Lalo (French Frigate Shoals) Resilience
Implementation Options Report

Aerial view of Lalo (French Frigate Shoals) with Tern Island on the right-hand side. Credit: Papahānaumokuākea Marine Debris Project

Report to the Papahānaumokuākea Marine National Monument Management Board

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1. Introduction

The Lalo Resilience planning process was initiated by the Papahānaumokuākea Marine National Monument (PMNM or Monument) co-managers: the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (FWS), the State of Hawaiʻi Department of Land and Natural Resources (DLNR), and the Office of Hawaiian Affairs (OHA), collectively referred to as the Monument Management Board (MMB) in January 2020 (Figure 1). The MMB established a Lalo Resilience Working Group and tasked this group to (1) create assessment of the existing state of knowledge, research, and management within the terrestrial and marine areas of Lalo (referred to as the "state of the knowledge report") and (2) develop a suite of management actions that could be implemented to enhance the resilience of Lalo (referred to as the "implementation options report"). The state of the knowledge report was submitted to the MMB in 2023 and the Lalo implementations options report is presented below. The MMB can then use this information to develop a shared vision for the resilience of Lalo and decide on the implementation strategies to meet that vision.

Recommended actions outlined below were developed during the March 2023 Lalo Adaptations Workshop, which brought together subject matter experts spanning numerous disciplines including climate science, wildlife biology, Native Hawaiian cultural practice, and coastal engineering. This group was convened to assess the current state of knowledge and identify the scope, timing, and priority of potential actions related to management, research, and monitoring processes needed to protect and maintain healthy ecosystems and ecosystem services within Lalo in the coming decades. The Lalo Adaptations Workshop and its outcomes are the culmination of a larger Lalo Resilience Strategy process based on the recognition that: 1) 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; and 2) efforts to better understand risks and identify mitigation actions at Lalo that optimize abundance and persistence of Hawaiian monk seals, Hawaiian green sea turtles, seabirds, corals and more broadly the overarching system of habitats these species rely on, must be undertaken with urgency.

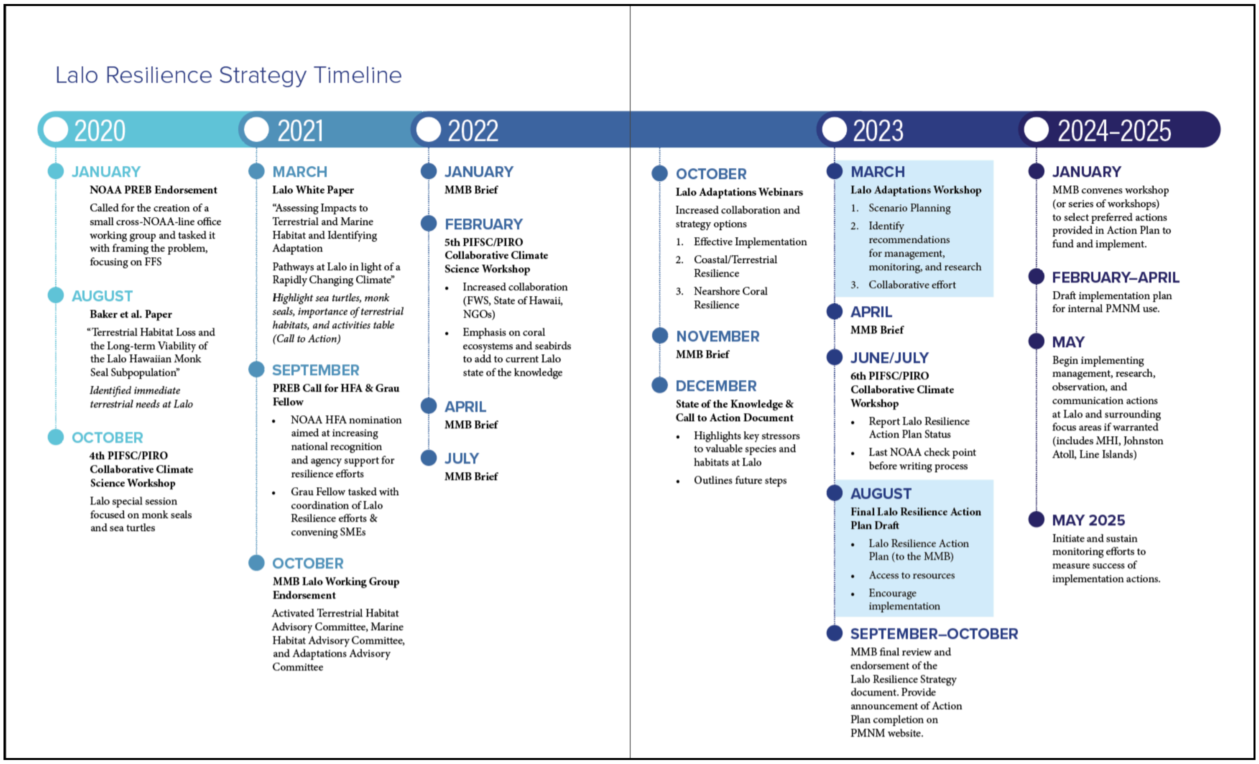

Figure 1: Lalo Resilience Strategy Timeline

2. Proposed Management Measures to Maintain and Enhance Habitat Quality and Quantity

Input from subject matter experts at the Lalo Adaptations Workshop resulted in recommendations for priority actions to ensure long-term persistence of Hawaiian green sea turtles, Hawaiian monk seals, seabirds, marine invertebrates (including corals) as well as the marine and terrestrial habitat. These recommendations are organized into six priority action categories (these appear in dark blue within Table 1) and are (1) habitat Improvements, (2) conservation interventions, (3) observations and monitoring, (4) research, (5) observational tools and (6) communications.

Actions within these categories are assigned rankings for level of urgency, impact, urgency, and overall cost. Urgency ranking included High, Moderate, and Low options based upon how relevant the proposed action is to meeting the short term (now-2030) Lalo Resilience Plan goal of reducing adverse impacts to habitat and species at Lalo as a way to ensure critical species abundance and persistence. Impact ranking also included High, Moderate, and Low options. Individual rankings for impact took into consideration the direct and indirect benefit of action implementation to meeting the short term (now-2030) Lalo Resilience Plan goal of reducing adverse impacts to habitat and species at Lalo as a way to ensure critical species abundance and persistence. Cost ranking was assigned on a range from $ to $$$, where the associated number of dollar signs indicates how expensive implementing and sustaining a specific action would be. Costly actions received multiple dollar signs while relatively inexpensive actions received a single dollar sign. Cumulative ratings for priority actions included High, Medium, and Low options, and considered a combination of the associated urgency, impact, and cost. High impact and urgency contributed to a higher cumulative rating, while higher cost actions had an inverse impact on cumulative ratings; where high cumulative ratings exhibited preference for lower cost actions.

Table 1. Priority action options (light blue) identified by subject matter experts during the Lalo Adaptations Workshop are organized by overarching categories (dark blue), which include: 1) Habitat Improvements; 2) Conservation Interventions; 3) Observations and Monitoring; 4) Research; 5) Observation Tools; and 6) Communications. Preliminary timelines for the implementation of each individual action recommendations are included, with available time scale of 2024-2050. Some or all of the implementation steps associated with actions have the potential to extend beyond 2050. Bulleted rows indicate specific sub actions that could happen simultaneously or independent of each other to address the associated priority action. Blank spaces in the timeline column are meant to be used by the MMB to make a determination of select actions to fund, and develop case-by-case determinations of anticipated timeline ranges to initiate, implement, and monitor the action(s). MMP Activity Numbers are derived from the 2008 Papahānaumokuākea Marine National Monument Plan.

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
Habitat Improvements						
Contaminants Removal	**High**	**Robust**	**$$$**	**Medium**	**2024-2040**	
➢ *Prioritize removal locations on Tern Island and transport mechanisms to move contaminants and sediment back to MHI for dumping*						*HMC-1.3* *HMC 2.1*
➢ *Encase remaining contaminants in concrete at Tern Island*						*HMC-1.3* *HMC 2.1*
➢ *Use of in-situ or ex-situ bioremediation techniques to reduce/remove contaminants*						*HMC-1.3* *HMC 2.1*
Infrastructure Modification (Improvements & Removal)	**High**	**Robust**	**$$$**	**High**	**2024-2037**	
➢ *Remove derelict infrastructure (barracks and outbuildings)*						*CFO-3.6* *HMC-3.2*
➢ *Improve boat ramp and davit*						*CFO-3.6*
➢ *Establish a more permanent field research shelter*						*CFO-3.6*
➢ *Break up Tern Island runway to enhance available outplanting area, nesting habitat for burrowing seabirds, and increase above-ground suitable nesting habitat*						*HMC-1.3* *MB-1.2*
➢ *Develop implementation plan for the removal and replacement of existing seawalls*						*CFO-3.6* *TES-1.3* *TES-3.2*
Habitat Stabilization	**High**	**Robust**	**$$$**	**High**	**2024-2050**	
➢ *Identify suitable plant species to outplant and supplement sand accretion and retention on Tern Island.*						*HMC-1.3* *MB-1.2*

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Install a shade house and water catchment system to facilitate germinate and sustain plant establishment*						*HMC-1.3 MB-1.2*
➢ *Strategic outplanting on Tern and East Island*						*HMC-1.3 MB-1.2*
➢ *Invasive plant species removal*						*AS-1.2 AS-6.2 MB-1.1*
Improve and Maintain Biosecurity Measures & Best Management Practices	**High**	**Robust**	**$**	**High**	**2024-2050**	
➢ *Evaluate efficacy of existing biosecurity measures and BMPs on a consistent time interval*						*AS-1.2*
➢ *Develop new biosecurity measures and BMPs as needed*						*AS-1.2*
➢ *Effectively enforce biosecurity measures and BMPs relevant to permitted activities within PMNM*						*AS-3.1, AS-3.2, EN-2.4*
Conservation Interventions						
Continue Field Research Efforts	**High**	**Robust**	**$$**	**High**	**2024-2050**	
➢ *Sustain activities conducted under the NOAA NMFS Hawaiian Monk Seal Recovery Plan*						*CFO-2.1 CFO-9.3 TES-1.1 TES-1.3*
➢ *Sustain activities conducted under the NOAA NMFS Marine Turtle Biology and Assessment Program*						*CFO-2.1 CFO-9.3 TES-3.2 TES-3.3*
➢ *Sustain FWS field research activities on Tern Island*						*CFO-2.1 CFO-2.4*
➢ *Support co-manager partner activities (e.g. Papahānaumokuākea Marine Debris Project (PMDP))*						*MD-1.1, MD-2.1, MD-3.1 CFO-2.1 TES-1.1*
Expand Interdisciplinary Field Research Deployments	**High**	**Robust**	**$$$**	**High**	**2024-2050**	
➢ *Increase Native Hawaiian involvement in field research, data collection, and site visit opportunities at Lalo*						*CFO-2.1 CFO-2.4, NHCH-2.3, NHCH-3.4*
➢ *Extend summer field research seasons and bolster monitoring efforts*						*CFO-2.1*

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
						CFO-2.4, CFO-9.3
Sustain Hawaiian Monk Seal and Seabird Translocations or Conservation Introductions	**Moderate**	**Moderate**	**$$**	**High**	**2024-2050**	
➢ *Support Pacific Rim Conservation collaboration with FWS to carry out translocation and conservation introduction efforts for Tern Island (No Net Loss Initiative)*						CFO-2.1
➢ *Move seabird chicks from Tern Island to new predator-free habitat such as O‘ahu‘s James Campbell National Wildlife Refuge*						CFO-2.1
➢ *Support NOAA NMFS Hawaiian Monk Seal Recovery Plan to move Hawaiian monk seal mother and pup pairs from smaller islets experiencing male Hawaiian monk seal aggression or shark predation to Tern Island, where Galapagos shark predation is not observed*						CFO-2.1 TES-1.6
Initiate Novel Conservation Techniques to Support Hawaiian Green Sea Turtle Recovery	**High**	**Robust**	**$$$**	**High**	**2025-2050**	
➢ *Identify suitable beaches within the Hawaiian Archipelago to support and enhance nesting activity*						*TES-3.2*
➢ *Initiate methodology to bolster population resilience*						*CFO-2.1*
➢ *Initiate movement of Hawaiian green sea turtle eggs from Lalo to other suitable beaches identified within the Hawaiian Archipelago*						*CFO-2.1*
➢ *Initiate captive breeding program using sexually mature male and female Hawaiian green sea turtles that have been previously observed at Lalo*						*CFO-2.1*
Initiate and Sustain Coral Restoration Nurseries	**Moderate**	**Moderate**	**$$$**	**Medium**	**2027-2050**	
➢ *Identify suitable locations for a coral restoration nursery facility with adequate infrastructure*						*HMC-1.3*
➢ *Identify desired coral species and specific resilient coral reef “bright spots” that are more resilient to climate change impacts for surveys and collections*						*HMC-1.1*
➢ *Develop a nursery biosecurity and operations plan*						*HMC-1.3*
➢ *Determine Lalo coral outplanting and monitoring protocols.*						CFO-2.2
Response and Scenario Planning	**High**	**Robust**	**$**	**High**	**2024-2030**	

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Improve existing response protocols for navigation aids, ship grounding response, and coral bleaching*						*ERDA-2.1 ERDA-2.2 ERDA-2.3 ERDA-3.1 ERDA-3.2*
➢ *Develop response and scenario planning for the following: 1) catastrophic storm events; 2) invasive species introductions and outbreaks (e.g. stony coral tissue loss disease, Unomia spp., Carijoa riisei, Acanthophora spicifera, Chondria tumulosa, Crown of Thorns, etc.); and 3) Coral Rubble Stabilization*						*ERDA-2.1 ERDA-2.2 ERDA-2.3 ERDA-3.1 ERDA-3.2*
Artificial Habitat Structure	**Moderate**	**Moderate**	**$$$**	**Medium**	**2027-2050**	
➢ *Install artificial above-ground roosting structure in the newly available substrate on the runway area for tree and bush nesters*						*HMC-1.3*
➢ *Introduce artificial (non-living) reef structure within select pockets of existing reef*						*HMC-1.3*
➢ *Install floating haul-out platforms anchored nearshore for Hawaiian monk seal resting and coral reef shading*						*HMC-1.3*
Island and Coastline Nourishment	**Moderate**	**Moderate**	**$$$**	**Medium**	**2027-2050**	
➢ *Identify local sources of sand/sediment within Lalo atoll to dredge and use for nourishment efforts*						*HMC-1.1 HMC-3.1*
➢ *Conduct sand renourishment using locally-sourced sand (within Lalo atoll), at Tern Island, East Islands, and the smaller islets within Lalo*						*HMC-1.3 HMC-3.1*
Observations and Monitoring*						
Climate and Atmosphere	**High**	**Robust**	**$$**	**High**	**2024-2050**	
➢ *Climate and ecosystem impacts of El Niño Southern Oscillation (ENSO) occurrence and shift to the warm phase of the Pacific Decadal Oscillation (PDO)*						*MCS-2.4*
➢ *Track broad climatic and atmospheric changes and impacts across the Pacific over time*						*MCS-2.4*
Habitat and Species Conditions	**High**	**Robust**	**$$**	**High**	**2024-2050**	
➢ *Support the continuation of PMNM Reef Assessment and Monitoring Program (RAMP) activities, including rapid ecological assessments (REA), coral disease surveys, bioerosion studies, and ecological acoustics research*						*MCS-1.2 MCS-1.4 MCS-2.4*
Research*						
Hydrodynamics and Morphodynamics	**High**	**Robust**	**$$**	**High**	**2024-2026**	

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Understand patterns and trends of circulation and sedimentation at Lalo*						*HMC-3.1 HMC-3.2 MCS-1.1 MCS-2.4*
➢ *Assess damage and recovery potential of coral reefs and terrestrial habitat that have been recently damaged*						*HMC-1.1 MCS-1.1 MCS-2.4*
➢ *Track total land area annually, particularly vegetative cover, ratio of hard ground structures (e.g. concrete) to natural sand and sediment, and island height*						*HMC-3.1 MCS-2.4*
➢ *Identify and establish alternative refugia within and outside of Lalo for key species which utilize Lalo*						*MCS-2.4*
➢ *Understand rates of net coastal and reef crest accretion and erosion, accounting for storms and seasonal variability*						*HMC-3.1 MCS-2.4*
➢ *High-resolution bathymetry and substrate mapping*						*MCS-1.3 MCS-2.4*
Habitat Improvement Alternatives Analysis	**High**	**Robust**	**$**	**High**	**2024-2030**	
➢ *Analyze the efficacy and challenges of current engineered headland designs worldwide to inform feasible options to best suit the dynamic ocean and sediment patterns found at Lalo*						*CFO-1.4 TES-1.3 TES-3.2 TES-3.3*
Habitat Suitability, Carrying Capacity & Vulnerability Thresholds	**High**	**Robust**	**$$**	**High**	**2024-2050**	
➢ *Impacts of sea level rise on nesting sites and rising sand temperature on Hawaiian green sea turtle hatchling success and sex ratios*						TES-3.1 TES-3.2 MCS-2.4
➢ *Presence, success, and locations of Hawaiian green sea turtle nesting sites throughout Lalo*						TES-3.1 MCS-2.4
➢ *Frequency and locations of shark-induced Hawaiian monk seal deaths*						TES-1.2 TES-1.6 MCS-2.4
➢ *Impact of male Hawaiian monk seal aggression on seal pup survival rates*						TES-1.2 MCS-2.4
➢ *Assess annual seabird populations on Tern Island (breeding potential and success, disease prevalence, number of active nests, number of individuals fledging, locations of nests, and the number of seabird entrapments (proportion of dead to rescued))*						MB-2.1 MB-3.1 MB-3.2 MCS-2.4
➢ *Identify annual seabird nest locations by species and season*						*MCS-2.4*

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Impacts of sea level rise and island overwash on winter-breeding seabirds (and other vulnerability indicator species)*						MB-3.1 MB-3.2 MCS-2.4
➢ *Understand the relation between frequency and duration of episodic flooding and inundation events at Tern Island and outer islets, sea surface height, ambient air temperature, and presence of introduced predators*						MCS-2.4
➢ *Determine source and movement patterns of coral recruits and components of successful recruitment with a focus on Southern area of Lalo (high coral recruitment)*						MCS-2.4
➢ *Understand ecological connections between seabirds and surrounding coral reef ecosystem*						MB-3.1 MB-3.2 MCS-2.4
➢ *Impacts of contaminant exposure on both terrestrial and marine wildlife*						MB-2.2 MB-3.1 MB-3.2 MCS-2.4
Ecosystem Characterization and Modeling	**High**	**Robust**	**$$$**	**High**	**2024-2035**	
➢ *Conduct pelagic and archipelagic ecosystem modeling, and provide better definition of the specific parameters and associated ranges that make marine habitat viable (e.g., thresholds, tolerances)*						*MCS-1.3* *MCS-2.4*
➢ *Determine the ecological and oceanographic factors driving regional, island, or site-specific genetic structure of corals and other marine species with larval stages*						*MCS-1.1* *MCS-1.2* *MCS-1.3* *MCS-2.4*
➢ *Develop new quantitative method for multispecies studies of connectivity among many locations*						*MCS-1.5* *MCS-2.4*
➢ *Determine the threshold for initiating active coral reef restoration and supplementation*						*MCS-1.1* *MCS-1.2* *MCS-2.4*
➢ *Understand rates of net coastal and reef crest accretion and erosion, accounting for storm and seasonal availability*						*HMC-3.1* *MCS-2.4*
➢ *Explore Native Hawaiian ethnography, oral histories, chants, and written articles to inform wildlife habitat use and other activities of daily living*						*NHCH-1.2* *NHCH-2.1* *NHCH-3.4*
Intra- and Inter-Species Interactions	**Moderate**	**Moderate**	**$**	**High**	**2024-2050**	
➢ *Understand Hawaiian green sea turtle nesting competition and nesting area requirements*						*TES-3.1* *MCS-2.4*
➢ *Understand inter-species competition for terrestrial space and habitat use*						*TES-3.1* *MCS-2.4*

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Evaluate effectiveness of mitigation options for land-based inter- and intra- species competition*						*MCS-2.4*
Islet Persistence	**High**	**Robust**	**$**	**High**	**2024-2035**	
➢ *Evaluate the viability, resilience, and capacity of the islands and islets within Lalo to provide long-term terrestrial habitat for resting and nesting habitat*						*HMC-3.1* *HMC-3.2* *MCS-2.4*
Observational Tools						
Remote Sensing	**High**	**Robust**	**$$**	**High**	**2025-2035**	
➢ *Island and coastal mapping to monitor shoreline changes, track sediment transport, and map coastal features*						*HMC-3.2* *MCS-1.1* *MCS-2.4*
➢ *Marine mapping to monitor ocean circulation and current systems, measure ocean temperature and wave heights, and detect coral bleaching using multispectral satellite imagery*						*MCS-2.4*
Remote Cameras	**Moderate**	**Robust**	**$$**	**High**	**2025-2035**	
➢ *Install automated stationary cameras on Tern Island and the other small islets within Lalo to capture year-round biological, terrestrial, and nearshore marine ecosystem data*						*TES-3.1* *MCS-2.4*
➢ *Collect terrestrial ecosystem and biological data using cameras on autonomous vehicles that are solar powered and can self-deploy and recharge*						*MCS-2.4*
Smart Buoys	**Moderate**	**Moderate**	**$$$**	**High**	**2025-2035**	
➢ *Identify strategic locations to deploy smart buoys and secure buoys to the seafloor with applicable sensors to collect a range of meteorologic, physical, hydrologic, chemical, biological, optical, and acoustic measurements*						*MCS-2.4*
Tern Island Weather Station	**Low**	**Moderate**	**$**	**Medium**	**2024-2030**	
➢ *Install weather station to collect real-time data throughout the year and provide insight into weather conditions (including wind speed, ambient air temperature, humidity, barometric pressure, rainfall, and UV or solar radiation) when temporary field researchers are not present at Lalo.*						*MCS-2.4*
➢ *Identify additional islands/islets to install a weather station(s)*						*MCS-2.4*
Communications						
Inreach	**High**	**Robust**	**$$**	**High**	**2025-2050**	

Recommended Action	Urgency	Impact	Cost	Cumulative Rating for Action Priority	Timeline	MMP Activity Number
➢ *Ensure interagency collaboration, engagement, and coordination for management and research efforts at Tern Island and other sites within Lalo*						*AC-1.1 AC-2.2 AC 2.3 AC-2.4 NHCH-3.3 CFO-2.1*
➢ *Ensure the Lalo Working Group tasked with overseeing the Lalo Resilience Strategy is consistently co-developing the content of the Lalo Resilience Strategy to meet the goals and needs of the different federal and state agency co-managers*						*AC-1.1 AC-2.2 AC 2.3 AC-2.4 NHCH-3.3*
Upreach	**High**	**Robust**	**$$**	**High**	**2025-2050**	
➢ *Ensure internal engagement focused on broader components of establishing resilience at Lalo (congressional engagement, establishing Lalo as a NOAA Habitat Focus Area, and garnering leadership buy-in to management and research decisions)*						*AC-3.1 AC-3.2*
➢ *Ensure funding, support, and traction for the Lalo Resilience Plan is maintained*						*AC-2.3*
Outreach	**High**	**Robust**	**$$**	**High**	**2025-2050**	
➢ *Maintain external communication between co-managing agencies and members of the public, including external collaborators, community members, and resource users.*						*AS-9.1 AS-9.2 CBO-1.1 CBO-1.3 NHCH-5.1 NHCH-5.2 NHCH-5.3*
➢ *Increase public education and awareness through newsletters, listening sessions, and other engagement opportunities*						*NHCH-5.1 NHCH-5.2 NHCH-5.3 CBO-1.4 CBO-1.5 MCS-3.4 TES-1.5*
➢ *Encourage open communication with Native Hawaiians about ways that Hawaiian culture can be more seamlessly integrated into the conservation, research, and reconnection occurring within PMNM*						*AC-2.1 CBO-3.6 NHCH-1.1 NHCH-1.2 NHCH-2.2 NHCH-3.2 NHCH-3.4 NHCI-2.1 NHCI-3.1 NHCI-3.2*

Dynamic Adaptation Pathways

Priority action items included in Table 1 and discussed above may be incorporated into a Dynamic Adaptive Policy Pathways (DAPP) framework (Figure A2). This framework shows sets of priority actions, the timeline over which they would occur (start and end), the relationships between them (dependencies and/or transitions), and decision points to establish an overall picture of how a complete set of resilience-related actions could play out in the coming decades.

The focus is on key actions to be initiated and implemented in the near term (by 2030). Some of these actions continue through and are completed over the mid-term (2030-2050), while others continue over the long term (2050-2070) depending partly on their success and partly on timing and severity of impacts. The latter will depend heavily on the net greenhouse gas emissions associated with the global pathway of human development. Specifically, dual timelines based on climate driven scenarios are in place to identify whether continued actions at Lalo are warranted beyond 2060 (Appendix B).

Under a less intense climate scenario, adverse climatic impacts reach a high level after mid-century (2050). Impacts peak, stabilize, then slowly decline. Under a severe climate scenario, adverse impacts reach a high level by mid-century and then continue to climb even higher. Although two alternative scenarios are in place, a single preferred pathway is in place under both scenarios until the year 2060 where the continuation of actions is dependent on the trajectory of greenhouse gas emissions (and global average air surface temperatures, rainfall, sea surface temperatures, sea level) play out (Figure B1). If greenhouse gas emissions begin to stabilize around mid-century, actions have the potential to continue. If greenhouse gas emissions continue to climb beyond mid-century, it may not be feasible to continue some actions. Decision points are critical to determine if the MMB should continue, or even enter, the preferred pathway.

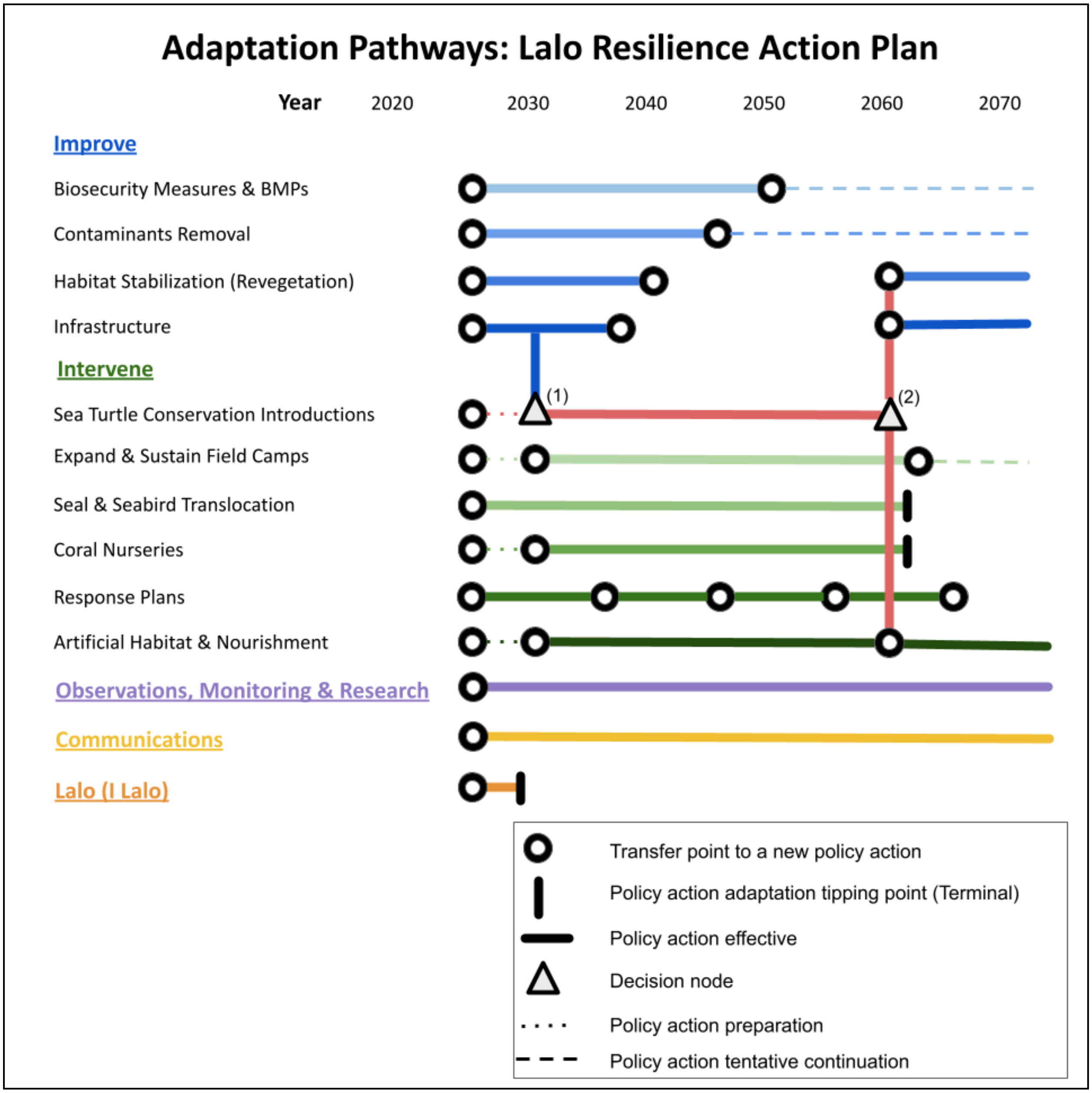

Figure 2. Potential adaptation pathways outlining policy actions that could be taken between 2025 and 2070. Actions are classified as either habitat and infrastructure improvements, new or existing conservation interventions, observations, monitoring, and research, observation tools, communications, or no action. (1) Associated connected actions are dependent on the decision to initiate Hawaiian green sea turtle translocation efforts by 2030; (2) Actions connected to this decision point are dependent on global climate, where continued action is contingent upon less intense projected climate scenario conditions and available terrestrial habitat present.

3. Cultural Context and Lalo I Lalo Option

The cultural and ecological significance of Papahānaumokuākea 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. 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 after death.

Lalo is an important geological transition point in the archipelago, where high volcanic islands shift to low diminished coral atolls. It also marks the first island that is “leeward” from Mokumanamana (Necker), an important spiritual transition point into the afterlife. It is said that on this low, flat sand island, Pele (a prominent Hawaiian deity) left one of her brothers, Kānemilohaʻi, as a guardian during her first journey to Hawaiʻi from Tahiti.

Lalo is recorded under multiple names. Lalo, a locative noun, meaning “down, downward, low, lower, under, below, west, leeward” (Pukui & Elbert, 1986, p. 192) or the direction of being westward or southernly (Handy, 1927, p. 70), was also known as Lalo-iho (Lower Lalo), Lalo-a’e (Upper Lalo), Lalo-hele (Continuous Lalo), Lalo-kona (Leeward or Southern Lalo), and Lalo-ho’āniani (Reflective Lalo) (Kikiloi, 2010). Lalo has a layered meaning of being closely associated with the direction of pō (darkness and obscurity) or ancestral lands “where dwelt the souls of gods” (Handy, 1927, p. 709).

During the Lalo Adaptations Workshop in March 2023, participating ʻōiwi (Native Hawaiian) cultural practitioners reinforced the continued importance of Lalo to Hawaiian communities both historically and in the present day. Insights from cultural subject matter expert groups included linking the “feminization” of honu (Hawaiian green sea turtle) populations at Lalo (associated to Hawaiian green sea turtle sex ratios skewing female as a result of increased ambient nest temperatures at Lalo) mentioned by sea turtle researchers, to multiple Native Hawaiian oral history accounts of such “feminization”. The climate stressors influencing the movement and home ranges of honu are speculated to be a repeating climatic and ecological cycle of climate-induced, cross-Pacific exoduses of wildlife and people previously documented in Hawaiian oral histories through the stories of Haumea (patron of childbirth and fertility) (Kikiloi, 2010). Applying this indigenous lens to the “feminization” mentioned by researchers is relevant as this could indicate a precursor of more drastic impacts to follow, and informs future management decisions to be taken at Lalo. These cultural experts view climate impacts at Lalo as an opportunity to apply traditional observational methods to record the changes in Lalo’s natural environment as they happen and accurately catalog data to inform future generations of Native Hawaiians, serving as a new present day account of recurring patterns observed and cataloged through indigenous knowledge systems and processes. Integrated (traditional and western) physical science observations emphasize the importance of preparing the new homes or environments for species who may be driven to new habitats outside of Lalo, in places like the southeastern Hawaiian islands. Incorporating these principles into the Lalo Resilience Plan ensures Hawaiian monk seals, honu, and other species will have alternative host habitat as they, and Lalo, respond to climate change impacts.

Additionally, cultural advisors expressed reservations about the cultural and ecological impacts associated with the potential installation of coastal engineering structures at Tern Island, including T and L groins. If replacement of the existing seawall at Tern Island was selected as a conservation intervention action to implement, comprehensive consultation with Native Hawaiian cultural groups is imperative to inform the potential cultural and ecological implications associated with this action.

ʻŌiwi culture emphasizes the connections between place and community. Although most people will never see Lalo in-person, Lalo serves as a window into the resources that were once prevalent across the Hawaiian Island chain. Through effective resource management at Lalo, practitioners may bring physical materials back (e.g. seabird feathers and bones) to continue cultural practices, craft implements, and initiate conversations with the next generation of local and Hawaiian students about the significance of cultural resources, practices, and cultural revitalization. Maintaining the connections between resources and resource users inherently strengthens individual and collective investment to mālama (care for) a far off place like Lalo ensuring that these practices and ways of knowledge can continue for future generations. Although an imminent climatic threat to Lalo highlights that resources collected from kūpuna islands by cultural practitioners may one day no longer be available, it also presents an exciting challenge for ʻōiwi to explore and discover how future generations of ʻōiwi will maintain pilina (connection) with Lalo into the future.

Hawaiian culture is dynamic, and the inherent pilina (connection) between kānaka ʻōiwi (Native Hawaiians) and Lalo extends beyond the physical presence of a group of sandy islets. Instead, the connection is primarily to a strong sense of cultural identity linking people to their homeland. Resilience planning reflects the evolution of Lalo and the kuleana (responsibility) of kānaka ʻōiwi to support the deep and enduring sentiment of aloha ʻāina by structuring research and management through Hawaiian cultural processes (Office of Hawaiian Affairs et al., 2021). Aloha ʻāina, or love for the land, represents Native Hawaiians' most basic and fundamental expression of the Hawaiian experience, embodying the tangible and intangible values of ʻōiwi culture that have developed and evolved over generations (Kikiloi, 2010). As a result of these discussions, the indigenous viewpoint of allowing Lalo to "return to its origin", allowing it to slowly return below (i lalo) the ocean's surface, was identified as a viable or potential option for the MMB to consider. Establishing a threshold and set of expectations to adopt the i lalo Lalo approach becomes increasingly important as climate impacts exacerbate conditions at Lalo over time. If this approach, i lalo Lalo, were endorsed by the MMB, continued monitoring, research, and field-based activities would provide valuable information on population dynamics, land area fluctuation, and an array of other biological, climate, and ecosystem metrics.

4. Components for Successful Implementation

Communication

Nurturing communication, coordination, and collaboration among stakeholders, agencies, institutions and organizations with management responsibilities and those conducting research is key to the successful development and implementation of a communication plan. Throughout all three modes of communication mentioned above, common threads identified as integral measures to ensure effective communication include the use of place-based storytelling, sharing, and common messaging. Who and how we communicate our work will determine the effectiveness of the communication strategy.

Monitoring

Robust and sustained monitoring of physical, biological, chemical, and climate conditions associated with marine and terrestrial habitats at Lalo are a priority for bolstering resilience at Lalo. Conservation interventions need to be measurable to evaluate their success, while detecting patterns and trends related to risks. A robust and long-term monitoring program will draw upon ongoing data collection and management efforts among the co-managing agencies. Comprehensive, action-specific monitoring plans will be implemented by the Monument Management Board (MMB) to track the success of the adaptation options selected.

Huli ʻIa Observational Process

Huli ʻia is a Native Hawaiian observational process documenting seasonal changes and shifts across entire landscapes, from uka (uplands) to kai (ocean,) identifying dominant correlating cycles to support and guide management and best-practices in supporting a productive and thriving community, known as ʻāina momona. Although no permanent, year-round human community is established at Lalo, Huli ʻia can assist managers, researchers, and cultural resource users to understand and connect to the biotic and abiotic processes at Lalo. Huli ʻia can strengthen and support the pilina (connection) of researchers, managers, and visitors to Lalo through its incorporation into monitoring activities, providing consistent annual data collection during field seasons. The observational process can collect data such as:

- natural cycles and their correlation to observed phenomena such as (e.g. fish spawning, recruitment, and migration);
- plant flowering, seeding, and fruiting;
- presence and absence of natural resources such as whales, birds, limu (algae), etc.;
- weather and climate activity such as temperature shifts, cloud formations, windy seasons, rain/drought, etc.; and
- Celestial movement and characteristics such as colors during sunset and sunrise, star line presence, and sun movement.

Archipelago-Level Planning

Addressing the goal of preserving key marine and terrestrial habitat for valuable species at Lalo, cannot be conducted in a silo or as an independent ecosystem. Lalo, PMNM and the islands within this area provide essential connectivity pathways of biogeographic “stepping stones” for species to travel vast distances within the archipelago (Toonen et al., 2010). Some species have specific connectivity highways that do not extend outside of PMNM or across all islands within PMNM. The connections between Lalo, the Main Hawaiian Islands, and Johnston Atoll provide vital species connectivity mechanisms that sustain genetic and larval flow to Lalo (Kobayashi, 2006). As climate change impacts directly affect Tern Island and the smaller surrounding islets, resident philopatric species such as seabirds, Hawaiian monk seals, and honu have shown the ability to relocate to more suitable habitat not historically used, without anthropogenic intervention. Additional geographic locations across the Hawaiian archipelago can be considered as alternate habitat for key wildlife species found at Lalo. These local shifts in species habitat use, may be considered in meeting the goals of the Lalo Resilience Plan. Additional information is included in Appendix A.

5. Summary

This document has identified high priority actions to consider for implementation before the end of the decade. These are necessary to maintain essential terrestrial habitat at Lalo in the face of climate and anthropogenic impacts, better understand risks and identify mitigation actions at Lalo that optimize management outcomes for the rich diversity of species and the habitats they rely on. Pending a determination by the MMB on the most appropriate path forward, this document, coupled with the State of the Knowledge report, seeks to identify, prioritize, and implement projects and activities tailored to meet mutually agreed upon research and management needs.

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Appendix A. Description of Priority Actions

Habitat Improvements

Contaminants Removal

Contaminant removal on Tern Island would need to include the prioritization of removal options, which includes the option of direct sediment removal and shipment back to the Main Hawaiian Islands (MHI) for disposal, or the local encasing of remaining debris and contaminants in cement directly on Tern Island (EPA, 2019). EPA contaminant assessments on Tern Island were done between 2018 and 2019. EPA is scheduled to engage in a contaminant removal effort on Tern Island in Summer/Fall of 2024.

An array of ex situ or in situ bioremediation strategies can be used to assist in contaminant removal on Tern Island, depending on a variety of factors, such as cost, pollutant types, concentration, physical environment characteristics (Bala et al., 2022). When used in conjunction with other physical and chemical methods employed by the EPA, bioremediation can provide a comprehensive approach toward removing pollution from the environment (Bala et al., 2022). Since it appears to be a long-term solution, there is a need for additional research in this area.

Infrastructure Modification

The first line of defense to climate stressors at Lalo involves improving existing habitat. The three greatest threats to the survival of Hawaiian monk seals, Hawaiian green sea turtles, seabirds, and coral ecosystems at Lalo consist of 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 present an entrapment hazard. Prioritizing areas of high degradation or accelerated erosion is essential to focus effort and funds to improve marine and terrestrial habitat. The varied habitat conditions of the different islands and islets within Lalo influence the type of habitat improvements that may be feasible. Tern Island is the only terrestrial land mass within Lalo with existing infrastructure left from prior occupation by the military and FWS, including barracks, outbuildings, a boat ramp, davit, an unused runway, and a degraded seawall put in place during naval occupation of Tern Island (FWS, 2020). The other small, sandy islands and islets within Lalo are devoid of infrastructure and are much more susceptible to episodic flooding and inundation, which limits the available habitat to manipulate from a land manager‘s perspective.

Infrastructure improvements and removal is another priority action, and would include the removal of derelict infrastructure (barracks and outbuildings), improving boat ramp and davit, establishing a more permanent field research shelter, breaking up the Tern Island runway to enhance nesting habitat for burrowing seabirds and increase suitable nesting habitat, and removing and replacing existing seawalls. Seawall replacement options must include accessibility for Hawaiian green sea turtles and monk seals to traverse between marine and terrestrial coastline for resting, nesting, and other activities of daily living. Specific seawall replacement options include the installation of sheet pile bulkheads on the North, East, and West sides of Tern Island along with engineered headlands using T and L groins on the South shore of Tern Island. Informed by a habitat improvement alternatives analysis, additional seawall replacement options may be feasible for implementation at Tern Island. Implementing this type of coastal engineering construction is to be determined pending the outcomes of engineering and hydromorphology studies.

Habitat Stabilization

In addition to infrastructure-focused activities, replanting vegetation, with specific interest on the center of Tern Island is a priority both to increase nesting, resting, and shading habitat for seabirds, as well as to capture and retain sediment to promote natural island build-up. Initial outplanting can commence quickly as part of summer field research actions, but long-term commitments to monitoring, outplanting, and invasive plant control are needed to maintain and restore terrestrial habitat and maintain genetic diversity of flora. Identifying suitable plant species to outplant and supplement sand accretion and retention on Tern Island is needed. Habitat managers could consider a variety of species indigenous to the tropical Pacific that would provide appropriate vegetation structure for nesting seabirds and shoreline erosion protection. FWS field teams have sown naupaka (*Scaevola* spp.) seeds on Tern Island several times at the end of summer since hurricane Walaka in hopes that winter rain will sprout the seeds. Successful large-scale revegetation efforts at Lalo may require a larger effort that includes a shade house and consistent watering to support germination and establishment. Managers should also consider a plan for ex situ storage, propagation, and cloning of wild plant specimens with the goal of maximizing genetic diversity. Strategic revegetation is aimed to naturally promote island accretion and long term habitat stability. Removal of contaminants would need to be executed and completed prior to the initiation of longer term habitat improvement actions.

Outplanting is recommended to occur in tandem with invasive plant species removal, with a focused removal of the following priority non-indigenous plant species at Lalo: common sandbur (*Cenchrus echinatus*), whorled dropseed (*Sporobolus pyramidatus*), lambsquarters (*Chenopodium spp.*), sow thistle (*Sonchus oleraceus*), and cheeseweed *(Malva parvifolia*). Previous invasive species control efforts occurred at Lalo from 2009-2012, including an attempted common sandbur eradication project.

Improved Biosecurity Measures and BMPs

Maintenance of Tern Island infrastructure will continue to be a high priority action once initial habitat improvements are made to ensure longevity and efficacy of actions. In conjunction with habitat improvement efforts, improving biosecurity measures and best management practices (BMPs) minimizes the chances of introducing unwanted species to Lalo, which could further decrease the resilience of both the coral reef and terrestrial ecosystems at Lalo. Effectively developed and enforced biosecurity measures and BMPs bolster the benefits of habitat stabilization efforts. An example, the current Papahānaumokuākea Marine National Monument (PMNM) BMP020 guidance document aimed at minimizing the spread of nuisance algae such as *C. tumulosa* and *A. specifira* has provided the nexus for permittees to access areas with nuisance algae present to conduct valuable work with confidence that the appropriate measures are taken to minimize the risk of unintentionally spreading this nuisance algae to other currently unexposed areas within PMNM. As the nature, composition, and distribution of algae within PMNM changes, consistent updates to the existing BMP020 will be necessary. PMNM BMP 007 is an additional example of biosecurity protocols, requiring all gear to be frozen or fumigated prior to use on Tern Island or any of the other islets. Ensuring that unwanted terrestrial and marine species from the MHI are not introduced to Lalo throughout the action implementation stage of the Lalo Resilience Plan is crucial.

Table A1: Recommended habitat improvement actions developed by habitat, wildlife, engineering, and climate subject matterexperts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Habitat Improvements					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**
Contaminants Removal	High	Robust	$$$	**Medium**	2024-2040
Infrastructure Modification (Improvements & Removal)	High	Robust	$$$	**High**	2024-2035
Habitat Stabilization	High	Robust	$$$	**High**	2024-2050
Improve and Maintain Biosecurity Measures & Best Management Practices	High	Robust	$	**High**	2024-2050

Conservation Interventions

Key conservation interventions include the continuation and expansion of interdisciplinary field research efforts, Hawaiian monk seal, seabird, and Hawaiian green sea turtle translocation, initiating and sustaining coral restoration nurseries, response and scenario planning, installing artificial habitat structure, and island and coastal nourishment.

Continuation and Expansion of Field Research Efforts

Continuing Field Research Efforts

Current field research actions are crucial for providing wildlife entrapment relief, up-to-date data on Hawaiian monk seal and Hawaiian green sea turtle population data, assessments on infrastructure conditions, and many other key metrics (e.g. island condition/movements, marine debris accumulation, Huli ‘ia observations, etc.). The research activities conducted by the NOAA Fisheries Hawaiian Monk Seal Research Program, Marine Turtle Biology and Assessment Program, and additional wildlife focused field research efforts will continue to be a priority at Lalo over the next 7 years (until 2030 when conservation measures may take precedence). Field research activities at Lalo include facilitating entrapment mitigation for all wildlife, seabird and Hawaiian monk seal translocations, captive care programs to nutritionally supplement emaciated juvenile Hawaiian monk seals, Hawaiian monk seal rehabilitation and recovery, seawall cutting, and Hawaiian green sea turtle life-history data collection.

FWS Refuges will continue to support FWS and NOAA field research on Tern Island in the future, focusing on monitoring seabird, monk seal, and turtle populations as well as conducting habitat restoration efforts. FWS Refuges is committed to monitoring wildlife around derelict infrastructure and near contaminated areas on Tern Island until the areas can be cleaned or removed. In addition to summer season field research teams, co-manager partners like the Papahānaumokuākea Marine Debris Project (PMDP) have secured funding to conduct annual debris removal operations in PMNM, with priority stops at Lalo to conduct debris removal and support opportunistic wildlife entrapment mitigation efforts. Should PMDP conduct debris removal operations during times when field research teams are not present at Lalo, entrapment mitigation on Tern Island becomes more crucial for PMDP to conduct.

Expanding Interdisciplinary Field Research Deployments

Data collection, population demographics, wildlife entrapments, intra- and inter- species conflict, and need for real time information on species and habitat conditions throughout the year become increasingly important. Optimizing the field research deployments on Tern Island to collect pertinent information within the limited time and resources allocated to these efforts is a high priority. Including Native Hawaiian scientists and resource users into the field research, data collection, and site visit opportunities at Lalo can contribute to increasing Native Hawaiian capacity for PMNM research and management efforts. Native Hawaiian Practice permits allowed through the PMNM permitting process provides a nexus for Native Hawaiian researchers and cultural practitioners to build pilina (connection) with Lalo in a variety of capacities. Inclusion supports new perspectives on data collection and observation while engaging cultural practices. Securing funding to extend the summer field seasons and bolster monitoring efforts would also strengthen field research deployments to Lalo.

Wildlife Translocations and Conservation Introductions

Translocations and conservation introductions are hallmark examples of proactive solutions to climate change impacts, specifically sea level rise impacts, where efforts initiated today will have long lasting impacts on the presence of new populations in areas that are farther removed from climate impacts. Translocations are the intentional capture and release of animals to the wild to establish, reestablish, or augment a population. Conservation introductions are the intentional movement and release or outplanting of an organism outside its indigenous range for the purpose of conservation. The preemptive and strategic moving of Hawaiian wildlife species at Lalo ensures healthy, and self-sustaining populations and ecosystems for years to come.

Seabirds and Hawaiian Monk Seals

PMNM co-managers and collaborating organizations are already implementing successful seabird and Hawaiian monk seal translocations to alternate suitable habitats both within Lalo and to external sites. Protection of suitable nesting habitat and creation of new colonies on higher islands are among the highest priority conservation actions to combat the threats of seabird colony inundation caused by sea level rise and storm surge associated with climate change (Selkoe et al., 2008). Pacific Rim Conservation is a key collaborator with FWS to carry out translocation efforts within PMNM. In support of Pacific Rim Conservation's No Net Loss Initiative, seabird chicks have been moved from Tern Island and Midway Atoll (Kuaihelani) to new habitat with predator exclusion fences at James Campbell National Wildlife Refuge (JCNWR) on O`ahu. Pacific Rim Conservation's No Net Loss Initiative is twofold: 1) to protect as much seabird nesting habitat in the MHI as is being lost in PMNM because of the effects of climate change; and 2) to establish new breeding colonies of vulnerable seabird species that are safe from sea level rise and non-native predators.

Tern Island serves as a principal source population for priority seabird species that are most vulnerable to sea level rise: Black-footed Albatross (*Phoebastria nigripes*), Laysan Albatross (*Phoebastria immutabilis*), Bonin Petrel (*Pterodroma hypoleuca)* and Tristram's Storm Petrel (*Hydrobates tristrami*), all of which have a high proportion of their global populations breeding on a small number of localities only a few meters above sea level. Current translocation efforts are focused in JCNWR as well as a newer partnership with Mexico's Isla de Guadalupe since 2021, moving high priority seabird species from both Tern Island and Kuaihelani in PMNM. Guadalupe is a large, high island that is protected as a Biosphere Reserve and supports a thriving colony of Laysan Albatrosses. As translocation efforts continue, Isla Guadalupe as well as other appropriate sites may become key conservation introduction areas for seabirds from Tern Island.

Existing Hawaiian monk seal translocations occur under the direction of NOAA NMFS Hawaiian Monk Seal Recovery Plan, aimed at assuring the long-term viability of the Hawaiian monk seal in the wild, allowing initially for reclassification to threatened status and, ultimately, removal from the List of Endangered and Threatened Wildlife. Efforts consist of Hawaiian monk seal mother and pup pair translocations from smaller islets experiencing male Hawaiian monk seal aggression or shark predation to Tern Island where Galapagos shark predation is rarely observed. Sustaining these efforts would ensure population sizes are maintained, allowing Tern Island to become a potential source for specific species, with species radiation back out to the smaller islets.

Hawaiian Green Sea Turtles

The threatened status of Hawaiian green sea turtles was determined in 2015 prior to the loss of Trig and half of East Island in 2018. Recent analysis of green sea turtle population trend data for the last 10-years shows a decreasing trend, instead of an increasing trend. The loss of terrestrial habitat at Lalo would likely lead to <10% of current population abundance. This urgency highlights the need for a new status assessment for Hawaiian green sea turtles. Initiation of Hawaiian green sea turtle conservation measures cannot occur until permit approval and the development of a DPS-specific recovery plan. Green sea turtles as a species will continue to persist, but the Hawaiian population is special (culturally, genetically, and behaviorally). Conservation introductions and captive breeding are not currently identified in existing green sea turtle recovery plans, highlighting the need to understand the path forward on such activities that will require FWS permitting. As a precursor to conservation introductions or captive breeding actions, reconvening a DPS-specific recovery team to draft a recovery plan will take time and agency support.

Initiating conservation introductions of Hawaiian green sea turtle eggs from Lalo to suitable locations within the Hawaiian Archipelago by 2030 is recommended. This would allow for the establishment of new cohorts of Hawaiian green sea turtles imprinted to alternative beaches with higher probability of withstanding sea level rise impacts. The urgency to initiate conservation introductions by 2030 is linked to the multi-decadal sexual maturity timeline of Hawaiian green sea turtles and provides proactive conservation measures to curb the impacts to the Hawaiian green sea turtle population by mid to long term sea level rise projections. The need to move green sea turtle eggs for conservation purposes is predicted to increase (Fuentes et al., 2012) and sustained hatchling production is a global priority (Rees et al., 2016).

Relocating green sea turtle nests and eggs via artificial incubation would need to be the primary action taken in order to maximize the number of clutches moved during an organized transport and hatching success of these clutches. A range of studies have evaluated the effects of relocating nests/eggs for artificial incubation on sea turtle populations. One study found that hatching success of leatherback and green turtle nests relocated for artificially incubation was similar to natural nests above the high tide line and may have been higher than for natural nests washed over by sea swells (Whitmore & Dutton, 1985). One study also found that careful handling of eggs during the first five days of incubation did not affect hatching success (Chan, 1989). Four studies (including one replicated study) in Surinam, Ascension Island and Costa Rica, the Cayman Islands, the USA and Mexico reported that hatching success of green, loggerhead and olive ridley turtle nests relocated for artificial incubation varied from 26% to >90% (Simon, 1975; Critchley et al., 1983; Cross et al., 1998; Hart et al., 2014). One study also reported that hatching success from two trials was 30% and 58% in foam-packed boxes and 26% and 48% in sand-packed boxes (Critchley et al., 1983). Three replicated studies (including two controlled studies) in Suriname and Malaysia found that green turtle and leatherback turtle nests relocated for artificial incubation produced fewer female hatchlings than eggs from natural nests and/or that all sexed hatchlings that were artificially incubated were male (Simon, 1975; Critchley et al. 1983). As the use of artificial incubation to relocate green sea turtle nests in PMNM would be a new conservation action in PMNM, additional research and trials to understand hatching success as it applies to PMNM, and specifically Lalo, is urgently needed to inform the successful large-scale movement of green sea turtle nests and eggs to the MHI, slated to tentatively begin in 2030.

In addition to the use of incubators for transporting eggs laid earlier in the season (i.e. > 24 hr), the use of hypoxia to extend developmental arrest of freshly-laid eggs, particularly with the relatively simple and inexpensive approach of using vacuum-sealed bags, provides a valuable tool for conservationists and researchers (Adams et al., 2022). This improves managers‘ capability to maximize positive outcomes during research and conservation practices involving egg conservation introductions. Hypoxic translocations would only be from a few clutches captured during one night and have a much higher risk of failure given the very limited window for success.

For application at Lalo, utilizing hypoxia is a time-constrained action that requires strategic and efficient coordination and execution. Egg collection is constrained to approximately one day, which limits the total egg collection amount. By returning green sea turtle eggs to a hypoxic environment before they have broken from embryonic arrest (i.e., within 12 hours of oviposition), it is possible to extend embryonic arrest for at least 3 days, with no apparent detriment to hatching success (Williamson et al., 2017). Therefore, hypoxic incubation may provide a new approach for avoidance of movement-induced mortality when conservation or research efforts require the relocation of eggs (Williamson et al., 2017). The one day window for egg collection, vacuum sealing, and storage of eggs, allows for approximately two days of transit between Lalo and other locations with the Hawaiian Archipelago before reintroduction of eggs to a normoxic (having a normal oxygen concentration; typically 20-21% in the atmosphere) nesting environment buried on stretches of beach pre-designated as suitable sites. These areas will need to be monitored by staff and ensure public use of beaches does not interfere with the egg incubation or hatching periods. This extra staffing effort needs to be factored into the conservation introduction consideration.

Alternatively or consecutively, sexually mature female and male Hawaiian green sea turtles previously known to reproduce at Lalo can be identified at foraging grounds or basking areas and be brought into captivity for captive breeding. Eggs are then taken and placed on beaches within the MHI or other suitable beaches within the Hawaiian archipelago to incubate. By incubating on beaches near foraging grounds outside of Lalo, hatchlings will imprint to the new area, rather than to Lalo, and increase their chances of returning to suitable nesting habitat in approximately 25-35 years when they return as sexually mature adults (Bowen et al., 1992; Pacific Sea Turtle Recovery Team, 1998). This effort would require additional human efforts once they are brought into captivity, including staff to monitor and provide care in holding areas while the green sea turtles acclimate to captivity. Staff would also need to be assigned to observe the captive Hawaiian green sea turtles to ensure successful nesting and hatch success data is collected.

Identifying suitable beaches is an integral step in the Hawaiian green sea turtle conservation introduction process. Potential suitable beach habitats include, but are not limited to, Midway Atoll (Kuaihelani), Kaua‘i, Moloka‘i, Lāna'i, and Ni‘ihau, where human interactions may be less intense in comparison to more populated areas such as Maui, Oʻahu, or Hawaiʻi Island. Investigating Niʻihau as a potential Hawaiian green sea turtle conservation introduction location would allow for new discussions of Hawaiian green sea turtle conservation in an area with high access-regulation due to private ownership by a Hawaiian family and strengthening cultural connection to Hawaiian green sea turtles through wildlife management.

Coral Restoration Nurseries

Coral restoration in Hawaiʻi presents several unique challenges. Due to geographic isolation, Hawaiʻi has one of the highest rates of endemism of any ecosystem worldwide; this includes both corals and coral reef-associated organisms such as fish, invertebrates, and limu (algae) (Randall et al., 1992). This means that much of this incredible marine life cannot be found anywhere else in the world. Additionally, compared to many other reef systems in the world, Hawaiʻi has some of the slowest growing corals, with most reef-building corals growing 1 – 2 cm per year, compared to 10 – 20 cm per year in the South Pacific and the Caribbean.

In 2018, Category 3 Hurricane Walaka directly impacted Laloʻs surrounding coral reefs including the notable “Rapture reef”. The reef was transformed to flat rubble, eliminating its role in shoreline protection and habitat for many species. Coupled with the storm damage, multiple bleaching events driven by rising ocean temperatures have resulted in substantial mortality to the corals surrounding the atoll (Selkoe et al., 2009). The combination of both short- and long-term pressures on coral reef ecosystems exacerbated by the effects of a changing climate underscore the need for coordinated research and planning to develop a coral restoration nursery. Lalo is the largest atoll in the NWHI chain and the largest reef in the Hawaiian archipelago containing approximately 67 acres of total emergent land surrounded by approximately 230,000 acres of coral reef habitat. The Lalo reef environment has the highest coral species richness in the NWHI with 41 species of stony corals, including one ESA listed coral, and five IUCN Red List coral species. These challenges highlight why coral restoration is incredibly important as bleaching and storm events, vessel groundings, pollution, and climate change all pose serious threats to the coral reef community at Lalo.

Supplementing existing coral reefs in Lalo by outplanting coral sourced from Lalo would provide added biomass, reef structure, habitat, and additional ecosystem services like wave attenuation that benefits both the nearshore marine and terrestrial habitat within the atoll. Actions to prepare for this monumental effort would first require a stepwise plan to: 1) identify suitable locations for a coral restoration nursery facility with adequate infrastructure; 2) identify desired coral species and specific colonies to survey and collect; 3) develop a nursery biosecurity and operations plan; and 4) determine Lalo coral outplanting and monitoring protocols and where corals will be outplanted.

Within PMNM, Kuaihelani may have the infrastructure and materials to support a nearby coral restoration nursery, but the presence of nuisance algae (*Chondria tumulosa* & *Acanthophora spicifera*) may pose a serious biosecurity risk to coral reintroduction if nursery filtration is not adhered to, as Lalo is currently devoid of these nuisance algae. Developing a coral restoration nursery in the MHI, potentially the Inouye Regional Center on Oahu, would be a feasible option due to the available infrastructure, space, and accessibility. Identifying a nursery location should also allow for an educational component where visitors can view and learn about the coral restoration and resilience efforts taking place to assist in bolstering Lalo resilience. Additionally, exploring collaborations with the Hawaiʻi Coral Restoration Nursery (HCRN) located at the DAR Ānuenue Fisheries Research Center, Hawaii Institute of Marine Biology coral labs, University of Hawaiʻi coral lab at Kewalo Basin, and the Maui Ocean Center, all of which are actively participating in coral husbandry, will be a valuable component to build a Lalo and broader PMNM focused coral restoration nursery. Adopting existing HCRN coral restoration nursery protocols developed through years of experience studying, growing, and restoring Hawaiian reefs will also expedite the establishment of a new coral restoration nursery. As coral restoration needs vary between increasing habitat complexity and the preservation of rare, uncommon, and endemic species, establishing a restoration nursery and/or collaborations to address both goals will be imperative to address long term coral reef resilience at Lalo and potentially, the broader PMNM.

Due to biosecurity concerns with nuisance algae within PMNM, sourcing coral to grow in nurseries in the MHI from within Lalo is highly recommended. Biosecurity measures should also be considered for the coral restoration nursery facility by applying strict quarantine and health assessment procedures for all corals entering and exiting the nursery as well as the water being used at the facility. Identifying the type of coral species and genetic types to harvest from Lalo and grow will be key. As some species or colonies may have developed resistance or tolerance to different climate stressors (e.g. heat, disease, acidification), ideally collecting a diverse assemblage of corals that have developed different resistances to these stressors, or represent a rare or uncommon species, would provide a resilient and diverse group of coral suited to provide a much needed buffer to a suite of climate stressors projected to increase in the coming decades. Growing desired coral genotypes would need to occur early to establish adequately sized colonies to plant at Lalo. In addition to growing corals sourced from within Lalo, growing corals from the MHI that have experienced more heat stress to outplant within Lalo will be an effective strategy to introduce additional genetic diversity and resilience to the existing coral assemblage at Lalo. Exploring cryogenics as a strategy to preserve rare and resistant coral genetics is also warranted.

Response and Scenario Planning

A suite of new climatic, biological, and anthropogenic threats have the potential of directly impacting Lalo in the near future, and comprehensive response protocols and associated scenario planning need to be in place to face these threats (Selkoe et al., 2008). Improvements to existing response protocols for navigation aids, ship grounding response, and coral bleaching should be conducted in tandem with the development of new response and scenario planning for the following: 1) catastrophic storm events; 2) invasive species introductions and outbreaks (e.g. stony coral tissue loss disease, *Unomia spp.*, *Carijoa riisei, Acanthophora spicifera, Chondria tumulosa*, Crown of Thorns, etc.); and 3) Coral Rubble Stabilization. An early detection rapid response plan would also need to be in place to employ in the event of new invasive species or disease introductions.

As many of these potential threats have the capability of causing damage in a very short amount of time, proactive planning and mitigation protocols need to be established before the threat is detected to ensure timely and effective response and mitigation efforts, and should include response times, pre-allocated funding sources, and methods of removal and containment. The remote nature and travel logistics to access Lalo further emphasize the need for proactive response protocols approved and adopted by the PMNM co-managers well ahead of the detection of a threat.

Artificial Habitat Structure

Roosting Structure

As available terrestrial habitat within Lalo slowly dwindles, finding ways to enhance and optimize the available space to be suitable and usable habitat for wildlife is recommended. A 3,100-foot long compacted coralline runway now majorly covered in sand, vegetation, and nesting seabirds occupies a large section of the center of Tern Island. Existing vegetation growing on the runway are very low-lying plants that don't need a lot of substrate for their roots, like grasses and vines; whereas, nesting birds would need larger vegetation like tree heliotropes and *Scaevola*. In addition to outplanting on Tern Island, which has proved challenging to produce large, healthy trees and bushes, installing raised artificial roosting structure within the inland seabird nesting area is a crucial benefit as ambient air temperatures increase due to climate change projections. Immediately available raised roosting habitat increases structure for tree and bush nesters, allowing for better thermoregulation during hot seasons. Existing examples of artificial roosting structure can be seen at the Marine Corps Base Hawaii on O'ahu, as well as across the Philippines.

Artificial Reefs

A combination of increased sea surface temperature, associated ocean acidification, coral diseases, and increased storm frequency and intensity highlight the potential need for supplementing naturally occurring coral growth at Lalo (Selkoe et al., 2009). Introducing artificial (non-living) reef structure within select pockets of existing reef would enhance reef habitat complexity, increase fish biomass and species diversity, and bolster coral reef ecosystem services. Artificial reef options employed by the Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR) include the use of derelict concrete modules, small sunken vessels, and most recently "z-modules" made of concrete. Cost and time to conduct the required environmental impact statement and deploy the artificial reef structures proposed by DLNR DAR are limiting factors to consider.

While sinking old ships and placing large concrete structures underwater can work, these structures may not mimic local coral species' ideal habitat structure. 3-D printing coral to mimic the shapes and textures of healthy natural coral ecosystems, provide habitat structure for wildlife, and provide the hard structural material to promote coral polyp settlement. Creating and installing a diverse mix of branching and mounding coral structure provides an array of structure for reef biota (holes and crevices), substrate for natural coral settlement to occur, supports nearshore marine biodiversity, and reduces and redirects wave energy. The goal of installing artificial reefs is to promote an ecologically productive system by providing structures that not only serve their role as coastal protection through wave attenuation, but also serve as habitat for other organisms which mimics natural reef restoration. This supports healthy herbivore populations on Lalo reefs, promoting natural algal management. Determining the scale at which 3D artificial reef structure installation would be feasible is a key component to consider. The efficacy of installing 3D-printed coral on a large scale has not been fully explored and will require additional research.

Alternative Haul-Out Platforms

As usable onshore resting and basking space decreases due to a combination of coastal erosion and wildlife overcrowding, installing floating haul-out platforms anchored nearshore would provide additional space for Hawaiian monk seal resting and pupping as well as Hawaiian green sea turtle basking. Platforms would be free of sand and not a viable structure for successful sea turtle nesting. This alternative habitat may potentially free up sandy portions of the coastline in hopes that Hawaiian green sea turtles and hawaiian monk seals may also utilize this space for basking/nesting and resting/pupping, respectively. Haul-out platforms could also be strategically placed above desirable coral outplanting locations, providing shade and potentially decreasing direct temperature and bleaching impacts to both naturally occurring and outplanted coral colonies.

Island and Coastline Nourishment

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 to mid-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, installed both at Tern Island and the smaller islets within Lalo. Ensuring that habitat engineering measures reduce the rate of wildlife entrapment while maintaining sand capture and wildlife access between marine and terrestrial areas are important. Utilizing local sand for nourishment efforts is highly recommended to reduce the chance of unintentional species introduction.

Table A2: Recommended conservation intervention actions developed by habitat, wildlife, engineering, and climate subject matterexperts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Conservation Interventions					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**

Continue Field Research Efforts	High	Robust	$$	**High**	2024-2050
Expand Interdisciplinary Field Research Deployments	High	Robust	$$$	**High**	2024-2050
Sustain Hawaiian Monk Seal and Seabird Translocation and Conservation Introductions	Moderate	Moderate	$$	**Medium**	2024-2050
Initiate Novel Conservation Techniques to Support Hawaiian Green Sea Turtle Recovery	High	Robust	$$$	**High**	2025-2050
Initiate and Sustain Coral Restoration Nurseries	Moderate	Moderate	$$	**Medium**	2027-2050
Response and Scenario Planning	High	Robust	$	**High**	2024-2030
Artificial Habitat Structure (Roosting, Reef & Haul-Outs)	Moderate	Moderate	$$$	**Medium**	2027-2050
Island and Shoreline Nourishment	Moderate	Moderate	$$$	**Medium**	2027-2050

Observations and Monitoring

Observation and monitoring action priorities include climate, ocean, and atmosphere, Tern Island weather station installation and maintenance, and habitat and species conditions. Key research topics need to be initiated with urgency in the near term to inform key information gaps about key ecosystems and species related processes. This valuable information is a necessary precursor to the initiation of numerous key management actions at Lalo.

Climate, Ocean, and Atmosphere

The occurrence of El Niño/Southern Oscillation (ENSO) and shift to the warm phase of the Pacific Decadal Oscillation (PDO) starting in 2023 will moderately increase the risk to survival of key species at Lalo and directly nearshore productivity. ENSO may also lead to a decreasing likelihood of widespread coral bleaching and promote productivity in the PMNM fishery, which could potentially lead to some level of inter and intra species competition for food as a result. This may be directly linked to higher seabird reproductive success due to better and closer food availability, a pattern also possible for resident Hawaiian green sea turtles who depend on feeding within Lalo or in the close vicinity of the atoll. Continued observations of these impacts will be valuable for managers.

Habitat and Species Conditions

Long-term monitoring of the abundance and distributions of reef fish, invertebrates, coral and algae are used to evaluate the status and trends of the health of remote coral reef ecosystems across PMNM. Lalo’s marine habitat and coral ecosystems are of particular interest due to the diverse coral assemblage and presence of endangered coral species. Monitoring activities will improve the MMB‘s understanding of the region's marine systems and allow for better management of PMNM.

The PMNM Reef Assessment and Monitoring Program (RAMP) cruises prioritize key stops at Lalo, Lisianski Island (Kapou), Pearl and Hermes Reef (Manawai), and Kure Atoll (Hōlanikū) and are a valuable contribution to the effort of understanding habitat and species conditions. RAMP activities include rapid ecological assessments (REA) of reef fish, corals, other invertebrates, and algae; coral disease surveys to determine disease presence in PMNM; a bioerosion study to determine the growth and erosion of corals in PMNM; and ecological acoustics research using underwater instrumentation. REAs have been conducted in PMNM since 2000. The last RAMP cruise occurred in 2017, prior to Hurricane Walaka and the resulting coral decimation within the atoll. As the current state of the coral reefs at Lalo are unknown, surveying and assessing the current state of coral reef ecosystems at Lalo before initiating any other coral projects should be an a top priority for managers to complete. This gap in data highlights the urgency to reinitiate these important observational efforts at Lalo and other important coral reef ecosystems within PMNM.

Table A3: Recommended observation and monitoring actions developed by habitat, wildlife, engineering, and climate subject matterexperts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Observations and Monitoring					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**
Climate and Atmosphere	High	Robust	$$	**High**	2024-2050
Tern Island Weather Station Installation	Low	Moderate	$	**High**	2024-2030
Habitat and Species Conditions	High	Robust	$$	**High**	2024-2050

Research

Research actions included hydrodynamics and morphodynamics, habitat improvement alternatives analysis, habitat suitability, carrying capacity and vulnerability thresholds, islet persistence, ecosystem characterization and modeling, and interspecies interactions.

Hydrodynamics and Morphodynamics

Understanding both hydrodynamics and morphodynamics are integral to formulating targeted management strategies for Pacific Islands like Lalo. Consideration should be given to conducting resilience assessments that include the 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., invasive macroalgae, disease) 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 recruitment, coral, and fish connectivity, temperature variability, and wave intensity. Researching the full extent of coral reef damage by Hurricane Walaka in 2018 has not been fully characterized and is of high and urgent priority to be evaluated by field surveys.

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). Monitoring the availability and shifts in emergent land is an incredibly important component of resilience planning. 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.

Utilizing effective metrics to track total land area 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. Implicit in the above is the suggestion that Tern Island should not be relied on as the sole terrestrial refuge for key wildlife species such as seabirds, Hawaiian monk seals, and Hawaiian green sea turtles. To minimize risks of species loss at Lalo, attention needs to be given to identifying and establishing alternative refugia should Tern Island fall victim to foreseen or unforeseen circumstances.

Understanding rates of net coastal and reef crest accretion and erosion in PMNM, while accounting for storm and seasonal variability, will also be important for modeling future changes in terrestrial abiotic habitats and supporting informed management of these resources. As a first step toward developing the ability to detect large changes in abiotic marine habitats, high-resolution bathymetry and substrate mapping should be continued for the entire PMNM.

Habitat Improvement Alternatives Analysis

How patterns and trends of nearshore circulation and sedimentation might change, in particular their scope and timing are not well understood. Interventions including 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. Understanding these circulation and sedimentation patterns and trends would directly inform appropriate engineering seawall alternatives. During the 2023 Lalo Adaptations Workshop, coastal engineering subject matter experts who proposed conservation actions (groins, etc), believed the seawalls couldn't be removed entirely because of the hydrodynamics around the island (i.e. the current in the channel that was dredged on the north side of Tern Island would rapidly erode Tern if the seawall were to be removed).

Coastal engineering alternatives were proposed as potential mitigation options for the Tern Island seawall during the Lalo Resilience Workshop and National Conservation Training Center (NCTC) Climate Adaptations Workshop, to maintain the integrity of remaining terrestrial habitat on Tern Island. Parameters for seawall interventions are Tern Island specific, and weighs the need for island stabilization while also maintaining wildlife access between marine and terrestrial areas. Propositions for seawall replacement included 1) sheet pile bulkhead on the North, East and West sides of Tern Island, and 2) Engineered Headlands incorporating L and T groins on the Southern shore of Tern Island to increase sand retention and broaden available terrestrial habitat. These actions are intended to increase Hawaiian green sea turtle nesting success and allow for higher Hawaiian monk seal pup survival and transition to the weaning stage.

Identifying and analyzing existing coastal engineering designs in comparable coastal sites across the MHI, broader Pacific, and internationally would be an effective strategy to identify feasible options to apply at Lalo. Reviewing the efficacy and challenges of current engineered headland designs will be imperative to inform which design, if any, would best suit the dynamic ocean and sediment patterns found at Lalo to decrease wildlife entrapment and increase both Hawaiian green sea turtle nesting success and Hawaiian monk seal pup survival to weaning. Current installed coastal engineering designs available for analysis include engineered headlands at Iroquois Point and Laʻie (Oʻahu), Poʻipū and Kipu Kai Beaches (Kauaʻi), Eastern Brazil, Western Africa, Baja Peninsula (Mexico), and Northwestern Ireland.

Habitat Suitability, Carrying Capacity & Vulnerability Thresholds

For Hawaiian green sea turtles, collecting data and developing models to predict the impacts of sea level rise on nesting sites and rising sand temperature on hatchling success and sex ratios is a priority. Monitoring of nesting sites throughout Lalo are also needed to assess the impact from the catastrophic habitat loss at East Island, caused by Hurricane Walaka, resulting in potential delayed nesting or nesting location shift.

For Hawaiian monk seals, continuing NOAA Fisheries field research observations on the number of shark-induced Hawaiian monk seal deaths and their locations within Lalo will help to establish a reasonable threshold to warrant initiating shark culling protocols at Tern Island. The number of Hawaiian monk seal pup deaths due to male aggression is also a key metric, as it will determine the need for strategic translocation of Hawaiian monk seal mom and pup pairs to Tern Island or other safe locations within PMNM (not including areas in the MHI) to assist in meeting the goal of ensuring long-term viability of the Hawaiian monk seal in their original home range.

In regard to seabirds, FWS annual seabird population monitoring on Tern Island, which stopped in 2012 due to severe weather damage to FWS field research facilities should be resumed. Up to that time, Lalo and in particular Tern Island, was the site of the most comprehensive and long-term population monitoring program of breeding seabirds in the U.S. Tropical Pacific. There are time series of more than 30 years for the parameters of number of breeding pairs, breeding chronology, and reproductive performance for most of the 21 PMNM species in the FWS database. Resuming annual Tern Island monitoring is particularly necessary to take advantage of the long-term demographic information collected there for Black-footed and Laysan Albatross and to continue measurements that will allow the evaluation of not only the effects of erosion and thermal stress on all the seabird species nesting but allow us to understand relationships between oceanic changes and seabird populations. In addition to population monitoring, there are numerous metrics imperative for continued research and monitoring, including studying the distribution of Lalo-based birds in their pelagic foraging grounds and the number of seabird entrapments (proportion of dead to rescued). Total area usage of nesting seabirds to monitor encroachment of other species (Hawaiian monk seals and Hawaiian green sea turtles) on available terrestrial habitat using drone data collected during summer field research would inform a key vulnerability threshold. FWS has trained drone operators and is authorized to fly over Lalo after appropriate consultations. Garnering funding to sustain longer field research seasons and more personnel would allow for the collection of this robust and valuable data.

Gray-backed Tern, Tristram's Storm-petrel, and Bonin Petrel in particular would serve as good vulnerability indicator species (Citta et al, 2007) because their breeding season overlaps with the period of highest wave energy and their life-history characteristics make them less able to adapt to rapid environmental change. Understanding the relation between frequency and duration of episodic flooding and inundation events at Tern Island and outer islets, sea surface height (collected monthly), ambient air temperature (collected monthly), and presence of introduced predators (rats, mongoose, cats, ants etc.) will contribute to establishing population and available land mass thresholds that trigger additional seabird translocations.

Ecosystem Characterization and Modeling

As a precursor to exploring impacts to ecosystems due to changing conditions, attention needs to be given to pelagic and archipelagic ecosystem modeling and better definition of the specific parameters and associated ranges that make marine habitat viable (e.g., thresholds, tolerances).

It will be valuable to determine the ecological and oceanographic factors driving regional, island, or site-specific genetic structure of corals and other marine species with larval stages; this will likely be important for ecosystem-based management of both the MHI and PMNM, and may provide general characteristics to predict ecosystem-level partitions among coral reefs elsewhere. There is an urgent need to develop a new quantitative method for multispecies studies of connectivity among many locations, bringing multispecies data sets together in a single analysis to determine both the relative strength and statistical confidence in each of the detected barriers (Toonen et al., 2010). 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 to determine the threshold for initiating active coral reef supplementation.

In addition to archipelago scale genetics barriers, understanding rates of net coastal and reef crest accretion and erosion in PMNM will be important for modeling future changes in terrestrial abiotic habitats and supporting informed management of these resources. Data are currently lacking to adequately evaluate the rate of erosion or long-term impacts of sea level rise and habitat loss, and more attention should be put toward monitoring shoreline erosion while accounting for storm and seasonal variability.

Intra- and Inter-Species Interactions

Hawaiian green sea turtles have been observed to nest in sandy areas on Tern Island, East Island, and on surrounding islets. The majority (50%) of 2018 nests (prior to Hurricane Walaka) were laid in 10% and 2% of the East Island and Tern Island areas, respectively; suggesting that if nesting females remain restricted to those areas, the carrying capacity prior to Walaka was already at 16-22% (Reininger et al., 2019). Due to limited available space, adult female Hawaiian green sea turtles have unearthed entire previously laid sea turtle nests to lay a new clutch. As a result, Hawaiian green sea turtle fecundity is impacted due to this competition for nesting space. Additionally, Hawaiian green sea turtles have moved further inland to lay their eggs - following the vegetation destruction (and loss of a black pipe barrier) by Hurricane Walaka - which has subsequently increased the destruction of seabird nests and incubating eggs. More frequent use of Tern Island by displaced monk seals also increases disturbance of more sensitive seals (e.g., moms and pups, molting individuals) by nesting turtles. Better understanding this intraspecies competition and how much viable nesting beach is needed for a single female to lay a clutch will help to inform managers of the amount of available beach needed to sustain certain population sizes of Hawaiian green sea turtles. For example, some females wander the island digging multiple nests in order to find the best location for laying her clutch of eggs. So even if there is a decent size sand area, if the depth of the sand (or substrate quality) isn't satisfactory, she will keep moving to find more suitable habitat to lay her clutch of eggs. Research to understand which methods of mitigating both inter- and intra-species competition (e.g. developing physical barriers, manually moving individuals to different parts of the beach, etc.) could be most successful, is needed.

Additionally, Hawaiian monk seals and Hawaiian green sea turtles on Tern Island have been found to unintentionally venture inland off of the sandy beaches on Tern Island and into the vegetated areas where seabirds nest. This observed habitat encroachment has increased the destruction of seabird nests and incubating eggs, resulting in increased seabird mortality. Understanding how to deter these coastal species from venturing over the middle of the island and off of the shorelines would assist in mitigating damage inflicted on seabirds and inland seabird habitat. The revegetation and remediation of the runway (described previously) will assist with keeping turtles on beaches and not impacting seabird habitat and therefore another good reason to prioritize habitat restoration actions.

Islet Persistence

Although Tern Island has the most available terrestrial land of any land mass within Lalo, evaluating the viability and resilience of the smaller islands and islets and their capacity to provide terrestrial habitat for resting and nesting habitat is needed. Species competition for space further highlights the need for clearer assessment of available terrestrial habitat for mixed wildlife use. As East Island, Gin and Little Gin, and other small islets are slowly accreting, these terrestrial areas will hopefully allow additional habitat and space to alleviate inter and intra species conflict and competition for space. Continuing investigations to understand the long-term persistence of islets within Lalo will greatly inform managers on the available terrestrial habitat that will be available for wildlife to utilize and help estimate population thresholds as they relate to habitat availability.

Table A4: Recommended research actions developed by habitat, wildlife, engineering, and climate subject matterexperts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Research					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**
Hydrodynamics and Morphodynamics	High	Robust	$$	**High**	2024-2026
Habitat Improvement Alternatives Analysis	High	Robust	$	**High**	2024-2030
Habitat Suitability, Carrying Capacity & Vulnerability Thresholds	High	Robust	$$	**High**	2024-2050
Ecosystem Characterization and Modeling	High	Robust	$$$	**High**	2024-2035
Intra- and Inter-Species	Moderate	Moderate	$	**High**	2024-2050

Interactions					
Islet Persistence	High	Robust	$	**High**	2024-2035

Observational Tools

Climate change impacts on intensity and size of storm events, ocean warming, coastal erosion, terrestrial habitat warming, and sea level rise inundation of low-lying areas are of concern. Terrestrial habitat warming is particularly true for sea turtles, which the nest incubation environment is critical for temperature dependent sex determination. Satellite derived products continue to improve and are highly useful for monitoring climate and sea level rise, however surface and subsurface on-site monitoring in the actual location continue to be critical for understanding small-scale, location specific conditions.

Ecosystem- and climate change-specific monitoring efforts are currently being employed by management agencies. Examples include assessments of fundamental changes in species composition and distribution for climate sensitive species such as corals, as well as direct monitoring of marine calcification rates. However, research gaps related to other aspects of climate change must continue to be evaluated. Monitoring changes is very important, and can help to tease out which impacts are caused by climate events outside of our control, versus direct anthropogenic impacts. Utilizing new research and observation tools places PMNM in a better position than ever to assess the impacts of climate change to coral reef ecology and habitats.

Remote Sensing

Remote sensing allows for the acquisition of information about an object or areas without making physical contact with the object, typically from aircraft or satellites, in contrast to on-site observation. This method of data collection is especially useful in remote locations - such as Lalo - where access is limited throughout the year. Both passive and active sensors mounted on satellites and aircrafts can be used to map the geographic makeup of the islands and islets within Lalo over time, monitor shoreline changes, track sediment transport, and map coastal features (such as habitat impacts at Lalo due to Hurricane Walaka, see Figure A1). This data can be used for coastal mapping, erosion prevention, and inform managers of the usable terrestrial nesting and resting habitat for vulnerable wildlife. In addition to island and coastal mapping, remote sensing can be applied to monitor ocean circulation and current systems, measure ocean temperature and wave heights, and detect coral bleaching using multispectral satellite imagery (Ma et al., 2023). Data can be used to better understand the oceans and how to best manage the wildlife that use these ocean habitats for feeding, migration, reproduction, and other critical life history activities.

Figure A1. Changes to East Island due to Hurricane Walaka. Photos obtained via Digital Globe.

Remote Cameras

There are very few opportunities to conduct in-depth coral ecosystem monitoring between the three-year National Coral Reef Monitoring Program timing, which is aimed at providing periodic assessments of the status and trends of the nation's coral reef ecosystems. In the context of monitoring, relying on a three-year interval for on-site monitoring is not sufficient as climate impacts are exacerbated and changes are seen on a shorter time interval. This need for year-round data is apparent for both the marine and terrestrial habitat within Lalo. Automated cameras can be used both on land at Tern Island and the other small islets within Lalo to capture valuable data (e.g., wildlife population metrics) as well as in select underwater locations to monitor biodiversity, species presence and activity, and habitat changes over time. The implementation of cameras on autonomous vehicles that are solar powered and can self-deploy and recharge is also a feasible option to consider in an extremely remote area such as Lalo. Sail Drone, Liquid Robotics, and other companies have the means to take all kinds of information for monitoring in near real time, uploaded to a satellite. Utilizing remote camera technology to automate data collection provides more complete datasets throughout the year, an important component to inform management decisions in between opportunities to collect in-person data.

Smart Buoys

“Smart buoys” are an effective alternative for ecosystem monitoring in remote locations - like Lalo - due to unmanned operation, easy deployment, customizability, real-time monitoring, and low cost. Buoy sensors are fully customizable and monitoring platforms can be adapted and modified as monitoring priorities change. Buoys can house from one to hundreds of sensors, meeting the needs and applications of the specific monitoring goal. In regard to data streaming, sampling can occur as frequently as every minute, providing data 24 hours a day, 7 days a week. Smart buoys provide autonomous operation due to wind, solar, or battery power options, and the use of satellites for long distance data transmission. Many global initiatives working on building ocean conservation technology (e.g. Aqualink, NOAA) have already utilized smart buoys to meet their conservation or research goals.

These buoys are secured to the seafloor and loaded with sensors to collect a range of meteorological, physical, water quality, water level, chemical, biological, optical, and acoustic measurements. Specific measurements include oxygen levels, surface and subsurface temperature, wave height, wave period, wave power, water temperature, air temperature, air pressure, atmospheric pressure, wind direction, wind speed, salinity, turbidity, pH, chlorophyll levels, and much more. Utilizing smart buoys assist in understanding the forces driving the change of valued marine and terrestrial resources at Lalo over time.

Smart buoys allow for long-term data collection at scales and resolutions that are difficult, if not impossible, to obtain otherwise. The remoteness and limited accessibility of PMNM is one such instance where this application would be beneficial. The information collected is relayed in near-real time from the buoys using wireless technology. The immediacy and accessibility of information from these smart buoys helps provide accurate, year-round data to inform an array of applications including: 1) science-based marine management; 2) climate change impact monitoring; 3) reducing wildlife and vessel collisions; 4) marine water quality monitoring; 5) coral reef ecosystems status and health monitoring; and 5) tracking derelict fishing gear to minimize unintentional wildlife entanglement.

Tern Island Weather Station

Tracking broad climatic and atmospheric changes and impacts over time across a wide range such as the Pacific should occur in tandem with fine-scale local trends and patterns at Lalo associated with this global shift. Establishing a permanent weather station at Tern Island would collect real-time data throughout the year and provide insight into the weather conditions (including wind speed, ambient air temperature, humidity, barometric pressure, rainfall, and UV or solar radiation) when temporary field researchers are not present at Lalo. FWS has purchased a weather station for Tern Island, with plans of installation in Spring 2024. Data collected at Tern Island would supplement climatic and atmospheric data captured at existing remote weather stations on Rose Atoll, Nihoa, and Kamole (Laysan Island). In addition to a weather station, marine temperature loggers and flow meters placed in nearshore locations around Tern Island would increase the available marine data collected throughout the year. As Lalo field seasons last between three to five months in the summer, having available data collected remotely by a permanent weather station to supplement in-person datasets would give managers and researchers a better understanding of what is happening at Lalo during the winter and spring seasons and supplement the annual changes field researchers observe when deployed on Tern Island to assess Hawaiian green sea turtle and Hawaiian monk seal populations.

Table A5: Recommended observation tools developed by habitat, wildlife, engineering, and climate subject matter experts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Observational Tools					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**
Remote Sensing	High	Robust	$$	**High**	2025-2035
Remote Cameras	Moderate	Robust	$$	**High**	2025-2035
Smart Buoys	Moderate	Moderate	$$$	**High**	2025-2035
Tern Island Weather Station	Low	Moderate	$	**Medium**	2024-2030

Communications

Inreach & Upreach

Communication was identified as a crucial component needed throughout each step of the Lalo Resilience Strategy, including inreach, upreach, and outreach. Inreach, or communication within the PMNM co-managing agencies is crucial for interagency collaboration and coordination for management and research efforts at Tern Island and other sites within Lalo. Effective inreach also ensures the Lalo Working Group tasked with overseeing the Lalo Resilience Strategy is consistently co-developing the content of the Lalo Resilience Strategy to meet the goals and needs of the different federal and state agencies. Upreach includes internal engagement focused on broader components of establishing resilience at Lalo, including congressional engagement, establishing Lalo as a NOAA Habitat Focus Area (Habitat Blueprint), and garnering leadership buy-in to management and research decisions. Upreach is a crucial step to check back on throughout the Resilience Strategy to ensure funding, support, and traction for the resilience plan is maintained.

Outreach

Outreach includes external communication between co-managing agencies and members of the public, including external collaborators, community members, and resource users. Outreach also includes increasing public education and awareness through newsletters, listening sessions, and other engagement opportunities such as directed efforts to enhance public intrigue and interest in specific unique habitats (e.g. mesophotic zones) or management initiatives such as the translocation of priority wildlife from PMNM to the MHI. Within the Hawaiian archipelago, communicating scientific work, management efforts, and conservation efforts being done within PMNM should not only be provided to Native Hawaiian communities who are inextricably connected to the natural resources within PMNM. Concerted efforts should be made to also encourage open communication with Native Hawaiians about ways that Hawaiian culture can be more seamlessly integrated into the conservation, research, and reconnection occurring within PMNM.

Table A6: Recommended communications actions developed by habitat, wildlife, engineering, and climate subject matterexperts from PMNM co-manager agencies, NOGs, and other external collaborators during the 2023 Lalo Adaptations Workshop. The suite of actions presented here were synthesized and selected as high priority items from a wider list of potential actions developed by workshop subject matter experts. Cumulative ratings developed by Lalo Adaptations Workshop Steering Committee based on subject matter expert input, urgency, impact, and cost factors.

Communications					
Recommended Action	**Urgency**	**Impact**	**Cost**	**Cumulative Rating for Action Priority**	**Timeline**
Inreach	High	Robust	$$	**High**	2024-2050
Upreach	High	Robust	$$	**High**	2024-2050
Outreach	High	Robust	$$	**High**	2024-2050

Additional Recommended Options

In addition to all the recommended actions mentioned above, a subset developed by co-manager agency and external collaborator subject matter experts during the Lalo Adaptations Workshop in March 2023 were not chosen by the Lalo Resilience steering committee to be carried forward in the Lalo Resilience Plan due to factors such as feasibility, budget constraints, and cumulative ecosystem impact (Table A7).

Table A7: Cumulative list of recommended actions not carried forward in the Lalo Resilience Plan. Preliminary timelines for the implementation of each individual action recommendations are included, with available time scale of 2023-2050. Some or all of the implementation steps associated with actions have the potential to extend beyond 2050.

Actions not carried forward in the Lalo Resilience Plan	
Recommended Action	**Timeline**
Establish Hawaiian green sea turtle genetic bank / breeding program	2037-2050
Wildlife enticement actions (e.g. lights to attract nesting Hawaiian green sea turtles, food for Hawaiian monk seals)	2024-2030
Reinstate Tern Island runway	2030-2050
Develop technology to alter the magnetic imprint of Hawaiian green sea turtles	2030-2050

Archipelago-Level Planning

The Hawaiian Archipelago has not been shown to be a single, well-mixed community, but rather there are at least four significant multi-species barriers to dispersal along the length of the island chain, including both PMNM and the Main Hawaiian Islands (Toonen et al., 2010). Toonen et al. (2010) found that the NWHI are far more connected on average (and therefore comparatively robust) than the MHI, but that connectivity between the MHI and PMNM is limited. The results of this study highlight that the MHI are isolated in terms of resource management and will not receive substantial subsidy from PMNM; the MHI serve more as a source for larval and species movement to PMNM, although limited.

Johnston Atoll has also been shown to be a stepping stone to marine species colonization in the Hawaiian Archipelago, serving as an important population maintenance vehicle in the Hawaiian Archipelago. Ocean currents that could facilitate larval transport from Johnston Atoll to the Hawaiian Archipelago include the subtropical countercurrent and the Hawaiian Lee countercurrent. A critical pelagic larval duration (PLD) of approximately 40-50 days for successful transport to the Hawaiian Archipelago from Johnston Atoll is required (Toonen et al., 2010). Specific larval transport corridors include both the mid-archipelago (e.g., Lalo) and the northern portion of the main island group (e.g., Kaua'i). Marine species larvae originating from Johnston Atoll with PLDs less than 40 days did not reach the Hawaiian Archipelago. Specific species with longer PLDs include *Acropora spp.* whose planula larvae can remain competent for up to 91 days and *Epinephelus quernus* (Hawaiian grouper) larvae whose PLD exceeds the necessary threshold (Toonen et al., 2010). Johnston Atoll shows the capacity to serve as a significant source location to supplement genetic flow and species colonization for Lalo.

Philopatry, or the tendency of an organism to stay in or habitually return to a particular area, although it may not be suitable, is a key component that highlights the significance and magnitude of emergent land loss at Lalo. The causes of philopatry are numerous, but natal philopatry, where animals return to their birthplace to breed, may be the most common. As beaches wash away due to storm surges and sea level rise, nesting Hawaiian green sea turtles and seabirds, along with resting Hawaiian monk seals will continue to return to ephemeral islets that experience periodic inundation. This philopatric behavior can lead to loss of nests, chicks, or pups who get washed away and die.

As climate change impacts continue to directly affect Tern Island, East Island, and the smaller surrounding islets, these philopatric species have shown the ability to relocate to new (usually less suitable) habitat not historically used, without anthropogenic intervention. Following the complete erosion of East Island by Hurricane Walaka in 2018, nearby Tern Island covered in discarded remnants from its military past became the new primary nesting site for the Hawaiian green sea turtle population. This resulted in a shift of nesting to degraded habitat and increased entrapment risk. The response of the sea turtles at Lalo to the impacts of dramatic habitat loss and degradation raises the question of the population‘s plasticity to disturbance events. As primary nesting, resting, and breeding habitats face continued climatic impacts, understanding the plasticity of species at Lalo, like the Hawaiian green sea turtle, is vital for creating a resilience plan to support maintaining viable population sizes over time.