Beach and Shoreline Habitats

Climate Change Vulnerability Assessment Synthesis for Maui, Lānaʻi, and Kahoʻolawe

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for beach and shoreline habitats on Maui Nui*[1] *based on expert input and existing information. Specifically, the information presented below comprises vulnerability factors selected and scored by habitat experts,*[2] *relevant references from the literature, and peer-review comments and revisions (see end of document for methods and defining terms). The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Habitat Description

Beach and shoreline habitats occur in low-lying coastal areas on Maui Nui and include sandy beaches, boulder/cobblestone/rocky beaches, rocky cliffs and coastal shelves (limestone or lava), dunes, coastal shrubs and strands, and manmade coastal structures (Vuln. Assessment Workshop, pers. comm., 2016). Beaches, cliffs, and coastal shelves are exposed to waves and tides, while dunes and strand communities experience less frequent exposure to these marine influences. Cumulatively, beach and shoreline habitats act as a buffer between the ocean and inland habitats and human communities (U.S. Fish and Wildlife Service 2011). Beach and shoreline habitats support wet, mesic, and dry vegetative communities, as well as a variety of wildlife species, including terrestrial and aquatic invertebrates, migratory shorebirds, seabirds, and nesting or basking marine species (Hawaiʻi Department of Land and Natural Resources 2015).

Habitat Vulnerability

Beach and shoreline habitats on Maui Nui were evaluated to have moderate-high vulnerability to climate change due to high sensitivity to

Beach and Shoreline Habitats	Rank	Confidence
Sensitivity	High	High
Future Exposure	High	High
Adaptive Capacity	Moderate	High
Vulnerability	**Moderate-High**	**High**

[1] Molokaʻi is considered separately from this assessment. The vulnerability assessment workshop approach was not applied to Molokaʻi as the PICCC funded Ka Honua Momona between 2014-2016 to host a workshop series to identify climate-related risks and vulnerabilities, and brainstorm potential solutions and partnerships. EcoAdapt and PICCC were invited to participate in a one-day workshop with the Molokaʻi Climate Change Network in April 2017 to discuss adaptation options.

[2] This information was gathered during a vulnerability assessment and scenario-planning workshop in August 2016 (http://ecoadapt.org/workshops/mauivulnerabilityworkshop). Further information and citations can be found in the *Hawaiian Islands Climate Vulnerability and Adaptation Synthesis* and other products available online at www.bit.ly/HawaiiClimate.

climate and non-climate stressors, high exposure to projected future climate changes, and moderate adaptive capacity.

Climatic factors such as sea level rise, tropical storms, and extreme precipitation events accelerate coastal erosion and increase susceptibility to inundation. Along with drought, wildfire, and flooding, these factors influence vegetative composition, with potential implications for the persistence of native species. Non-climate stressors (e.g., development, agricultural conversion, roads, recreation, invasive ungulates, and invasive vegetation) compound climate-driven habitat reductions and vegetative shifts, and also degrade remnant habitat quality by promoting runoff and erosion and facilitating invasive vegetation establishment.

The adaptive capacity of beach and shoreline habitats is bolstered by the fact that they are highly valued, highly managed, and in some areas, have protected status. However, the majority of beach and shoreline habitats have been degraded and fragmented by human activity. Development and other human land uses also prevent landward habitat migration in response to sea level rise and impair the natural resistance and recovery of coastal habitats experiencing disturbance. Workshop participants evaluated societal support for managing and conserving beach and shoreline habitats to be low.

Sensitivity and Exposure

Climatic Factors and Disturbance Regimes

Beach and shoreline habitats on Maui Nui are sensitive to climate factors that increase erosion and inundation, such as sea level rise, coastal flooding, tropical storms, and runoff from extreme precipitation events (Table 1). These climatic factors, along with drought, can alter or diminish beach and shoreline habitat extent and drive shifts in community composition, affecting available wildlife habitat and the provisioning of ecosystem services (e.g., storm protection). Beach and shoreline habitats are also sensitive to disturbance; many coastal species are not adapted to wildfire, and flooding can accelerate coastal erosion.

Beach and shoreline habitats are likely to experience accelerated erosion, shoreline retreat (Fletcher et al. 2012), and bluff failure (Eversole & Andrews 2014) due to the combined impacts of sea level rise, altered storm patterns, waves, and tides. Additionally, coastal erosion will likely increase if shifts in flood frequency and severity surpass the buffering/storage capacity of coastal wetlands (U.S. Fish and Wildlife Service 2011). These changes are likely to cause further loss of beach and shoreline habitats if habitats are unable to migrate landward (Eversole & Andrews 2014; Hawaiʻi Department of Land and Natural Resources 2015). Shifts in storm patterns are likely to have different impacts than precipitation shifts due to the added impact of waves and wind (Vuln. Assessment Workshop, pers. comm., 2016).

Table 1. Current and projected future trends in climatic factors and disturbance regimes, as well as their potential impacts on beach and shoreline habitats. These habitats are sensitive to the climatic factors and disturbance regimes listed below, and will likely be exposed to projected future changes in them. Factors presented are those ranked as having a moderate or higher impact on these habitats; additional factors that may influence these habitats to a lesser degree include precipitation timing, soil moisture, solar intensity, and disease.

Climatic factors and disturbance regimes High impact (high confidence)		
Sea level rise & shoreline change	***Historical and current trends*** • At Kahului station, sea levels rose an average of 2.1 mm/year (0.08 in) from 1947–2016 (equivalent to a change of 0.21 m [0.69 ft] in 100 years; NOAA/National Ocean Service 2017) • Rising sea levels over the past century have accelerated beach erosion; Maui beaches are the most erosive in Hawaiʻi (Fletcher et al. 2012) • Maui beaches eroded by an average of 0.17 m/year [0.56 ft] across all beaches, with 85% of beaches eroding and 14% to 18% of beaches accreting since the early 1900s; in that time, 11% of total beach length (6.8 km [4.23 miles]) was completely lost to erosion and is now seawalls (Romine & Fletcher 2012) • No historical/current trends are available for Lānaʻi and Kahoʻolawe ***Projected future trends*** There is high certainty that sea levels will continue to rise at increasing rates, but the magnitude and timing of change is less certain. Possible future scenarios include: • By 2100, global sea level will likely rise between 0.3 to 2.5 m (0.98 to 8.2 ft); relative sea level may be higher in the Hawaiian Islands compared to global levels, ranging from 0.4 to 3.3 m (1.3 to 10.8 ft; Sweet et al. 2017); no regional sea level rise projections are available	***Potential impacts on habitat*** • Rising sea levels contribute to habitat loss due to cliff collapse (Fletcher 2010), enhanced coastal and beach erosion (Fletcher et al. 2012), and increased inundation (U.S. Fish and Wildlife Service 2011; Rotzoll & Fletcher 2013) • Sea level rise may reduce beach haul-out habitat for ʻIlio-holo-i-ka-uaua (Hawaiian monk seals; *Neomonachus schauinslandi*; Baker et al. 2006), nesting and basking habitat for honu (green sea turtles; *Chelonia mydas*) and honu ʻea (hawksbill sea turtle; *Eretmochelys imbricata*), and seabird nesting habitat (Hawaiʻi Department of Land and Natural Resources 2015) • Sea level rise may reduce intertidal foraging opportunities, affecting bird populations (Kane et al. 2014) • Sea level rise also exacerbates high wave events and extreme tides, which cause erosion and occasional overtopping of coastal strand systems (U.S. Fish and Wildlife Service 2011; Eversole & Andrews 2014) ***Potential refugia*** • Undeveloped flatlands (Vuln. Assessment Workshop, pers. comm., 2016) • ʻAhihi-Kinaʻu Natural Area Reserve (Vuln. Assessment Workshop, pers. comm., 2016)

	• Sea level rise will contribute to increased saltwater intrusion, shoreline loss, coastal inundation, and groundwater inundation (Ferguson & Gleeson 2012; Cooper et al. 2013; Rotzoll & Fletcher 2013; Kane et al. 2015) • Historical rates of beach erosion on Maui are likely to double with sea level rise by mid-century; 87% of beaches are likely to be eroding by 2050 (Anderson et al. 2015) • No projected future trends are available for Lānaʻi and Kahoʻolawe	
Coastal flooding	***Historical and current trends*** • Sea level rise (SLR) has contributed to both marine inundation (i.e. direct hydrological connection to ocean) and groundwater inundation (i.e. indirect due to elevated water table; Rotzoll & Fletcher 2013) ***Projected future trends*** Coastal flooding projections are relatively uncertain because there are no downscaled sea level rise projections for this region. Possible future scenarios include: • At 0.74 m (2.4 ft) of SLR (estimated to occur around 2100), 25.3% of the total area of Kanaha Pond State Wildlife Sanctuary in north Maui and 28.2% of the area of Keālia Pond National Wildlife Refuge in south Maui would be inundated (Kane et al. 2015) • At 0.75 m (2.5 ft) of SLR, 0.55 km^2 (135 acres) would flood in Kahului with saltwater intrusion significantly impacting the Kanaha Pond State Wildlife Sanctuary, and 0.04 km^2 (~10 acres) would flood in Lahaina (Cooper et al. 2013) • At 1.9 m (6 ft) of SLR, 2.13 km^2 (526 acres) would flood in Kahului and 0.37 km^2 (91 acres) would flood in Lahaina (Cooper et al. 2013) • No projected future trends for coastal flooding are available for Lānaʻi and Kahoʻolawe	***Potential impacts on habitat*** • Flat, low-lying coastal areas are vulnerable to marine inundation (Kane et al. 2014, 2015); areas with hydric soils are particularly vulnerable due to low drainage potential (Kane et al. 2015) • Increased inundation could reduce existing coastal strand habitat area (U.S. Fish and Wildlife Service 2011; Rotzoll & Fletcher 2013) • Keālia Pond will likely experience accelerated flooding earlier than Kanaha Pond due to lower overall site elevations (Kane et al. 2014)

Tropical storms/ hurricanes	***Historical and current trends***
	• Tropical storm frequency was particularly high from 1982–1995, but then decreased slightly from 1995–2000 (Chu 2002)
	• Overall, tropical storm frequency increased slightly since 1966–1981 (Chu 2002)
	
	Projected future trends
	Tropical storm projections are highly uncertain because they are influenced by large-scale patterns within the ocean and atmosphere (Murakami et al. 2013). Possible future scenarios include:
	• Increased frequency and strength of tropical storm activity around the Hawaiian Islands due to a northwest shift in storm track and increased strength because of large-scale changes in environmental conditions (Murakami et al. 2013)
		Potential impacts on habitat
		• Wind and wave events associated with storms can damage coastal vegetation and/or alter coastal vegetative community composition by changing soil salinity and moisture (Warshauer et al. 2009)
		• Runoff, altered wave direction, amplified wave energy, and winds associated with storms accelerate beach erosion and promote beach inundation (Fletcher et al. 2002, 2012)
		  ○ Seasonal high waves and storms can drastically alter beach width and grade; for example, Kihei's coastal habitats occasionally experience increased erosion during Kona storms (Fletcher et al. 2012)
		  ○ Hurricane-generated waves can be very large and destructive, causing overwash, erosion and inundation, particularly when combined with storm surge and high tides (Fletcher et al. 2002)
		  ○ Low-gradient, narrow beaches are particularly vulnerable to storm-related inundation (Fletcher et al. 2012)
		• Storms that co-occur with high tides or king tides can have extensive impacts on coastal habitats (Vuln. Assessment Workshop, pers. comm., 2016)
		
		Potential refugia
		• Depends on location; habitat areas that are being actively managed and restored with climate impacts in mind may serve as refugia (e.g., 'Ahihi-Kina'u Natural Area Reserve; Vuln. Assessment Reviewers, pers. comm., 2017)

Drought	***Historical and current trends*** • Drought length increased in 1980–2011 compared to 1950–1979 (Chu et al. 2010)	***Potential impacts on habitat*** • Drought may confer an advantage to alien vegetation and displace native vegetation (Natural Areas Reserve

	• Drought conditions are usually less prevalent during La Niña years, and more prevalent during El Niño years (Dolling et al. 2009; Chu et al. 2010) ***Projected future trends*** Drought projections are highly uncertain because they are primarily dependent on precipitation projections, which are variable and have high uncertainty. Possible future scenarios include: • Maui drought risk is likely to increase by 2100 for low- and mid-elevation leeward slopes, decrease on mid-elevation windward Haleakalā slopes and the summit of Mauna Kahālāwai, and remain static elsewhere (Keener et al. 2012) • Drought risk is likely to increase by 2100 for Lānaʻi and Kahoʻolawe, except for the summit of Lānaʻi, which may not experience a change in drought risk (Keener et al. 2012)	System 2012) • Drought conditions enhance fire risk (Conry & Cannarella 2010) ***Geographic variation*** • Drought impacts are particularly severe on Maui's leeward side (Vuln. Assessment Workshop, pers. comm., 2016)
Extreme precipitation events	***Historical and current trends*** • Since 1950, overall trend towards decreased intensity and frequency of extreme precipitation events (Chu et al. 2010) • However, in recent years this trend appears to be reversing direction, with more frequent extreme events occurring except on Lānaʻi, where the frequency of extreme events has continued to decline (Chu et al. 2010) • From 1960–2000, the annual maximum one-day precipitation volume has decreased (Chen & Chu 2014) ***Projected future trends*** Extreme precipitation projections are highly uncertain because of the variability associated with precipitation projections. Possible future scenarios include: • Reduced frequency of extreme precipitation events by 2100, particularly in dry areas (Elison Timm et al. 2011,	***Potential impacts on habitat*** • Intense rain often causes flash flooding in Maui's low-lying coastal areas (Richmond et al. 2001); West Maui and the Waiheʻe-Waiehu sub-region of North Maui are particularly vulnerable (Fletcher et al. 2012) • Extreme precipitation events increase erosion due to runoff (Fletcher et al. 2012)

	2013) • Little to no change in the frequency of extreme precipitation events by 2100 (Takahashi et al. 2011) • Significant increase in extreme precipitation events by 2100 (Zhang et al. 2016)	

Wildfire	***Historical and current trends***
	• From 1904–2011, the overall trend has been towards increases in area burned across all of the Hawaiian Islands, but with high interannual variability (Trauernicht et al. 2015)
	• The majority of wildfires on Maui occur during summer (June–Aug.), when conditions are warm and dry, accounting for 57% of the annual area burned (Chu et al. 2002)
	• No wildfire data is available for Lānaʻi and Kahoʻolawe
	
	Projected future trends
	• No regional wildfire projections are available, but increased wildfire is likely if drier conditions and more drought occur (Trauernicht et al. 2015)
		Potential impacts on habitat
		• Fires in coastal strand communities are typically infrequent due to low fuel loads and saline conditions; however, when these communities do burn, vegetation mortality is very high, particularly amongst succulents (Smith & Tunison 1992)
		• Frequent fires promote monotypic stands of invasive vegetation and displace native bunchgrasses, forbs, and shrubs (U.S. Fish and Wildlife Service 2011)
		• Wildfire increases runoff and erosion by removing vegetation (Trauernicht et al. 2015)
		• Wildfire alters habitat availability:
		  ○ Wildfire causes a temporal loss of habitat during and immediately following fire (Vuln. Assessment Reviewers, pers. comm., 2017)
		  ○ Wildfire may temporarily increase bird nesting habitat by removing invasive vegetation (e.g., pickleweed [*Batis maritima*]; Pacific Coast Joint Venture Hawaiʻi 2006)

Riverine flooding	***Historical and current trends*** • No consistent trends were found in stream peak discharge statewide (Oki et al. 2010) ***Projected future trends*** • No regional stream/river flooding projections are available, but flows may become more variable/flashy if mean annual precipitation declines (Strauch et al. 2015)	***Potential impacts on habitat*** • Flooding increases beach erosion (Fletcher et al. 2012)

Non-Climate Stressors

Sensitivity of the habitat to climate change impacts may be highly influenced by the existence and extent of, and current exposure to, non-climate stressors (Table 2). Non-climate stressors such as coastal development, roads, recreation, agriculture, invasive ungulates, and invasive trees, further exacerbate coastal habitat loss and degradation by altering habitat extent, connectivity, and ecological processes.

Table 2. Key non-climate stressors that affect the overall sensitivity of beach and shoreline habitats to climate change. Factors presented are those ranked as having a moderate or higher impact on these habitats; additional factors that may influence these habitats to a lesser degree include water diversions.

Non-climate stressors High impact (high confidence)	
Residential & commercial development	***Potential impacts on habitat*** • Development can destroy coastal habitats and degrade remnant habitats by increasing disturbance, exacerbating erosion, and contributing to pollution (Pacific Coast Joint Venture Hawai‘i 2006; Bruland & MacKenzie 2010; U.S. Fish and Wildlife Service 2011; Hawai‘i Department of Land and Natural Resources 2015) • Development can prevent landward migration of coastal habitats in response to sea level rise and coastal erosion (Kane et al. 2014, 2015); for example, roads, development, and sand removal practices are preventing landward migration of dunes at the former Maui Lu Resort in North Kihei (Vuln. Assessment Reviewers, pers. comm., 2017) • Shoreline hardening used to protect coastal properties and infrastructure contributes to erosion, narrowing, and loss of fronting beach, and flanking erosion on adjacent beaches (Fletcher et al. 2012); for example, seawalls have contributed to beach loss in North Kihei (Vuln. Assessment Reviewers, pers. comm., 2017) • Shoreline hardening affects natural patterns of beach accretion and erosion by altering longshore sediment transport and restricting upland sediment contributions (Fletcher et al. 2012) • Coastal lighting associated with development can negatively impact seabirds and turtles (Hawai‘i Department of Land and Natural Resources 2015) • *Pattern of exposure:* Localized (west Maui, Kihei and southward)
Pollution & poisons	***Potential impacts on habitat*** • Pollutants degrade coastal habitats, reducing habitat suitability for valued wildlife including seabirds and shorebirds (Hawai‘i Department of Land and Natural Resources 2015); pollutants can remain in sand/sediment for long periods of time (Thompson et al. 2002) • Marine debris (e.g., abandoned fishing gear, trash) can be deposited on Hawai‘i’s beaches and cause monk seal or turtle mortality via entanglement or ingestion (NOAA 2010) • *Pattern of exposure:* Widespread exposure to non-point source pollution, including all of Kaho‘olawe and Lāna‘i and much of Maui; localized exposure to point-source pollution

Invasive/ problematic trees & shrubs	***Potential impacts on habitat*** • Without restoration intervention, invasive trees and shrubs often displace native species in beach, coastal strand, and cliff habitats by shading out low-growing vegetation (Warshauer et al. 2009) • Invasive trees can increase the likelihood of cliff and/or bluff area collapse, compounding losses in native vegetation (Warshauer et al. 2009) • *Pattern of exposure:* Consistent across habitat
Invasive/ problematic ungulates	***Potential impacts on habitat*** • Ungulate grazing (cattle, goats, sheep, pigs, axis deer) has caused extensive loss and degradation of native coastal vegetation on Lānaʻi, Kahoʻolawe, and Maui by increasing erosion rates and invasive plant dominance (Warshauer et al. 2009; Natural Areas Reserve System 2012; Hawaiʻi Department of Land and Natural Resources 2015) • *Pattern of exposure:* Localized areas occur across the island
Roads, highways, & trails	***Potential impacts on habitat*** • Depending on location, roads and highways can prevent landward migration of coastal habitats threatened by sea level rise and coastal erosion (Kane et al. 2015); for example, South Kihei Road is blocking dune migration in North Kihei (Vuln. Assessment Workshop, pers. comm., 2017) • Roads and highways typically increase runoff, which contributes to higher flood volumes (Conry & Cannarella 2010) • Roads and highways elevate non-point source pollution and erosion (Trombulak & Frissell 2000) • *Pattern of exposure:* Localized areas occur across the island
Recreation	***Potential impacts on habitat*** • Pedestrian and off-road vehicle use can trample dune vegetation, contribute to erosion, and reduce habitat for nesting seabirds (U.S. Fish and Wildlife Service 2011; Hawaiʻi Department of Land and Natural Resources 2015) • Recreation may introduce non-native vegetation, exacerbating associated impacts (Conry & Cannarella 2010) • *Pattern of exposure:* Variable across habitat
Agriculture	***Potential impacts on habitat*** • Agriculture has contributed to the loss and alteration of Hawaiʻi's coastal habitats (Bantilan-Smith et al. 2009) • *Pattern of exposure:* Variable across habitat

Adaptive Capacity

Although some of the less developed regions of Maui retain beach and shoreline habitats with high ecological integrity, a significant portion of Maui's beach and shoreline habitat area has been lost or degraded as a result of development, agriculture, and invasive species (Table 3). These stressors also limit habitat connectivity and the potential for landward migration. In

general, human activities and land-use decisions impair the ability of coastal habitats to resist and recover from stressors, and can contribute to permanent ecological changes. Beach and shoreline habitats support many wildlife species and are highly valued by the public. Many of these habitats are also highly managed and have some type of protected status, which may enhance management potential in the face of climate change. However, workshop participants indicated that there is low overall societal support (including regulatory support) for coastal habitat management intervention and conservation.

Table 3. Adaptive capacity factors that influence the ability of beach and shoreline habitats to adapt to projected future climate changes. Factors that receive a ranking of "High" enhance adaptive capacity for these habitats (+), while factors that receive a ranking of "Low" undermine adaptive capacity (-).

Adaptive capacity factors	Moderate adaptive capacity (high confidence)
Extent & integrity Moderate (high confidence)	+ East Maui's coastal habitats are less altered and degraded due to their remoteness and more rugged terrain (Pacific Coast Joint Venture Hawai'i 2006) + Northern West Maui and southern East Maui retain good representation of wet, mesic, and dry coastal communities, more continuous shoreline, and limited development (Warshauer et al. 2009) +/- Coastal terrestrial habitats have a high extent but low habitat integrity (Vuln. Assessment Workshop, pers. comm., 2016) +/- Very few Maui beaches remain in good condition, with the exception of Kanaio, Waiohue, and Punalau beaches (Warshauer et al. 2009) - In a regional study of beaches exposed to erosion, Maui had the highest percentage of beach loss (11%) during the study period when compared to other islands (Fletcher et al. 2012) - Waihe'e has the only remnant coastal dunes in North Maui (Pacific Coast Joint Venture Hawai'i 2006)
Habitat isolation High (high confidence)	- Dune habitats are highly isolated (Vuln. Assessment Workshop, pers. comm., 2016). - Roads, agriculture, alien vegetation, and development/shoreline hardening prevent coastal migration (Vuln. Assessment Workshop, pers. comm., 2016)
Resistance & recovery Moderate-high (moderate confidence)	- Coastal systems (e.g., beaches) have a limited capacity to accrete sediment and keep pace with sea level rise due to small tidal ranges (<2 m [<6.5 ft]; Kane et al. 2015) - Hawaiian beach sand is primarily marine-derived carbonate skeletal material, not terrestrially sourced material (Anderson et al. 2015); armoring interrupts terrestrially sourced sediment accretion and prevents beaches from migrating landward (Romine & Fletcher 2013), increasing sandy shoreline vulnerability as sea levels rise - Human impacts on coastal strand vegetation are often permanent (Warshauer et al. 2009) - Human-driven degradation of coastal habitats impairs their ability to recover from natural stressors such as drought, storms, and landslides by

	reducing seed sources (Warshauer et al. 2009), and by physically limiting space needed for natural processes associated with these dynamic ecosystems (Vuln. Assessment Reviewers, pers. comm., 2017)
Habitat diversity Moderate (high confidence)	+/- Coastal areas provide habitat for a variety of endangered and endemic species, particularly coastal strand areas (Kane et al. 2015) - Several shoreline bird species have been lost in the past (Olson & James 2004)
Management potential Moderate-high (high confidence)	+ High public value: Coastal habitats are valued for their economic contributions, tourism, food security, lifestyle, and Hawaiian identity (Vuln. Assessment Workshop, pers. comm., 2016) + Coastal habitats provide a variety of ecosystem services, including food provisioning, tourism/recreation, storm protection, flood and erosion control, and water filtration (Hawaiʻi Department of Land and Natural Resources 2015; Kane et al. 2015) + Many coastal strand habitats are highly managed (Kane et al. 2014) and have some type of protected status, which may help buffer some non-climate and climate change impacts (Pacific Coast Joint Venture Hawaiʻi 2006) +/- A massive hurricane or other extreme event that impacts the economy would likely increase support for coastal habitat management (Vuln. Assessment Workshop, pers. comm., 2016); however, there is less support for habitat management in response to chronic stressors (e.g., slow habitat degradation as a result of development), and responses tend to be patchy (e.g., erosion mitigation at specific locations) rather than at a system or region-wide level (Vuln. Assessment Reviewers, pers. comm., 2017) +/- Land-use planning affects coastal habitats, and planning processes will be impacted by population growth, future development, political will, carbon reduction efforts, and success of green technology (Vuln. Assessment Workshop, pers. comm., 2016) +/- Moderate likelihood of alleviating climate change impacts, but low societal support (including regulatory support) for coastal habitat conservation and management: Impacts will depend on management choices (Vuln. Assessment Workshop, pers. comm., 2016)

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Hawaiian Islands Climate Synthesis Project:

Vulnerability Assessment Methods and Application

Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: A function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007).

Vulnerability Assessment Model

The vulnerability assessment model applied in this process was developed by EcoAdapt[3] (Hutto et al. 2015, EcoAdapt 2014a, EcoAdapt 2014b, Kershner 2014), and includes evaluations of relative vulnerability by local stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to focal habitats and ecosystem services. Stakeholders evaluated vulnerability of each resource by discussing and answering a series of questions for sensitivity and adaptive capacity. Habitat exposure was evaluated by EcoAdapt using future climate projections from the scientific literature; ecosystem service exposure was evaluated by workshop participants using the climate impacts table provided by EcoAdapt. Each vulnerability component (i.e. sensitivity, adaptive capacity, and exposure) was divided into specific elements. For example, habitats included three elements for assessing sensitivity and five elements for adaptive capacity. Elements for each vulnerability component are described in more detail below.

Stakeholders assigned one of five rankings (High, Moderate-high, Moderate, Low-moderate, or Low) for sensitivity and adaptive capacity. Stakeholder-assigned rankings for each component were then converted into scores (High-5, Moderate-high-4, Moderate-3, Low-moderate-2, or Low-1) and the scores averaged (mean) to generate an overall score. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity; this was due to greater uncertainty about the magnitude and rate of future change. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - Adaptive Capacity

[3] Sensitivity and adaptive capacity elements were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2013, and Lawler 2010.

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2013) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings, and uses these rankings to estimate the overall level of confidence for each component of vulnerability as well as overall vulnerability.

Rankings and scores presented should be considered measures of relative vulnerability and confidence (i.e. comparing the level of vulnerability between the focal resources evaluated in this project).

Vulnerability and confidence rankings and scores for a given element were supplemented with information from the scientific literature. The final vulnerability assessment summaries for a given resource include stakeholder-assigned rankings, confidence evaluations, and narratives summarizing expert opinions and information from the scientific literature.

Habitat & Ecosystem Service Elements

Sensitivity & Exposure (Applies to Habitats and Ecosystem Services)

1. Climate and Climate-Driven Factors: e.g., air temperature, precipitation, freshwater temperature, sea surface temperature, sea level rise, soil moisture, altered streamflows, etc.

2. Disturbance Regimes: e.g., wildfire, flooding, drought, insect and disease outbreaks, wind, etc.

3. Future Climate Exposure: e.g., consideration of projected future climate changes (e.g., temperature and precipitation) as well as climate-driven changes (e.g., altered fire regimes, altered flow regimes, shifts in vegetation types). Experts were provided with a summary of historical, current, and projected future climate changes for the main Hawaiian Islands.

4. Non-Climate Stressors: e.g., land-use conversion (e.g., residential or commercial development), agriculture and/or aquaculture, transportation corridors (e.g., roads, railroads, trails), water diversions, invasive and other problematic species, pollution and poisons, etc. For non-climate stressors, experts were asked to evaluate sensitivity, whether the habitat or ecosystem service is currently exposed to that stressor, and whether the pattern of exposure is widespread and/or consistent across the study area or is highly localized (e.g., exposure to aquaculture is highly localized but exposure to invasive grasses is often widespread).

Adaptive Capacity (Habitats)

1. Extent and Integrity: e.g., habitats that occur in multiple locations vs. single, small areas; high integrity vs. degraded habitats

2. Habitat Isolation: e.g., adjacent to other native habitat types vs. isolated habitats, barriers to dispersal (e.g., development, energy productions, roads, water diversions, etc.)

3. Resistance and Recovery: e.g., *resistance* refers to the stasis of a habitat in the face of change, *recovery* refers to the ability to "bounce back" more quickly from stressors once they do occur

4. Habitat Diversity: e.g., diversity of component native species and functional groups in the habitat

5. Management Potential: e.g., ability of resource managers to alter the adaptive capacity and resilience of a habitat to climatic and non-climate stressors (societal value of habitats, ability to alleviate impacts)

Adaptive Capacity (Ecosystem Services)

1. Intrinsic Value and Management Potential: e.g., ability of managers to alter the adaptive capacity and resilience of a service to climatic and non-climate stressors (societal value of ecosystem services, ability to alleviate impacts)

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