Recreation and Tourism

Ecosystem Service 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 recreation and tourism 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 ecosystem service vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Ecosystem Service Description

Maui Nui's native ecosystems and cultural landscapes provide a diversity of tourism opportunities, including ecotourism, geotourism, and cultural/historic tourism (Conry & Cannarella 2010; Hawaiʻi Tourism Authority 2015). Additionally, distinct mountainous, forested, and coastal habitats provide both mauka (upland) and makai (seaward) recreation opportunities (Hawaiʻi Department of Land and Natural Resources 2015a), which are utilized by visitors and residents alike (Conry & Cannarella 2010). Mauka activities include hiking, camping, bird watching, and sport hunting, among others; makai activities include hiking, wildlife viewing, beach access, sport fishing, snorkeling and scuba diving, whale watching, and other water-based activities (Conry & Cannarella 2010; Hawaiʻi Department of Land and Natural Resources 2015a). Cultural tourism (e.g., visiting historic sites), ecotourism (e.g., enjoying scenic views/forested landscapes), and geotourism (e.g., visiting volcanic areas) occur across the mauka to makai continuum (Conry & Cannarella 2010; Hawaiʻi Tourism Authority 2015).

Ecosystem Service Vulnerability

Recreation and Tourism	Rank	Confidence
Sensitivity	Moderate-High	Moderate
Future Exposure	High	Moderate
Adaptive Capacity	Moderate-High	High
Vulnerability	**Moderate-High**	**Moderate**

Maui Nui recreation and tourism was evaluated as having moderate-high vulnerability to climate change due to moderate-high sensitivity to

[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-high adaptive capacity.

Recreation and tourism are sensitive to climatic factors that reduce the integrity or naturalness of native systems or affect the health and behavioral patterns of wildlife, including drought, low streamflow, sea surface temperature changes, and increasing air temperatures. Recreation and tourism are also sensitive to factors such as sea level rise, flooding, tropical storms, extreme precipitation events, and wildfire, which contribute to loss of recreation and tourism opportunities (e.g., physical loss of beaches, loss of access in burned or flooded areas). Insects and disease also degrade tourism and recreation experiences by negatively impacting Hawaiian landscapes and wildlife, and posing a health hazard to visitors. A variety of non-climate stressors threaten recreation and tourism by affecting natural landscape integrity and access and degrading water quality via elevated runoff. Land-use changes (e.g., urban development, agriculture, roads/highways/trails, water diversions, energy development) eliminate natural areas and alter ecosystem processes, impacting valued wildlife and native plant species characteristic of Hawaiʻi and exacerbating some impacts of climate change (e.g., flooding, erosion). Similarly, invasive species (e.g., ungulates, flammable grasses, trees, reptiles/amphibians, parasites/pathogens, social insects) displace native species and alter regional forest and watershed processes, affecting tourism and recreation access, quality, and safety.

As a main component of Maui Nui's economy, recreation and tourism are highly valued and management for these ecosystem services has moderate-high societal support. However, management can be challenging because recreation and tourism can potentially degrade other ecosystem services (e.g., fresh water, food production, aesthetic values, cultural services), though recreation and tourism can benefit some services as well (e.g., provide support for biodiversity and conservation).

Sensitivity and Exposure

Climatic Factors and Disturbance Regimes

Climatic factors and disturbance regimes can impact recreation and tourism through three mechanisms: altering or degrading natural landscapes that provide these opportunities, damaging or destroying infrastructure, and directly affecting human participants (Table 1). For example, sea level rise, tropical storms, extreme precipitation events, flooding, and wildfire can reduce the availability of or limit access to natural landscapes used for tourism and recreation (e.g., beaches, upland areas), as well as damage or destroy tourism infrastructure. Other factors such as sea surface temperature increases, drought, and low streamflows degrade natural systems, reducing the quality of recreation and tourism experiences. In addition to degrading natural landscapes, warmer air temperature, insects, and disease also contribute to unenjoyable visiting conditions, which ultimately affect long-term visitation trends.

Table 1. Current and projected future trends in climatic factors and disturbance regimes, as well as their potential impacts on recreation and tourism. This ecosystem service is sensitive to the climatic factors and disturbance regimes listed below, and will likely be exposed to projected future changes in them.

Climatic factors and disturbance regimes	High impact (high confidence)	
Sea level rise, shoreline change, & coastal flooding	***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 0.21m [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 for sea level or shoreline change are available for Lānaʻi and Kahoʻolawe • Sea level rise has contributed to both marine inundation (i.e. flooding in areas with a direct hydrological connection to ocean) and groundwater inundation (i.e. flooding in areas with an indirect hydrological connection due to an elevated water table; Rotzoll & Fletcher 2013) ***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	***Potential impacts on ecosystem service*** • Sea level rise may reduce coastal area available for recreation and tourism by accelerating beach erosion/loss and increasing coastal inundation (Cooper et al. 2013) • Large increases in sea level (+1.9 m) may impair drainage by raising water tables, impacting Lahaina tourism by affecting drainage along coastal roads and at resorts (Cooper et al. 2013) • Sea level rise increases the inland reach of storm surge and high tides, increasing potential damage to tourism and recreation infrastructure (Cristini et al. 2013) • The annual upward growth of coral is 10–20 mm per year; sea level rise exceeding that rate could cause coral in deeper areas to die from lack of sunlight (Grigg & Epp 1989; Eversole & Andrews 2014), affecting recreational viewing opportunities ***Potential refugia*** • Beach erosion may be less on Lānaʻi (Vuln. Assessment Workshop, pers. comm., 2016)

	to 3.3 m (1.3 to 10.8 ft; Sweet et al. 2017); no regional sea level rise projections are available • 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 projections are also relatively uncertain because there are no downscaled sea level rise (SLR) 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	
Sea surface temperature	***Historical and current trends*** • Sea surface temperatures in the Pacific Ocean increased by 0.07°C to 0.23°C (0.13°F to 0.41°F) per decade from 1970–2010 (Australian Bureau of Meteorology & CSIRO 2011; IPCC	***Potential impacts on ecosystem service*** • Increasing sea surface temperatures may degrade nearshore recreation and tourism opportunities in Hawaiʻi (Cristini et al. 2013) by:

	2013) • In the Northeast Pacific, temperatures increased by 0.12°C (0.22°F) per decade from 1960–1990 (Casey & Cornillon 2001) ***Projected future trends*** There is high certainty that sea surface temperature will increase, but the magnitude of change is less certain and depends on large-scale patterns of ocean mixing and atmospheric processes (e.g., El Niño-Southern Oscillation [ENSO] and Pacific Decadal Oscillation [PDO]). Possible future scenarios include: • By 2100, increase between 1.3°C and 2.7°C (2.3°F and 4.9°F) compared to 1970–2010 (Australian Bureau of Meteorology & CSIRO 2011)	○ Promoting coral bleaching (Keener et al. 2012) ○ Facilitating marine invasive species expansions (Cristini et al. 2013) ○ Increasing harmful algal blooms and jellyfish incidence (Vuln. Assessment Reviewers, pers. comm., 2017)
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 ecosystem service*** • Storms typically increase runoff and erosion, which can impair coastal recreation and tourism opportunities by degrading nearshore water quality (Cristini et al. 2013) • Runoff and altered wave energy/direction associated with storms accelerates beach erosion (Fletcher et al. 2012) • Major hurricanes and other large storm events increase visitor risk of injury/suffering and may affect long-term tourism trends by altering social perception of regional storm risk (Cristini et al. 2013) and causing wind and wave damage to tourism areas (Coffman & Noy 2009) • Canopy damage associated with hurricanes and other large storm events can increase forest vulnerability to invasive species establishment (Loope & Giambelluca 1998; Denslow 2002), altering native ecosystems and related ecotourism attractions (Vuln. Assessment Reviewers, pers. comm., 2017)

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, 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)	***Potential impacts on ecosystem service*** • Heavy rains cause flooding in Kihei (Vuln. Assessment Workshop, pers. comm., 2016) and other low-lying coastal areas on Maui (Richmond et al. 2001) that typically house tourism and recreation amenities (Cristini et al. 2013) and infrastructure (Chu et al. 2009) • Extreme precipitation events increase flash flood warnings on Maui and degrade nearshore water quality, exposing tourists and recreationists to unsafe conditions (Vuln. Assessment Reviewers, pers. comm., 2017) • Extreme precipitation events frequently limit access and car travel to outlying areas such as Hana on Maui (Vuln. Assessment Reviewers, pers. comm., 2017) • Erosion and road damage due to extreme precipitation events causes road closures, limiting travel to and recreation on Maui; this is less likely to be an issue on Lānaʻi (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) • 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:	***Potential impacts on ecosystem service*** • Past droughts have caused declines in other economic sectors (e.g., ranching, agriculture), increasing the importance of recreation and tourism to Hawaiʻi's economy (Maly & Wilcox 2000) • Drought may negatively affect Maui's waterfalls (King 2013) and other locations providing terrestrial water tourism (Cristini et al. 2013) by reducing or eliminating streamflow (Bassiouni & Oki 2013) • Drought may degrade land-based recreation and tourism quality (e.g., hiking, bird watching) by affecting the health and integrity of native

	• 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 Lāna'i and Kaho'olawe, except for the summit of Lāna'i, which may not experience a change in drought risk (Keener et al. 2012)	ecosystems and species (Cristini et al. 2013) • Drought may reduce available water supply for the tourism industry, potentially increasing visitor costs (Cristini et al. 2013) • Drought may reduce food security and the availability of local produce, which tourists expect (Vuln. Assessment Reviewers, pers. comm., 2017)
Precipitation (amount & timing)	***Historical and current trends*** • Since 1920, precipitation has decreased across the Hawaiian Islands, with the strongest drying trends occurring over the last 30 years (Frazier et al. 2016; Frazier & Giambelluca 2017) • From 1920 to 2012, dry season (May–Oct.) precipitation declined 1% to 5% per decade for most areas on Maui and Lāna'i, particularly in leeward areas; Kaho'olawe experienced more modest declines of up to 1.2% per decade (Frazier & Giambelluca 2017) • From 1920–2012, Maui experienced the most significant wet season (Nov.–April) precipitation declines of any island in the state, decreasing 27.6 mm per decade, which ranged from 2% to 5% per decade in East Maui (Frazier & Giambelluca 2017) • The frequency of trade wind inversion (TWI) occurrence increased an average of 20% since 1990, resulting in a 31% reduction in wet-season rainfall and a 16% reduction in dry season rainfall at nine high-elevation sites on Maui (over 1,900 m [6,234 ft]; Longman et al. 2015) ***Projected future trends*** Precipitation projections are highly uncertain because they vary in projected direction and magnitude, and will be affected by shifts in the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), as well as the amount of future greenhouse gas emissions. Possible future scenarios include: • Little to no change in average precipitation by 2100 (Keener et	***Potential impacts on ecosystem service*** • Low precipitation periods may increase coastal tourism and recreation opportunities by decreasing runoff and erosion and increasing the number of beach days (Vuln. Assessment Workshop, pers. comm., 2016) • Reduced precipitation may decrease freshwater recreation opportunities (e.g., rafting, waterfall viewing; Cristini et al. 2013) by reducing streamflow (Bassiouni & Oki 2013) • Decreased rainfall would reduce available water supply for the tourism industry, potentially increasing visitor costs (Cristini et al. 2013)

	al. 2012) • Significant decreases in precipitation across all seasons by 2100, particularly in leeward areas (30% to 80% decrease in wet-season leeward precipitation and -20% to +20% change in wet-season windward precipitation; 10% to 90% decrease in dry-season precipitation; Elison Timm et al. 2015) • By 2100, increased rainfall on windward slopes of Maui (up to 30% in the dry season), and decreased rainfall on Lānaʻi and leeward slopes of Maui in both seasons (Zhang et al. 2016)	

Streamflow	***Historical and current trends***
	• Streamflow is typically highest from Jan.–March (wet season) and lowest during July–Sept. (dry season; Bassiouni & Oki 2013)
	• From 1943–2008, streamflow declined by 22% and baseflow declined by 23% compared to 1913–1943, with larger declines during the dry season and increased high-flow variability (Bassiouni & Oki 2013)
	• Jan.–March streamflow is typically low following El Niño events, and high following La Niña events; this pattern is enhanced during positive Pacific Decadal Oscillation (PDO) phases (Bassiouni & Oki 2013)
	
	Projected future trends
	• No regional streamflow projections are available, but if mean annual precipitation were to decline, streamflow scenarios may include:
	    ○ Continuing decline of low flows and baseflow (Strauch et al. 2015)
	    ○ Flashier and/or more variable streamflow (Strauch et al. 2015)
		Potential impacts on ecosystem service
		• Declining streamflows can reduce water-based terrestrial activities, including waterfall viewing and rafting (Cristini et al. 2013)

Air temperature	***Historical and current trends*** • From 1975–2006, the rate of air temperature increases has accelerated to 0.2°C (0.36°F) per decade, compared to overall increases of 0.04°C (0.07°F) per decade for all records from 1919–1975; the strongest warming is found at high elevations and in winter minimum temperatures (Giambelluca et al. 2008) • The annual number of freezing days on Haleakalā has declined since 1958 (Hamilton 2013) ***Projected future trends*** Projections that air temperature will increase are highly certain, although the magnitude of change is less certain. Possible future scenarios include: • Air temperature increases of 2.0°C (3.6°F) to 3.5°C (6.3°F) across the Hawaiian Islands by 2100, with more significant increases at higher elevations (Zhang et al. 2016) • More frequent and more intense extreme heat days (Keener et al. 2012)	***Potential impacts on ecosystem service*** • Warming air temperatures are likely to increase visitation to Haleakalā National Park in all seasons, resulting in an overall +5 to +15% increase in annual visitation (National Park Service 2015); crowding negatively affects overall visitor experiences (Hawaiʻi Department of Land and Natural Resources 2015a) • Increased air temperatures may degrade flora and fauna utilized for land-based tourism and recreation (Cristini et al. 2013) • Increased air temperatures may increase likelihood of disease spread, including pathogens that affect humans (e.g., dengue fever; Cristini et al. 2013) • Warmer temperatures may create uncomfortable conditions for visitors (Cristini et al. 2013)
Wind & circulation	***Historical and current trends*** • Since the 1990s, the Pacific trade winds (both the Walker and Hadley cells) have increased, corresponding with a negative Pacific Decadal Oscillation (PDO) phase (England et al. 2014) • Trade wind direction has shifted from predominantly northeast to east from 1973–2009 (Garza et al. 2012), which represents a cyclical shift that is known to complete its cycle approximately every 45 years (Wentworth 1949) • The frequency of trade wind inversion (TWI) occurrence increased an average of 16% starting in 1990 (Longman et al. 2015)	***Potential impacts on ecosystem service*** • Trade winds sustain recreation and comfortable temperatures (Vuln. Assessment Workshop, pers. comm., 2016) • Persistent winds (often associated with La Niña conditions) can accelerate beach erosion, affecting coastal recreation opportunities (Fletcher et al. 2012)

	Projected future trends Projections for the TWI are moderately uncertain due to the influence of large-scale atmospheric patterns (e.g., El Niño-Southern Oscillation [ENSO] and Pacific Decadal Oscillation [PDO]). Possible future scenarios include: • 8% increase in TWI frequency of occurrence, corresponding to an almost 50% decrease in days without a well-defined TWI (decrease from 17% of days currently to 9% of days by 2100; Zhang et al. 2016) • Possible decrease in TWI base height, ranging from small (Zhang et al. 2016) to more significant (Lauer et al. 2013) Surface wind speed and direction may change, but studies have reached varying conclusions: • Nov.–Dec. surface wind speeds across the Hawaiian Islands may decrease strongly by 2100, with small changes in surface wind speed possible in other seasons (Storlazzi et al. 2015) • Surface winds in the Hawaiian Islands may increase modestly, with a very modest increase in frequency of strong wind days (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	***Potential impacts on ecosystem service*** • Wildfire can destroy or damage recreation value of land (Hawaiʻi Department of Land and Natural Resources 2015a) • Wildfires can cause road closures and burned areas can be inaccessible for days to months due to hazardous conditions, reducing recreation opportunities (Trauernicht et al. 2015) • Active wildfires and burned areas undermine the aesthetic quality of Hawaiʻi's landscapes, potentially decreasing tourism (Trauernicht et al. 2015) • Wildfire increases erosion and sedimentation in

	(Trauernicht et al. 2015)	nearshore habitats, potentially affecting recreation opportunities and quality (Trauernicht et al. 2015)
Riverine flooding	***Historical and current trends*** • No consistent trends were found in stream peak discharge statewide (Oki et al. 2010a) ***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 ecosystem service*** • Flooding can damage tourism and recreation infrastructure (Chu et al. 2009; Cristini et al. 2013) • Flooding can increase surface water contamination, potentially increasing human exposure to pathogens or illness during recreation (Eversole & Andrews 2014)

Insects	***Historical and current trends***
	• No information is available about trends in insect outbreaks
	
	Projected future trends
	• 0.4 million forested acres across the Hawaiian Islands are at risk of experiencing a 25% decrease in standing live basal area by 2027 due to the combined threat of insects and disease (not taking climatic changes into account; Krist et al. 2014)
	  ○ 61,000 acres across the Hawaiian Islands are at risk due to myoporum thrips (*Klambothrips myopori*); on Maui, the greatest threat is in low-elevation forests on the leeward side (Krist et al. 2014)
	• 12,000 acres across the Hawaiian Islands are at risk due to Erythrina gall wasp (*Quadrastichus erythrinae*); on Maui, the greatest threat is in low-elevation forests on the leeward side (Krist et al. 2014)
		Potential impacts on ecosystem service
		• Insects can degrade tourism and recreation experiences by acting as a nuisance to humans:
		  ○ Little fire ants (*Wasmannia auropunctata*) are easily dislodged from vegetation and deliver painful stings, which can degrade human enjoyment of forested and other recreation areas (Starr et al. 2008; Lee et al. 2015)
		  ○ Little fire ants also infest lodging accommodations, which could ultimately affect tourism revenue (Lee et al. 2015)
		  ○ Mosquitoes (various species) act as vectors for human disease (LaPointe 2007)
		• Insect outbreaks have the potential to impact large areas of forest, targeting keystone species such as koa (*Acacia koa*; Haines et al. 2009) and wiliwili (*Erythrina sandwicensis*) trees (Rubinoff et al. 2010), potentially impacting recreation and tourism by affecting aesthetic quality
		• Warmer temperatures may alter insect development, reproduction, survival, and distribution (Régnière et al. 2012), exacerbating the above effects

Disease	***Historical and current trends***
	• No information is available for plant disease
	
	Projected future trends
	• Warming temperatures are expected to increase the distribution of avian diseases spread by mosquitos, such as avian malaria (Fortini et al. 2015)
	  ○ Within the Hanawi Natural Area Reserve on Maui, areas of montane forest where birds are at low risk of contracting malaria may be reduced by up to 47% by 2100 (Lānaʻi and Kahoʻolawe do not receive enough precipitation to support mosquito habitat; Benning et al. 2002)
	• 0.4 million forested acres across the Hawaiian Islands are at risk of experiencing a 25% decrease in standing live basal area by 2027 due to the combined threat of insects and disease (not taking climatic changes into account; Krist et al. 2014)
	  ○ On Maui, the greatest threat from ʻōhiʻa rust (*Austropuccinia psidii*) is on mid-elevation windward slopes (Krist et al. 2014)
	  ○ 53,000 acres across the Hawaiian Islands are at risk due to koa wilt (*Fusarium oxysporum* f. sp. *koae*); on Maui, the greatest threat is on mid-elevation windward slopes (Krist et al. 2014)
	• Little change is expected in the suitable climatic space for ʻōhiʻa rust (Hanna et al. 2012)
		Potential impacts on ecosystem service
		• Disease outbreaks close beach parks and other areas, limiting recreation opportunities (Vuln. Assessment Workshop, pers. comm., 2016)
		• Diseases can undermine recreational experiences and affect future tourism by increasing local fauna mortality (e.g., avian malaria contributes to endemic forest bird decline; Atkinson & LaPointe 2009)

Non-Climate Stressors

Sensitivity of the ecosystem service to climate change impacts may be highly influenced by the existence and extent of, and current exposure to, non-climate stressors (Table 2). Recreation and tourism are sensitive to a variety of non-climate stressors that impair functioning of Hawaiʻi's terrestrial habitats and watersheds, which are essential for maintaining tourism and recreational opportunities into the future.

Table 2. Key non-climate stressors that affect the overall sensitivity of recreation and tourism to climate change.

Non-climate stressors	Low-moderate impact (low confidence)
Residential & commercial development	***Potential impacts on ecosystem service*** • Too much development is unsightly (Vuln. Assessment Workshop, pers. comm., 2016), which can affect the natural character and tourism appeal of the island (Assante et al. 2012) • Development increases runoff, sedimentation, and contaminant loads, affecting surface water and nearshore water quality (Conry & Cannarella 2010; Hawaiʻi Department of Land and Natural Resources 2015b) • Trash and debris associated with developed areas degrades aesthetic value and visitor experience at beaches (Tudor & Williams 2003)
Agriculture & aquaculture	***Potential impacts on ecosystem service*** • Aquaculture has contributed to invasive fish (Brasher 2003) and invasive marine algal introductions in Hawaiʻi, which can undermine tourism experiences by degrading natural systems (Hunter 2007; Havird et al. 2013) • Agricultural water diversions exacerbate modified streamflows (Oki et al. 2010b), affecting water-based recreation and tourism • Agriculture has contributed to the loss and degradation of native Hawaiian moist and dry forest habitat (Pau et al. 2009) that supports bird viewing and mauka recreation activities (Conry & Cannarella 2010)
Pollution & poisons	***Potential impacts on ecosystem service*** • Waste runoff from wastewater plants and industrial facilities can degrade nearshore water quality, which may affect future recreation and tourism access and experience (Conry & Cannarella 2010) • Pollution can damage Hawaiʻi's identity as a pristine tourism destination (Conry & Cannarella 2010)
Energy production	***Potential impacts on ecosystem service*** • Wind farms may affect aesthetic views and recreational access (Vuln. Assessment Workshop, pers. comm., 2016)

Roads, highways, & trails	***Potential impacts on ecosystem service*** • Runoff from roads, highways, and trails increases erosion and can contain contaminants, affecting surface water and nearshore water quality and the health of native ecosystems valued for recreation and tourism (e.g., coral reefs; Conry & Cannarella 2010; Hawaiʻi Department of Land and Natural Resources 2015b; Oleson et al. 2017)
Groundwater development	***Potential impacts on ecosystem service*** • Continued population growth and increased tourism will increase water demand, likely leading to development of new groundwater sources (e.g., Launiupoko aquifer; Grubert 2010; Gingerich & Engott 2012) • However, a lack of new groundwater sources may limit water supply in dry conditions (Vuln. Assessment Workshop, pers. comm., 2016)
Water diversions	***Potential impacts on ecosystem service*** • Surface water diversions reduce water delivery to downstream areas, affecting scenic quality as well as impacting future water supply and quality (Oki et al. 2010b; Gingerich & Engott 2012)

Recreation	***Potential impacts on ecosystem service***
	• Depending on scale, intensity, and management, tourism and recreation can degrade the very habitats and species that provide this service (Bhattacharya et al. 2005; Hawaiʻi Department of Land and Natural Resources 2015b). Examples include:
	    ○ High visitation can compromise or eliminate sensitive systems (e.g., anchialine pools, caves/lava tubes) and species (e.g., Lānaʻi tree snail; Hawaiʻi Department of Land and Natural Resources 2015b)
	    ○ Sunscreen use degrades water quality and can harm corals (Downs et al. 2015)
	    ○ Boat harassment, swimming, and visitation can decrease marine mammal fitness (Vuln. Assessment Reviewer, pers. comm., 2017)
	• Recreation has introduced invasive fish in Hawaiʻi (Brasher 2003), which can degrade tourism value of some sites (e.g., anchialine pools; Havird et al. 2013)
	• Recreation can also introduce non-native vegetation, exacerbating associated impacts (Conry & Cannarella 2010)

Invasive/ problematic parasites & pathogens	***Potential impacts on ecosystem service*** • Introduced pathogens and parasites decrease wildlife viewing opportunities by decreasing habitat availability (Hawaiʻi Department of Land and Natural Resources 2015b) or by causing mortality of endemic species (e.g., forest birds are vulnerable to avian malaria and pox; Benning et al. 2002; Atkinson & LaPointe 2009)
Invasive/ problematic flammable grasses	***Potential impacts on ecosystem service*** • Invasive grasses increase wildfire risk and associated impacts on recreation and tourism (Trauernicht et al. 2015)

Invasive/ problematic reptiles & amphibians	***Potential impacts on ecosystem service*** • Coqui frogs (*Eleutherodactylus coqui*) and veiled chameleons (*Chamaeleo calyptratus*) may compete with Maui's native forest birds for food, ultimately affecting wildlife viewing opportunities (Hawai'i Department of Land and Natural Resources 2015b)
Invasive/ problematic ungulates	***Potential impacts on ecosystem service*** • Feral ungulate browsing increases erosion (Bruland et al. 2010), which can affect coastal tourism by smothering nearshore reefs (Hawai'i Department of Land and Natural Resources 2015b) • Feral ungulate presence is linked with higher fecal indicator bacteria in surface water (Strauch et al. 2016), posing potential health risks • However, many non-native ungulates are utilized as game species in Hawai'i; hunting is an important aspect of cultural identity and is practiced for subsistence, as well as being a recreational opportunity (Hawai'i Department of Land and Natural Resources 2015b)
Invasive/ problematic trees & shrubs	***Potential impacts on ecosystem service*** • Invasive trees (e.g., *Morella faya*, *Falcataria moluccana*, *Miconia calvescens*) displace native forests and in many cases alter soil biochemical or hydrological processes favoring further invasion of non-native species (Smith 1988; Seibold 2000; Gallaher & Merlin 2010; Atwood et al. 2010) • Invasive trees modify and degrade native forest habitats, bird populations, and other natural resources attractive for ecotourism, bird and wildlife watching, and cultural tourism (Conry & Cannarella 2010; Hawai'i Department of Land and Natural Resources 2015b) • Invasive trees may also affect nearshore recreation and tourism by impacting upland erosion and runoff (Conry & Cannarella 2010; Hawai'i Department of Land and Natural Resources 2015b) • Thorns from the invasive long-thorn kiawe (*Prosopis juliflora*) can pierce automobile and bicycle tires and/or injure people (Gallaher & Merlin 2010) • Kiawe can form dense thickets, restricting coastal access (Hawai'i Invasive Species Council 2017)
Invasive/ problematic fish	***Potential impacts on ecosystem service*** • Invasive fish can displace or eliminate native aquatic species, degrading tourism value of some sites (e.g., elimination of shrimp in Waianapanapa Cave anchialine pool; Havird et al. 2013)

Invasive/ problematic social insects	***Potential impacts on ecosystem service*** • Social insects were not historically present in Hawaiian ecosystems (Wilson 1996); their introduction has facilitated enhanced forest disease and damage (Conry & Cannarella 2010) and undermined native plant reproductive potential by increasing predation on and/or food competition with native pollinators (e.g., insect and birds; Wilson & Holway 2010; Hanna et al. 2013), which may affect natural resources valued for recreation and tourism (Conry & Cannarella 2010) • By competing for food with Maui's native forest birds, invasive social insects may ultimately affect wildlife viewing opportunities (Vuln. Assessment Reviewers, pers. comm., 2017) • Invasive social insects can directly degrade recreation and tourism experiences by acting as nuisance to visitors (e.g., little fire ant stings), which may ultimately impact tourism revenue (Starr et al. 2008; Lee et al. 2015)

Adaptive Capacity

Recreation and tourism are major contributors to the Hawaiian economy, which increases public value and support for management of this service (Table 3). Recreation can benefit some other ecosystem services such as biodiversity, but can also have varying or conflicting impacts on services such as cultural knowledge and heritage, fresh water, aesthetic values, and food production. Despite the value placed on recreation and tourism, there is only moderate willingness for humans to change their behavior to maintain this service.

Table 3. Adaptive capacity factors that influence the ability of recreation and tourism to adapt to projected future climate changes. Factors that receive a ranking of "High" enhance adaptive capacity for this ecosystem service (+), while factors that receive a ranking of "Low" undermine adaptive capacity (-).

Adaptive capacity factors	Moderate-high adaptive capacity (high confidence)
Intrinsic value & management potential	+ High public value and moderate-high societal support for management: Tourism is the largest economic sector on Maui, and represents 26% of the Hawaiian economy (Leong et al. 2014); recreation also benefits residents (Vuln. Assessment Workshop, pers. comm., 2016) + Promoting tourism and recreation may reduce land-use conversion pressure by emphasizing the value of open space and natural landscapes (Bhattacharya et al. 2005) + Visitor education and outreach may help minimize impacts on natural landscapes, particularly sensitive ecosystems (Hawai'i Department of Land and Natural Resources 2015b) + Recreation and tourism support some other ecosystem services, such as biodiversity (Bhattacharya et al. 2005) +/- Recreation and tourism have variable impacts on cultural services and values: Cultural tourism can help revive cultural lifestyles and practices, but recreation and tourism can also displace local communities and/or reinforce stereotypes (Bhattacharya et al. 2005)

	- Moderate (Maui) and low-moderate (Lānaʻi) human willingness to change behavior to maintain access to service: People value recreation and tourism opportunities, but do not always take action to protect service provisioning (e.g., people want more water but will not fence/restore habitat to promote healthy watersheds; Vuln. Assessment Workshop, pers. comm., 2016) - It is important to maintain tourism and recreation opportunities on Maui because visitors could easily go to other islands; residents have less opportunity to access recreation on other islands if services are not maintained on Maui (Vuln. Assessment Workshop, pers. comm., 2016) - Recreation and tourism conflict with other ecosystem services, including fresh water, aesthetic values, commercial agriculture (Vuln. Assessment Workshop, pers. comm., 2016), and food provisioning (e.g., recreational vs. subsistence fishing; Bhattacharya et al. 2005) - There are limited management opportunities to address coral bleaching and sea level rise (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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