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

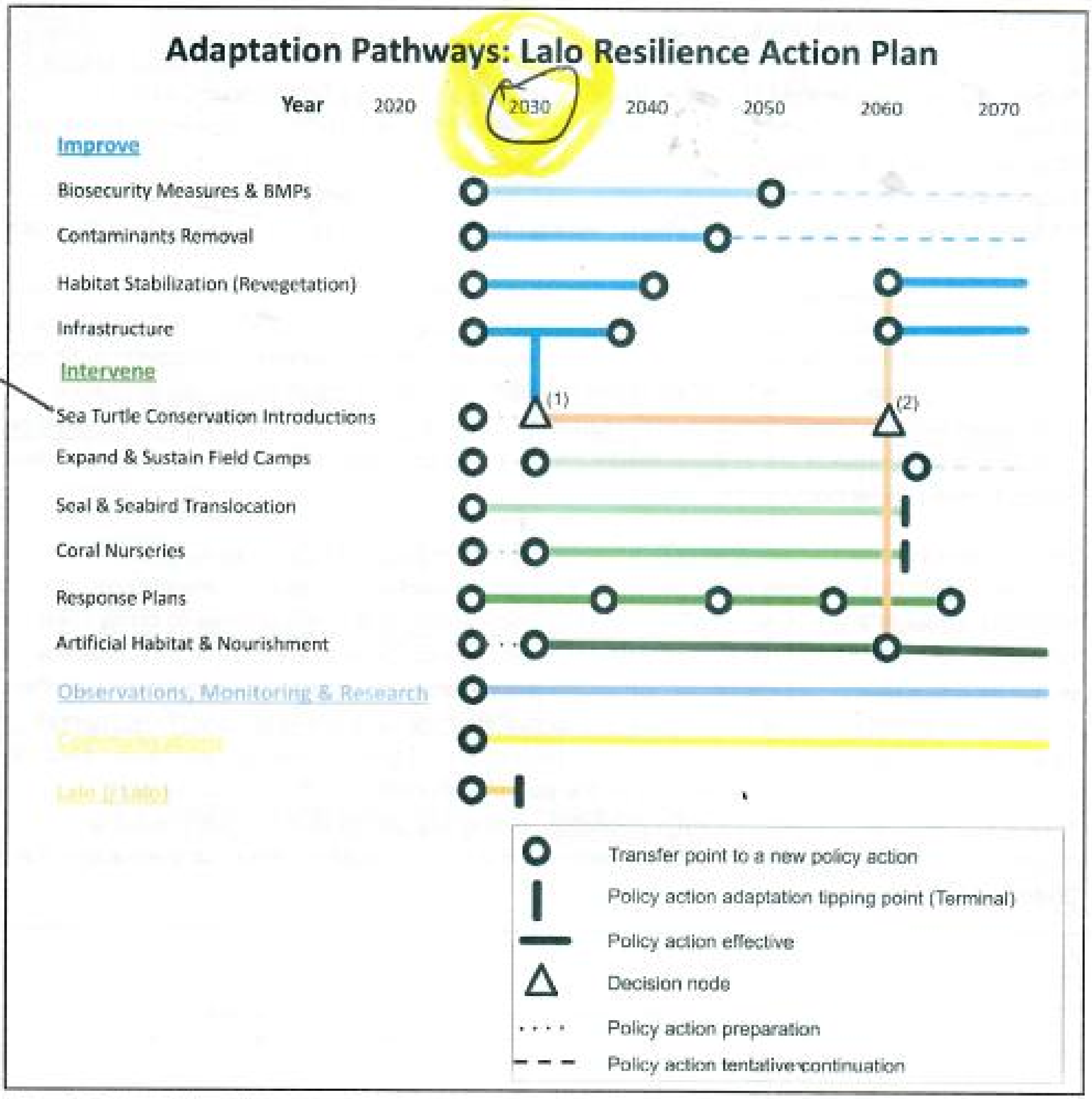

Figure 2. Potential adaptation pathways outlining policy actions that could be taken between 2025 and 2070. Actions are classified as either habitat and infrastructure improvements, new or existing conservation interventions, observations, monitoring, and research, observation tools, communications, 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, 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, O'ahu, or Hawai'i Island. Investigating Ni'ihau 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 Hawai'i presents several unique challenges. Due to geographic isolation, Hawai'i 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 iimu (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, Hawai'i 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 Lalo's 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

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.