DEFINING RESTORATION GOALS FOR THE HUMBOLDT COASTAL NATURE CENTER, MANILA, CALIFORNIA BASED ON AN ANALYSIS OF ECOLOGICAL PROCESSES IN COASTAL DUNES

by

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A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements of the Degree

Master of Science

In Natural Resources: Natural Resource Planning and Interpretation

November, 2010

ABSTRACT

Defining Restoration Goals for the Humboldt Coastal Nature Center, Manila, California Based on an Analysis of Ecological Processes in Coastal Dunes

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Invasive plants have had significant impacts on the dune ecosystem on the North Spit of Humboldt Bay, where they have modified ecological processes. A large area of these dunes lies adjacent to the community of Manila, including Friends of the Dunes' Humboldt Coastal Nature Center, where restoration activities are under close public scrutiny. Management recommendations for the Humboldt Coastal Nature Center were identified through an analysis of key ecological processes: examination of vegetation succession using a Geographic Information System (GIS), mapping invasive plants and endangered plants with a Global Positioning System (GPS), investigating dune morphology with local experts, and gathering input from residents of the community of Manila on how they feel about restoration activities. Findings from the analysis show that the Humboldt Coastal Nature Center landscape went from being composed of 32.4 ha of active coastal dunes in 1948 to having only 7.9 ha of active coastal dunes in 2009. It appears that vegetation began stabilizing some of the active dune areas through natural succession between 1954 and 1970, and it is plausible that invasive plants, which covered 20.7 ha by 2009, sped up the process of this stabilization. Along with the stabilization of the dunes, geomorphic processes have been impeded by European beachgrass invading the foredune which cuts off inland sand supply from the beach. The main concern from residents of the community of Manila was that restoration activities

could compromise their safety, but investigation of geomorphic processes found that restoration activities could strengthen the community's defense against storm waves and tsunamis. From these findings, management recommendations for the Humboldt Coastal Nature Center were compiled in a GIS. Management recommendations focused on restoring ecological processes and native vegetation across the entire property, and restoring geomorphic processes in the foredune area. Furthermore, recommendations suggested adaptive management strategies for dune management near human communities and identified areas of further research that will benefit coastal dune restoration efforts in the region and beyond.

ACKNOWLEDGEMENTS

Many people have made completion of this thesis possible. First and foremost, I thank Dr. Yvonne Everett for her guidance, support, and exceptional patience throughout my time as a graduate student. Additionally, I thank my other committee members: Andrea Pickart for sharing her knowledge of coastal ecosystems with me for nearly ten years now, and Dr. William Weaver and Dr. Alison Purcell O'Dowd for providing valuable insight, support and countless hours reviewing my thesis.

Thank you to all of the people who shared their expertise with me: Tom Leroy who had the patience to explain the geomorphic history of the North Spit to me in a variety of ways until I could truly understand, and Jennifer Wheeler who was always quick to respond to questions.

Finally, I thank all of my friends and family who supported me throughout this process: the staff at Friends of the Dunes for being flexible and helpful, all of my friends who cheered me on and believed I could do this, Trevor who made sure my basic needs were always met and offered more support than I could have ever wished for, and my parents who first introduced me to coastal ecosystems, and who I can always count on for support.

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INTRODUCTION

With a growing human population, development, and ease of transportation, humans have increased the rate of spread of invasive plants. Invasive plants are a primary threat to approximately 57% of imperiled plant species and 49% of all other life forms (Wilcove et al. 1998). Two key reasons the introduction of invasive plants disrupt ecosystems are: (1) the elimination or suppression of native plants that require the pre-invaded ecosystem, and (2) decrease in the altered ecosystems' resistance to further invasions (Dukes and Mooney 2004).

Areas where invasive plants have caused enough disturbances to alter ecosystem structure or function need management intervention in order to restore natural diversity and functionality (Wali 1992, Jordan et al. 1988). The Society for Ecological Restoration International (Society for Ecological Restoration Science and Policy Working Group 2004) defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."

Restoration management plans are created and used for the purpose of guiding the process of restoration. A restoration management plan should incorporate four fundamental components: (1) clearly stated and scientifically valid goals of the project, (2) a technically feasible restoration design based on ecological knowledge, (3) methods for assessment of restoration success, and (4) analysis of assessment findings and application of results through adaptive management (Falk et al. 2006, Picket and Parker 2004). Adaptive management is a method of using the combined knowledge of ongoing

practice, research and monitoring to assess and improve management practices (Duncan and Wintle 2008).

In addition to adaptive management, successful restoration projects are said to depend upon the integration of applied ecological and social science. In 2003, Dr. Edith Allen, Editor-in-Chief of *Restoration Ecology*, announced that the journal would broaden its focus to include more of the social dimension of restoration and emphasized that "restoration is not only about the science of ecology but it also includes societal decisions on appropriate end points for restoration, economics of restoration and the valuation of nature, policy and planning, education and volunteerism, and other social and philosophical issues."

Consideration of the ecosystem alone is not adequate during the process of creating a restoration management plan. Social and economic aspects of restoration planning are critical to the success of a project (Cairns 2000, Choi 2004). Social constraints may, for example, include public perceptions of restoration activities. If public opinion is ignored, contention can arise during the restoration process, potentially leading to wasted efforts and money.

Four methods widely used to manage invasive plants and to restore ecosystem function are (1) prevention, (2) early detection, (3) eradication and (4) control (Hulme 2006, Secretariat of the Convention on Biological Diversity 2001). Prevention incorporates methods to keep invasive plants from entering a specific area. Early detection is being watchful for new introductions of invasive species so that they can be managed while their populations are small. Early detection of invasive plants and rapid

management response has been shown to be less time consuming and therefore, less costly to land managers (Smith et al. 1999). Most importantly, there is a better chance of successful eradication with early detection and rapid response (Smith et al. 1999, Rejmánek et al. 2005). Eradication is the removal of all plants of a target species and their viable seed bank in a specified area. Control is used when eradication is not feasible, with the goal of reducing the population size to an accepted level. It is important that managers understand that there are circumstances when these four methods are inadequate due to lack of control techniques or cost and alternative management schemes, such as mitigation, need to be considered (Wittenberg and Cock 2001). Educating the public and enlisting their support in prevention and early detection is a great help to land managers. Public support of eradication and control can also speed up the process of restoration and lower financial costs of eradication and control.

Isolated ecosystems are often highly sensitive to invasion by invasive plants (D'Antonio and Dudley 1995, Dukes and Mooney 2004). Native plants in isolated systems are not able to migrate or expand their populations when encroached upon and displaced. This is true for fragmented coastal dune ecosystems along the Pacific Ocean of northern California.

Dune ecosystems make up roughly 40% of the coastline of northern California from the California-Oregon border, south to Point Arena (Cooper 1958). The Humboldt Bay dune ecosystem stretches 34 miles starting with Little River State Beach to the north and extending south to include Centerville Beach (Pickart and Sawyer 1998). Humboldt Bay is within the Klamath bioregion on the north coast of California; approximately 250

miles north of San Francisco. Climate around Humboldt Bay is maritime due to its close proximity to the Pacific Ocean. This climate type has moderate year-round temperatures with average daily temperatures generally varying by only 11 °C. Winter temperatures include colder lows down to -1 °C and in the summer, warmer highs up to 21 °C. Ninety percent of rainfall, an average of 101-114 centimeters annually, occurs October through April. May through September are dry and commonly associated with fog or low cloud cover. Northwesterly winds prevail during the warm, dry season and southwesterly winds dominate in the wet, cool season (National Weather Service 2009).

Topographic features of coastal dunes in northern California are classified into four areas: (1) beach, (2) nearshore dunes, (3) moving dunes, and (4) backdunes (Pickart and Barbour 2007). The beach is the area between the mean low tide and mean high tide. The nearshore dunes include the foredune, dune ridges, dune swales and deflation plane features. The primary foredune is a vegetated ridge adjacent and parallel to the beach, and behind it are alternating dune ridges and depressions. Dune swales are located between dune ridges and are known as deflation planes when they occur on the windward side of inland moving dunes. Moving dunes are generally located between the foredune and the stabilized backdunes. Moving dunes include transverse and parabolic dunes. Transverse dunes occur when there is a large sand supply that is able to move over a wide area. Parabolic dunes are more narrow, or U-shaped, and move over vegetated areas. Backdunes are generally located inland from the nearshore and moving dunes and are comprised of older, stabilized dune ridges and parabolic dunes.

The Humboldt Bay dunes have been negatively impacted by human activities including off highway vehicle use, mining of sand, development and the introduction of invasive species (Pickart and Sawyer 1998). Introduced invasive plants have had severe impacts where they have interfered with ecological processes by encroaching upon native plant species and altering dune morphology. These impacts to coastal ecosystems have created the need for special rankings and protection status for specific plant species. In 1990, two plant species, Menzies' wallflower (*Erysimum menziesii*) and beach layia (*Layia carnosa*), were State-listed endangered by the California Department of Fish and Game (2010) (Figure 1). Both species were then federally listed as endangered in 1992 by the U.S. Fish and Wildlife Service (1992). Both the Humboldt Bay wallflower and beach layia inhabit the North Spit of Humboldt Bay (see Figure 2) and were listed due to drastic reduction of suitable habitat, caused in part by invasive plants.

There are three non-native plants in the Humboldt Bay dunes ecosystem that have been targeted over the past two decades as having the most negative impact to dune ecosystems: (1) European beachgrass (*Ammophila arenaria*), (2) yellow bush lupine (*Lupinus arboreus*), and (3) iceplant (*Carpobrotus edulis*) (Pickart and Sawyer 1998) (Figure 3). In addition to European beachgrass, yellow bush lupine and iceplant, there are now several invasive annual grasses that are becoming dominant and are of concern to land managers (Pickart and Barbour 2007).

European beachgrass is native to the coastlines of Europe and was introduced to the North Spit of Humboldt Bay in 1901 to prevent sand encroachment at a timber mill (Buell et al. 1995). European beachgrass expanded on the North Spit from 53.4 ha in

(a)

(b)

Figure 1. Federally endangered plants that inhabit the Humboldt Bay dune ecosystem: (a) Humboldt Bay wallflower (*Erysimum menziesii* ssp. *eurekense*); and (b) beach layia (*Layia carnosa*)

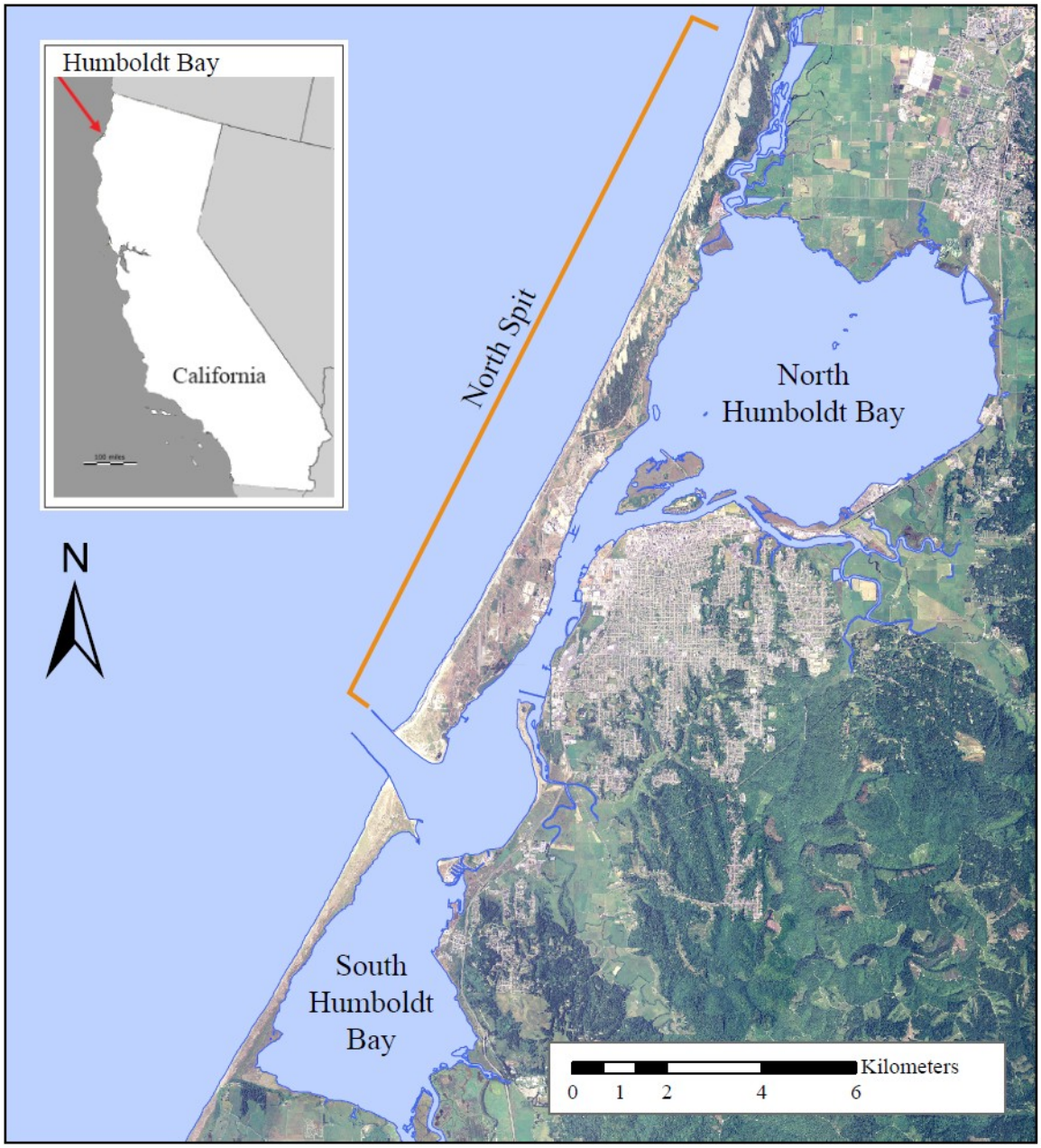

Figure 2. Location of the North Spit, Humboldt Bay, California

(a)

(b)

(c)

Figure 3. Three invasive plants that have been highly targeted for treatment in the Humboldt Bay dunes: (a) European beachgrass (*Ammophila arenaria*); (b) yellow bush lupine (*Lupinus arboreus*); and (c) iceplant (*Carpobrotus* ssp.)

1939 to 196.3 ha in 1988. Repeated introductions occurred along railroads, roads and other developments on the North Spit into the 1960s and its population continues to spread in unmanaged areas (Buell 1992). European beachgrass negatively effected the abundance and diversity of native dune plants due to its monotypic habit. This is because it can alter dune morphology by creating high and steep foredune features that hinder natural sand movement (Cooper 1958, Danin et al. 1998, Wiedemann and Pickart 2004, Pickart and Barbour 2007).

Native to central and southern California, yellow bush lupine was first introduced at the southern tip of the North Spit of Humboldt Bay in 1908 (Miller 1988). Yellow bush lupine fixes nitrogen and changes the nutrient balance in the nitrogen-deficient dune soils. The nutrient rich dune soils alter the composition of vegetation and facilitate secondary invasions of both native and non-native species (Pickart et al. 1998, Cipra 2006).

Two species of iceplant are present on the North Spit, Hottentot fig (*Carpobrotus edulis*) and sea fig (*Carpobrotis chilensis*). Hottentot fig is native to South Africa and was widely planted along highways and railroads for erosion control by the California Conservation Corps throughout California in the 1930s (Washburn and Frankie 1985). There is no documented history of introduction of Hottentot fig to the North Spit. There have been several studies to examine the origin of sea fig in California, but disagreement exists as to its native status, leading to the species being referenced as both native or naturalized (Albert et al. 1997, Gallagher et al. 1997, Vivrette 2011). Hottentot fig is disruptive to the dune environment because it grows in clonal mats displacing native

plants (D'Antonio 1993). It also alters soil pH and natural sand movement (Albert 2000). Sea fig is not known to be invasive, but does hybridize with iceplant (*C. edulis* x *C. chilensis*) resulting in hybrids with the invasive characteristics of Hottentot fig (Albert 1995).

In the 1980's the Nature Conservancy began experimenting with restoration methods at the former Lanphere-Christensen Dunes Preserve. The land was transferred to the USFWS in 1997, and is now known as the Lanphere Dunes Unit of the Humboldt Bay National Wildlife Refuge. Using extensive research, invasive species removal methods were developed to help restore dune ecosystems on the Lanphere Dunes Unit and on other coastal dunes of the North Spit of Humboldt Bay. These efforts continue today and have been expanded to other dune locations along the Pacific Northwest Coast (Pickart and Sawyer 1998). Restoration activities involving the removal of European beachgrass, yellow bush lupine and iceplant on coastal dunes of northern California have increased native diversity, restored partial to complete ecosystem function, increased endangered plant populations and entailed a generally low maintenance program (Pickart 2010, personal communication). Much of the restoration efforts on the North Spit of Humboldt Bay have focused on restoring areas of dune mat habitat in the nearshore dunes.

Populations of the endangered Humboldt Bay wallflower on the North Spit have been monitored and mapped by the USFWS as part of its recovery plan since 1988. The most recent inventory, in the spring of 2006, estimated the total population of plants larger than 2 cm in diameter at 55,600. These results reveal more than a doubling in the

population of Humboldt Bay wallflowers since 1988 and show increases of wallflower populations in areas being actively managed with invasive plant removal and decreased or unchanging population sizes in areas with no management of invasive plants (Pickart 2009). With proven increase of wallflower populations in restored sites it is hopeful that expansion and connectivity of restoration sites across jurisdictional boundaries on the North Spit will bring this endangered plant closer to becoming delisted.

In 2007, Friends of the Dunes, a 501(c)3 non-profit and land trust, purchased 24.75 ha of coastal dune property located on the North Spit of Humboldt Bay in Manila, California. The unincorporated community of Manila was established at the end of World War II (Turner 1992) and is home to approximately 1000 residents. U.S. Highway 255 is directly to the west of the study area. An additional 21 ha of adjacent property was purchased by Friends of the Dunes in 2008, bringing their total land holdings to 45.75 ha. Friends of the Dunes established the Humboldt Coastal Nature Center at the site. The previous owners of the property retained a 6.1 ha area and signed a conservation easement with Friends of the Dunes to allow them to restore their 6.1 ha parcel. This brought the total area Friends of the Dunes aims to restore to 51.85 ha (Figure 4).

Invasive plants have dispersed onto the property at the Humboldt Coastal Nature Center from adjacent areas and have become wide spread. This has resulted in significant degradation of the native plant communities throughout the Humboldt Coastal Nature Center property and significantly altered natural geomorphic processes.

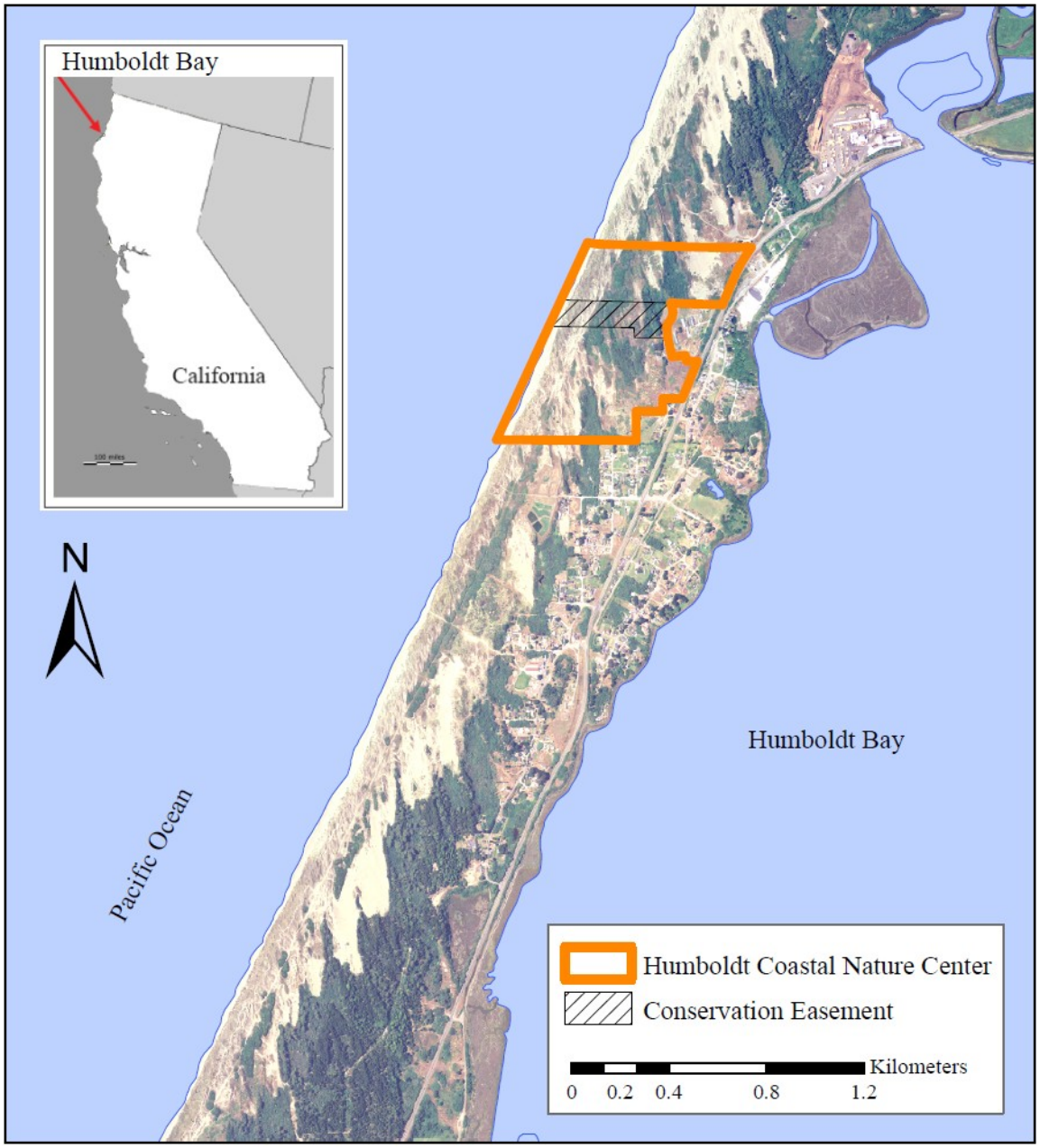

Figure 4. Location of the Humboldt Coastal Nature Center on the North Spit of Humboldt Bay, California.

Friends of the Dunes' mission is to "conserve the natural diversity of coastal environments through community supported education and stewardship programs" (Friends of the Dunes 2009). In adherence with their mission, Friends of the Dunes aims to restore natural diversity at the Humboldt Coastal Nature Center with the support of the community. An initial, short-term restoration management plan for the Humboldt Coastal Nature Center was completed in 2008 for the first 24.7 ha that Friends of the Dunes purchased along with a 6.1 ha restoration easement conveyed by the Stamps Family (Walter 2008). The remaining 21 ha of adjacent dune property purchased by Friends of the Dunes in 2008 was not included in the original short-term management plan.

Due to the checkerboard pattern of land ownership on the North Spit, the Humboldt Bay dunes ecosystem is fragmented. In some areas natural diversity and ecosystem processes have been restored, or are in the process of being restored, while other areas have either been developed or are now dominated by invasive plants. Reducing fragmentation within an ecosystem is a key objective in ecological restoration (Roth et al. 2006). Restoring the 51.85 ha of coastal dunes at the Humboldt Coastal Nature Center would be a significant step in reducing fragmentation of dune ecosystems on the North Spit, as the site is located between two existing restoration areas (Figure 5). To the north, a 4 km stretch of coastal dunes on Bureau of Land Management (BLM) and USFWS lands have been restored while to the south, 1.85 km of nearshore dunes on Manila Community-owned lands have been restored, with complete restoration of the area anticipated in the near future.

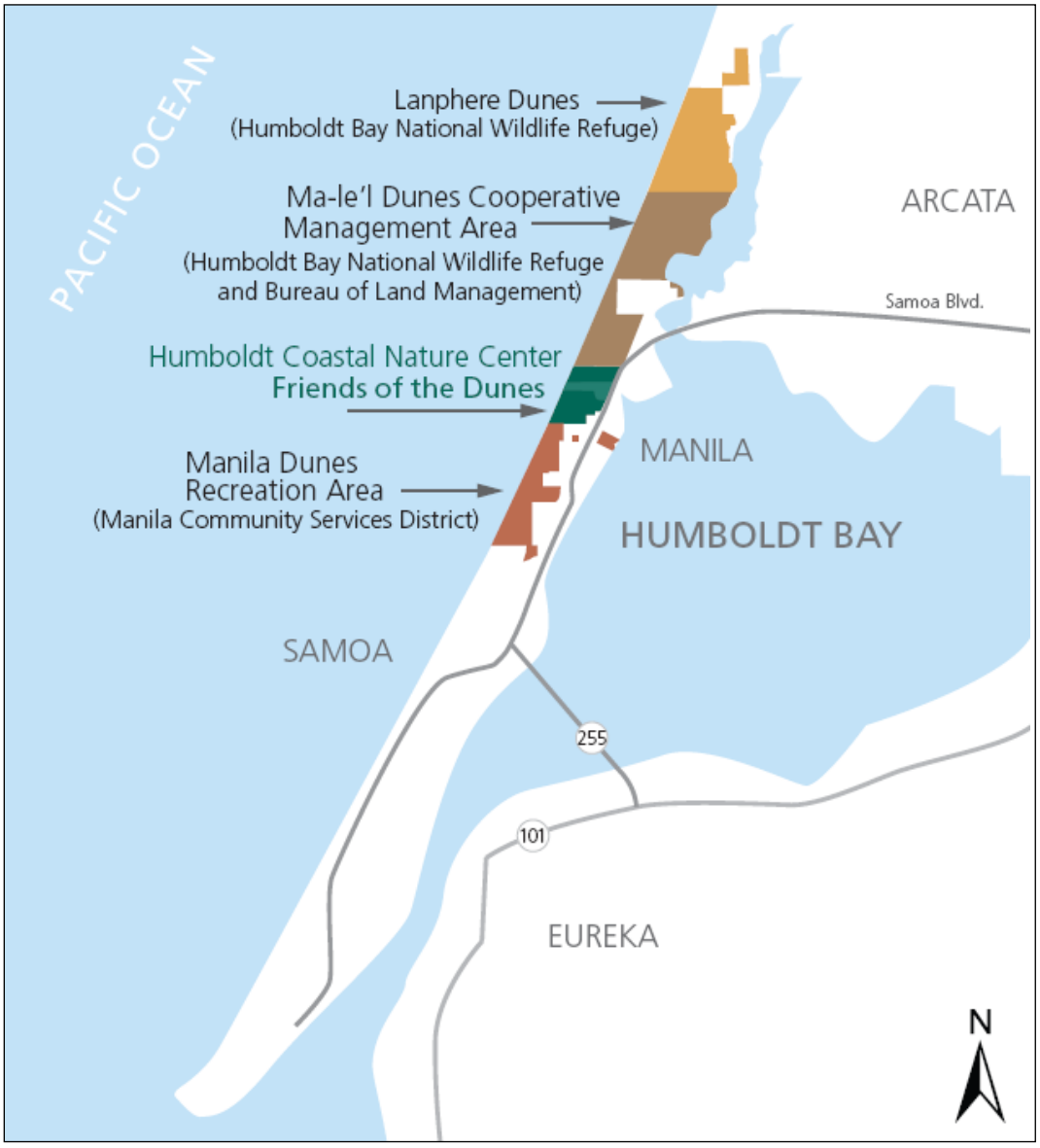

Figure 5. Location of the Humboldt Coastal Nature Center and adjacent properties where restoration activities are or have taken place.

In addition, restoration of the Humboldt Coastal Nature Center property would eliminate this area as a source of invasive plants that threaten adjacent restored areas, or areas still free of invasive plants. It is imperative that a restoration management plan for the entire Humboldt Coastal Nature Center property be completed in order to restore and manage the property with ecological integrity, to minimize fragmentation of the Humboldt Bay dune ecosystem, and to maintain public support for the process by addressing social constraints and fully disclosing and describing anticipated restoration activities.

In my study, the following questions pertinent to creating scientifically based and socially inclusive recommendations for restoration will be addressed:

1) In what way have plant communities on the Humboldt Coastal Nature Center property changed over the last sixty years?
2) What is the current distribution of invasive plants on the Humboldt Coastal Nature Center property?
3) What constraints, including physical structures, access easements, geomorphic processes and local community concerns, will influence proposed management on the Humboldt Coastal Nature Center property? and,
4) What goals and broader implications emerge for dune ecosystem management at the Humboldt Coastal Nature Center based on this analysis?

METHODS

In order to manage land for natural biological diversity and natural ecological processes one must have a clear understanding of its ecosystems' past and current composition, structure and function. To develop restoration goals for the Humboldt Coastal Nature Center, it is particularly important to understand underlying abiotic processes and plant community development, and to recognize any potential constraints or barriers to restoration efforts. To gather this information, changes in vegetation were mapped between 1948 and 2009, invasive plants were inventoried, interviews with local geologists were conducted to gain an understanding of past, current, and possible future dune geomorphic and geologic processes, concerns of local residents were gathered, and land managers who were restoring dune properties on the North Spit were consulted.

Mapping Invasive Plants

Before removal of invasive plants begins as part of a restoration program, it is important to define the full extent of the problem. A list of target species and watch list species was created using the Humboldt Weed Management Area (2006) weed ratings list and the California Invasive Plant Council (2006) weed ratings (Table 1) (Appendix A). The Humboldt Weed Management Area is a consortium of public agencies, organizations and private landowners who work towards cooperative relationships that are necessary for effective management, coordination and implementation of invasive plant species programs. The California Invasive Plant Council is a 501(c)3 not-for-profit organization

Table 1. Weed categories and ratings for the Humboldt Coastal Nature Center. The target list and watch list were defined and compiled for this thesis. This table shows the ratings given to each species by the Humboldt-Del Norte Weed Management Area and the California Invasive Plant Council. Definitions for the Humboldt-Del Norte Weed Management Area and the California Invasive Plant Council weed rating categories are in Appendix A.

	Humboldt-Del Norte Weed Management Area	California Invasive Plant Council
TARGET LIST		
European beachgrass (*Ammophila arenaria*)	High Priority	High
iceplant (*Carpobrotus chilensis* x *C. edulis*)	High Priority	High
jubata (pampas) grass (*Cortaderia jubata/selloana*)	High Priority	High
invasive annual grasses (*Briza maxima*, *Bromus diandrus, Aira caryophyllea*)	High Priority	Moderate
star-mustard (*Coincya monensis*)	Red Alert	n/a
yellow bush lupine (*Lupinus arboreus*)	High Priority	n/a
WATCH LIST		
bellardia (*Bellardia trixago*)	Early Detection	Low
Bermuda buttercup (*Oxalis pes-caprae*)	Red Alert	Moderate
bull thistle (*Cirsium vulgare*)	High Priority	Moderate
cotoneaster (*Cotoneaster franchettii*)	High Priority	Moderate
English holly (*Ilex aquifolium*)	High Priority	Alert
English ivy (*Hedera helix*)	High Priority	High
fertile capeweed (*Arctotheca calendula*)	Monitor	Moderate
gorse (*Ulex europaeus*)	Red Alert	High
Himalayan blackberry (*Rubus armeniacus*)	High Priority	High
Mediterranean mustard (*Hirschfeldia incana*)	Moderate	Moderate
pennyroyal (*Mentha pulegium*)	n/a	Moderate
purple ragwort (*Senecio elegans*)	Early Detection	n/a

whose mission is to "protect California wildlands from invasive plants through restoration, research and education" (California Invasive Plant Council 2009).

Target list species were known to be present at the Humboldt Coastal Nature Center with high priority or red alert ratings from the Humboldt Weed Management Area. The watch list was composed of plants that were thus far undetected at the Humboldt Coastal Nature Center, had a variety of ratings from the Humboldt Weed Management Area, were known to grow and be invasive in coastal dune areas and had widely accepted treatment methods.

During the fall of 2007 and spring of 2008, presence/absence data were collected for all but the invasive annual grass species on the target and watch lists, on the 24.7 ha purchased by Friends of the Dunes in 2007, as well as the 6.1 ha conservation easement. In 2009, mapping of target and watch list species was completed for the additional 21 ha purchased by Friends of the Dunes in 2008. Annual grasses from the target list were mapped for all of the Humboldt Coastal Nature Center and the 6.1 ha easement in the summer of 2009.

Mapping of target and watch list species, not including the annual grasses, involved the use of remotely-sensed data and digital mapping using Geographic Information Systems (GIS) technology. Background layers of a natural color aerial orthophoto and a digitized polyline shapefile outlining the property boundary were downloaded onto a Holux GM-270 CF card Global Position System (GPS) unit in a Compaq Ipaq 3900 and viewed in ArcPad 6.02 software (Environmental Systems Research Institute 2001). Positional accuracy of the GPS was estimated to be ±5 m on

average. A data dictionary was loaded onto the GPS unit utilizing the North American invasive plant mapping standards by the North American Weed Management Association (2002) for entering attributes in the field and office (Appendix B).

Mapping was conducted by traversing the entire 51.8 ha area on foot with the GPS unit. All occurrences larger than 5 m^2 were mapped as polygons. All occurrences smaller than 5 m^2 and that were not within 5 m of another infestation of the same species were mapped as points, except for iceplant. Only clonal mats of iceplant larger than 5 m^2 were mapped as polygons. Iceplant occurrences smaller than 5 m^2 were widely scattered throughout the property. These small occurrences were not mapped as they were not exhibiting invasive characteristics. Land managers on the North Spit often only remove iceplant that exhibits invasive characteristics, such as growing in dense clonal mats (Pickart 2010, personal communication). Cover classes were recorded for each polygon and adjacent polygons of the same species were created where a change in cover class occurred (Appendix C). Data collected in the field were downloaded each day onto a computer and reviewed in ArcView 9.3 for accuracy (Environmental Systems Research Institute 2008).

Invasive annual grass species mapping was conducted separately in August and September of 2009, as part of a larger effort funded by the USFWS to map invasive annual and perennial grasses on the entire North Spit of Humboldt Bay (Pickart 2010, personal communication). Invasive annual grass species mapping was accomplished by taking hard copies of color aerial photographs at a scale of 1:1500 into the field and hand drawing polygons where the grasses were present.

Grass species' cover class was recorded as low (1-20%), medium (21- 50%) or high (51-100%). Most species were recorded individually, but several commonly co-occurring species were grouped together (Table 2). A total cover measurement was documented for each species, and or group of species, for each polygon. These field maps were then digitized in ArcView. Digitized maps were taken onsite for ground-truthing and all errors were corrected in ArcView.

Locating Endangered Plants

Two federally endangered plant species, Humboldt Bay wallflower and beach layia are present at the Humboldt Coastal Nature Center. Knowing where the populations occur and in what habitat types is important for prioritizing restoration strategies.

Humboldt Bay wallflowers were mapped in May of 2008 while they were in bloom and easy to locate. A GPS was used to create polygons where groups of Wallflower were present. Beach layia was mapped at the Humboldt Coastal Nature Center in 1999 by the USFWS as part of an effort to map its populations on the entire North Spit of Humboldt Bay (Pickart 2009, personal communication). A map of the 1999 data was taken into the field in the spring of 2009 to verify if it was still accurate at the Humboldt Coastal Nature Center.

Mapping Habitats

Accurate habitat maps to monitor vegetation succession are an essential part of creating an effective management program for a coastal dune landscape (Shanmugan and Barnsley 2002). The aim of habitat mapping at the Humboldt Coastal Nature Center was

Table 2. Invasive grasses mapped at the Humboldt Coastal Nature Center. Cover classes were recorded for rabbit grass, rattlesnake grass, ripgut brome and sweet vernal grass. Barren fescue, silver European hairgrass, and little European beachgrass were recorded as a group.

	Common Name	Scientific Name
Locations and cover classes recorded seperately	Rabbit grass	*Polypogon maritimus/monspeliensis*
	Rattlesnake grass	*Briza maxima*
	Ripgut brome	*Bromus diandrus*
	Sweet vernal grass	*Anthoxanthum odoratum*
Locations and cover classes recorded as a group	Barren fescue	*Vulpia bromoides*
	Silver European hairgrass	*Aira caryophyllea*
	Little European beachgrass	*Aira praecox*

to describe vegetation patterns and understand what factors were shaping these patterns over time. This procedure involved the use of remotely-sensed data (aerial photography from 1948, 1970, 1988, and 2009) and digital mapping using GIS technology.

The most current vegetation trends were gathered using 2009 color aerial photography from the Humboldt Bay - Eel River Historic Atlas Project. These photos, with 0.5 m spatial resolution, were used in ArcView to delineate plant communities in 2009 using heads-up digitizing of polygon features. These polygon features were downloaded onto the same GPS unit as described in the invasive plant mapping method section. This GPS unit was taken into the field with a hard copy of the digitized plant community map for ground truthing. If the digitized polygons were not accurate, they were redrawn using streaming vertices on the GPS unit. In some cases the polygons were redrawn by hand on the hard copy, to be corrected later with heads-up digitizing in ArcView.

To attain a better understanding of how the landscape has transitioned over the last fifty years, a set of black and white georectified aerial photographs from the Humboldt Bay – Eel River Atlas Project showing the Humboldt Coastal Nature Center in 1948, 1970, and 1988 were analyzed. In addition, photographs taken by the California Coastal Records Project (2010) in 1972, 1979 and 1987 were used to assist in identifying plant communities (Appendix D). This was accomplished with heads up digitizing in ArcView. This process will reveal changes in vegetation's areal extent and geographic location.

Restoration Constraints on the North Spit

Constraints on restoration activities involve a combination of social, physical and financial factors. Public opinion of restoration efforts on the North Spit was gathered through informal discussion with residents of Manila and by attending a Manila Community Services District sponsored restoration information session at the Manila Community Center on February 21, 2009. Topics of the information session included the history of dune restoration and dune geology on the North Spit, an overview of Friends of the Dunes' involvement in restoration and education activities at the Manila Dunes Recreation Area, and a walking tour at the Manila dunes Recreation Area to view areas where restoration had occurred. Community members were invited to the meeting by posted fliers on community billboards in Manila and approximately twenty people attended the meeting. Additional comments were collected from informally speaking with neighbors who were interested in how the land at the Humboldt Coastal Nature Center was going to be managed.

Physical constraints to ecological restoration included roads, housing, public access plans, and easements through the property. Physical constraints were investigated and digitized in ArcView by reviewing maps, aerial photos and legal documents pertaining to easements. This information was used to understand how restoration might be constrained because of its potential impact on structures, roads, utilities and utility easements on, or running across, the Humboldt Coastal Nature Center property, public access trails, and other dedicated easements.

Dune Geology on the North Spit

A combination of geologic factors including: seismic uplift, subsidence, and offshore sand transport, influence dune morphology on the North Spit of Humboldt Bay. How these factors interact and have an affect on dune morphology is not completely understood. I held two consultations with local experts to discuss the best available site specific knowledge of dune morphology on the North Spit.

Consultations and site visits to the USFWS and BLM Ma-le'l Dunes Cooperative Management Area and the USFWS Lanphere Dunes Unit with a local geologist, geomorphologist, botanist and ecologist took place on February 22, 2010 and April 16, 2010. These areas were chosen because they were adjacent to the Humboldt Coastal Nature Center and because European beachgrass had been removed from the foredune at these sites at known intervals. Therefore, the sites offered a chronosequence of vegetation and geomorphic changes following restoration activities. The same historic and current aerial photographs of the North Spit used for the habitat mapping were reviewed at these site visits. The discussions focused on vegetative succession and how invasive plants, as well as native dune vegetation, affect, and are affected by, geomorphic processes, and how large tectonic events influence dune geomorphology.

RESULTS

Mapping Invasive Plants

On the ground mapping of invasive plants showed that 20.7 ha (40% of the property) was infested with species from the target and watch lists (Figure 6). The dominant invaders were the invasive annual grasses with 11.6 ha (22.46% of the property). These grasses were often found growing as an understory to yellow bush lupine (Figure 6). The largest infestations occurred on the eastern side of the property with over half of the infestations having a 50% cover or higher. Ripgut brome (*Bromus diandrus*) and rattlesnake grass (*Briza maxima*) comprised the majority of the infestations.

Yellow bush lupine was the second most prominent invasive species with occurrences on 7.9 ha (15.23% of the property), followed by European beachgrass with 6.1 ha (11.72% of the property). Clonal mats of iceplant were mapped and covered 1.1 ha (2.15% of the property). Jubata (pampas) grass (*Cortedaria jubata/selloana*) had 15 occurrences mapped as points, in addition to four larger occurrences mapped as polygons, the largest of which occupied an area of 0.2 ha. Star-mustard (*Coincya monensis*) had five occurrences mapped as points and four mapped polygons that totaled 0.15 ha. Three invasive plants from the watch list were documented, including 0.1 ha of Mediterranean mustard (*Hirschfeldia incana*), one occurrence smaller than 5 m^2 in area of pennyroyal (*Mentha pulegium*), and 0.1 ha of English ivy (*Hedera helix*).

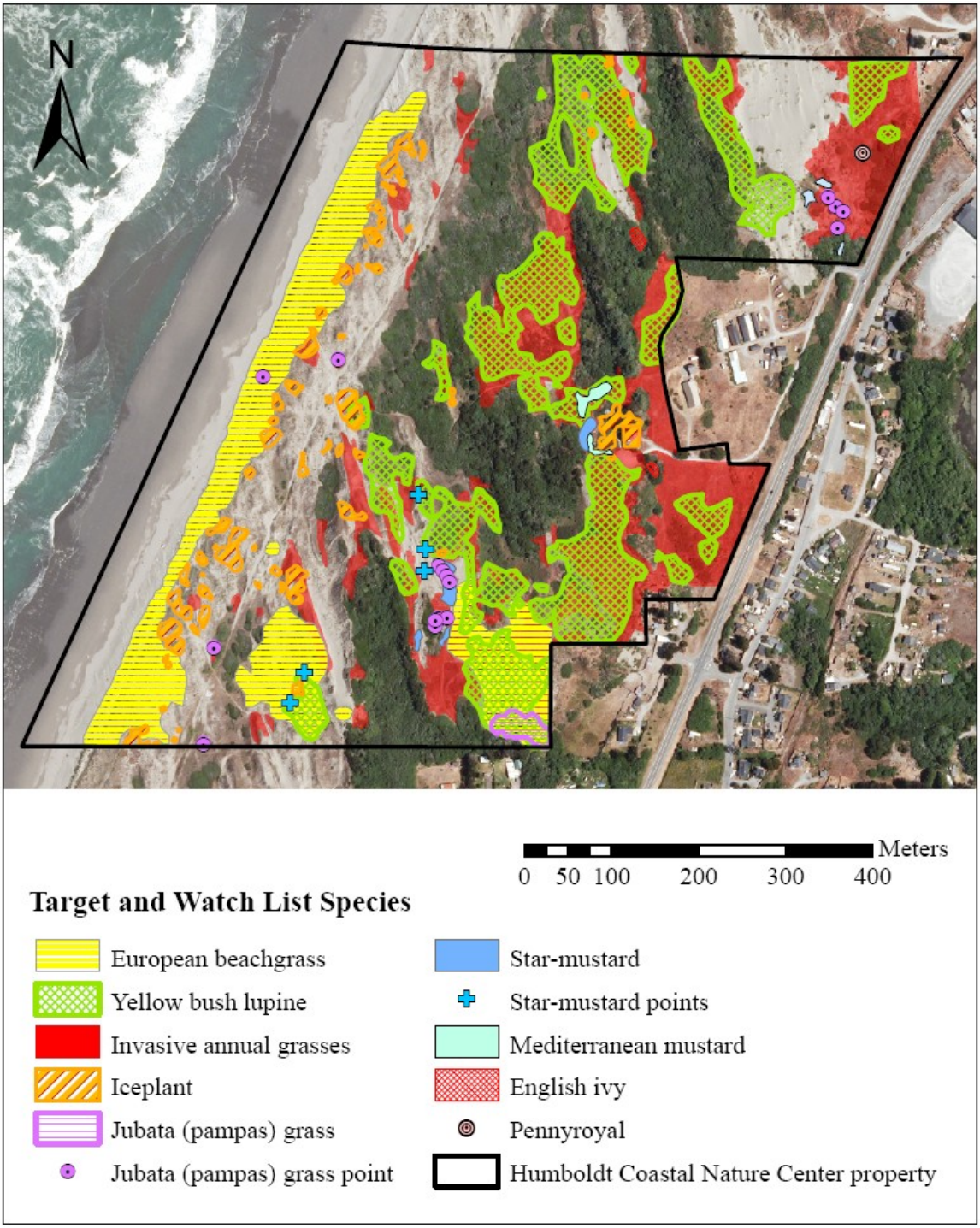

Figure 6. Map of target and watch list species located at the Humboldt Coastal nature Center during 2008 and 2009.

Locating Endangered Plants

Three geographically distinct occurrences of Humboldt Bay wallflower covering 1.9 ha were mapped in 2009 (Figure 7). Plants were concentrated in the southwest quadrant of the property in the nearshore dunes. A visual inventory showed that an occurrence on the primary foredune had the fewest plants. The highest concentration of wallflowers was in an area farther from the ocean, between dune ridges in the nearshore dunes.

Beach layia thrives in areas with some open sand, and is highly associated with dune mat habitat (US Fish and Wildlife Service 1998). Its association with dune mat habitat was apparent from maps created in 1999, as shown in Figure 7. Ground truthing of the 1999 map in 2009 indicated that beach layia distribution remained fairly consistent. Because beach layia appeared highly abundant and wide-spread throughout the nearshore dunes, except in areas newly invaded by European beachgrass, it was not necessary to remap it again.

Mapping Habitats

Six vegetation classes at the Humboldt Coastal Nature Center were identified using Sawyer et al. (2009) (Table 3). The classification of active coastal dunes came from Holland (1986). Additional categories that were mapped, but did not fall under any formal classifications, included invasive annual grasses (Table 2), "developed" areas and an "unknown" category. Areas where human activity had or was scheduled to take place were classified as "developed." Due to lower resolution black and white photography for

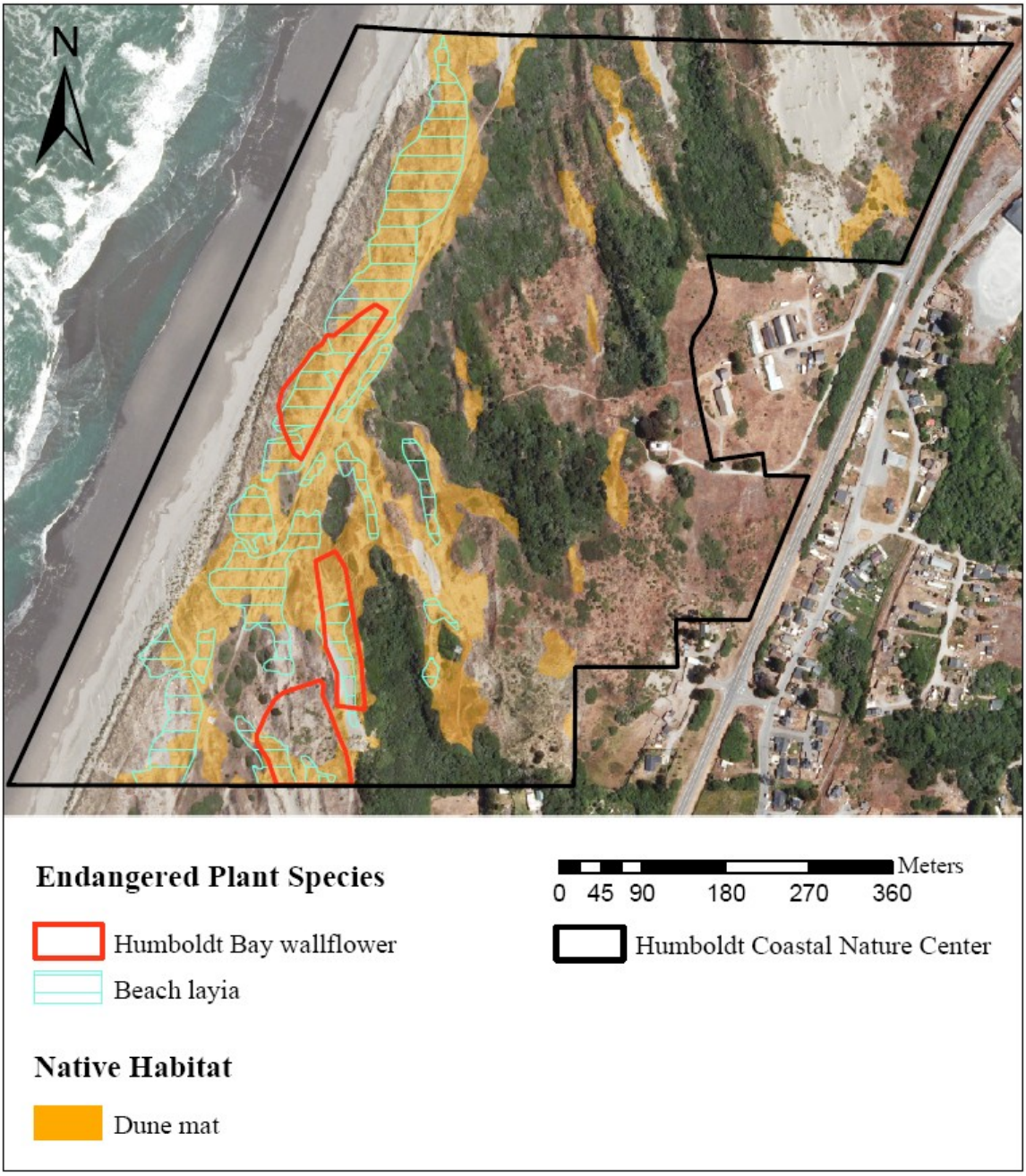

Figure 7. Areas of endangered Humboldt Bay wallflower and beach layia at Humboldt Coastal Nature Center.

Table 3. Six identified vegetation classes at the Humboldt Coastal Nature Center. Vegetation at the Humboldt Coastal Nature Center was classified using Sawyer et al. (2009) and Holland (1986). Additionally, a specific suite of invasive annual grasses were mapped that had no official classification and were described in Table 2.

Scientific Name	Common Name
Abronia latifolia-Ambrosia chamissonis Alliance*	Dune mat
Ammophila arenaria Semi-Natural Stand**	European beach grass swards
Lupinus arboreus Alliance	Yellow bush lupine scrub
Pinus contorta ssp. *Contorta* Alliance	Beach pine forest
Rubus (*parviflorus, spectabilis, ursinus*) Alliance	Coastal brambles
Salix hookeriana Alliance	Coastal dune willow thickets

* An alliance is part of a hierarchical vegetation classification system based on dominant species in the vegetation (Sawyer et al. 2009).

** A Semi-Natural Stand is vegetation dominated by non-native plants that have become naturalized. Non-native plants are not categorized as alliances (Sawyer et al. 2009).

the years 1948, 1970 and 1988, there were areas mapped as "unknown" along the eastern property line where it was not possible to decipher what was present. In consideration of the lower quality of the black and white aerial photography, the habitat mapping results were approximate, but offered a qualitative synopsis of how habitats had evolved at the Humboldt Coastal Nature Center since 1948 (Figure 8).

It was not possible to definitively map invasive annual grasses from the historic aerial photos and thus, there are no data for them in 1948, 1970, or 1988. Data from mapping invasive annual grasses were used to depict areas of invasive annual grasses in the 2009 habitat map. In addition to the 1.2 ha area of invasive annual grasses shown in Table 4, invasive annual grasses were often an understory to yellow bush lupine scrub and occupied an additional 6.9 ha area with 50% cover or higher, as seen in Figure 6.

A change in dune habitats is clearly seen by looking at Table 4, Figure 8, and the habitat maps between 1948 and 2009 (Figures 9-12). Appendix E shows aerial maps for 1948, 1970, 1988 and 2009 with only the outline of the Humboldt Coastal Nature Center property to better see the imagery. The most visible change in habitats is that of active coastal dune areas that covered 32.4 ha (62.5% of the property) in 1948 and continuously declined in area, with only 7.9 ha (15.23% of the property) remaining in 2009.

European beachgrass swards were not visible in the 1949 or 1970 aerial imagery. Review of aerial photos from the California Coastal Records Project (Appendix D) confirmed small areas of European beachgrass swards along the foredune in 1979, along with the first signs of the beginning of a foredune. By 1988, European beachgrass was

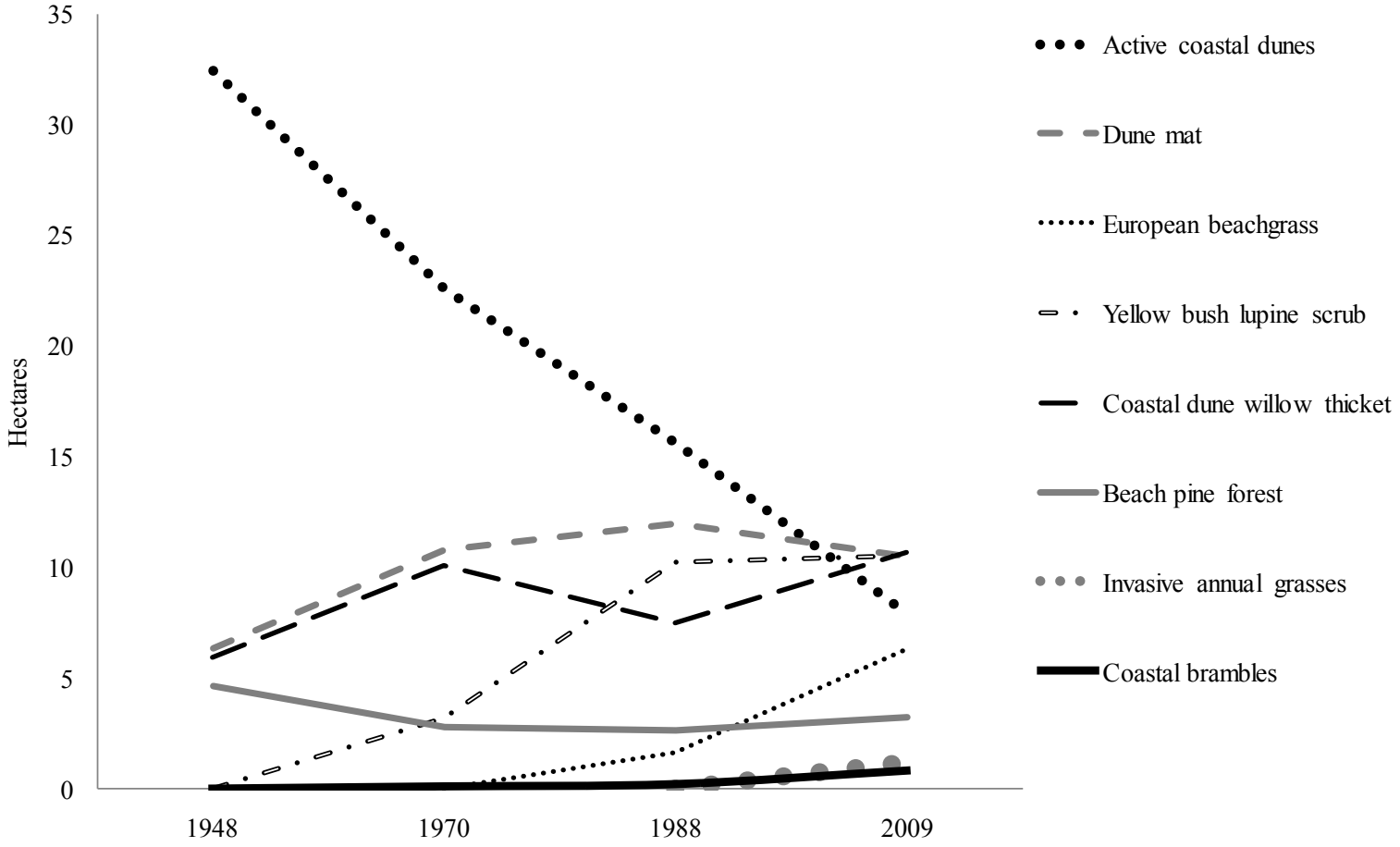

Figure 8. Change in area of habitat types between 1948 and 2009 at the Humboldt Coastal Nature Center. It was not possible to decipher invasive annual grasses prior to 2009 and thus, they do not appear on this chart until after 1988.

Table 4. Results of mapping habitats for 1948, 1970, 1988 and 2009. Note that invasive annual grasses inhabit an additional 7 ha area as an understory in yellow bush lupine scrub.

	1948	1970	1988	2009
	Hectares			
Active coastal dunes	32.4	22.6	15.6	7.9
Dune mat	6.3	10.8	12	10.5
European beachgrass	0	0	1.6	6.3
Yellow bush lupine scrub	0	3.2	10.2	10.5
Coastal dune willow thicket	5.9	10.1	7.5	10.7
Beach pine forest	4.6	2.8	2.6	3.2
Invasive annual grasses	0	0	0	1.2
Coastal brambles	0	0	0.2	0.8
Developed	0	0.1	0.2	0.6
Unknown	2.5	2.1	1.8	0
Total Area	51.7	51.7	51.7	51.7

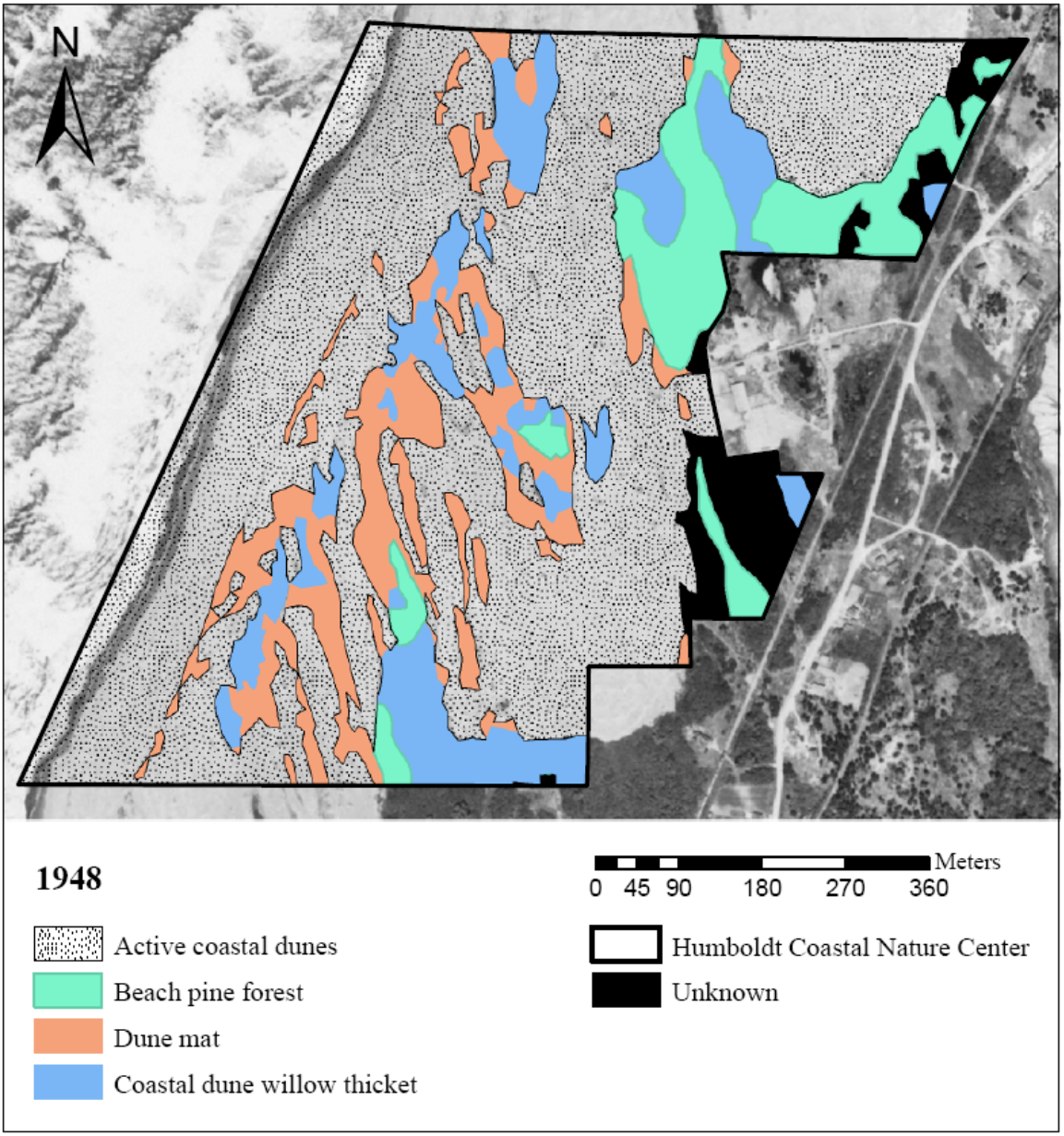

Figure 9. Habitat map of the Humboldt Coastal Nature Center in 1948.

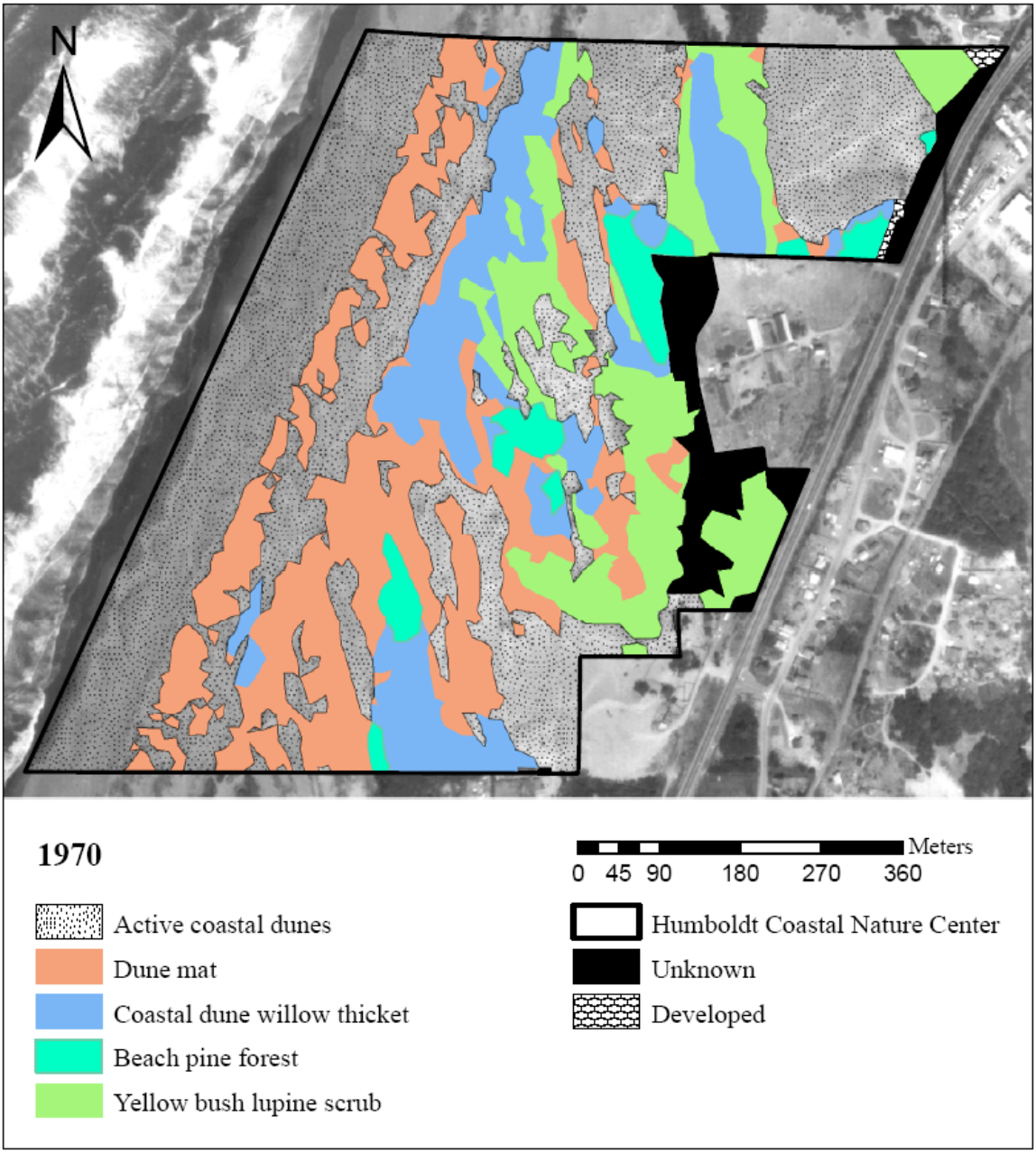

Figure 10. Habitat map of the Humboldt Coastal Nature Center in 1970.

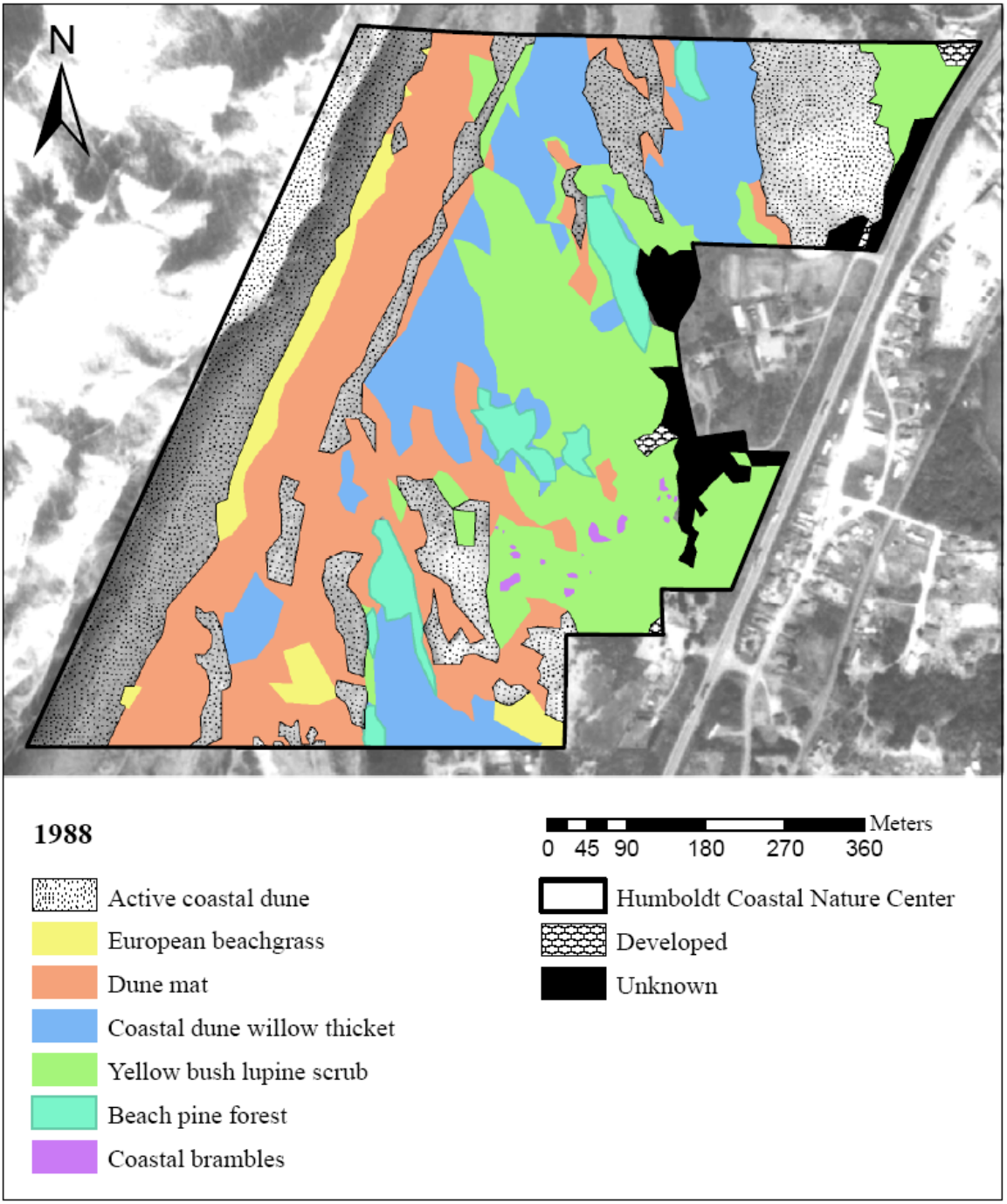

Figure 11. Habitat map of the Humboldt Coastal Nature Center in 1988.

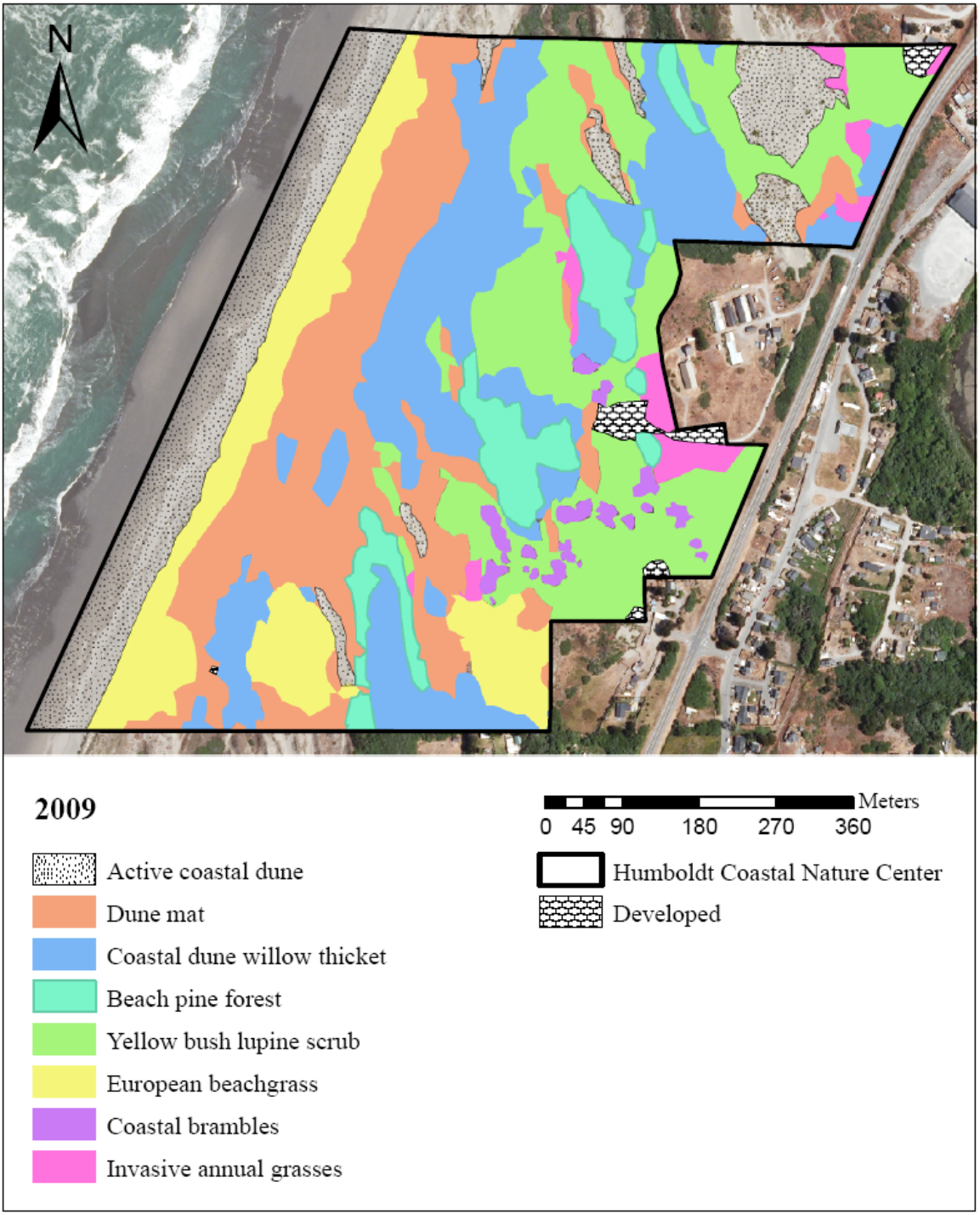

Figure 12. Habitat map of the Humboldt Coastal Nature Center in 2009.

growing in patches on the foredune, covering 1.6 ha (3.52% of the property). The real invasion of beachgrass appeared to have taken place in the 1980s, continuing to spread over 6.3 ha (12.11% of the property) by 2009. As shown in Figure 6, while the majority of European beachgrass was located on the nearshore dunes, there were a few areas in the backdunes, on the southern part of the property, where it encroached, or was planted to stabilize moving dunes.

Dune mat habitat was one of the most dominant habitat types in each year of this study. It was shown growing on the margins of active sand dunes in 1948, when it covered 6.3 ha (12.11% of the property). It continued to spread along active sand dune margins, as well as colonize areas of the nearshore dunes by 1970, with an area of 11.1 ha (21.48% of the property). Between 1970 and 1988 dune mat increased slightly, by 0.9 ha, as it continued to spread into areas that were once active sand dunes. Dune mat habitat decreased for the first time in this study between 1988 and 2009, when its area was reduced to 10.5 ha (20.31% of the property). It decreased in areas where European beachgrass had expanded. It also decreased due to the expansion of yellow bush lupine scrub and coastal dune willow thickets.

This study showed that yellow bush lupine scrub continuously increased in area between 1948 and 2009. Yellow bush lupine scrub was detected for the first time in the 1970 photographs covering 6.6 ha (12.7% of the property). The areas it inhabited in 1970 were on the eastern side of the property, near the urban interface, and on the eastern edge of the nearshore dunes and into the backdunes. Its area increased by 4.2 ha to 10.8 ha (20.9% of the property) between 1970 and 1988, as it continued to spread to the west in

the backdunes. There was only a slight change in yellow bush lupine scrub area between 1988 (10.8 ha) and 2009 (10.5 ha or 20.31% of the property). Overall, yellow bush lupine scrub inhabited stabilized backdune areas at the Humboldt Coastal Nature Center.

Coastal dune willow thickets had a continuous increase in area between 1949 and 2009. Between 1948 and 1988 coastal dune willow thickets had a steady increase in area, starting with 5.9 ha (11.52% of the property) in 1948 and ending with 7.8 ha (15.23% of the property) in 1988. During this time it continued to expand into areas that were stabilizing, while at the same time competing with yellow bush lupine scrub. Between 1988 and 2009 it had its largest increase in area changing from 7.9 ha to 10.7 ha (20.7% of the property). This increase occurred in areas where the coastal dune willow thickets were maturing and eventually able to outcompete what was yellow bush lupine scrub.

Beach pine forests covered more of the Humboldt Coastal Nature Center with 4.7 ha (8.98% of the property) in 1949 than at any other time reviewed in this study. The biggest decrease of beach pine forest habitat happened between 1948 and 1970, with a decrease of 1.8 ha, as forested areas were covered by moving sand. It also appeared that some areas had been logged on the northeastern margin of the property. Beach pine forest area remained static between 1970 and 1988 as moving sand continued to bury it, while at the same time it was expanding in areas not affected by moving sand. As active sand dunes continued to stabilize between 1988 and 2009, beach pine forest continued to slowly increase in area to a total of 3.2 ha (6.25% of the property) in 2009.

Coastal brambles were first detected in 1988 covering 0.1 ha and expanded from their original location to cover 0.8 ha (1.56% of the property) in 2009. Brambles were

located growing amongst yellow bush lupine scrub in stabilized backdune areas. "Developed" areas on the property increased between 1970 when they covered 0.2 ha, to 0.6 ha in 2009. All development occurred along the eastern side of the property, near the urban interface. Like the "developed" areas, unknown areas were all located on the eastern edge of the property. "Unknown" areas continuously decreased from 1949 when they were recorded with 2.5 ha, to 0.0 ha in 2009, as imagery was able to be ground-truthed in 2009.

Restoration Constraints on the North Spit

Public comments about restoration activities in Manila that pertained to the Humboldt Coastal Nature Center focused on several issues. A common concern from neighbors was a tsunami evacuation point designation that had been made on an elevated dune on the southeast corner of the Humboldt Coastal Nature Center. Neighbors worried that removing European beachgrass would allow the tsunami evacuation dune to migrate (making it too low in elevation to be an evacuation point), make the top of the dune difficult to access in an emergency, as well as facilitate unwanted sand movement onto private residential properties. Another concern of some Manila residents was that blowouts would occur where European beachgrass was removed from the foredune, and these blowouts would eventually migrate east and cover their homes. Foredune blowouts are wind-scoured gaps that occur in weak points in foredunes. Some Manila residents also believed that removing European beachgrass would create a less effective barrier against storm surges and tsunamis.

Some of the Humboldt Coastal Nature Center lands have been modified by past earthmoving activities. Review of aerial photographs from the California Coastal Records Project (2010), showed that sand mining occurred in the early 1970s on the southeastern and northeastern extent of the property. In the early 1960's a commercial water line was constructed across the Humboldt Coastal Nature Center property by the Humboldt Bay Municipal Water District, just east and parallel of the primary foredune. A right-of-way for the Humboldt Bay Municipal Water District allows for maintenance of the buried water line, as well as an access road through the dunes just to the west of the pipeline. Friends of the Dunes has a Memorandum of Understanding with the Humboldt Bay Municipal Water District. Part of this Memorandum of Understanding states that Friends of the Dunes will not plant any endangered, threatened, rare or sensitive plant species on the Humboldt Bay Municipal Water District easement or immediately adjacent to the easement. Three electric towers are located on the Humboldt Coastal Nature Center property, along with a right of way for the Pacific Gas and Electric Company to maintain vegetation clearance around the towers.

In 1983 the property was purchased by Charles and Rachael Stamps, who owned the property until 2007. Construction of the Stamps' house resulted in the grading and modification of a dune ridge along the eastern margin of the property to create a building site and related parking area. In November of 2010, Friends of the Dunes began renovating the former Stamps house into an interpretive center which would include adding a parking lot on the east side of the property. The renovation began in the spring of 2010, to be completed in 2011. Friends of the Dunes designated a public trails system at the Humboldt Coastal Nature Center in 2010. All past developments that showed long

term effects and current and proposed development that will impact the natural ecosystem at the Humboldt Coastal Nature Center were compiled in Figure 13.

Dune Geology on the North Spit

Analysis of dune morphology included conducting site visits with local geologists, geomorphologists, botanists and ecologists. During these site visits we discussed what shaped the dunes on the North Spit in the past and present and hypothesized about what could be expected in the future. Additionally, results from the restoration constraints section dealing with concerns of Manila residents were addressed.

Some researchers have speculated that the most recent (historical) dune advancement on the North Spit was triggered by the last large earthquake on the Cascadia Subduction Zone (Pacific Watershed Associates 1991, Leroy 1999). This likely magnitude 9 earthquake caused regional subsidence in the Humboldt Bay area (Vick 1988, Jacoby et al. 1995, Patton and Leroy 2006), and likely caused coastal inundation along the western edge of the North Spit.

Subsequent infilling of the inundated area by longshore drift may have provided a source of sand for the most recent dune pulse observed on the North Spit (Leroy 2010, personal communication). This pulse of sand can be observed as large sand sheets at the Ma-le'l Dunes Cooperative Area and in other areas to the north and south. Under the current sand supply system, smaller parabolas forming from foredune blowouts migrate inland (east), but at a slower rate, and with much less volume than older sand sheets

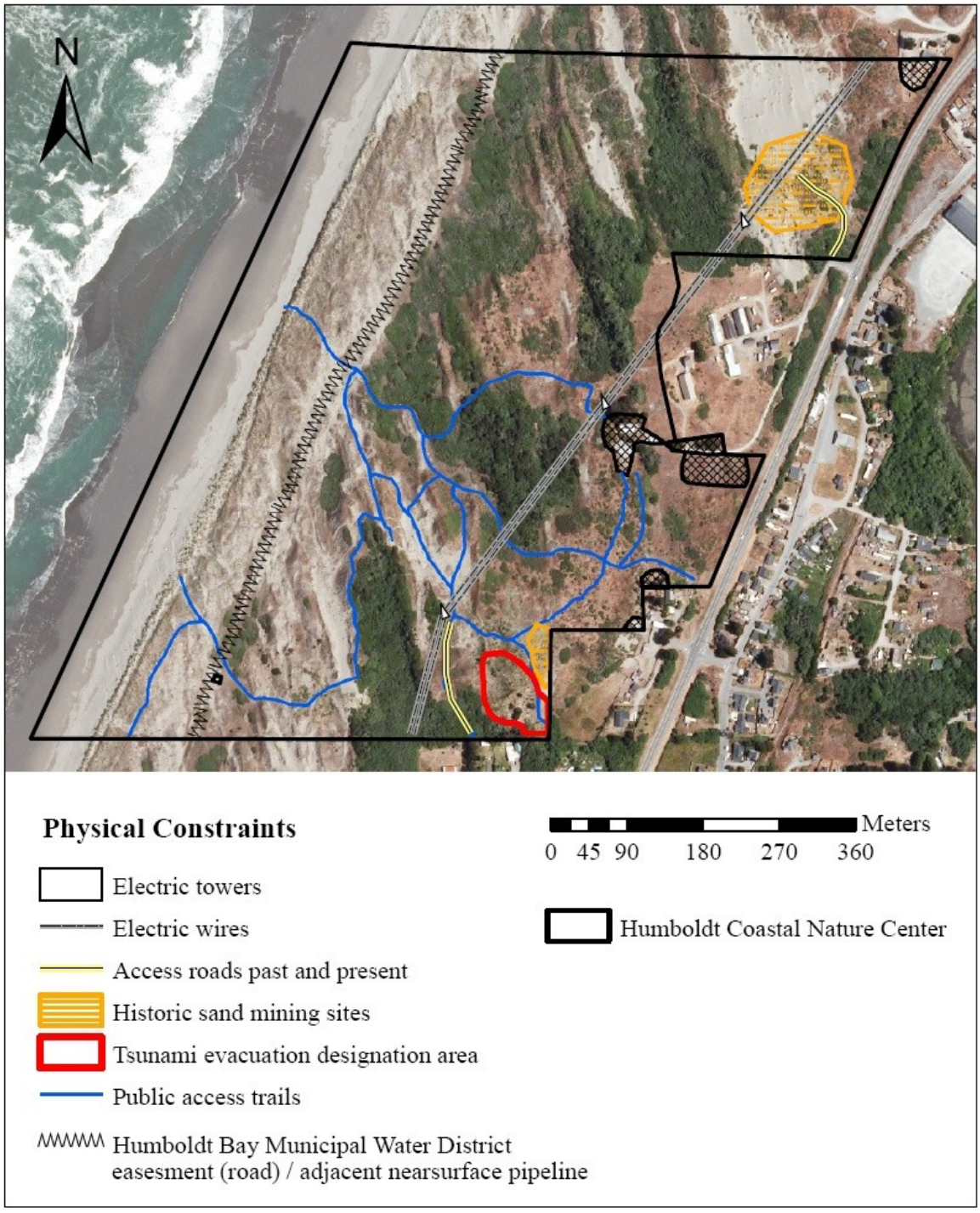

Figure 13. Past development that shows long term effects, and current and proposed development that will impact the natural ecosystem at the Humboldt Coastal Nature Center.

created from the Cascadia earthquake event in 1700 (Leroy 1999; Leroy 2010, personal communication).

Another important topic was how much sand movement could be expected following the removal of European beachgrass from nearshore dunes. Blowouts are a natural process and occur in a foredune that has been slightly destabilized in a variety of ways, including removal of vegetation, scouring by waves, and animal and human paths (Pacific Watershed Associates 1991, Thom et al. 1994, Maun 2009). European beachgrass grows densely with deep rhizotimous roots, and therefore, it is less common for blowouts to occur in a foredune infested with European beachgrass. Removal of European beachgrass and reestablishment of the native dune mat community restores the foredune to a more natural ecosystem where blowouts are likely to be more common.

By reviewing aerial photographs in ArcView it was possible to see foredune blowouts on the North Spit stretching up to 71.5 m inland from the beach in areas at the Ma-le'l Dunes Cooperative Area, where European beachgrass was removed. In areas directly south of the Humboldt Coastal Nature Center, at the Manila Dunes Recreational Area, foredune blowouts remained smaller, proceeding inland up to 58 m. These foredune blowouts are a natural process of coastal dune ecosystem formation and are what keep the dunes in a myriad of successional stages (Pacific Watershed Associates 1991, Pickart 2010, personal communication).

According to Leroy (2010, personal communication), blowouts of the foredune will not lead to massive sand movement. Large tectonic events, such as a locally generated 8 or 9 magnitude earthquake, could possibly create larger, more extensive

moving sand sheets (Pacific Watershed Associates 1991). Foredune blowouts eventually become vegetated along their margins where sand movement is not as active and the moving sand eventually becomes stabilized once again (Carter et al. 1990, Pacific Watershed Associates 1991, Pickart and Barbour 2007).

Understanding the rate at which active sand formations can travel is an important component of their management. Transverse dunes travel at an average rate of 1.4 m a year (Pacific Watershed Associates 1991). This rate of movement is slow enough to allow for adaptive management strategies and mitigation. A preferred method by local dune managers to prevent or minimize the extent of foredune blowouts has been to plant native dune grass (*Leymus mollis*). Native dune grass grows in a less dense manner than invasive European beachgrass, allowing some sand movement while also causing general stabilization. Successful transplanting of native dune grass was achieved at the Ma-le'l Dunes Cooperative Area just north of the Humboldt Coastal Nature Center (Pickart and Goodman 2010, Wheeler 2010, personal communication). In areas other than the foredune, various types of reforestation, revegetation or structural control could also be applied.

Other sand stabilizing techniques include using soil-binding emulsions, sand netting and sand fencing. Sand-binding emulsions temporarily bind sandy substrates, while allowing vegetation to grow and eventually act as sand stabilizers themselves (Pickart and Sawyer 1998). Sand fences have been used around the world as a way to collect and stabilize sand (Pye 1990). There are a variety of materials that can be used as

a layer on a dune to stabilize sand while allowing plants to grow and stabilize the sand themselves (Maun and Krajnyk 1989).

Results from the restoration constraints section confirmed that some Manila residents were concerned about foredune height as a form of protection from tsunamis. There were two main hypotheses on this topic. One hypothesis was that foredunes stabilized with European beachgrass are higher, and therefore they act as a good barrier. The second hypothesis was that removing European beachgrass from foredunes allows some sand to move inland, and therefore a wider foredune is created that serves as a stronger barrier. Weaver (2010, personal communication) and Leroy (2010, personal communication) indicated that both hypotheses have some validity. High, continuous foredunes could act as a wall and simply not allow smaller tsunamis past; this would depend on the size of the wave. However, a taller, European beachgrass covered foredune is typically narrow because it prohibits most sand movement from the beach inland.

A foredune devoid of European beachgrass with natural blowout processes will be wider and contain a larger volume of sand than a tall, narrow foredune. (Hart and Knight 2009). Hesp (2010, personal communication) believed that a high, narrow foredune is weaker because it is more prone to slope failure with wave attack, which causes instability. He also believed a lower, wider dune will remain more stable under wave attack. Additionally, the newest potential tsunami inundation mapping from the California Geologic Survey (2010) suggested the worst case scenario would completely overtop the foredunes on the entire North Spit. This map depicts areas along the backdune ridge of the Humboldt Coastal Nature Center as being safe from tsunami

inundation (Figure 14). This suggests the foredune will only provide protection from a very narrow range of tsunami heights. For example, the foredune could act as a sufficient barricade for the smallest tsunamis, whether it was colonized by European beachgrass or not, and regardless of vegetation, would not provide any barrier for the largest tsunamis.

For areas with narrow dune fields adjacent to urban interface the height and continuity of the primary foredune is an important factor in protection from storm surges and tsunamis. However, areas such as those at the Humboldt Coastal Nature Center, with multiple dune ridges in the nearshore and further inland exhibit a complex dune topography which should slow inundation from waves. Thus, the primary foredune is not the sole measurement of vulnerability (Hart and Knight 2009). Weaver (2010, personal communication) and Leroy (2010, personal communication) agreed that it is not the height of the foredune that offers significant protection from tsunamis in the community of Manila or at the Humboldt Coastal Nature Center. Rather, it is the height and geographic extent (width) of the backdunes. Several high dune ridges and dune parabolas exist at the Humboldt Coastal Nature Center, affording protection from tsunamis that may overwash the primary foredune, as long as the tsunami is not of a magnitude that would also overcome the higher backdune ridges.

An additional safety issue concerning European beachgrass was beachside dune cliffs, which are formed when winter storm waves create steep scarps in the foredune. These events are natural processes that remove sand from the beach and foredune annually, by undercutting the primary foredune and creating a near-vertical scarp (Maun 2009). European beachgrass has a deep root system which holds sand together, with large chunks or sheets of sand breaking off when the dune is undercut by waves, leaving

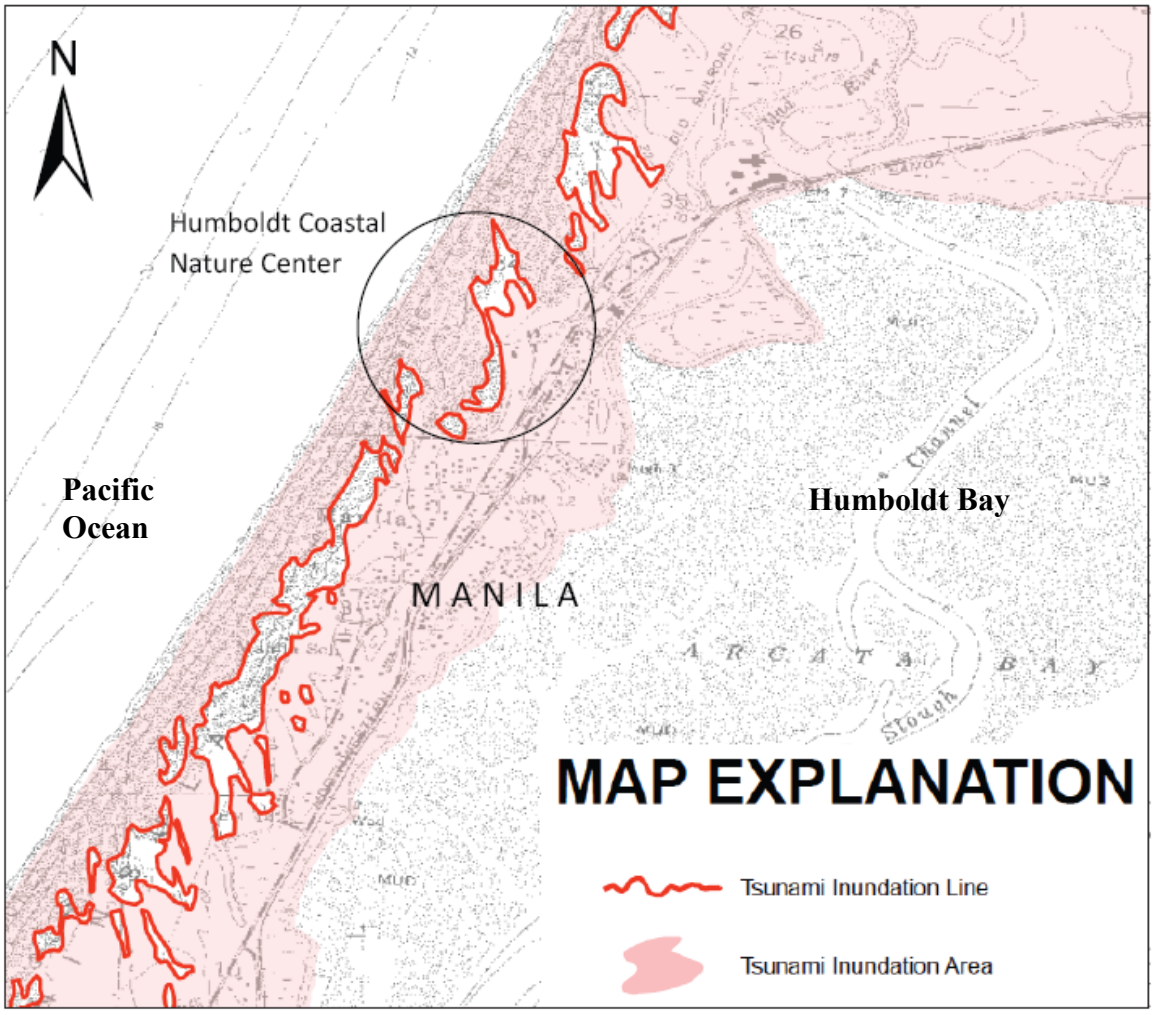

Figure 14. California Geographic Society tsunami inundation map showing the community of Manila, California on the North Spit of Humboldt Bay.

behind a vertical sand cliff (Figure 15). These temporary foredune cliffs impede beachgoers' quick retreat off the beach, which is important in circumstances of "sneaker" waves or tsunamis. A foredune devoid of European beachgrass generally has a less steep slope face, allowing quicker and easier exit from the beach. In some circumstances, foredunes colonized with native plants may at first have a steep slip face when undercut but will return to a gentle slope more quickly than a European beachgrass covered foredune (Maun 2009). For that reason, removal of European beachgrass from foredunes should promote beachgoer safety.

Figure 15. Example of a European beachgrass dominated foredune that was undercut by winter storm surges leaving a vertical cliff of sand. This photo was taken at the Humboldt Coastal Nature Center in 2009.

DISCUSSION

The results of this study raise a series of questions that influence recommendations for management of the Humboldt Coastal Nature Center in consideration of ecological resilience, social constraints and physical constraints. How have dune ecosystems at the Humboldt Coastal Nature Center changed over time, and further, to what degree have ecological processes been altered by invasive plants? While it is impossible to obtain definitive answers to all of these questions, a discussion of the results of this study can bring us closer to an understanding, allowing for improved management for restored coastal ecosystems at the Humboldt Coastal Nature Center and on the North Spit of Humboldt Bay.

A significant question raised by this research is the rate of vegetation colonization at the Humboldt Coastal Nature Center, and much of the North Spit. Why were the dunes active for nearly 250 years following the 1700 Cascadia earthquake, only to be rapidly colonized by vegetation over the last 70 years? Hypotheses to explain this include: (1) there could have been a tsunami between 1700 and 1900 that retriggered rapid movement of sand; (2) there was a lag period of 240 years before native vegetation was able to re-colonize; or (3) invasive plants sped up the process of stabilization.

Overall, it appears that natural succession of the dune ecosystem at the Humboldt Coastal Nature Center began stabilizing some of the active dune areas between 1948 and 1970 (Figures 9, 10). This is seen with the expansion of dune mat habitat in the nearshore dunes, as well as coastal dune willow thickets in the deflation plain on the west

side of the backdunes. Formation of the foredune began with native vegetation prior to the spread of European beachgrass. This leads me to conclude that the geomorphic processes at the Humboldt Coastal Nature Center were moving towards a stabilized state prior to the introduction of invasive plants. It appears that invasive plants sped up the process of stabilization (Figures 10, 11). This increased stabilization could have resulted in immobilization of most active sand dunes at faster rates and obstructed inland sand movement from the beach.

By looking at the physical constraints map (Figure 13), it is possible to examine human activities that have affected, or could potentially influence, the environment and restoration practices at the Humboldt Coastal Nature Center. The Humboldt Bay Municipal Water District easement is a road through the property that runs adjacent to a near surface pipeline. The easement allows for routine maintenance of the road and pipeline, and therefore, permanently fragments the landscape.

In addition to the spread of vegetation, installation of this pipeline could have further advanced the stabilization of active sand dunes (east of the foredune) at the Humboldt Coastal Nature Center. The areas adjacent to the road and pipeline will most likely remain in an early successional state, with continued use of and regular maintenance of the road. Other human impacts at the Humboldt Coastal Nature Center include past sand mining as shown in Figure 13. This sand mining explains the halt of some of the active sand dunes and helps to explain the types of vegetation that were mapped in these areas in 2009.

Dunes are naturally dynamic and their morphology will evolve in the future, especially considering predicted effects of climate change that will include sea level rise. Due to the large array of factors, including: vegetation, beach width, wind speed, wind direction, sand size, and sand moisture, predicting dune morphology is complex and challenging (Hesp 2002). Further research, particularly local modeling, is needed to get a better understanding of how the coastline might change with sea level rise.

Recommendations for management based on analysis of the results were compiled in Figures 16 and 17. A discussion of these recommendations follows, with discussion starting at the nearshore dunes on the west side of the property and moving east, discussing the backdunes and transverse dunes.

Restoration of nearshore dunes involves restoring inland sand movement, including foredune blowouts, and supporting dune mat habitat. Dune mat is an important, early successional habitat where both federally endangered plant species, Humboldt Bay wallflower and beach layia, occur at the Humboldt Coastal Nature Center (Figure 7). Restoration of the nearshore dunes would mainly involve removal of European beachgrass, and areas of iceplant, in order to restore the natural process of foredune blowouts. By restoring nearshore dunes an important physical component of the ecosystem would be re-established and an early successional component of the ecosystem could be conserved.

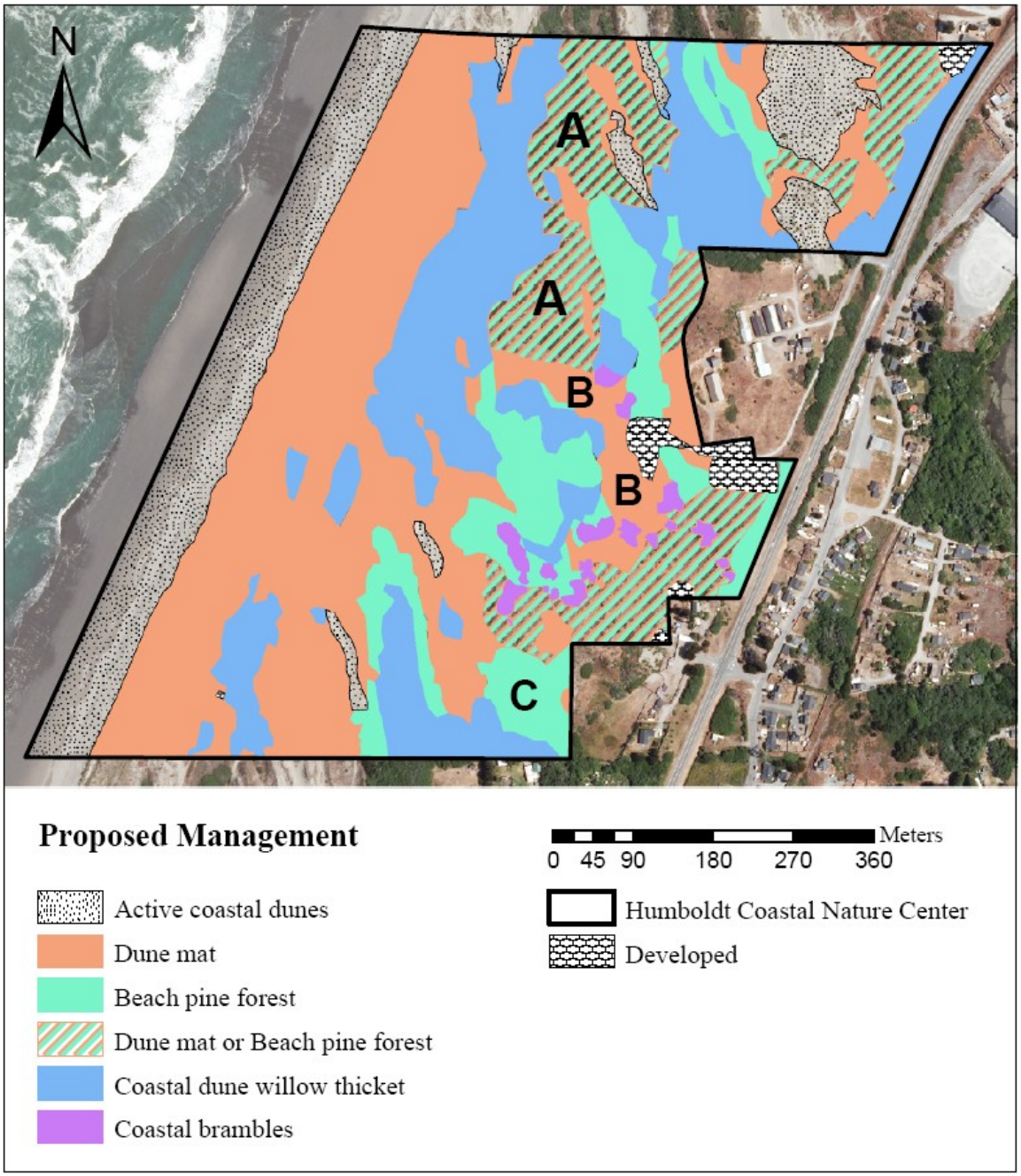

Figure 16. Recommended areas for habitat restoration at the Humboldt Coastal Nature Center.

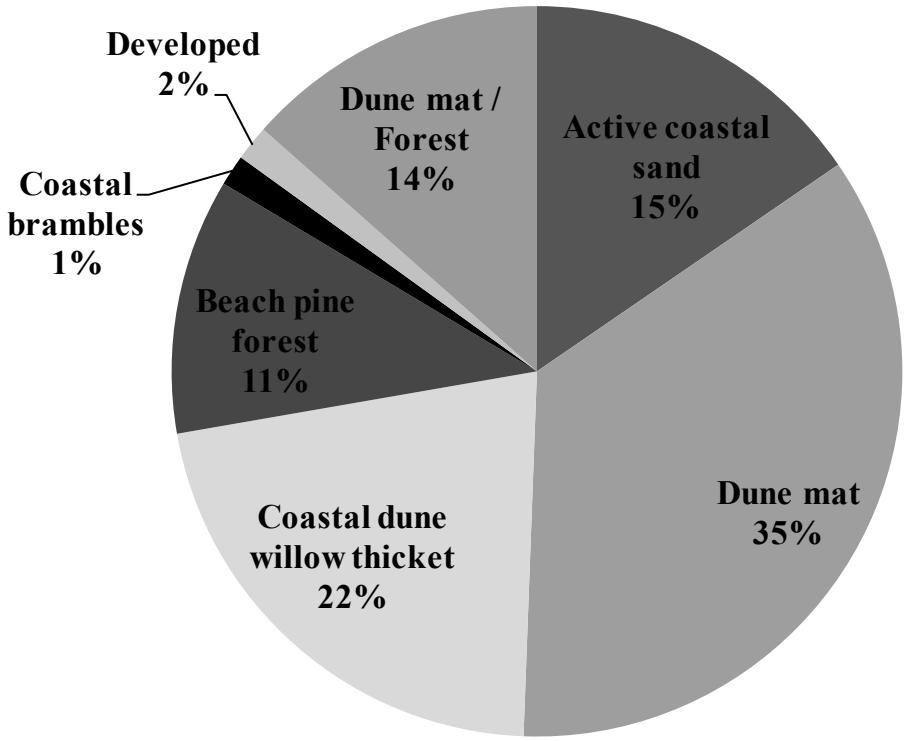

Figure 17. Goals for what type of habitats to manage for at the Humboldt Coastal Nature Center.

It is recommended that 18.2 ha (35.16% of the property) be restored to or managed for dune mat. This is an increase of 7.7 ha from 2009. An additional 6.9 ha should be managed for dune mat or beach pine forest with this decision to be made after completion of a comprehensive assessment of dunes on the North Spit by the Humboldt Coastal Dunes Cooperative. The Cooperative is a group of stakeholders consisting of landowners, non-government organizations, tribes, land managers and agencies with jurisdiction of beach and dune areas of Humboldt County, California. Their mission is to "facilitate coordinated ecosystem management of coastal dune environments, through collaboration among stakeholders" (Humboldt Coastal Dunes Cooperative 2006). In addition, the comparable costs of these two restoration activities will need to be considered in determining which to manage for at the Humboldt Coastal Nature Center.

Backdunes at the Humboldt Coastal Nature Center underwent a rapid stabilization starting in the 1970s, and have been the most heavily impacted by human activities and invasive plants. In the past, backdune areas have not been prioritized for restoration activities because the habitats and species they support were not considered as imminently threatened as those of the nearshore dunes. With many nearshore dunes now restored on the North Spit, and endangered plant populations increasing, land managers are beginning to turn their focus to the backdunes (Pickart 2010, personal communication).

A 3.7 ha area (area A on Figure 16) is recommended to be restored to dune mat or beach pine forest. This area was shown as a moving sand sheet in 1948 and has since transitioned and stabilized with yellow bush lupine scrub, invasive annual grasses, and

dune mat species. The coastal dune willow thicket area to the west, and the beach pine forests on the east, of this proposed dune mat area create some protection from strong coastal winds. Therefore, native dune mat plants should be able to re-establish quickly, and densely, allowing for little to no sand movement.

Some areas of dune mat habitat are proposed for a combination of educational and aesthetic preservation purposes near and adjacent to the Humboldt Coastal Nature Center visitor center building (area B in Figure 16). Dune mat is proposed along the two main public access trails leaving from the Humboldt Coastal Nature Center visitor center. This would allow visitors to experience this vegetation type even if they are not physically capable of walking farther out to where this habitat is more abundant. Managing for low growing dune mat species along these two trails will additionally insure ocean views for the public, both from the trails and the visitor center building. Assisted dispersal of endangered Humboldt Bay wallflower into areas that are restored to dune mat habitat would contribute to conservation of this endangered species.

The map of habitat types from 2009 (Figure 10) showed that a total of 8.3 ha (16% of the property) was infested with a combination of invasive annual grasses and yellow bush lupine scrub. These areas were generally located in the backdunes, on the eastern side of the property, and historic aerial photographs showed that much of these areas were once transverse dunes. Due to the fact that these areas are near private structures, removing all of the invasive vegetation without additional stabilization could possibly lead to re-activation of sand movement into areas where it is not desired. Thus, restoring natural geologic processes in these areas is not recommended. Much of these

8.3 ha should be managed for later successional habitat types, such as beach pine forest, in order to maintain stabilization while fulfilling a need to replace forest habitats that have been overcome by sand or logged on the North Spit. Planting of forest species would help connect currently fragmented areas of beach pine forest habitat and connect to established forest habitats adjacent to and north of the Humboldt Coastal Nature Center.

It is clear that invasive annual grasses are a factor to contend with in the dunes, especially in backdune areas as seen in Figure 12. While manual methods for removing yellow bush lupine scrub, iceplant and European beachgrass have been used for over thirty years, and are widely accepted by dune managers in the area, this is not the case for invasive annual grasses. Methods for removal of invasive annual grasses have been researched for the past decade at the USFWS Lanphere Dunes Unit with successful outcomes (Pickart 2010, personnel communication). Removal of invasive annual grasses on this scale (11.6 ha), with nearly half of that area having a 75% cover density, has not been attempted locally.

Since invasive annual grasses are wind dispersed, a large scale management plan for the North Spit would be helpful in order to control seed source and minimize seed from spreading into already treated areas. A subcommittee has been formed within the Dunes Cooperative to evaluate invasive annual grasses on the North Spit, in order to create a comprehensive invasive annual grass management plan. The recent mapping and inventory of invasive annual grasses on the North Spit by the USFWS was to gather baseline information that will be further compared and evaluated with a similar 1998

invasive annual grass inventory. Results from this USFWS mapping indicating the increase in annual grasses are expected to encourage land managers on the North Spit to collaborate to control invasive annual grass populations.

All 3.2 ha of beach pine forest habitat should be managed for continued natural expansion with an additional 2.6 ha proposed, totaling 5.9 ha (11.33% of the property). Depending upon whether certain areas of invasive annual grass/yellow bush lupine scrub habitats were managed as dune mat or beach pine forest, there could be an additional 6.9 ha restored to beach pine forest, totaling 12.7 ha (24.61% of the property). The most southern extent of this type of maritime forest is located on the North Spit and for that reason, beach pine forest is a limited and important habitat type.

A 0.7 ha area (area C in Figure 16) that is proposed to be restored to beach pine forest is located on the southeast corner of the property and is currently covered largely in European beachgrass, some jubata (pampas) grass and a few scattered coniferous trees. This area should be restored to beach pine forest because this particular dune is adjacent to Manila residences and has been designated a tsunami evacuation zone. Creation of beach pine forest has been accomplished in areas of coastal dunes in the state of Oregon with success (Green 1965, Schwendiman 1977). It is being attempted locally at the USFWS Ma-le'l Dunes Unit as of the winter of 2010.

Coastal dune willow thickets can be found in the nearshore dunes as well as the backdunes. It is recommended that these willow thickets be managed at their extent of 10.7 ha (20.07% of the property) and allowed to naturally expand. An additional expansion of 0.6 ha (area C in Figure 16) of coastal dune willow thickets on the

northeastern edge of the property is proposed. These 0.6 ha were classified as yellow bush lupine scrub and invasive annual grasses in 2009, prior to which the vegetation type at that site was unknown. Coastal dune willow thickets are recommended, as opposed to dune mat, because the area is near Highway 255 and good sand stabilizing vegetation would be appropriate. Another option to consider at this site would be to manage for beach pine forest species.

All areas of active coastal dunes located in the backdunes should be managed to allow for their natural processes. These active sand areas are expected to continue decreasing in size as the sand stabilizes with no significant sand supply. These areas should then be managed as appropriate, some of which will be determined by adjacent plant community types and presence or adjacency to endangered plants.

In this thesis, a generalized habitat mapping scheme was employed, using eight habitat classifications. Mapping of all coastal vegetation to the alliance level was completed for Humboldt Bay's North Spit and beyond by a consortium of agencies and private contractors that were coordinated through the Dunes Cooperative in 2008. Results from the alliance level mapping is expected to be published and publicly released in the summer of 2011, providing valuable and useful information that should be incorporated into the ecological management of the Humboldt Coastal Nature Center.

With a map displaying goals for habitat types to manage for at the Humboldt Coastal Nature Center, it will be feasible to create a prioritization plan for removal of invasive plants. In addition to implementing these habitat management goals, it will be essential to monitor and assess the progress of restoration activities and ecological

processes at the Humboldt Coastal Nature Center in order to incorporate adaptive management strategies. For example, if beach pine forest, or coastal dune willow thicket, began to naturally expand into an area of dune mat, where federally endangered plants were present, it might be appropriate to actively remove these encroaching plants in order to maintain areas for the endangered plants.

By mapping invasive plants that are impeding natural ecological and physical processes, looking in-depth at vegetation patterns between 1948 and 2009, researching coastal dune geomorphology processes and listening to community concerns, one can more clearly understand the historic ecological processes, the current ecological state of the property and the constraints to restoring it. This analysis led to the creation of management recommendations, including management for a diversity of habitat types and ecological processes. Wildlife is an additional component of the ecological processes at the Humboldt Coastal Nature Center that was not addressed in this study and that is in need of further assessment.

In the case of coastal dune restoration near a community, social and physical constraints must be weighed accordingly, and responsibly, in order to maintain public safety and community support. For example, some of these constraints have lead to the recommendation of restoring what is now a European beachgrass covered dune to one with beach pine forest habitat, rather than restoring it to the moving dune that existed prior to the invasion of European beachgrass.

While dune restoration activities have been taking place on the North Spit for over 20 years, it is apparent that more can be done to explain coastal dune ecosystems,

and expected outcomes from restoration and management activities, to the general public and those who live near the dunes. It would be valuable to implement ongoing educational outreach about dune geology and restoration practices, including the importance of ecological restoration. Continuing education about restoration and land management practices is crucial in order to maintain community support of these practices and to calm inaccurate fears, and assumptions, about the affects of restoration practices. Continued support is necessary to maintain restored areas in perpetuity and to build on the success of past efforts.

Outcomes from this study suggested adaptive management strategies for dune management near human communities and identified areas of further research that will benefit coastal dune restoration efforts in the region and beyond. Lastly, this thesis has provided fundamentally important information needed to create a scientifically-based, and socially inclusive, restoration management plan for the Humboldt Coastal Nature Center.

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Appendix A. Definitions for Humboldt Weed Management Area and California Invasive Plant Council Weed Rating Categories

California Invasive Plant Council

Weed Categories

Each plant on the list received an overall rating of High, Moderate or Limited based on evaluation using the criteria system.

- High – These species have severe ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. Most are widely distributed ecologically.
- Moderate – These species have substantial and apparent—but generally not severe—ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance. Ecological amplitude and distribution may range from limited to widespread.
- Limited – These species are invasive but their ecological impacts are minor on a statewide level or there was not enough information to justify a higher score. Their reproductive biology and other attributes result in low to moderate rates of invasiveness. Ecological amplitude and distribution are generally limited, but these species may be locally persistent and problematic.

Humboldt Weed Management Area

Weed Categories

- Red Alert – The species is not present in WMA area OR has very FEW populations/ and or very limited distribution, such that complete eradication is possible, even if it takes repeated eradication efforts. It's potential for spread and agronomic, economic or wildland impact is severe. This is an early detection, rapid response action category. These localized and satellite species, once located, will be actively managed.
- Monitor – The group is uncertain where to rank these species; they seem like they could be a problem, are showing signs and patterns of invasiveness; but are not as high a priority as others. For now, the best course of action taken for these species is to observe, map or set up study plots to quantify its spread or patterns of invasiveness.
- Priority Management – These species are present in the WMA and are under ongoing, active management. They are impacting agronomic, economic, or wildland resources. Combined efforts between members of the WMA can significantly work towards complete containment. Efforts include direct weed control, public education and outreach, prevention mapping, etc.

Appendix B. North American Invasive Plant Mapping Standards by the North American Weed Management Association. This data table was used to standardize and record information during the inventory of invasive plants.

FIELD
ID
DATE
OBSERVER
WEED NAME
PLANT CODE
SPECIES
GENUS
COVER CLASS
% COVER
AREA
AREA UNIT
SHAPE
PHOTO ID
NOTES
ACCURACY
OWNER
COUNTY
STATE
COUNTRY
QUAD #
QUAD NAME
LATITUDE
LONGITUDE
EASTING
NORTHING
ALTITUDE

Appendix C. Cover classes recorded for each polygon while mapping invasive plants.

Cover Class
1-5%
6-25%
26-50%
51-75%
76-95%
96-100%

1972

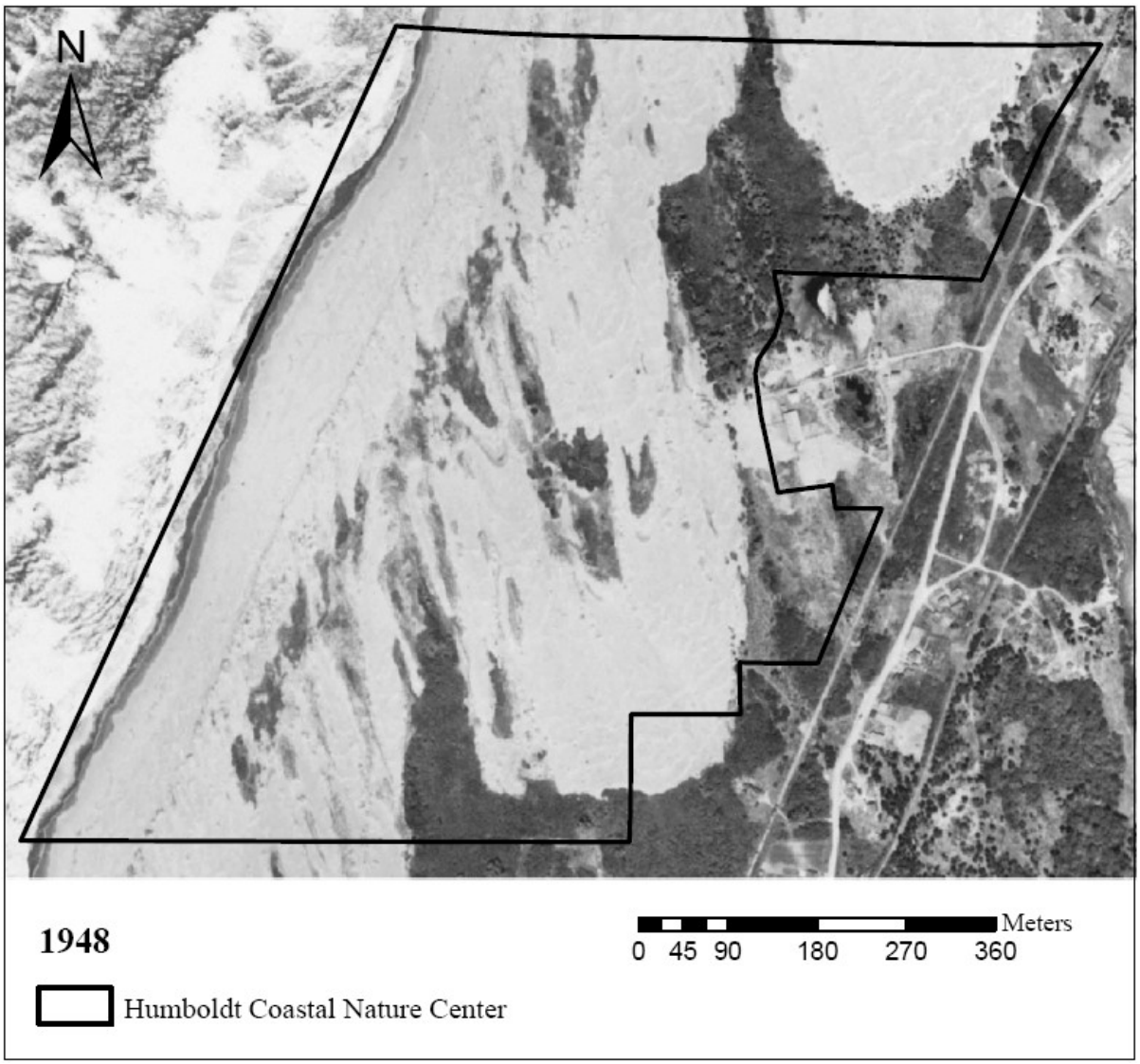
1979

Appendix D. California Coastal Records Project aerial photographs of Humboldt Coastal Nature Center in 1972, 1979, 1987, and 2009.

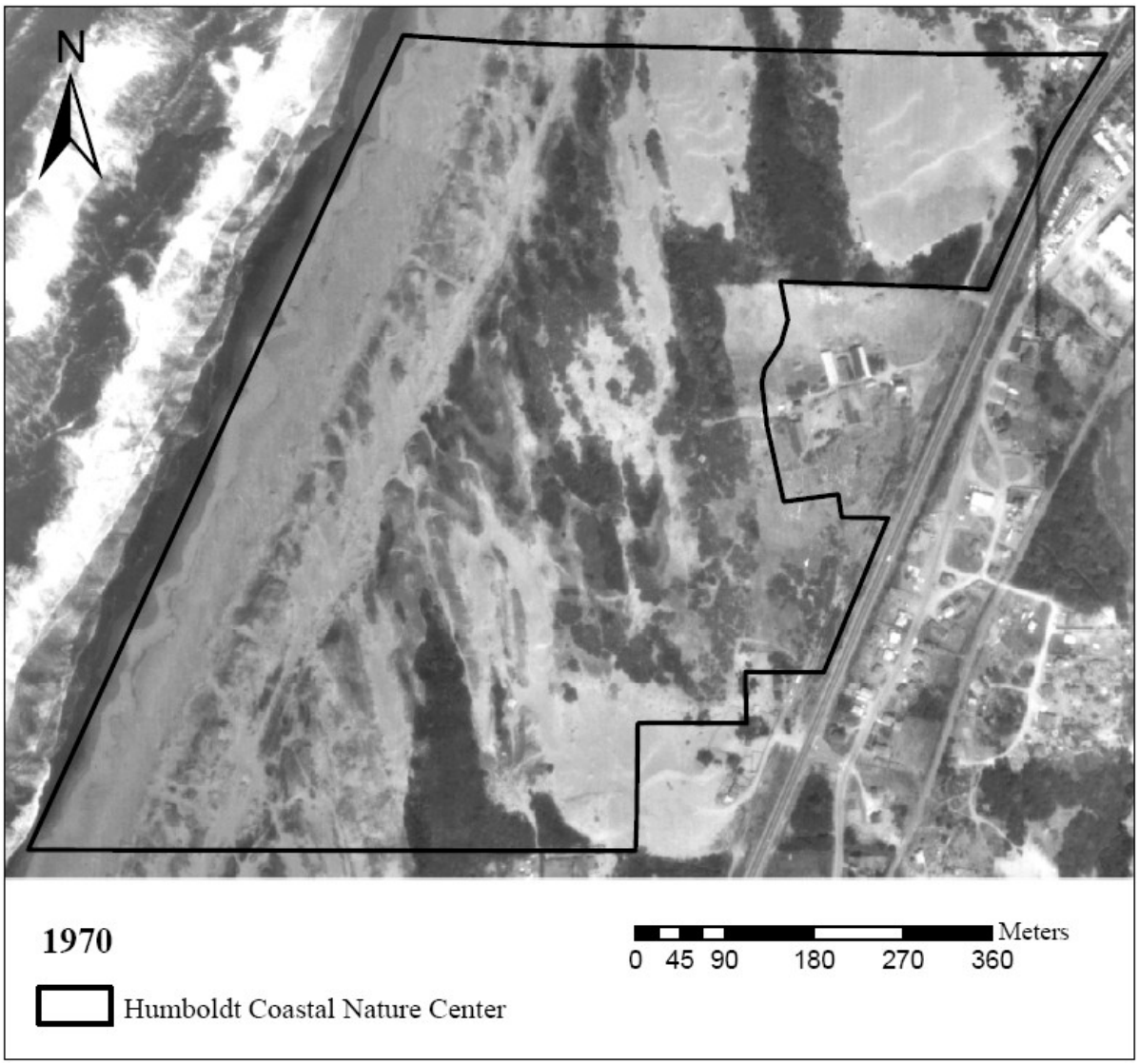
1987

2009

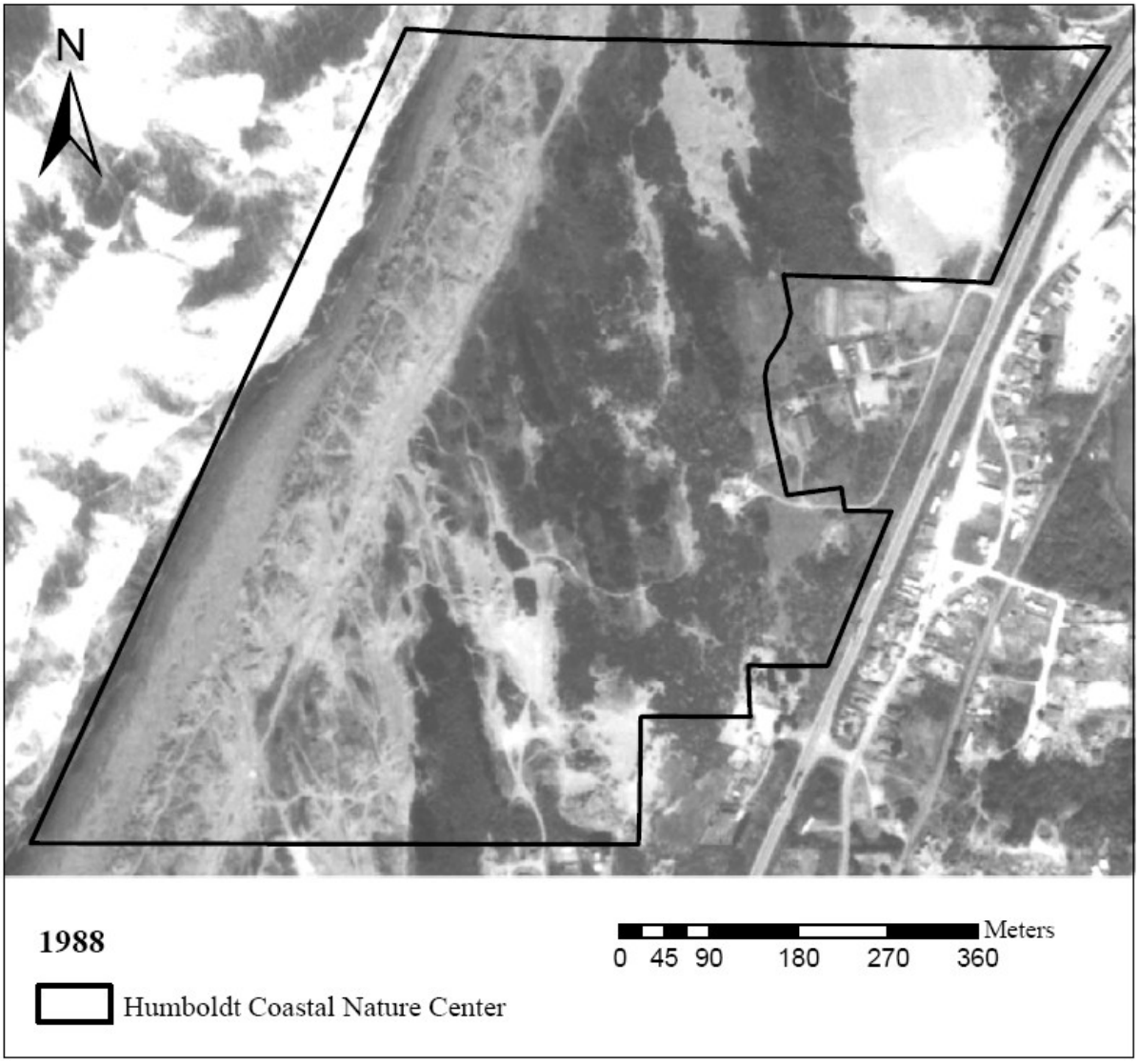
Appendix D. California Coastal Records Project aerial photographs of Humboldt Coastal Nature Center in 1972, 1979, 1987, and 2009. Copyright © 2002-2006 Kenneth and Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org (continued).



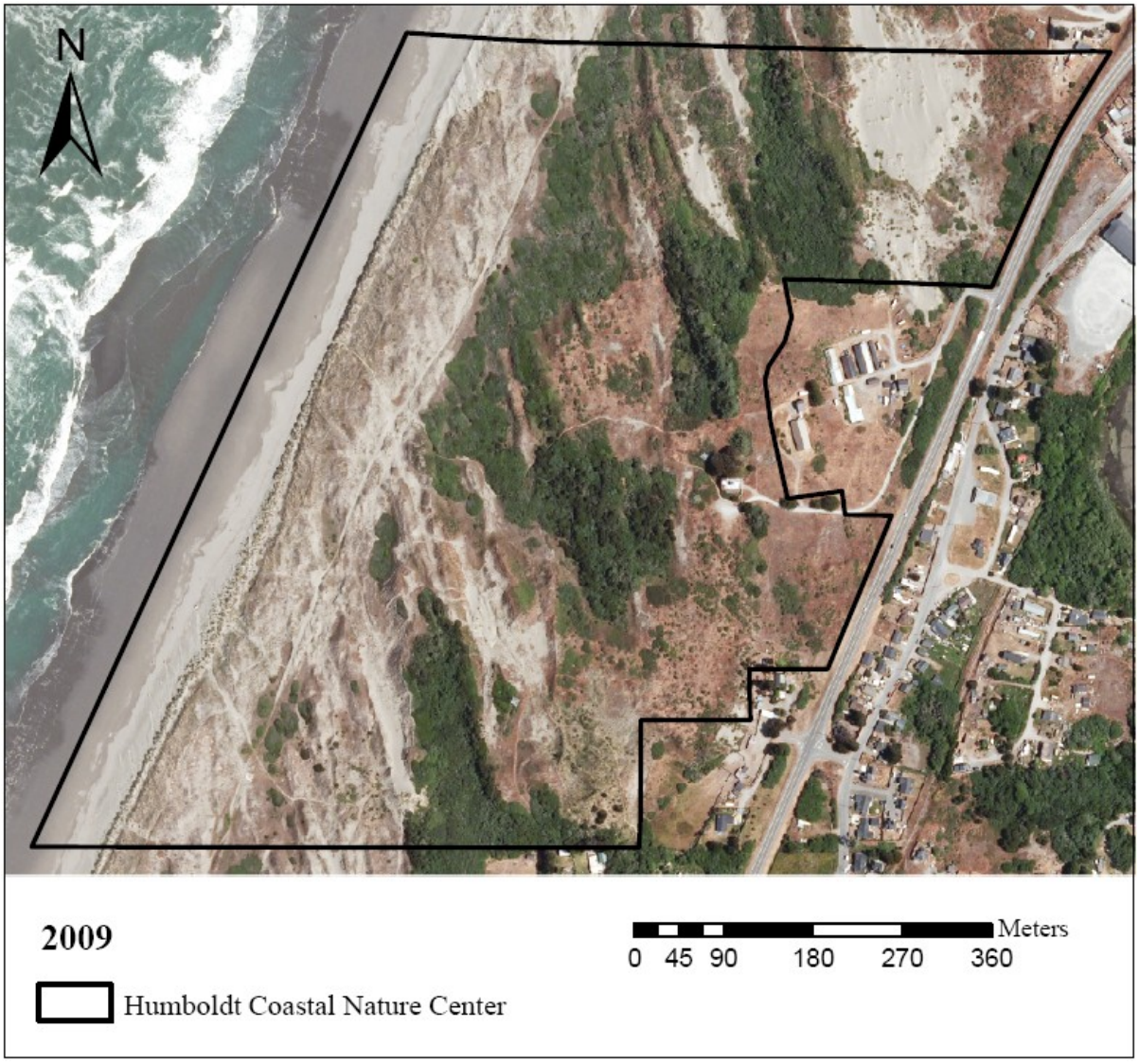
Appendix E. Aerial photographs of Humboldt Coastal Nature Center in 1949, 1970, 1988 and, 2009.



Appendix E. Aerial photographs of Humboldt Coastal Nature Center in 1949, 1970, 1988 and, 2009 (continued).



Appendix E. Aerial photographs of Humboldt Coastal Nature Center in 1949, 1970, 1988 and, 2009 (continued).



Appendix E. Aerial photographs of Humboldt Coastal Nature Center in 1949, 1970, 1988 and, 2009 (continued).