et al., (2020) suggest that, assuming competition for space is not the primary issue; Tern Island could accommodate the entire current population because seal subpopulation abundance appears to be constrained more by foraging habitat availability than by terrestrial habitat area. That said, Tern Island, in effect the last island standing at Lalo, is far from ideal. The human-built infrastructure and marine debris that currently exists there has proven to be an entrapment hazard for both monk seals and green sea turtles (Figure 7). Since 1989, 70 monk seal entrapment cases have been documented, 25 of which occurred just during 2017 to 2019 (Baker et al., 2020). Numerous turtles have been saved from death by NMFS field researchers present on island during nesting/pupping season. For example, eight adult female turtles were found dead in 2020 when no field researchers were present on Tern Island due to the pandemic. Thus, entrapment hazards represent a significant and immediate threat to the survival of both monk seals and green turtles. Attention to mitigating adverse impacts due to the damaged and decaying infrastructure and marine debris that currently exists at Tern Island is of the highest priority. With respect to other anthropogenic hazards at Tern Island, the potential for detrimental effects due to chemical contaminants (e.g., PCBs, heavy metals, etc.) is also a concern but to a lesser degree than entrapment (Ylitalo et al., 2008).


*Figure 6. Aerial imagery of East Island in Lalo before (top) and after (bottom) Hurricane Walaka. Source USFWS.*

For both species, **more storms and higher sea level**s would undoubtedly be detrimental. Increased drowning of seal pups and incubating sea turtle embryos as well as disruption of nesting, incubation, hatching and emergence of hatchlings is highly likely. For turtles as noted above, adequate sand depth is an issue in this regard. As sea level rises, developing embryos could be drowned by high tides, even without storms. Though not directly related, **increases in land surface temperature due to climate change** warrant note as it affects green sea turtle nesting activities (Hays et al. 2003, Laloë et al. 2014, Esteban et al. 2016). In the long run this may prove to be a limiting factor in the viability of green turtle populations in and of itself because sea turtle sex and hatchling survivorship is determined by the environment (i.e., warmer incubation temperatures produce more female hatchlings, but at some point, incubation environments that are too warm cause embryonic death). For seals, another consideration associated with terrestrial habitat loss due to storms and sea level rise is the potential for increased mortality associated with shifting to alternative habitats that are suboptimal due to the increased threat of shark predation that exists at these alternative locations compared to those used historically.

*Figure 7. Aerial Imagery showing human-built infrastructure that currently exists at Tern Island and has proven to be an entrapment hazard (inset) for both monk seals and green sea turtles. Source NOAA/USFWS.*

The sea turtle remigration interval is between four and five years. Understanding what happens if turtles return to East Island and land is gone is currently unknown. Additional research is needed to understand turtle movement in response to land erosion. Only a small portion of an entire island is considered usable turtle habitat. With less vegetation, turtles may be more prone to crawl and explore areas more into the center of the island, and with space permitting will try to nest, most likely unsuccessfully because of suboptimal turtle nesting habitat. Sea turtle population decline will be observed many decades in the future, due to its slow growth. Turtles utilize the earth's magnetism to return to the nesting area in which they are born, and will take many generations for turtles to shift to new habitat if Tern Island is lost and nesting habitat is no longer available, leading to a delayed decrease in population. We won't see a direct loss to sea turtle populations until current hatchlings return to nest once they reach sexual maturity. In response to loss of usable resting space on Tern Island, monk seals will see temporary population loss. If Lalo is lost, they may move to other islands such as Nihoa and Mokumanamana, where resting space is available, but may not be as good a habitat for seals. This need to relocate may negatively affect them because they are farther away from the optimum feeding area near Lalo.

**Marine habitat.** Threats to pelagic and archipelagic marine habitat are a concern for both species, but probably more so for monk seals because of their reliance on benthic foraging. In this case anticipated and unanticipated changes to ocean conditions such as **sea surface and subsurface temperature, chemistry (e.g., salinity, dissolved oxygen, pH, etc.), and nutrients, as well as changes in large scale circulation and stratification** could dramatically impact specific predator/prey relationships and the food chain more broadly. Changes in the quantity and quality of prey might mean changes in foraging patterns that require increased expenditure of energy and risk of predation. For turtles, sea surface temperature (SST) has been correlated with the length of the nesting season for some populations (Pike et al. 2006, Mazaris et al. 2008), but not for others (Pike 2009). It might also influence when breeding and migration is triggered, and even migration corridors themselves. Changes in food availability is also a potential concern for sea turtles. These concerns, primarily related to food availability, are applicable to Lalo as a whole and the NHWI and MHI area more broadly.

**Anthropogenic hazards in this context include the effects of commercial fishing**. Indirect impacts may manifest as food availability decreases. Direct impacts, to turtles in particular, include mortality associated with incidental catch by commercial and recreational fisheries, as well as entanglement in floating marine debris such as nets and other fishing gear. Introduction of contaminants, disease, and invasive species to the turtle populations and their habitat also fall into this category. Sea turtles on Hawai'i island have already been filmed eating invasive grass that grows into the ocean. This grass has poor nutritional value and they do not digest it well.

Though not considered in the workshop, similar concerns have been raised with respect to other species. Reynolds et al. 2010 for example, focused on threats to the Laysan Duck and identified catastrophic risks such as **disease, invasive mammal introductions, tsunamis, and hurricanes, as well as the longer-term risk of inundation due to sea level rise**. Such concerns apply to a number of sea and shorebirds at Lalo (Reynolds et al., 2016), and a host of terrestrial species more broadly (Figure 8). In the shallow-nearshore, corals and the ecosystems they support are particularly at risk (Figure 8). Understanding changes in patterns of nearshore circulation and how it affects nutrient flow and larval distribution (also relevant to understanding potential changes in terrestrial habitat) is important in this context. Finally, the threats to historical heritage and cultural resources associated with both terrestrial and marine habitats cannot be overlooked. The extent to which critical habitat and stressors overlap across the spectrum of species that inhabit Lalo and PMNM provide rationale for prioritization of actions, but need to be followed by additional investigation and application of a combination of interventions. Considered further below, the NOAA Habitat Blueprint Initiative and a potential Habitat Focus Area designation for Lalo is noted as a mechanism to support the type of holistic planning effort that is called for.

*Figure 8. A White Tern at Tern Island (left) and coral reef at Lalo (right). From USFWS and NOAA.*

## NMFS 5th Annual Collaborative Climate Science Workshop Special Session on Lalo

This special session was held in February 2022 as a follow-up to the 4th Lalo special session. Science staff from each of the co-managing agencies as well as external research scientists, conservation managers, and cultural experts again employed the systems and stressor-based vulnerability assessment protocol described previously (Figure 3) to identify knowledge gaps and prioritize mitigation measures. This 5th special session focused on extending the current state of knowledge to a wider range of valued wildlife species at Lalo, with a focus on seabirds and coral ecosystems. A gap in the first round of assessments, and accounted for in this second round, was consideration of direct impacts to nearshore as well as deep water marine ecosystems and species. Including seabirds and coral ecosystems into the system stressors assessment protocol strengthens our understanding of terrestrial species connections while also broadening the understanding of ecosystem-wide considerations and direct impacts climatic stressors have on these key marine-dependent species. The Lalo special session proved useful as a way to help frame the problem and provide a way to integrate across species via habitat. While a seminal component of the evaluation, the results are not viewed as the complete picture. The needs (i.e., defining the respective system in terms of habitat characteristics and associated critical life history activities and exploring the stressors, relationships, thresholds and tolerances) of other species will also need to be considered. In this way investigations and actions will be carried out in a collective, ecosystem wide-context.

## Defining the System.

**Terrestrial habitat.**

Lalo is one of the largest tropical seabird rookeries in the world with at least eighteen species of seabird nesting within the atoll (Black-footed Albatross (BFAL), Laysan Albatross (LAAL), Bonin Petrel (BOPE), Bulwer's Petrel (BUPE), Wedge-tailed Shearwater (WTSH), Christmas Shearwater (CHSH), Tristram's Storm-Petrel (TRSP), Red-tailed Tropicbird (RTTR), Masked Booby (MABO), Red-footed Booby (RFBO), Brown Booby (BRBO), Great Frigatebird (GREF), Gray-backed Tern (GBAT), Sooty Tern (SOTE), Blue-gray Noddy (BGNO), Brown Noddy (BRNO), Black Noddy (BLNO), and White Tern (WHTT). In addition, Lalo is a wintering ground for several species of shorebirds such as the Pacific Golden-Plover (PAGP), Ruddy Turnstone (RUTU) and Bristle-thighed Curlew (BTCU). Terrestrial habitat is critical for breeding, roosting, foraging, and seasonal visitations. Breeding includes courtship behavior, nesting, and fledging; roosting includes both space and cover requirements; foraging occurs at the intertidal, nearshore, and pelagic zones; and seasonal visitation of Lalo includes year-round residents, winter breeding season residents, and summer breeding residents.

Many seabird species exhibit courtship behavior, some which require substantial space to perform courtship dancing displays including BFAL, and to a lesser extent SOTE who perform both aerial and on-ground courtship displays. Nesting requirements vary greatly. Some species prefer barren sandy areas with limited vegetation near the tidal line (BFAL), while some nest off the ground on shrubs or trees, making nests out of twigs, grass, and other vegetation (e.g. RFBO), and there are also crevice and burrow nesters that require shade either from vegetation or substrate like the BGNO and WTSH, respectively. Seabirds also require specific terrestrial habitat for roosting behavior, which occasionally differs from nesting requirements.

Vegetation allows for resting, preening, drying plumage, and thermoregulation. Vegetation also adds elevation and facilitates convective cooling from wind, a strategy employed by seabirds to prevent overheating. Overheating is an especially imminent challenge to ground nesters as both ambient and sand temperatures increase throughout PMNM.

Foraging behavior also varies greatly across seabird species. All nesting species on Lalo forage offshore, with onshore foraging and feeding limited to a few non-nesting migrating species (e.g. RUTU) who use Lalo as a rest stop during their transit to and from wintering grounds. Of the nesting seabird species, brooding adults remain relatively close to the colonies and forage, with feeding ranges varying from 100 square kilometers (BFAL, BGNO, WTSH), up to 500 km from colonies (SOTE) to ensure the ability to incubate their eggs. After brooding, some seabirds increase their feeding range farther from colonies. Non-breeding seabirds leave Lalo to feed far offshore ranging from the easterly section of the Pacific, usually off the coast of the continental US and Canada (BFAL), while some head to pelagic areas devoid of cold-water upwelling (SOTE).

Terrestrial habitat is used by seabirds throughout the year, but species assemblage on Lalo varies depending on nesting times. On Tern Island, winter season breeders include BFAL and BGNO (breed November-June) and are much more susceptible to winter storm inundation, increasing the probability for egg loss. On La Perouse Pinnacle, BGNO breeding occurs March-June, and is less susceptible to winter storm inundation. Summer breeding seabirds include SOTE and WTSH (breeds June-December), which experience temporal segregation in the use of breeding burrow habitat with BOPE, a winter breeder that uses the same burrows.

**Marine habitat.**

Marine habitat is a crucial component to the health and resilience of Lalo. Two distinct habitats were prioritized and addressed separately within the special session - nearshore (coral and archipelagic) habitat and offshore marine (pelagic) habitat. Both nearshore and offshore marine habitat health are critical for building resilience to climate and anthropogenic impacts.

Coral ecosystems serve as an essential component of long-term marine resilience to climate change impacts on low elevation atolls and sandy islets. The importance of corals is highlighted in Hawaiian culture, being considered the seat of Hawaiian creation (Office of Hawaiian Affairs et al. 2021). Both branching and mounding corals provide 3-D structure for reef biota, "raw" calcium carbonate for corallivores to break down into sand for land/island growth, food for herbivores which in turn keep fast-growing algae under control and help to provide appropriate structure for coral recruits, and indirectly provide food for other predators by housing prey items. Branching coral are fast growing corals with an open skeletal structure, varying between species, in comparison to the dense, slow growing mounding corals. Both of these coral functional groups also provide primary productivity via symbionts. Mounding and branching coral functional groups also provide specific services, facilitating the wide range of biodiversity seen in the reefs and marine habitat at Lalo. Coral polyps house photosynthetic dinoflagellates within their tissues that photosynthesize and provide energy to the coral. The coral, in turn, provides shelter and waste removal.

Branching corals provide structure for reef biota such as fish and invertebrates to carry out their activities of daily living, while also providing some degree of shading for corals and other organisms living below the upper canopy. Mounding corals specifically provide 3-D structure for reef biota and a dense platform for other organisms to settle. Crustose coralline algae (CCA) are calcareous red algae that serve as binders to cement and strengthen the interstices of coral reefs. They also are vital for larval settlement for many benthic organisms, such as corals, and provide much of the sand for atolls and islands. They also provide competition with fleshy macroalgae which could quickly overgrow a reef. Halimeda is a CCA that provides 3-d structure for reefs, and is a key flora within the Lalo marine habitat. In association with healthy and resilient marine habitat at Lalo, fish, bioeroders, and marine predators all serve key roles, but are dependent on the coral reef as the keystone species group and the major focus of marine resilience planning for Lalo.

Healthy coral reef ecosystems also provide wave attenuation for the sandy islets of Lalo and support the terrestrial habitat for seabirds. Although distinct habitats, the terrestrial and marine habitats of Lalo are tightly interwoven. Coral reef ecosystems are highly reliant on terrestrial habitat change, while reef growth and health are highly dependent on both sediment and substrate movement as well as terrestrial nutrient inputs.

Seabirds also rely on nearshore and offshore marine habitats for their foraging, both during nesting periods on Lalo and during the non-breeding season. Nearshore marine habitats surrounding Lalo are especially important to nesting seabirds, as they tend to remain near the nesting colony in the brooding period of the breeding season, feeding in between periods of egg incubation. The ability for large colonies of seabirds to feed near Lalo is highly dependent on the health of the marine habitat, promoting healthy fish, invertebrate, and other species' population numbers. The health of the surrounding coral ecosystem will dictate the distance that nesting seabirds must travel to feed, and influences the success of breeding seasons in the future.

*Table 3. Critical life history activities and associated habitat types/locations for seabirds (top) and corals (bottom)*

| Terrestrial Habitat | | | | | Marine Habitat | | |
|---|---|---|---|---|---|---|---|
| Breeding | | | Roosting | | Foraging | | |
| Courtship | Nesting | Fledging | Space | Cover | On-island/ Intertidal | Nearshore | Far Shore |
| Seabirds require island habitat to conduct courtship displays. | Seabird nesting habitat varies across species, ranging from nesting on the bare ground, shrub nesting, and burrowing. Shifting habitat will strongly dictate species assemblages. | Fledging occurs throughout the year, and varies by species' breeding seasons. | Required features for roosting habitat varies by species, with time allocated on bare ground or vegetation varying. | Required features for cover varies by species, ranging from little to no need for cover, to full dependence on vegetative or substrate cover for shading. | Nesting bird species on Lalo do not feed on land, and on land feeding is reserved for non-breeding migratory species such as the Ruddy Turnstone (RUTU). | Nesting seabirds tend to feed closer to breeding colonies and depend on nearshore food availability in the early stages of brood care, until chicks begin to fledge. | For breeding seabirds, after chicks fledge, adults begin to feed farther from colonies, ranging up to 500mi away from breeding colonies. |

| Marine Habitat | | | | | | | |
|---|---|---|---|---|---|---|---|
| Growth | | | Feeding | | Reproduction | | |
| Accretion & Erosion | Calcium Carbonate Production | Growth Rates | Primary Production | Secondary Production | Spawning | Settling | Recruitment |
| Different corals have different growth rates (with branching coral having faster growth and mounding coral growing slower). | Branching coral have an open skeletal structure but varies between species; whereas, mounding coral are dense and produce large quantities of calcium carbonate. | Branching corals are a fast-growing coral, in contrast to mounding coral, a slower growing coral group. | Corals house photosynthetic dinoflagellates within their tissues that serve to break down CO2 into energy for the coral polyp, in turn, the coral assists the symbiont by providing shelter and removing waste products. | Corals are soft-bodied organisms that feed corallivores. They also provide structure to house other biota that in turn feed predators. | Requires appropriate lunar conditions and appropriate water temperature to trigger a spawning event. Other factors like tides, day length, rate of temperature change, and salinity impact spawning. Spawning does not happen to all corals at the same time. | Settlement is when coral larvae transition from free-swimming plankton to benthic organisms. This requires appropriate substrate for attachment. | Recruitment includes the rate at which adults reproduce, their fecundity, the make-up of species, the number of successful larval settlements, the area of hospitable settlement sites. |

## Exploring Stressors.

**Terrestrial habitat.**

At the top of the list for threats to terrestrial habitat necessary for both seabirds and healthy coral ecosystems in Lalo is **periodic inundation due to increased storm intensity and frequency.** Inundation leads to the loss of emergent land and vegetation as secondary effects of sea level rise. For seabirds, Tern Island is the priority land mass in terms of species diversity and population size, and will be the dominant focus of the terrestrial island habitat resilience strategy. Inundation is already happening on Tern, where emergent land is eroding, resulting in sediment redistribution throughout Lalo and other atolls within PMNM. Loss of emergent land may dictate the distribution and seabird species assemblages based on land availability and differing habitat requirements, with direct impacts to shrub nesters (RFBO, WTSH, BLNO, RTTR) who require vegetation for either cover, shade, or nesting structure reliant on the presence of vegetation. Burrowing seabirds are particularly impacted by vegetation loss due to the lack of roots to secure sand and burrows. Shrub populations are already almost lost due to the effects of Hurricane Walaka. Tern Island is the last remaining islet in Lalo with living vegetation present. This loss of vegetation has also led to indirect effects for ground nesting birds who don't require vegetation for nesting, but utilize vegetation for other activities of daily living, including roosting, on-ground courtship displays (BFAL) and temperature regulation.

Sea surface height will increase the ratio of sandy habitat to thick vegetation on islets, with impacts to the ratios of seabird species present. BFAL and other ground nesters prefer open areas and may be at an advantage, compared to LAAL and RFBO both prefer vegetation dominated areas. Some seabird species are more adaptable (SOTE) and will be less susceptible to this stressor. There are also linkages between breeding season and anticipated storm surges, in which summer breeders and winter breeders will have differing levels of impact, as high intensity storms are generally associated with the winter season.

With the loss of emergent land and increased erosion due to intense storm inundation, **infrastructure entrapment, specifically seawall and debris on Tern Island,** was also identified as a key stressor to seabirds who depend on terrestrial habitat for nesting and resting. Seabirds commonly get caught in damaged sections of the Tern Island seawall and subsequently drown. Seabirds have also been killed by falling debris from buildings and existing infrastructure on Tern Island due to high winds, heavy rain, and storms. As more emergent land is lost, the remaining terrestrial habitat on Tern Island is considered poor quality for wildlife due to the amount of entrapments and obstructions, a compounding effect of emergent land loss.

**Ambient air temperature increase** was also identified as a direct stressor on seabird populations as nesting seabirds can become heat stressed while sitting on their nest, resulting in panting or standing off of their nest to cool down. Associated with air temperature, wind velocity in relation to convective and evaporative cooling becomes an important factor for seabirds at Lalo. As air temperatures increase, seabirds will become more reliant on steady wind velocity to cool themselves, especially ground nesting birds who do not use vegetation or burrows for cover. In addition to thermoregulation, increased ambient air temperature also leads to increased egg and chick mortality, and may facilitate nest and colony abandonment if the chronic stressor persists. Albatross breed during autumn, winter, and early spring, which perhaps is related to targeting cooler times of the year in an attempt to avoid their ground-laid eggs overheating. Increased ambient air temperature mainly impacts seabird nesting and fledging activities. Effective metrics to measure effects of ambient air temperature on seabirds include necropsies to see if a chick died of thermal stress versus lack of food or other reason. Fat content is an effective metric to determine cause of death in seabirds. Seabirds full of fat upon necropsy indicates that they were fed at time of death and died from hyperthermia. Increased ambient air temperature is a chronic stressor acting on a range of variation based on seabird species, and is highly dependent on nest site, food availability, and accessibility to wind.

To a lesser extent, **changes in soil moisture, unintentional introduction of non-native predators including rats and mongoose, native species competition for space (e.g. seals and turtles), seabird philopatry, longline bycatch, and gear entanglement were identified as important stressors to Lalo resilience planning.** Soil moisture may have a direct effect on the prevalence of ticks, but the direction of that effect, whether beneficial or deleterious to seabird populations, requires additional research. Increased tick abundance has the potential to initiate nest and colony abandonment.

Competition for space in a limited area between native wildlife will increase as islands shrink. Turtles and monk seals will move inland to rest and bask, encroaching on existing seabird colonies and destroying ground nests, resulting in seabird egg and chick mortality. Monk seals may also be intrusive to other native wildlife, as they don't share space as well. As smaller islets within Lalo disappear, sea turtles and monk seals will be forced to utilize Tern Island as their resting site, where seabirds have staked their last stand. Because seabirds are already established on Tern Island, their chance of persisting is potentially increased, but the interaction between species at Tern Island will need to be observed more to confirm impacts to seabird populations over time. Seabirds also have strong philopatry, an evolutionary tactic to go back to where it was safe before, and as a result are not so flexible about moving to new, "more suitable" habitats, in the event of total habitat loss.

**Marine habitat.**

*Physical Stressors:*

**Increased sea surface temperature and associated ocean acidification** was identified as one of the two key stressors to marine habitat crucial for coral reef ecosystems and all wildlife at Lalo. Increases in acidification negatively impact coral and crustose calciferous algae (CCA) growth and reproduction while facilitating a habitat favorable to fleshy algae competitors. Increased acidification reduces the rate of accretion, the ability of CCA such as Halimeda and corals, to calcify, changing ecosystem composition within the Lalo atoll. Increased acidification also reduces branching and mounding coral spawning cycles as well as their polyps' ability to sense appropriate substrate, impacting coral reproduction cycles, leading to chronic stress of coral ecosystems at Lalo. Algal growth rates increase with warmer temperatures and can overgrow both mounding and branching coral, limiting their access to sunlight. Due to the rapid growth rate of fleshy algae, compared to coral and CCA, algae outcompeting coral for space and light is a serious and impending stressor to marine habitats in Lalo and around the world. The frequency of temperature spike events and stresses to corals eventually reduces the marine system's ability to recover and adapt before the next serious climatic event occurs. Regular bleaching is becoming a normalized phenomenon, with branching coral more susceptible to bleaching events. In addition to direct impacts to coral, CCA, and coral ecosystems as a whole, sea surface temperature increase could also affect foraging of terrestrial wildlife, including sea turtles, seabirds, and monk seals. Recent bleaching events are different from past bleaching, possibly alluding to coral adaptation. Mounding coral are more heat resistant than branching coral, and are slowly building a resistance to heat or broadening their temperature threshold to account for these now common temperature spikes.

The second key stressor identified to have direct impacts on marine habitats at Lalo was **increased storm frequency and intensity**. Increased wind and bigger waves damage or sever branching coral branches, reducing reef structure and rugosity, impacting long-term ability for coral reefs to buffer terrestrial islets. These storm events increase suspended and deposited sediment in the water, lowering water quality and hampering sunlight penetration for symbionts, diminish recruitment of corals, decrease available area for coral polyp settlement, and impact subsequent survival and reproduction of both branching and mounding corals. On a hopeful note, mounding corals with flatter surfaces and CCA with more resilient structuring, may both be better able to withstand wave action and storms moving across the ocean's surface, making these particularly important species when considering building reef ecosystem resilience into the future. In instances of potential coral planting at Lalo, focusing on the introduction of mounding corals and tough CCAs like Halimeda may be crucial to build the Lalo reef ecosystem's resilience. Sediment is a key component of atolls and shallow islets such as Lalo, with almost 60% of sand to the islands at Lalo being produced by CCA.

Coral growth may not keep up with the pace of sea level rise and may eventually reach a depth threshold too deep for coral symbionts to photosynthesize. Without access to the energy provided by the symbionts, both branching and mounding corals "starve", leading to loss of rugosity and reduced coral reproduction over time. Sea level rise is a chronic stressor projected to have long-term impacts on coral reef ecosystems at Lalo.

**Pollution and marine debris** pose two distinct challenges for coral reef and CCA ecosystems. Chemical pollution originating from uncovered terrestrial debris, eroded sediments, or newly introduced pollution during atoll construction or maintenance may influence water chemistry and both coral and algae's abilities to reproduce. Marine debris also poses the risks of entanglement for marine species as well as physical damage when contact is made with corals and CCA. The discharge of waste materials, including fishing gear and plastics introduce a host of potential issues including physical damage and shading coral and CCA from sunlight essential for growth. Entanglement of reef fish and other marine wildlife who utilize reefs is an added impact. Corals are also susceptible to microplastic ingestion (Reichert et al. 2018, Hall et al. 2015, & Chapron et al. 2018).

**Stony coral tissue loss disease (SCTLD)** has also been identified as a catastrophic stressor with the most serious cases most recently reported throughout the Caribbean, and has the potential to affect Pacific Stony corals due to inadvertent spread originating from ship transmission via hotspots of SCTLD. The threat of new unforeseen disease to corals and algae will have deleterious impacts on the marine habitat at Lalo and across PMNM because it can show up quickly and unexpectedly. The volatility and unpredictability of this disease highlights the need for contingency and containment plans in place to address potential outbreaks. SCTLD preparedness measures should include studying and raising disease resistant coral for introduction to Lalo if needed. Increased studies on SCTLD are needed to better understand and prepare for this looming threat.

In the nearshore habitat, wildlife species that utilize terrestrial habitat will be impacted to varying degrees as a result of current and future loss of reef productivity. For sea turtles and seabirds that use the terrestrial area in Lalo primarily as a nesting place and not for foraging, the overall impact to population health may be less severe. In contrast, monk seals may be impacted to a higher degree because they are directly foraging in the nearshore and loss of fish will be deleterious. Resilience strategies must consider the degree of impact.

*Biological Stressors:*

Biological stressors are another important category to consider when addressing resilience in the marine habitat. These stressors are commonly responses to physical stressors. Natural species competition can be important when thinking about resilience to disturbance and larval settlement processes. Species assemblage may shift due to the new habitat post-disturbance.

Nutrient input and the facilitation of algae growth and impact to corals are important to consider, especially when linking processes that span both terrestrial and marine habitats. These interconnections and feedback loops between terrestrial environments can be seen in many ecological processes and need to be both understood and addressed when developing an effective resilience strategy for Lalo.

## Implications and Recommendations:

**Essential terrestrial habitat at Lalo has been lost or degraded and the remaining islands remain at risk to a combination of climate change and anthropogenic factors. Efforts to better understand risks and identify mitigation actions at Lalo that optimize outcomes in terms of the abundance and persistence of seals, turtles, seabirds, and coral must be undertaken with urgency. As a result of both the 2020 and 2022 Lalo state of knowledge special sessions, participating specialists identified priority stressors anticipated to have the highest impact to both the specific species at Lalo as well as the overarching system of habitats these species rely on within Lalo (Table 4).**

*Table 4. Top climatic or anthropogenic stressors for Hawaiian monk seals, Hawaiian green sea turtles, seabirds, coral ecosystems, and the overarching Lalo system. Stressor prioritizations were conducted by agency specialists and climate/research collaborators at the 4th and 5th NMFS Collaborative Climate Science Workshops.*

| Species Group/System | Top Stressors |
|---|---|
| Hawaiian Monk Seals | 1. Direct loss of terrestrial habitat due to inundation and flooding (Storms and higher sea level)<br>2. Competition for space both within and among species (i.e., seals, turtles, seabirds)<br>3. Sea surface and subsurface temperature<br>4. Commercial fishing bycatch |
| Hawaiian Green Sea Turtles | 1. Direct loss of terrestrial habitat due to inundation and flooding (Storms and higher sea level)<br>2. Competition for space both within and among species (i.e., seals, turtles, seabirds)<br>3. Increases in land surface and ambient air temperature<br>4. Commercial fishing bycatch |
| Seabirds | 1. Periodic inundation due to increased storm intensity and frequency<br>2. Infrastructure entrapment (Tern Island)<br>3. Increased ambient air temperature<br>4. Changes in soil moisture, unintentional introduction of non-native predators including rats and mongoose, native species competition for space (e.g. seals and turtles), seabird philopatry, longline bycatch, and gear entanglement |
| Coral Ecosystems | 1. Increased sea surface temperature and associated ocean acidification<br>2. Increased storm frequency and intensity<br>3. Terrestrial pollution and marine debris<br>4. Stony coral tissue loss disease (SCTLD) |
| Lalo (Atoll-wide system) | 1. Sea level rise (episodic flooding and inundation)<br>2. Sea surface and subsurface temperature<br>3. Infrastructure entrapment (Tern Island) |

When considering the overarching Lalo atoll system, the stressor of highest importance was identified as sea level rise and coastal storms that result in episodic flooding and inundation and direct loss of terrestrial habitat. Identified as the second highest priority was sea surface and subsurface temperatures that adversely impact nearshore and offshore marine habitat. The third key stressor at Lalo was identified as infrastructure entrapments at Tern Island. Understanding that management efforts need to be focused and prioritized, addressing these key stressors - in particular the scope and timing of associated impacts - will be an important step towards developing a MMB Action Plan.

Such efforts need to be framed within an action plan to maintain and enhance the resilience of terrestrial and marine habitats at Lalo. This plan should outline research and management objectives. It should call for actions that include short-term, mid-term, and long-term targets in the context of adaptation pathways; some of which can be implemented in parallel. It should identify the technical and financial resources that will be required. It is imperative that the plan be a collaborative effort among PMNM co-managing agencies that possess the critical expertise and resources needed to ensure its successful development and implementation. This means that engagement with the co-managing agencies and other stakeholders should occur early and often. Critical components needed to support the development of a MMB Action Plan are outlined below (Table 5). Due to their pressing need, some of these components and the actions may require implementation in parallel or even in advance of the development of the full action plan.

**A. Grow and nourish a vibrant and enduring dialog among monument co-managers and stakeholders to ensure that a broad range of interests are considered as actions are identified and implemented, support for such actions among stakeholders and the public is widespread, and consequential demand for a range of technical and financial resources can be met.**

1. **As a next step and of highest priority. Engage with the MMB composed of the co-managing agencies and other important stakeholders to review the information presented here and receive their input regarding the way forward.** At a minimum, representatives from the four principal entities responsible for managing the lands and waters of PMNM - the Secretary of Commerce through the National Oceanic and Atmospheric Administration (NOAA), the Secretary of the Interior through the U.S. Fish and Wildlife Service (USFWS), the State of Hawaiʻi through the Department of Land and Natural Resources and the Office of Hawaiian Affairs- should be briefed on these internal to NOAA discussions as soon as it is deemed practicable. This action is consistent with the goal the co-trustees have established to provide seamless and unified management in the spirit of cooperative conservation. The co-managing agencies are already preparing for a management plan review for PMNM as well as evaluating the possible designation of a sanctuary framework. The call to develop an action plan is well timed to complement these efforts. With the support of the co-managing agencies, management planning-related efforts outlined below could begin to move forward under the auspices of the interagency working group that the MMB has formed and tasked with addressing management needs at Lalo and have indicated an interest in this process. This group is best positioned to align these efforts with individual agency goals and plans and has the best understanding of and responsibilities for the entire management landscape of Lalo.

2. **Within the next 6 months and of high priority. Convene a series of webinars focused on ‘innovation in adaptive management’ to discuss the management options successfully**

**employed in marine and island conservation areas worldwide and their potential for consideration and implementation within the context of building resilience at Lalo.** These webinars would be held to address the following habitat-specific management priorities: 1) Increasing terrestrial and island ecosystem resilience, 2) Nearshore ecosystem resilience, and 3) Successful establishment and implementation of resilience strategies. Webinars will be convened with local, regional, national, and international managers and subject matter experts, including academic researchers to facilitate the collective development of management options to employ at Lalo, both for short, mid, and long management goals. Webinars will include conservation, engineering, and research specialists currently employing management strategies or research in marine and island conservation areas to provide management option ideas to implement at Lalo. Goals of the webinars include:

- Understand current management options employed in marine and island conservation areas worldwide
- Assess how habitat-specific management has impacted surrounding ecosystems
- Understanding cultural considerations employed (if any) in the implementation of these resilience plans

3. **Within the next 12 months and of high priority. Convene a large workshop with local, regional, national and international managers and subject matter experts, including academic researchers to facilitate the collective development of a comprehensive action plan for Lalo.** Participants will conduct a scenario planning exercise to assess the feasibility of implementing potential adaptative management, research, and monitoring options at Lalo under varying climate projections. Particular emphasis will be placed on an exploration of examples of successful management measures and techniques used elsewhere (e.g., Florida Keys and Great Barrier Reef, New Zealand). Goals of the workshop include:
    1. Establish a shared understanding of how marine and terrestrial ecosystems, climate and human-induced stressors, and the potential scope and timing of impacts to these systems, habitats, and the species they support, all contribute to the selection of adaptation options that will drive the Lalo Resilience Action Plan;
    2. Identify elements of strategy for enhancing resilience at Lalo in terms of actions that can be taken over the near to long term including adaptation management measures, monitoring and assessment programs, and areas of future research;
    3. Examine observations and recommendations through a biocultural lens that incorporates Native Hawaiian cultural considerations of managing tangible and intangible biocultural resources within Lalo;
    4. Articulating collective research and management goals;
    5. Establishing a support network including funding mechanisms, community engagement, and climate collaborators to ensure continued progress and development of an adaptive resilience strategy into the implementation, monitoring, and evaluation stages of this effort;
    6. Codifying the multi-agency collaboration as a means to grow a vibrant and enduring inter-agency planning effort while establishing active ownership over the implementation of selected adaptation options.

**B) Form a series of working groups under the auspices of the interagency working group that the MMB has formed and tasked with addressing management needs at Lalo. These topical working groups will identify priority information needs that will likely have the greatest impact, develop**

**plans to address these needs via additional investigations that include identification of preferred management actions, oversee the implementation of these preferred actions, and conduct monitoring to evaluate their success.** With MMB concurrence, various scientific and engineering investigations that may be called for by these working groups should be undertaken as soon as circumstances permit. In this way the gathering of actionable information will not be delayed while waiting for the adoption of an action plan and the outcomes of such potentially important investigations may be incorporated into the overarching plan

1. **Highest Priority. Continuously engage the Lalo MMB Working Group throughout the Lalo Resilience Strategy development process.** This group of monument co-managers has been formed with goals to stay apprised of management needs and initiatives that relate to Lalo and to provide management advice, direction and support toward relevant initiatives in addition to supporting Lalo components in management planning. Members of this group also serve as the nexus to the agency specialists within their respective agencies, and can relay information regarding the status of the action plan development process or garner additional agency-specific support for this effort.

2. **High Priority. Engage the Lalo Terrestrial Habitat Advisory Committee for specialized and technical advice on terrestrial and island habitat components of developing a Lalo Resilience Strategy.**

   **The Lalo Terrestrial Habitat Advisory Committee has provided preliminary recommended research, monitoring, and management actions to incorporate into a Lalo resilience action plan; all of which will need to be revisited in the action plan development workshops.**

   **High Priority. Investigations and actions to maintain and/or enhance Terrestrial Habitat quality at Tern Island in the short term.** Tern Island currently does and will continue to play a vital role in providing terrestrial habitat necessary to ensure the abundance and persistence of monk seals, green sea turtles, and seabirds at Lalo. The loss of Tern Island within several decades due to flooding and inundation is a very real possibility. However, of more immediate concern is entrapment hazards at Tern Island. Damaged and decaying infrastructure are trapping seals, turtles, and seabirds at an alarming rate. Marine debris (i.e., derelict nets and fishing gear) on the islands enhances these risks. With respect to the seawalls and other structures that exist along portions of the shore, neither complete removal nor replacement are likely viable immediate options. Rather some form of strategic repair or mitigation may be required as an interim measure, and a multi-disciplinary approach is needed to determine exactly what that entails. As for other anthropogenic hazards (e.g. buried and damaged infrastructure, marine debris, etc.) timely removal (and not just maintenance of marine debris removal) to the extent practicable is warranted. Plans for such actions need to be further developed. Regular strategically timed visits, if not year-round staffing of Tern Island to monitor conditions and perform rescues until such time that the aforementioned measures can be developed and implemented, should be part of such plans. Discussions to identify the short term “micro intervention'' options to implement at Lalo have already occurred; however, additional research and discussions to identify unintentional negative or unequal impacts these micro intervention options may have on the variety of wildlife found within Lalo is needed. **The reactivated Lalo Terrestrial Habitat Advisory Committee (THAC) identified the need to**

**facilitate the annual post field season debriefings with all field crews deployed within PMNM to emphasize short-term planning for mitigation efforts in following field seasons. The Lalo THAC also highlights the need to establish systematic image and data collection requirements for NOAA and USFWS field crews to capture annually (more frequently when possible), including monthly aerial transects, pictures at set locations, specific GPS locations of areas of particularly high entrapment rates, and other crucial monitoring data.** Establishing frequent collaboration and communication between USFWS and NOAA NMFS through the Lalo THAC is essential. Post-implementation monitoring and evaluation is also called for.

**High Priority. Investigations and actions to maintain and/or enhance Terrestrial Habitat quality at Tern Island in the mid-term.** NOAA NMFS summer research teams who contribute to implementing short term mitigation efforts to combat entrapments on Tern Island are limited in the scope and complexity of work that can be done within their roles, given their access to larger equipment and training. To supplement the immediate response work field technicians conduct, establishing a mid-term maintenance plan for more technical entrapment mitigation efforts can be implemented to provide temporary entrapment solutions to buy more time while the research and planning is conducted to establish the long-term entrapment mitigation strategy at Tern Island and the surrounding sandy islets within Lalo. The occurrence of these activities may range from daily, weekly, or seasonally, depending on the access to the technical gear and trained personnel to conduct the work. These mid-term mitigation activities will be conducted within the next four years. Maintaining information flow between the responsible agencies will be imperative.

**High Priority. Investigations and actions to maintain and/or enhance Terrestrial Habitat quantity at Tern Island and elsewhere within Lalo over the long-term.** Historic observations and future projections of morphologic change at Lalo due to storms and rising sea levels suggest that terrestrial habitat could be greatly diminished over the next few decades. Interventions along the lines noted above, which includes repairs and/or modifications to existing and/or even new shore protection structures may have a role to play in ensuring habitat and, in turn, species viability over the near term. However, other interventions might be warranted over the long-term. These include various types of habitat engineering measures, such as sand re-nourishment or capture, deployed alone or in combination at Tern Island and elsewhere at Lalo. Ensuring that habitat engineering measures reduce the rate of wildlife entrapment while maintaining sand capture is of high priority. Identification of such measures would, as a precursor, require a deep understanding of the complex patterns and trends of circulation and sedimentation at Lalo. Attention would need to be given to potential adverse impacts on adjacent habitat (e.g., coral ecosystems). Ultimately, management measures such as artificial island building elsewhere in NWHI or the MHI may be required to preserve species. The scope and timing of such measures will be dictated in part by physical considerations such as an understanding of the timeframes over which sea level rise and erosion will fundamentally change the terrestrial habitat at Tern Island and elsewhere within Lalo such that it is no longer a viable habitat. Economic, social and cultural considerations will also need to be considered. **All of these considerations should be a part of a study commenced within the next year, that begins with development of understanding of the factors affecting morphologic change at Lalo through monitoring and modeling, then moves through a process of scenario development and alternatives analysis, and ends with identification of an adaptive management plan that includes details regarding design and implementation**. Monitoring the availability and shifts in emergent land is an incredibly important component of resilience planning. Utilizing effective metrics to track total islet areas annually, looking particularly at vegetative cover, ratio of hard ground structures (e.g. concrete) to natural sand and sediment, and island height will be crucial for long-term planning. Seabird nest locations by species are crucial to track, with an emphasis on shoreline nesting birds, as they will be the first species to abandon Lalo islands with continued emergent land loss. Remote storm monitoring is also crucial to prepare for future storm and inundation events at Lalo. Post implementation monitoring and evaluation is also called for. Implicit in the above is the suggestion that Tern Island should not be relied on as the sole terrestrial refuge. To minimize extinction risks attention needs to be given to identifying and establishing alternative refugia should Tern Island fall victim to foreseen or unforeseen circumstances. Pre and post implementation monitoring and evaluation is also called for.

3. **High Priority. Engage the Lalo Marine Habitat Advisory Committee for specialized and technical advice on terrestrial and island habitat components of developing a Lalo Resilience Strategy.** One likely focus for this working group is (pelagic and archipelagic) ecosystem modeling. As a precursor to exploring impacts due to changing conditions, attention needs to be given to better definition of the specific parameters and associated ranges that make the marine habitat viable (e.g., thresholds, tolerances). A better understanding of predator/prey relationships, as well as changes in circulation/stratification are also warranted.

   **The Lalo Marine Habitat Advisory Committee has provided preliminary recommended research, monitoring, and management actions to incorporate into a Lalo resilience action plan; all of which will need to be revisited in the action plan development workshops.** Modeling work could highlight key uncertainties that require additional data or could identify keystone species and potential tipping points that should be monitored. Assessing the potential for interventions may also be a focus for this working group. The full extent of damage by Hurricane Walaka in 2018 to coral reefs has not been fully characterized and should be evaluated by field surveys. Consideration should be given to the conduct of resilience assessments that include understanding of vulnerability and recovery potential of key habitats such as coral reefs. Understanding the physical variables (e.g., temperature, flow, etc.) and biological stressors (e.g., macroalgae) which are major drivers influencing resilience of specific habitats (e.g., forereef, backreef, and lagoonal) is needed. For reefs that have been recently damaged, a detailed assessment of the recovery potential may be warranted and should consider key variables such as: substrate suitability, larval coral and fish connectivity, temperature variability, wave intensity etc. In the case that natural recovery of such reefs is determined to be highly limited, then the need for active coral reef restoration should be evaluated and include feasibility assessments. Restoration strategies should consider resilient species assemblages that provide ecosystem services (e.g. create habitat complexity for other species). Ecosystem and hydrodynamic modeling could support such efforts.

   **Robust and sustained monitoring of physical, biological, and chemical conditions associated with marine and terrestrial habits at Lalo were identified as a priority to include in the development of a MMB Action Plan.** We can't manage what we don't measure, and what we measure needs to be meaningful. We need to be able to measure the impacts of conservation interventions to evaluate their success, as well as detect concerning patterns and trends related to risks. The precision and accuracy of these measures needs to be at a scale relevant to that of the interventions and risks. Additional sensors and platforms may be required, even if only temporarily. Considerable resources are required - trained staff, gear and supplies, and platforms for ship-based access to PMNM for field season research each year - for population assessment and monitoring interventions of the type considered here. **Drawing on ongoing data collection and management efforts among the co-managing agencies (see below), attention needs to be given to the considerable task of establishing a multi-faceted and lasting monitoring program.**

C) **Ensure continuity of existing projects (including marine debris removal) and programs and facilitate communication, coordination, and collaboration across multiple line offices.** A number of successful efforts have already been conducted or are under way. Research on the suitable nesting habitat and carrying capacity of green sea turtles serves as a case in point. This work is contributing valuable insights, uncovering what may prove to be the existential threat due to a rapidly changing climate- warming sand temperatures. Other on-going activities to be maintained include the ONMS and PIFSC's routine coral reef monitoring at several key locations at Lalo; and habitat assessments both in the field and from remote sensing data. Important information is not limited to that being collected by ONMS. NOS for example supports the collection of high-resolution topographic and bathymetric data essential to hydrodynamic modeling. NWS and NESDIS provide value observations of environmental conditions from in-situ and satellite-based observing systems. The Papahānaumokuākea Marine Debris Project (PMDP) have secured five years of funding to conduct annual debris removal operations in PMNM, with priority stops at Lalo to conduct crucial debris removal and opportunistic wildlife entrapment mitigation efforts annually. One goal of this document is in fact laying the groundwork for identifying how these various efforts can be targeted to the purposes herein of improving the condition of habitat and resilience of species at Lalo.

D) **Highest Priority and starting now. Make a more concerted effort to secure financial and technical resources necessary to preserve and ideally restore terrestrial and marine habitats at Lalo that are essential to the long-term viability of a suite of threatened and endangered species.** The comprehensive collaborative planning activities called for here will serve as foundation for establishing technical and financial resource needs. A process to support the implementation of the actions outlined in the action plan is critical. Thus, the planning activities also need to lay out a framework for capacity building that includes diverse funding mechanisms as well as funding sources. Opportunities may be found in existing programs and budgets in NOAA, USFWS, the State of Hawai'i, and the Office of Hawaiian Affairs to catalyze the development of a strategy. The recent efforts concerning observations and vulnerabilities of Lalo have initiated interest amongst these groups to conduct formal reviews complementary to what is called for here. Examples include:

- <u>Papahānaumokuākea Marine National Monument Management Plan Review</u>: PMNM will be initiating management planning for the entire monument in the near future. Management plans typically include management priorities and plans for 10-15-year timeframes and Lalo relevant material may be included in the management plan and the accompanying NEPA statement.
- <u>Office of National Marine Sanctuary Designation Process</u>: As part of the FY21 omnibus appropriations bill, NOAA has been directed to initiate a process to designate PMNM as a national marine sanctuary. The planning and designation process could include components relevant to Lalo.

- Habitat Blueprint Focus Area: The national NOAA Habitat Blueprint Initiative builds on existing programs, prioritizes activities, and guides future actions to collaboratively protect and restore habitat across NOAA line offices. Lalo is under consideration for nomination as a potential Habitat Focus Area (HFA). If designated, resources to support collaborative planning and habitat improvements may be more readily available.

Each partner has various resources and access to varying funding sources including line office program funds, external and internal federal funding opportunities, and NGOs (e.g., friends groups and foundations). In this regard, ONMS & the National Fish and Wildlife Foundation (NFWF) currently have some funding available to jump-start the development of a resilience strategy. Initiatives such as Mission: Iconic Reefs in Florida have been able to leverage private and charitable funding sources and mechanisms. **An important conclusion as a result of this work is that securing funds necessary to commence an investigation of circulation and sedimentation patterns and trends in Lalo through one or a combination of these mechanisms should be very high on the list of priority actions.**

*Table 5. Summary of critical components needed to develop a MMB Action Plan, their priority and timing. Red denotes activities of high priority. See text for further detail.*

| Critical Components for MMB Action Plan Development | NOW | 6 Months | 12 Months | 18 Months and Beyond |
|---|---|---|---|---|
| **A) Engaging Co-Trustees and Stakeholders** | | | | |
| 1. Partners/Stakeholders agree on next steps and formulate overall resilience strategy | X | X | X | X |
| 2. Hold webinars to include Nat'l and Int'l participation with a focus on exploration of successful management measures used elsewhere | X | X | | |
| 3. Convene large adaptations workshop to include Nat'l and Int'l participation with a focus on developing a comprehensive MMB Action Plan | | | X | |
| **B) Engaging Working Groups** | | | | |
| 1) Lalo MMB Working Group provides management advice, direction and support toward relevant initiatives in addition to supporting Lalo components in management planning | X | X | X | X |
| 2) Terrestrial Habitat Advisory Committee provides specialized and technical advice on terrestrial and island habitat components of developing Lalo Resilience | X | X | X | X |
| 3) Marine Habitat Advisory Committee provides specialized and technical advice on nearshore reef and pelagic habitat components of developing Lalo Resilience | X | X | X | X |
| **C) Ensuring Continuity of Projects and Programs** | X | X | X | X |
| **D) Securing Financial and Technical Resources** | X | X | X | X |

**The outcomes of the 2023 Lalo Adaptations Workshop, previous work (e.g. Lalo special sessions, Lalo webinar series, white papers), and subsequent robust and sustained dialog with the managing partners would form the basis for development of a formal research, monitoring, and management action plan intended to maintain and strengthen ecosystems and ecosystem services at Lalo over the coming decades. Ultimately, such a plan would be endorsed and implemented by the MMB.**

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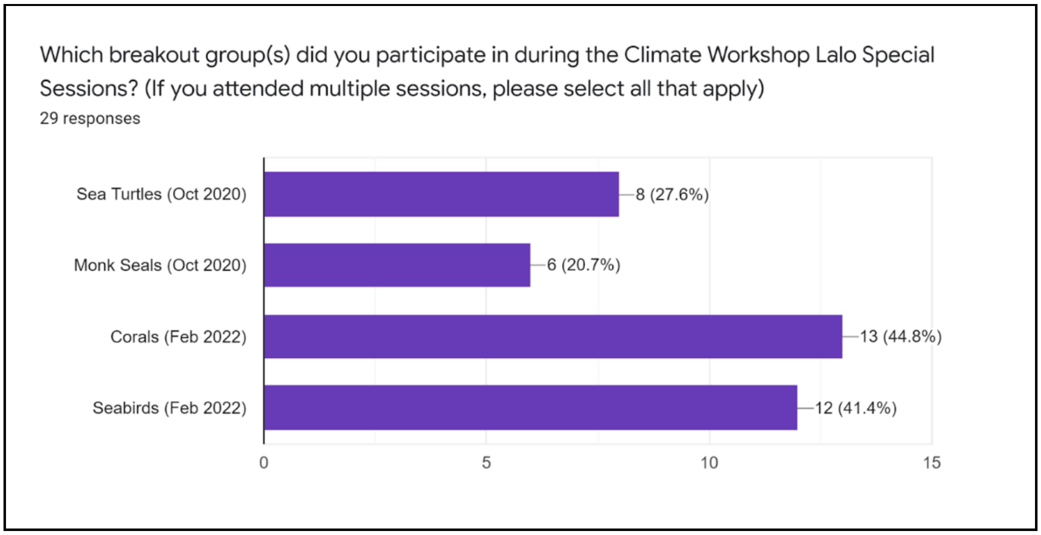
## Appendix



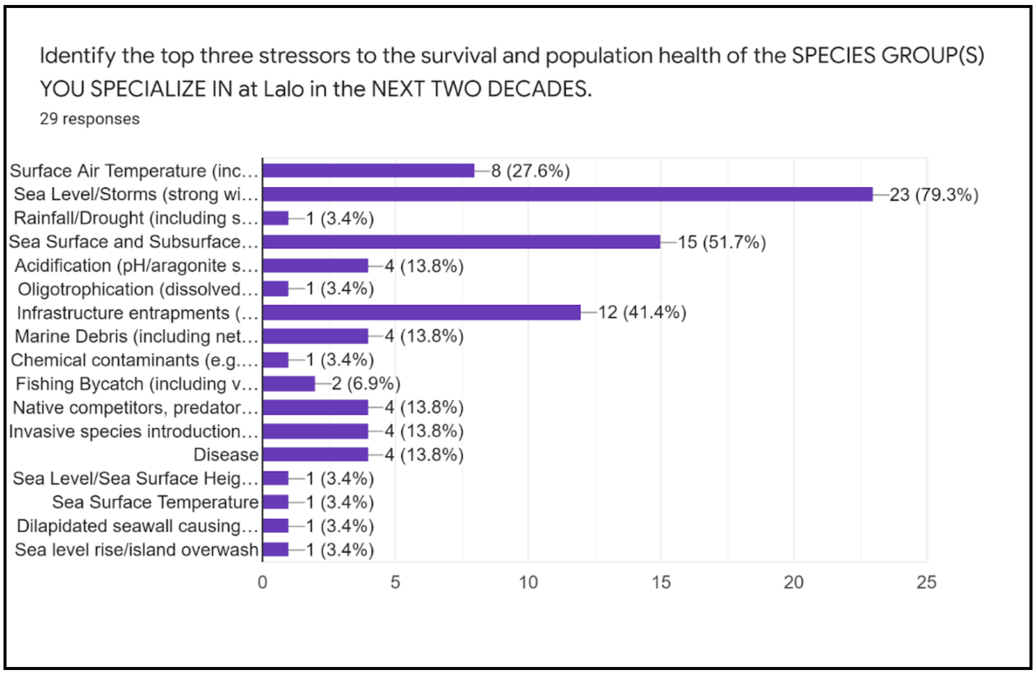




*Figure 9. Top three stressors to the survival and population health of the key wildlife species at Lalo, identified by Lalo special session attendees.*

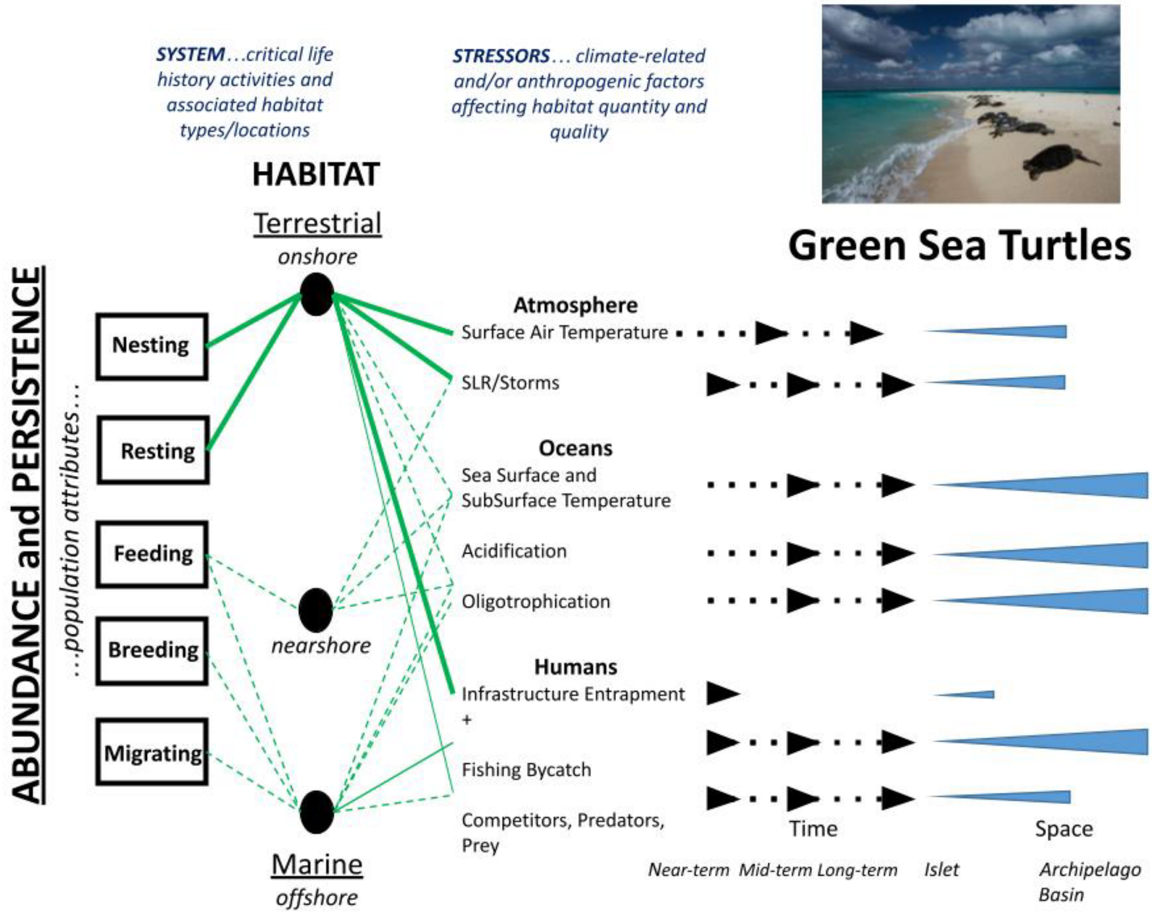



*Figure 10. System and stressor elements associated with Hawaiian green sea turtles at Lalo outlined using the system/stressor assessment framework.*

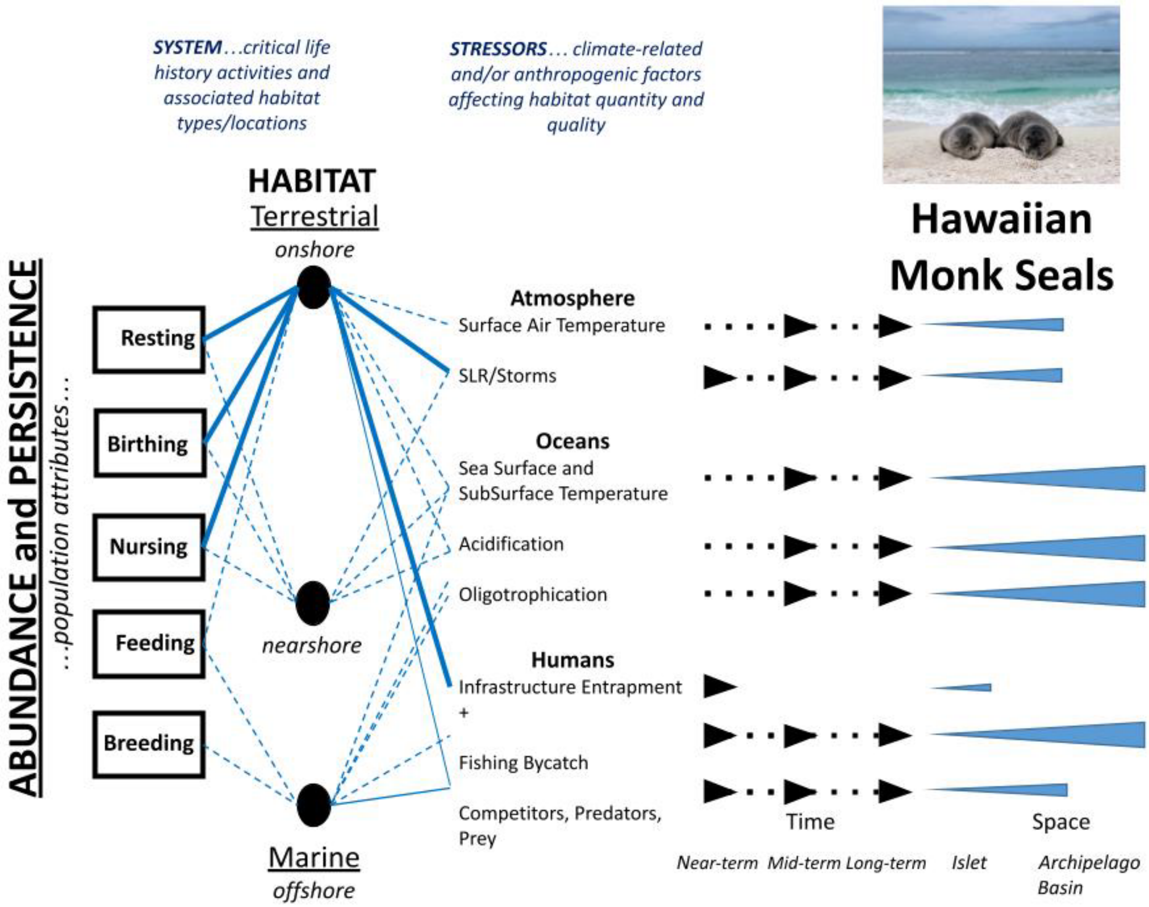



*Figure 11. System and stressor elements associated with Hawaiian monk seals at Lalo outlined using the system/stressor assessment framework.*

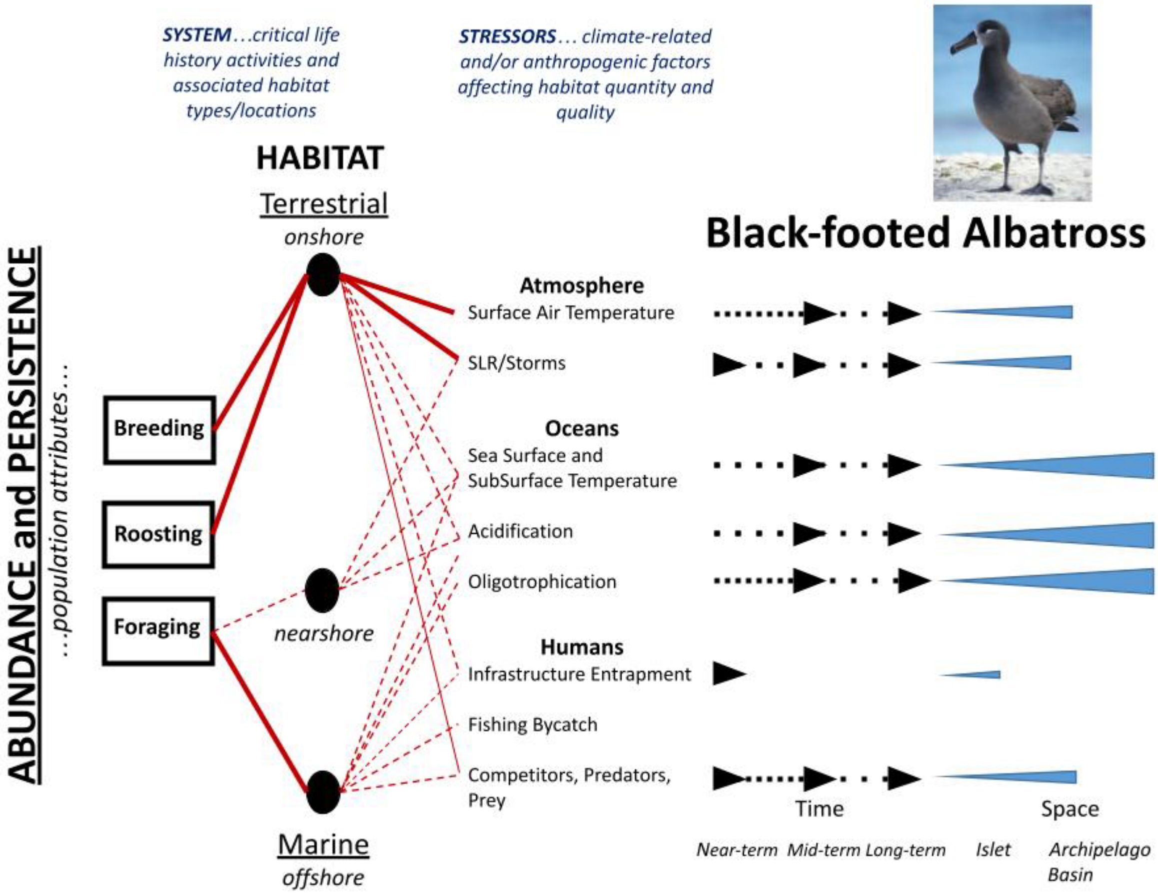



*Figure 12. System and stressor elements associated with Black-footed Albatross at Lalo outlined using the system/stressor assessment framework.*

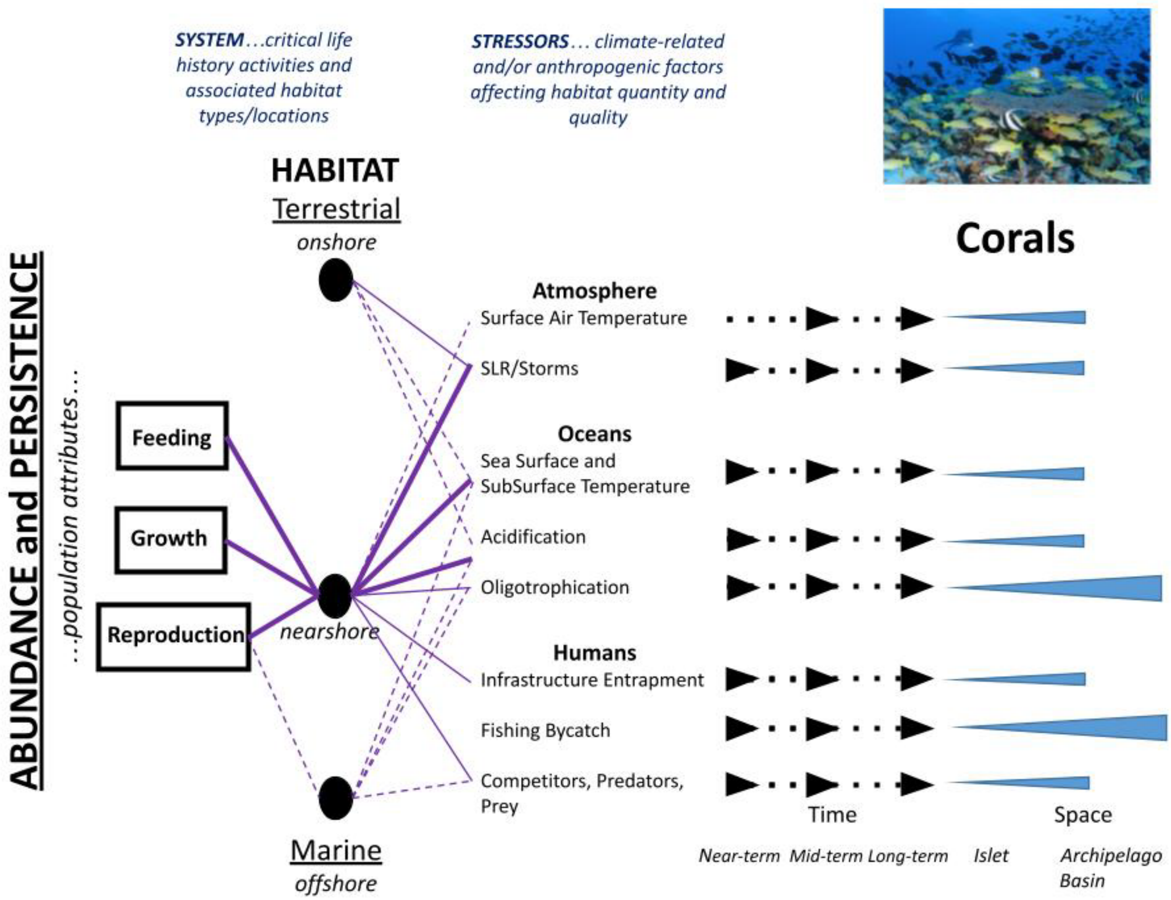



*Figure 13. System and stressor elements associated with corals and coral ecosystems at Lalo outlined using the system/stressor assessment framework.*