FINAL REPORT

1. ADMINISTRATIVE:

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Project Title: Potential impacts of sea level rise on native plant communities and associated cultural sites in coastal areas of the main Hawaiian Islands

Agreement Number: 4500055126

Report Date: June 12, 2017

Reporting Period: September 1, 2013 – December 31, 2015

Total Project Cost: $ 109,758.00

2. PUBLIC SUMMARY:

Hawaiian coastal vegetation is comprised of plant species that are adapted to growing in extremely harsh conditions (salt spray, wave wash, wind, and substrates with limited nutrients) found in this habitat zone. Prior to human colonization of Hawai‘i coastal vegetation extended as a continuous ring around each of the islands, broken only by stretches of recent lava flows or unstable cliff faces. However, since humans arrived in Hawai‘i many areas that originally supported native coastal plant communities have been highly altered or the native vegetation totally removed for agriculture, housing, or resort development, destroyed by fire, displaced by invasive plants, eaten by introduced mammals, or damaged by recreational use. This study was focused on identifying sites that still retain relatively intact and highly diverse native coastal plant communities throughout the main Hawaiian Islands that may be further impacted by projected sea level rise. Approximately 40 percent of Hawai‘i’s coastlines were found to still contain high quality native coastal plant communities. Most of these sites were located in areas where the coastal vegetation can still migrate inshore in response to rising sea level and associated inundation by waves. However, six sites with high-quality native coastal vegetation were found on low-lying offshore islets that will be totally inundated with a one meter increase in sea level and thirty sites were found to have some type of fixed barrier, such as a paved road

or structure, which would restrict the plants from colonizing the adjacent inland areas. Many of these sites also have other cultural resources that are fixed in place and will definitely be impacted by rising sea level. The results of this study can help refine our understanding of Hawai‘i’s remaining native coastal vegetation and aid with the development of management and restoration strategies to ensure the long-term survival of these unique plant communities.

3. PROJECT REPORT

A. INTRODUCTION

a. TECHNICAL SUMMARY:

Hawaiian coastal vegetation is comprised of plant species that are adapted to growing in the extremely harsh conditions found in this habitat zone that include inundation by salt spray, wave wash, wind, and substrates with limited nutrients. Coastal plant communities are found across a broad range of moisture and substrate conditions, from arid to wet habitats, and on various types of basaltic and carbonate substrates. Prior to human colonization of these islands, the Hawaiian coastal vegetation extended as a continuous ring around each of the islands, broken only by stretches very young substrates (*e.g.,* recent lava flows) or unstable cliff faces. However, since humans arrived in Hawai‘i and started occupying the coastal zone on each island, many areas that originally supported native coastal plant communities have been highly altered or the native vegetation totally removed as a result of land use practices (housing, agriculture, urban development), use of fire, degraded by competition from invasive plants, or eaten by introduced ungulates, particularly feral goats (*Capra hircus*), axis deer (*Axis axis*), and cattle (*Bos taurus*). Many coastal areas in Hawai‘i are now also subject to high recreational use including shoreline fishing, camping, hiking, and driving recreation vehicles over the sand and through the vegetation. These threats continue to degrade the native plant communities found along the coast and today less than half of the coastlines on the main Hawaiian Islands are still dominated by native plant species. This study was focused on identifying sites that still retain relatively intact and highly diverse native coastal plant communities throughout seven of the main Hawaiian Islands (Kaua‘i, O‘ahu, Molokai, Lāna‘i, Kaho‘olawe, Maui, and Hawai‘i) that may be further impacted by projected sea level rise. Within these identified threatened coastal sites we also attempted to determine if other important cultural sites (*e.g.,* Hawaiian house or wall structure, burial sites, *etc.*) found there may also be threatened by projected sea level rise. The results of this study are intended to provide a spatial foundation for identifying priority sites containing native coastal vegetation

which may be used for the development of management strategies to help maintain the viability of native coastal plant communities and other important cultural resources found at these sites.

A total of 565 coastline segments were assessed for their composition, status, site characteristics, and vulnerability due to sea level rise on the seven major Hawaiian Islands. The coastlines of each island were visually divided on a GIS map layer into linear segments that were determined to contain relatively continuous extents of coastal vegetation that were classified into one of four status categories, based on two factors: condition of plant community structure, and number of native species found at the site. The vegetation status categories were defined as follows: 1) very high quality coastlines (green units on maps), with moderate to good vegetation structure and greater than ten (up to thirty) native coastal plant species; 2) high quality coastlines (blue units on maps), with moderate vegetation structure and seven to ten native species; 3) moderate quality coastlines (yellow units on maps), with little or moderate natural vegetation structure and with four to six native species; and 4) poor quality coastlines (red units on maps), with little or no natural vegetation structure and less than four native coastal plant species. For coastal areas containing native plant communities that appear to be most threatened by sea level rise we also attempted to determine if other cultural resources found there might be impacted.

For this study we focused on the 207 coastal segments in just the high and very high vegetation status categories to assess their potential vulnerability to projected one meter sea level increase by the year 2100. We found that 171 of these sites currently appear to have adequate space and conditions to allow the vegetation to move inland in response to sea level rise. However, 36 of the high and very high quality vegetation sites appear to be located in areas that currently have barriers or other limitations that may restrict their establishment inland from their present locations in response to sea level rise. Six of these vulnerable sites are small offshore islets that do not have enough vertical extent to provide space for the coastal vegetation currently found there to survive any significant increase in sea level; based on the current sea level rise model they will be regularly washed over by waves by the end of the century. The other 30 sites with high and very high quality coastal vegetation that appear to be most threatened by projected sea level rise are located in areas that currently have human-related barriers that will likely restrict inland movement in some parts of

their mapped extent as the coastline recedes with a projected increase of sea level by the year 2100. These barriers include roads, structures, and highly managed vegetation (*e.g*, golf courses, parks, lawns, *etc*. Twenty of the 36 high and very high quality coastal vegetation segments that were considered to be most vulnerable to impacts from sea level rise had one or more important cultural resource sites identified along that shoreline, even though we suspect the current cultural site database is not comprehensive or complete.

Projected sea level rise adds another, previously unanticipated problem to the management of these coastal ecosystems. While it is clear that sea level rise will have an impact on the native plant communities found along all of the coastlines in the Hawaiian Islands, the results of this study indicate that, under current conditions, in most areas the vegetation may be able to move inshore as the coastline recedes if unimpeded in the future. The results of this study and associated database and GIS files depicting the distribution and status of Hawaiian coastal plant communities can serve as a foundation for developing management strategies to protect and enhance these coastal resources into the future. Unfortunately, the protection of cultural resource sites from the impacts of projected sea level rise poses a nearly intractable problem. Unlike coastal plant communities which have to potential to become established inland with a decreasing coastline, cultural resources are fixed in place and those close to the shoreline will undoubtedly be heavily impacted or destroyed with an increase in sea level.

b. PURPOSE AND OBJECTIVES:

One of the anticipated impacts of global climate change for the Hawaiian Islands is a projected increase in sea level of approximately one meter by the year 2100 (Fletcher 2009). Any increase in sea level will have impacts on biological and cultural sites located along the coastline; the degree of impact will depend on the level of rise, changes in wind and wave activity, and barriers to the movement of plant communities inland in response to a changing coastline.

Hawaiian coastal vegetation is comprised of plant species that are adapted to growing in the extremely harsh conditions found in this habitat zone that include inundation by salt spray, wave wash, wind, and substrates with limited nutrients (Figure 1). These plant communities are unique from a global perspective with approximately 58 percent of the native species endemic to Hawai‘i (Wagner *et*

al. 2005-present, Warshauer *et al.* 2009) (Figure 2). Two major environmental factors influence the composition and structure of the coastal vegetation: available moisture and substrate type. Hawaiian coastal plant communities are found across a broad range of moisture and substrate conditions, from arid to wet habitats, and on various types of basaltic and carbonate substrates. Although these communities are most abundant along the shoreline just above the high tide line, the coastal habitat may extend many hundreds of meters inland as well as up several hundred meters in elevation, particularly on the high windward cliffs on several of the Islands (*e.g.,* north coasts of Maui, Molokai, Kauaʻi, and Hawaiʻi) where the salt spray and plant propagules are blown upslope (Figure 3). In some areas the coastal vegetation may also anchor extensive sand dune systems that help to protect the inshore areas from wave inundation. Warshauer *et al.* (2009) described several native plant species groups that help define the different plant communities along the coasts of the main Hawaiian Islands relative to the wet, mesic, and dry moisture zones mapped by Price *et al.* (2012) (Appendix 1). Eight of the 44 native species listed in Appendix 1 are recognized by the U.S. Fish and Wildlife Service as Endangered, one is considered Threatened, two species are candidates for listing, and four are considered to be species of concern.

Prior to human colonization of these islands, the Hawaiian coastal vegetation extended as a continuous ring around each of the islands, broken only by stretches of very young substrates (*e.g.,* recent lava flows) or unstable cliff faces (Figure 4). With no artificial barriers to movement, the coastal vegetation responded to previous changes in sea level by receding inland with an increase in sea level height, or extending outward following a decrease. However, since humans arrived in Hawaiʻi and started occupying the coastal zone on each island, many areas that originally supported native coastal plant communities have been highly altered or the native vegetation totally removed as a result of land use practices (housing, agriculture, urban development), use of fire, degraded by competition from invasive plants, or eaten by introduced ungulates, particularly feral goats (*Capra hircus*), axis deer (*Axis axis*), and cattle (*Bos taurus*). Additionally, in many places the landscapes immediately inland of the coastline have been developed or altered in ways that damaged or eliminated the natural sand dune systems and established fixed barriers that could restrict movement of the native vegetation inward from the coast. Many coastal areas in Hawaiʻi are now also subject to high recreational use including shoreline fishing, camping, hiking, and driving recreation vehicles over the sand and through the

vegetation (Figure 5). These threats continue to degrade the native plant communities found along the coast and today less than half of the coastlines on the main Hawaiian Islands are still dominated by native plant species (Warshauer *et al.* 2009).

This study was focused on identifying sites that still retain relatively intact and highly diverse native coastal plant communities throughout seven of the main Hawaiian Islands (Kauaʻi, Oʻahu, Molokai, Lānaʻi, Kahoʻolawe, Maui, and Hawaiʻi) that may be further impacted by projected sea level rise. The island of Niʻihau was not included in the survey since there is very limited information for this island on its coastal plant community composition and structure, and very-high-resolution imagery is not available to use for assessing the status of its coastal vegetation. Within the identified threatened coastal sites, we also attempted to determine if important cultural sites (*e.g.,* Hawaiian house or wall structures, burial sites, *etc.*) found there might also be threatened by the projected sea level rise. The results of this study are intended to provide a spatial foundation for identifying priority sites containing native coastal vegetation which can be used for the development of management strategies to help maintain the viability of native coastal plant communities and other important cultural resources found at these sites.

c. ORGANIZATION AND APPROACH:

The distribution and status of plant communities and selected site characteristics were assessed along the coastlines for the seven main Hawaiian Islands and their large offshore islets to identify sites that were most vulnerable to one meter sea level rise projected by Fletcher (2009) by the year 2100. While all coastal areas in Hawaiʻi will experience some level of impacts with any rise in sea level, most of the plant communities found there are expected to be able to move inland or upslope unless there are specific barriers (*e.g.,* roads, structures, walls, etc.) that impede this movement (Enwright *et al.* 2016). Coastal vegetation sites are considered to be most threatened if they are currently found to contain high quality native plant communities (*i.e.,* intact vegetation structure and high species richness), and occur in areas that have fixed barriers to inland movement of the vegetation in response to sea level rise.

Data Sources

Projected change in sea level was based on a static model developed by Dr. Charles Fletcher's research group at the University of Hawai'i at Mānoa and published by NOAA Coastal Services Center (2013). This model and related geographic information system (GIS) layers were produced for the main Hawaiian Islands and include projections of sea level rise in one foot (0.3 meter) increments up to six feet (1.8 meters). We had originally hoped to use a dynamic sea level rise model that included wave inundation in its projection of areas to be impacted. Dynamic sea level rise inundation models have been compiled by the Fletcher research group at the University of Hawai'i for several areas in the Hawaiian Islands but the results have not yet been published. However, even with using the static sea level rise model, we felt that we were able to identify the most important native coastal vegetation areas that could experience restricted inshore movement in response to sea level rise.

Information for the vegetation component of this study was obtained by compiling the results from several earlier surveys of Hawaiian coastal vegetation (Forbes 1913, Corn *et al.* 1980, Clarke 1982, Starr *et al.* 2006c, a, b, Wood 2008, Warshauer *et al.* 2009, Wood 2010, Pratt *et al.* 2011, Starr and Starr 2013). These data were augmented by new field work that was conducted in some selected areas that had been missed by the previous studies.

For coastal areas containing native plant communities that appear to be most threatened by sea level rise, we also attempted to determine if other cultural resources found there would be impacted. Presence of these resources at each sites was assessed by examining a cultural resource database compiled by the Hawai'i State Historic Preservation Division (HSHPD), as well from several other published accounts (Clark 1977, 1985, 1989, 1990, Kane *et al.* 2012) that made reference to cultural resources at specific sites. However, we found that the HSHPD database was not comprehensive in its coverage along all coastlines since, using very-high-resolution imagery, we were able to identify certain types of cultural sites, particularly ancient house sites and platform structures, many of which were not recorded in the HSHPD database. Therefore, we have limited confidence in the completeness of our assessment of other cultural resources found at the native coastal vegetation sites identified during our survey.

Characteristics of each coastal vegetation site were determined using various published GIS data and imagery layers. We used WorldView2 high-resolution

digital imagery collected by Digital Globe (2010) and very-high-resolution color imagery collected by Pictometry International (2008-present) to assess coastline topography, vegetation type and condition, potential barriers to inward movement, land use, and presence of selected invasive plant species along the coastlines surveyed. Substrate type was recorded for each coastal segment based on the geologic maps produced by Sherrod *et al.* (2007). Information on moisture zones was obtained from the maps prepared by Price *et al.* (2012). We also recorded data on land use and land ownership using GIS layers obtained from the Hawai'i State GIS Program portal (Hawaii State GIS Program 2013, 2016).

Assessment of Plant Community Status and Habitat Characteristics

The coastlines of each island were visually divided on a GIS map layer into linear segments that were determined to contain relatively continuous extents of coastal vegetation that were classified into one of four status categories, based on two factors: condition of plant community structure, and number of native species (Appendix 1) found at the site. The vegetation status categories were defined as follows: 1) very high quality coastlines (green units on maps), with moderate to good vegetation structure and greater than ten (up to thirty) native coastal plant species; 2) high quality coastlines (blue units on maps), with moderate vegetation structure and seven to ten native species; 3) moderate quality coastlines (yellow units on maps), with little or moderate natural vegetation structure and with four to six native species; and 4) poor quality coastlines (red units on maps), with little or no natural vegetation structure and less than four native coastal plant species; (Figure 6). Vegetation structure and species richness was initially determined at selected coastal sites based on previously published field surveys (Clarke 1982, Hobdy and Clarke 1982, Gon III and Chun 1992, Starr and Starr 2006, Starr *et al.* 2006b, a, c, Warshauer *et al.* 2009, Pratt *et al.* 2011, Starr and Starr 2013). We then visually compared the appearance of these sites to other coastal areas using the very-high-resolution Pictometry imagery. This methodology allowed us to identify and delineate coastline segments into the one of the four status categories for the entire coastlines of the seven main Hawaiian Islands that we surveyed. Additional fieldwork was then conducted in many of the newly mapped areas to verify the vegetation on the ground, particularly for sites that appeared to be in the high quality and very high status categories.

Identification of Barriers to Inland Movement of Coastal Vegetation

For coastal sites that were identified to have native coastal plant communities in the high and very high status categories we examined the inshore extent of the vegetation to determine if there were any fixed human-related barriers to inland movement of the native plant species. Several types of barriers were identified including paved roads; permanent structures; intensive agriculture; highly managed vegetation such as a landscaped yard, park, or golf course; or other paved areas such as an airport runways and related infrastructure (Figure 7). A site was considered to be threatened if it was in either the high or very high quality vegetation status categories, and if it was found to have a fixed barrier anywhere along its linear extent that could restrict the inshore movement of the native plant community located less than twice the current maximum inshore distance of the coastal vegetation. For example, a site would be considered to be vulnerable if the native plant community in a high or very high quality vegetation site was currently found to extend 100 meters inland from the high water line and there was a paved road located anywhere within 200 meters inland from the high water line. Although this distance rule is somewhat arbitrary, it allowed us to use a consistent measure to help identify sites that may have a potential inland movement restriction. Unlike plant communities that can potentially migrate inland with rising sea level, other cultural resources are fixed in place and will likely be damaged or destroyed if the water level and/or wave surge overruns their location.

B. PROJECT RESULTS:

A total of 565 coastline segments were assessed for their composition, status, site characteristics, and vulnerability due to sea level rise on the seven major Hawaiian Islands (Table 1) (Figure 8). The length of coastline segments that were mapped varied considerably since each one was delineated solely based on the fact that it had a relatively continuous strip of vegetation in one of the four status categories. When the vegetation status categories were summarized, we found that 60.8 percent of the coastline in the main Hawaiian Islands had native coastal vegetation that was mapped as highly disturbed and in the poor quality status category, 18.5 percent was described as being in the moderate status category, 9.1 percent of the coastline was considered to be in high quality status, and 11.5 percent as very high quality status (Table 2).

The percentage of coastline length in the different status categories varied by island with the islands of Maui and Molokai showing the greatest extents of their coastlines in

the very high status categories (Maui with 28.6 percent and Molokai with 24.0 percent). However, when the high and very high categories were combined the island of Kauaʻi had the highest percent of its coastline (46.1 percent) in this grouped high vegetation quality status (Table 3) (Figure 9). The islands of Maui and Molokai also had greater than 30 percent of their coastlines mapped in the high or very high category (Maui 39.3 percent and Molokai 36.7 percent); and the islands of Oʻahu, Kahoʻolawe, Hawaiʻi, and Lānaʻi were all mapped with less than 15 percent of their coastlines in these two categories combined. For all of the islands surveyed, the majority of the coastline segments in the high and very high status categories were in the dry moisture zones as described by Price *et al.* (2012), with most of the remainder found in the mesic zone (Table 4). Only the islands of Hawaiʻi, Maui, and Molokai had high or very high quality coastal vegetation mapped in the wet moisture zone.

For this study we focused on the 207 coastal segments in just the high and very high vegetation status categories (Table 3) to assess their potential vulnerability to projected one meter sea level increase by the year 2100. We found that 171 of these sites still appear to have adequate space and habitat conditions to allow the vegetation to move inland in response to sea level rise. However, 36 of the high and very high quality vegetation sites appear to be located in areas that currently have barriers or other limitations that may restrict their establishment inland from their present locations in response to sea level rise (Table 5) (Figure 10). Seventeen of these most vulnerable sites are on Oʻahu (Figure 11), eight are on Maui (Figure 12), six are on the island of Kauaʻi (Figure 13), three on the island of Hawaiʻi (Figure 14), and two are on Molokai (Figure 15). All of these sites occur in dry or mesic moisture zones; many of them are found on public lands (county, state, federal), while others are located on lands controlled by the Department of Hawaiian Home Lands or owned by various other large or small landowners (Table 6).

Six of these vulnerable sites are small offshore islets that do not have enough vertical extent to provide space for the coastal vegetation currently found there to survive any significant increase in sea level; based on the current sea level rise model they will be regularly washed over by waves by the end of the century (Figure 16). Portions of one other site, Kaʻena Point on Oʻahu, may also be washed over by large waves regularly in the future. Very high quality native coastal vegetation is found there in the sandy and rocky flat areas near Kaʻena Point as well as extending a short way upward on the talus slopes below the cliffs in this area. The vegetation on the talus slopes is situated well above the projected water and potential surge zone in 2100 and should not be impacted much by projected sea level rise. The coastal plant communities on the flat areas near

Ka‘ena Point could be vulnerable to higher sea level and associated wave action on this north-facing high-energy shoreline. However, the current management of this area, which is designated as a State Natural Area Reserve, has resulted in the elimination of all vehicles from the area and is encouraging the restoration of this extremely diverse native coastal plant community. These actions should also foster the reestablishment of an active sand dune system there, potentially offering some additional protection from the impacts of higher sea level and associated wave inundation to this site in the future.

The other 30 sites with high and very high quality coastal vegetation that appear to be most threatened by projected sea level rise are located in areas that currently have human-related barriers that will likely restrict their inland movement in some parts of their mapped extent as the coastline moves inland. These barriers include roads, structures, and highly managed vegetation (golf courses and landscaped yards or lawns, often with a wall constructed on the side fronting the ocean) (Figure 17). One threatened site on the island of Molokai is located immediately adjacent to the Kalaupapa airport runway.

Twenty of the 36 high and very high quality coastal vegetation segments that were considered to be most vulnerable to impacts from sea level rise had one or more important cultural resource sites identified along that shoreline (Table 6), even though we suspect the current cultural site database is not comprehensive or complete. For the most part, the location and description information for these cultural resource sites is vague, and we were not able to assess further the degree and types of impacts that changes to the shoreline and impacts from rising sea level and wave action would have on these sites. However, given the fact that the majority of these sites had some indication of extant sites with cultural value, it is expected that any increase in sea level will have a definite impact on some of these cultural sites since they are fixed in place.

C. FINDINGS/EVALUATION

a. FINDINGS AND CONCLUSIONS:

Despite major changes that have occurred, particularly to lowland ecosystems since human colonization of Hawaii, most of the main Hawaiian Islands still have many sites containing relatively intact and diverse examples of native-dominated coastal vegetation. This is particularly the case for the islands of Kaua‘i, Maui, and Molokai which still have over 30 percent of their coastlines with viable high quality native coastal plant communities that occur in dry, mesic, and wet habitats. The lower percentages of coastlines with relatively intact native coastal

vegetation on the other four islands are a result of heavier combined impacts of human development and recreational use (Oʻahu), invasive plants and animals (Lānaʻi and Kahoʻolawe), as well as many areas with very young substrates, particularly downslope of the active volcanoes on the island of Hawaiʻi. All of the factors currently impacting native-dominated Hawaiian coastal plant communities, including the certainty of new lava flows on the island of Hawaiʻi, may continue to degrade these ecosystems and threaten their long-term stability and existence.

Projected sea level rise adds another, previously unanticipated problem to the management of these coastal ecosystems. While it is clear that sea level rise will have an impact on the native plant communities found along all of the coastlines in the Hawaiian Islands, the results of this study indicate that, under current conditions in most areas, the vegetation may be able to move inshore as the coastline recedes if unimpeded in the future. However, we identified 36 high quality coastline segments that appear to have restrictions or barriers to the inshore movement of the vegetation. The results of this study may help with the development of management strategies to alleviate or reduce these movement restrictions which will allow some portions of the important native coastal plant communities found there to continue to occupy these sites inshore. In some cases the barriers, such as roads or structures, only restrict inshore movement of the vegetation across a small portion of their coastal extent. If future development plans can include an adequate setback distance from the vegetation that will allow it to move inland with rising sea level, the coastal vegetation at these sites may be able to continue to occupy these areas and still be maintained as high diversity native plant communities. In other areas, however, the barriers completely block potential inshore movement of the vegetation and, unless these are removed or altered, the high quality native coastal plant communities currently found at these sites will likely be highly impacted or destroyed with sea level rise. Unfortunately, there appear to be no practical solutions for protecting the vegetation on six of the offshore islets that were found to have high or very high quality native coastal vegetation but were projected to be completely inundated with a one meter sea level rise. However, it may be possible to use some of these sites as source locations from which propagules can be collected from some of the native coastal plant species found there to be used for vegetation restoration in conjunction with management at other nearby coastal areas.

There are both challenges and opportunities that should be considered for long-term management of all remaining native coastal plant communities in Hawai‘i. The challenges include controlling the expansion of several key invasive plant species, including ironwood (*Casuarina equisetifolia.*), kiawe (*Prosopis pallida*), mangroves (*Rhizophora mangle*), and various grass species, particularly bufflegrass (*Cenchrus ciliaris*) and seashore paspalum (*Paspalum vaginatum*), which, in conjunction with impacts from feral ungulates, continue to threaten the remaining areas with high and very high quality native coastal vegetation. Additionally, use of the coastal zone for housing and resort development with its associated infrastructure continues to increase in some areas. With the recognition of projected sea level rise as an additional threat in the coastal zone, more actions are being proposed and, in some places, implemented to protect these human occupied areas from the impacts of sea level rise by constructing sea walls and initiating other shoreline stabilization measures. Finally, there appears to be an increasing amount of damage to both coastal plant communities and important cultural sites found there by intensive recreational use. It may be possible to reduce or control this impact, particularly in sites that have high quality native plant communities, by developing designated access routes through the vegetation and by restricting two- and four-wheel vehicle access to some areas. However, the success of these management efforts will need strong support from the public. It would be important to couple this initiative with a well-developed public awareness and outreach program that emphasizes the uniqueness and value of Hawai‘i’s coastal vegetation.

On the positive side, the Hawaiian coastal plant communities exhibit some degree of inherent resilience to disturbance given the fact that these communities and the species that compose them have evolved to survive under the extremely harsh and changing conditions found at the coastline. For example, if the coastal landscape is not actively disturbed by development and the most invasive plant and animal species are controlled or kept out of an area, the native Hawaiian coastal plants appear to be very able to remain established on a site and even have the potential to become established well inshore of the coastline. One example of this is the extension of the native coastal vegetation several hundred meters inland in the Wai‘ōhinu area at the southern tip of the island of Hawai‘i (Figure 18). Also, the coastal vegetation restoration effort conducted by The Nature Conservancy of Hawai‘i at its Mo‘omomi site on the island of Molokai demonstrates the ability of the native plant species found there to recover following control of the highly invasive tree kiawe and several

introduced grass species (Figure 19). Additionally, if the coastal vegetation is restored, particularly in windward areas, the vegetation structure should be able to facilitate the reestablishment of the sand dune system which will offer additional protection from higher sea level and increased wave action to the coastline and areas lying behind it.

b. LESSONS LEARNED:

When this project was originally proposed, we identified three types of information that we felt were necessary for it to be successfully conducted: 1) detailed information on the current distribution, composition, and status of coastal plant communities for the main Hawaiian Islands; 2) published GIS layers depicting changes in Hawaiian coastlines as a result of projected sea level rise by the year 2100; and 3) information on the location of other cultural resources found along the coastlines. Once we started the project, we realized that the only state-wide model of projected sea level rise that was published and available for use was based on a static rise in mean high tide level (NOAA Coastal Services Center 2013), and did not have a dynamic component that included zones of potential wave and surge inundation based on ocean energy and of the near-shore and coastal topography. As a result, the static model provides a very conservative estimate of potential impacts of sea level rise along the coastlines of the Hawaiian Islands. In many cases, a projected one meter sea level rise in this model will show the water line moving up to just the current coastal vegetation line, which does not adequately depict even the influence of wave action at current sea level. However, for some sites, for example at Anaehoʻomalu Bay on the island of Hawaiʻi (Figure 20), even the static model of sea level rise projects an enormous change in the coastline which would have large impacts on the native coastal vegetation found there. For many other sites we had less confidence in how much area behind the current coastal vegetation line would be impacted with sea level rise based on the static model.

Another component of this study was to also evaluate the potential impacts of projected sea level rise on other cultural resources found at the coastal sites that are most threatened by this change in the coastline. Two issues arose once we started compiling data on the locations of cultural sites. First, the location of these resources in many areas represents sensitive data which can only be depicted in a way that will not compromise the exact location these features. Secondly, we found that the most comprehensive cultural resource database,

compiled by the Hawai‘i State Historic Preservation Division, was inconsistent in its completeness as well as having only very general location information for cultural features at many sites. We therefore decided to identify cultural resources very generally at a site without including any information on the types, numbers of, and specific locations of cultural resources found there. As a result, we have limited confidence in the completeness of our assessment of other cultural resources found at the most vulnerable native coastal vegetation sites found during our survey.

We were generally satisfied with the methods we used to classify and map the coastlines of the main Hawaiian Islands to identify the status of native coastal plant communities found there. The combination of field-based information compiled from previously conducted surveys augmented by additional field work in conjunction with examining the patterns of the vegetation on the very-high-resolution Pictometry imagery allowed us to map the vegetation and its status along each of the coastlines with relatively high confidence. Now that these maps have been produced they can serve as a foundation to guide additional field surveys along the coast to better refine our understanding of Hawai‘i’s remaining native coastal vegetation and aid with the development of management and restoration strategies on a site-by-site basis to ensure the long-term survival of these unique plant communities.

c. IMPLICATIONS AND RECOMMENDATIONS:

The results of this study and associated database and GIS files depicting the distribution and status of Hawaiian coastal plant communities can serve as a baseline for developing management strategies to protect and enhance these coastal resources into the future. Although we were able to classify all of the coastlines that were surveyed into one of four status categories ranging from very high quality to poor quality, we realize that even the moderate and poor quality sites have the potential for restoration of a native species-dominated coastal plant community if the current threats are reduced or eliminated and the vegetation is allowed to recover. However, besides finding ways to control or reduce the impacts of a number of detrimental factors that are currently acting on these plant communities, we see that it is now also important to integrate the potential impacts or sea level rise into site-based management strategies, particularly for the 36 threatened sites identified in this study that appear to

have restrictions for inshore movement of the native vegetation as sea level increases.

Unfortunately, the protection of cultural resource sites from the impacts of projected sea level rise poses a nearly intractable problem. Unlike coastal plant communities which have to potential to move and become established inland with a decreasing coastline, other cultural resources are fixed in place and those close to the shoreline will undoubtedly be heavily impacted or destroyed with an increase in sea level. A more detailed study is needed using more accurate dynamic sea level rise projection models to identify what parts of the coastline will be most impacted by this change. This information can then provide the basis to conduct more detailed surveys of these areas to determine what cultural resources are found there. Once this is done, strategies can be developed to decide how best to respond to the potential impacts on these other important resources.

Finally, the information on Hawaiian coastal ecosystems compiled in this study may also be used to develop or expand public education and outreach efforts that can encourage more public awareness of the value of these unique Hawaiian natural resources and to encourage expanded participation in managing them for future generations. All of the results of this study are publicly available for these types of expanded use.

D. INFORMATION DISSEMINATION

a. OUTREACH:

- USGS Brown Bag Seminar presentation in March 2017, Hawai‘i Volcanoes National Park
- PICCC Webinar planned for 2017
- Summary of results on PICCC and PIERC Webpages

b. SCIENCE OUTPUTS:

- Oral presentation: Potential impacts of sea level rise on Hawaiian coastal vegetation and cultural resource sites. Hawai‘i Conservation Conference, Hilo, HI, July 2016.
- Planned: peer reviewed report planned summarizing the results of this study to be published as a USGS Open File Report in 2017.

- Oral presentation planned for June 2017 at the Vitousek Hawai‘i Ecosystems Meeting

ACKNOWLDEGEMENTS

Funding for this project was provided by the Pacific Islands Climate Change Cooperative (Agreement # 4500055126). Additional administrative support was provided by the U.S. Geological Survey's Pacific Islands Ecosystems Research Center. We would also like to thank Sam Gon, Steph Tom, Jon Price, and Linda Pratt for their review and constructive comments on the manuscript; and Chip Fletcher and Matt Barbee from the University of Hawai‘i at Mānoa SOEST proagram who provided data and other information on their projected sea level rise models.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Table 1. Count of all coastal segments by status and island.

Island	Poor	Moderate	High	Very high	Total
Hawai‘i	74	89	22	3	188
Kaho‘olawe	3		2	2	7
Kaua‘i	16	25	22	8	71
Lāna‘i	11	15	3		29
Maui	24	38	29	39	130
Molokai	12	15	13	33	73
O‘ahu	20	16	13	18	67
Total	160	198	104	103	565

Table 2. Summary of A. length (km) and B. percent of coastline of all coastal segments by status and island.

A.

Island	Poor	Moderate	High	Very high	Total
Hawai‘i	332.4	196.3	29.1	9.2	567.0
Kaho‘olawe	61.1		3.7	1.6	66.4
Kaua‘i	55.6	46.9	55.6	32.0	190.1
Lāna‘i	80.6	6.1	3.5		90.3
Maui	133.2	43.7	31.2	83.4	291.5
Molokai	105.2	18.6	24.9	47.0	195.6
O‘ahu	311.6	17.2	14.5	31.3	374.5
Total	1,079.7	328.9	162.4	204.5	1,775.4

B.

Island	Poor	Moderate	High	Very high
Hawa`i‘i	58.6%	34.6%	5.1%	1.6%
Kaho‘olawe	92.1%	0.0%	5.6%	2.3%
Kaua‘i	29.2%	24.7%	29.2%	16.8%
Lāna‘i	89.3%	6.8%	3.9%	0.0%
Maui	45.7%	15.0%	10.7%	28.6%
Molokai	53.8%	9.5%	12.7%	24.0%
O‘ahu	83.2%	4.6%	3.9%	8.4%
Total	60.8%	18.5%	9.1%	11.5%

Table 3. Summary of A. count, B. length (km), and C. percent of coastline of high and very high status segments by status and island.

A.

Island	High	Very high	Total
Hawai‘i	22	3	25
Kaho‘olawe	2	2	4
Kaua‘i	22	8	30
Lāna‘i	3		3
Maui	29	39	68
Molokai	13	33	46
O‘ahu	13	18	31
Total	104	103	207

B.

Island	High	Very high	Total
Hawai‘i	29.1	9.2	38.3
Kaho‘olawe	3.7	1.6	5.3
Kaua‘i	55.6	32.0	87.6
Lāna‘i	3.5		3.5
Maui	31.2	83.4	114.6
Molokai	24.9	47.0	71.9
O‘ahu	14.5	31.3	45.8
Total	162.4	204.5	366.9

C.

Island	High	Very high	Total
Hawai‘i	5.1%	1.6%	6.8%
Kaho‘olawe	5.6%	2.3%	7.9%
Kaua‘i	29.2%	16.8%	46.1%
Lāna‘i	3.9%	0.0%	3.9%
Maui	10.7%	28.6%	39.3%
Molokai	12.7%	24.0%	36.7%
O‘ahu	3.9%	8.4%	12.2%
Total	9.1%	11.5%	20.7%

Table 4. Summary of A. length (km) and B. percent of coastline of high and very high status segments by general moisture zone and island.

A.

Island	Dry	Mesic	Wet	Total
Hawai‘i	19.7	14.2	4.4	38.3
Kaho‘olawe	5.3			5.3
Kaua‘i	61.9	25.6		87.6
Lāna‘i	3.5			3.5
Maui	45.7	44.5	24.4	114.6
Molokai	40.3	29.4	2.2	71.9
O‘ahu	45.3	0.5		45.8
Total	221.7	114.1	31.1	366.9

B.

Island	Dry	Mesic	Wet
Hawai‘i	51.4%	37.0%	11.5%
Kaho‘olawe	100.0%	0.0%	0.0%
Kaua‘i	70.7%	29.3%	0.0%
Lāna‘i	100.0%	0.0%	0.0%
Maui	39.9%	38.8%	21.3%
Molokai	56.1%	40.9%	3.1%
O‘ahu	98.9%	1.1%	0.0%
Total	59.6%	31.8%	8.7%

Table 5. Summary of A. count, B. length (km), and C. percent of coastline of vulnerable coastline segments in the moderate and high status categories by general moisture zone and island.

A.

Island	High	Very high	Total
Hawai‘i	3		3
Kaho‘olawe			
Kaua‘i	5	1	6
Lāna‘i			
Maui	2	6	8
Molokai	1	1	2
O‘ahu	9	8	17
Total	20	16	36

B.

Island	High	Very high	Total
Hawai‘i	1.7		1.7
Kaho‘olawe			
Kaua‘i	5.6	15.8	21.4
Lāna‘i			
Maui	3.0	13.1	16.1
Molokai	0.1	2.6	2.7
O‘ahu	12.0	13.5	25.5
Total	22.5	45.0	67.5

C.

Island	High	Very high	Total
Hawa`i‘i	0.3%	0.0%	0.3%
Kaho‘olawe			
Kaua‘i	3.0%	8.3%	11.3%
Lāna‘i			
Maui	1.0%	4.5%	5.5%
Molokai	0.1%	1.3%	1.4%
O‘ahu	3.2%	3.6%	6.8%
Total	1.3%	2.5%	3.8%

Table 6. Site characteristics for the 36 native coastal vegetation sites that appear to be most vulnerable to a projected 1 m sea level rise due to elevation limitations or human related barriers to inward movement of the vegetation.

Site number	Length (km)	Island	Coastal segment name	Segment type	[1]Moisture zone	[2]Land ownership	[3]Land use zone	Limitation to inshore movement	Cultural resources
52	0.1	Hawai'i	S of Pūhili Pt	Coastline	A	private	U; C	managed veg	Y
53	0.7	Hawai'i	Wawahiwa'a Pt	Coastline	A	private	U	managed veg	Y
51	0.8	Hawai'i	Anaeho'omalu Bay	Coastline	A	private	U; C	managed veg; structure	Y
4	0.5	Kaua'i	Hā'ena Bay	Coastline	SM	county; private	C	road; structure; managed veg	Y
11	1.5	Kaua'i	Maka'uhena Point to Keoneloa Bay	Coastline	VD	private	U; C	road; structure; managed veg	Y
18	1.1	Kaua'i	'Aliomanu Coast	Coastline	MD	private	C	managed veg; structure	Y
7	15.8	Kaua'i	Polihale to Kokole Point	Coastline	A	federal; state	C	structure road; managed veg	Y
3	2.1	Kaua'i	Hanalei Bay	Coastline	MM	state; Kamehameha Schools; county	U	managed veg; structure	N
24	0.4	Kaua'i	Pīla'a Bluff	Coastline	MD; SM	private	C	managed veg	N
131	2.5	Maui	Ma'alaea Beach	Coastline	A	Alexander & Baldwin	C	road; wetland	N
138	5.6	Maui	Mū'olea Point to Maka'alae Point	Coastline	SM	private; county; Hana Ranch	R; C	road; managed veg; structure	Y
141	1.1	Maui	Nānu'alele Point	Coastline	SM	state; Hana Ranch; private	R; C	managed veg	Y
200	0.8	Maui	Mākaluapuna Point	Coastline	VD	private	C	managed veg	Y
202	1.1	Maui	Hāwea Point	Coastline	VD	private	C	managed veg; structure	Y
207	2.0	Maui	Lelekea Bay	Coastline	SM	federal; private	C	road	N
185	2.1	Maui	Kanaha Coast	Coastline	A	state	C	road; managed Veg	N

Table 6 (continued).

201	0.9	Maui	Oneloa Bay	Coastline	VD	private	C	managed veg; road	N
116	2.6	Molokai	Kāhili	Coastline	VD	state	C	airport runway and infrastructure	Y
155	0.1	Molokai	Pāʻūonuʻakea Islet	Islet	MM	state	C	inadequate elevation	N
63	1.7	Oʻahu	Kaʻena Point	Coastline	VD	state	C	inadequate elevation	Y
72	0.3	Oʻahu	Makapuʻu Rocks	Coastline	VD	DHHL	C	road; structure; managed veg	Y
74	0.9	Oʻahu	Kāohikaipu Islet	Islet	VD	state	C	inadequate elevation	N
78	0.4	Oʻahu	Popoiʻa Islet	Islet	MD	state	C	inadequate elevation	N
81	0.2	Oʻahu	Kekepa Islet	Islet	MD	federal	C	inadequate elevation	N
82	0.6	Oʻahu	Kapapa Islet	Islet	MD	state	C	inadequate elevation	Y
86	1.3	Oʻahu	Mokuʻauia Islet	Islet	VD	state	C	inadequate elevation	N
88	8.1	Oʻahu	Makahoa Point to Kahuku Point	Coastline	VD	private; federal	A	road; managed veg; structure	N
61	6.3	Oʻahu	Mokuleʻia Beach	Coastline	VD	federal; private; county	C; A	road; managed veg	Y
66	0.6	Oʻahu	Paikō Lagoon	Coastline	VD	state; private	U	structure; managed veg	Y
69	0.7	Oʻahu	Sandy Beach Rocks	Coastline	VD	county	C	road; managed veg	Y
71	0.4	Oʻahu	Makapuʻu Beach	Coastline	VD	DHHL	C	structure; managed veg; road	N
73	0.5	Oʻahu	Sea Life Park Coast	Coastline	VD	DHHL	C	road; managed veg	Y
80	0.8	Oʻahu	Fort Hase Cove	Coastline	VD	federal	C	structure; road; managed veg	N

Table 6 (continued).

85	1.7	Oʻahu	Lāʻie Point	Coastline	MD	private; state	U	structure; managed veg	N
87	0.6	Oʻahu	Makahoa Point	Coastline	VD	private	U	structure; managed veg	Y
89	0.4	Oʻahu	Kuilima Point	Coastline	VD	private	U	structure; managed veg	N

[1]Moisture zones: A = arid; VD = very dry; MD = moderately dry; SM = seasonal mesic; MM = moist mesic (Price et al. 2012)

[2]Land ownership: county = county of Kauaʻi, Honolulu (Oʻahu), Maui (Maui, Molokai), Hawaiʻi; DHHL = Department of Hawaiian Home Lands; federal = U.S. Government; private = various private landowners; state = State of Hawaiʻi; other landowners as named (Hawaii State GIS Program. 2013)

[3]Land use zones: A = agriculture; C = conservation; R = rural; U = urban (Hawaii State GIS Program. 2016)

Appendix 1. List of native plant species that are primarily found in the coastal zone on the main Hawaiian Islands. Taxonomy follows Wagner et al. (2005 – present); moisture zones from Price et al. (2012).

Family	Species	Federal Status[1]	Moisture zones			
			Arid	Dry	Mesic	Wet
	Dry habitat species					
Euphorbiaceae	*Euphorbia celestroides* var. *Ka'enana*	E		X		
Amaranthaceae	*Chenopodium* sp. ('Ilio Pt)		X			
Convolvulaceae	*Cressa truxillensis*		X	X		
Convolvulaceae	*Cuscuta sandwichiana*		X	X		
Convolvulaceae	*Ipomoea imperati*		X	X		
Convolvulaceae	*Jacquemontia sandwicensis*		X	X		
Marsileaceae	*Marsilea villosa*	E	X	X		
Scrophulariaceae	*Myoporum sandwicense*			X		
Poaceae	*Panicum niihauense*	E	X			
Aizoaceae	*Portulaca molokiniensis*	SOC	X			
Asteraceae	*Pseudognaphalium sandwicensium* var. *molokaiense*	C	X	X		
Santalaceae	*Santalum ellipticum*			X		
Solanaceae	*Solanum nelsonii*	C	X	X		
Asteraceae	*Tetramolopium rockii*	T	X			
Zygophyllaceae	*Tribulus cistoides*		X	X		
	Dry and mesic habitat species					
Euphorbiaceae	*Euphorbia degeneri*		X	X	x	
Boraginaceae	*Cordia subcordata*		X	X	X	
Cyperaceae	*Cyperus polystachyos*			X	X	
Convolvulaceae	*Ipomoea pes-caprae*		X	X	X	
Rubiaceae	*Kadua st.-johnii*	E		X	X	
Brassicaceae	*Lepidium bidentatum* var. *o-waihiense*	SOC		X	X	
Poaceae	*Panicum fauriei* var. *carteri*	E		X	X	
Goodeniaceae	*Scaevola coriacea*	E		X	?	
Aizoaceae	*Sesuvium portulacastrum*		X	X	X	
Asteraceae	*Tetramolopium sylvae*			X	X	
	Mesic habitat species					
Pittosporaceae	*Pittosporum halophilum*				X	
Asteraceae	Tetramolopium sp. (Kalaupapa)	SOC			X	

Appendix 1 (continued).

Family	Species	Status	Moisture zones			
			Arid	Dry	Mesic	Wet
	Mesic and wet habitat species					
Asteraceae	*Bidens hillebrandiana* subsp. *hillebrandiana*	E				X
Asteraceae	*Bidens hillebrandiana* subsp. *polycephala*			X	X	X
Poaceae	*Ischaemum byrone*	E			X	X
Rubiaceae	*Kadua littoralis*	SOC			X	X
Rubiaceae	*Kadua* sp. (Kohala, eMaui)				X	X
Asteraceae	*Lipochaeta succulenta*			X	X	X
Plantaginaceae	*Lysimachia mauritiana*			X	X	X
	Species in all moisture zones					
Plantaginaceae	*Bacopa monnieri*			X	X	X
Cyperaceae	*Fimbristylis cymosa*		X	X	X	X
Boraginaceae	*Heliotropium anomalum*			X	X	x
Boraginaceae	*Heliotropium curassavicum*			X	X	x
Convolvulaceae	*Ipomoea littoralis*		X	X	X	X
Solanaceae	*Lycium sandwicense*		X	X	X	X
Poaceae	*Sporobolus virginicus*		X	X	X	X
Malvaceae	*Thespesia populnea*			X	X	X
Fabaceae	*Vigna marina*			X	X	X
Lamiaceae	*Vitex rotundifolia*		X	X	X	X

[1]Federal status: E = Endangered, T = Threatened, C = candidate for listing, SOC = species of concern

Figure 1. Example of a very high quality native coastal plant community on the north-facing shore of west Maui.

Ipomaea pes-caprae (pōhuehue)

Sida fallax (orange flower - ‘ilima) and *Heliotropium anomalum* (hinahina)

Brighamia rockii (pua‘ala)

Scaevola taccada (naupaka)

Capparis sandwichiana (maiapilo)

Coastal form of *Myoporum sandwicense* (naio) and *Scaevola taccada* (naupaka) in the background

Melanthera integrifolia (nehe)

Tetramolopium sp. From Kalaupapa Molokai

Figure 2. Examples of some of the native plant species found in Hawaiian coastal plant communities.

Figure 3. Coastal vegetation extending along the beach and up the vertical cliffs on the north coast of east Molokai.

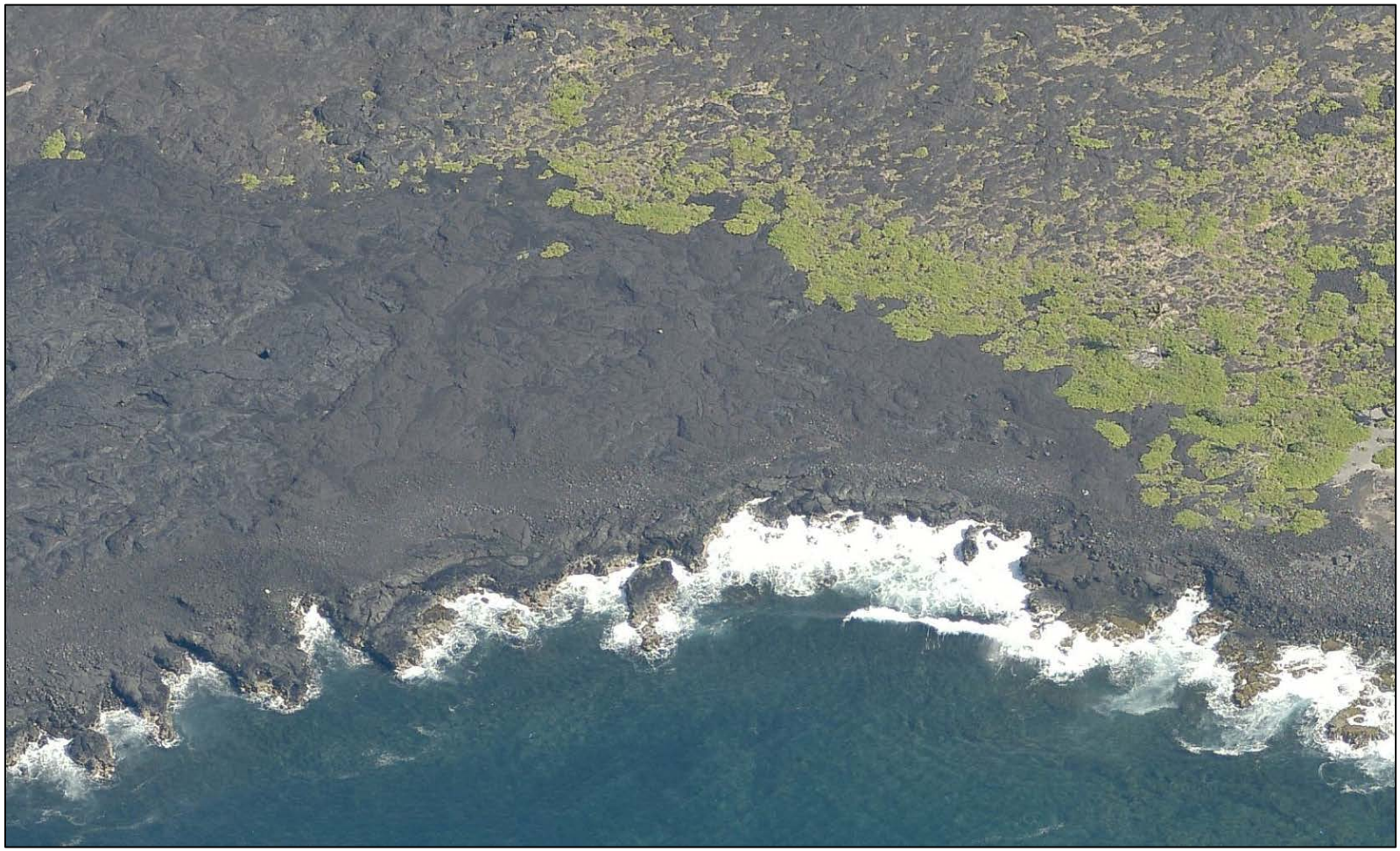

Figure 4. Section of the coastline just southwest of ʻĀpua Point on the island of Hawaiʻi showing no coastal vegetation on a recent lava flow on the left and a relatively intact and diverse coastal plant community on the right. Image provided by Pictometry International.

Figure 5. Examples of factors that impact native coastal plant communities: invasive tree ironwood (*Casuarina equisetifolia*) (top left); B. recreational use at Makapuʻu Beach Park on Oʻahu (top right); C. resort development in Waikīkī Oʻahu (bottom left); D. feral goats in coastal forest on the island of Molokai (bottom right).

Figure 6. Examples of the four coastal vegetation status categories: very high quality - Waiʻōhinu, Hawaiʻi (top left); high quality - Kanahā Beach, Maui (top right); moderate quality - Mokulēʻia Beach, Oʻahu (bottom left); poor quality - south slope of east Molokai near Kawela showing the coastal area dominated by kiawe (*Prosopis* pallida) and mangrove (*Rhizophora mangle*) (bottom right). Images provided by Pictometry International.

Figure 7. Example of a fixed barrier (paved road) that will restrict the inshore movement of coastal plant vegetation in response to sea level rise.

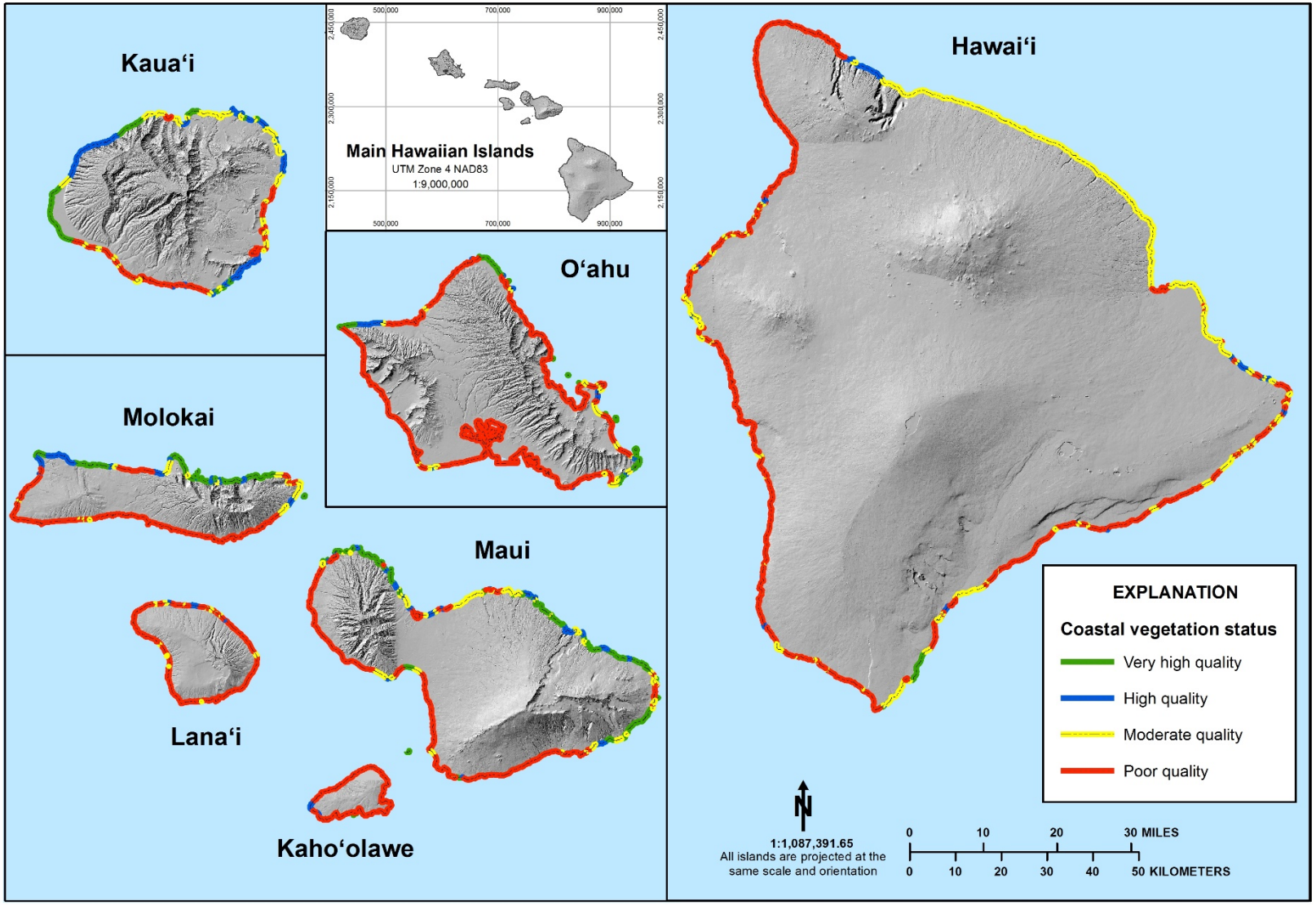

Figure 8. Map showing the coastal areas surveyed on the main Hawaiian Islands and status of the native plant communities in each segment.

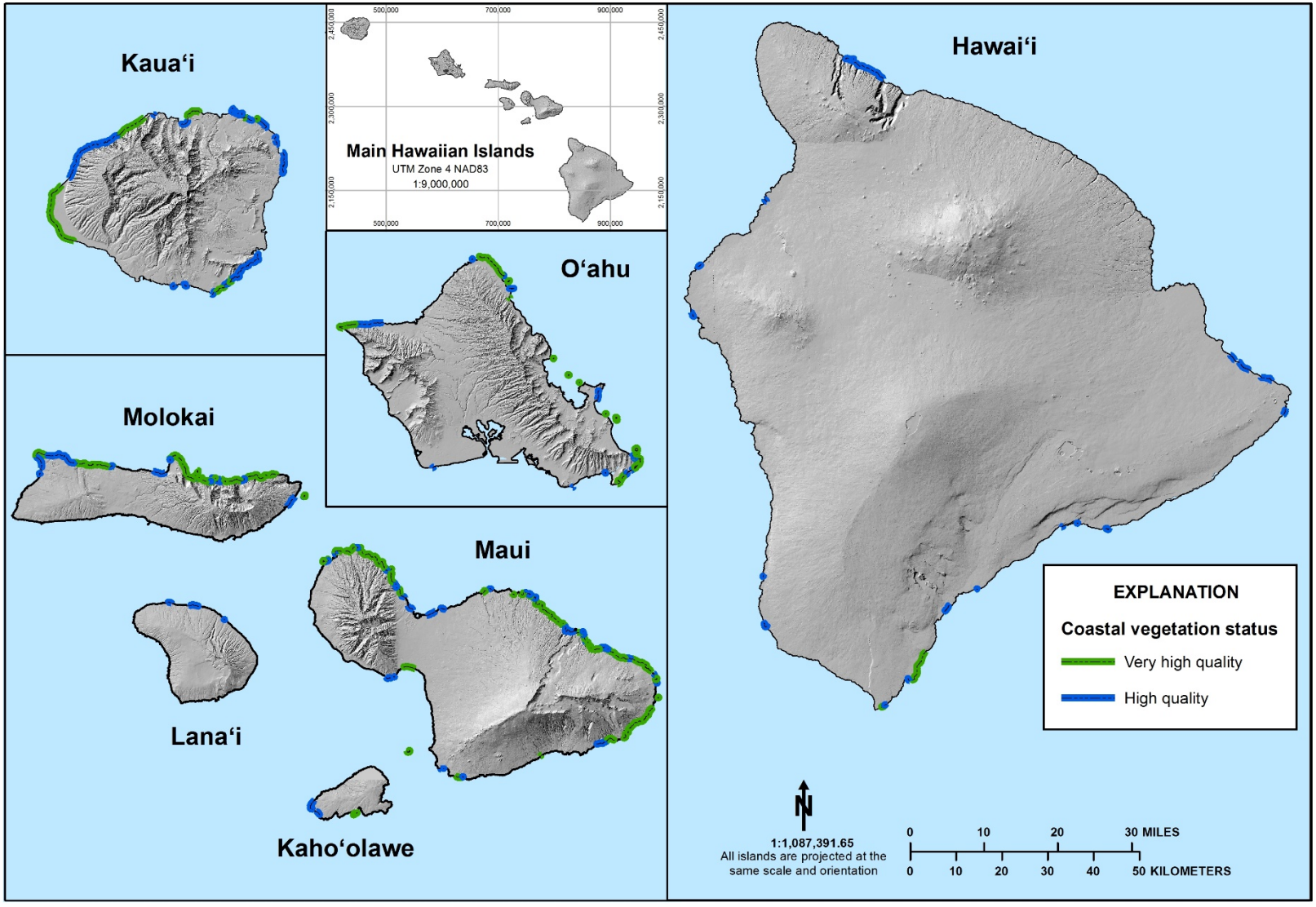

Figure 9. Map showing the areas surveyed on the main Hawaiian Islands that contain high and very high quality native coastal plant communities.

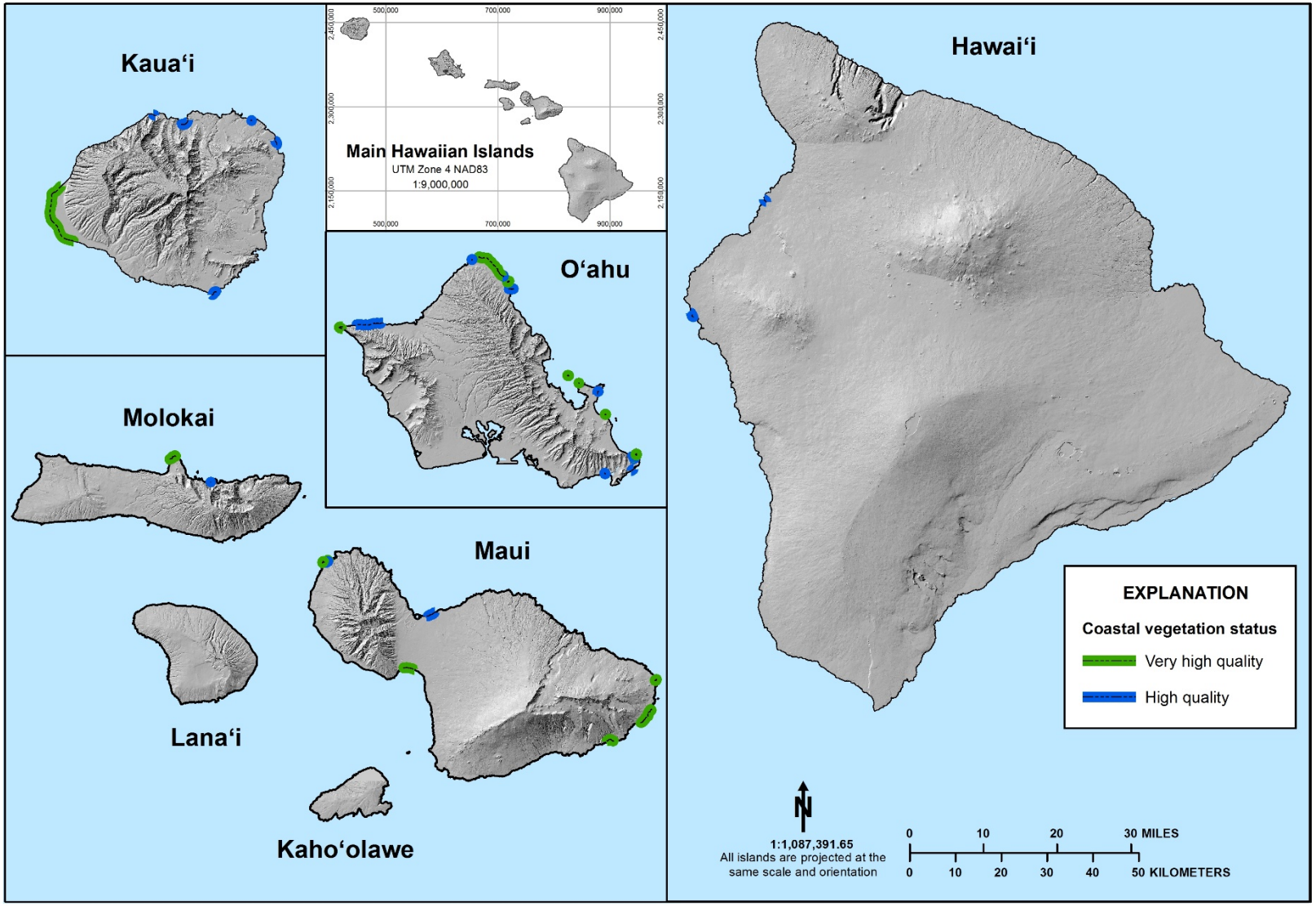

Figure 10. Map showing the 36 areas on the main Hawaiian Islands that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

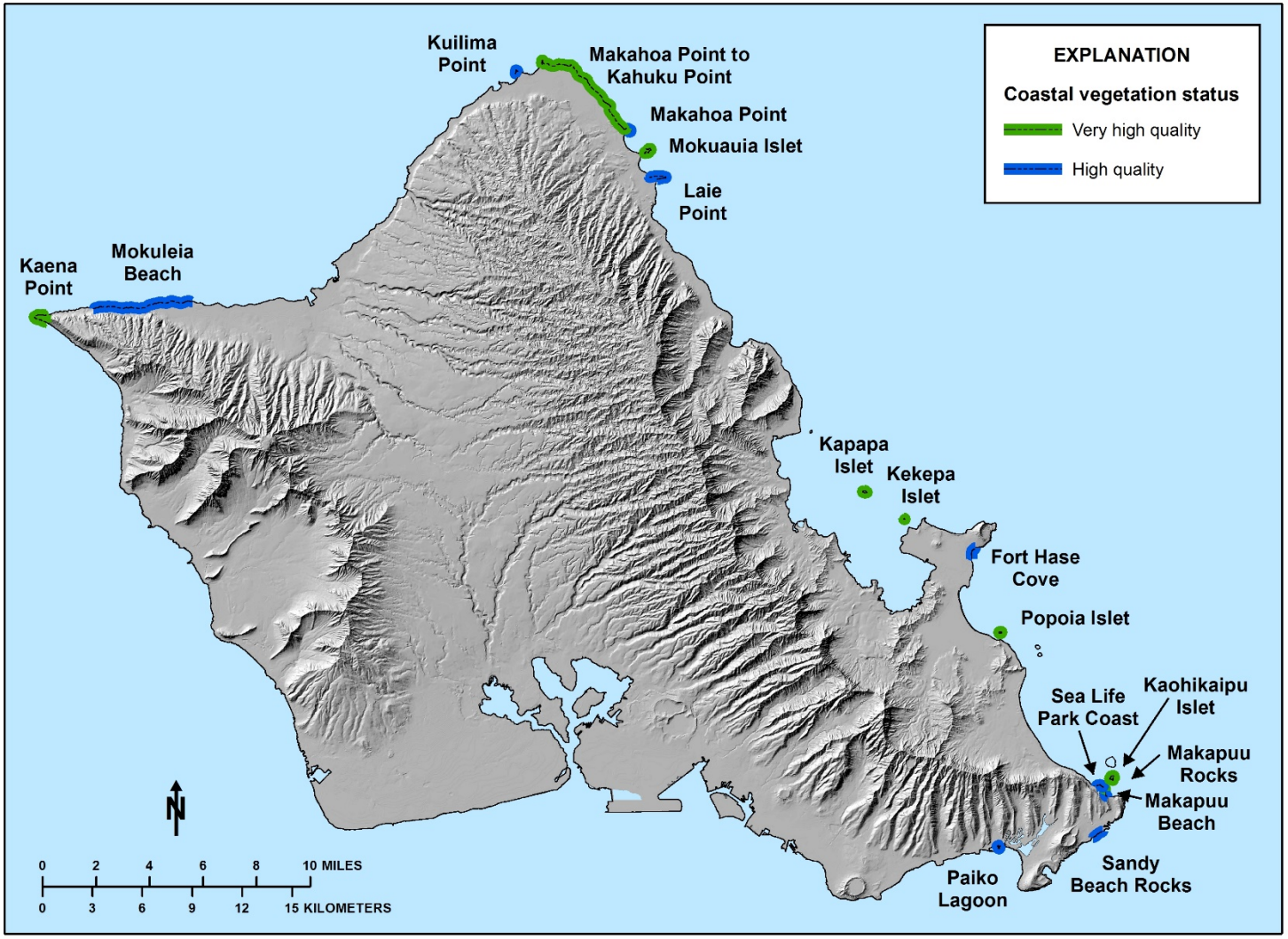

Figure 11. Map showing the 17 areas on the island of O‘ahu that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

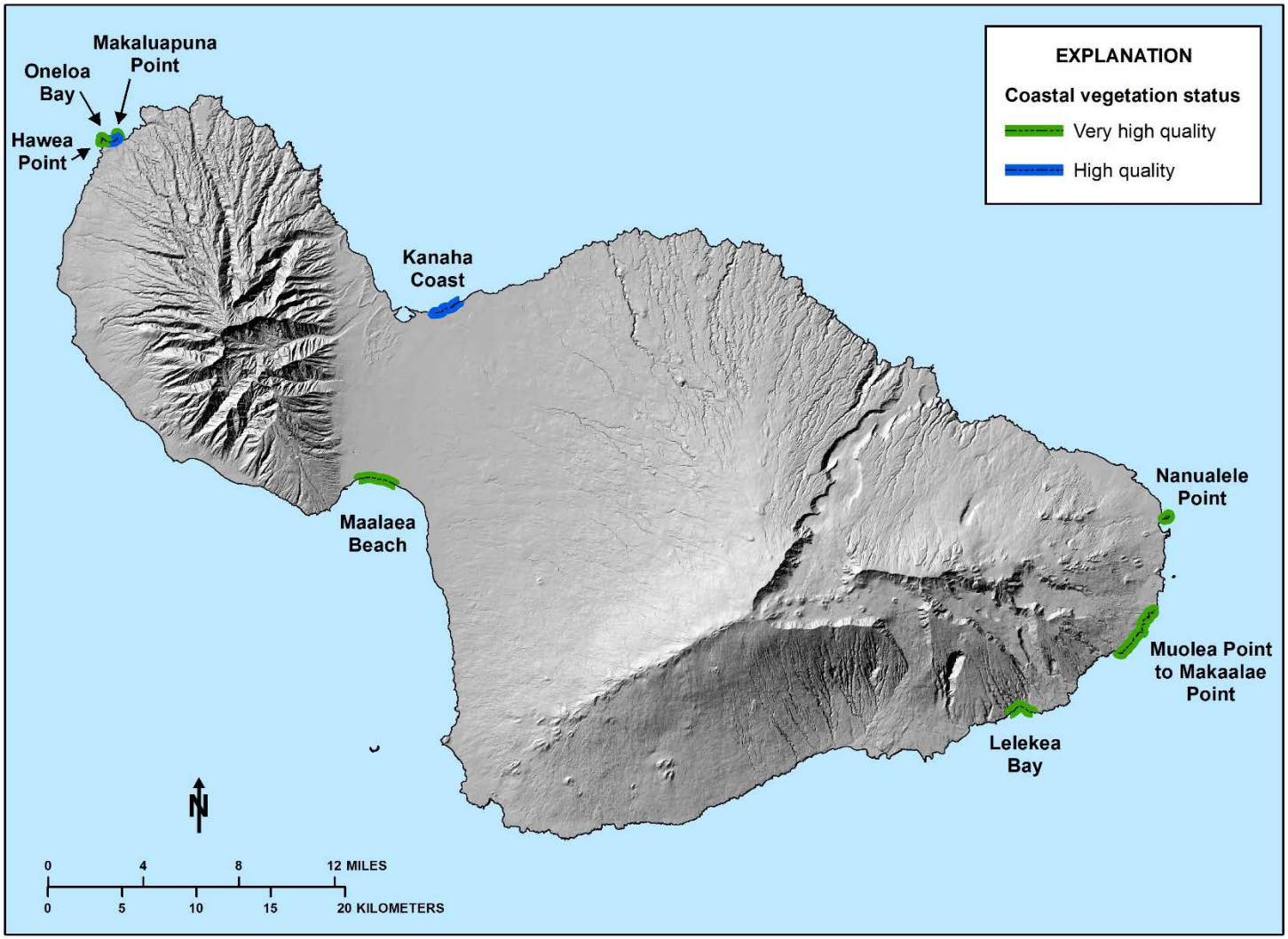

Figure 12. Map showing the eight areas on the island of Maui that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

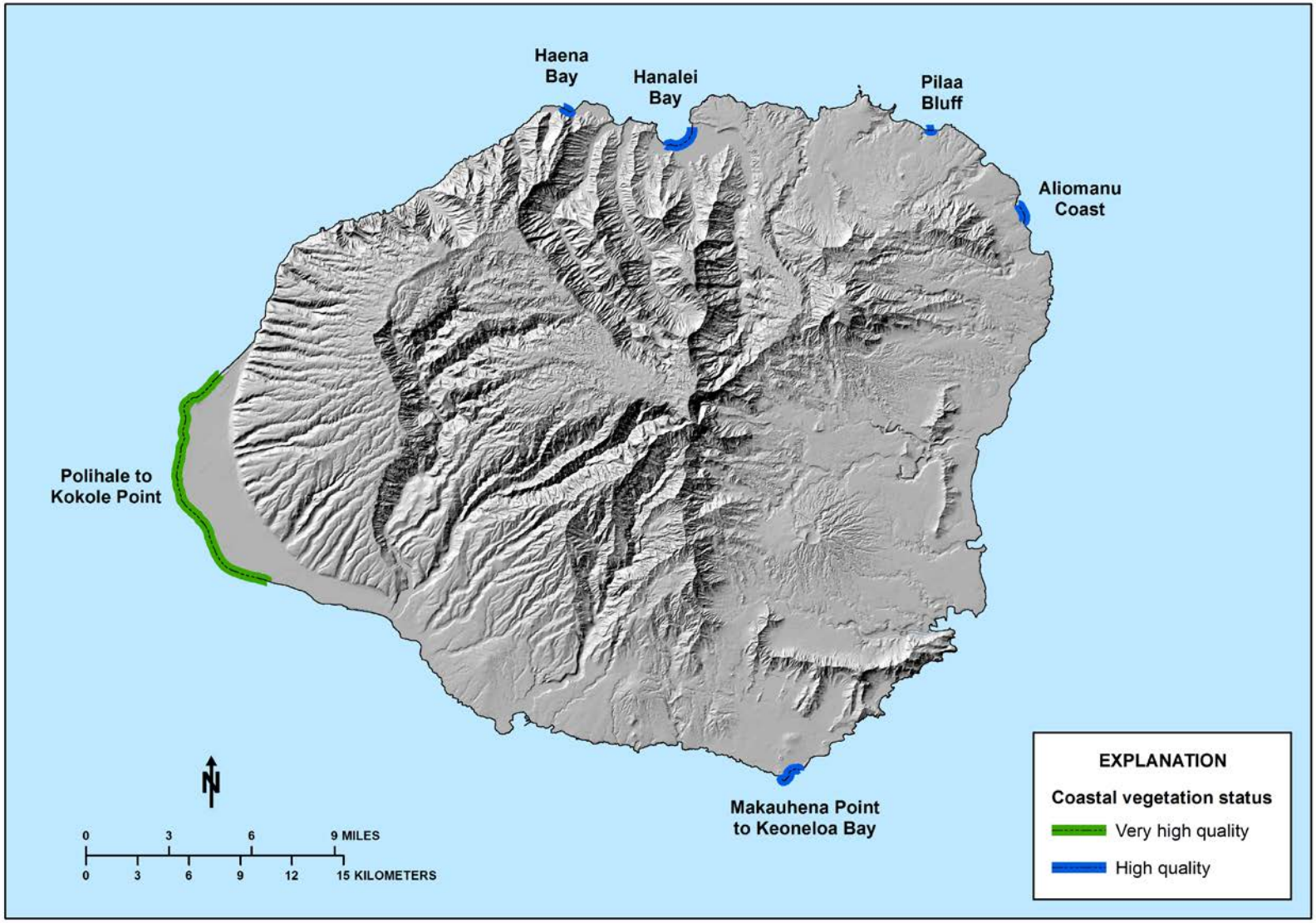

Figure 13. Map showing the six areas on the island of Kaua‘i that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

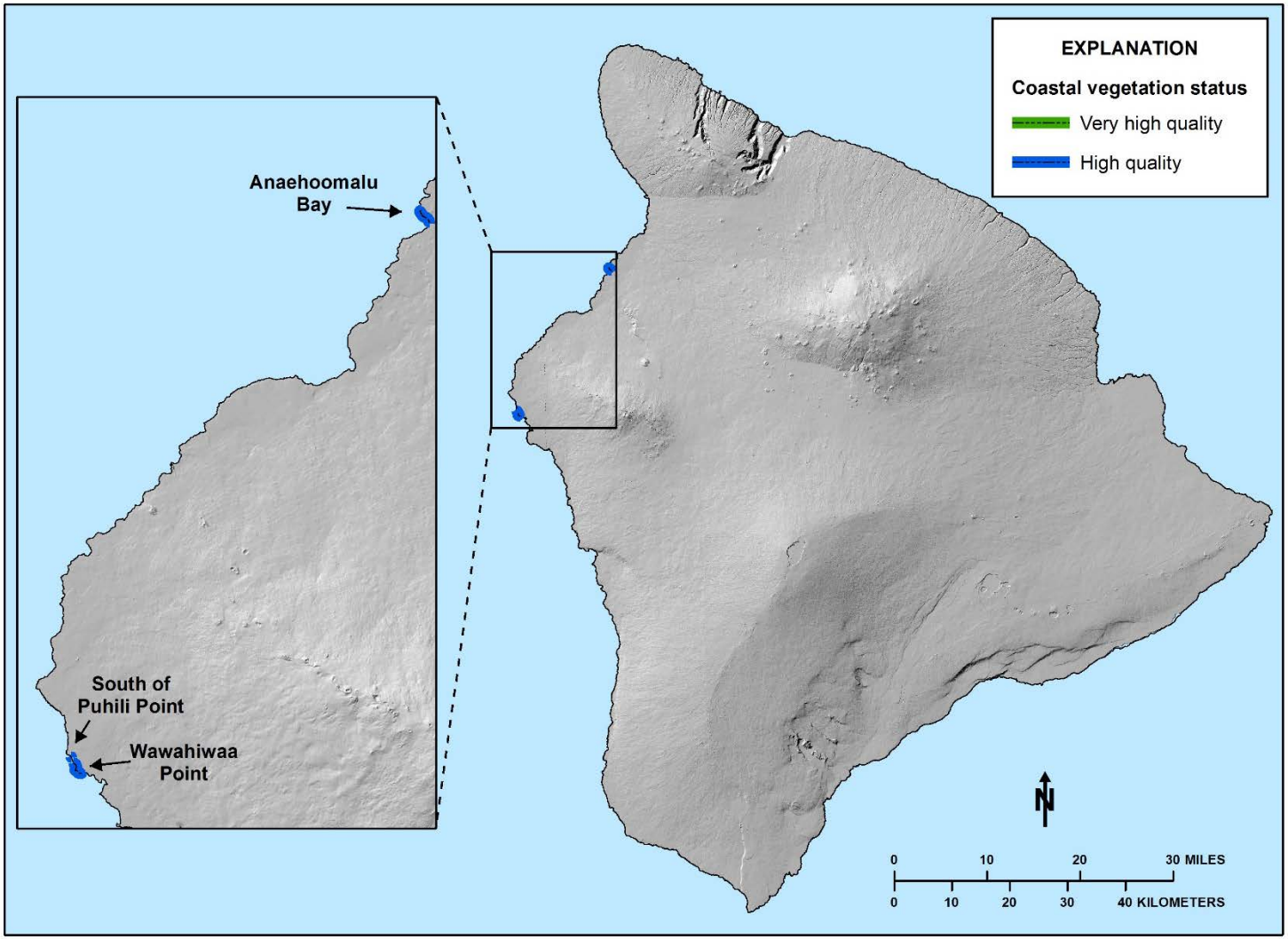

Figure 14. Map showing the three areas on the island of Hawai‘i that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

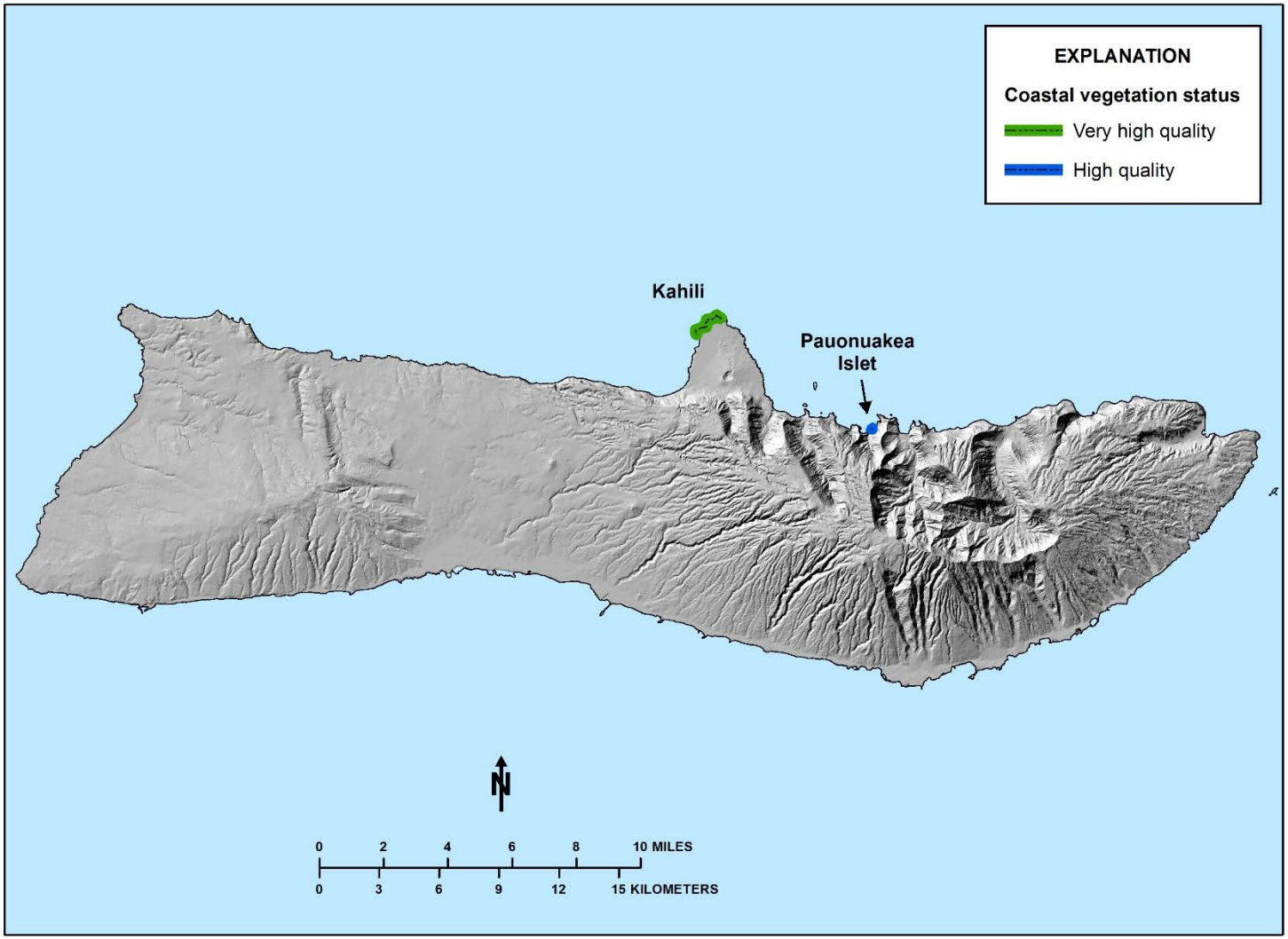

Figure 15. Map showing the two areas on the island of Molokai that contain high and very high quality native coastal plant communities and appear to have restrictions to inland movement in response to projected sea level rise.

Figure 16. Images of Kīpapa Islet off the island of O‘ahu showing current sea level (top image) and projected three foot sea level rise (light blue overlay on the bottom image). Imagery provided by Pictometry International. Sea level data based on a projected three foot sea level rise (NOAA Coastal Services Center 2013).

Figure 17. Examples of barriers to inland movement of native coastal plant communities: road along the Māʻalaea area on Maui (top left); resort development at Kuʻilima Point, Oʻahu (top right); coastal vegetation extending up to airport infrastructure and runway at Kalaupapa, Molokai (bottom left); parking area, structures, and managed lawn at Haʻena Beach Park on Kauaʻi (bottom left). Imagery provided by Pictometry International.

Figure 18. View of very high quality native coastal vegetation at the Waiʻōhinu coastline on the island of Hawaiʻi showing the extent of the vegetation several hundred meters inland from the coast. The lightly maintained four-wheel-drive road does not appear to imped movement of the vegetation. Image provided by Pictometry International.

Figure 19. View of ongoing coastal vegetation restoration by The Nature Conservancy of Hawai‘i just west of Mo‘omomi beach on the island of Molokai. The low-stature light green areas are where native coastal plant species are expanding following removal of invasive kiawe (*Prosopis pallida*) trees that previously covered this entire area. Image provided by Pictometry International.

Figure 20. View of Anaehoʻomalu Bay on the island of Hawaiʻi showing current sea level (top image) and projected three foot sea level rise (light blue overlay) and other inundated areas (green overlay) on the bottom image. Imagery provided by Pictometry Internal. Sea level data based on a projected three foot sea level rise (NOAA Coastal Services Center 2013).