A “Primer” on Climate Change and Hawai‘i

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“Developing Environmental Grantmaking Strategies”

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A "PRIMER" ON CLIMATE CHANGE AND HAWAIʻI

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A "Primer" on Climate Change and Hawaiʻi

This section of the report serves as an introduction to climate change, focusing on projected impacts to Hawaiʻi and potential adaptation measures. It is intended to provide background information for Hauʻoli Mau Loa Foundation regarding the issues that are likely to occur as a result of climate variation in Hawaiʻi.

I. Overview

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Changes to the earth's climate system are taking place on a scale not seen in thousands of years (IPCC, 2007). Climate change is predicted to have numerous detrimental effects on the world's environments and ecosystems. Projected impacts include: sea level rise and associated salt water inundation, alterations of various forms to terrestrial and marine ecosystems, and subsequent modifications to socio-economic systems. These effects will vary geographically. In many cases, the locations contributing the least to global climate change will be affected in the most extreme ways (Adger et al., 2003 and Smit et al., 2000).

In the case of Hawaiʻi, and more specifically, in the context of a strategy for environmental grantmaking for Hauʻoli Mau Loa Foundation, knowledge of the challenges presented by climate change and of the appropriate mechanisms to address these problems is essential so that informed decisions in regards to funding can be made. Funding is one of the most critical determinants of adaptation success, as strategies are often formulated yet lack the monetary backing to be implemented.

II. An Introduction to Climate Science

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The Intergovernmental Panel on Climate Change (IPCC) is recognized as the world's premier research body regarding climate change and its reports are critical to the understanding and dissemination of climate change science.

Global climate change, more popularly discussed as global warming, is caused by an increased level of carbon dioxide and other greenhouse gases, such as water vapor, methane, and ozone in the earth's atmosphere (IPCC, 2007 and Watson et al., 1990). Since the Industrial Revolution, the level of greenhouse gases in the earth's atmosphere has risen exponentially, with increases in carbon dioxide concentration from approximately 280 ppm (parts per million) in 1750 to a level of 382 ppm in 2006 (EPA, 2008). It is this increased concentration of greenhouse gases that is driving global climate change. The role of greenhouse gases within the earth's atmosphere is to prevent the Sun's energy from immediately escaping, in theory providing a consistent climate (Mitchell, 1989). With increased levels of greenhouse gases, not enough energy is escaping from the atmosphere, causing an abundance of energy and an accompanying increase in temperature. This is comparable to a greenhouse holding in the Sun's energy and creating an artificially warm temperature, hence the popularized name.

The IPCC's 2007 "Report for Policy Makers" is perhaps the most appropriate source of information given the scope of understanding necessary for Hauʻoli Mau Loa Foundation in relation to climate change science. The Report provides a sufficient perspective of climate change science and would be an invaluable resource for those wishing to understand the phenomenon more completely.

Within this report, the IPCC asserts that global observations of the earth's climate indicate temperatures, ice accumulations, weather patterns, and storm activity are changing. Observations indicate that between the years 1995 and 2006, the world experienced the warmest temperatures on instrumental record. As a result, ice accumulations in the form of glaciers and snow covers are retreating in both hemispheres. Recent observations, since 1961, also demonstrate global sea level rise of 1.8 mm per year. Therefore, increasing volumes of greenhouse gas emissions in the 21st century raise atmospheric temperatures, compounding the effects of the previous century. These effects of anthropogenic activity will continue many years into the future, regardless of stabilization efforts achieved today (IPCC, 2007, 5-16). The magnitude of future climate change, however, is certainly dependent on proper mitigation actions today.

The IPCC findings are critical to understanding potential impacts of climate change, specifically in relation to the severity of change over time. Nonetheless, there is a level of uncertainty involved with all aspects of climate change, particularly at understanding impacts at the local leve, and therefore there are difficulties in predicting effects and implementing adaptation measures (Barnett, 2001 and Heal and Kristrom, 2002).

The potential for "positive feedback loops," a phenomenon that is generally recognized but the scale of which is not agreed upon (Scheffer et al., 2006 and Defresne et al., 2002), severely complicates predictions of climate change and its associated effects. For eample, as discussed by Scheffer et al. (2006), there is a scientific consensus that there is a positive feedback loop at work in which rising temperatures will further promote increased greenhouse gas levels, driving continued increases in temperature. The research predicts that this effect could be in the range of 15-78% on a century scale—a very wide-range, but nonetheless illustrative for planning purposes.

One specific example of this phenomenon of feedback loops is the concept of "albedo." Albedo describes the absorptive or reflective characteristics of a surface, and is critically important when discussing the absorption of the sun's energy by the earth's surface. Ice, which presently covers a large portion of the earth's surface, has a (high) albedo and therefore reflects the sun's energy very well. As global warming occurs, ice melts and the accompanying reflective capacity is reduced. As ice melts and the earth absorbs higher amounts of energy, the process will accelerate with greater rates of ice melt (Hall, 2004).

"Tipping points" (Lenton et al., 2008) or "abrupt climate changes" (Alley et al., 2005) are also critical, but remain to a large extent not well understood. One such "tipping point" deals with the issue of global water cycling or the Atlantic thermohaline circulation (THC). It is believed by some (Lenton et al., 2008) that if too much fresh water enters the world's oceans as a result of melting, that the world-wide oceanic conveyor system that contributes to global climate stability could essentially shut down because of changing water density dynamics. A similar event, known as the Younger Dryas, occurred approximately 1300 years ago, causing the planet's abrupt entry into a 1300-year ice age (Fairbanks, 1989). While there is a great deal of uncertainty surrounding the issue of threshold dynamics, its occurrence throughout geologic history serves as a warning of the possibilities (Alley et al., 2003).

While the most obvious and frequently discussed effect of global warming is increased atmospheric and ocean temperatures, there are a number of direct and indirect effects that are important to understanding the complexity and scale of current and future climate changes. Some of the physical effects include the rise of sea levels, changing weather dynamics with severe weather events, altered precipitation patterns, and disruptions to many of the earth's critical systems and cycles (Meehl et al., 2000 and Trenberth, 2006).

III. Climate Change and Islands

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Islands are expected to be particularly disadvantaged by the effects of climate change. Typically, possessing very fragile and sensitive ecosystems, islands often serve as the "canary in the coalmine" for climate change effects that may eventually be experienced by larger landmasses. As stated by Mimura et al. (2007), "Small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea level rise, and extreme weather events" (Mimura et al., 2007, 689). The relationship between islands and climate change, though Hawaiʻi is not amongst the worst-off, warrants specific discussion for the case of Hawaiʻi.

For some locales, the issue is not one of quality of life, but one of sovereignty and national existence. Entire island communities may disappear as a result of global climate change. For instance, low-lying islands such as The Republic of the Maldives and Kiribati may be completely inundated, essentially ceasing to support habitation. Low-lying islands face serious threats such as saltwater intrusion and the disappearance of fragile fresh water supplies (Barnett and Adger, 2003).

More generally, the IPCC (2007) states that there is high confidence that sea level rise will continue causing the inundation of fresh water resources, while also posing a threat upon infrastructure, real estate, and habitats that are essential to sustaining island life. Climate change impacts upon coral reefs and fisheries are highly anticipated, while it is currently observed that species found in high elevation habitats have already been affected (IPCC, 2007, 689).

Not only are the challenges often much greater for islands, but the ability to adapt is often much lower than compared to other areas. This low *adaptive capacity* means that adequate responses are often difficult and sometimes impossible to implement. This inability to adapt is often the product of a variety of local characteristics, among them are geography and socio-economics (Paavola and Adger, 2006 and Mortimore and Manvelle, 2006). The relatively small size of islands reduces the ability to adapt through retreat, the adaptation measure that provides the most certain and predictable results. As such, other options must be employed. These often include technological or hard-engineering solutions that are expensive and are not necessarily long-term, a socio-economic challenge that further complicates the adaptive capacity of islands.

IV. Climate Change and Hawaiʻi

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Each and every location is unique, and thus challenges and potential adaptive measures occur on a local scale—Hawaiʻi is no different. Hawaiʻi is a very unique place, being a geographically diverse island chain. Hawaiʻi is home to a variety of unique environments spread across a landmass of about 6,500 square miles (U.S. Census Bureau, 2010), across a geographic area spanning 2500 miles from the Northwest Hawaiian Islands to the Main Hawaiian Islands (Tissot et al., 2009) and having altitudes that range from sea level to 13,796 feet at the peak of Mauna Kea. These various environments provide habitats for over 25,000 species (Eldridge and Evenhuis, 2003), making Hawaiʻi a "hotspot" of biodiversity.

While Hawaiʻi shares many of the same challenges associated with climate change as other islands and, more broadly, the global community, there are certain attributes that make Hawaiʻi's experience different. Perhaps most significant is the fact that Hawaiʻi is a U.S. state and, as such, has comparatively high levels of adaptive capacity. Specifically, Hawaiʻi possesses greater access to monetary funding, in relation to other island settings, such as those in the developing world. Also, Hawaiʻi is not made up of what would traditionally be considered "low-lying" islands such as the coral atolls such as the previously mentioned nations of Kiribati and the Maldives. As such, the problems faced in Hawaiʻi are not as extreme and the ability to adapt is much better than other geographically similar locations.

Hawaiʻi is, however, extremely vulnerable when compared to states in the continental United States (Moser, 2006). These threats include: sea level rise that encompasses the issues of inundation, altered erosion dynamics, and complications for storm water management, ocean acidification and associated effects on the marine environment, and the escalating incidence of invasive species and the associated decline of native and endemic species' productivity.

V. The Challenges

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This section presents a review of expertise regarding climate change impacts to Hawai'i. Potential challenges include: sea level rise, storm water management, ocean acidification, and invasive species.

A. Sea Level Rise

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Sea level rise is perhaps the greatest immediate, known threat to Hawai'i in terms of climate change, given the proximity of land and population to the sea, as well as a myriad of indirect effects (Klein and Nicholls, 1999, Moser, 2006, and Church et al., 2005). From so called "dooms day" scenarios of Honolulu being completely under water to projections of less severe sea level rise resulting in periodic flooding, it is clear that accelerated sea level rise will require improved planning and adaptation.

As previously mentioned, the IPCC stated with high confidence that, "Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities" (Mimura et al., 2007, 689). The current estimates project a sea level rise of approximately 5mm per year with a total of one meter by the year 2100 (Mimura et al., 2007, IPCC, 2007 and Fletcher, 2009). Sea level rise to this point can primarily be attributed to the thermal expansion of water as a result of increased temperature. This is significant because many predictions only incorporate this aspect of sea level rise into their models, ignoring the potential for massive increases that could occur with the melting of Greenland and Antarctic ice sheets (Fletcher, 2009). Recent predictions that take into account all of these various aspects, potential feedbacks, and the most up-to-date data, place upper estimates of potential sea level rise closer to two meters by 2100 (Allison et al., 2009).

The Hawaiian Islands are unique in terms of sea level rise, as the volcanic origin of the islands indicates a unique topography. Relative sea level rise is more difficult to compute for the area, as certain locations may have declining net sea levels because of rising land and others are experiencing net sea level rise (Apple and MacDonald, 1966 and Moser, 2006). This creates significant challenges in formulating a statewide policy for climate change and sea level rise because some parts of the state are experiencing different relative sea level changes than others.

Dr. Chip Fletcher's "Blue Line Project" presents a visual representation of just how significant sea level rise may be on O'ahu. The graphic representation of the inundation that may result from sea level rise is quite alarming, showing that significant portions of Oʻahu and the other islands may be under water (or consistently flooded) if actions are not taken to adapt to sea level rise. It should be noted that the scenario considers a one-meter rise in sea level and the absence of protective measures.

The fact that over 90% of Hawaiʻi's population lives in a small coastal strip is thus disconcerting (Moser, 2006). Yet Hawaiʻi is by no means alone, considering estimates that 13% of the world's population lives within a 10 meter elevation above a major body of water, an area that represents only 2% of the earth's surface (McGranahan et al., 2007). In addition, coastal infrastructure, such as the coral reef runway at the Honolulu International Airport and the industrial zone at Barber's Point, will need to either be protected or moved. Given the proximity of people and infrastructure to the sea, inundation resulting from sea level rise is a very serious concern.

Beyond the loss of infrastructure due to sea level rise, there are many additional effects that can be found in Hawaiʻi. Such issues involve changing coastal erosion dynamics and the depletion of fresh water sources. Erosion dynamics are very important in Hawaiʻi, and are likely to be an issue prior to full-on inundation of the coastline. Hawaiʻi's beaches experience variable erosion rates, with entire beaches forming and disappearing in relatively short periods of time. Sea level rise and other effects associated with climate change are expected to exacerbate erosion impacts (Mimura et al., 2007). This issue is critical for the state, amongst other reasons, because of its dependence on the beaches for economic vitality. Approximately 60% of the jobs in Hawaiʻi are related to the tourism industry, an industry that depends on the appeal of the state's beaches. The effects of increased erosion will impose consequences on the state economy (Genz et al., 2007). The beaches are a part of every day life on the islands, and the loss of these precious resources will damage the character of Hawaiʻi.

The depletion of fresh water reserves as a consequence of sea level rise is another potentially damaging effect (Mimura et al., 2007). There is concern that as sea levels rise, salt water intrusion will occur, damaging fresh water reserves (Hawaiʻi CZM Program, 2009).

B. Storm Water Management

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Storm water management has significant connections to climate change impacts. Global climate change is expected to not only raise sea levels, but also cause fluctuations in precipitation and increase the frequency and intensity of extreme weather events (Mimura et al., 2007, Chu et al., 2009, and Shaw et al., 2005). All of these events are critical aspects of the storm water management system (Titus et al., 1987). Coupling these effects with the degree to which Hawaiʻi is developed, specifically in and around Honolulu, raises real issues when thinking about the control of rainwater and impervious surfaces.

The rate of future climate change may outpace both retrofits as well as new construction of storm water systems (Bronstert et al., 2002). These systems utilize gravity to aid in the capture and disposal of excess water generated from storms. Without technological upgrades, it is critical that elevation differences and volume capacities remain sufficient to maintain functionality. The capacity and efficiency of storm water systems are determined by the difference in elevation of where water is collected and where it is disposed of and as this difference shrinks, so too does the efficiency of the system (Titus et al., 1987). These environmental characteristics that affect the function of storm-water systems will come under pressure as climate change alters conditions (Titus et al., 1987). Storm-water systems may not be able to handle the effects of climate change and is due in large part to the fact that design standards have remained consistent through time, reflecting the relatively constant environmental conditions and hydraulic loads the systems must handle (Titus et al., 1987).

The 2004 flood of Mānoa Valley on Oʻahu, provides an illustrative example of the failure of Honolulu's storm water systems (Chu et al., 2009). Increased precipitation as a result of climate change will present problems for storm water management throughout the state, but more specifically in the urban areas. Impervious surfaces prevent infiltration of storm water, which stresses the capacity of the management systems and can lead to significant problems such as flooding of inhabited areas and runoff into fragile terrestrial and marine ecosystems (Booth et al., 2002).

Storm water management problems affect human health through a variety of mechanisms (Gaffield et al., 2003). One major issue that may arise as a result of sea level rise and increased precipitation is the emergence and outbreak of infectious diseases—if standing water is allowed to persist, disease vectors like mosquitoes will thrive. In addition, poor runoff management can also impact human health through drinking water supplies, the consumption of seafood, and recreational activities.

C. Ocean Acidification

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Sometimes referred to as the "other CO2 problem" (Doney et al., 2009), ocean acidification is a serious threat to Hawaiʻi's marine ecosystems. Ocean acidification occurs as a result of increasing levels of carbon dioxide in the atmosphere. Carbon dioxide is absorbed by the ocean water, forming carbonic acid, which then separates and yields increased levels of hydrogen ions which contribute to decreased pH (Doney et al., 2008). Species that depend on calcium for the formation of skeletons and shells are most severely and affected by ocean acidification because calcification rates are regulated by the pH of the ocean (Guinottoe and Fabry, 2008).

Coral reefs and associated ecosystems are already in poor condition throughout the world, with as many as 30% considered to be severely damaged (Hughes et al., 2003). What is most troubling is that many reef ecosystems do not have comparable forms and therefore entire ecological communities may disappear (Hughes et al., 2003). These same reefs, compared to rainforests in their wealth of biodiversity (Hoegh-Guldberg, 1999), are considered "hot spots of diversity," providing the habitats for countless rare aquatic species.

Corals serve as the basis for entire ecosystems that depend on and foster symbiotic relationships among species. These species include not only corals, but also any species that depend on calcification for its survival, such as mollusks. Laboratory research has shown that increased levels of carbon dioxide can lead to the complete dissolution of shells made of calcium, and reintroduction to water with a normal pH can result in recalcification—thus displaying the powerful effect of ocean pH (Fine and Tchernov, 2007). This issue of acidification, as it relates to corals, is further compounded by rising sea levels that increase the distance between photosynthetic corals and the sunlight, reducing the amount of energy absorbed by the corals, resulting in warmer water temperatures that inhibit growth (Doney et al., 2008).

The most commonly discussed example of the effects of ocean acidification on the marine environment is coral bleaching. This process involves the breakdown of the critical symbiotic relationship between a coral and its photosynthetic material through the actual expulsion of the photosynthetic material (Hoegh-Guldberg, 1999). While corals have been shown to recover from bleaching events (Fine and Tchernov, 2007), recovery takes time and the associated habitats are severely affected.

While coral bleaching is most commonly discussed in terms of occurring as a result of increased sea surface temperatures (Jokiel and Brown, 2004, Hughes et al., 2003, and Brown, 1997), acidification is also a cause with emerging validity (Doney et al., 2008 and Guinotte and Fabry, 2008). This means that other previously known causes of bleaching are further exacerbated by elevated carbon dioxide levels in the water, likely magnifying the chances and ultimately the occurrence of the phenomenon. Previous bleaching events in Hawaiʻi were shown to have been caused by temperature increases of approximately 1 degree Celsius, an anomaly that may eventually become the norm as average water temperatures increase over time (Bindoff et al., 2007).

Ocean acidification will significantly affect fisheries. The habitat loss resulting from coral reef declines will reduce the area available to certain fish species. Declines in these reef fish will then be magnified up and including all levels of the food chain. Additionally, some research shows that acidification may directly affect the behavior of fish at various life cycles, adding to the indirect effects already discussed (Guinotte and Fabry, 2008). Ocean acidification not only directly affects the corals, but also affects all the other organisms living within the same ecosystem. Commercial consumption, including seafood, tropical aquarium use, as well as sporting and recreational fishing industries will likely be affected.

D. Invasive Species and Ecosystem Changes

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Native ecosystems are extremely vulnerable to climate change. Under extreme pressure from human activities and requiring extensive terrestrial and marine conservation, native habitats will face further pressure from climate change. The threat of invasive species to ecosystems will be substantially exacerbated as a result of rapid climate change. Endemic species (species that exist nowhere else on earth) are generally well-adapted to their current environment and do not respond well to ecological changes such as the introduction of non-native species.

Hawaiʻi is considered perhaps the most vulnerable U.S. state in terms of invasive species (Simberloff, 2000 and Federal Office of Technology Assessment). Given the already alarming rate of invasion, climate change has the potential to increase the effects of invasive species by allowing for more rapid colonization and also reduce the ability of native species to compete and survive (Simberloff, 2000 and Hellman et al., 2008).

While plants and animals will generally be able to adapt to climate change through altitudinal and geographic range changes, species in Hawaiʻi are generally limited by the lack of available space (Dukes and Mooney, 1999). While there are quite large altitudinal gradients throughout the state, the amount of land at the varying altitudes is quite limited. Additionally, the land that is available on "high islands" such as Oʻahu may not be suitable because of human inhabitation.

One of the more unique ecosystems in Hawaiʻi is the tropical montane, or "cloud" forest that occupies an altitudinal range with nearly constant cloud cover. These environments tend to harbor large proportions of endemic species that cannot survive outside of these small habitat ranges (Still et al., 1999). These lands are already vulnerable and severely threatened by environmental hazards such as deforestation, fragmentation, and general habitat destruction (Nadkarni and Solano, 2002). This threat is compounded by impending issues of climate change and shifts among ecological niches. Changing climate patterns are likely to shift these cloud forests to higher altitudes as the area of required relative humidity rises, perhaps at a rate faster than species will be able to migrate (Still et al., 1999). This issue is related to the problem of invasive species in that native species may actually become invasive in the context of climate change (Rejmanek, 2000). That is, the altitudinal range alteration in response to changing climate may drive one native species into another native species' habitat—causing unnatural competition.

The potential for large-scale disturbances such as hurricanes and forest wildfires will exacerbate the issues of invasive species. It is predicted that global climate change will produce conditions in which forest fires (Flannigan et al., 2000) and hurricanes (Mirza, 2003) will occur more frequently and with greater intensity, increasing the overall level of disturbance experienced within the forest ecosystem. The reason why invasive species are successful is in large part due to their ability to propagate quickly and colonize areas more rapidly than native species—an ability that will be especially advantageous in a situation of disturbance. Overall, it is expected that increasing disturbance events, will also increase the number and success of invasive species (Dukes and Mooney, 1999).

With invasive species come new diseases and parasites (Rahel and Olden, 2008), affecting not just plants and animals, but humans as well. Not only does climate change allow disease organisms to spread through new habitats, it also encourages more rapid lifecycles (Rahel and Olden, 2008 and Dukes and Mooney, 1999). In terms of invasive diseases and parasites related to human health, research has shown that climate change may alter the range of different disease vectors, exposing humans to diseases for which the human population lacks immunities (Githeko et al., 2000). This may be especially applicable at either end of the temperature extremes, exposing the Hawaiian population to diseases, such as Malaria and Dengue Fever.

VI. Adaptation Measures

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Formulating and implementing climate change adaptation measures will become essential as the effects of global change are experienced at the local level. The fact that global climate change will continue regardless of whether mitigation of greenhouse gas emissions occurs (IPCC, 2007) means that adaptation measures will be necessary regardless of the successes mitigation efforts achieve (though the level of necessary adaptation will clearly vary with mitigation). Therefore, the types of adaptation chosen and the effectiveness with which they are implemented will be critical to reducing the negative impacts of currently unavoidable global climate change.

Climate change adaptations can take numerous forms, both physical as well as social. Physical adaptations are characterized by a reliance on technology and infrastructure, resulting in large expenditures of capital. Social mitigation and adaptation, on the other hand, occur when people change their behaviors.

The state of Hawaiʻi has made some progress in addressing climate change mitigation. Efforts such as *Act 234*, "The Global Solutions Act of 2007," and the Hawaiʻi Clean Energy Initiative, demonstrate commitment to greenhouse gas emissions reduction strategies. But there is great need for additional attention to be paid to strategic adaptation measures. While mitigation is certainly desirable, adaptation is becoming an increasingly pressing issue for coastal areas.

A. Sea Level Rise

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Adaptation measures to sea level rise generally take two forms—protection and retreat. Protective measures tend to be realized in three different ways: erecting walls to hold back the sea (dikes), allowing the sea to advance and adapting to the advance (floating housing) and raising the land through infill (Scheraga and Grambsch, 1998).

One of the most popular forms of adaptation in Hawaiʻi, generally occurring on a household basis, is the construction of sea walls. Utilized as a way to prevent further erosion and encroachment of the sea, this protective measure is becoming increasingly common throughout the state. While these structures certainly serve as a stop-gate measure, protecting one's property, there are a number of downfalls. Most significantly, it has been shown that beach armament actually increases the rate of beach erosion, the opposite effect of what is desired (Fletcher et al., 1997). While private real estate may temporarily be protected, the beach itself and the public right-of-way can be further lost.

In terms of dealing with increased beach erosion as a product of climate change, it is possible to replenish beaches with sand brought from outside sources. Normally conducted at a large scale, nourishment involves utilizing large amounts of foreign sand to replace sand that has eroded. This is a successful measure only in the short-term as sand is likely to continue eroding. To a certain extent this is an aesthetic adaptation measure. Nourishment does not prevent further erosion and as such must often be repeated if results are to be maintained.

There are also potential adaptation measures that focus on the alteration of human behavior within the coastal zone, through voluntary or compulsory means. For instance, an institutional adaptation to sea level rise can be achieved through new zoning and building regulations, reflecting the expected water levels and mandating anticipatory adaptation. Such measures have already been taken in the county of Maui through innovative zoning that defines setbacks based on erosion rates (Genz et al., 2007). Kauai has adopted similar setback standards. While it is true that the sea will continue to encroach for many years to come, if sufficient anticipation occurs, development can occur at safe distances. The best adaptation measure in terms of protecting property and infrastructure is selective shoreline retreat in which development and infrastructure is moved inland (Fletcher et al., 1997).

B. Storm Water Management

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The direct improvement of storm water systems can occur in two different ways by retrofitting existing systems and/or constructing replacement systems. Budgetary concerns weigh heavily on the decision to replace or retrofit therefore careful and thorough analysis of the merits and costs of each should be explored. Critical to the storm water system issue is understanding whether retrofitting to the point possible will be sufficient to handle potential increased storm activity, while retrofitting that proves too little may ultimately prevent expenditures for the construction of new systems.

Storm water systems will require capacity improvements to handle increased rainfall and runoff events. It is predicted that extreme weather events will significantly increase in the future resulting in storms that produce rainfalls exceeding what occur today (IPCC, 2007). The need to construct storm-water systems that pump water rather than rely on gravity is also likely as elevation gradients become insufficient to handle large volumes of storm water. If storm water systems are not upgraded and capacities not improved, flooding is likely.

Any measure that reduces the amount of water that enters the storm water system by way of natural infiltration, will benefit storm water management. The larger the loads experienced by the systems, the greater the danger of failure or malfunction. Rather than focus on the system itself, measures can be taken to improve the environment within which the systems operate. For example, reducing the area covered by impervious surfaces is one potential strategy. One way to reduce the strain on storm water systems is to promote the natural filtration and expulsion of rainwater through such innovations as rain gardens and alternative pavement methods.

Protecting and maintaining upland forests through protective zoning is also an excellent method to help solve the problems of storm water management. In fact, Booth et al. (2002) state that the protection of upland watersheds is actually a better way to reduce the pressure on storm water systems than reducing impervious surfaces. If watersheds or ahupuaʻa, outside of major population centers are protected, rainfall in those areas will not contribute to urban storm water load, thus reducing the pressures put on the systems and reducing the chances of major failure. Additionally, the protection of forests and other natural lands prevents harmful effects such as agricultural runoff and sedimentation of marine ecosystems.

C. Ocean Acidification

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Adapting to ocean acidification is unlikely to occur by any current technological means. Compared to other challenges presented by climate change, adaptation to acidification will almost certainly have to occur through indirect means. Rather than engineering a solution, the general goal (while the scientific understanding of impacts of acidification are still relatively unknown) is to protect the marine ecosystem through preventing additional damage that will compound the effects of acidification. Enhancing the adaptive capacity of the marine ecosystem can occur through a number of different methods. An important distinction should be made whether actions will be taken to fix problems that already exist, or actions will be taken to address future needs and challenges. These different methods should be employed to varying degrees depending on the actual condition of the ecosystem in question, as well as the predicted effects of climate change.

Repairing damage that has already occurred is important to restore ecosystems to their natural conditions. Things like beach cleanups, while seemingly unrelated to adapting to ocean acidification, actually address the problem indirectly. Much of this adaptation work is low-tech and requires large amounts of social capital; mainly people to volunteer their time. Cleanup activities are often organized by local environmental organizations and can be an important piece of a broader strategy to protect the marine environment.

Protective or preventative measures against marine degradation may also be critical and often occur on a much larger scale. Additionally, this method is effective because it eliminates the need for restoration efforts which are often more difficult and costly than conservation or protection. Management tools such as the designation of Marine Protected Areas (MPA's), or Marine Life Conservation Districts (MLCD's) in Hawaiʻi, have the potential to reduce harm caused by humans. Currently, there are a total of thirteen MLCD Systems set up throughout the state (National Marine Protected Areas Center, 2010), but the need for additional protected areas remains. These management tools that limit, to varying degrees, commercial or recreational use of certain environments encourage the existence of healthy marine ecosystems that may have the natural capability to adapt to more acidic waters.

D. Invasive Species

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Addressing invasive species in Hawaiʻi is a long-term battle. Dealing with the problem of invasive species involves both the prevention of invasive species entry and the protection of native and endemic species.

The prevention of invasive species entry into Hawaiʻi will need to improve by implementing effective stop-gate measures that prevent the introduction of new species. Observations have shown that a greater number of invasive species will increase competition for resources held previously by endemic and native species, thus creating a difficult situation for their survival. Prevention occurs by strengthening the regulations that control the entry of goods and cargo from other places that often carry these biological invasive species. Preventing invasive species from entering Hawaiʻi is by far more effective, in nearly every way, than eradication after infestation. As discussed by Burnett (2006), a real lack of focus has been placed on prevention, with eradication being more common, despite its comparative ineffectiveness.

By protecting forests or marine ecosystems such as montane forests and coral reefs, the natural resilience and competitive abilities of native species are strengthened so that invasive species do not have such a significant competitive advantage. This protection can occur through a number of means; protection through private land trusts, designation as a preserve, or even through protective zoning measures by local communities. Specific methods utilized by a number of organizations interested in preservation have found conservation easements to be useful incentives to encourage landowners to place their lands in conservation, either for a specific amount of time, or in perpetuity. By preserving the natural environment and native species that inhabit them from as many dangers as possible, the native populations will be healthier and better able to compete with invasive species.

There are a number of entities, both government and non-governmental organizations, that are working in Hawaiʻi committed to the protection of native species and the prevention and eradication of invasive species. Such organizations include the Hawaiʻi Invasive Species Team, part of the U.S. Forest Service, and the Hawaiʻi Invasive Species Council – a partnership of various agencies and organizations from around the state that work to combat invasive species. Some of the common invasive species targeted by these organizations include miconia, the little fire ant, coqui frogs, ungulates, and the brown tree snake, all of which can be devastating to the native environment.

Adaptation to climate change as it relates to invasive species must be more broadly focused on conservation as a whole. The protection of the native flora and fauna as well as the prevention and eradication of invasive species are both critical aspects of conserving the unique Hawaiian environment.

VII. Conclusions

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Climate change is sure to have a number of detrimental effects to Hawaiʻi's environment, people and economy. The pressing and known issues include sea level rise, storm water management, ocean acidification, and invasive species. Climate change is not only creating a whole host of new environmental challenges, but it is also complicating existing conservation efforts. The science behind climate change is well established and, while a degree of uncertainty exists, the fact remains that rapid environmental change is occurring.

As many estimates fail to include the issues of feedback loops and tipping points, predictions as to the extent of climate change and the severity of its effects may be underestimated. As the science and predictive capability of climate models become more refined, particularly at understanding regional impacts, the level of uncertainty will reduce.

This is not to say, however, that adaptation measures should be delayed. Planners and policy-makers should follow the "precautionary principle," meaning that it is prudent to take cautious action, even when there is not full scientific certainty, in the face of "serious or irreversible damage" (United Nations Environment Programme, 1992 Principle 15).

In reality however, uncertainty tends to slow down decision-making, as officials try to avoid less than clear-cut decisions for fear of being wrong (Dessai and Humle, 2004). Nonetheless, it is critical for decision-makers and the general public to support climate change adaptation measures, following the precautionary principle, and, in particular, focus on "no regrets strategies." Take for example the issue of sea level rise. There may not be perfect predictions on exactly when Hawaiʻi's shores will experience a meter of sea level rise, but we know that it will happen at an accelerated pace. We can certainly plan for that.

VIII. List of Acronyms

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CZM .... Coastal Zone Management
EPA .... Environmental Protection Agency
IPCC .... Intergovernmental Panel on Climate Change
ppm .... parts per million
SRES .... Special Report on Emissions Scenarios (IPCC)
TAR .... Third Assessment Report (IPCC)
THC .... thermohaline circulation
UNEP .... United Nations Environment Programme

IX. References

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