Department of Defense
Legacy Resource Management Program

PROJECT NUMBER 11-320

Developing Coastal Wetland Restoration Techniques to Enhance Coastal Habitats at Āhua Reef, Hickam AFB, HI

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November 2012

Developing Coastal Wetland Restoration Techniques to Enhance Coastal Habitats at Āhua Reef, Hickam Air Force Base, Oʻahu, Hawaiʻi

PREPARED FOR

Department of Defense
Legacy Resources Management Program
Project 11-320
Under
US Army Corps of Engineers
Cooperative Agreement W912DY-07-2-0008

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

This report represents the final deliverable for the 2011 Legacy Resource Management Program project number 11-320 (Cooperative agreement **W9132T-11-2-0037**), titled *Developing coastal wetland restoration techniques to enhance coastal habitats at Āhua Reef, Hickam Air Force Base, Hawai'i*. This project was developed and completed by SWCA Environmental Consultants (SWCA) to investigate species-specific techniques for seeding and outplanting Hawaiian coastal wetland plant species following different invasive species removal strategies and subsequent management activities (i.e., weeding and supplemental watering).

This experimental restoration project was carried out at Āhua Reef on Joint Base Pearl Harbor-Hickam (JBPHH), formerly Hickam Air Force Base, O'ahu. Āhua Reef is a 1.6 hectare (4 acre) wetland and an adjacent expanse of mud and reef flat habitat located within the Hickam Air Force Base portion of JBPHH. Eight experimental squares were established in September 2011 and the following two treatments were applied in replicates of four: 1) mechanically removing *Batis maritima* (pickleweed) followed by rototilling the soil and 2) applying the herbicide Habitat® followed by brushcutting *B. maritima*. Data were collected on the following variables of interest: survival of outplanted native species, percent cover of outplanted and volunteer species, and height of *B. maritima* and the outplanted species. The first set of data, prior to application of the treatments, was collected during September 2011. The experimental treatments were applied in October-November 2011 and five native species: *Cyperus javanicus, Cyperus polystachyos, Fimbristylis cymosa, Lycium sandwicense* and *Sesuvium portulacastrum* were outplanted during the first week of December 2011. A total of three sets of post-treatment data were collected. The first was in January 2011, directly after the application of the treatments, the second was in March 2012 and the final data set was collected in May 2012, five months after the application of the treatments.

The coastal wetland of Āhua Reef is a harsh environment with uneven topography, complex hydrology, and very diverse and patchy soil conditions. Soil pH, moisture and temperature widely vary at the study site. The areas also appear to be hydraulically connected to the ocean, fluctuating with the tide. The ponds at Āhua Reef were hyper saline with salinity ranging from 65 to 126 parts per thousand, suggesting high soil salinity as well.

Prior to beginning treatments, the invasive *B. maritima* was the dominant species at Āhua Reef, with a mean percent cover of 91% within the experimental area. No native species were present in the experimental area prior to application of the treatments. At the end of the study (five months after outplanting), the mean percent cover of native outplanted species was 25% and the mean percent cover of *B. maritima* was 13%. Among the outplanted species, *S. portulacastrum* had the highest survival and cover while *C. polystachyos* had the lowest survival and cover at the end of the experiment. The survival and growth of all outplanted native species was significantly higher in the plots from which *B. maritima* was removed by herbicide compared to the mechanical removal plots. The overwhelming poor survival and growth of the native species in the herbicided plots might have been due to the residual effects of the herbicide Habitat® in the soil at the time of outplanting the native species.

SWCA did not find conclusive evidence suggesting that weeding invasive species and regimented watering of plots improved the survival and growth of native outplanted species at Āhua Reef. In the plots that did not receive weeding or watering, the mean percent cover of weeds was 28% and percent cover of native species was 46% five months after outplanting. It is possible that the differential response of the wetland species to various abiotic factors in harsh coastal wetland of Āhua Reef facilitated their coexistence through a decrease in soil salinity and increase in soil moisture. It is also possible that five months was too short a period of time to observe the onset of competitive effects of the weedy species.

Very limited seed germination was observed in the seeded areas. The high saline conditions recorded at Āhua Reef could have impeded germination. Other site conditions, such as temperature, may also have prevented germination during the study period. Although a tackifier slurry was used to keep seeds within the experimental area, it is possible that heavy rainfall (134 mm or 5.3 inches) over a period of two days following seeding could have also washed the seeds out of the experimental plots.

Despite there being four waterbird management wetlands within five miles of Āhua Reef, few Hawaiian waterbird species were observed at Āhua Reef. Endangered Hawaiian stilts were only occasionally observed flying over Āhua Reef by SWCA. This lack of waterbirds could be due to the presence of invasive mammals such as mongoose and cats, as well as the lack of restrictions for off-leash dogs in the wetland.

The results of this study show that it is possible to at least partially restore a highly degraded coastal wetland such as Āhua Reef. Because the mechanical removal of *B. maritima* can be very labor intensive and costly, SWCA recommends the use of Habitat® for the control of this weed at Āhua Reef. However, managers need to be cautious about planting of native species following application of Habitat®. All five species tested in this study are suitable for outplanting at Āhua Reef with *S. portulacastrum* having the highest mean survival (85.4%) and cover (34.3%) and *C. polystachyous* the least mean survival (44.1%) and cover (3.9%). More research should be conducted to test environmental factors which may hinder the survival and growth of these and other native species. Further research is also needed to test the ability of native wetland plant species to directly compete with invasive wetland plant species. Planting native species can jump-start the growth and production of native vegetation; however, long-term management and invasive species control programs will be needed to restore Āhua Reef to a functional coastal wetland.

2.0 INTRODUCTION

Heavy rainfall, porous volcanic soil, steep terrain, and its isolated geographic location have resulted in the coastal wetlands of Hawaiʻi harboring a unique assemblage of flora and fauna (Cuddihy and Stone 1990). These wetlands play an essential role in maintaining water quality of nearshore environments and protecting reefs from sediments, nutrients and pulses of fresh water during heavy rains (Bruland 2008). Nearly 31% of the original coastal wetlands throughout the Hawaiian Islands have been lost, primarily due to human activities (Dahl 1990; Kosaka 1990). Coastal wetlands in Hawaiʻi have been extensively altered as a result of agriculture, aquaculture and urban development (Cuddihy and Stone 1990). Most of Hawaiʻi's remaining coastal wetlands have been further degraded due to invasion by non-native plant species (Elliot 1981; Ducks Unlimited 2000). Invasive species, such as *Rhizophora* spp. (mangroves), *Batis maritima* (pickleweed), and *Typha* spp. (cat tail), are fast growing and can form monotypic stands that displace native vegetation, choke out open water and mudflats necessary for Hawaiian waterbirds, trap sediments, and negatively affect the water quality and hydrology (Rauzon and Drigot 2002).

Several Hawaiian waterbirds, such as Hawaiian stilt or aeʻo (*Himantopus mexicanus knudseni*), Hawaiian coot or ʻalae keʻokeʻo (*Fulica alai*), Hawaiian gallinule or ʻalae ʻula (*Gallinule chloropus sandvicensis*), and Hawaiian duck or koloa maoli (*Anas wyviliana*), are endangered (USFWS 2009) and, therefore, it is not surprising that most wetland research in Hawaiʻi has focused on understanding the life history and habitat use of Hawaiian waterbirds (Brimacombe 2003). Constructed and restored wetlands in Hawaiʻi are primarily designed and managed for open space and appropriate water levels which is desirable for waterbird habitat and thus having a high percentage of vegetative cover is not appropriate to maximize this function (Bantilan-Smith 2009). Past Hawaiian wetland restoration efforts mostly involved removal of invasive vegetation to create habitat for endangered waterbirds.

Much less attention has been given to developing restoration techniques for native wetland plants. To date, most wetland "restoration" efforts have involved removal of non-native invasive vegetation (e.g., Drigot 1999, Rauzon and Drigot 2002, AECOS 2006); however, to fully restore a wetland it is not only necessary to control invasive species, but also to return native plant species to these sites. A comprehensive investigation of vegetation characteristics of wetlands in the state of Hawaii recommends that management strategies include seeding with native plant species be incorporated into wetland restoration and creation practices in Hawaii in order to facilitate the colonization and proliferation of native vegetation (Bantilan-Smith 2008).The native planting efforts in Hawaiian wetlands are based on managers sharing knowledge via personal communication. Rarely has there been consistent monitoring of the outplanted native species for establishment success and survival; with the exception of Brimacombe's (2003) work in Honouliuli (Pearl Harbor), records of success and failure of native wetland plant restoration efforts are largely anecdotal.

2.1 Coastal Wetland at Āhua

Āhua Reef is a 1.6 hectare (4 acre) wetland and an adjacent expanse of mud and reef flat habitat located within the Hickam Air Force Base portion of Joint Base Pearl Harbor-Hickam (JBPHH). This wetland is largely degraded with the majority of area being invaded by non-native species, primarily *Batis maritima*. Other common non-native plants at the coastal wetland include *Rhizophora mangle* (red mangrove), *Prosopis pallida* (kiawe) and *Pluchea indica* (Indian fleabean).

For several years, the managers of Āhua Reef have been working closely with the community and various volunteer groups (e.g., Boy Scouts) to restore native plants to the site by organizing periodic weeding and outplanting events; however, these managers were seeking site-specific information on the most effective methods to control invasive vegetation and restore Hawaiian wetland plants. Because the managers are faced with the challenge of implementing and maintaining the wetland with minimal resources, they were particularly interested in techniques that would minimize future intensive management.

2.2 Project Objectives

The overarching objective of this study was to develop seeding and outplanting techniques for several wetland plant species under various invasive species control strategies in order to guide wetland restoration or mitigation projects on DoD installations in the Pacific Island region.

The specific objectives of this study were:

1. Investigate species-specific techniques for outplanting and seeding Hawaiian coastal wetland species and determine species-specific responses to different weed control methods and watering regimes at Āhua Reef.
2. Communicate the findings to managers of Āhua Reef and help them incorporate the findings into broader management and conservation goals for Āhua Reef.

There were a few secondary goals of the project. Land managers were interested in monitoring endangered waterbird activity at the site to observe any changes in waterbird activity following application of the treatments. Greater usage of Āhua Reef by Hawaiian waterbirds may reduce take by attracting birds away from the neighboring Bird Aircraft Strike Hazard (BASH) zone. Secondly, by involving volunteers from the Boy Scouts, Americorp interns and several AFB citizens and staff for the mechanical removal of weeds and planting native species, this project also aimed to educate military personnel and civilians about coastal wetlands and DoD's challenges, efforts and achievements in conserving these systems in the Pacific.

3.0 METHODS

3.1 Study Site

SWCA conducted this experiment on JBPHH, which encompasses roughly 11,207 hectares (27,694 acres) scattered at various locations throughout the Island of O'ahu (Figure 3-1). JBPHH is a joint installation combining the former Naval Station Pearl Harbor and Hickam Air Force Base. The landscape at JBPHH has been highly altered by humans. The installation supports both Air Force and Navy missions and is a very busy stopover hub for military aircraft traveling throughout the Pacific. It also serves as a residential area for Service personnel and their families.

Āhua Reef is a 1.6 hectare wetland and an adjacent expanse of mud and reef flat habitat located within the Hickam Air Force Base portion of JBPHH (Helber Hastert and Fee Planners, Inc. 2009). The area is on the coastal plain of O'ahu's south shore, west of the Honolulu International Airport and immediately south of Seaman Avenue. This wetland is largely degraded with the majority of area being invaded by non-native species, *Batis maritima*. Other common non-native plants at the coastal wetland include *Rhizophora mangle*, *Prosopis pallida* and *Pluchea indica*.

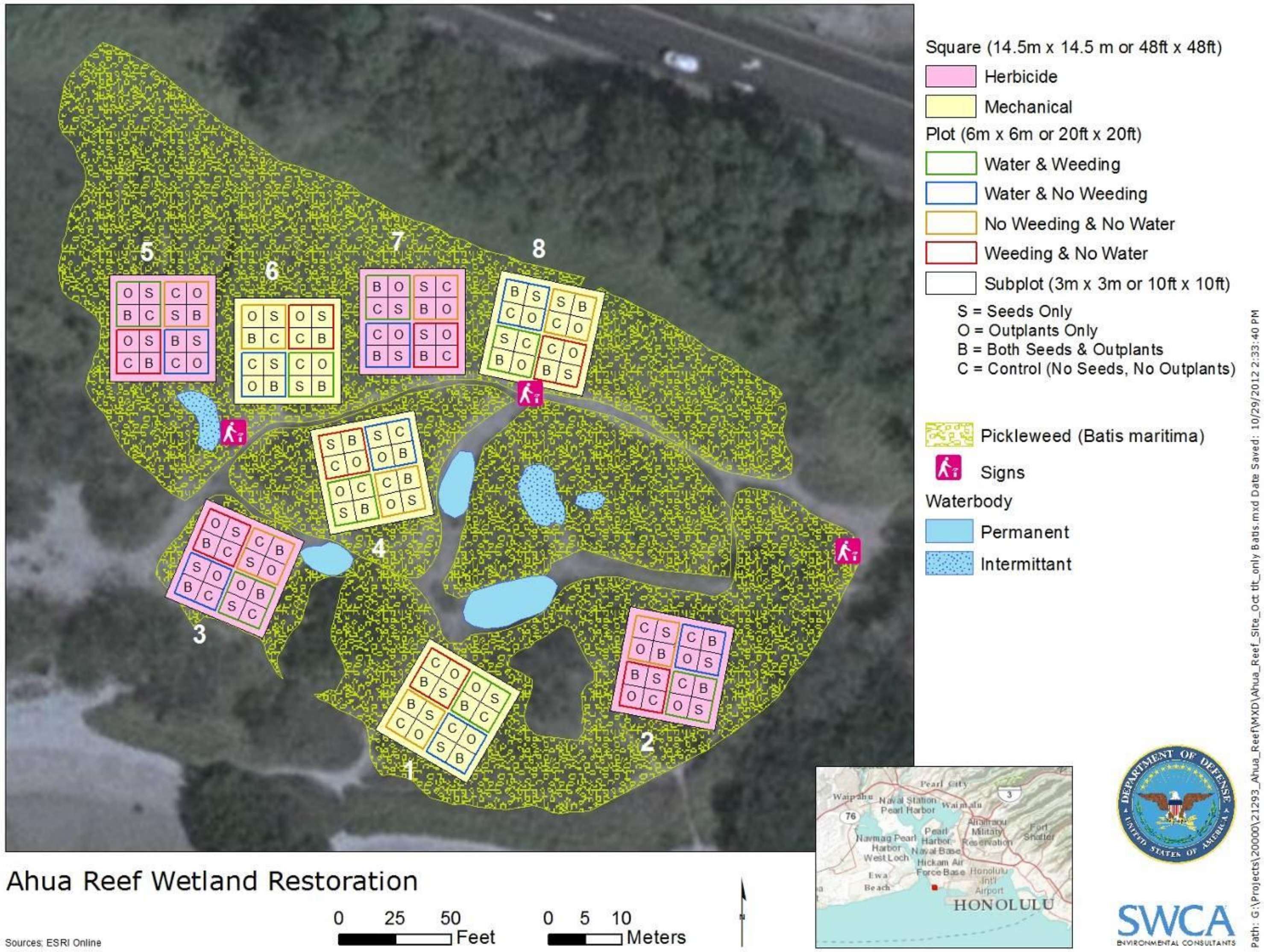

Figure 3-1. Experimental Design at Āhua Reef, Joint Base Pearl Harbor-Hickam, O‘ahu.

Āhua Reef has complex microtopography, with repeated small changes in elevation occurring over short distances creating mosaics of submerged/non-submerged areas (USACE 2012). Several inundated areas are scattered throughout the site (Figure 3-2). Water levels in these inundated areas fluctuate owing to natural conditions such as rainfall and evaporation. The areas also appear to be hydraulically connected to the ocean, fluctuating with the tide. Water quality measurements taken in these areas in October 2011 showed salinity ranging from 65 to 126 parts per thousand (ppt) (SWCA unpublished data). Salinity levels likely fluctuate tremendously depending on the season and water levels. Portions of Āhua Reef also appear to receive runoff from upland areas.

Figure 3-2. Inundated area showing fluctuation in water levels between June 2010 (left) and October 2012 (right).

Rainfall at the study site is typical of dry coastal sites. Average monthly precipitation at the Honolulu International Airport (NOAA station ID 511919), located about 3.9 km (2.4 mi) from the study site at Āhua Reef, ranges from 58.5 mm (2.31 inches) in January to 6 mm (0.26 inches) in June (NOAA 2012). Rainfall was generally lower than the 30 year average during the study, except during March (Figure 3-3). This was largely because of heavy rains (134 mm or 5.3 inches) recorded over two days (March 5-6, 2012).

According to the Integrated Natural Resources Management Plan (INRMP) for JBPPH, the objective of management activities at Āhua Reef is to provide habitat for endangered Hawaiian waterbirds outside of the BASH zone and restore native vegetation. This includes managing vegetation, controlling mammalian predators, and restricting domestic pets (USFWS 2009; C. Campora, Natural Resources Manager, NAVFAC Hawaii, pers. comm.). Four endangered Hawaiian waterbird conservation areas are located within 8 km (5 miles) of Hickam Air Force Base that support the four endangered Hawaiian waterbirds. Only the Hawaiian stilt has been observed at Āhua Reef.

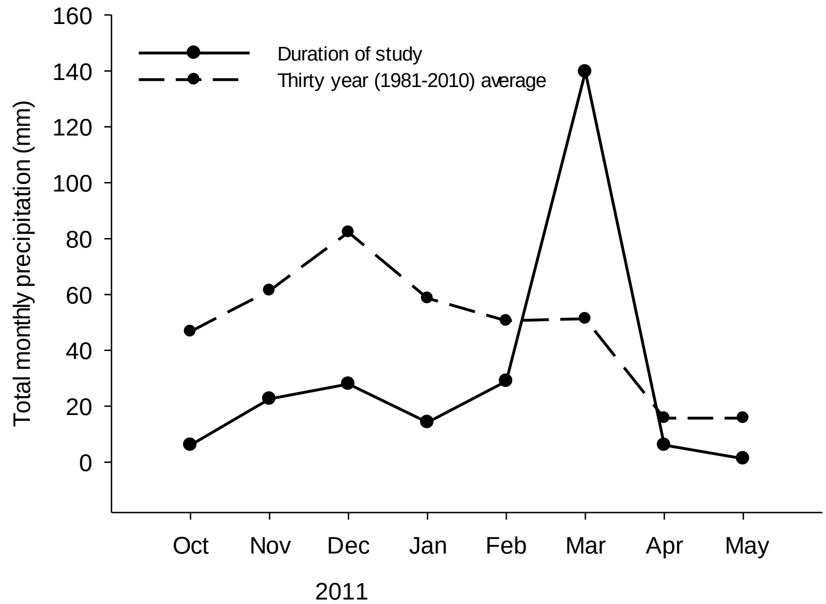

Figure 3-3. Total monthly precipitation over the course of the study, recorded from a rain gauge located at the Honolulu International Airport (NOAA station ID 511919) ~ 3.9 km from the study site at Āhua Reef.

3.2 Experimental Design

SWCA adopted a randomized complete block design to investigate the effect of two invasive species removal methods (herbicide versus mechanical removal), weeding and supplemental water on outplantings and seeds of five native wetland species.

Between September and October 2011, SWCA biologists established eight 14.5 m x 14.5 m (48 x 48 ft) **squares** at Āhua Reef (Figures 3-1). The squares were set up in areas dominated by *Batis maritima*, avoiding large areas of *Rhizophora mangle* and *Prosopis pallida*, as well as recreational trails. We blocked the squares into groups of two based on proximity to the ocean and general *B. maritima* cover. Within each block, we randomly assigned one square to receive the mechanical removal treatment and the other to receive the herbicide treatment.

In each square, four 6 x 6 m (20 x 20 ft) **plots** were then established. Each plot was randomly designated one of the four weeding and supplemental water treatments (watering + weeding, watering + no weeding, no watering + weeding, and no weeding + no watering) (Figures 3-1 and 3-4). Each plot was further subdivided into four 3 m x 3 m (10 x 10 ft) **subplots**. The four subplots were randomly assigned one of the following four species addition treatments: outplants only, seeds only, outplants + seeds, and control (no outplants or seeds). Buffers were left between each plot and from the edge of each square.

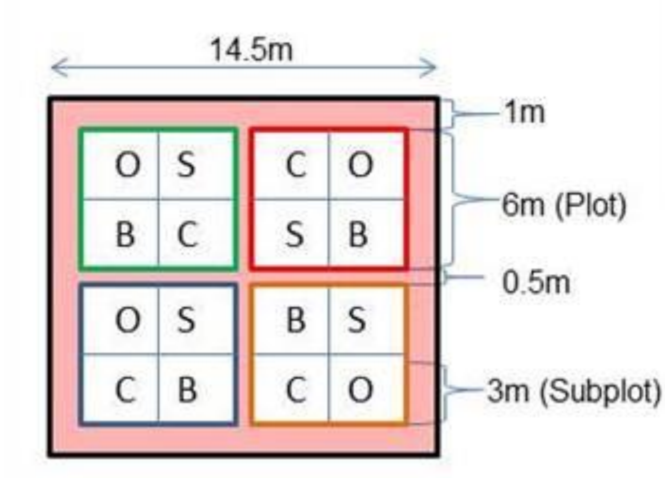

Figure 3-4. Dimensions of an experimental square at Āhua Reef.

3.3 Primary Species

Batis maritima (pickleweed)

Batis maritima is a creeping subshrub found throughout the tropical and subtropical coastlines of North America, Central America, northern South America, and the Caribbean Islands. This subshrub can be prostrate or upright, reaching up to 1.5 m (5 ft) tall. The green, succulent leaves are oppositely arranged on the stem and linear to linear-oblanceolate in shape (Wagner et al. 1999; Lonard et al. 2011). The tiny unisexual flowers occur on separate plants in short spikes. The adventitious root system is extensive. *Batis maritima* is a salt-accumulating halophyte that is broadly tolerant to a wide range to environmental conditions, including frequent to infrequent flooding by high tides (Wagner et al. 1999; Lonard et al. 2011).

In Hawaiʻi, *B. maritima* is naturalized on all the main Hawaiian Islands, commonly occurring along coastal areas in brackish ponds and marshes and on saline soils. Throughout the state it is known to be invasive, displacing coastal native species and habitats and excluding waterbirds (Rauzon and Drigot 2002). Because *B. maritima* typically grows in harsh environments (i.e., dry and saline), it has little competition from other species and often forms monotypic stands (Francis 2000).

Cyperus javanicus (ʻahuʻawa)

Figure 3-5. *Cyperus javanicus.*

Cyperus javanicus (ʻahuʻawa) (Figure 3-5) is a perennial indigenous sedge that prefers salty waters and soils. It has bluish green leaves, an umbelliform inflorescence, and short rhizomes. *Cyperus javanicus* is common in marshes, taro paddies, coastal pastures, and along streams and ditches from sea level to 180 m (590 ft) (Wagner et al. 1999). Seedlings and seeds of this species are commonly used for restoration of wetlands in Hawaiʻi (Brimacombe 2003). *Cyperus javanicus* was not growing naturally at Āhua Reef prior to the study; however, several plants outplanted during volunteer restoration events at the site appear to do well in most areas, particularly in the wet season. In locations devoid of substantial organic matter in the soil substrates (i.e., sandy areas lacking clays or organic material) this species struggles to maintain vigor during the dry season (J. Helm, Biologist, NAVFACPAC, pers. comm.).

Cyperus polystachyos

Figure 3-6. *Cyperus polystachyos*.

Cyperus polystachyos (no common name) is another indigenous sedge (Figure 3-6). This species is an annual or short-lived perennial with fibrous roots or short rhizomes depending on conditions. *Cyperus polystachyos* is relatively common and often occurs in disturbed areas in the main Hawaiian Islands. It is found from coastal sites to mesic and wet forests up to 1,420 m (4,659 ft) in elevation (Wagner et al. 1999). It was not seen growing naturally at Āhua Reef prior to the study; however, several plants outplanted during volunteer restoration events at the site appear to do well.

Fimbristylis cymosa (mauʻu ʻakiʻaki)

Figure 3-7. *Fimbristylis cymosa*.

Fimbristylis cymosa (mauʻu ʻakiʻaki) is a small, grass-like indigenous sedge (Figure 3-7) that grows in sunny, dry coastal areas. It can grow in shallow sand or soil and among rocks and cracks in lava (Wagner et al. 1999). The rusty brown flowers and seed heads are clustered on the stem tips. The leaves do not have sharp edges like other sedges. Instead, the leaves are short and pointed at the ends. *Fimbristylis cymosa* was not seen growing naturally at Āhua Reef and it had not been outplanted there during previous restoration efforts.

Lycium sandwicense (ʻōhelo kai)

Figure 3-8. *Lycium sandwicense.*

Lycium sandwicense (ʻōhelo kai) is a low-growing shrub (Figure 3-8) that is found in subsaline and rocky coastal sites. The white or slightly bluish-pink flowers are tubular and the fruits are bright red. It occurs on all the main Hawaiian Islands from sea level to 40 m (131 ft) (Wagner et al. 1999). *Lycium sandwicense* was not seen growing naturally at Āhua Reef prior to the study. It has also not been outplanted there during previous restoration efforts.

Sesuvium portulacastrum ('ākulikuli)

Figure 3-9. ***Sesuvium portulacastrum.***

Sesuvium portulacastrum ('ākulikuli) is an indigenous succulent plant with prostrate growth habit. It produces pinkish purple to white solitary flowers. In Hawai'i it occurs in a variety of coastal habitats on all main Hawaiian Islands (Wagner 1999). The species is a halophyte and has been used as a groundcover in several wetland restoration projects in Hawai'i. It has been observed growing naturally at Āhua Reef.

3.4 Pre-Treatment Data Collection

Prior to any manipulation, baseline data were collected on the following variables:

- Percent cover of all vegetation and substrate:

In October 2011, percent cover of existing vegetation was recorded in each 3 X 3 m subplot (total of 128 subplots at the site). Percent cover for each species in each subplot was estimated using PVC reference frames. In addition to vegetation cover, percent of substrate (i.e., bareground, litter, and other debris) was also recorded. All cover estimates were taken by the same individual to minimize observer bias. Note that percent cover can exceed 100% due to overlap of various strata.

- Average height of *Batis maritima*:

Batis maritima height was taken at four points in each 3 X 3 m subplot in October 2011. For the *B. maritima* measurements, height is defined as "the perpendicular distance from the soil at its base to the highest point reached within all parts in their natural position" (Heady 1957). Owing to the dense cover of *B. maritima*, biologists stood at the four corners of each 3 X 3 m subplot, and at an arms distance, used a yard stick ruler to measure the distance between the soil and the highest point where the *B. maritima* naturally touched the ruler. These four heights were then averaged to determine the average height of *B. maritima* in each subplot. Height was measured to the nearest 0.1 cm. This method was used due to dense *B. maritima* cover and to increase objectivity.

- Soil temperature:

Soil temperature was recorded in each 3 X 3 m subplot between 3:00PM-4:00PM on October 18, 2011. A digital rugged T-shape handle thermometer (Hanna Instruments, Woonsocket, RI) was placed into the top 5 cm (2 inches) of the soil surface in the center of each subplot. The probe was left in the soil for at least one minute or until a stable temperature was attained. Soil temperature was recorded to the nearest 0.1°F. These measurements were used to determine if soil characteristics were correlated with plant survival or growth.

- Soil pH and moisture:

Prior to collecting soil samples, plant material and surface litter was manually cleared from the center of each 3 X 3 m subplot. Using a garden trowel, soil was collected from the upper 10 cm (4 inches) of the soil profile, or to the maximum depth possible in areas with minimal soil. Roughly 1 cup of soil was placed into a sealable plastic bag and large stones, sticks, and vegetation were removed from the sample. All samples were taken to the University of Hawaiʻi, College of Tropical Agriculture and Human Resources, Agricultural Diagnostic Service Center within 48 hours of collection and analyzed for pH and soil moisture. Soil moisture was determined as the water/oven dried weight of a sample. All soil samples were collected between October 13 and 20, 2011.

- Waterbird activity:

Waterbird activity at Āhua Reef was estimated using the variable circular-plot (VCP) count methodology (Reynolds et al. 1980). VCP counts are recorded at observation points (i.e., stations) that serve as the centers for estimating radial distances to birds during a count period (Figure 3-10). Two permanent bird point count stations were established at the site, one on the western side of the site immediately northwest of Square 3, and one on the eastern side of the project site north of Square 2. These stations were chosen because they provided good vantage points of all eight experimental squares and adjacent inundated areas.

Figure 3-10. Biologist recording waterbird activity at Āhua Reef.

During eight-minute counts, observers recorded the species, number, location, and activity (e.g., foraging, loafing, and nesting) of all waterbirds seen or heard. Date and time of sampling, as well as weather conditions, were also recorded. Pre-treatment bird point counts were conducted weekly from October 12, 2011 to October 31, 2011. All surveys were conducted before 1100 hrs or after 1600 hrs. Incidental observations were also recorded for rare, threatened or endangered waterbirds seen or heard at the site outside of the point count surveys.

3.5 Treatment Application

3.5.1 Invasive Plant Removal Treatments

The following two invasive plant removal treatments were applied to the 14.5 x 14.5 m squares in replicates of four between October and November 2011:

1. Mechanical removal:

Mechanical removal of *B. maritima* (and other non-native species) was accomplished by hand pulling or using various hand tools (e.g., pick-axes, shovels, spades, trowels, etc.) (Figure 3-11). All attempts were made to remove as much as the *B. maritima* plant as possible, including the root system. *Prosopis pallida* trees within the mechanical removal squares were chain-sawed near the base, but not entirely removed. The pulled material was removed from the squares, as much as possible, and piled elsewhere on-site. Because manual removal of *B. maritima* is labor intensive and volunteer events were largely held on weekends, manual removal of *B. maritima* from the four squares occurred from October 22, 2011 to November 29, 2011. Mechanical removal of all four squares was estimated to take 225 hours (of this total, ~129 hours were from individuals under 16 years of age). On November 29, all manual removal squares were tilled using an eight horsepower Troy-built® walk-behind rear-tine rototiller (Figure 3-12). The rototiller was used to expose the seed bank and aerate the soil. The peak effectiveness of the mechanical treatment was considered to be immediately following tilling.

Figure 3-11. Mechanical removal of *B. maritima* by volunteers.

Figure 3-12. Tilling in mechanical removal square.

2. Herbicide application:

A 1% solution of the herbicide Habitat® (EPA Reg No. 241-426) was applied to all four herbicide squares on October 31, 2011. Habitat® is specifically used for aquatic systems to control vegetation in and around standing and flowing water. The herbicide was applied using backpack sprayers (Figure 3-13). Roughly 44 gallons of solution was used over 0.2 acres (11 gallons/square). All squares were sprayed by two individuals in roughly 4 hours. Herbicides were only applied by trained and certified herbicide applicators.

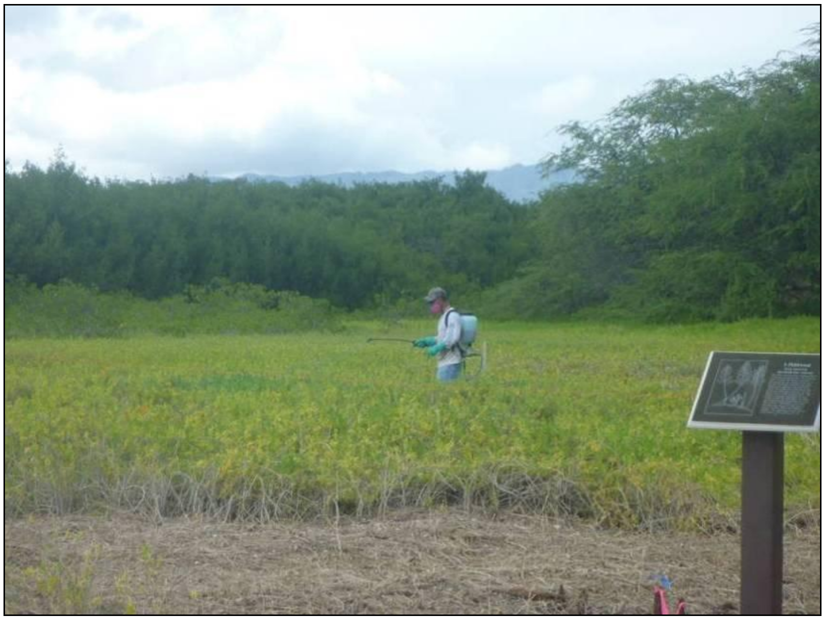

Figure 3-13. Applying herbicide Habitat® to herbicide square using backpack sprayer.

To make space for outplanting, the dead material within the herbicided squares was brushcut at the soil surface using handheld metal-bladed brush cutters on November 29, 2011 (roughly 1 month after herbicide application). Large pieces of biomass were removed, but smaller pieces were left in place or distributed over the square to function as mulch. Figure 3-14 shows and example of an herbicided square before spraying, 15 days after spraying, and after dead material in the square was brushcut and removed. The peak effectiveness of the herbicide treatment was considered to be a few weeks following spraying when the chemical had taken full effect and plant material was dead.

Figure 3-14. Herbicide square before treatment (upper left), 15 days after treatment application (upper right), and after brushcutting (lower).

3.5.2 Native Plant Addition Treatments

The following native plant addition treatments were applied to each 3 x 3 m subplot:

1. Outplants Only (O):

Five native wetland plant species were chosen for outplanting including: three sedges (*Cyperus javanicus, Cyperus polystachyos,* and *Fimbristylis cymosa*); *Lycium sandwicense*, a low-growing shrub; and *Sesuvium portulacastrum*, a succulent groundcover. These species were chosen based on their availability and tolerance of dry and saline environments. In each outplant only subplot (O), 25 outplants (5 individuals/species) were planted in the same arrangement (Figure 3-15) for a total of 800 seedlings in the outplant only subplot (25 plants/32 subplots). All planting occurred between December 1-15, 2011. To assist establishment, each outplant was watered 3 times per week for the first month after outplanting and once a week for the following month. Each seedling was watered manually for approximately 10 seconds. Subsequently, only the plots that were designated to receive supplemental water received a fixed amount of water. All seedlings were obtained from Hui Kū Maoli Ola Native Plant Nursery.

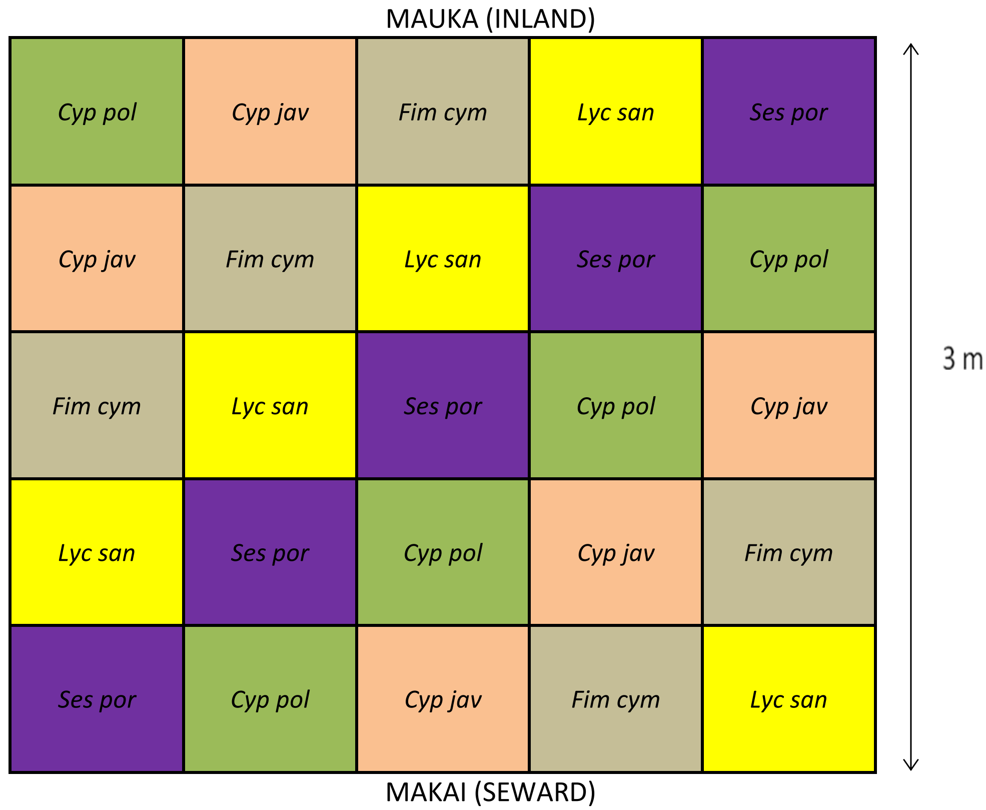

Figure 3-15. Schematic of outplant arrangement in outplant only subplot.

2. Seeds Only (S):

Due to seed availability, only the three sedge species (*Cyperus javanicus, Cyperus polystachyos,* and *Fimbristylis cymosa*) were seeded at the site. Prior to seeding, three 1 m^2 (10.8 ft^2) rectangles were demarcated in each of the seed only subplots (S) for a total of 96 seed rectangles (4 subplots x 3 species x 8 squares) in the subplots (Figure 3-16). For each square, a tackifier solution was prepared for each species using 53.9 g (0.12 lbs) of TripleTac® tackifier and 37.4 L of water. The slurry was well agitated in a container. SWCA weighed out the amount of seed material per species that was estimated to contain 1,000 seeds. A seed + tackifier solution was prepared for each rectangle, which contained roughly 1,000 seeds of one of the sedge species, 6.7 g (0.015 lbs) of tackifier and 4.7 L of water. The seed + tackifier solution was well stirred and poured into the demarked seed rectangles by hand (Figure 3-17). This method was used instead of broadcast seeding to minimize seed loss due to wind or high tide events (Tilley and Hoag 2006).

All seeding occurred on February 23, 2012 to allow for the maximum time before a high tide event. To assist establishment, each rectangle was watered 2 times per week for the first three weeks after seeding. Supplemental watering of the seeding rectangles was discontinued the following week due to an extreme rain event that caused flooding throughout the site. All seeds were obtained from Hui Kū Maoli Ola Native Plant Nursery.

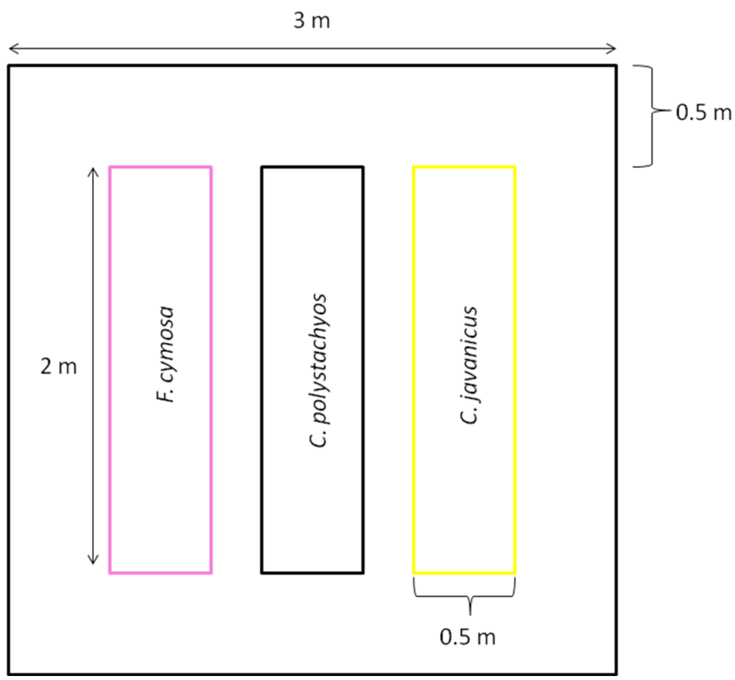

Figure 3-16. Example of seeding configuration within seed only and outplants + seeds subplots.

Figure 3-17. Manually pouring seed + tackifier solution in seeding rectangles.

3. Outplants + Seeds (B):

The outplants + seeds subplots (B) were planted with the five native species and were seeding with the seed + tackifier solution. In each outplant + seeds subplot, 20 outplants (4 individuals/ species) were planted in the same arrangement for a total of 640 seedlings in the outplant + seeds subplots (20 plants/32 subplots). All planting occurred between December 1-15, 2011.

The three sedge species (*Cyperus javanicus, Cyperus polystachyos, Fimbristylis cymosa*) were also seeded in the outplant + seeds subplots. Similar to the seeds only subplots, three 1 m^2 rectangles were demarcated in each of the outplant + seed subplots prior to seeding (for a total of 96 seed rectangles in the subplots) (Figure 3-16). A seed + tackifier solution was prepared for each rectangle, which contained roughly 1,000 seeds of one of the sedge species, 6.7 g of tackifier and 4.7 L of water (see #2 above). The seed + tackifier solution was well stirred and poured into the demarked seed rectangles by hand (Figure 3-17).

All seeding occurred on February 23, 2012 to allow for the maximum time before a high tide event. To assist establishment, each rectangle was watered 2 times per week for the first three weeks after seeding. Supplemental watering of the seeding rectangles was discontinued the following week due to an extreme rain event that caused flooding throughout the site. All seeds were obtained from Hui Kū Maoli Ola Native Plant Nursery.

4. Control:

No native species were outplanted or seed + tackifier solutions were poured within the control subplots.

3.5.3 Supplemental Weeding and Watering Treatments

The following supplemental weeding and watering treatments were applied to each 3 x 3 m subplot:

1. Supplemental weeding:

The supplemental weeding treatment was conducted in late January 2012 and late March 2012, following each data collection. All non-native plants within the 6 x 6 m designated weeding treatment plots were pulled by hand or using various hand tools (e.g., spades, trowels, etc.).

2. Supplemental watering:

The supplemental watering treatment occurred from February 6, 2012 to May 28, 2012. Each 6 x 6 m plot designated to receive supplemental water was manually watered once per week with a hose for 8 minutes.

3. Supplemental watering + weeding:

The watering + weeding plots received both supplemental watering and weeding throughout the experiment. In each 6 x 6 m watering + weeding plot, all non-native plants were pulled by hand or using various hand tools (e.g., spades, trowels, etc.) in late January 2012 and late March 2012. Between February 6, 2012 and May 28, 2012, all watering + weeding plots were manually watered once per week for 8 minutes.

4. Control:

The control plots did not receive any supplemental watering or weeding treatments.

3.6 Post-Treatment Data Collection

Data for the following variables were collected after applying the manual and herbicide treatments and after planting native species:

- Percent cover of all vegetation and substrate:

In January 2012, March 2012, and May 2012, percent cover of vegetation and substrate was recorded in each 3 X 3 m subplot (Figure 3-18) using the same methodology described in Section 3.4 above. All cover estimates were taken by the same individual to minimize observer bias.

Figure 3-18. Reading cover in herbicide square in January 2012.

- Average height of *Batis maritima*:

Data on *B. maritima* height was collected using the same methodology described in Section 3.4 above. This was collected after *B. maritima* removal and planting in January 2012, March 2012, and May 2012.

- Percent survival of outplants:

Survival was measured by assessing the presence or absence of living aboveground plant material. Plants were considered living if at least one green leaf, stem, shoot, or culm was present. Survival data was collected in January 2012, March 2012, and May 2012.

- Growth of outplants:

Growth of each outplant was measured bimonthly after outplanting in January 2012, March 2012, and May 2012. For all species except *Fimbristylis cymosa*, the maximum length of each individual was recorded as the length from the base of the plant to the longest/tallest leaf, shoot, or reproductive stem. Each plant was straightened to its fullest length and the maximum length was determined by placing a fiberglass measuring tape alongside. For *F. cymosa*, growth was determined by measuring the diameter of vegetative material (excluding reproductive culms). It was also noted whether each outplant was vegetative or reproductive.

- Seed germination:

Within each seeding rectangle, three 900 cm^2 (139.5 $inch^2$) squares were systematically placed to record seedling germination as a result of seeding. Observations of the squares were conducted weekly between March and May 2012.

- Waterbird activity:

Information on the presence and activity of waterbirds at the site was recorded at the two permanent bird point count stations using the same methodology described in Section 3.4 above. Bird point counts were conducted weekly from January 2, 2012 to May 14, 2012. All surveys were conducted before 1100 hrs or after 1600 hrs. Incidental observations were also recorded for rare, threatened or endangered waterbirds seen or heard at the site outside of the point count surveys.

4.0 DATA ANALYSES

For illustrative purposes, we graphically present the temporal patterns in the percent cover of outplanted native species, *B. maritima*, other weeds, and outplant species height and survival as a function of *B. maritima* removal and weeding/watering treatments. We only used the final (May 2012) percent cover and height of the species to run a three-way nested ANOVA model. In this model, we specified the *B. maritima* removal, weeding/watering, and species addition as the fixed main effects and the experimental blocks, squares nested within block, and subplots nested within plot as the random effects. Because species were only outplanted in the “outplant only” (O) and in the “seed + outplant” (B) subplots, we only included these subplots for analyzing the percent cover and height of the outplanted species. The percent cover and height data was transformed using the $\log_{10}$ transformation to meet the distribution assumptions of the ANOVA model. All statistical analyses were performed using SYSTAT 12.0 software (SPSS, Inc., Chicago). We used chi-square test to compare the final survival proportions of individual outplanted species for the *B. maritima* removal treatment and for the weeding/watering treatment.

5.0 RESULTS

5.1 Survival of outplanted natives

Overall, *S. portulacastrum* had the highest survival of all native outplanted species, with 85.4% of the outplants surviving until the end of the experiment in May 2012. *C. polystachyos* had the lowest survival, with 44.1% outplant survival at the end of the experiment. Survival for all species decreased over time during the course of the experiment (Table 1, Figure 5-1).

The percent survival of all outplanted species pooled together decreased over time. Percent survival in the mechanical (83.2%) removal squares was more than double the percent survival of all outplanted species within the herbicide (38.9%) application squares ($\chi^2 = 25.6$, df = 3, $P < 0.001$). For each of the five outplanted native species, the percentage of outplants surviving to the end of the experiment was significantly greater in the mechanical versus the herbicide treatment squares (Tables 1).

The effect of weeding and watering on the survival of outplanted species varied. Across all the five species, the percent of outplants surviving to the end of the experiment appeared to be consistently higher in the plots that did not receive the weeding and watering treatment (NWt NWt); however, these differences were not statistically significant for the three monocot species: *C. javanicus, C. polystachyos,* and *F. cymosa* (Table 1). For *L. sandwicense*, the survival rate in plots that did not receive water and weeding treatment (NWd NWt: 80.6%) was significantly higher than in plots that received either one of the weeding or watering (NWd Wt: 58.3%, $\chi^2 = 8.37$, df = 1, $P < 0.001$; Wd NWt 48.6%, $\chi^2 = 16.06$, df = 1, $P < 0.001$) treatment; but, was not significantly different from plots that received both water and weeding treatment (Wd Wt: 75%). For *S. portulacastrum,* the survival rate in the weeding and no watering (Wd NWt) plots was the lowest (73.6%) compared to the other treatment plots (Wd Wt: 87.5% $\chi^2 = 4.43$, df = 1, $P = 0.035$; NWd Wt: 88.9%, $\chi^2 = 5.51$, df = 1, $P < 0.019$; NWt NWd: 91.7%, $\chi^2 = 8.18$, df = 1, $P = 0.004$) (Table 1).

Table 1. Outplant survival data, shown by percent surviving to the end of the experiment. Percent survival shown separately for the removal and weeding/watering treatments.

Species	Total Out-planted (N)	Survival (%)	Removal Treatment			Weeding/Watering Treatment*				
			Mechanical (%)	Herbicide (%)	*P*~	Wd Wt (%)	NWd Wt (%)	NWd NWt (%)	Wd NWt (%)	*P*~
All species	1,440	61.0	83.2	38.9	<0.001	64.4[ab]	59.4[a]	68.9[b]	51.4[c]	<0.001
C. javanicus	288	57.7	78.5	36.6	<0.001	62.5	52.9	65.3	50.0	0.19
C. polystachyos	288	44.1	74.3	14.4	<0.01	47.2	41.9	48.6	38.9	0.61
F. cymosa	288	52.4	77.1	27.8	<0.001	50.0	55.6	58.3	45.8	0.44
L. sandwicense	288	65.6	89.6	41.7	<0.001	75.0[a]	58.3[b]	80.6[a]	48.6[b]	<0.001
S. portulacastrum	288	85.4	96.5	74.3	<0.001	87.5[a]	88.9[a]	91.7[a]	73.6[b]	<0.01

*Wt = watering, NWt = No watering, Wd = weeding, NWd = No weeding; ~Values of *P* are from chi-square tests comparing the proportion of individuals surviving in removal and weeding/watering treatment.

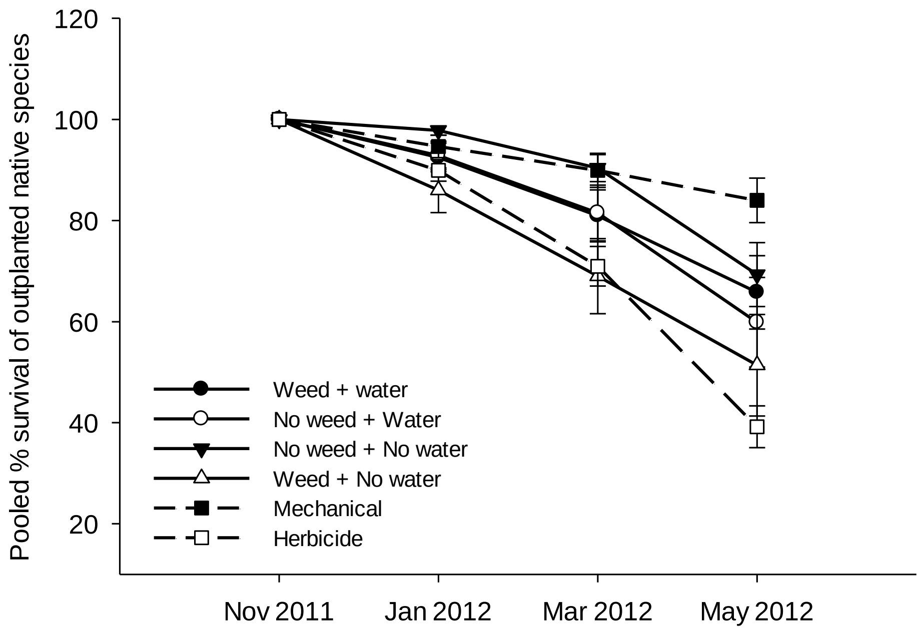

Figure 5-1. Survival of all outplanted natives over time as a function of the weeding and watering treatment and the *B. maritima* removal (mechanical versus herbicide) treatment.

5.2 Percent cover of outplanted natives

In general, the mean percent cover of all outplanted native species pooled together in the two *B. maritima* removal treatments and the four weeding/watering treatments increased during the course of the study (Figure 5-2). The mean cover of all outplanted species increased by 41% in the herbicide removal squares (11.6% mean cover in January 2012 to 16.4% mean cover in May 2012), and by 83% in the mechanical squares (17.8% mean cover in Jan to 32.5% mean cover in May) (Figure 5-2). There was a significant ($P < 0.001$) effect of *B. maritma* removal treatment on the final percent cover of all outplanted native species (Table 2). Mean cover of outplanted species in the mechanical squares (61.3%) was double that in the herbicide (31.2%) treated squares (Table 2, Figure 5-2, 5-3, 5-4).

There was also a significant effect of the weeding/watering treatment on the final percent cover of outplanted species (Table 2, Figure 5-3). As determined by one-way ANOVA, this effect was largely due to the significant differences in mean percent cover within the herbicided squares ($F_{3,28} = 5.32$, $P = 0.005$) rather than the mechanical removal squares (Figure 5-3). In the squares where *B. maritma* was treated with herbicide, there was no difference ($P = 0.999$); in the percent cover of outplants between the weed + water (54.6%) and the no weed + no water (38.8%) plots, and both these treatment plots had significantly ($P = 0.018$ and $P = 0.023$ respectively) greater cover of outplanted species than the plots that received weed + no water (15.7%) (Tukey's pairwise comparisons) (Figure 5-3). The weed + water plots (54.6%) had marginally ($P = 0.08$) higher cover than the no weed + water plots (15.8%); but, there were no statistical differences ($P = 0.103$) between the no weed + no water plots (38.8%) and the no weed + water plots (15.8%) (Figure 5-3).

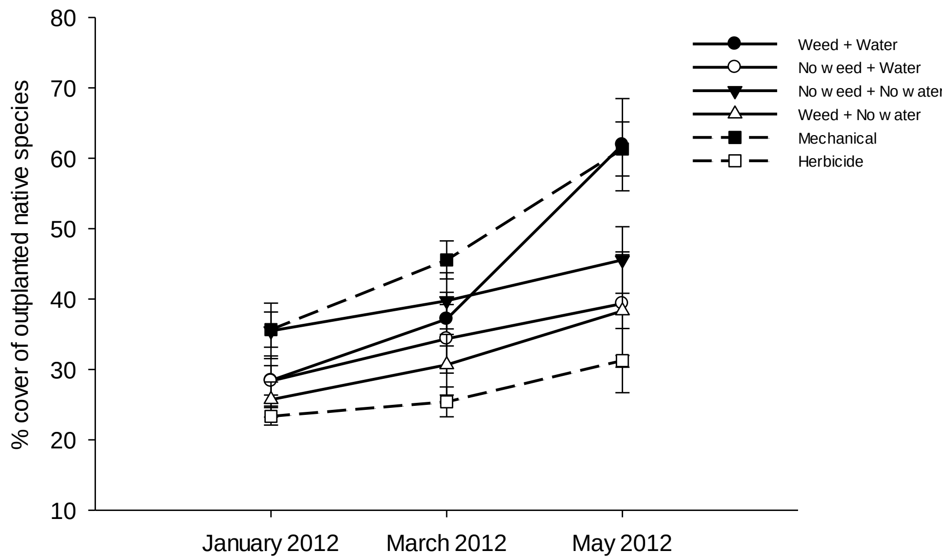

Figure 5-2. Mean percent cover of all outplanted species for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

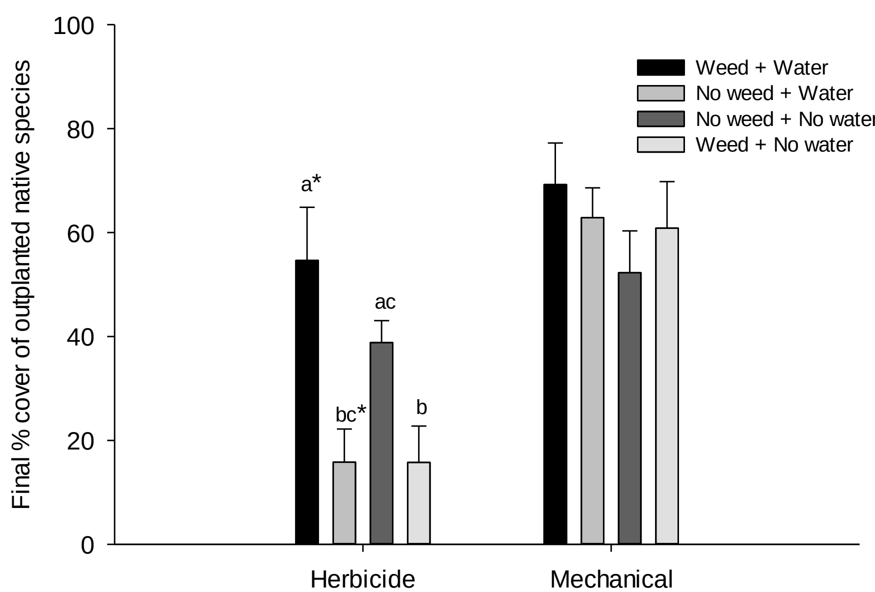

Figure 5-3. Final percent cover of all native outplanted species at the end of the experiment by *B. maritima* removal and weeding/watering treatments. Data are means ± 1 SE. *Difference between Weed + Water and No weed + Water was only marginally (P = 0.08) significant.

Figure 5-4. Cover of outplanted native species in the mechanical plots (above) was nearly twice that in the herbicide treated plots (below).

There was no effect of the species addition treatment on the final cover of outplanted species (Table 2).

Table 2. Nested ANOVA results for the effects of the experimental treatments on final percent cover of native outplants, *B. maritima* and other voluntary species.

Note: “B and O” only indicates that only subplots that had native species outplanted in them (B = outplant + seeds and O =only outplant) were included.

Source of Variation	df	*F*	*P*
Cover of all outplanted native species (B and O only)			
Mechanical/herbicide	1, 48	25.94	<0.001
Weeding/watering	6, 48	2.55	0.032
Species addition	8, 48	1.1	0.441
***Cyperus javanicus* cover (B and O only)**			
Mechanical/herbicide	1, 46	70.58	<0.001
Weeding/watering	6, 46	2.06	0.077
Species addition	8, 46	0.67	0.719
***Cyperus polystachyos* cover (B and O only)**			
Mechanical/herbicide	1, 46	35.61	<0.001
Weeding/watering	6, 46	0.54	0.193
Species addition	8, 46	0.56	0.156
***Fimbristylis cymosa* cover (B and O only)**			
Mechanical/herbicide	1, 47	30.06	<0.001
Weeding/watering	6, 47	1.64	0.159
Species addition	8, 47	1.13	0.364
***Lycium sandwicense* cover (B and O only)**			
Mechanical/herbicide	1, 48	19.52	<0.001
Weeding/watering	6, 48	1.04	0.007
Species addition	8, 48	0.36	0.338
***Sesuvium portulacastrum* cover (B and O only)**			
Mechanical/herbicide	1, 48	14.34	<0.001
Weeding/watering	6, 48	4.16	0.002
Species addition	8, 48	0.83	0.579
Volunteer natives cover			
Mechanical/herbicide	1, 96	41.46	<0.001
Weeding/watering	6, 96	0.62	0.711
Species addition	24, 96	1.06	0.396
***Batis maritima* cover**			
Mechanical/herbicide	1, 96	57.94	<0.001
Weeding/watering	6, 96	38.63	<0.001
Species addition	24, 96	0.48	0.997
Bare ground cover			
Mechanical/herbicide	1, 96	63.96	<0.001
Weeding/watering	6, 96	38.63	0.227
Species addition	24, 96	0.48	0.196
Litter cover			
Mechanical/herbicide	1, 96	301.50	<0.001
Weeding/watering	6, 96	5.52	<0.001
Species addition	24, 96	1.86	0.018

5.2.1 Cyperus javanicus cover

The final percent cover of *C. javanicus* was significantly higher in plots that were mechanically treated (9.1%) than herbicided (2.1%) (Table 2, Figure 5-5). Throughout the experiment, the percent cover of *C. javanicus* appeared to be consistently higher in the mechanical than in the herbicide squares. From January to May 2012, *C. javanicus* cover increased by 5% in plots that were mechanically treated (from 8.7% in Jan to 9.1% in May), and decreased by 69% in plots that were treated with herbicide (from 6.8% in Jan to 2.1% in May) (Figure 5-5).

There was no significant effect of the weeding and the watering treatment on the final percent cover of *C. javanicus* (Table 2). For all weeding/watering treatments, percent cover of *C. javanicus* appeared to decline fairly consistently throughout the experiment and the final percent cover in plots that did not receive weeding and watering was relatively higher than in the other weeding/watering treatment plots (Figure 5-5). There was no effect of species addition treatment on *C. javanicus* cover (Table 2).

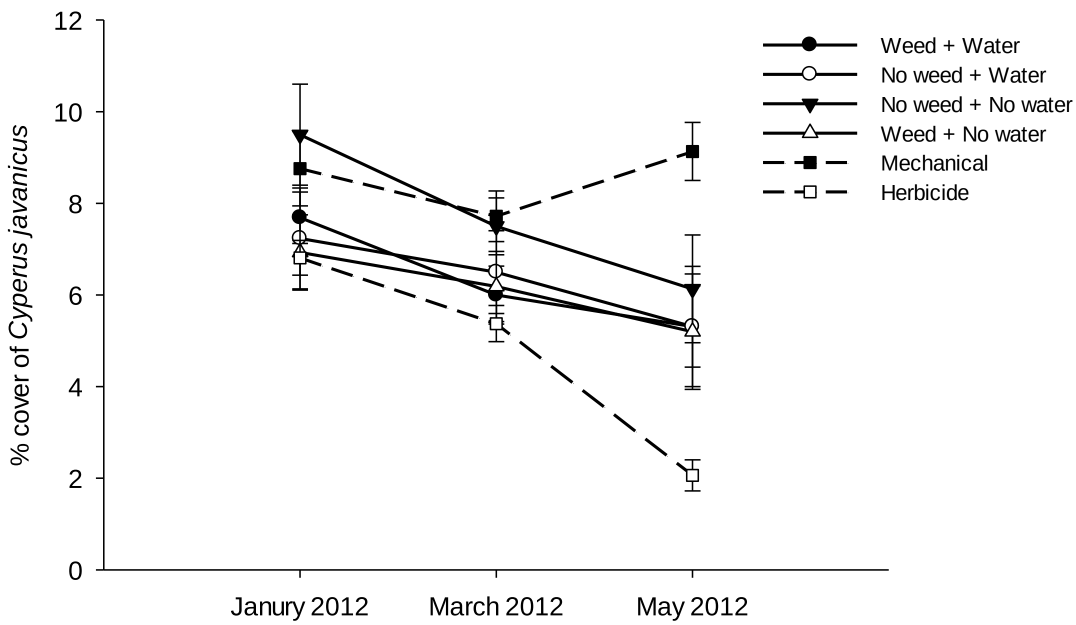

Figure 5-5. Final percent cover of *Cyperus javanicus* for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

5.2.2 Cyperus polystachyos cover

The final percent cover of *C. polystachyos* was significantly higher in the mechanical (7.2%) than in the herbicide (0.9%) treated plots (Table 2, Figure 5-6). There was no effect of weeding/watering and species addition treatment on *C. polystachyos* final percent cover (Table 2).

Throughout the experiment, there was a decreasing trend in the percent cover of *C. polystachyos* across both the *B. maritima* removal and the weeding/watering treatments (Figure 5-6). From January to May 2012, the *C. polystachyos* cover decreased by 11% in the mechanical treatment (from 8.1% in Jan to 7.2% in May), and decreased by 86% in the herbicide treatment (from 6.3% in Jan to 0.9% in May) (Figure 5-6). For all weeding/watering treatments, percent cover of *C. polystachyos* appeared to decline fairly consistently throughout the experiment (Figure 5-6).

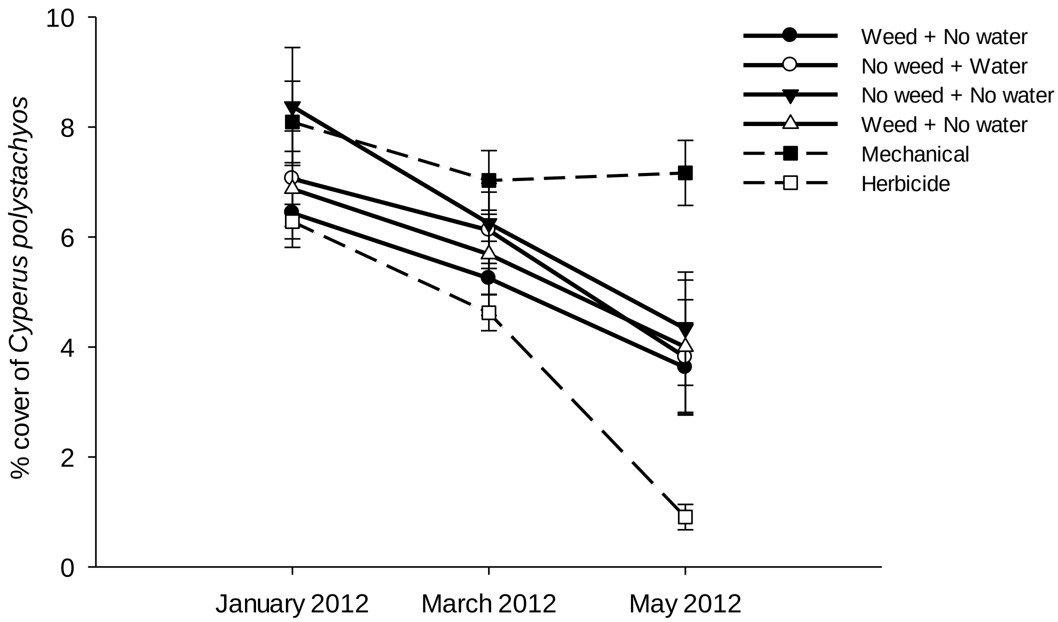

Figure 5-6. Percent cover of *Cyperus polystachyos* for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

5.2.3 Fimbristylis cymosa cover

Removal treatment had a significant effect on the final percent cover of *F. cymosa*. At the end of the experiment, *F. cymosa* mean cover in the plots that were mechanically treated (2.4%) was significantly greater than that in the herbicide (0.9%) treated plots (Table 2, Figure 5-7). From January to May 2012, the *F. cymosa* cover increased by 33% for the mechanical treatment (from 1.8% in Jan to 2.4% in May), and decreased by 33% for the herbicide treatment (from 1.2% in Jan to 0.8% in May) (Figure 5-7).

There was no significant effect of weeding/watering and species addition treatment on *F. cymosa* final percent cover (Table 2). Relative to the other weeding/watering treatments, the percent cover of *F. cymosa* appeared to consistently increase over time in the plots that received the weed + no water treatment, and consistently decrease over time in the no weed + water treatment plots. From March and May 2012, cover increased in the weed + water plots and decreased in the no weed + no water plots (Figure 5-7).

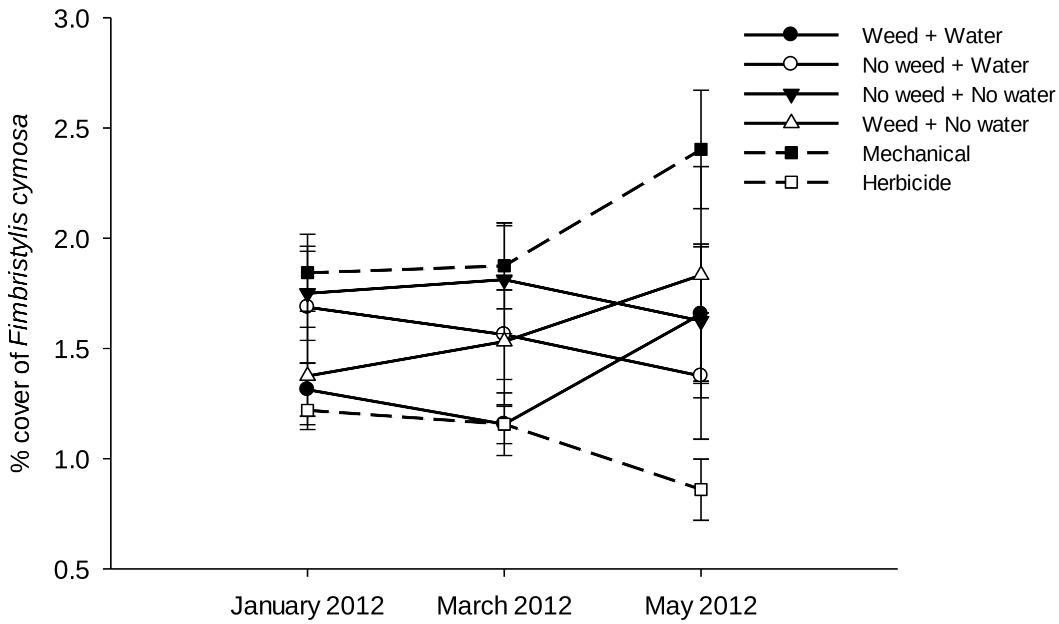

Figure 5-7. Percent cover of all *Fimbristylis cymosa* for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

<u>*5.2.4 Lycium sandwicense cover*</u>

The final percent cover of *L. sandwicense* was significantly higher in mechanical (6.4%) than in the herbicide (1.9%) control squares (Table 2). For the duration of the study, the percent cover of *L. sandwicense* appeared to be consistently higher in the mechanical removal squares than in the herbicide squares. From January to May 2012, *L. sandwicense* cover increased by 27% (from 1.5% in Jan to1.9% in May), and 23% (from 5.2% in Jan to 6.4% in May) in the herbicide and mechanical squares, respectively (Figure 5-8).

There was also a significant effect of the weeding/watering treatment, but no significant effect of species addition treatment, on the final percent cover of *L. sandwicense* (Table 2). As determined by one-way ANOVA, the differences among the weeding/watering treatment plots were significant ($F_{3,28}$ = 4.85, P= 0.008) only for the herbicide squares, but not for the mechanical removal squares (Figure 5-9). In the herbicide squares, the final percent cover of *L. sandwicense* was significantly greater in the no weed + no water plots (3.1%) than in the no weed + water (0.9%) and weed + no water plots (0.8%). *Lycium sandwicense* cover did not differ significantly between the weed + water (2.8%) and the no weed + no water (3.1%) plots (Tukey's pairwise comparisons) (Figure 5-9). Only plots that receive weed + water and weed + no water showed a consistent increase over time in the cover of *F. cymosa* (Figure 5-8).

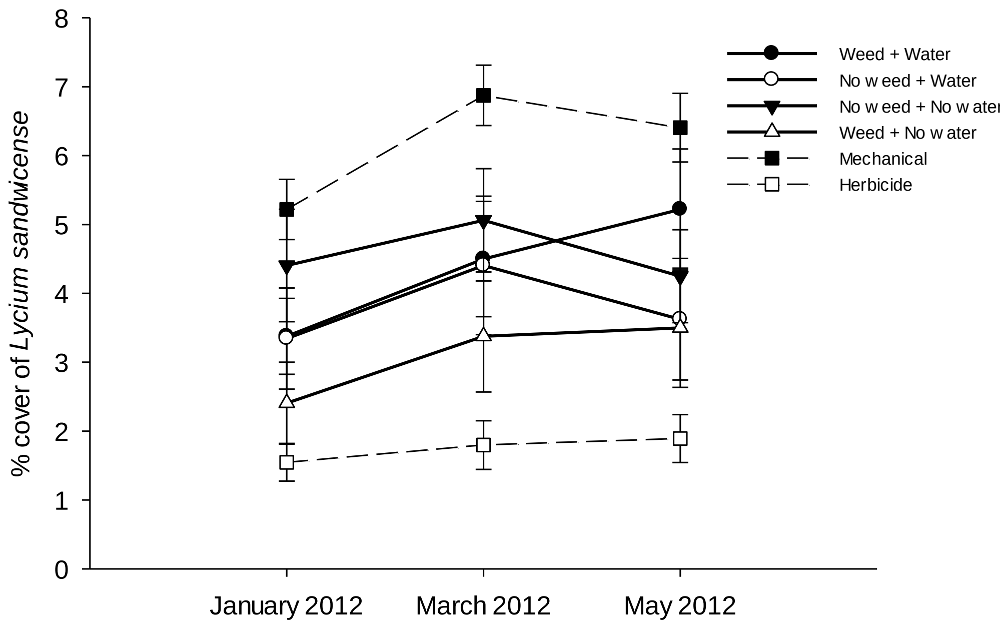

Figure 5-8. Percent cover of all *Lycium sandwicense* for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

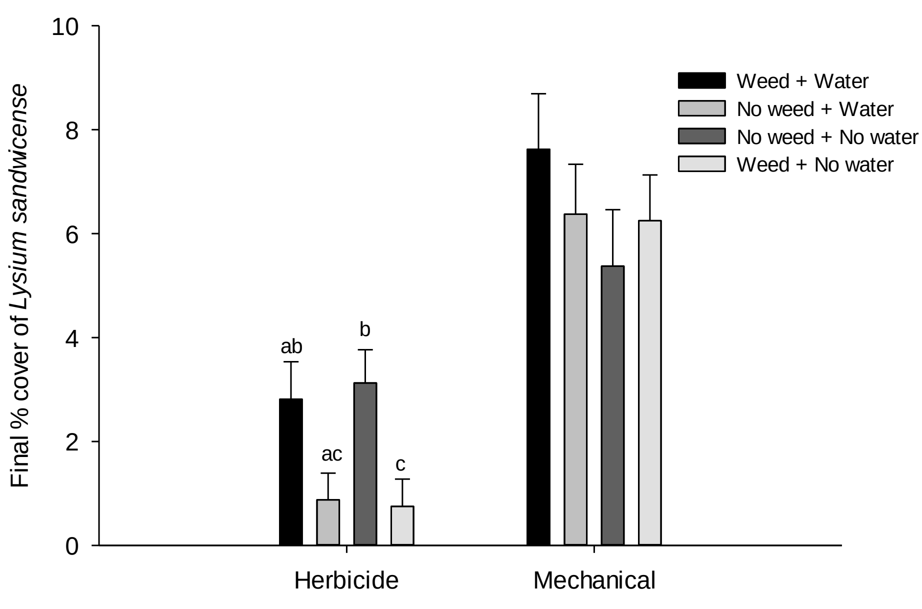

Figure 5-9. Final percent cover of *Lycium sandwicense* at the end of the experiment by *B. maritima* removal and weeding/watering treatments. Data are means ± 1 SE.

5.2.5 Sesuvium portulacastrum cover

During the course of the experiment, *S. portulacastrum* cover consistently increased for all *B. maritima* removal and weeding/watering treatments (Figure 5-10). The final percent cover of *S. portulacastrum* was significantly higher in mechanical (37.3%) than in the herbicide (25.5%) control squares (Table 2). From January to May 2012, *S. portulacastrum* cover increased by 240% (from 7.5% in Jan to 25.5% in May), and 233% (from 11.2% in Jan to 37.3% in May) in the herbicide and mechanical squares, respectively (Figure 5-10).

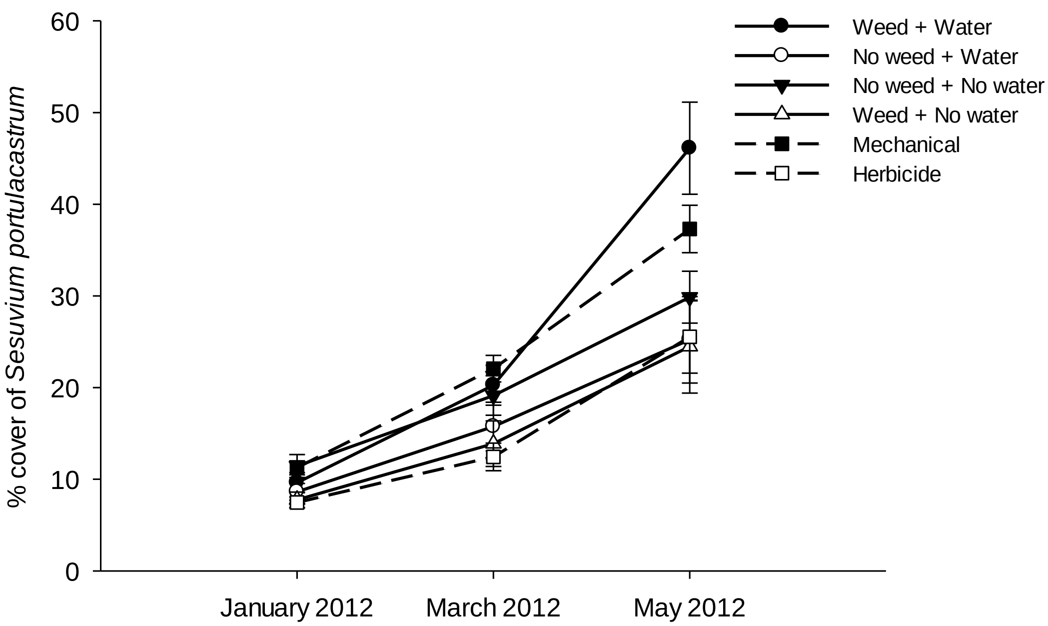

Figure 5-10. Percent cover of all *Sesuvium portulacastrum* for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

The weeding/watering treatments also had a significant effect on the final cover of *S. portulacastrum*; however, species addition treatment did not (Table 2, Figure 5-10). Differences among the weeding/watering treatment plots were only significant for the herbicide treatment plots ($F_{3,28}$ = 5.04, P= 0.006). For the herbicide treatment, as determined by one-way ANOVA's, there was no difference in the final cover of *S. portulacastrum* between the weed + water (46.1%) and the no weed + no water (30.2%) plots (Tukey's pairwise comparisons). The weed + water plots (46.1%) had significantly higher cover that the plots that got only water (12.7%) or only the weeding treatment (13.1%). The no weed + no water plots (30.2%) also had higher cover than the plots that received only water (12.7%) or only the weeding treatment (13.1%); however, this difference was only statistically significant for the latter (Tukey's pairwise comparisons). In the herbicided squares, the weed + water and the no weed + no water plots had significantly greater cover of *S. portulacastrum* compared to plots that received just watering and just weeding (Figure 5-11).

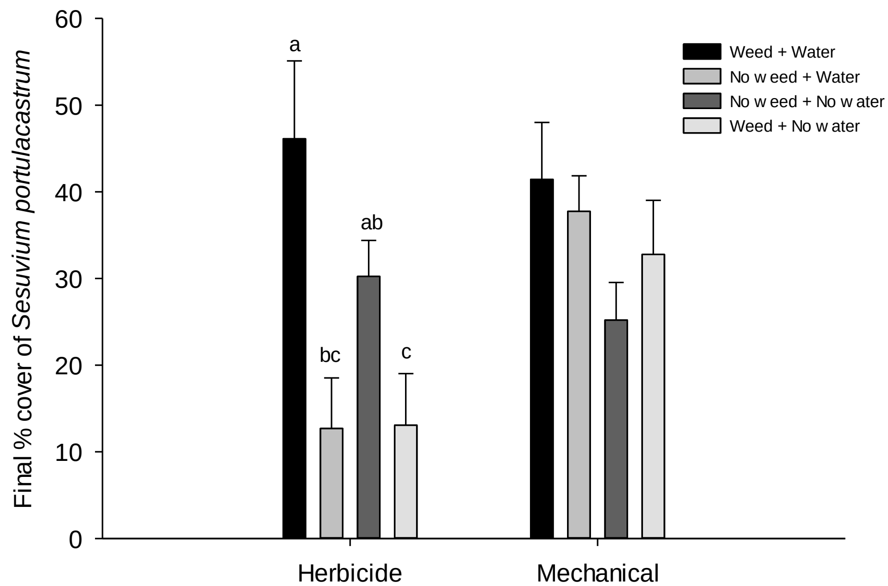

Figure 5-11. Final percent cover of *Sesuvium portulacastrum* at the end of the experiment by *B. maritima* control and weeding/watering treatments. Data are means ± 1 SE.

5.3 Percent cover of volunteer native species

Only two native species, *Solanum americanum* (pōpolo) and *Heliotropium curassavicum* (kīpūkai), came up voluntarily in the experimental plots. Pooled mean cover of these volunteer native species was generally low (<3%), but appeared to increase over the course of the experiment in the mechanical squares. No native species came up voluntarily in the herbicided squares (Figure 5-12).

At the end of the experiment (May 2012), only *B. maritima* removal treatment had a significant effect on the abundance of volunteer native species. In May 2012, the cover of volunteer natives in the mechanical squares (1.9%) was significantly greater than that in the herbicide squares (0%) (Table 2). There was no significant effect of the weeding/watering treatments or the species addition treatments on the cover of native species that came up voluntarily.

5.4 Percent cover of non-native/weedy species

Seventeen non-native species were identified within the squares during the study. This includes *Ageratum conyzoides* (maile hohono), *Alternanthera pungens* (khaki weed), *Atriplex suberecta* (saltbush), *Batis maritima*, *Euphorbia hypericifolia* (graceful spurge), *Chenopodium murale* (goosefoot), *Chloris* sp. (fingergrass), *Conyza bonariensis* (hairy borseweed), *Flaveria trinervia*, *Desmanthus pernambucanus* (slender mimosa), *Lactuca sativa* (prickly lettuce), *Prosopis pallida*, *Sesuvium verrucosum*, *Solanum lycopersicum* (tomato), *Solanum seaforthianum*, *Sonchus oleraceus* (sow thistle), and *Sporobolus indicus* (West Indian dropseed).

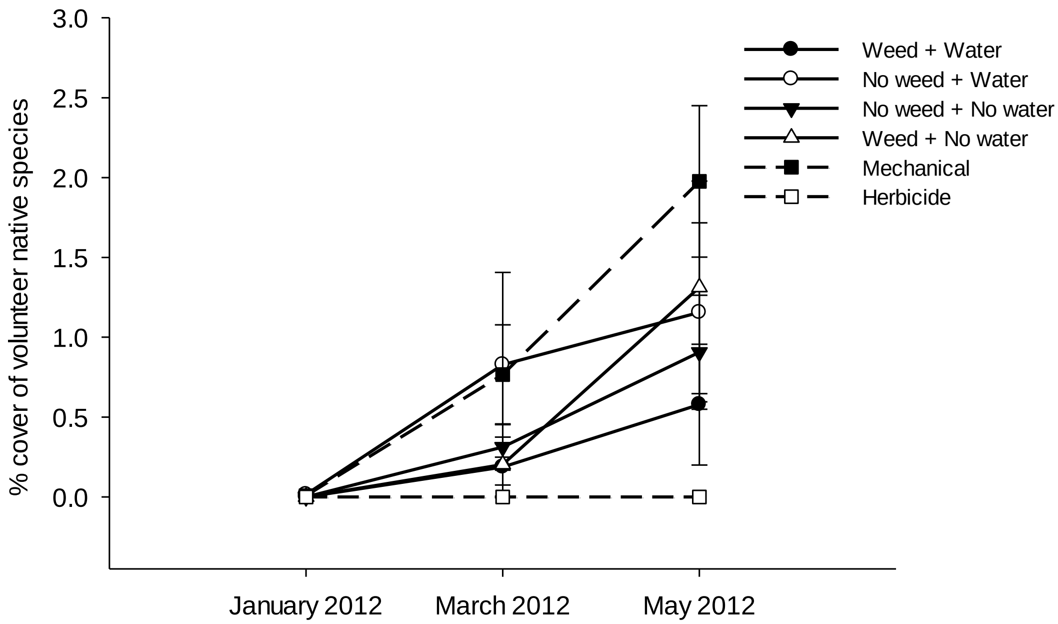

Figure 5-12. Percent cover of two volunteer native species for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

Irrespective of the treatments, the average percent cover of all non-native weedy species in May 2012 was 15.9%, of which the average cover of sixteen weedy species combined (excluding only *B. maritima*) comprised of only 2.7% . Average *B. maritima* cover in May 2012 was 13.2% (± 1.86 SE). Therefore, *B. maritima* was the most abundant weed species in the experimental plots (Figure 5-13).

Batis maritima removal treatment had a significant effect on the final percent cover of *B. maritima*. Percent cover of *B. maritima* at the end of the study was significantly ($P < 0.001$) greater in the mechanically treated plots (20.1%) compared to that in the herbicided plots (6.3%) (Table 2, Figure 5-14).

There was also a significant ($P < 0.001$) effect of weeding and watering treatment on the final percent cover of *B. maritima* (Table 2). As determined by one-way ANOVA's within both the herbicide and the mechanical squares, plots that were not weeded (No weed + No water: 10.4% for herbicide and 35.1% for mechanical; No weed + Water: 14.1% for herbicide and 41.6% for mechanical) had higher abundance of *B. maritima* than plots that were weeded (Weed + Water: 0.5% for herbicide and 2.1% for mechanical; Weed + No water: 0.1% for herbicide and 1.4% for mechanical). There were no significant differences in percent cover of *B. maritima* between the weed + water and weed + no water treatments plots (Figure 5-15).

Figure 5-13. Among the weeds that reinvaded the experimental plots, *B. maritima* was the most abundant weed.

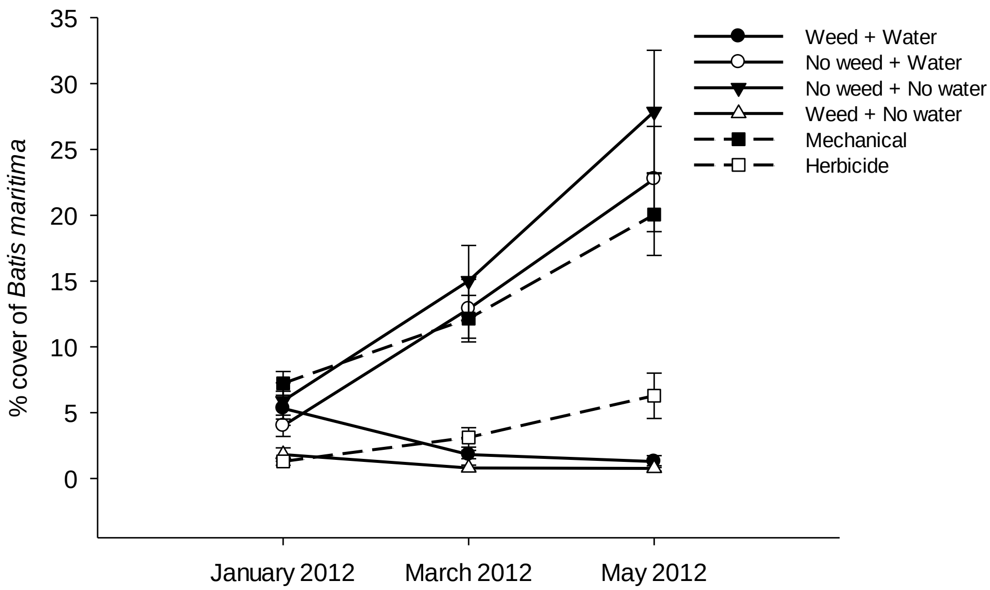

Figure 5-14. Percent cover of *B. maritima* re-growth for the two *B. maritima* removal treatments (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

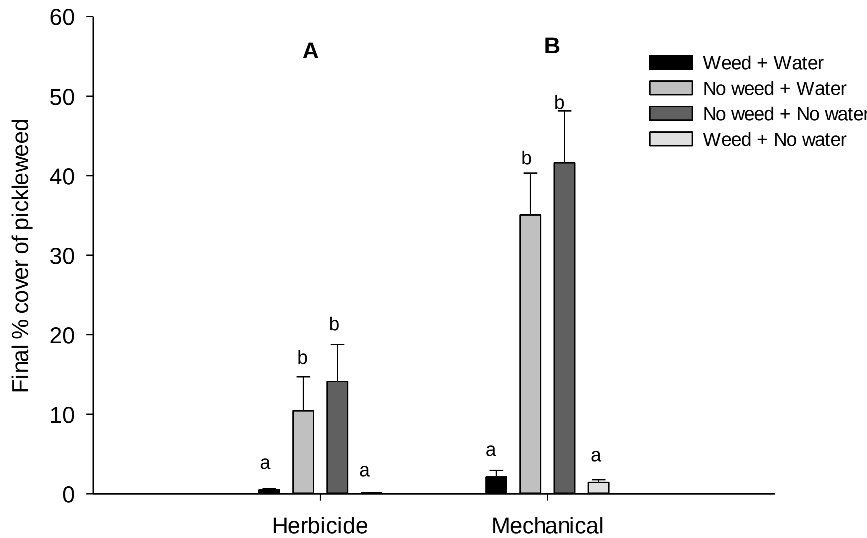

Figure 5-15. Final percent cover of *B. maritima* at the end of the experiment by *B. maritima* removal and weeding/watering treatments. Data are means ± 1 SE.

5.5 Percent cover of bareground and litter

At the end of the experiment, the percent cover of bareground available was significantly higher in the mechanical (36%) than in the herbicide (12%) treated plots (Table 2, Figure 5-16). The weeding/watering treatments and the species addition treatments did not have any effect on the percent of bareground available (Table 2).

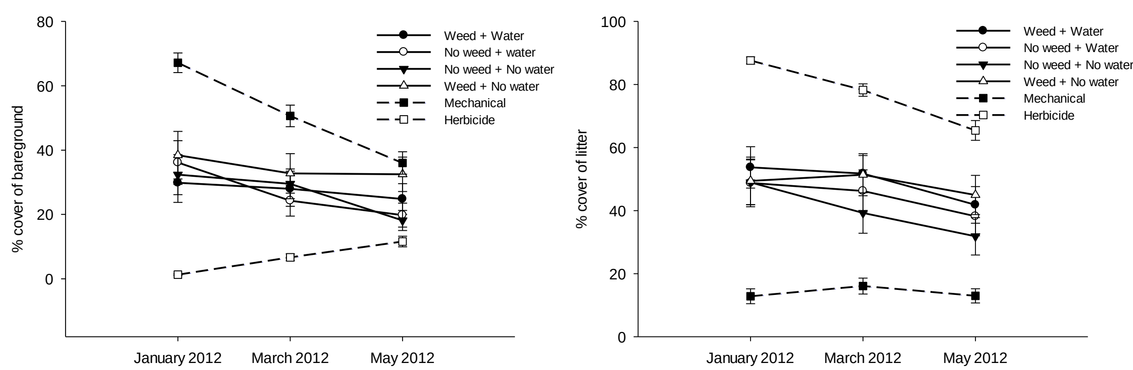

Figure 5-16. Percent cover of bareground and litter for the two *B. maritima* removal (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

The final percent cover of litter had the opposite trend of bareground cover and was significantly greater in the herbicided (65%) than the mechanically (13%) treated plots (Table 2, Figure 5-16). The weeding/watering treatment also had a significant effect on the final percent cover of litter (Table 2). Within the mechanically treated squares, plots that were weeded and watered had the highest cover of litter (24%), followed by weed + no water (16%), no weed + water (7%) and no weed + no water (5%) plots ($F_{3,60}$ = 6.04, P = 0.001 followed by Tukey's pairwise comparisons). In the herbicided squares, there were no significant differences among the weeding/watering treatments ($F_{3,60}$ = 1.94, P = 0.133).

The species addition treatment also had a significant effect on the final percent cover of litter (Table 2). The final litter cover in the control (88%) and the seeding only (71%) subplots was higher than in the subplots that received outplant only (27%) and both the outplant and seeding treatment (52%); but the difference was only statistically significant for the former ($F_{3,12}$ = 5.04, P = 0.017 followed by Tukey's pairwise comparisons).

5.6 Height

None of the three treatments (*B. maritima* removal, weeding/watering, species additions) had a significant effect on the final (May 2012) height of the five outplanted species (Table 3).

Paired Sample t-tests revealed that the three outplanted monocot species [*C. javanicus* (Jan: 81 cm, May: 38 cm, t = 12.88 df = 52 P <0.01), *C. polystachyos* (Jan: 50 cm, May 32 cm, t = 5.04 df = 47 P < 0.001), and *F. cymosa* (Jan: 15 cm, May 12 cm, t = 3.59 df 48 P = 0.001)] on average were significantly shorter in May 2012 than in January 2012. On the contrary, the two dicot species [*L. sandwicense* (Jan: 24 cm, May: 33cm, t = -3.85 df = 50 P < 0.001) and *S. portulacastrum* (Jan: 43 cm, May: 8 cm, t = 6.09 df = 61 P < 0.001)] on average grew in size and were significantly bigger in May 2012 compared to their height in January 2012 (Figure 5-17).

B. maritima removal method had a significant effect on the final height of *B. maritima* in May 2012. *B. maritima* height in the mechanically treated squares (10.3 cm) was significantly higher than that in the herbicide (6.5 cm) squares (Table 3, Figure 5-18). Weeding/watering treatment also had a significant effect on the final height of *B. maritima* (Table 3). As determined by one-way ANOVA's and Tukey's pairwise comparisons for each *B. maritima* removal treatment, plots that did not receive the weeding treatments had significantly (Herbicide: F = 16.91; df = 3, 60; P < 0.001; Mechanical: F = 18.54; df = 3, 60; P < 0.001) taller *B. maritima* than plots that received the weeding treatment in May 2012 (Figure 5-19).

Table 3. Nested ANOVA results for the effects of the experimental treatments on final height of outplanted species and on the final height of *B. maritima*.

Source of Variation	df	*F*	*P*
Height of *Cyperus javanicus*			
Mechanical/herbicide	1, 37	1.716	0.198
Weeding/watering	6, 37	0.440	0.847
Species addition	8, 37	0.123	0.998
Height of *Cyperus polystachyos*			
Mechanical/herbicide	1, 40	0.423	0.519
Weeding/watering	6, 40	1.130	0.363
Species addition	7, 40	0.394	0.900
Height of *Fimbristylis cymosa*			
Mechanical/herbicide	1, 41	0.237	0.629
Weeding/watering	6, 41	1.013	0.430
Species addition	7, 41	0.188	0.986
Height of *Lycium sandwicense*			
Mechanical/herbicide	1,43	0.011	0.916
Weeding/watering	6, 43	0.374	0.891
Species addition	7, 43	0.070	0.999
Height of *Sesuvium portulacastrum*			
Mechanical/herbicide	1, 46	0.159	0.692
Weeding/watering	6, 46	0.256	0.955
Species addition	8, 46	0.072	1.000
Height of *Batis maritima*			
Mechanical/herbicide	1, 48	12.660	0.001
Weeding/watering	6, 48	6.955	<0.001
Species addition	8, 48	0.478	0.865

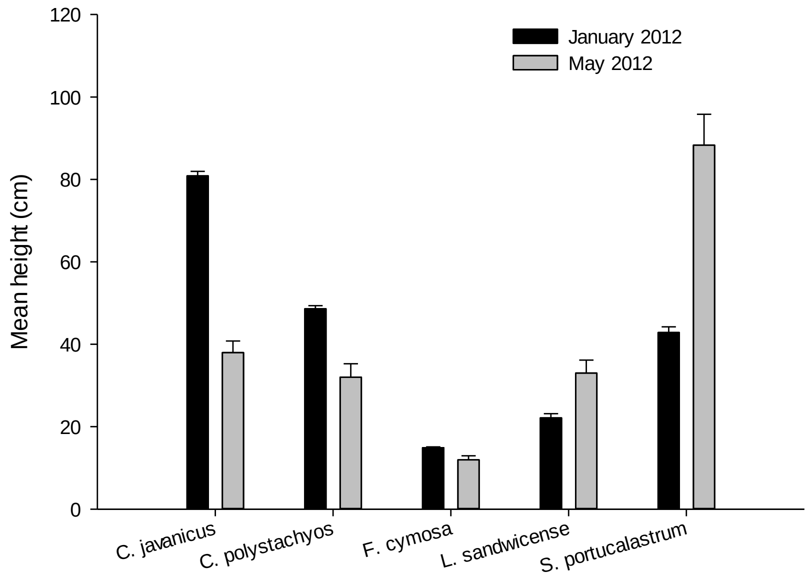

Figure 5-17. Mean height of outplanted native species across all treatment plots.

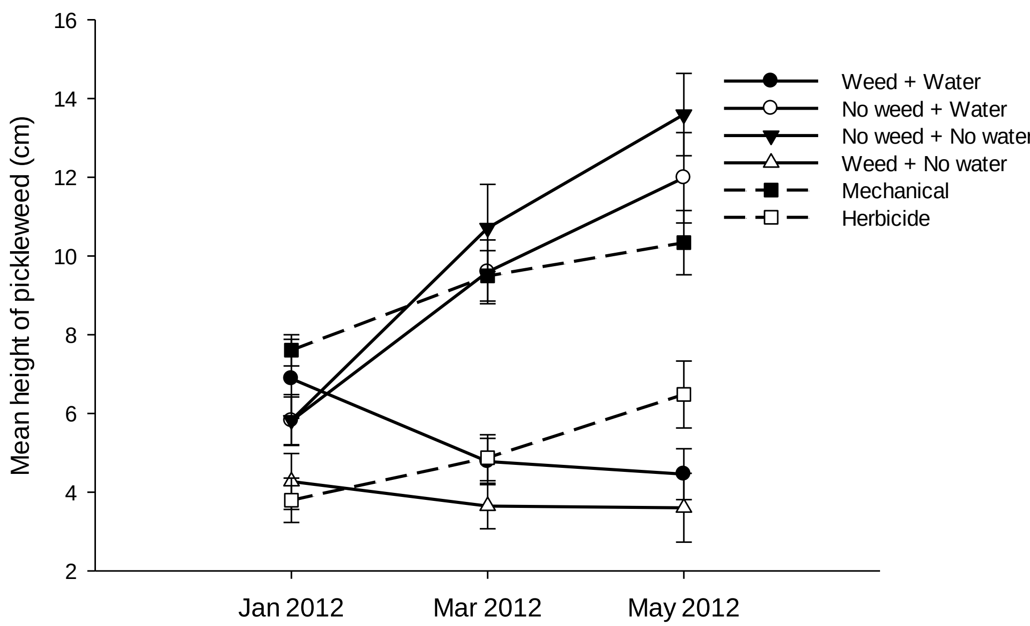

Figure 5-18. Mean height of *B. maritima* for the two *B. maritima* removal (dash lines) and the four weeding/watering treatments (solid lines) over the course of the experiment. Data are means ± 1 SE.

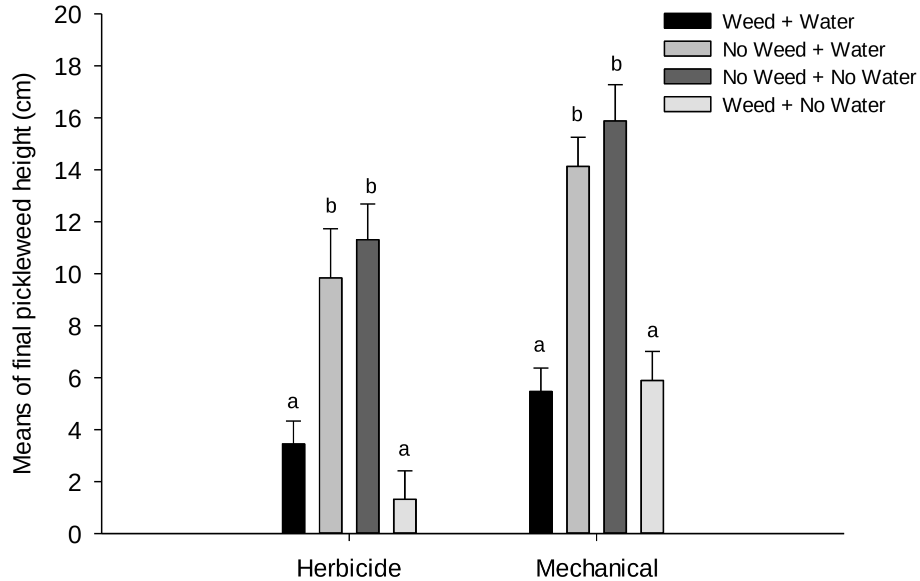

Figure 5-19. Mean height of *B. maritima* in May 2012 by *B. maritima* removal and weeding/watering treatments.
Data are means ± 1 SE.

5.7 Reproduction of the outplanted species

Except for *C. javanicus*, all outplanted native species were flowering throughout the five month duration of the study. On average, the percentage of plants flowering during the course of the experiment was highest for *C. polystachyos* (71.4%) followed by *S. portulacastrum* (65.2%), and *F. cymosa* (52.1%). However, less than 3% of the *C. javanicus* and less than 12% of the *L. sandwicense* plants were flowering during the five month study period (Table 4).

Table 4. The percentage of plants reproducing for each of the outplanted species and the mean percentage reproducing during the five month period of this study.

Outplanted Species	**% of plants reproducing**			**Mean % of plants reproducing (N=3: Jan, Mar, and May data)**
	January 2012	March 2012	May 2012	
C. javanicus	0.3	0.0	7.7	2.7
C. polystachyos	97.6	74.1	42.4	71.4
F. cymosa	75.3	42.0	38.9	52.1
L. sandwicense	3.5	20.1	10.4	11.3
S. portulacastrum	60.4	66.0	69.1	65.2

5.8 Seeding

No seedlings germinated in the squares monitored as a result of pouring the seed + tackifier solution. Some *Cyperus* seeds did germinate outside of the monitoring squares, although this was very limited (Figure 5-20). See SWCA's report titled *Direct Seeding for Restoration of Coastal Wetlands in Hawaii* (DoD Legacy Report No. 11-320) for more information.

Figure 5-20. Carpet of *Cyperus* sp. within one of the seeding rectangles roughly one month after seeding.

5.9 Abiotic Variables

5.9.1 Rainfall

Compared to the thirty year average, rainfall was generally very low and patchy through the study period, with seven out of the eight months having less than 30 mm of total monthly precipitation (Figure 3-3). March was the wettest month with 140 mm of total monthly rainfall. This was largely because of heavy rains (134 mm or 5.3 inches) recorded over the two days of March 5th and 6th.

5.9.2 Soil Moisture

Three subplots in Square 2 were submerged in water and had soil moisture content of 339%, 320%, and 669%. Even after removing these outliers, the soil moisture in the experimental study site was highly variable and ranged from 0.9% to 123% with an average of 32.2% (± 2.65 SE). Square 1 and 4 had the lowest soil moisture content; although this difference was not statistically significant from all of the other squares. There was also considerable variation in soil moisture within each experimental square (Figure 5-21).

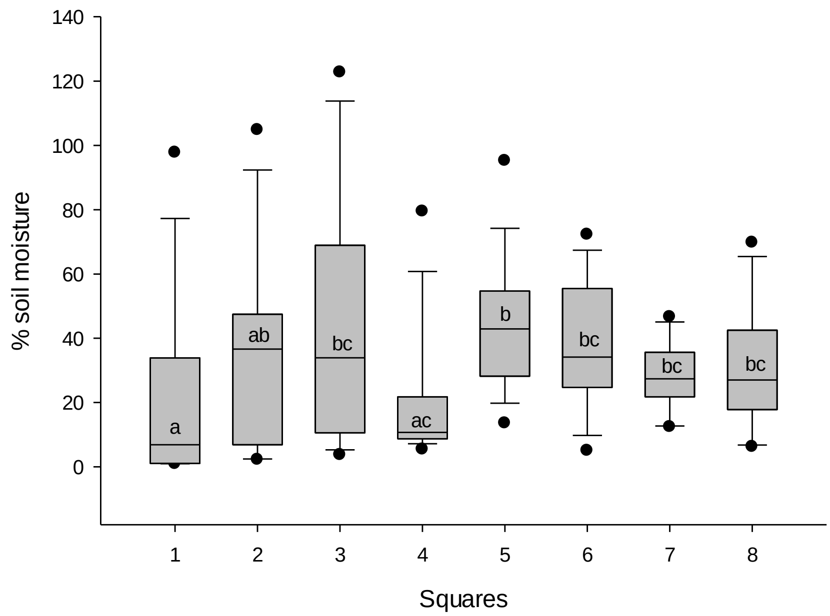

Figure 5-21. Percent soil moisture range and means for the eight experimental squares. Letters denote significant differences in the mean % moisture as determined by one-way ANOVA and Tukey's pairwise comparisons.

5.9.3 Soil Temperature

In October 2012, the soil temperature across the experimental plots ranged from 23.2 ^{o}C to 33.6 ^{o}C with an average of 26.8 ^{o}C (± 0.2 SE). Square 1 had the highest soil temperature (28.2 ^{o}C) and was statistically different compared to all other squares, except Squares 3 and 4. In general, it appeared that Squares 5- 8 (which are more inland) had lower soil temperatures compared to Squares 1- 4 (Figure 5-22).

5.9.4 Soil pH

In general, the soils in the experimental plots were moderately alkaline; pH ranged from 7.1 to 8.4 with average of 7.7 (± 0.02 SE) (Figure 5-23). One-way ANOVA followed by Tukey's pairwise comparisons revealed that Square 4 (8.1 pH) had the highest pH compared to all other squares (Figure 5-23).

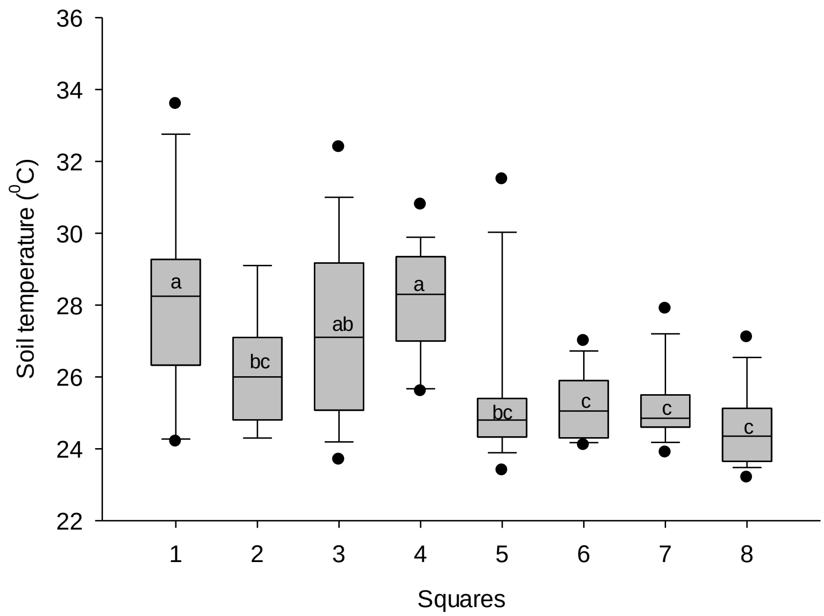

Figure 5-22. Soil temperature range and means for the eight experimental squares. Letters denote significant differences in the mean temperature as determined by one-way ANOVA and Tukey's pairwise comparisons.

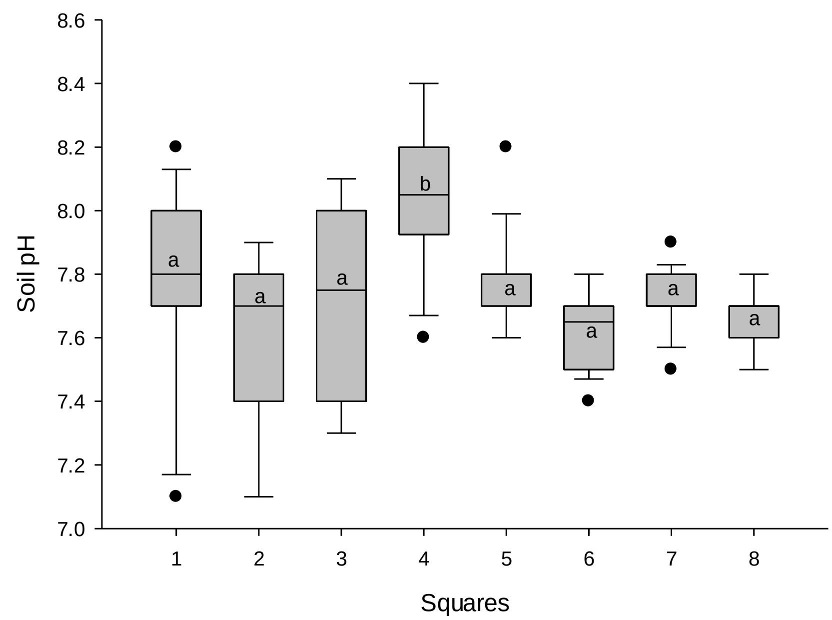

Figure 5-23. Soil pH range and means for the eight experimental squares. Letters denote significant differences in the mean pH as determined by one-way ANOVA and Tukey's pairwise comparisons.

5.10 Waterbird Activity

Five waterbird species were recorded during the point count surveys - ‘auku‘u or black-crowned night heron (*Nycticorax nycticorax hoactli*), kōlea or Pacific golden-plover (*Pluvialis fulva*), ‘ūlili or wandering tattler (*Tringa incanus*), manu-o-kū or white (fairy) tern (*Gygis alba*), and mallard x Hawaiian duck hybrid (*Anas platyrhynchos* x *wyvilliana*). These birds were recorded in very low numbers, averaging one individual or less per point count (Figure 5-24). All of these species are indigenous to the Hawaiian Islands or are common migratory birds. The white tern is listed by the State of Hawai‘i as a threatened species on O‘ahu. The Pacific golden-plover and wandering tattler, both migrants, were the most common species observed during the point count surveys (Figure 5-24). Migratory birds typically winter in the main Hawaiian Islands from August through May.

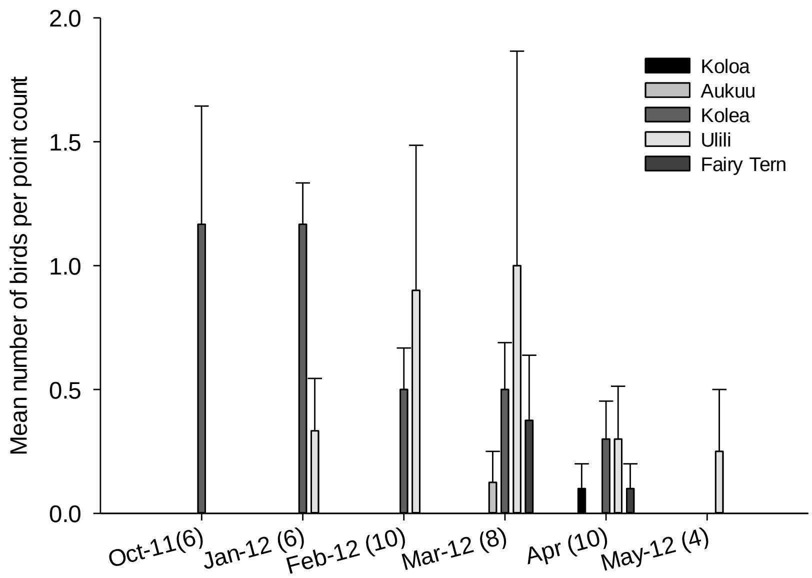

Figure 5-24. Mean number of waterbirds seen or heard per point count from October 2011 to May 2012. Numbers in parentheses is the number of point counts per month.

Five additional waterbird species were observed incidentally on dates or during times outside of the timed point counts. These include: the endangered Hawaiian stilt (*Himantopus mexicanus knudseni*) (2 observation days), black-bellied plover (*Pluvialis squatarola*) (1 observation day), ‘akekeke or ruddy turnstone (*Arenaria interpres*) (2 observation days), cattle egret (*Bubulcus ibis*) (1 observation day), and hunakai or sanderling (*Calidris alba*) (1 observation day). Only the cattle egret is not native to the Hawaiian Islands. SWCA observed the Hawaiian stilts flying over Āhua Reef, but did not observe them landing at this site.

Only the Pacific golden-plover and wandering tattler were observed foraging or loafing within the experiment areas. The other waterbird species were only seen flying over the site. No nesting was observed at the study site.

6.0 DISCUSSION

6.1 Effects of herbicide versus mechanical removal of *B. maritima*

An overwhelming result of this study was that survival and growth of all outplanted species was significantly and consistently higher across all outplanted species in mechanical treated areas than in the areas treated with the herbicide Habitat®. The re-growth of weedy species, especially *B. maritima*, was also lower in the plots treated with Habitat® than in the plots from which *B. maritima* was manually pulled and then tilled.

Absorption of Habitat® takes place both through foliage and roots (BASF 2004). Habitat is a nonvolatile, water soluble herbicide and degradation primarily occurs as a result of microbial degradation in soil and photolysis in water (BASF 2004). In water, Habitat® dissipates rapidly (3 to 5 days and 1.9 to 14.5 days in murky pond waters) and the majority of it remains in the water, with very little dissipation into the sediment. However, soil dissipation of Habitat® under aerobic conditions has a half-life of 26 to 143 days (BASF 2004). SWCA applied the Habitat® herbicide on October 31, 2011 and outplanting of the seedlings of wetland species started 30 days post application during the first week of December 2011. Because of the complex microtopography of the site and the low rainfall during that time, large areas of the site where Habitat® was applied and species were outplanted were not inundated or saturated. It is possible that residual Habitat® persisted in the soil at the time of outplanting and for several weeks afterwards at Āhua Reef due to these dry conditions. This might have caused the observed drastic decrease in the survival of outplanted species and the growth of all species (natives and weeds) in the herbicide versus the mechanical removal plots. All plants in the mechanically treated squares appeared healthier than those in the squares treated with herbicide (Figure 6-1).

SWCA chose to use the herbicide Habitat® because of its proven effectiveness to control *B. maritima* in the wetlands of James Campbell National Wildlife Refuge (NWR) on Oʻahu. Managers of this NWR have used several methods such as water level management, mechanical, and chemical methods to control *B. maritima*. They also tested the effectiveness of three herbicides approved for wetland use: AquaMaster®, Habitat®, and Rodeo® and found that Habitat® provided a more complete control and longer period of control of *B. maritima* than other tools and herbicides used in the past (M. Silbernagle, Biologist, USFWS, pers. comm.). No native wetland plant species were outplanted at the James Campbell NWR following treatment with Habitat®; therefore, the potential impacts of Habitat® on native outplants at this site is not known.

However, at the Hāmākua marsh on Oʻahu, managers observed negative impacts of Habitat® on their outplanted species. *Cyperus javanicus* seedings did not survive in areas even six month post application of 1% Habitat®. Other coastal species such as *Scaevola* sp. (naupaka) and *Myoporum sandwicense* (naio) died when outplanted 90 days post application with 1% Habitat®. In areas herbicided with higher (3%) concentration of Habitat®, outplanting with native species was unsuccessful even 12 month post application (K. Doyle, Biologist, DLNR, pers. comm.)

Figure 6-1. Plants in the mechanical squares (above) appeared healthier than those in the squares treated with herbicide (below).

6.2 Effects of weeding and watering

Another unexpected result of this study was that removal of weedy species and addition of supplemental water did not improve the survival and growth of the outplanted species. There were no differences in the survival and growth of the five outplanted native species between the two treatments of weed + water and no weed + no water. Furthermore, the survival and growth of *L. sandwicense*, *S. portulacastrum,* and all outplanted species combined was higher in the no weed +

no water plots than in the plots that received just weeding or just watering treatments; however, these differences were only observed in the herbicided squares.
The reason why we did not see any positive effects of weeding could be because the experiment was only conducted for a period of five months. At the end of five months, the mean percent cover of the outplanted native species and invasive weeds (including *B. maritima*) in the no weed + no water plots were 46% and 28%, respectively. It is possible that the invasive weeds were not abundant enough at the end of five months to have a negative impact on the survival and growth of the outplanted species through competition. These results suggest that these outplanted native species can at least establish under harsh biotic and abiotic conditions at Āhua Reef; however, long term data is needed to provide better insight into the ability of these species to persist at Āhua Reef. Another explanation for the observed effects of weeding and watering could be that the disturbance caused by watering the plants with a hose and using hand tools to remove weeds that were in close proximity to the native outplanted species had a negative effect on outplant seedlings. It is also possible that the amount of supplemental water (eight minutes of spray over the entire plot once per week) was insufficient to have an overall positive impact in a harsh coastal wetland system such as Āhua Reef.

Environmental conditions at a restoration site greatly influence the establishment of outplanted species (Fattorini 2001; Zedler 2000). In wetland systems, hydrology and water level play an important role in the establishment of wetland plant species (Callaway et al 1997; Keddy 1999; Middleton 1999). Salinity has shown to be an important factor that profoundly restricts the survival and establishment of outplanted wetland species (Callaway et al 1997; Hootsmans and Wiegman 1998; Keddy 1999). The coastal wetland of Āhua Reef is a harsh environment with uneven topography, complex hydrology, and very diverse and patchy soil conditions (Figure 6-2). During the course of the study, SWCA observed that at high tide (> 2 m) inundated areas expanded and areas that typically did not have surface water were submerged in water for varied periods of time. The wide range in soil pH, moisture content and temperature suggests that these soil parameters probably vary widely at any given time at Āhua Reef.

The relative tolerance of the six major species in the experimental study to abiotic factors such as soil salinity and temperature is also known to vary (Brimacombe 2003). *Batis maritima* and *S. portulacastrum* are halophyte species known to thrive under saline and even hypersaline conditions (Wagner et al. 1999, Brimacombe 2003). *Lycium sandwicense* is known to occur in subsaline coastal habitats (Wagner et al. 1999), while the three sedge species (*C. javanicus*, *C. polystachyos* and *F. cymosa*) are known to occur in coastal, brackish, and even freshwater systems (Stemmermann 1981; Wagner et al. 1999; Brimacombe 2003). It is possible that the differential response of the wetland species to various abiotic factors in harsh coastal wetland of Āhua Reef facilitated their coexistence.

Stress mediated positive interactions are common in plant communities in physically harsh environments, through amelioration of local stressful conditions such as increasing salinity (Bertness and Leonard 1997; Hacker and Bertness 1999). It is possible that the shading effect of weeds increased soil moisture in the plots and the presence of the halophyte weed *B. maritima* resulted in lower soil salinities thereby facilitating the survival and growth the other sedge species that are relatively less tolerant of high salinity and low moisture conditions. Such positive interactions among species have been observed in several salt marsh habitats, where under high salt stress, plants interacted positively by shading the soil and reducing porewater salinities (Bertness 1991; Bertness and Shumway 1993). In a restoration experiment in the wetlands of the

Honouliuli Unit of the Pearl Harbor NWR on Oʻahu, Brimacombe (2003) outplanted four sedge species and three ground cover species and found that *C. javanicus, C. polystachyos, C. laevigatus* (makaloa)*,* and *Jacquemontia ovalifolia* (pāʻū o hiʻiaka) were not affected by competition from weed species while S*. portulacastrum, Bolboschoenus maritimus* (kaluhā)*, and Sporobolus virginus* (ʻakiʻaki) performed better in absence of invasive weeds. The results were however attributed to the different growth habits of the natives (upright) versus the invader (prostrate). In upland harsh systems such as dry forests in Hawaiʻi, Cabin et al. (2002) found that the establishment of seeded natives was higher in the non-weeded plots because of the lower soil moisture conditions.

Figure 6-2. Soils at Āhua Reef ranged from sandy (above) to clay (below).

6.3 Seeding

Very little germination was observed as a result of seeding with the seed + tackifier solution. The three Cyperaceae species used are known to germinate relatively quickly and are not expected to take more than 3 months to germinate in appropriate conditions (Lilleeng-Rosenberger 2005). Thus, seeding did not have a measurable effect on native species cover. Although a tackifier slurry was used to keep seeds within the experimental area, it is possible that heavy rains washed seeds outside of the area. As shown in Figure 3-3, March was the wettest month at Āhua with 140 mm of total monthly precipitation; however, this was largely because of heavy rains (134 mm) recorded during March 5 and 6, 2012. Brimacombe's (2003) lab germination trials also suggest that the two *Cyperus* species will not germinate under dry conditions or in high salinity levels. See SWCA's report titled "*Direct Seeding for Restoration of Coastal Wetlands in Hawaiʻi*" for more information.

6.4 Waterbirds

There are four endangered Hawaiian waterbird conservation areas within five miles of Āhua Reef: Pohala Marsh, the Honouliuli Unit and Waiawa Unit at the Pearl Harbor National Wildlife Refuge (NWR), and the Haseko Inc. Army Corps of Engineers Wetland Preservation Area in ʻEwa. Pouhala Marsh and Pearl Harbor NWR have sizable populations of endangered Hawaiian waterbirds at these wetlands (USFWS 2009). In spite of the close proximity of Āhua Reef to these wetlands, few native Hawaiian waterbird species were observed at Āhua Reef. Endangered stilts were only observed flying over Āhua Reef by SWCA; however, others have observed this species loafing and foraging at the study site (J. Fujimoto, Wildlife Biologist, NAVFACPAC, pers. comm.). However, the native endangered waterbirds that do visit this coastal wetland do not seem to utilize it for nesting. A likely reason for this could be because the dense cover of *B. maritima* and *Rhizophora* at Āhua Reef harbors invasive mammals such as rats, cats and mongoose. SWCA on several occasions during the course of this experiment observed mongoose around the study area. Managers of JBPHH are actively trapping for these small mammals; the removal of dense vegetation such as invasive *B. maritima* and *R. mangle* will further reduce suitable habitat for these predators.

Another factor that may contribute to low waterbirds levels at Āhua Reef is the heavy daily traffic of fisherman and residents of Hickam Air Force Base for recreational activities. More importantly, there is no enforcement against people bringing dogs to this wetland and dogs have been seeing running off leash through the wetland. The immediate coastal area (less than a ¼ mile away) to the west of the study site has earned the name "Dog Beach" because at low tide, dogs are let off their leashes to play in the water. During annual statewide bird counts, biologists have observed off leash dogs in this area and have documented them flushing entire flocks of shorebirds including ruddy turnstones, Pacific golden plovers, and sanderling (J. Helm, Biologist, NAVFACPAC, pers. comm.). These unnecessary influences will discourage waterbirds from nesting and foraging in the area, due to the constant disturbance, even if the wetland is restored.

6.5 Restoration implications

This study provides insights into the restoration of coastal wetlands in Hawaiʻi. Results of this study suggest that it is possible to at least partially restore a highly degraded coastal wetland such as Āhua Reef. Before the experiment began, roughly 91% of the study site was covered with *Batis* *maritima* and no native species were present. At the end of the five month study, the mean percent cover of *B. maritima* was 13% and native species cover (including outplanted and volunteer species) was 25%. According to the INRMP, Āhua Reef should be managed to have less than 25% cover of pest plants including *B. maritima* and *R. mangle*. Planting native species can jump-start the growth and production of native vegetation; however, long-term management and invasive species control program will be needed to restore Āhua Reef to a functional coastal wetland.

7.0 CONCLUSIONS AND RECOMMENDATIONS

1) A long-term restoration plan with perhaps a phased approach should be developed for restoring Āhua Reef to a fully functioning coastal wetland. Habitat® is an effective herbicide that could be used for large scale control of invasive plants in wetlands. However, managers need to be cautious about planting of native species following application of Habitat®. The dissipation of Habitat® in the field varies with soil and water conditions. It is important to ensure that there is no residual Habitat® herbicide in the substrate at the time of outplanting with native wetland species. A time interval of 100-200 days is recommended between site preparation and outplanting (particularly with imazapyr, active ingredient in Habitat®) to observe efficacy of the initial treatment, provide follow up treatment if necessary, and, more importantly, to allow for natural dissipation of the herbicide to occur (J. Leary, Invasive Weed Specialist, CTHAR, pers. comm.).
2) Watering during the first month might be essential for the establishment of the outplanted species. However, subsequent weeding and watering of the outplanted species may not be necessary at least for the first few months when the weeds are not abundant. However, if not weeded later it is likely that the outplanted native would succumb to the aggressive growth of *B. maritima*, the dominant weed at Āhua Reef.
3) Selection of plant species for restoration should be based on environmental tolerances, growth requirements, competitive abilities and (if known) whether the species previously existed there at the restoration site. All five species tested in this study are suitable for outplanting at Āhua with *S. portulacastrum* having the highest survival and growth and *C. polystachyos* having the lowest survival and growth. More research should be conducted to test environmental factors which may hinder the survival and growth of these species. Factors examined should include tolerances to salinity, water and nutrient levels and soil composition. Further research also needs to test the ability of native wetland plant species to directly compete with invasive wetland plant species.
4) The fact that we did not see recruitment of any of the native wetland species within our study plots; not even in the mechanical plots that were rototilled suggests that there is no seed bank of native coastal wetland plant species at Āhua Reef. Restoration efforts in the near future should focus on outplanting of native species. However, strategies for direct seeding should be explored under the different topographic and soil conditions because natural recruitment of native plants can provided a tremendous boost to the restoration efforts at Āhua Reef.
5) Endangered Hawaiian stilts have occasionally been observed foraging at Āhua Reef (USFWS 2009). Limited studies on Hawaiian wetlands indicate that native wetland plants harbor diverse and richer arthropod communities and, therefore, are more attractive to Hawaiian waterbirds than wetlands dominated by monocultures of invasive species, such as *Rhizophora* spp. and *B. maritima* (Rador 2005). Due to the proximity of Āhua Reef to the Honolulu International Airport and the BASH zone, it is not currently managed for

waterbirds. The USFWS Biological Opinion however stipulates that Āhua Reef be managed for open waters of 1 to 6 inch depth and that JBPHH should enforce their policy to restrict dogs from Āhua Reef. It is possible that the restoration of Āhua Reef to a fully functional coastal wetland might in fact draw certain species of waterbirds away from the BASH zone. In a recent study in the Goleta Slough wetlands near Santa Barbara Airport, researchers found that dangerous bird flights over the airfield were less frequent to and from the tidal basin opened up for restoration than from the non-tidal basin. They expect airfield crossings to further decline as native plants grow in this tidal basin (Kwok 2011).

8.0 ACKNOWLEDGEMENTS

SWCA gratefully acknowledges the support and input received for this project from NAVFAC Hawaii and NAVFAC Pacific. Special thanks to Joel Helm, Cory Campora, Justin Fujimoto, Patricia Coleman, and Aaron Hebshi. This project would also not have been possible without assistance from Hui Kū Maoli Ola and Eagle Scout Troop 97 and their families. We would like to thanks volunteers from Hickam AFB, University of Hawaiʻi, and Kupu's Urban Corps. Most importantly, SWCA acknowledges the DoD Legacy Resource Management Program and the support staff in allowing this project to take place.

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