Climate Change and Maui: Indicators, Impacts, and Responses

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Introduction

On the Pacific seafloor, a plume of superheated magma continues to rise from deep within the mantle, some 80-100 km below the Earth's crust. It is believed that this relatively stationary magmatic hotspot is responsible for the construction of each of the 107 islands that stretch 6,100 km northwest from the island of Hawai‘i in the south to the Emperor Seamounts in the north (Fig 1). This continuous volcanic process, along with the steady northwesterly movement of the Pacific Plate at 8.6 cm per year, creates a new volcanic summit roughly every 500,000 years (Juvik et al., 1998).

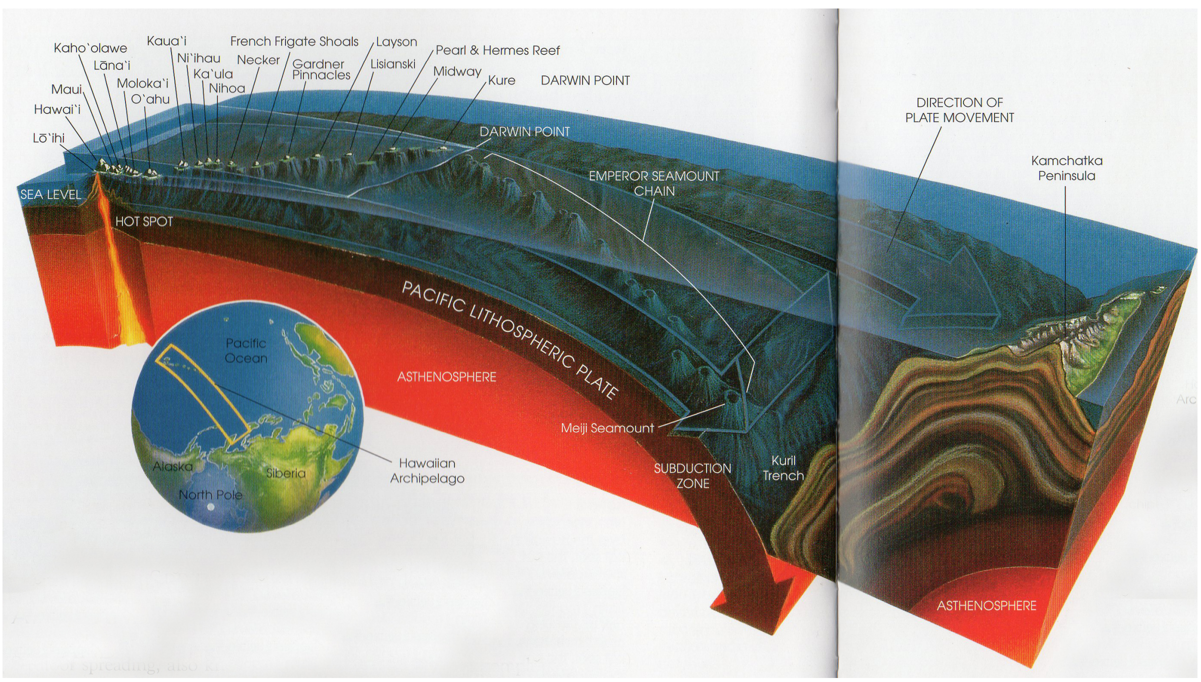

FIGURE 1 - This illustration depicts the formation of the Hawaiian Archipelago over roughly 65 million years (Grigg, 2012)

The Hawaiian Archipelago began its formation 80 million years ago near the end of the dinosaurs' reign. All Hawaiian Islands are classified as shield volcanoes and undergo a similar life cycle "from a deep submarine volcano to a drowned reef-topped island" (Ziegler, 2002, p.

23). These shield volcanoes build up slowly over time, layer after layer, as magma oozes from the vent and "spread[s] out in flows rarely more than 30 feet thick" (Hazlett, 1996, p.11).

Maui is located in the Central Pacific Ocean between 20 and 21 degrees North latitude approximately 4,000 km southwest of Los Angeles, CA and 6,600 km southeast from Japan. It is found near the southeastern end of the larger Hawaiian Archipelago, which stretches 2,400 km to the northwest. The second youngest island, at 1.75 million years old, Maui is comprised of two volcanoes, West Maui and Haleakalā. A narrow isthmus formed when the Haleakalā lavas banked against the older West Maui's and connected these two geological features (Macdonald, 1983). The formation of Haleakalā on the island of Maui was a geologic process that spanned 700,000 years and it is still considered to be an active volcano in its rejuvenated stage (Culliney, 2006).

During the last ice age of the Pleistocene era, Maui was part of a greater island mass called Maui Nui that was comprised of six volcanoes (Fig 2). Sea level during this time was nearly 100 m below its current levels. As the water trapped in continental glaciers was released by melting ice 12,000 years ago, the low areas of Maui Nui became the shallow straits between the islands that exist today (Hazlett, 1996).

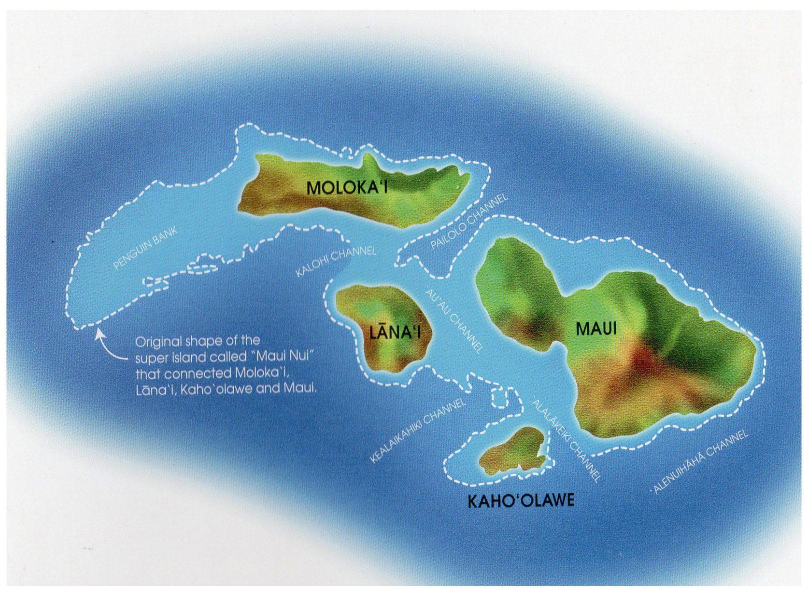

FIGURE 2 - Maui Nui during the early Pleistocene Era when sea level was 100 m below current levels. As continental glacial ice melted, sea level rose and filled in the narrow straits between the islands (Grigg, 2012)

Although it is believed that Haleakalā experienced Pleistocene glaciations at its summit, Porter

(2005) argued that there was only circumstantial evidence to support the theory (unlike the physical evidence found on Mauna Kea and Mauna Loa on the neighboring island of Hawai‘i).

Although marine organisms arrived relatively early as Maui broke the surface of the ocean, it took an additional 300,000 years to complete its post-shield-stage development and for erosion to till the land in preparation for the small number of immigrant species that began populating the island during the late Pleistocene epoch (Juvik et al., 1998). These hardy pioneer species, primarily from the Indo-West Pacific, populated reefs and newly formed lava fields with the aid of the wind, the prevailing the Kūrōshio and North Pacific Currents, and ancient island “stepping stones” (Ziegler, 2002).

Prior to human settlement, native ecosystems consisted of six major terrestrial and three marine ecosystems that evolved over time through a combination of ecological succession and changing vegetation zones (Juvik et al., 1998) (Fig. 3). Ziegler (2002) suggested that as new lava cooled enough to allow plant growth,

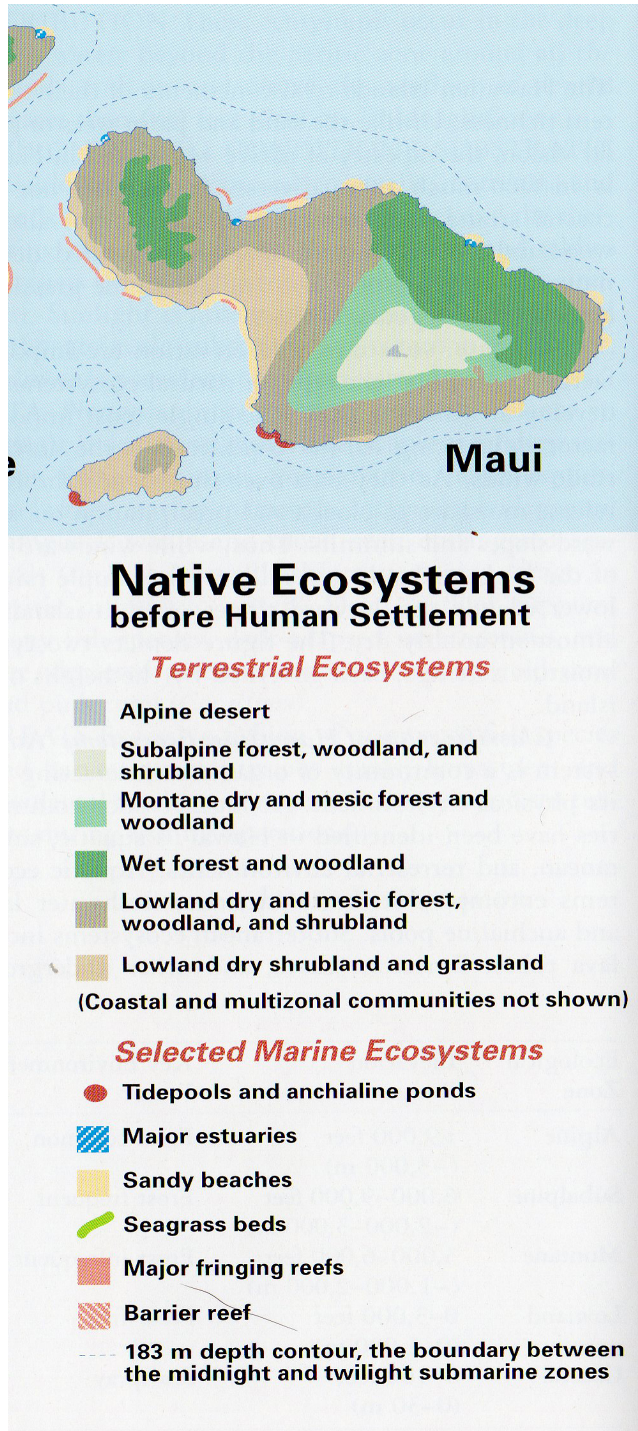

FIGURE 3 - Native ecosystems prior to human settlement (Juvik et al., 1998).

spores settled in the moist cracks and resulted in the growth of ferns, mosses, lichen, and fungi. After a period of four to five years, numerous flowering plants, trees, and shrubs began to appear and established in small pockets of soil that developed from organic material and weathered basalt (Ziegler, 2002). After 150 years or so, the trees increased in size and number and shaded out the lower plants. Three to four hundred years later, the ecosystems reached their climax stage (Ziegler, 2002).

It is generally accepted that the first human colonizers arrived in Hawaiʻi from the Marquesas Archipelago, some 4,000 km to the southeast, between 300-500 AD. Pratt & Stone (1990) suggested that the original population may have been as few as 100 people and the initial impact on the environment was small at first, but after about 1200 AD, with the arrival of the Tahitians, the population increased dramatically and doubled every century. The success of irrigation and subsistence practices and a highly stratified hierarchical system of governing led to a rapid population expansion from 40,000 people in 1200 AD to a peak of 200,000 in 1500 AD (Grigg, 2012).

Subsistence agriculture in the first few decades following Western contact in 1778 gave way to commercial harvesting of resources for trade. The export of goods such as sandalwood, pulu (pillow and mattress stuffing), firewood, endemic olonā for ship's cordage, and agricultural provisioning of whaling and trading vessels with pigs, bananas, taro, and sweet potatoes dominated the early to mid 19th century (Pratt & Stone, 1990). "Beginning in the 1850's, modern agriculture, ranching, and varied forest management practices, […] brought rapid and large-scale land use changes to Hawaiʻi" (Pratt & Stone, p.41).

The 20th and 21st centuries saw a rise of mixed-use development on the isthmus of the

Central Valley in support of the growing sugarcane, pineapple, and tourism industries. Culliney (2006) stated "Major threats come from an invasive community of international private enterprise, exemplified by large resource extractors and land developers, in affiliation with certain agencies of federal, state, and county governments" (p. 343). Residential, retail, and industrial areas have sprawled across Maui's best arable soils, and the recent end to the sugarcane industry has us all wondering if Maui is destined to rival Oahu in development density.

Humanity has occupied Hawai'i for a little over 1,500 years and has drastically affected the established ecosystems of the Archipelago (Fig. 4). Non-regenerative agricultural practices, natural resource abuses, introduced plant and animal species, non-place-based management strategies, and destructive land-use patterns have significantly impacted Maui's native flora and fauna. In addition to the activities listed above, humanity can now lay a claim to anthropogenic climate change impacts. Through this new development, we are not only affecting flora and fauna, but we are threatening our very way of life as a species.

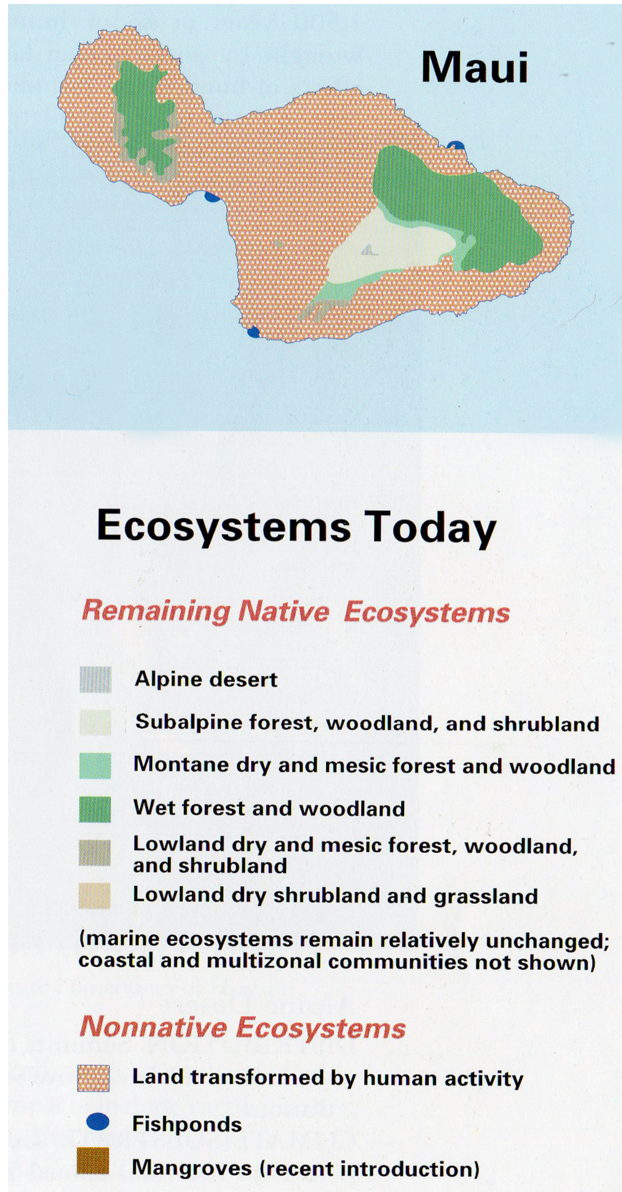

FIGURE 4 – Human practices have altered the location and biodiversity of Maui's native ecosystems (Juvik et al., 1998).

Current Climate Conditions

Maui’s balmy subtropical climate, characterized by uniform temperatures, moderate humidity, and cool breezes, is the result of four interconnected and contributing factors: 1) latitude, 2) the Pacific Ocean, 3) atmospheric circulation, and 4) mountainous terrain (Juvik et al., 1998 and Ziegler, 2002).

Maui’s proximity to the equator results in minimal seasonal differences within average length of day and annual variation in mean monthly temperatures. Twice per year the sun is directly above Maui and results in the longest days between May and July, lasting a little over 13 hours; while in December, the sun descends to 45 degrees above the horizon and results in a daytime length of just under 11 hours, a difference of only 2 ½ hours (Ziegler, 2002). The annual variation in mean monthly temperatures at sea level varies 5°C, while diurnal variations can change by as much as 5.5°-8.3°C (Juvik et al., 1998). Through a process known as adiabatic cooling, temperature decreases with elevation by roughly 1.8°C for every 305 m of elevation gained. Ricklefs (2000) defined this function as a “decrease in temperature, which is caused by the expansion of air with lower atmospheric pressures at higher altitudes” (p. 149). Therefore, the adiabatic cooling between sea level and the 3,055 m summit of East Maui’s Haleakalā results in a 18°C drop in temperature. This drastic variation in temperature creates 10 of the 14 zones of the Koppen Climate Classification System (Paiva, 2015) and makes Maui one of the most spatially diverse areas on Earth (Juvik et al., 1998).

The Pacific Ocean and its prevailing currents play a significant role in maintaining equable temperatures on Maui. The high latent heat capacity of water allows the ocean to readily “release and absorb large amounts of heat to and from air passing over it without its own average temperature changing substantially" (Ziegler, 2002, p. 70). This physical property has the effect of dampening the seasonal and daily temperature effects of solar radiation on the island. The North Pacific Current influences temperature on the island as well. As it travels clockwise in the North Pacific Basin, it picks up cold water from the Bering Sea and carries it south to Maui. Ziegler reasoned, "Cooler trade winds moving over the eastern loop of the current gradually warm to about the same sea temperature, and warmer ones cool to it, subsequently serving to provide the archipelago with an equable ambient temperature" (p. 70).

Maui's climatic patterns are derived from the atmospheric circulation systems present in the equatorial and subequatorial regions and the seasonal north to south shifting of the solar equator (the latitude which lies 90 degrees below the sun at any given time). Bailey's (1995) hierarchical ecoregional classification system places Maui, whose climate is "largely controlled by equatorial and tropical air masses," in the "Humid Tropical Domain" that is characterized by seasonally variable heavy annual rainfall. The effects of regional air mass circulations found at this latitude create a two-period seasonality, *kau wela* or the dry season in May-October and *ho'oilo* or the wet season in November-April (Ziegler, 2002). The general components responsible for this idealized pattern of seasonality are the Intertropical Convergence Zone (ITCZ), the Hadley Cell, the North Pacific High, the Aleutian Low, and the Coriolis effect.

The ITCZ is the low-pressure belt that stretches across the middle of the globe and seasonally coincides with the solar equator that shifts between 5.3°S in the Austral Summer and 7.2°N in the Boreal Summer (Donohoe et al., 2013) (Fig. 5). As the sun heats the equatorial air, it becomes less dense and rises into the atmosphere carrying evaporated moisture from the ocean below; the rising air mass spreads to the north, cools, condenses, and descends in an area of high-pressure, generally 30° north from its origin, only to travel southward across the ocean's surface until it converges with the Southern Ocean Hadley Cell (traveling northward across the ocean's surface) and begins the process over again at the ITCZ (Ricklefs, 2000). This circulating air mass is called the Hadley Cell.

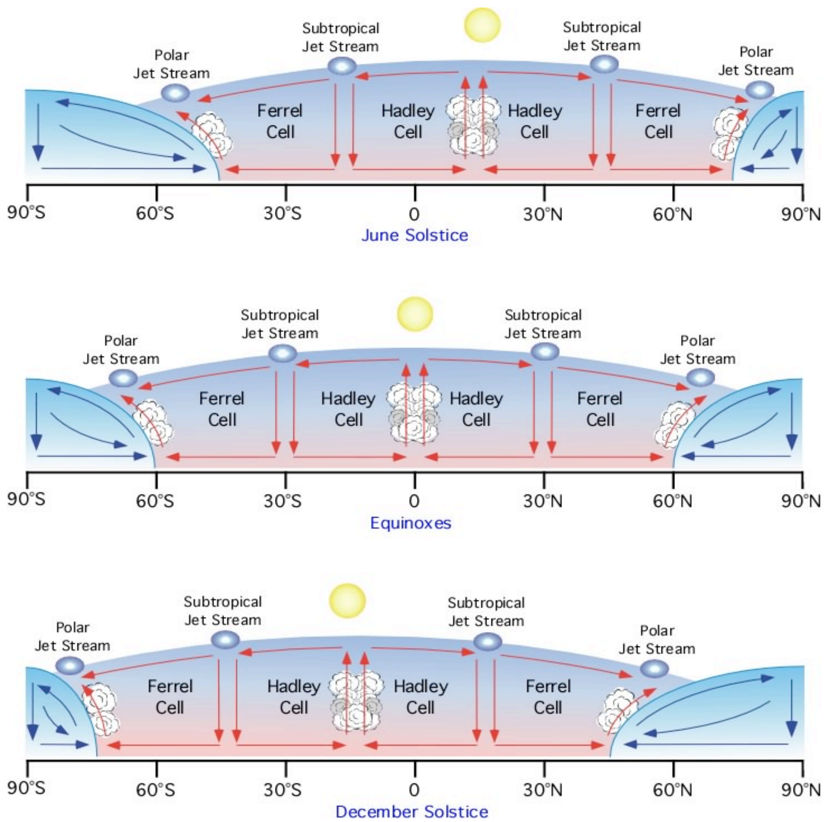

FIGURE 5 - The ITCZ moves southerly during the Austral Summer and northerly during the Boreal summer. This is a direct result of the movement of the solar equinox. (image retrieved from http://www.physicalgeography.net/fundamentals/7u.html)

The descending air mass of the Hadley Cell results in a massive high-pressure system to the north of the archipelago called the North Pacific High (NPH). It is the NPH winds deflected to the southwest by the Coriolis effect that generates the consistent northeasterly trade winds, which dominate the Hawaiian climatic pattern during the dry season (Ziegler, 2002).

As the solar equator seasonally moves southward, due to the Earth's rotation around the sun and corresponding tilt of its axis, so to does the ITCZ, Hadley Cell, and NPH. It is this southerly movement that weakens the NPH and allows the Aleutian Low and its corresponding Westerlies from the north to herald in Maui's wet season and its variable wind patterns (Juvik et al., 1998).

Precipitation levels on Maui range from 25 to 1015 cm and result from the orographic mountain effect (generated by the trade wind inversion layer) as well as the wet season frontal passages, Kona storms, thunderstorms, and hurricanes that "either enhance the orographic pattern or produce widespread, uniform rainfall" (Ziegler, 2002, pp. 72-79). As the NE trade winds travel over the ocean's surface, they accumulate evaporated moisture and carry it to Maui's windward shores, are then deflected upslope, and cool and condense at the temperature inversion layer (between 1,500 and 2,100 m in altitude) that is formed by anomalously descending warmer Hadley Cell air. When the moisture-laden air mass cools and condenses, it releases precipitation that supplies the bulk of Hawai'i's water resources (Juvik et al., 1998).

However, the entirety of the island does not reap the benefits of the water cycle that occurs on the windward side of the island (Fig. 6). The steep terrain and inversion layers on East and West Maui prohibit the moisture-laden air from passing over the summits and nourishing the dry, leeward sides of Maui. This rain shadow effect accounts for the drastic disparity in rainfall amounts totaling 1015 cm annually on West Maui and less than 38 cm in Kihei and Lahaina on the leeward side; they receive their annual precipitation from other rain producing mechanisms (Juvik et al., 1998).

Disturbances in the climatic patterns exist in the form of El Niño Southern Oscillation (ENSO), La Niña, and hurricane events. An exploration into the incompletely understood complexities and mechanisms of these events are beyond the scope of this assignment.

However, as they relate to Hawai'i, Ziegler (2002) stated, "an El Niño episode [with corresponding warmer surface waters] typically causes lower than usual rainfall and fosters the development of hurricanes" (p. 84). Conversely, a La Niña event with its colder surface waters generates higher than average rainfall and less hurricanes.

Maui is a unique place that is filled with tremendous biodiversity due to its isolated location and spatial diversity. The climatic patterns that have existed for millennia have and will continue to shape our biotic communities and abiotic processes on Maui. However, humanity's recent influence in these climatic processes cannot be overstated and demands equal consideration.

Climate Projections & Data Sources

As the global climate changes, Hawaiʻi is beginning to experience the effects of this phenomenon in a multitude of ways. Regional indicators of climate change in Hawaiʻi are supported by the following data sources:

- Rising Surface Air Temperatures – Climate Impact Lab
- Rising Sea Surface Temperatures - NOAA
- Changes in Patterns of Natural Climate Variability (Pacific Decadal Oscillation

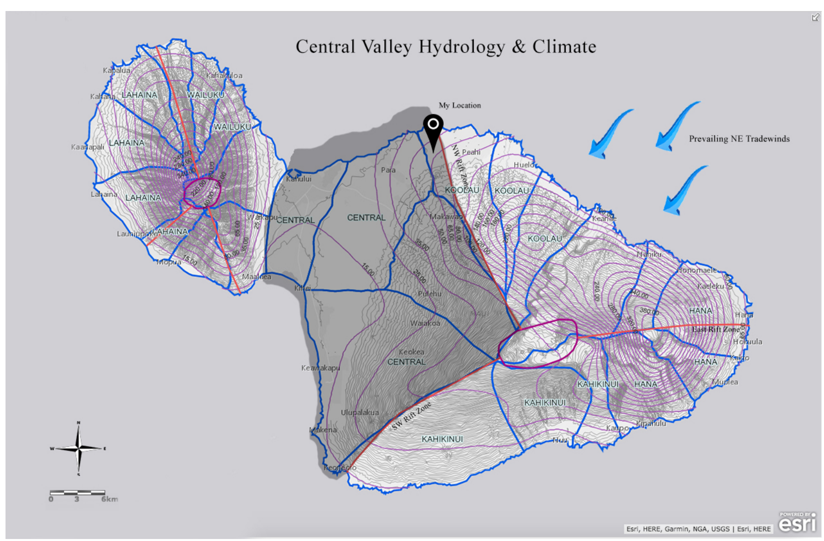

FIGURE 6 - The prevailing northeast tradewinds generate high levels of rainfall (maroon isohytes) on the windward side of Maui while the leeward side receives considerably less due to the rain shadow and orographic rain pattern (map created using ArcGIS Online, 2017).

[PDO] and El Niño Southern Oscillations [ENSO]) - Columbia University's Earth Institute

- Changing Frequencies and Intensities of Storms and Drought – NOAA
- Sea Level Rise – PacIOOS
- Increasing Ocean Acidification – IPCC Publications and Data

Rising Surface Air Temperatures

Giambelluca et al. (2008) have recorded a rapid rise in Hawai‘i's air temperature of 0.17°C over a recent period of 30 years. This rise in temperature occurs as an increase in the minimum daily temperature and is anomalous to the periodicity of the Pacific Decadal Oscillations during the past 85 years. The Climate Impact Lab (2018), under a high emissions scenario of RCP 8.5, suggested a median probability of a 3°C rise in Hawai‘i's temperature by the end of the century.

Rising Sea Surface Temperatures

University of Hawai‘i researchers have measured an increase in sea surface temperatures (SST) of 0.12°C per decade, prior to 2010 (Fletcher, 2010). Sea surface temperature, a key variable in the climate system that regulates ocean-atmospheric interactions, is projected to increase globally by 0.05 – 0.5°C per decade under an RCP8.5 scenario (Alexander et al., 2018).

Changes in Climate Patterns

In response to global warming, climate modeling has provided evidence for a doubling of future occurrences of El Niño Southern Oscillation (ENSO) events in the Pacific (Cai et al., 2014). La Niña and El Niño conditions govern rainfall and temperature trends in the Pacific. Due to the shifting Hadley Cell and surface waters in the region, El Niño events in Hawai‘i are characterized by a decrease in rainfall, while La Niña events herald wetter conditions (Fletcher et al., 2010). Higher sea surface temperatures may play a role in increasing El Nino-like conditions (PICEP, 2016). This shift could effectively alter the North Pacific High, which controls the trade wind patterns during the dry season, and thereby decrease annual rainfall while simultaneously increasing the frequency of high intensity rainfall events.

Another regional climate pattern that impacts rainfall in Hawaiʻi is the Pacific Decadal Oscillation (PDO). Like ENSO events, it too is caused by shifting surface waters and is characterized by a "warm" or "positive" phase (cool western Pacific and warm eastern Pacific) and a "cool" or "negative phase" (warm western Pacific and cool eastern Pacific). Hawaiʻi tends to receive more rainfall during cooler PDO periods, which can stimulate La Niña events (Fletcher et al., 2010). Normal shifting between phases typically occurs approximately every 20 to 30 years. However, Zhang & Delworth (2016) demonstrated through climate modeling that the time scale of the PDO shortens to ~12 years in response to climate change.

Rainfall amounts and intensity have changed drastically in Hawaiʻi during the past several decades. Although rainfall has decreased ~15% over the past 20 years (Fig. 7), "the amount of rain falling in the very heaviest downpours (defined as the heaviest 1% of all events) has increased approximately 12% in Hawaiʻi" (Fletcher, 2010, p. 3) (Fig. 8).

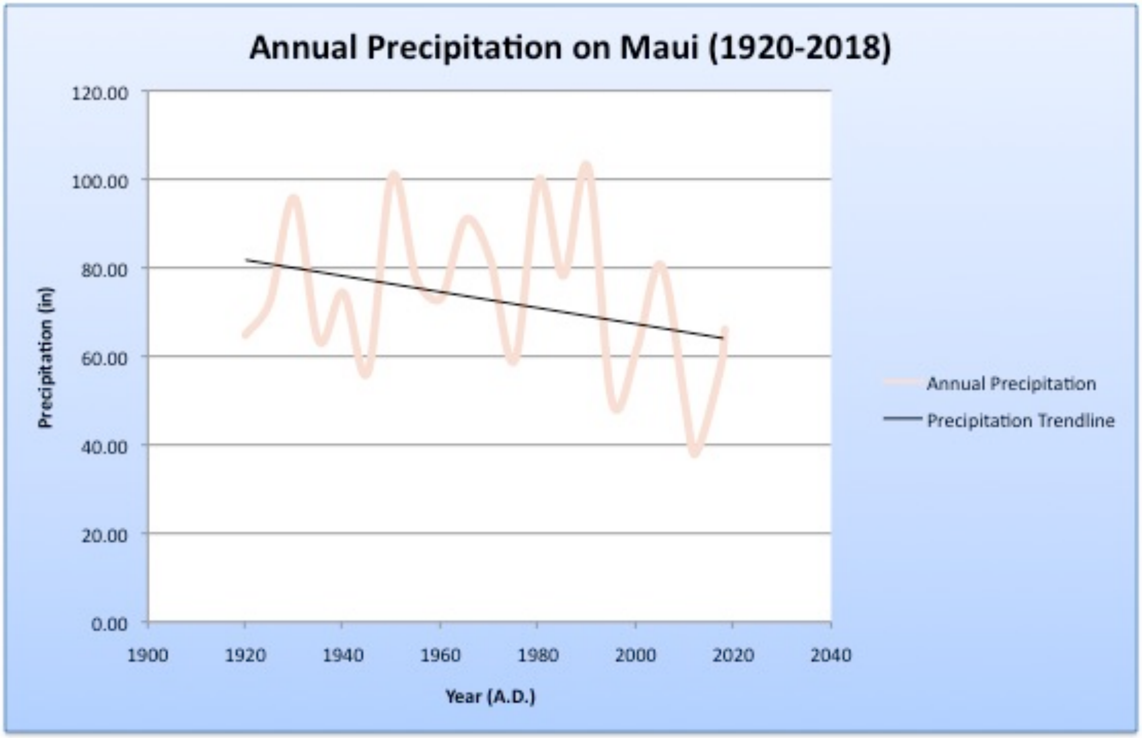

FIGURE 7 - Although the annual precipitation amounts vary from year to year, the trend demonstrates an overall steady decrease in annual volume from 1920 to 2018 (Giambelluca et al., 2016).

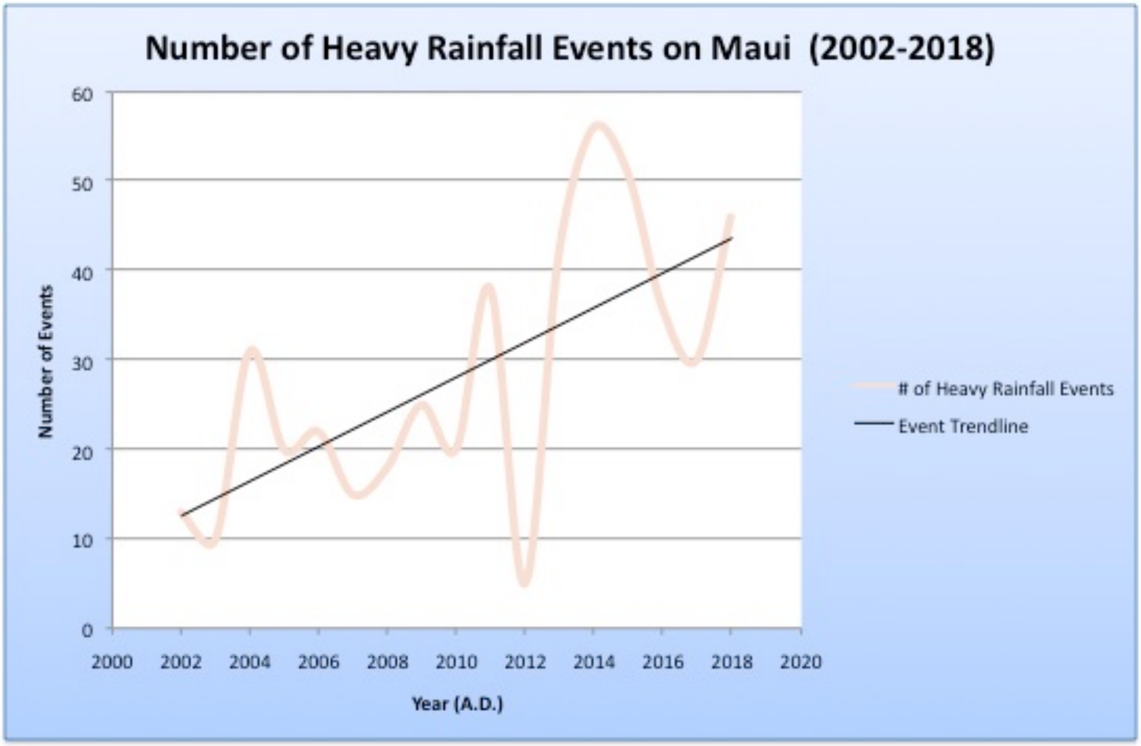

FIGURE 8 - Although the number of heavy rainfall events fluctuates annually, the overall trend suggests that there has been an increase in frequency during the time period from 2002-2018 (NOAA, 2018b).

Due to geographical location and topography, Hawai‘i’s precipitation levels vary annually from island to island. However, this fact does not account for the decrease in rainfall and increase in intensity exhibited by the data. Diaz et al. (2016) reconstructed the Hawaiian Islands rainfall from 1500-2012 CE and noted a general drying trend in the region, which is supported in part by the data illustrated above. Further studies are necessary to determine the associations between ENSO events, sea surface temperatures, and the North Pacific High.

Sea Level Rise

Sea level change is primarily caused by **“**warming the ocean and decreasing the global volume of ice” (Fletcher et al., 2007, p. 215). Sea level in Hawai‘i has risen ~ 1.5 cm per decade over the past century (NOAA, 2018a). By 2100, rising sea levels (RSL) in Hawai‘i are predicted to range from 0.4 m – 3.5 m above current levels based upon low to extreme scenarios of global mean sea level rise (GMSLR) (NOAA, 2017).

Ocean Acidification

Half of the anthropogenic CO_2 produced after the Industrial Revolution has dissolved into the world's oceans, lowering its pH and making it more acidic (Kennedy, 2010). "Over the past 250 years, the mean pH of the surface global ocean has decreased from ~8.2 to 8.1, which is roughly equivalent to a 30% increase in $[H^+]$" (Dore et al., 2009, p. 12235). Depending upon the emission scenario, current models predict that surface ocean pH may decline by an additional 0.3–0.4 during the 21st century (IPCC, 2007).

Climate-Related Risks

Hawaiʻi is experiencing climate change. Regional indicators include rising air and sea surface temperatures, increased levels of atmospheric CO_2, sea level rise, increasing ocean acidity, changing patterns of natural climate variability, irregular rainfall patterns, decreasing base flow in streams, and altered habitats and species distributions (Keener et al., 2012). These changing patterns are associated with increased environmental, social, cultural, and economic impacts to Hawaiʻi, which is especially vulnerable due to its concentration of infrastructure and economy along the coastline.

As sea levels rise due to increasing temperatures and melting ice, the proximity of road networks, residences, resorts, and critical infrastructure, (airports, power plants, wastewater treatment facilities, and shipping ports) to the ocean will place them and coastal ecosystems in extreme peril. More frequent extreme weather events such as hurricanes, storm surges, king tides, and ENSO-related sea level changes will exacerbate the losses further and "pose multiple challenges to habitability" (USGCRP, 2018). Additionally, saltwater intrusion of aquifers threatens to impact food and water security in addition to inducing groundwater flooding in low-lying coastal areas (Habel et al., 2017). Also accelerated by sea level rise, coastal erosion, flooding, and drainage problems will significantly contribute to the impacts experienced by climate change (Fletcher et al., 2010).

Higher sea surface temperatures and ocean acidification, as the result of absorbed anthropogenic increases of atmospheric CO_2, will negatively impact marine ecosystems. Due to the rise in ocean temperatures, coral reef bleaching, which can weaken or kill coral colonies, is expected to occur annually in Hawaiʻi by 2040, and by the end of the century, ocean acidification levels will "severely compromise their [corals'] ability to grow" (USGCRP, 2018). Coral reefs provide shoreline protection against storm waves and erosion, create a unique habitat for a diversity of marine organisms, and support local fisheries and tourism industries.

Economic losses associated with coral reef degradation in Hawaiʻi are substantial. Burke et al. (2011) estimated present-day annual tourism and fisheries losses in Hawaiʻi of $430.2 million and $3.5 million, respectively (adjusted to 2018 dollars). By 2050, coral reef cover in Hawaiʻi is expected to decline from 38% to 11% and to 1% by 2100, representing total economic losses (tourism, fisheries, and shoreline protection) of $1.3 billion annually in 2050 and $1.9 billion annually in 2090 (both in 2015 dollars) (USGCRP, 2018).

As an island state, Hawaiʻi is especially vulnerable to water shortages that result from increased air temperatures and changing rainfall, El Niño, and Pacific Decadal Oscillation (PDO) patterns. While heavy rain equates to erosion, flash flooding, landslides, road and business closures, infrastructure damage, and loss of public services, drought conditions that often accompany El Niño and PDO result in the decreased base flow of stream systems across the state (Fletcher, 2010). As surface air temperatures rise throughout the region, evaporation is increased and results in reduced water supply and increased demand (Keener et al., 2012).

The warming trend may also increase ecological impacts from increasing numbers of invasive plant and animal species and the spread of avian disease (Fletcher, 2010). As temperatures rise, the existing climate zones are expected to shift upwards in elevation and provide an opportunity for invasive species to displace natives that cannot adapt (Benning et al., 2009). Disturbances from extreme weather, increased CO_2 levels, and warmer temperatures will also improve the ability of alien species to replace native plants, pollinators, and seed dispersers (Melillo et al., 2014). As temperatures rise, mosquitoes carrying avian malaria will migrate upslope and threaten to reduce the amount of safe habitat for endemic bird species that have co-evolved over the millennia to pollinate endemic trees that are critical to the health of our watersheds (Benning et al., 2009).

Climate change impacts also threaten cultural practitioners and indigenous communities in Hawai'i. As sea levels rise, traditional fishpond maintenance and salt cultivation are increasingly coming under threat even as decreased base flows of streams result in lower production of *loi kalo*, or wetland taro. Ocean warming and acidification also adversely impact the local fisheries and threaten the food security of Hawaiians practicing subsistence methods of food production. Consequences of climate change impacts will also have a lasting effect on the health and well being of our host culture (USGCRP, 2018). As their sacred sites are washed away by extreme weather events and sea level rise, cultural practices and the passing of traditional knowledge will forever be changed. The loss of their local observational knowledge and traditional resource management and adaptation strategies will negatively impact their ancestral connections to land and sea and also represent a significant loss to humanity as a whole.

Resilience Recommendations

As the impacts of climate change increasingly manifest in Hawaiʻi, policy makers, conservationists, and community members have begun in earnest to assess the associated climate change risks in order to better safeguard our infrastructure, environment, safety, and way of life. Melillo et al. (2014) defined resilience as "A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment." To prepare for these social, environmental, and economic changes, society as a whole must preemptively participate in the planning and policy changes that are necessary to protect our vulnerable community. The Hawaiʻi Conservation Alliance (2009) recommended four general actions that could help reduce the negative impacts of a changing climate in Hawaiʻi:

- Be well informed of potential climate change impacts,
- Maintain the resilience of environmental and societal systems by minimizing non-climate stressors
- Engage stakeholders in creating culturally appropriate adaptation and mitigation management options, and
- Actively plan for a changing climate so that today's short-term decisions do not make future actions more difficult. (p. 3)

In addition to these basic recommendations, resiliency and adaptation must be examined within the contexts of the regional climate change impacts in Hawaiʻi. Increasing sea level rise, coral reef loss, decreased freshwater supplies, biome shifts, and changes in cultural practices and traditional knowledge will each involve different stakeholders and require specific policy changes and adaptive strategies. Conceptual frameworks can assist communities in planning and response efforts for a multitude of climate impacts (Fig. 9). In all cases, planning, regulatory, spending, and market-based tools and strategies are available to help implement the resulting recommendations and initiatives (Hawaiʻi Climate Adaptation Portal, 2018).

FIGURE 9 - This conceptual framework was used to evaluate sea level rise threats in Hawaiʻi and is intended to inform the process of identifying and managing other regional climate threats (Hawai'i Climate Change Mitigation and Adaptation Commission [HCCC], 2017).

Sea Level Rise Recommendations

HCCC (2017) provided the following summarized recommendations for various stakeholders to improve our regional resiliency with respect to sea level rise (SLR):

1) Support sustainable and resilient land use and community development
2) Prioritize smart urban redevelopment outside the sea level rise exposure are (SLR-XA) and limit exposure within the SLR-XA
3) Incentivize improved flood risk management
4) Enable legacy beaches to persist
5) Preserve native Hawaiian culture and communities

6) Protect nearshore water quality
7) Develop innovative and sustainable financing incentives
8) Support research, assessment, and monitoring
9) Promote collaboration and accountability for adaptation (pp. 213-257)

Coral Reef Recommendations

Recommendations to enhance the resiliency of the coral reef communities in Hawaiʻi focus mainly on reducing stressors, (outside of climate change) so that corals may better adapt to increasing sea surface temperatures and ocean acidity. Overfishing, sedimentation, pollution, and habitat destruction are considered stressors that can be effectively managed (Coral Reef Alliance, 2018). More direct recommendations, such as the selective breeding of resilient coral species, establishing of permanent no-take Marine Protected Areas (MPAs) and Herbivore Fishery Management Areas (HFMAs) are among the top listed suggestions to decrease outside stressors (Rosinski et al., 2017).

Freshwater Loss Recommendations

The National Weather Service defined drought as "a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people" (One World One water, 2017, p. 13). In response to increasing episodes of water shortages, Hawaiʻi has approached freshwater resiliency from a variety of perspectives. Watershed partnerships restore and conserve natural areas that capture and infiltrate rainwater, the Commission on Water Resource Management focuses on drought planning and overall water management, and the Hawaiʻi Freshwater Initiative (2018) was created to bring various stakeholders together "to develop a forward-thinking and consensus-based strategy to increase water security for the Hawaiian Islands" (p. 3). Recommendations put forth by the Hawaiʻi Freshwater Initiative include the following actions that were intended to create 100 million gallons per day (mgd) in additional reliable freshwater capacity by 2030:

1) Conservation: Improve the efficiency of our population's total daily fresh groundwater water use rate by 8% from the current 330 gallons per day/person to 305 gallons per day/person. By 2030, this goal will provide 40 mgd in increased water availability.
    a. Reduce Potable Water Use On Landscape Areas.
    b. Encourage Leak Detection Systems.
    c. Improve Agricultural Water Efficiency.
2) Recharge: Increase Hawai‘i's ability to capture rainwater in key aquifer areas by improving storm water capture and nearly doubling the size of our actively protected watershed areas. By 2030, this goal will provide 30 mgd in increased water availability.
    a. Authorize and Implement Storm Water Utilities.
    b. Enhance and Increase Large Recharge and Reservoir Areas.
    c. Strengthen Watershed Partnerships.
3) Reuse: More than double the amount of wastewater currently being reused in the Islands to 50 mgd. By 2030, this goal will provide an additional 30 mgd in increased water availability.
    a. Revise Water Reuse Guidelines.
    b. Revise Greywater Guidelines.
    c. Increase Water Reuse for Large Landscape Areas. (pp. 12-15)

Biodiversity Loss Recommendations

The Hawaiian Islands Climate Vulnerability and Adaptation Synthesis report provides impact vulnerability, adaptation approaches, strategies, and actions to protect native flora and fauna, their diverse ecosystems, and their critical ecosystem services. The fourteen detailed adaptation summaries (alpine/subalpine, dry forest, mesic/wet forest, estuaries, streams, beaches and shorelines, etc) for each of the eight major islands are far too extensive to include with this paper. However, a concise look at the overall project is available here. What is especially noteworthy is that the vulnerabilities, recommendations, and feasibility assessments are thoroughly site specific to each ecosystem and each island. The report provides ample direction for decision makers within resource conservation, tourism, economic, government, and cultural organizations. "Through research and collaboration with Indigenous communities and land managers, ecosystem resilience to climate change can be enhanced and the most severe climate change effects on biodiversity decreased" (USGCRP, 2018).

Cultural Practices

Adaptation strategies to protect cultural knowledge and indigenous communities in Hawaiʻi involve specific actions as suggested by Gregg (2018):

1) Protect water rights and public access to the shoreline and forest
2) Protect/create dedicated spaces for cultural practices
3) Implement ahupua'a practices to encourage geographically-based restoration and sustainability mindset
4) Aquire land for *mauka* migration in anticipation of sea level rise
5) Restore culturally significant habitats from *mauka* to makai
6) Collect data from the community in order to protect cultural resources
7) Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change
8) Increase cultural community input on water use decisions

Stakeholders

Identifying regional stakeholders is critical to the success of resilient climate change policy and educational initiatives that aim to effectively address multiple social, environmental, and government perspectives. Once clear goals and objectives are identified for a particular issue, stakeholder groups can be analyzed and should be included early on in the process; this is an important first step to building relationships and thereby increasing the chances of a successful outcome (Allen & Kilvington, 2010).

Regional stakeholders in Hawaiʻi include "persons, groups, or institutions with interests in a policy, program or project" (Allen & Kilvington, 2010, p. 251). These stakeholders offer a variety of perspectives, which reflect differing interests and expectations. As challenging as it is, it is absolutely necessary for decision makers to include the primary stakeholders, which are found at all levels of the community. Landowners, activist groups, attorneys, economists, cultural traditionalists, engineers, and scientists are just some of the people who are invested in the outcomes of policies enacted to promote resiliency in a community. Government agencies, utility companies, and land managers, although typically in control of the problem-solving process, should also be considered stakeholders in the collaborative and interdisciplinary processes that are required to create effective and resilient actions in the face of climate change.

Conclusion

Hawaiʻi can be considered a microcosm of the globe in much the same way as the Earth may be viewed as an island in space. It is from this perspective that we must consider the environmental impacts from our anthropogenic forcing of Earth's climate. As an island state with abundant social resources, we are uniquely positioned to share our successes and failures concerning resiliency and adaptation measures. Hawaiʻi is already on the path towards resiliency. Discussions and initiatives produced throughout the State are originating from the top down and bottom up across multiple sectors. In this way, Hawaiʻi is moving forward with direct and measurable actions that will help us protect our island home and our island Earth. We must and we shall, there is no other alternative.

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