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NATIVE COASTAL FLORA AND PLANT COMMUNITIES IN HAWAI`I: THEIR COMPOSITION, DISTRIBUTION, AND STATUS

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EXECUTIVE SUMMARY

The Hawaiian coastal flora primarily includes the halophytic (salt-adapted) plants closest to the area of salt spray and wave wash, often concentrated within a distinct strand zone, and usually growing as low mats. However, behind the strand is a zone of vegetation that is quite varied in composition and structure, but somewhat less specialized in life form, which is also adapted to the specific conditions of the coastal environments and to those at different locales. Coastal plant communities in Hawaiʻi are distributed across a very wide range of conditions, and are anything but homogeneous. Primary factors that influence their composition and structure include moisture, substrate, and exposure to wind and salt water. Some of these factors also have roles in dispersal, competition, trauma, and periodic reordering of local community compositions. External to these are anthropogenic impacts which may have a similar scale of influences today.

Between 2000 and 2005 we surveyed a total of 133 coastal sites on the islands of Molokaʻi, Maui, and Oʻahu. On Oʻahu we visited 28 sites, 50 sites were surveyed on Molokaʻi, 36 sites on West Maui, and 19 sites on East Maui. The survey areas were selected primarily to sample a region's community variety and composition, and were distributed within the diversity of moisture zones found in the coastal regions of each island. A few sites were visited on Kauaʻi and Hawaiʻi, but these islands are in need of much more survey work and thus have limited commentary in the current summary. The smaller main islands (Niʻihau, Lānaʻi, and Kahoʻolawe), as well as many of the small offshore islets, were not visited at all in this assessment.

During this project we recorded 142 taxa of native plants out of 169 that were expected based on past plant collections and from the literature. A total of 105 coastal plants were recorded on Molokaʻi, 85 on Maui, and 52 on Oʻahu. Thirty-eight species were found on all three of the islands we surveyed, 53 on at least two islands, and 51 plants were found on only one of these islands. We encountered 12 listed endangered taxa, 2 threatened taxa, and 13 species of concern (SOC) but with no official listing status, as well as many other taxa that are now relatively uncommon within the Hawaiian coastal zone.

The number of plants per site varied considerably between the areas surveyed, but the greatest diversity was found on Molokaʻi and Maui, with their richest sites containing 30 and 32 species, respectively. On Maui 22 (40%) of the sites had less than 10 native coastal plant species, 30 (55%) had 10 – 20 species, and 3 (5%) with more than 20 species. A different situation was found on Molokaʻi where only 10 (20%) of the sites had less than 10 native coastal plant species, 28 (56%) had 10 – 20 species, and 12 (24%) with more than 20 species. On Oʻahu seven (25%) sites had less than 10 native plant species, 20 (71%) had 10 – 20 species, and only one site (Kaʻena Point) had over 20 species, but, in this case just a total of 21 coastal plant species. The current coastal flora of Oʻahu was somewhat reduced compared to the other two islands, likely a result of the much greater human-related impacts on the coastal zone of Oʻahu. Additionally, the remaining coastal vegetation on Oʻahu is nearly all within the dry zone.

The most influential site factor for Hawaiian coastal communities is the range of moisture that occurs across any particular area. The greater the moisture zone range, the more species are likely to be found in a region. The composition of strand communities varies considerably spatially, but in most given locations communities contain limited subsets of the species richness potentially available. The coastal vegetation is characterized by low growing and mat forming species in areas closest to the ocean and by taller plants farther inland or where available soil has accumulated locally. In the arid and dry zones, a few annual species, mostly grasses, are seen; the rest of native coastal flora is perennial. Exposure to salt water and onshore flow of salt mist (*‘ehukai*) comprise the harshest ecological factors within the coastal zone. Exposure to *‘ehukai*, strong winds, and brackish basal ground water all influence this generalization and add variegation to an area’s vegetation structure and composition. A range in other site conditions helps to further diversify the structural and species composition of the communities. Understanding of these conditions can assist managers with identification of areas to preserve and manage, and help to guide restoration attempts.

Alien plants represent one of the greatest threats to native coastal vegetation in that any one of several invasive species can completely displace or prevent the colonization of entire suites of native species. Alien animals are another important threat, one that frequently opens the door for, or tips the balance to, alien plants. The most obvious and widespread animal species are pastured and free-roaming ungulates, particularly cattle, goats, sheep, pigs, and deer. The numbers and distributions of some ungulate species may have surged and waned variably over time and space, but their impacts are unequivocally negative in the coastal zone in any abundance.

Human development and use of coastal areas continues to exert severe, usually permanent, impacts to remaining native coastal vegetation. Recreational activities, in particular, tend to be a widespread detriment to coastal plant communities. The fragmentation of habitats and compounding affects of an associated array of disturbances resulting from urban and agricultural activities have led to considerable attrition of species from predominately native dominates areas in the coastal zone. These losses are continuing, perhaps accelerating, with the expanding use of the limited coastal areas throughout the islands for resort, residential, and recreational activities.

Given the cumulative stresses that Hawai‘i’s coastal communities have experienced in recent years, the few plant extinctions that have occurred in that habitat indicates there is still time to employ effective management to prevent more loss of diversity. However, the widespread damage to coastal vegetation and the rarity of so many species indicates the urgency for supplying sufficient targeted management to preserve species and to restore community composition, structure, and function. The coastal vegetation’s adaptation to natural disturbance, as evident from the harsh environment it occupies, coupled with its regenerative capability, may have helped these communities survive thus far. This suggests a good potential for preservation of the biota of these regions if effective and strategic management actions are effected soon.

A conservation strategy that incorporates both protected regions and species augmentation may be able to reverse declining trends in Hawaiian coastal communities if applied in time and at sufficient scale. Protection of coastal regions should feature reduction or elimination of the major stress factors that accompany alien plants and ungulates, as well as reducing and compensating for the adverse consequences of land use. A number of sites on each island stand out with high species diversity and/or populations of rare plant species, as well as still having an established connection with contiguous lowland vegetation. These sites can serve as core areas for a regional approach to managing strips of coastal communities and their associated lowland vegetation.

The following conclusions and potential management strategies have been derived from our survey observations:

- A regional approach to coastal resource conservation is likely to be the most effective approach to secure an island’s native coastal vegetation.
- It is important to identify and prioritize coastal vegetation areas that still retain connections to native lowland plant communities. Even depleted communities can still contribute to the coastal areas’ biodiversity, and both could be stabilized

and augmented where warranted. Managing both coastal and lowland areas together can be an efficient strategy for conserving a variety of resources and processes across modestly-sized areas.

- Removal or significant reductions of feral ungulates is one of the most pressing management needs along certain stretches of the coastlines of the main Hawaiian Islands. Strategic fencing can be an effective tool for excluding ungulates and potentially predators. However, high installation and maintenance costs limit their use presently, particularly near shorelines. Development of cost-effective corrosion-resistant materials and appropriate designs could encourage increased use of fences in coastal areas.
- Given the ongoing spread of numerous alien plants into new regions, immediate removal of the early colonizing individuals of particularly threatening species from native coastal vegetation can proactively prevent an increase in ecosystem disruption.
- Expand public education and outreach programs to enlist more support of coastal community conservation from the public.

These surveys have provided more and current information on the ecology, composition, distribution, and status of coastal plant communities and species in selected portions of the main Hawaiian Islands. Although not as rich in endemic species as are upland communities, the Hawaiian coastal flora is relatively diverse, and taken as a whole, is still quite intact with very few historically known species that are now extinct. Although the coastal zone has been heavily impacted over the past 250 years, many high quality examples of diverse plant communities can still be found, particularly in the wet and mesic habitats on the islands of Maui and Molokaʻi. Management efforts that are regionally focused on reducing the impacts of invasive species (both plants and animals) and maintaining the connection between the coastal strand and lowland vegetation, coupled with expanding public awareness of the value of coastal communities, can allow for effective restoration and maintenance of this unique set of ecosystems for the future.

INTRODUCTION

Most conservation efforts in Hawai‘i have focused on upland terrestrial communities which harbor a great diversity of native ecosystems with their associated endemic plants and animals, many of which are listed as threatened or endangered. Less attention has been given toward understanding the composition, structure, status, and conservation opportunities for lowland ecosystems, and in particular native coastal plant communities.

This survey of Hawaiian native coastal vegetation started out looking at the “strand” plants (Wagner et al. 1990, Mueller-Dombois and Fosberg 1998) that are generally restricted to the immediate shoreline area. As work progressed it became apparent that strand plants were just a portion of a larger coastal flora which results from an overlap of strand, coastal “wet-site” plants, and portions of the lowland flora that extended their distributions to the shore area. A number of site and geographic conditions interact to select from this flora the various species associations that comprise the coastal vegetation.

Joseph Rock (1913) was among the first to segregate the strand portion of the Hawaiian flora within a scheme of six floral regions, which he based on elevation and further subdivided by moisture. Rock pointed out that the strand-restricted plants were accompanied by some species “which have descended from the lowlands and are found on the beaches,” and that some of the endemic strand plants were found only on one or a few islands. In this report we further expand upon Rock’s themes based on results of our recent surveys of coastal communities in various locations throughout the main Hawaiian Islands.

Overview of the Coastal Flora

The Hawaiian coastal flora primarily includes the halophytic (salt-adapted) plants closest to the area of salt spray and wave wash, often concentrated within a distinct strand zone, and usually growing as low mats (Rock 1913, Wagner et al. 1990, Mueller-Dombois and Fosberg 1998). However, behind the strand is a zone of vegetation that is quite varied in composition and structure, but somewhat less specialized in life form, which is also adapted to the specific conditions of the coastal environments and to those at different locales. These taller plants tend to be found farther inland or where available soil and/or talus have accumulated.

Particularly on coastlines with windward exposures, the vegetation is tolerant of elevated stress, much of it coming from exposure to high salt concentrations from the sea. Some less tolerant plants may find refuge from the harshest of these conditions in protected microhabitats, including sites bathed by fresh water. Strong winds, seasonal washing by waves or blown splash, and soil limitations also help to define the community characteristics and tolerance needed by species of the coastal vegetation. Local coastal species composition may also be constrained by sites on calcareous deposits with their associated alkalinity and nutrient balance issues. Other community restrictions or specializations appear to be found on sea cliffs and on some beaches that are subjected to the intense erosive environment of exposed windward conditions.

On a global scale the coastal flora of Hawai‘i is a relatively diverse one, given the limited size of its habitat and the absence of a native mangrove component, a specialized forest ecosystem on tidal flats on other Pacific Islands (Mueller-Dombois and Fosberg 1998). The broad ranges in coastal site conditions in Hawai‘i and the Islands’ evolutionary setting have richly complemented a substantial indigenous assemblage of coastal plant species with many endemic species. Several of the larger angiosperm groups have extended their radiations into the coastal environment, but few ferns have.

While the coastal flora, as a whole, is relatively well preserved, the extents of native coastal vegetation that it comprises are not. Many areas that formerly supported diverse strands of coastal communities have been degraded or lost as a result of human land use or impacts from introduced species. Local endemics are particularly vulnerable to extirpation, and a number have gone extinct.

The coastal flora that we have recognized during this survey consists of 169 native taxa (Table 1, Appendix 1), of which 142 were seen in the field. These 169 taxa represent approximately 13% of the native vascular flora of Hawaiʻi (Wagner et al. 2006). Coastal communities have a smaller percentage of endemic species (58%) than the overall vascular flora (90%). Nonetheless, this is very high on a global scale of endemism (Whitaker and Fernandez-Palacios 2007).

Both previous collection data and our observations suggest that only about 45 taxa of native plants are generally restricted to the near-shore strand. Additionally, there are about 14 - 18 wet area plants that appear to be limited to perennial or seasonal wetland basins or their edges, to seeps or rheocrenes, to waterfall mist zones, or to contact with shallow basal water within the near-shore zone. The presence of a local water source allows these species to exist in the coastal environment where conditions would otherwise be too dry or saline.

There are 152 native taxa, including many of the wet-area plants which extend their coastal distributions variable distances back from the shore, or primarily have inland distributions that continue down to the shore. It is this latter, larger group of the coastal flora that is the most depleted from the majority of Hawaiʻi's coastlines. In large portions of the main Hawaiian Islands the native vegetation back from the shoreline has been truncated by a long history of intensive human use or secondary disturbance of the landscape. The shoreline vegetation as well has been mostly or completely displaced in many areas. This fragmentation and isolation has left the remaining coastal plant communities reduced in both composition and distribution. The areas of coastal vegetation with the greatest diversity and contiguity remaining tend to be those which still retain a connection with native lowland vegetation.

The Hawaiian coastal flora is very similar in size to the alpine/subalpine flora, its biogeographic antipode. Price (2004) lists 146 coastal and 119 alpine/subalpine species (not including subspecific taxa). Both floral subsets are also similar in the small number of known plant extinctions. The currently small extinction rate in both of these zones has been surprising, given the degree of human impact and the fragmentation of the limited habitat for both zones. However, these impacts have resulted in a considerable number of rare or extinct species in the coastal flora (Table 2) (U.S. Fish and Wildlife Service 2008). While only two of the 169 coastal taxa are believed to already be extinct, over 25% of the Hawaiian coastal flora is rare and on the brink of extinction, or is found in very limited distribution. It is also likely that some of the original coastal plant species perished before western documentation, and that even more of the lowland species extensions had lost their coastal representatives before this survey was accomplished. That being said, nearly all of the historically recorded coastal plant species are still known to thrive or survive somewhere in the state, making the coastal flora one the best-surviving groups of the known Hawaiian flora.

Not included in the statistics above are 16 species of plants introduced by the initial Polynesian settlers of the Hawaiian Islands that are also found in the coastal zone (Sohmer and Gustafson 1987). Observations of these along the sampled coastlines are reported below the native species in Appendices 1, 3 - 9. Most of the Polynesian introduced species do not naturally disperse far from the sites in which they were originally planted, and they are living artifacts of the original Hawaiian cultural use of the landscape. The observations of these species, particularly in the places less frequented today, have cultural value and are worth reporting.

The wet and mesic shores of north Molokaʻi harbor the richest representation of both native and Polynesian species of coastal plants. Along this coast, our surveys from these and previous visits to the shore and lowland areas witnessed an intensive prehistoric use of the landscape, as evidenced by a high density of structural and living cultural artifacts. It is notable that this heavy land use still left behind a very rich coastal flora and excellent examples of diverse coastal vegetation types. This generalization contrasts markedly with the consequences of current land use trends throughout Hawaiʻi. The north Molokaʻi coastal vegetation is heavily stressed today, primarily as a consequence of historic species introductions, particularly ungulates, and land use changes.

Ecological Relationships

More so than most subsets of the Hawaiian flora, the coastal plant communities are distributed across a very wide range of conditions, and are anything but homogeneous. Hawaiʻi is known to display continental-scale ranges of ecological conditions within small areas, and coastal situations are no exception. Primary factors that influence the composition and structure of coastal communities include moisture, substrate, and exposure to wind and salt water. Some of these factors also have roles in dispersal, competition, trauma and periodic reordering of local community compositions. External to these are anthropogenic impacts which may have a similar scale of influences today.

METHODS

Survey Sites

We surveyed a total of 133 coastal sites on the islands of Molokaʻi, Maui, and Oʻahu between 2000 and 2005. On Oʻahu we visited 28 sites (Table 3), (Figure 1); 50 sites were surveyed on Molokaʻi (Table 4), (Figure 2); 36 sites on West Maui (Table 5), (Figure 3); and 19 sites on East Maui (Table 6), (Figure 4). The survey areas were selected primarily to sample a region's community variety and composition, and were distributed within the diversity of moisture zones found in the coastal regions of each island. The location of most sites along moisture gradients and at different conditions of substrate and site variability was an effort to explore the effects of these variables upon community composition. Other sites visited represent opportunistic replication. We made specific efforts to survey areas that were known or suspected to have better preserved coastal vegetation. We regrettably overlooked several sites known to harbor rare species when logistics were not favorable, and plan to return to them on future surveys. Not all regions were sampled with comparable effort. Constraints of time, weather, and opportunity diminished the actual coverage from the desired.

Island Focus

After some initial field work on Oʻahu, Hawaiʻi and Kauaʻi, a decision was made to focus more of our survey effort on the islands of Molokaʻi and Maui. Our initial trips to some of the drier sites occurred during prolonged drought conditions. We suspect this resulted in incomplete observations due to the dormant state of the vegetation. A switch in field emphasis was made toward visiting the wetter coastal habitats on Molokaʻi and

Maui. The generally elevated quality and quantity of these islands' native coastal vegetation, and the full moisture gradients available along this coastline, suggested that a focus on these islands would yield a much better understanding of the Hawaiian coastal flora in general, and that this would provide a better framework for future surveys both there and elsewhere in Hawai‘i.

The present assessment of results uses Moloka‘i as a model of the variations found in coastal ecosystems in Hawai‘i, and discusses sites on Maui and O‘ahu as examples that are environmentally contrasting but similarly exposed to development pressures. The remaining coastal vegetation on O‘ahu is nearly all within the dry zone and survey site selection reflected this. Much of O‘ahu has been impacted by intense and growing land use near the coast. Both factors suggested that a limited pool of species would remain along its coastline and that patterns of survivorship, of species distribution, and of vegetation would be important to assess on this island. A few sites were visited on Kaua‘i and Hawai‘i but these islands are in need of more survey work and thus have limited commentary in the current summary. The smaller main islands (Ni‘ihau, Lāna‘i, and Kaho‘olawe), as well as many of the small offshore islets, were not visited at all during this project.

Field Survey Methods

A rapid assessment was made of sites within coastal areas selected for their likely prospects of retaining strand elements. Kayaks or small boats were used to get to more inaccessible areas when needed, and to allow carrying of provisions for longer trips. However, watercraft were not particularly useful to gather data from directly. Cliff areas were viewed from above or below and binoculars were used to scan areas in between. While walking along shore segments, we compiled lists of native species that were observed and collected data on their relative abundance, characterizations of physical site conditions, and selected notations regarding significant conditions and threats to the area. Survey segment lengths varied with the heterogeneity of the coastal areas and the distribution of remnant native coastal vegetation. Wider extents of coastal vegetation required additional backshore coverage. While some collections of coastal plants were made, this was not a major goal of the surveys. A liberal record of digital photos will supplement this report and helps to characterize community composition and structure. Most of the specific observation data are presented in tabular form as appendices to this report due to the large volume of information they contain. Many of these tables are meant to be viewed primarily in electronic format, as printed copies of some are large and difficult to read. Survey site presentation within the tables proceeds in a clockwise manner around an island that corresponds to the site location maps. Also included with this report is a MS Access database from which detailed data can be selected, sorted, and further analyzed.

The extensive coverage and rapid nature of the surveys limited the thoroughness of searches of any given area. Consequently, we may have overlooked some species at any site. This shortcoming is more likely to occur with cryptic and uncommon species and within broad swaths of coastal vegetation. However, these limitations are compensated for by the number and range of areas surveyed and the patterns that emerged in distributions of species and vegetation across the many sites visited.

Community and Species Analyses

We analyzed species composition and habitat relationships of the coastal plant communities using various methods. Species diversity (specifically richness) was calculated by adding up the total number of species recorded for each site from the field surveys. Relationships between sites and their habitat for each island surveyed were evaluated with a two-way cluster analysis (sites and species) using the PC-ORD community analysis software (McCune and Grace 2002). We also used the PC-ORD nonmetric multidimensional scaling analysis (NMS) (Kruskal 1964, Mather 1976) using the Sorensen (Bray-Curtis) distance measure, to assess the relationship between sites on each island and habitat moisture zones.

Image Database

Several thousand digital photographs were taken during this survey. This collection of images is currently being edited, labeled, and further organized. Representative images from this database will be provided to federal and state agencies and private conservation organizations as a supplement to this report, when editing is completed. The images include oblique aerial and along-shore views, much more detailed views of smaller segments of areas, close-up examples of community composition, and a large selection of individual species observed. These images are often more useful than written descriptions in recording the nature of the vegetation. The considerable heterogeneity in the coastal communities, much due to disturbance, makes detailed written community descriptions and generalizations difficult to construct.

Taxonomy

The angiosperm taxonomy used for this report was based on Wagner, et al. (1990), and the updates posted on the Simthsonian Institution's Flora of the Hawaiian Islands web site (Wagner et al. 2006). Palmer (2002) was followed for pteridophytes. New additions to the flora were integrated into our list of Hawaiian coastal plants as we became aware of them, such as the revision of *Chamaesyce skottsbergii* by Morden and Gregoritza (2005). Specific taxonomic problems and explanations of how we dealt with them in this report are described below. Periodic consultation was made with other botanists and field specialists, and previously collected specimens were reviewed at the Bishop Museum Herbarium (BISH) to aid species identification. Photographs of a selection of verified specimens from BISH were useful for identification of some plants in the field. A summary of plant label information from Hawaiian coastal plant specimens held at BISH was prepared by staff at BISH and provided to us by Chris Swenson of U.S. Fish and Wildlife Service. We used this information to compare past and present species composition at selected sites.

During the course of identifying plants seen on the survey some taxonomic issues emerged; working resolutions for these problems and relevant observations are noted here. Two species we encountered are currently being described as new, and more previously undescribed taxa may emerge as our coastal flora is given closer scrutiny.

Tetramolopium

A distinct, small population of *Tetramolopium* occurs at Kuololimu (Mo-240) on windward Kalaupapa, Moloka‘i (Photo 1). This taxon would not key out to a described species. Examination of specimens at BISH herbarium found a 1980s Lani Stemmermann specimen of the same entity and location. This sheet was annotated as an undescribed species under study by the authorities of the genus. Communications with Tim Lowrey (Univ. New Mexico Herbarium, personal communication) have confirmed this is a new taxon and he is currently writing up its description for publication. For this report we refer to this taxon as *Tetramalopium* sp. nov.

Hedyotis

We found *H. littoralis* in mesic and wet habitats on Kauaʻi and Molokaʻi, all with leaves clustered at the base of the stem. However, the plants from Kohala volcano on Hawaiʻi, and on East Maui (from mesic and wet habitats, and planted into dry) are similar to each other but quite different from the preceding. The leaves of the latter plants are thicker, somewhat convex, and distributed along a longer stem. The inflorescence seems more robust as well, similar to that of *H. st.-johnii* of dry coastal cliff habitats on Kauaʻi, which is what we first called the one from Kohala. Tim Motley (personal communication, Old Dominion University) had seen the Kohala population and is planning to describe it as new; he will also be evaluating the East Maui material. Consequently, for the purposes of this survey reporting, *H. littoralis* is used as the species from Molokaʻi and wet-mesic Kauaʻi; and the species from Kohala and East Maui are called *Hedyotis* sp. nov.

Myoporum sandwicense

We note separately the unique *Myoprum* that is distributed intermittently from Kaʻaluʻalu to Kāhilipali, Kaʻū on the island of Hawaiʻi, is a scandent shrub with multiple, very long branches. One cannot discern the basal part of the stem from within the flat, dense and undifferentiated ground cover. It is known only from this island on a large, flat lava delta just above sea level, and it may be associated with basal ground water. The two subspecies of *Myoporum sandwicense* recognized in Wagner et al. (1990) (*M. sandwicense* subsp. *st.-johnii* and subsp. *sandwicense*), were also recognized as part of the coastal flora.

Chenopodium

The *Chenopodium* found at ʻĪlio Pt. (Mo-70) and PuʻukaPele (Mo-150), Molokaʻi, seems quite different from the rest of the *C. oahuense* and is referred to here as a separate entity (*Chenopodium* undescribed taxon). It forms a prostrate mat with dense foliage of very succulent leaves and bears reduced, congested inflorescences and branching. Other coastal occurrences of the genus do not display the distinct characters of the PuʻukaPele entity. This *Chenopodium* taxon is limited to these two very small calcareous substrate sites on Molokaʻi: one (ʻĪlio Pt.) on a wind-swept point near sea level, and the other (PuʻukaPele) at the top of a 140 m high bluff. It appears more distinct than simply a response to the stressful strand environment, and it survives only in quite small numbers at these two locations.

Panicum fauriei

The three currently recognized varieties of *Panicum fauriei* have been described differently and revised more than once, and they continue to confound many observers. Varieties *P. f. latius* and *P. f. fauriei* are annuals from arid and dry habitats, and are all but indistinguishable in the field, as well as not being separated by habitat characters or geography. Samples from a small-area portion of one population were identified as both varieties, suggesting possible natural variation within a single taxon. They both are reported as one taxon (*P. f. fauriei / latius*) here. A third variety, *P. f. carteri*, seems to be limited to mesic-to-dry habitats and appears perennial, at least in some habitats. It has been found on four islands close to the shore (Davidse 1990, Wagner et al. 1990). Its appearance is recognizably different so much so that E.Y. Hosaka, in his 1942 paper, elevated it to a species (Hosaka 1942).

Cyperus polystachyos var*. miser*

This diminutive entity has sometimes been recognized as a variety. It has shown up in low coastal turfs or singly in at least four survey sites, three mesic (Molokaʻi, all remote) and one dry (West Maui). It may be more common, but we were well into the surveys before recognizing it as consistently different.

Boerhavia

Numerous plants of this genus were seen, but the determination of the species was often difficult to make. The available description of *B. herbstii* is vague at best, and was not consistently supported by our field observations. The issues were resolved satisfactorily if the choices were limited only to *B. acutifolia* and *B. repens*, which is what the tallied data reflect. This approach was endorsed by Warren Wagner (Smithsonian Institution, personal communication).

Chrysopogon aciculatus

This grass was very frequently difficult to discern from associated dried up alien grasses because many of the surveys were undertaken during a prolonged drought when the plants were long-dead and fragmented. The inconsistency in observations led us to dismiss any occurrences of this species in the analyses. Given that the plant is common and questionably indigenous, this choice is fairly inconsequential.

Even if the taxonomic novelties noted herein are slow or not to gain taxonomic recognition, it is recommended that, with the exception of *Chrysopogon aciculatus*, they are treated as rare and unique entities for coastal planning and management.

RESULTS

Species Distribution

During this survey we recorded 142 taxa of native plants out of 169 that were expected based on past plant collections and from the literature (Appendix 1). A total of 105 coastal plants were recorded on Molokaʻi, 85 on Maui, and 52 on Oʻahu (Table 7). Thirty-eight species were found on all three of the islands we surveyed, 53 on at least two islands, and 51 plants were found on only one of these islands. Detailed information on species occurrence and abundance at different survey sites is provided in the accompanying Appendices for Molokai (Appendix 3), East Maui (Appendix 6), West Maui (Appendix 7), and Oʻahu (Appendix 8).

The number of plants per site varied considerably between the areas surveyed, but the greatest diversity was found on Molokaʻi and Maui, with their richest sites containing 30 and 32 species, respectively (Appendix 10) (Figure 5). On Maui 22 (40%) of the sites had less than 10 native coastal plant species, 30 (55%) had 10 – 20 species, and 3 (5%) with more than 20 species. A different situation was found on Molokaʻi where only 10 (20%) of the sites had less than 10 native coastal plant species, 28 (56%) had 10 – 20 species, and 12 (24%) with more than 20 species.

The current coastal flora of O‘ahu was somewhat reduced compared to the other two islands (Table 7) (Appendix 10) (Figure 5). This is likely a result of the much greater human-related impacts on the coastal zone on O‘ahu. If you were to include the additional species that were previously known from the sites surveyed on this island, based on herbarium records and other sources (Appendix 8), its coastal flora is more in line with what we found on the other two islands. However, during our survey only 7 (25%) sites on O‘ahu had less than 10 native plant species, 20 (71%) had 10 – 20 species, and one site (Ka‘ena Point, Oa-1) had over 20 species, but, in this case just a total of 21 coastal plant species.

Rare Species

We encountered 12 listed endangered taxa, 2 threatened taxa and, 13 species of concern (SOC) but with no official listing status, as well as many other taxa that are now relatively uncommon within the Hawaiian coastal zone (Appendix 1). The most widespread rare coastal plants were *Lepidium bidentatum o-waihiense* (SOC), *Schiedea globosa* (SOC), and *Sesbania tomentosa* (E), which were found on all three islands we surveyed. A total of 17 (63%) of the rare (E, T, and SOC) species we encountered were only found on one island, 6 (22%) were found on two different islands, and the remaining 4 species (15%) on all three islands surveyed.

Regional Synopses of the Coastal Habitats and Flora

Each major island has its own set of general conditions and overlapping suites of coastal plants. Differences in island age and geologic history tend to determine a unique set of geologic site conditions on each island.

<u>Kaua‘i</u>

Kaua‘i exhibits a varied range of conditions, including expanses of broad, arid beaches and dunes, bluffs and low shores of saprolite, some consolidated calcareous shores, weathered basalt, and some wide protective reefs. Tall cliffs run along a moisture gradient and these environments are further complicated by clefts from large and small valleys. Kaua‘i’s coastline experiences considerable amounts of arid, dry and mesic conditions, and some areas border on wet. Development along portions of its shoreline is still limited, but many of these coastal plant communities are depleted by impacts of feral ungulates or from off-road vehicles.

<u>O‘ahu</u>

O‘ahu shorelines are predominantly calcareous sediments that are perched upon raised-reef substrates. Smaller areas along the coastline of the island are found with exposed basaltic rock or softer tuff or spatter deposits. Soil texture and amount vary enormously at the various sites surveyed. Most of the coastal vegetation on O‘ahu survives only in dry areas; mesic areas support just a few relicts amid human disturbance. Several sections of the coastline of O‘ahu are relatively undisturbed and support moderately diverse assemblages of dry region flora. In some areas the seas are usually moderated by offshore reefs. The topographic range of O‘ahu coastlines is limited.

The richest site we surveyed on O‘ahu was Ka‘ena Point (Oa-1) which had 21 native coastal species (Appendix 10). The next richest site, Hanauma (Oa-29), had 18 species. While most of the areas surveyed on this island had more than 10 native plant species, 25% (7 sites) were relatively depauperate with fewer than 10 natives.

Molokaʻi

The 75 km of Molokaʻi's north and west shores, which houses most of its remaining coastal vegetation and contains samples of all its species, ranges from arid through wet, and from flat to imposing 1,000 meter high cliff topographies. This coastline includes a broad range of mineral substrates and textures, and in many areas it still has contiguous native lowland vegetation along mesic and wet shores.

Molokaʻi had, by far, the largest number of native coastal species for the three islands surveyed (105 *versus* 85 for Maui and 52 for Oʻahu) (Table 7). The more intact nature of the coastal communities on this island is further shown by the fact that 80% of the sites that were visited had more than 10 native species, and 24% (12 sites) had more than 20 native species (Appendix 10). In contrast, only 60% of the sites on Maui had more than 10 native species and only 5% (3 sites) had more than 20 natives. Most of the sites with high coastal plant biodiversity were found along the north shore of Molokaʻi, extending from arid sites like ʻĪlio Point (Mo-70) (Photo 2) and around Moʻomomi and PuʻukaPele (e.g., sites Mo-120 and Mo-150) (Photo 3), across the Kalaupapa peninsula (Hoʻolehua beach Mo-220), and along the wetter cliffs extending to the east (many rich sites including Kūkaʻiwaʻa Mo-280, Anapuhi Mo-300, and Kikipua Mo-400).

The extensive north shore cliffs' coastal vegetation is shaped in part by prodigious amounts of falling rock and water. All these factors contribute to the island's collective complement of over a hundred species that were observed in the coastal flora, nearly twice as many as we observed on Oʻahu. Such conditions suggest that preserving and managing much of this coastline would be an excellent conservation focus since it houses approximately 60% of the total Hawaiian coastal flora.

Maui

Maui, like Molokaʻi, has remnant coastal vegetation along a wide moisture gradient growing on old and young volcanic substrates and calcareous material. It also has significant lengths of continuous shoreline that still have only minimal development or human-related pressures. Long shoreline segments on northwest-to-northeastern West Maui, and on north-east- and southern East Maui support good to decent representation of dry, mesic, and wet coastal plant communities (Photo 4). Southeastern or East Maui lava flows retain some of the arid coastal communities. Good beach habitats are very limited in extent and type, but the Kanaio Beach area (MaE-35) is in outstanding condition, as are Waiohue (MaE-16) on East Maui, and Punalau (MaW-7) on West Maui (Appendix 10). Grazed and feral ungulates are still a widespread stressor of coastal communities over large areas on Maui, as they are on Molokaʻi. However, there are still good connections between the coastal and lowland vegetation in some arid (Kanaio beach area), dry (northern West Maui) and wet (Waiʻānapanapa to Makaīwa Bay) regions.

Island of Hawaiʻi

The island of Hawaiʻi's shores are usually lava flow flats, bluffs or cliff faces. Sediments are usually basaltic or of mixed origins, and calcareous sediments are less common. Moisture conditions range from arid to wet. This island has the longest shoreline in the state, the greatest extent of "wild" shore, and less development, but its coastal vegetation's species composition and total extent is relatively limited. There are few beaches on Hawai'i and these have generally suffered from anthropogenic modification. Most of the coast on this island was formed from relatively young lavas, much of it is edged by bluff or cliff, and large portions have been (or still are) overrun with ungulates. The coastal communities here have also experienced severe losses of native plant species due to replacement by invasive species. However, overall the island of Hawai'i also has one of the most extensive and diverse coastal areas in the Islands (Photos 5 and 6), and relicts or expanses of other coastal compositions can be found in numerous other locations on the island.

DISCUSSION

Moisture

The most influential site factor for Hawaiian coastal communities is the range of moisture that occurs across any particular area. The greater the moisture zone range, the more species are likely to be found in a region. A comparison of coastal plants on Maui relative to moisture is presented in Appendixes 6 and 7. The reliably wetter windward (northeast) exposures are present for most islands. These moisture conditions are orographically amplified in areas with coastal cliffs. The general moisture range is also extended locally by fresh water inputs from streams, waterfalls and seeps, basal ground water, and by proximity to brackish ponds and marshes.

Moisture stress is also locally modulated with limited or increased exposure to sun or wind in topographically complex sites. A large-scale example of this is seen on the northeastern shore of Molokai, where the extreme height of the north-facing coastal cliffs reduces and defines full-sun exposures. That, plus water that spills or seeps down from the wetter planeze above, makes large portions of the region more moist than precipitation and moisture zone maps indicate. Varied soil and substrate conditions throughout the coastal zone can also contribute to the local range of moisture conditions.

Price, et al. (2007) recently defined seven moisture zones for the Hawaiian Islands (Figures 6 and 7). These seven zones describe existing gradients and boundaries that are found throughout the archipelago. The moisture zones are based on integrating precipitation ranges with evaporation potential at different elevations, in this case sea level. These moisture zones are also displayed on the site location maps for the islands covered during this survey (Figures 1 – 4).

The Price et al. (2007) moisture zones correspond quite closely to older categories and mapped depictions that were developed from prevailing vegetation zone patterns recognized by Ripperton and Hosaka (1942) which we used in our initial assessments of coastal vegetation. Ripperton and Hosaka's mapped zones were quite useful, but lacked a numerical reference to either rainfall or evaporation potential. Gagne and Cuddihy (1990) recognized three zones (wet, mesic and dry) in their community classification, and while there was no connection to a map portraying such distributions, they did make reference to rainfall ranges for each category. Price et al.'s (2007) new moisture zone maps deal with both of these previous shortcomings.

Our field observations and previous collections of coastal plant species fall into one or more of the seven moisture zones (Appendix 11). Six species: *Chenopodium oahuense*, *Fimbristylis cymosa*, *Lycium sandwicense*, *Pandanus tectorius*, *Scaevola taccada*, and *Vigna marina* were found in all of the mapped moisture zones. Nine species, including *Cyclosorus interruptus*, *Deschampsia nubigena*, *Machaerina angustifolia*, *Sphenomeris chinensis*, and *Pisonia umbelifera*, were restricted to wet habitats; and 36 species, such as *Chamaesyce celestroides kaenana*, *Gossypium* *tomentosum*, *Myoporum sandwicense*, *Scaevola coriacea*, and *Sesbania tomentosa* were found only in dry or arid habitats. However, most species showed intermediate tolerances and were found across several zones. Overall, moist-mesic sites had the greatest diversity of species, while the mean and median number of species in the other moisture zones was relatively similar (Figure 8). However, the greatest number of species (32) was found at an arid site, Kanaio Beach (MaE-35) on East Maui (Appendix 10).

A two-way cluster analysis of the coastal species on Molokaʻi illustrates some of these moisture relationships (Figure 9). Examination of the two-way cluster plot shows two groups of species (outlined in yellow) that appear to be regularly found either in arid or dry sites, another set (outlined in red) that is primarily in arid sites, two groups that are predominately found in mesic or wet sites (outlined in green), and a final group only in wet sites (outlined in blue). Additionally there are many species that are either too widespread or too restricted in their distributions, or are found in only a few sites, to be used as indicators of moisture zone.

The two-way cluster analyses for both Maui (Figure 10) and Oʻahu (Figure 11) do not show any obvious indicator groups. The absence of clear groups on Oʻahu is likely due to the limited number of moisture zones surveyed there (primarily dry and arid sites), coupled with much more disturbance to the coastal zone due to development and other human activities. The lack of clear patterns between species and moisture zones on Maui is more puzzling, but may reflect the fact that there were fewer coastal plant species found on Maui (85) *versus* 105 species on Molokaʻi.

Ordination graphs, utilizing nonmetric multidimensional scaling (NMS), of the species found in each of the sites that were surveyed further support the idea that the distribution of plant species are correlated with the recognized moisture zones. This relationship appears to result in distinctive zonation of the sites by moisture for both Molokaʻi (Figure 12) and Maui (Figure 13), but again does not show any clear relationship to moisture on Oʻahu (Figure 14), likely for the reasons given earlier.

Various site factors may affect the range and frequency of moisture zone occupation at a particular site. For example, in the wettest zone additional species that are not very tolerant of sea salt were found to extend into the backshore areas or far down wet coastal cliffs. Finally, we found a set of 18 wet-area plants that, in at least the more stressed coastal environment, appears to be restricted to perennial or seasonal wetland basins or their edges, to springs ranging from slow seeps, to flowing rheocrenes, to waterfall mist zones, or to contact with shallow basal water (Appendix 1, identified with "W" in Wet Site column). The presence of these additional local water sources allows typical wet zone species to exist where conditions would otherwise be too dry or too saline.

Shoreline Conditions

Growing conditions along Hawaiian shorelines differ with the amount and nature of the sediments or soils and that of the basement rock beneath. Calcareous and basaltic sands, as well as various alluvial and colluvial deposits of a wide range of coarseness, are found situated on top of much of the supporting base rock substrate. Tuff deposits, saprolite, clays, dunes, and young lava may provide more localized variation to that of the basic supporting rock substrate. Topography further complicates the mix of conditions. Flat shores, dunes, low bluffs, cliffs ranging up to nearly 1,000 meters in elevation, and talus deposits all form shorelines that may select subsets of plants within an area's particular moisture range. Descriptions in Appendix 4 provide examples of the wide range and variety of site conditions for the fifty Molokaʻi sites.

Annotations on site conditions on Maui, Molokaʻi and Oʻahu can also be found in Appendix 4, 6, 7, and 9.

Consolidated sand dunes (eolianite) or raised reef material have formed solid calcareous material in numerous locations on most of the Islands. Oʻahu is the only island that exhibits extensive solid raised reef material. Calcareous sands or raised calcium-rich lagoon deposits also extend their influence to other substrates they overlie. The extensive Mānā plain of western Kauaʻi is surfaced or underlain with several types of these deposits, as are smaller areas elsewhere on that island. Niʻihau, Molokaʻi, and Maui also have significant areas of calcium-rich habitats, including loose and consolidated dunes occurring both within the coastal habitat and inland. Calcareous beach areas are found extensively on Lānaʻi, but these substrates are only sparsely represented on Kahoʻolawe and Hawaiʻi. The distribution of calcareous features and other aspects of shoreline geology around the main islands has been compiled by Sherrod et al. (2007) (Figure 15). Appendices 2 and 8 indicate sites with calcareous substrates on Molokaʻi and Oʻahu.

The range in shoreline configurations and conditions is considerable throughout the Islands. Some contain significant areas of reef-protected shoreline and others have very little. Consequently, sea conditions range from generally protected bays, to full exposure, to seasonally violent waves and wind. The latter can greatly amplify physical trauma and the quantities of salt spray at a site.

Environment and Strand Community Composition

The composition of strand communities varies considerably spatially, but in most given locations communities contain limited subsets of the species richness potentially available. The coastal vegetation's physiognomy is usually characterized by low growing and mat forming species in areas closest to the ocean and by taller plants farther inland or where available soil has accumulated locally. In the arid and dry zones, a few annual species, mostly grasses, are seen; the rest of native coastal flora is perennial. Exposure to salt water and onshore flow of salt mist (*ʻehukai*) comprise the harshest ecological factors within the coastal zone. Exposure to *ʻehukai*, strong winds, and brackish basal ground water all influence this generalization and add variegation to an area's vegetation structure and composition. A range in other site conditions helps to further diversify the structural and species composition of the communities. Understanding of these conditions can assist managers with identification of areas to preserve and manage, and help to guide restoration attempts.

Moisture is the next strongest factor influencing species composition of coastal vegetation. Plant communities in each of the seven moisture zones appear very different from one another in species composition, in general appearance and physiognomy, as well as in the range of life forms. The tabulated species pools available for communities in each of the seven moisture zones tend to be considerably larger than the observed communities due to additional moisture sources at the local level. Availability of additional moisture from seeps, groundwater and the like can extend a species natural range, as is reflected for several species in Appendix 1. If additional moisture is available at a specific site, it might add some representatives from the wet-site pool of species to an otherwise drier area.

While windward exposure increases stress in some sites, its overall affect on coastal vegetation tends to be favorable. Windward shores are characterized by the frequent on-land exposure to strong winds and *ʻehukai*. For relatively flat coastlines, this exposure can markedly increase the breadth of the coastal vegetation, as it favors species with creeping life forms. Windward exposure can extend coastal vegetation, including mat-forming species, to the tops of substantial coastal bluffs in places like north-central Molokaʻi, Makapuʻu to Koko Head on southeastern Oʻahu, and the northern part of West Maui. Windward exposure also favors inland dispersal of native propagules, while it decreases the seaward advance of most fringing alien species. This factor can be utilized in management design where the winds tend to keep weedy species from colonizing back into the wind. These strong winds also help with dispersal of species like *Schidea globosa* by transporting vegetative fragments within its cliff face habitat. Extremes of wind and sea conditions can also provide seasonal to infrequent trauma or stresses of various sorts to affected portions of the coastal vegetation, and thereby select for particular subsets of the coastal flora. For certain windward exposures seasonal wave inundation, periods of heavy sea spray, and long periods of *ʻehukai* are forceful shapers of community composition. Infrequent storm surf may cause sufficient removal or disruption of long-established communities that regeneration with different compositions may occur.

The texture of substrates that support coastal vegetation ranges from fine clays to coarse talus deposits, and to solid rock surfaces with barely perceptible soil content. Particle size provides further variation; different-sized particles may wick, mulch, or block the moisture at a site. The influence of each of these variations can be seen in the corresponding species composition found on each substrate.

The mineralogy of the rock supporting coastal soils also appears to influence the composition of communities. Nutrient availability to plants differs above juvenile basalt, older saprolite, and calcareous substrates, the latter being associated with phosphate fixation and pH-related nutrient deficiencies in many soils (Brady 1974). Juvenile and highly weathered basalts each provide quite different availabilities of cations and anions in their soils (Vitousek 2004), which, in turn, influence what species can colonize these sites. It is also possible that the considerable exposure to calcareous materials over the long history of the Hawaiian flora has played a significant selection role for species in communities assembled on calcareous substrates. This question should be addressed with future research.

Species Interactions

The role of competition within established communities and the relative advantage afforded to first-arrivals in colonizing renewed communities appears evident in observed community compositions, but are not well understood. Nor can we evaluate the relative frequency of chance dispersal of new community members or of local extirpations in the variegated pattern of vegetation that is often found within an otherwise uniform area.

Given that Hawaiʻi's shorelines are no longer pristine, the communities that were observed during these surveys can all be assumed to have suffered from some degree of species attrition or community alteration. Examining long-term specimen collection data for known sites verifies a trend of decline. Many of the species that have been extirpated from sites appear to have been lost in recent decades. Attrition of species from communities might play as important a role in present community compositions as do site factors. Reversing this loss through restoration activities is desirable, but the extent of species packing at any given site that will provide long-term stability is unknown. A conservative approach might be to simply reintroduce different species at a variety of proximate locations that represent a range of appropriate site conditions. These sites can serve as *inter situ* holding sites where more species may be preserved under semi-natural conditions.

Local Endemism

Thirty percent of the coastal flora consists of local endemic taxa that are found on one, two, or three islands (Appendix 1). Conversely, just over half of the taxa are widely distributed either on six, seven, or eight of the main islands. In the present general environment of habitat degradation the chances of extinction are elevated for the local endemics. Particular attention needs be taken to managing specific populations to prevent the loss of some species.

In addition to allopatric speciation of separate-island endemics, some of the local endemism we found across the areas surveyed may reflect specialization to local site conditions and ultimately to sympatric speciation. Some moisture zone partitioning can be seen within several genera's coastal taxa (Appendix 1). For example, our numerous observations of *Tetramolopium* on the northern coast of Molokaʻi led to the following conclusions on their distributions. These coastal *Tetramolopium* species seem to be associated with specific habitats and substrates: *T. rockii* with arid calcareous rock, *T. sylvae* with mesic and dry saprolite and older basalt, and the new species at Kalaupapa with mesic younger basalt. In addition, Joseph Rock (1913) placed an unnamed species of *Tetramolopium* (now extinct?) from the now-degraded habitat of "the more muddy flats of [south] Molokai" on a list of strand vegetation plants. There is need for much more assessment of substrate influences in regard to speciation.

As the coastal vegetation has become fragmented by land use and other factors, it is likely that many other local endemic species may have been extirpated. The new Kalaupapa *Tetramolopium* survived only because its last few individuals were fenced from ungulates before they could disappear.

Direct threats to Coastal Ecosystems in Hawaiʻi

<u>Alien Plants</u>

Alien plants represent one of the greatest threats to native coastal vegetation in that any one of several invasive species can completely displace or prevent the colonization of entire suites of native species. Alien trees constitute the greatest threat in these communities, especially tree species that disperse readily and form dense cover above the native vegetation. Particularly problematic plant species include the two invasive mangroves (*Rhizophora mangle* and *Bruguiera sexangula*), *Casuarina equisetifolia*, *Prosopis pallida, Prosopis julifera*, *Terminalia catappa*, *Schinus terebinthifolius, Hibiscus tiliaceus,* and *Leucaena leucocephala*. There are numerous examples of places where these invasive trees have become well established and they continue to expand and displace the native coastal vegetation. In some places the scale of this invasion is kilometers long. Several of these alien trees are dispersing progressively farther afield as their populations increase. *Rhizophora mangle* and *Terminalia catappa* can float to distant sites and start new populations. Infestations of these species should be targeted for rapid removal. Invasive species are also transported intentionally as landscaping elements. In some areas huge expanses of *Casuarina* extend down to the wave wash. Elsewhere, these trees have extensively draped bluff and cliff zones, where they cause additional losses of coastal vegetation by predisposing areas to landslips (e.g., north Haleakalā, windward Mauna Kea). *Prosopis* shades the shores of large areas of leeward coasts all over the Islands. One or more of these invasive tree species thrives in each of the moisture zones and on all coastal substrates, and collectively the two mangrove species also occupy much mud flat and reef area, as well as both tidally submerged and emergent lava flows along the coast in the Puna district of the island of Hawaiʻi.

Weeds of much smaller stature can be similarly disruptive of native coastal vegetation. These include *Tetragonia tetragonioides,* wedelia (*Sphagneticola trilobata*), *Pluchea indica*, *Cenchrus ciliaris*, *Kalanchoe pinnata, Coccinia grandis, Verbesina encelioides* and more. In wetland areas, *Batis maritima,* wedelia and *Paspalum vaginatum* are all capable of displacing native coastal wetland plants. Wedelia and *Paspalum vaginatum* disperse by sea as fragments, readily initiating distant incipient populations. Numerous other species, such as *Philoxerus vermicularis* and *Aptenia cordifolia* on windward Oʻahu beaches, are now being recognized as invasive as they are spreading within the coastal environment. The impacts of these weeds could be avoided by rapid removal wherever possible. *Canavalia sericea* is also somewhat widespread in the same habitat and places, but its impact is unknown. Appearing "native" and/or attractive, this species may be spread intentionally by humans. *Prosopis julifera* was observed on the Mānā plain and Gilin's Beach on Kauaʻi to expand its shrubby branches below the line of native vegetation. Some alien species have more targeted impacts, such as *Polypogon interruptus*, which occupies the same small soil spots and habitat on Molokaʻi and Maui as does the endangered grass *Ischaemum byrone*, displacing it along with the other native species that grows in this same habitat.

Alien Animals

Alien animals are another important threat, one that frequently opens the door for, or tips the balance to, alien plants. The most obvious and widespread animal species are pastured and free-roaming ungulates, particularly cattle, goats, sheep, pigs, and deer. The numbers and distributions of some ungulate species may have surged and waned variably over time and space, but their impacts are unequivocally negative in the coastal zone in any abundance. Even horses can be damaging when they graze sand dunes that are generally avoided by cattle, as we observed at Kahuku, Oʻahu. Whole sections of coastlines were found to be seriously impacted by abundant pig, goat, and deer populations in many areas throughout the state.

Native coastal vegetation in south Kona, north Molokaʻi, Kohala cliffs, Nā Pali Coast and south Haleakalā are examples where prolonged ungulate damage has been taking place. In Hawaiʻi Volcanoes National Park damage from ungulates proceeded to the point that recovery of native coastal and lowland vegetation following goat removal was largely prevented since many of the coastal plant species had been locally extirpated, except at a few locations. If ungulate problems are addressed in time the remaining native coastal vegetation in a damaged area has a better chance to recover. For example, large scale goat reductions on the northeast coast of Molokaʻi have allowed temporary recovery of the coastal vegetation, even curtailing the once-constant fall of browse-loosened rocks in areas we revisited after years-earlier experiences of enormous erosion.

Fences recently built by the National Park Service in the Kalaupapa area have had enormous positive affects for the areas they are now protecting. In one place within the park that had been fenced, endangered *Canavalia molokaiensis* vines were released from heavy goat and deer browsing, and were observed covering alien weeds when we surveyed that area. Nearby, in a tiny exclosure on the eastern edge of the peninsula, the last few individuals of an undescribed species of *Tetramolopium* were spared extinction, and are now expanding the population to outside the fence since a larger 315 ha (780 acre) coastal fence unit was constructed to further exclude deer, pigs, and goats. Not far away, also on the Kalaupapa peninsula, ungulate control has given remaining individuals of endangered *Centaurium sebaeoides* and *Panicum fauriei carteri* relief from depredations by deer and pigs. Farther west at Moʻomomi, a decision to halt cattle grazing in a large coastal pasture allowed a broad, diverse swath of native coastal vegetation, which included *Centaurium sebaeoides,* to recover and thrive. Similarly, Kahoʻolawe experienced profound recovery in its lowest elevations after goat eradication, albeit with a very truncated suite of native species that remains mixed with aliens on that island. The cost of trying to restore some of the lost diversity to Kahoʻolawe has been enormous, and the scale of recovery still is limited. Clearly, timely actions are essential in the conservation of ungulate-impaired native vegetation.

Smaller animals also degrade coastal ecosystems. Ants have largely removed the native arthropod fauna from many native coastal ecosystems (Perkins 1913, Zimmerman 1948), but the consequences to pollination and the spread of ant-tended plant pests has yet to be documented. Rats, cats, mongooses, and dogs have also been identified repeatedly for their adverse impacts on breeding seabirds and turtles along main-island shores, and widespread attempts of such breeding are regularly thwarted or curtailed by these mammals in nearly all main-island attempts.

Human Impacts

Human development and use of coastal areas continues to exert severe, usually permanent, impacts to remaining native coastal vegetation. Recent examples seen during or before our survey attest to the rapid pace of this impact. On Oʻahu, the Kapoho Point area of Kailua once supported at least eleven coastal species on raised–reef rock and dune sand until a recent residential development displaced it, dune and all. The dune was removed to provide front-room access to an ocean view and, as it soon turned out, it also provided the ocean access to the houses' front-rooms. Regulators, the building industry, and real estate buyers can all benefit from the value of having native coastal vegetation on a stable, protective dune.

Recreational activities, in particular, tend to be another widespread detriment to native coastal vegetation, as demonstrated by the impacts of off-road vehicles on Oʻahu at Mokulēʻia - Kaʻena (Oa-2) and near the Kahuku Point (Oa-7 and 8) survey areas. Note the high numbers of native species at risk in Appendix 8 at these areas. This is a problem shared by other high-value coastal vegetation at places like South Point and Kohanaiki on the island of Hawaiʻi. This statewide problem is widespread on Kauaʻi, including Polihale State Park and near the Pacific Missile Range Facility, all with adverse consequences to the vegetation. In all these areas there are nearby locations devoid of native coastal vegetation that could serve as alternative sites for vehicular access. Given the adverse impacts of human activities to coastal resources, increased consideration to resource values in regulating coastal land use and in educating individuals recreating at the coast should be encouraged.

On Oʻahu, the high value native vegetation found in the Makapuʻu survey areas (Oa-22, 23, 24) was directly impacted by recent construction of a viewing area parking and walkways at the lookout, and by building expanded parking and camping areas at the park area below. This followed significant impacts on the native vegetation from temporary "homesteading" over the previous decade. In all the areas adjacent sites with alien-dominated vegetation was available, but, unfortunately, the construction and usage occurred in areas of the remnant coastal vegetation, rich in native species. Human traffic fostered by the construction has spread the damage and displacement even farther into the adjacent surviving vegetation. Proposed highway improvements could also threaten additional coastal vegetation in the immediate vicinity of Makapuʻu. Very similar problems have occurred at Kohanaiki, south of the Keāhole Airport, one of the high-value coastal development areas on the island of Hawaiʻi. In this area the native coastal vegetation has been caught between vying development and recreational interests.

Other serious conflicts were observed during a coastal survey trip to an extensive development at Kaʻūpūlehu in the northwestern North Kona district on the island of Hawaiʻi. There, next to foraging endangered Hawaiian Stilts (*Himantopus mexicanus knudseni*), gigantic piles of siliceous sand, imported from Asia, were seen being spread over diverse native vegetation to compensate for the area's naturally limited coralline sand. Constructed features, sand, and soil were emplaced over and in native anchialine ponds (land locked pools with subterranean connection to the ocean), and the diverse native coastal vegetation was converted to managed, artificial landscaping. Nearby, a gazebo was labeled to have been constructed of wood logs and grass thatch imported from Africa, both potential sources of alien pests. All of these activities put the native coastal resources even more at risk. Along dry lava shores, most of the richness in coastal vegetation occurs sporadically, and much of it tends to be associated with the few beaches and anchialine ponds. Both of these habitats tend to be targets of development and/or recreational activities. The cumulative degradation and loss of anchialine ponds along these lava shores is particularly serious, given the uniqueness and rarity of these communities.

An easily overlooked contributor to coastal resource decline derives from a very limited awareness by the general public in recognizing coastal vegetation. Most residents have trampled or driven over it at some time in their lives, but few are likely to realize what they have done. However, even in areas where human disturbance is a major factor causing strand loss, the interest of Hawaiʻi's people in the shoreline might be harnessed to support conservation efforts. More interpretive material and guidance could enhance this option.

Indirect Threats

As a region's native coastal vegetation is stressed and suffers cumulative degradation and partial community replacement by alien species, it first loses native species replication, followed by loss of species representation throughout the region as a whole. Overall native species diversity and cover decline as more native species become rare. Dispersing propagules diminish, and the vegetation's ability to replace local losses of cover and native diversity decline accordingly. It is a positive feedback system with negative consequences. Eventually, there is just a continued loss of native species over a large region coupled with an increase in the number and abundance of alien species.

Another pattern that results in an indirect loss of diversity occurs when remnant or substantial sources of lowland vegetation loses contact with its coastal portion. This can occur via gradual loss of the inland vegetation elements, which in turn cannot be maintained in only the coastal portion of its range, perhaps because the latter may be marginal habitat. Within the framework of ongoing habitat fragmentation, the inland connection could either be destroyed outright or the contiguity with the coastal portion is severed. Either course might reduce the flow of replacement individuals into the coastal area.

The fragmentation of habitats and compounding affects of an associated array of disturbances resulting from urban and agricultural activities have led to considerable attrition of species from predominately native areas in the coastal zone. These losses are continuing, perhaps accelerating, with the expanding use of the limited coastal areas throughout the islands for resort, residential, and recreational activities. This situation is further confounded by species and community losses that have been proceeding due to prolonged presence of ungulates within much of the Islands' coastal vegetation, and leads to even more fragmentation of the communities.

Species Attrition

A growing problem is the spread of alien plant species capable of displacing or altering the nature of native communities. Other aliens may be implicated in depressing pollination (e.g., ants), or reducing success of seabird nesting through predation, or in directly impacting native coastal plants and animals. Most of the areas we surveyed contained a number of rare species and presumably had lost others. Without management intervention, the number of extirpations in coastal communities can be expected to continue to increase.

Loss of plant species can be tracked by examining past collection records through herbarium specimen label data. The disappearance of species from whole islands are a particular cause for concern as the scale of inter-island dispersal is probably minimal today and local endemics that are extirpated will be lost forever. For example, Appendix 1 shows that O'ahu had 126 taxa recorded historically from its coastal environment, but only 54 were observed on this survey (Appendix 8). Appendix 8 includes, for the same O'ahu sites and species, the last collection years when some of these 54 species had been collected at or near the same sites. Appendix 9 lists 17 additional species collection records for these same general areas for species that were not observed during this survey at any of the same sites. Some of these species may well be now extirpated from O'ahu. More species are absent from other areas of coastal O'ahu, including nine more rare or listed endangered taxa. Due to the limitations of using herbarium collections data to reconstruct species distributions, this example undoubtedly understates the scale of the problem but it illustrates its pattern.

Generally, offshore islets are much less subject to detrimental pressures from human activities, ungulates and other alien species than are most main-island coastal sites. For the offshore islets near O'ahu, significant species loss has recently occurred from these relatively protected locations within the short time spans that are indicated in the collection date range (Appendix 8 and 9). We interpret this to reflect attrition of species from a given area when there are not enough individuals and source populations remaining in the region to repopulate them. There is not enough regional flow of propagules of many species to re-populate the islets from periodic losses. These natural limitations could be offset through augmentation by out-planting species formerly known from that site.

When the species lists for any main island's sites are examined, there are areas where the number of native species is minimal, but a few "survivor" species do remain. Most of such sites observed were not even placed in our summary tables. In large regions, for example most of arid leeward O'ahu and the windward mesic zone between Hau'ula and Kailua on that island, very little of the coastal flora remains except on offshore islets, and even these refugia have lost considerable numbers of native plant species. Both of these heavily impacted shoreline regions have lost too much habitat and too many species, and suffer too much human traffic for any local area to still have but a few of the hardiest species. These areas have also lost most of the potential for recruitment of other native species due to species-dependant nature of the regions. As richer areas like Makapu'u are developed further for parking, camping, highway improvements and similar forms of traffic, the same result may be expected to occur. Severe attrition can also be seen outside of urban-affected areas. For example, large portions of the island of Hawai'i's shoreline vegetation have been rendered depauperate of native species by ungulates or displaced by alien plants (or both), and it can be assumed that natural recruitment of most native coastal species is also nearly absent under these continued pressures.

Maintaining Regional Perspective and Process

The coastal environment is closely associated with periodic trauma through natural stressors such as salt water, wind, and surf. An important process within the natural maintenance of coastal vegetation is the regeneration of that which is lost or heavily damaged due to severe storms, tsunami, landslides, or prolonged drought. Recovery of plant communities over time has been dependent upon replicate species components being available to supply source material for regeneration elsewhere. This parallels the establishment of vegetation and faunal elements within areas of high lava flow coverage on Hawaii, where *kīpuka* (islands of older substrate and vegetation surrounded by more recent lava flows) are essential to provide propagules for distribution to younger flows. In lower Puna on the island of Hawai‘i, where severe loss of native vegetation has occurred in recent years, the colonization of lava flows by native species has been curtailed due to lack of source populations on adjacent lands, which are now displaced by weeds. Recently expanding populations of alien plants are also shedding propagules to new flows more frequently, which subsequently results in the conversion of these habitats to alien-dominated vegetation. This model is directly analogous to the coastal situation.

Continued dispersal of native propagules to any coastal area from local and more distant sources has managed to maintain this ecosystem over the long term. However, the process has been severely compromised by recent cumulative degradation, fragmentation, and loss of large portions of the coastal communities. As noted in the O‘ahu example above, many plant species are now depleted or extirpated from large regions of that island. Float dispersal occurs along shore via buoyant or rafted seeds or plant fragments, and by wind carrying seeds, spores and fragments. Evidence of this was observed during the surveys. It can also be assumed that shorebirds, such as `Ulili (*Heteroscelus incanus*), Kolea (*Pluvialis fulva*), and `Akekeke (*Arenaria interpres*) also play a part in dispersal of some plant species as well. The key to re-colonization of disturbed sites is having enough source areas and enough representation of both common and less common elements available to maintain the dispersal process.

We saw one example of a large-scale disturbance and colonization situation during the surveys of the north coast of Moloka‘i, just beneath the Oloku‘i plateau. In approximately February 2000, a huge landslide slipped off the western seaward face of the Oloku‘i planeze (a triangular land surface facing outward from a conical volcanic peak). The fallen material’s source extends up to over 900 m elevation at the slide’s edge of detachment. Enough material fell into the ocean to build a three-hectare land shelf that now extends 200 m out from the shore at the cliff base (Mo-341). The fallen rock was reduced to cobbles, pebbles, and fine-particle material, with some large blocky material. It formed a new sloping land surface that even contains a small wetland area. Given that the material fell from the rainforest above, and emplaced rather catastrophically, it can be assumed that all the vegetation that has germinated since the slide has come subsequently from propagules arriving from the adjoining cliff face and from along-shore dispersal from the nearby areas. When we surveyed the site just over one year after the slide, it was partially vegetated with a mix of native and alien plants. Of the dozen native species, a third were not found growing on either the adjacent rich cliff face or on the narrow apron of talus beneath it, nor were they found closer than a 3-5 km straight-line distance along the coast. This gives an indication of the potential for dispersal within a region when collectively the areas can maintain an adequate flora with sufficient replicate representation.

The trade winds which blow along northeastern Molokaʻi are definitely a prominent force in local dispersal, at least 70% of the time. Winds from other directions can also contribute a smaller set of propagules as can shorebirds. The point here is that when there are sufficient replicates of community elements in a region, dispersal and colonization of native plants happens. A lack of replicates along a coastline tends to result in static or declining community richness.

If the coastal flora is to survive in a region, there needs to be enough cumulative representation and maintenance of all the species elements to allow for dispersal and recolonization within this community. In any area that we surveyed, there were always some species that were infrequently found. Given current trends and the essential need to maintain sufficient propagules for dispersal, it can be reasonably assumed that these species are not “naturally rare”, but have been depleted by recent factors that have impacted the coastal zone. These rarities are likely to be the next species that may be lost from the area or from the flora as a whole. It can also be assumed that isolated coastal sites and heavily fragmented regions will continue to suffer losses in species composition, even if some representative elements of the coastal flora remain, unless management intervention is successful.

CONSIDERATIONS FOR CONSERVATION OF COASTAL ECOSYSTEMS

Given the cumulative stresses that Hawaiʻi’s coastal communities have experienced in recent years, the few plant extinctions that have occurred indicates there is still time to employ effective management to prevent more loss of diversity. However, the widespread damage to coastal vegetation and the rarity of so many species indicates the urgency for supplying sufficient targeted management to preserve species and to restore community composition, structure, and function. The coastal vegetation’s adaptation to natural disturbance, as evident from the harsh environment it occupies, coupled with its regenerative capability, may have helped these communities survive thus far. This suggests a good potential for preservation of the biota of these regions if effective and strategic management actions are effected soon.

Basic Model for Conservation of Coastal Plant Communities

A conservation strategy that incorporates both protected regions and species augmentation may be able to reverse declining trends in Hawaiian coastal communities if applied in time and at sufficient scale. Protection of coastal regions should feature reduction or elimination of the major stress factors that accompany alien plants and ungulates, as well as reducing and compensating for the adverse consequences of land use.

The coordinated work done by the Resource Management staff at Kalaupapa National Historical Park working along its moisture gradient and within its contiguous lowland vegetation exemplifies the design and implementation that are needed at a much larger scale across the Islands. Within large-area ungulate reduction zones, they are managing specific costal sites with planned and prioritized alien plant control and native species augmentation. All of this activity is occurring within a well preserved larger coastal region where beneficial conservation consequences can be mutually reinforcing. The Kalaupapa National Historic Park includes the transition zone to where upland vegetation can also be found, and stabilization and enhancement of the native plant communities here is especially important to counter the overall trend in vegetation disconnection. At points within the larger north Molokaʻi region, other land managers (e.g., The Nature Conservancy of Hawaiʻi) are also making significant contributions to protecting and enhancing coastal communities within important areas of other moisture zones along the gradients. Collectively, the local coastal zone on the northern coast of Molokaʻi is receiving positive management. Nonetheless, there is need for further expansion of these efforts, even across that island.

Managed areas within a region should be numerous and attention should be paid to examples of management, including species augmentation, that have been successful in establishment of a full suite of coastal species. Success in maintaining ecological function within a community is far more difficult to demonstrate and may not be evident or even detectable for years. Nonetheless, if a good coastal strategy effectively addresses the primary problems through its management actions, it should be seriously considered for implementation before even more losses reduce the chances for success. If there is active monitoring to detect declining species within a managed region, the results can trigger additional management actions, as well as indicate whether the overall regional scale might be adequate to maintain natural ecological processes.

This model for coastal conservation is recommended as a general approach for regions selected for conservation management. There are numerous places within the Hawaiian Islands where this model can be applied. Places that still have significant or relict backshore elements and lowland vegetation connections to the strand should be high priority for such management. Every island has some areas that are still in this state, despite continuing degradation of these connections. In some regions, the remnant coastal vegetation is limited in both extent and diversity, but as this is all that remains, it still should be considered for protection and management. In order to conserve most of the species and their communities within a region, preservation and restoration of numerous sites are required along broad ranges of habitat conditions on different islands. Collectively, habitats and examples of all the coastal floral elements should be included in an overall coastal conservation plan for each island. Even though it is likely some species elements may be difficult to be conserved *in situ*, translocations or reintroductions of such species as a primary approach to restoration should be kept to a minimum in favor of management of the original site to allow for natural regeneration of both matrix and rare species elements.

Important Coastal Sites for Conservation

Within the context of conservation of coastal plant communities at a regional area, a number of sites on each island stand out with high species diversity and/or populations of rare plant species (Appendix 10), as well as still having an established connection with contiguous lowland vegetation. These sites can serve as core areas for a regional approach to managing strips of coastal communities and their associated lowland vegetation.

On the island of Molokaʻi, many sites on the north shore were found to be extremely diverse with over 20 native coastal plant species. These included Anapuhi (Mo-300), Kūkaʻiwaʻa (Mo-280), Kaholaiki (Mo-330), ʻOloʻupena (Mo-360), and Kikipua (Mo-400). Additionally, the only populations of the undescribed *Tetramalopium* species are found along the northeastern coast of the Kalaupapa peninsula at Kuololimu (Mo-240). On Maui, the richest sites were Kanaio Beach (MaE-35) and Waiohue (MaE-16) on the east side of the island, and Punalau (MaW-7) on West Maui. On the island of Oʻahu, Kaʻena Point (Oa-1) particularly stands out, with 21 native coastal plant species.

Additionally, we found 18 species at Hanauma (Oa-1), and 17 species at Mokulēʻia - Kaʻena (Oa-2).

While information identifying diverse sites exists for rare species locations and regions worth placing into conservation management, more shoreline assessments and identification of better coastal segments is still desirable. Existing information is enough, however, to guide the initial prioritization and additional management of coastal conservation areas. Where knowledge of specific areas of richness is incomplete, some guidance can be taken by utilizing moisture gradients and habitat heterogeneity to guide selection of management areas.

Selected Examples of Successful Coastal Habitat Management

Moʻomomi Preserve, Molokaʻi

In this management example, just west of Kaiehu Point (Mo-110), The Nature Conservancy took advantage of a strong windward exposure to enhance native species' colonization of areas cleared of *Prosopis pallida* next to the coast. The trees were cut and chipped in place, with the stumps and chips left spread over the site. As a result, the native vegetation to the windward side of the site was nearly free of alien species, and the subsequent colonization of the cleared areas was by a broad selection of native coastal species. Little evidence of the former mono-specific stands of *Prosopis* remains in the cleared areas and the restored coastal community is now dominated by a diverse suite of native plant species. This method could be applied to other similar areas with windward exposure in the coastal zone, such as on the east side of the Kalaupapa peninsula, where *Schinus terebinthifolius* has created nearly mono-specific stands in many areas over the last two to three decades.

Department of Hawaiian Homes Lands Near Moʻomomi, Molokaʻi

From Naʻaukāhihi and east to PuʻukaPele (Mo-120, 130, 140, 150), cattle grazing was recently ended in these coastal pastures, removing one of the primary stress factors for the area. The broad swath of native vegetation that recovered along the shoreline now forms diverse and healthy native dominated plant communities. Some augmentation of locally extirpated species has enhanced the area even more. A cadre of young residents has become quite knowledgeable about the local native coastal plants as a result of their participation in the project. This is an ideal site for possible clearing and recolonization of larger swaths of low alien vegetation flanking the native communities, in a manner similar to that used by The Nature Conservancy at Moʻomomi.

Kalaupapa National Historical Park

Management of the Kalaupapa peninsula by the National Park Service represents a regional approach that combines a number of integrated management actions at sites over a large area, including maintaining the connection between the coastal and lowland plant communities wherever possible. Ungulate exclusion or reduction of their numbers enables other actions to be implemented, including coastal plant species augmentation. Appropriate species were selected for out-planting in particular sites along the moisture gradient. Careful selection of propagation stock helped to implement a well thought out management plan that integrated field survey results with restoration management goals. Targeted weed control reduced other threats and freed areas for restoration. Management of the Kūkaʻiwaʻa portion (Mo-280) has also taken advantage of a strong windward exposure and the seaward strip of native vegetation.

Northeast Coast of Molokaʻi

Along this coastline, east of Kalaupapa, periodic aerial shooting of goats by the State Division of Forestry and Wildlife alone has resulted in widespread recovery of many native species in the degraded coastal vegetation. This large area has benefited by this single management technique (*i.e.*, ungulate removal), buying time for potential planning of more long-term control and restoration measures. Erosion that included constantly falling rocks and boulders at areas such as Kikipua (Mo-400) was significantly diminished with the reduction of the impacts of goats. The accumulating talus was burying expanses of native vegetation as well as archaeological features on the *mauka* (upland) end of this once heavily-utilized land shelf. This is a management strategy worthy of frequent and widespread replication, here and elsewhere.

Kanahā Beach County Park, Maui

While a number of native species remained in primarily undeveloped portions of Kanahā Beach Park (MaE-1), most of the area's native vegetation was long lost, displaced by human disturbance and alien plant species. Well planned restoration actions have since led to the reconstruction of large areas of native vegetation. This is a site with considerable public use that also presents increased opportunities for learning about and appreciating the diversity of species native to the arid zone vegetation. Primary hurdles to management here included creating cost-effective vehicle barriers to limit physical damage to the site and replacing much of the alien vegetation that covered the area with native species. Out-plantings of both common and rare native plants expanded their cover to produce what is now a self-maintaining plant community. Once a recognizable landscaping effort was in place behind the barriers, vandalism and littering of the site was curtailed. Adjacent to the managed area is a concrete-channeled storm drainage way where beach sand and other sediments have accumulated, that supports a variety of native wetland and shore species along one side of its lower reaches. Overall, a diverse native vegetation cover has been established at this site in a self-maintaining manner where long-standing alien vegetation previously dominated.

General Management Strategies

The following conclusions and potential management strategies have been derived from our survey observations, discussion of considerations presented above, and from experiences elsewhere.

Regional Planning

Taking a regional approach to coastal resource conservation is likely to be the most effective approach to secure an island's native coastal vegetation. Prioritization of areas that appear to have significant values for representation and retention should be an initial step of this process. Isolated smaller areas are likely to continue their attrition of species if they lose their regional connections. Conservation managers should work with multiple jurisdictions and with other land owners, wherever possible, to achieve protection of the coastal zone within the context of larger regions. This partnership approach may well work in the coastal area successfully, even if various landowners do not all have the same primary goals. For example, where there is a mix of wild and developed shores in some regions, even replacing portions of the existing urban/resort landscaping with appropriate native coastal species can contribute to maintaining the overall dispersal capacity of native species that are regionally depleted.

Maintaining a Connection With Contiguous Lowland Vegetation

Given the value of managing coastal vegetation in areas where it is still adjacent to native-dominated lowland vegetation with a modicum of native composition, it is important to identify and prioritize coastal vegetation areas that retain these lowland connections. Even depleted communities can still contribute to the coastal areas' biodiversity, and both could be stabilized and augmented where possible. Managing both coastal and lowland areas together can be an efficient strategy for conserving a variety of resources and processes across modestly-sized areas.

The few surviving coastal areas throughout the Islands that are still connected with native-dominated sections of the lowland flora are particularly important to place into conservation management (e.g., ungulate removal, weed control, etc.), along with their upland connections. This will help prevent the detachment of the surviving coastal vegetation from the rest of the Hawaiian terrestrial biota. Examples of such areas that would benefit from this landscape management approach include the Nā Pali coast on Kaua'i; Ka'ena Point and eastward, Makapu'u -Koko Head on O'ahu; Kalaupapa and eastward to at least Puahaunui on Moloka'i; Honokāhau to Waihe'e, Makaīwa Bay to Nāhiku and intermittently to Wai'ānapanapa, Kanaio Beach area (broadly) on Maui; and Manukā, Ka'alu'alu to Waikapuna, and intermittent areas in south Kona and northeast Kohala on the island of Hawai'i.

Ungulate Control

Given the severe impacts caused by ungulates within the coastal environment, significant reductions or removal of these animals is one of the most pressing needs along certain stretches of the coastlines of the main Hawaiian Islands. These areas include the Napali coastline on Kaua'i; northeast Moloka'i; northern West Maui and southern Haleakalā, also on Maui; and south Kona Ka'ū, and eastern Kohala on the island of Hawai'i. By utilizing natural barriers to ungulate movements afforded by steep topography in many of these areas, even short spans of strategically placed fences can facilitate the exclusion of ungulates from the coastal vegetation, as has been demonstrated at Kalaupapa. Additionally there are many areas where pastured livestock can be separated from the coastal vegetation by fences.

Controlling Invasive Alien Plants

Given the ongoing spread of numerous alien plants into new regions, immediate removal of the early colonizing individuals of particularly threatening species from native coastal vegetation can proactively prevent an increase in ecosystem disruption. High priority invasives for removal include tree species such as *Casuarina, Rhizophora mangle*, *Prosopis julifera*, *Terminalia catappa* and *Schinus terebinthifolius.* Additionally, elimination of aggressive herbaceous species such as *Batis maritima,* Wedelia, *Tetragonia tetragonioides* and *Paspalum vaginatum,* and any emerging new invasive plants within coastal environments, is equally important. All of these species reproduce and spread readily, and most are well-adapted to further dispersal along the shoreline during stormy periods. Control of these invasive species is especially important and feasible where new or growing infestations threaten existing coastal native vegetation. A useful early step might be to conduct surveys to map where these troublesome weeds are located, including the use of aerial reconnaissance for the more evident species.

Assisting with the development or encouraging the use of additional control methods for some of these invasive species, especially those in and next to wetland areas, might also be worthwhile. A biological control option should be considered for species like *Casuarina, Schinus,* and *Rhizophora*. These species have well documented severe impacts, large existing distributions in Hawai‘i, and a strong capacity for dispersal. Since these invasive species have few or no native relatives, it may be easier to implement biological control programs for them if effective agents can be identified.

In residential settings close to important coastal vegetation, implementing a program to exchange invasive alien plants with appropriate cultivated native taxa might be a way to promote a voluntary means for public participation as well as to provide an educational opportunity to foster greater public awareness of the values of the native species and ecosystems.

Species Augmentation

Used here, augmentation is the restoration of selected depleted species within managed regions by means of planting out the species into appropriate sites. The goal of augmentation is to reduce the risk of loss of these species' populations and to restore their numbers to the point that natural dispersal processes resume within the region.

A necessary part of an augmentation strategy is to have the nursery capacity to provide plants for replenishing coastal areas in different regions. The species selected and grown should be appropriate for the region, kept within the region, and be raised in clean nursery environments to prevent spread of additional greenhouse-associated pest organisms into the restored region. In regions where augmentation is to be utilized, linking nursery output with release/sales to the general public of surplus stock could both enhance the appreciation of natives in landscaping local coastal properties and contribute to the general availability of dispersible propagules. Special attention should be paid to ensuring good genetic representation of cultivated taxa as well as maintaining data on founder plants' provenance, particularly for rare species. The latter might be supplied and maintained with agency guidance and monitoring, such as through the Hawai‘i Rare Plant Recovery Group, to prevent pitfalls and impacts to wild stocks. Many coastal species already have a long history of successful cultivation and their propagation methods are well established, particularly since many of these species propagate easily from cuttings.

Co-manage Coastal Sites for their Faunal Elements

Building from the preceding section, it is important to identify numerous sites that might be suitable for enhancing faunal components along with the vegetation. Areas that are somewhat isolated from human disturbance, defensible against mammalian and/or arthropod predators, and contain good coastal vegetation are possible candidates for this type of management. Even sites with lesser native vegetation qualities have been used for breeding or nesting areas by seabirds, turtles, and even endemic monk seals (*Monachus schauinslandi*). Lack of protection from humans and animals (domestic and feral) at many sites has resulted in frequent predation and disturbance of these animals, although native species continue to attempt to utilize these areas. Points, peninsulas, wetland features (such as islands in marshes and canals) and easily defended shoreline configurations could be reasonable candidate sites to encourage and expand use by native animals. Anchialine pond communities are another depleted resource that can be managed within their limited geographic extent to benefit plant, arthropod and vertebrate groups. The new land shelf off Oloku‘i, on the northern coast of Moloka‘i, might be a good site for additional management, and possibly may still be free of predators and ungulates.

A similar regional management approach has been refined and expanded in New Zealand with their "mainland island" concept (Saunders and Norton 2001). There, considerable research has gone into developing management tools that allow for the local reductions of selected pest species to below levels that create significant adverse impacts on a variety of vulnerable native species, all within an ecosystem focus rather than one more species-oriented. The larger size scale and variety of management techniques that are implemented there make them very effective at a regional scale. The smaller local examples seen at Kilauea Point National Wildlife Refuge on Kaua‘i and the Ka‘ena Point Natural Area Reserve on O‘ahu, where nesting seabirds have increased despite periodic incursions of dogs, represent great management examples that can be expanded further. As with the “mainland islands” in New Zealand, these sites have been effective in raising public awareness of coastal ecosystem values in Hawai‘i.

Assessment of Arthropod Components of Coastal Vegetation

One of the least-known portions of the coastal biota is its invertebrate complement. Anchialine invertebrates and native bees are only a few of those taxa known to have been studied in the coastal ecosystem. We recommend that an archipelago-wide evaluation of the extent and diversity of native arthropods in coastal vegetation be initiated, assessing what has been known historically, and what might be remaining in native coastal vegetation today. Arthropods that are commensal with native plant species should be considered when conducting management activities, such as plant species augmentation efforts; especially those associated invertebrate species that might be important pollinators.

Coastal Fencing

Strategic fencing can be an effective tool for excluding ungulates and potentially predators. However, high installation and maintenance costs limit their use presently, particularly near shorelines. Development of cost-effective corrosion-resistant materials and appropriate designs could encourage increased use of fences in coastal areas. Innovative designs suited for points where fences meet the ocean (such as bifurcated entry segments), as well as strategic location of ocean entry points (such as cliff edges and cantilevered limestone points or shores) might do much to prevent animal incursions around fence endpoints. In addition, it is worthwhile to evaluate designs capable of excluding predators as well as ungulates, as has been demonstrated at Kilauea Point and Ka‘ena Point, and more extensively in New Zealand.

Windward Exposure Management

Areas with windward exposures have an advantage for weed removal efforts to foster recolonization by native coastal species, because wind is a major factor governing the direction and source of propagule dispersal. For example at Mo‘omomi on Moloka‘i and Kanahā on Maui, invasive species were progressively controlled inland from the shore where native species were able to quickly recolonize cleared sites with assistance from prevailing winds. Additionally, prior to control of established and incipient weed species, augmentation with appropriate native species upwind may expand the capacity for native-only colonization.

Shoreline Setback Areas

Shorelines are inherently dynamic areas where erosion, mobile sand, storm waves, and other features are problematic for human occupation. Each county independently regulates structures and uses at distances from the shoreline that vary according to locally determined criteria. State and county agencies are presently developing and adopting new erosion-rate-based shoreline setback designations for new developments, wherein a broad swath of setback is gradually sacrificed to the calculated erosion rate for the site. As this rule-making process progresses within the counties, it may be useful to also encourage the retention and development of appropriate native coastal vegetation in setback areas above the shoreline. This strategy can be most effective when dune sand stabilization is the goal, especially where pedestrian and vehicular traffic can be controlled. In addition to benefits of public awareness and appreciation, important native coastal vegetation within developed areas might serve as sources for the dispersal of native species to nearby areas. Conservation easements featuring native coastal vegetation might also be encouraged for some of the setback areas where no uses are contemplated other than vegetation buffers.

Coastal Vehicular Access

Another severe source of degradation is that derived from vehicular access to and along coastal areas still containing native vegetation. This includes organized “thrill rides” and eco-tours and individual recreational access, as well as fishermen driving to shore areas where they can park, camp, and fish. An effective solution to these impacts would be to eliminate, restrict, or redirect vehicular traffic from beaches and other shoreline areas supporting native vegetation to sites that are more tolerant of these impacts. In most places where this type of damage occurs, convenient, non-damaging routing or other alternatives can be found, sometimes a very short distance away. As most of the coastal areas are in the state Conservation Land Use District and the County Special Management Areas, these regulatory systems could possibly be used to help achieve better control of traffic impacts at important coastal sites. It is essential to share information and awareness of native resource values and locations with these regulating agencies, and perhaps to suggest alternative areas for diverting the traffic. Native vegetation of some state and county park areas is particularly vulnerable due to high use of the areas by the public. Signage and effective but inexpensive traffic barriers may be adequate management actions in some areas, such as are utilized at Kanahā Beach Park on Maui, while more aggressive measures might be necessary in other areas.

Education and Outreach

The development of educational materials and efforts focusing on conservation of natural resources in Hawai‘i has been increasing recently, but this effort can still be expanded. Certain subsets of both residents and visitors present an elevated probability of creating adverse impacts on coastal resources, and these groups are good candidates for more attention through both education and possibly regulation. A growing cadre of individuals and businesses are involved in off-road vehicular tours and rentals and could be specifically targeted for educational efforts and to assist with finding more appropriate locations or paths for these activities. Preventing vehicular access into specific areas altogether is likely to be the most effective management approach, but it is not always possible to do so. Prioritization of these types of actions at sites such as Mokulei`a-Ka‘ena on O‘ahu, Polihale-Barking sands on Kaua‘i, and at other high-value coastal areas throughout the state, should be further evaluated.

Demonstration restoration projects at heavily degraded but easily accessible sites might also be a good way to elevate public involvement and media coverage regarding values of the native coastal communities. At the same time community efforts could possibly be harnessed to encourage landscaping with appropriate natives in the coastal environment. Recent efforts at Kanahā Beach and Kanahā Pond on Maui can serve as good examples of this approach.

Growing tourist industry facilities and eco-touring visitation can also add significant adverse impacts on native ecosystems, but alternatively, they could contribute more potentially constructive interactions in the much-visited coastal areas. Both groups have considerable potential for being utilized to reduce impacts along the coast. At the same time they might be sources to both fund and distribute educational materials relevant to coastal ecosystems. Guidance to both as to alternative places or methods of visitation might also be helpful.

Conflicts between coastal resources and both individual land use actions and larger development activities occur continuously along Hawaiʻi coastlines. Numerous county, state and federal agencies have the potential to lessen or increase various adverse consequences within their coastal jurisdictions. Therefore, an elevated awareness of native coastal communities and their associated resource values needs to be cultivated and more benign guidance of land use should be implemented at regulatory and administrative levels if public use at individual and agency scales are to follow.

CONCLUSIONS

These surveys have provided more and current information on the ecology, composition, distribution, and status of coastal plant communities and species in selected portions of the main Hawaiian Islands. Although not as rich in endemic species as are upland communities, the Hawaiian coastal flora is relatively diverse, and taken as a whole, is still quite intact with very few historically known species that are now extinct.

Although the coastal zone has been heavily impacted over the past 250 years, many high quality examples of diverse plant communities can still be found, particularly in the wet and mesic habitats on the islands of Maui and Molokaʻi. Management efforts that are regionally focused on reducing the impacts of invasive species (both plants and animals) and maintaining the connection between the coastal strand and lowland vegetation, coupled with expanding public awareness of the value of coastal communities, can allow for effective restoration and maintenance of this unique set of ecosystems for the future.

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