Aerial Invasive Plant Survey

Guadalupe-Nipomo Dunes National Wildlife Refuge

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Acronyms and Abbreviations

CDFW	California Department of Fish and Wildlife
Cal-IPC	California Invasive Plant Council
CCP	Comprehensive Conservation Plan
CNPS	California Native Plant Society
DPAs	Dune Protection Areas
GIS	Geographic Information Systems
GNDNWR	Guadalupe-Nipomo Dunes National Wildlife Refuge
GPS	Global Positioning System
IPMP	Invasive Plant Management Plan
kph	kilometers per hour
LCSLO	Land Conservancy of San Luis Obispo County
mi	mile(s)
mph	miles per hour
NDC	Nipomo Dunes Complex
NNG	Non-native grass
NRI	Native Range, Inc.
The Dunes	Nipomo Dunes Complex
Refuge	Guadalupe-Nipomo Dunes National Wildlife Refuge
RPMA	Refuge Priority Management Area
USFWS	United States Fish and Wildlife Service
WCS	Wildlands Conservation Science, LLC.

1.0 Introduction

At 2,553-acres, the Guadalupe-Nipomo Dunes National Wildlife Refuge (GNDNWR, the Refuge; Figure 2) was established in 2000 and is part of the 18-mile long Nipomo Dunes Complex (NDC, the Dunes) along the Central Coast of California (Figure 2). This dune system is generally sub-divided into three zones: The Callendar Dunes (Pismo Beach to Oso Flaco Lake), Guadalupe (Oso Flaco Lake to Santa Maria River) and Mussel Point Dunes (Santa Maria River and Mussel Rock; Holland et al 1995). The Refuge and the greater NDC represent one of the largest coastal dune landscapes along the west coast of North America and provides habitat for a variety of state and federally listed plant and animal species. In 1974, the NDC was designated a National Natural Landmark in recognition of its unique natural heritage (USFWS 2016).

Habitats at GNDNWR include fore dune, open sand, back dune, coastal dune scrub, dune swale, and several wetland types (Holland et al 1995). Home to more than 120 species of rare plants and animals, GNDNWR provides refuge for species such as La Graciosa thistle (*Cirsium loncholepis*), surf thistle (*Cirsium rhothophilum*), beach spectaclepod (*Dithyrea maritima*), giant coreopsis (*Leptosyne gigantea*), Marsh sandwort (*Arenaria paludicola*), Gambel's watercress (*Rorippa gambellii*), California red-legged frog (*Rana draytonii*), western snowy plover (*Charadrius nivosus* ssp. *nivosus*), and California least tern (*Sternula antillarum* ssp. *browni*).

In support of the United States Fish and Wildlife Service's (USFWS) mission statement, the Refuge was designated to conserve central California coastal dune and associated wetland habitats as well as to promote the recovery of native plants and animals. Because non-native and invasive species have become a significant threat to native habitats, the Federal government directs Federal entities to prevent, control, and minimize invasive species and their impacts (E.O. 13112). GNDNWR management strategies support these goals and in August 2016, a final Comprehensive Conservation Plan (CCP) was developed to specify a management direction for the Refuge for the next 15 years (USFWS 2016). Goals include:

1. Protect, restore, and enhance native habitats to aid in the recovery of endangered, threatened, and other special status species.
2. Protect, manage, and restore coastal dune and other natural communities to support the diverse species of the central California coast.
3. Provide safe and high-quality opportunities for compatible wildlife-dependent educational and recreational activities to foster public appreciation of the natural heritage of the central California coast region (USFWS 2016).

As part of these goals, various objectives further direct GNDNWR to: continue invasive plant control, especially around such listed species such as la Graciosa thistle; maintain natural, shifting open sand-cover; reduce cover of species such as jubata grass (*Cortaderia jubata*), perennial veldt grass (*Ehrharta calycina*), and European beachgrass (*Ammophila arenaria*); and develop an early detection and rapid response program for invasive plants.

Appendix H of the CCP directed special protections to resources occurring within areas termed *Refuge Priority Management Areas* (RPMAs; USFWS 2016; Figure 6, Table 18). These areas were identified by Refuge staff as important and unique habitat types requiring focused conservation efforts.

In addition to management goals outlined in the GNDNWR CCP, there is a regional effort underway to manage the entire Nipomo Dunes Complex through a partnership known as the Dunes Collaborative. This partnership is made up of federal, state, private, and non-profit organizations such as GNDNWR, the Land Conservancy of San Luis Obispo County (LCSLO), Guadalupe - Nipomo Dunes Center, California State Parks - Oceano Dunes State Vehicular Recreation Area, County of Santa Barbara, State of California Coastal Conservancy and California Department of Fish and Wildlife (CDFW). The Dunes Collaborative set forth a vision for future conservation that is very much in line with management goals identified in the CCP. This vision states:

> *The Dunes Collaborative promotes connected and continuous coastal dune complexes which support a diverse and healthy native ecosystem where plants and wildlife thrive and the dynamic nature of the dunes is preserved. These dunes will provide places of wonder for the local community, visitors, and future generations to explore and enjoy* (LCSLO in prep).

In order to promote this vision, the Dunes Collaborative is developing a conservation plan to achieve the following goals (LCSLO in prep):

- Preserve and Promote Native Biodiversity
- Maximize Resiliency to a Changing Climate
- Maintain Ecological Processes that Promote the Dynamic Nature of the Dunes
- Preserve and Promote Wetland and Upland Habitat Quality and Connectivity

The backbone of the Dunes Collaborative conservation plan is a network of high priority conservation areas called the "Dune Protected Areas Network" or DPA Network (Figure 1). The DPA Network is based loosely on the "Green Infrastructure Network" concept used in urban environments to protect natural habitats and pathways (Conservation Fund 2017). It is an interconnected system of protected natural areas that conserve ecosystem functions while providing benefits for wildlife. Each DPA consists of *core areas* and *hubs*, which will be connected by *corridors*.

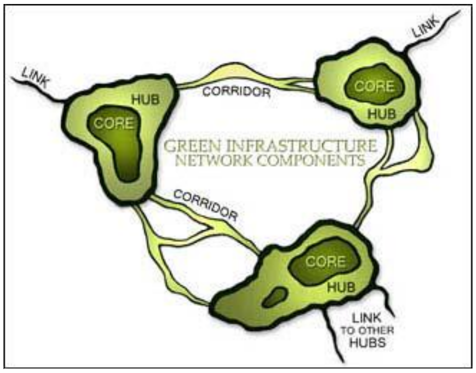

Figure 1. The "Green Infrastructure Network" serves as the model for the DPA Network.

Core areas are the nucleus of the network and are selected by their biological significance, pristine condition, or habitat uniqueness. Conservation modeling was first reviewed as the preliminary task of this process, using Marxan and Zonation software. Consultation with experts in various taxonomic disciplines and available occurrence data of rare and listed species also assisted in selection of each core area. These selected areas should be relatively undisturbed and have low invasive species intrusion.

Hubs buffer the core areas in order to offer additional protection against invasion and disturbance. These extensions of the core areas allow for less fragmentation of habitat types and offer continuous native cover. Hubs may contain multiple core areas, connecting them together as a unit. *Corridors* are linear features linking hubs together to facilitate wildlife movement and gene flow between core areas freely. Connectivity between hubs is essential for preservation of species in perpetuity.

Collection of baseline invasive species data is critical to the proper placement and management of these DPAs. Furthermore, geospatial invasive plant occurrence data assists landscape managers in determining which populations should be targeted for control (or eradication when possible) based on the current management objectives, available resources, and threatened natural resources.

In February 2016, Wildlands Conservation Science, LLC (WCS) was contracted to support the management goals outlined in the CCP and supply information necessary for the selection of DPAs, by conducting a complete aerial survey of the GNDNWR to:

- map the distribution and extent of 18 invasive plant species across the Refuge (Table 1),
- map the distribution and extent of eight invasive plant species in the RPMAs (Figure 6),
- perform early detection monitoring for eight previously undocumented invasives,
- determine the distribution and ground cover of four special status native plant species, &
- document the population, distribution, and habitat impacts of invasive feral pigs (*Sus scrofa;* Table 1).

These baseline data provide land managers a quantifiable means of planning future treatment actions and measuring progress towards management goals.

Upon completion of the survey, WCS was tasked to analyze GNDNWR invasive plant survey data with the intention to develop an invasive species eradication priority index for the Reserve. This analysis will also be utilized by the LCSLO and the Dunes Collaborative as they develop an invasive species management plan for the NDC DPA network. This document, currently in preparation, will outline a strategic approach to invasive species management that focuses on prevention of pest problems; identifies target species for control or eradication; determines priority treatment areas; provides guidelines for when management action is needed; estimates the costs of treatment; and proposes monitoring strategies that will measure progress towards conservation goals and objectives and provide critical information needed for adaptive management (LCSLO in prep).

This report summarizes the results of the GNDNWR aerial invasive, native plant, and feral pig survey conducted during a six-day period in February 2016 and provides an invasive plant interim prioritization for species documented during the survey.

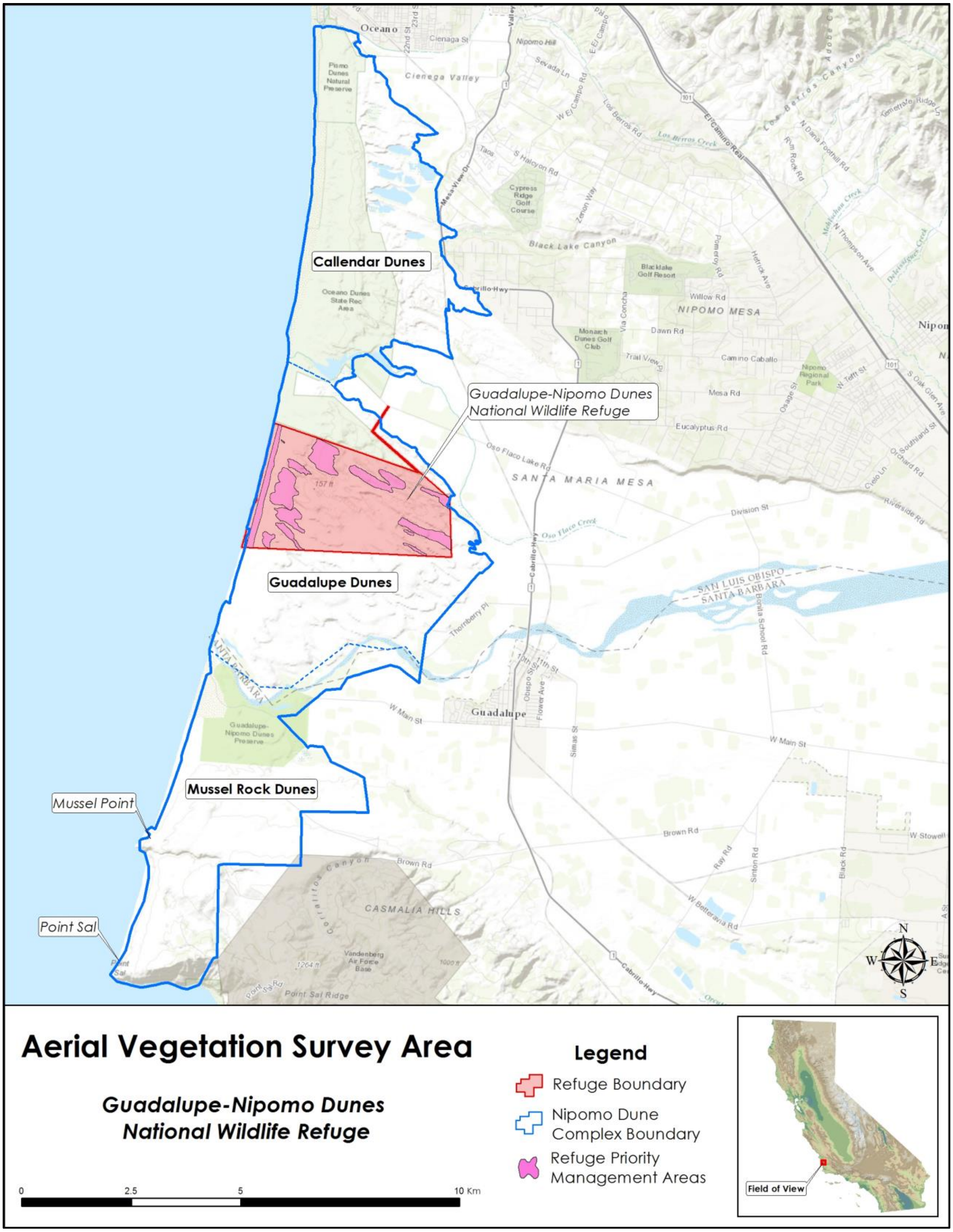

Figure 2. Aerial vegetation survey area of the Guadalupe-Nipomo Dunes National Wildlife Refuge in context of the greater Nipomo Dune Complex.

Table 1. List of 39 plant species and one vertebrate species that WCS was contracted to survey for and document within the GNDNWR.

#	Method	Species	Common Name	Family	Conservation Status	Fed Status	State Status	CNPS Status	Cal-IPC Ranking
1	**Documented Invasive Plants** *Map Using a Grid System* *(4 Species)*	*Ammophila arenaria*	European beachgrass	Poaceae	*invasive plant*				High
2		*Carpobrotus chilensis*	sea-fig iceplant	Aizoaceae					Moderate
3		*Carpobrotus edulis*	hottentot fig iceplant	Aizoaceae					High
4		*Ehrharta calycina*	perennial veldt grass	Poaceae					High
5	**Documented Invasive Plants** *Map Using Points or Polygons* *(14 Species)*	*Cardaria draba*	whitetop	Brassicaceae	*invasive plant*				Moderate
6		*Cirsium vulgare*	bull thistle	Asteraceae					Moderate
7		*Conicosia pugioniformis*	narrow-leaved iceplant	Aizoaceae					Limited
8		*Conium maculatum*	poison hemlock	Apiaceae					Moderate
9		*Cortaderia jubata*	jubata grass	Poaceae					High
10		*Cynodon dactylon*	Bermuda grass	Poaceae					Moderate
11		*Foeniculum vulgare*	fennel	Apiaceae					High
12		*Lepidium draba*	heart-podded hoary cress	Brassicaceae					Moderate
13		*Mentha* sp.	mint	Lamiaceae					Moderate
14		*Nicotiana glauca*	tree tobacco	Solanaceae					Moderate
15		*Oxalis pes-caprae*	Bermuda buttercup	Oxalidaceae					Moderate
16		*Senecio elegans*	red-purple ragwort	Asteraceae					*Not Rated*
17		*Silybum marianum*	milk thistle	Asteraceae					Limited
18		*Tamarix ramosissima*	tamarisk	Tamaricaceae					High
19	**Documented Invasive Plants Map in RPMAs Only *(Mustards)*** *Map Using Points or Polygons* *(3 Species)*	*Brassica nigra*	black mustard	Brassicaceae	*invasive plant*				Moderate
20		*Hirschfeldia incana*	perennial mustard	Brassicaceae					Moderate
21		*Sisymbrium irio*	London rocket	Brassicaceae					Moderate
22	**Documented Invasive Plants Map in RPMAs Only *(NNG*)*** *Map Using Points or Polygons* *(5 Species)*	*Avena barbata*	slender wild oats	Poaceae	*invasive plant*				Moderate
23		*Avena fatua*	common wild oats	Poaceae					Moderate
24		*Bromus diandrus*	ripgut brome	Poaceae					Moderate
25		*Bromus madritensis* ssp. *rubens*	red brome	Poaceae					High
26		*Hordeum murinum*	foxtail barley	Poaceae					Moderate
27	**Early Detection Invasive Plants (Undocumented)** *Map Using Points or Polygons* *(8 Species)*	*Cirsium arvense*	Canada thistle	Asteracea	*invasive plant*				Moderate
28		*Cuscuta japonica*	Japanese dodder	Cuscutaceae					Watch List
29		*Dittrichia graveolens*	stinkwort	Asteracea					Moderate - Alert
30		*Emex spinosa*	spiny emex	Polygonacea					Moderate-Alert
31		*Euphorbia terracina*	carnation spurge	Euphorbiacea					Moderate-Alert
32		*Limonium sp.*	Algerian sea lavender	Plumbaginaceae					Limited - Watch List
33		*Linaria dalmatica ssp. dalmatica*	Dalmation toadflax	Scrophulariaceae					Moderate
34		*Thinopyrum junceiforme*	Russian wheatgrass	Poacea					Watch List
35		*Brassica tournefortii*	Sahara mustard	Brassicaceae					High
36	**Documented Special Status Native Plants** *Map Using Points or Polygonss* *(3 Species)*	*Cirsium rhothophilum*	surf thistle	Asteraceae	CT; 1B.2		CT	1B.2	*na*
37		*Cirsium scariosum* var. *loncholepis*	La Graciosa thistle	Asteraceae	FE; CT; 1B.1	FE	CT	1B.1	
38		*Dithyrea maritima*	beach spectaclepod	Brassicaceae	CT; 1B.1		CT	1B.1	
39	**Undocumented Special Status Native Plants** *Map Using Points or Polygons* *(1 Species)*	*Layia carnosa*	Beach layia	Asteraceae	FE; CET; 1B.1				*na*
40	**Non-native Vertebrates** *Map Using Points or Polygons* *(1 Species)*	*Sus scrofa*	Feral Pig	Suidae	invasive animal				*na*

**NNG= Non-native grasses*

Total - 35 Invasive Plants, 4 Special Status Native Plants & 1 Invasive Animal

2.0 Aerial Survey Methodology

Given the large proportion of annual plants occurring on the proposed target species list, the ideal survey period would have been mid to late spring to match species' phenology. However, the survey window was selected to avoid conflicts with the western snowy plover and least tern breeding season between 1 March and 1 October. For this reason, surveys were conducted over six-days from 8 to 15 February 2016. Flights originated each morning from the helicopter hangar at Lompoc Airport and mid-day refueling occurred at the Santa Maria Airport.

A team of two individuals conducted the surveys: helicopter pilot Ken Hutchins (Native Range Inc.; NRI) and surveyor Morgan Ball (WCS). The aerial survey team has professional botanical training as well as extensive experience surveying plants and vertebrates in California from helicopters. Additional aerial observer support was provided by Jon Hall, GNDNWR Survey Project Manager and LCSLO Restoration Manager on 9 February and Katrina Olthof (WCS) on 15 February. Project coordination occurred via daily cellular phone calls and text message to Jon Hall to discuss project progression, notifications, and challenges.

Figure 3. Botanical surveyors demonstrating ease of detection and maneuverability at 15-feet altitude in a Schweizer-333 turbine-helicopter.

Surveys were started no earlier than 0700 and concluded no later than 1800 each day to avoid low light conditions. On average, 5.5-hours of flight time were logged each day. Aerial surveys were conducted using a Schweizer-333 turbine-helicopter. This helicopter model has the lowest noise signature (85 decibels at 100 feet above the ground) in its class (small turbine helicopters). The spacious side-by-side seating configuration of the 333 is ideal for botanical surveys allowing two surveyors and pilot to comfortably scan the entire terrain. The 333 is a stable platform due to its power and maneuverability which enables low-level flights (Figure 3).

Prior to the surveys, an Xplore technologies ruggedized tablet operating ESRI ArcPad 10.2 Geographic Information Systems (GIS) software and equipped with a global positioning system (GPS) was loaded with the survey boundaries overlaid on a high-resolution orthophotograph of GNDNWR. A GIS shapefile was provided by USFWS employee Ken Convery identifying locations of RPMAs (Figure 6). These data were used to guide the surveys. The geospatial data for this survey is provided in addition to this report on a portable hard drive.

Invasive plant target species were selected by the Dunes Collaborative and was informed by the *Invasive Plant Inventory and Early Detection Prioritization Tool* (Olsen et al 2015). Native plants La Graciosa thistle, beach spectaclepod, and surf thistle which are known to occur on the Refuge were added due to their special status (USFWS 2016, Table 1). Federally endangered beach layia (*Layia carnosa*) was added to the proposed survey list because of its known occurrence in similar coastal dune habitats on Vandenberg Air Force Base, to the south of the Refuge. In addition to plants, feral pig localities, numbers observed, and habitat damage was also documented (Table 1). While conducting these surveys, a total of 3,682 geocoded aerial photographs were taken of the Refuge and provided with this report on a portable hard drive.

All target species were mapped throughout the extent of the Refuge; however, eight species (three mustard species and five non-native grass species) have wide-ranging and diffuse populations and were only mapped if populations occurred in RPMAs (Figure 6). Targeted mustards and non-native grasses were mapped as general taxa groups because the surveys occurred outside of an optimal window for distinguishing annual grass species (Table 1).

During the surveys, terrain was flown at approximately 24 to 32 kilometers per hour (kph; 15 to 20 miles per hour [mph]) and between 4.5-meters to 45-meters above the ground. The aerial survey team systematically searched the mostly open and flat terrain following a serpentine transect pattern made up of parallel paths that allowed for a thorough examination of all vegetation and terrain (Figure 4). Special attention was given to heavily wooded and wetland habitats because heavy vegetation cover limits visibility from the aircraft. The swath width of transects varied based on the density and height of vegetation, the degree of topography, and the size and detectability of the target species. The optimal swath width allowed observers to properly identify the furthest observable target species on two consecutive flight passes ensuring that no detectability gaps existed in the search pattern. Given the openness of the habitat and the survey species, optimal swath widths were between 15-meters to 30-meters. Flight routes were digitally recorded to ensure total coverage and avoid recounting populations (Figure 4).

When target species were encountered, their location, distribution and ground cover were recorded using one of three mapping methods herein referred to as point, polygon, or grid. Point and polygon mapping was restricted to plant populations with a discernible boundary extent, these mapping units are herein referred to as populations or stands. An individual population was defined by a single contiguous infestation or a cluster of infestations separated by no more than 30-meters.

Descriptions of the three mapping methodologies are provided below:

> **Point** - Discrete populations with easily identifiable (circular) boundaries were mapped using a single data point collected at the population centroid. For each population, diameter and percent ground cover and attribute information listed in Table 2 was collected. Plant populations mapped as points were later buffered by their infestation radius and converted to polygons for the final product. All feral pigs were mapped using discrete point data.
>
> **Polygon** – Populations with a discernible, irregular-shaped boundary were mapped using a polygon drawn atop a high-resolution orthophotograph. Additional population attributes listed in Table 2 were also collected.
>
> **Grid** - European beachgrass, perennial veldt grass, sea-fig iceplant (*Carpobrotus chilensis*), and hottentot fig iceplant (*Carpobrotus edulis*) cannot be mapped using point

or polygon methods because there were no discernible population boundaries to be delineated (Figure 4). Therefore, these widespread and/or diffusely occurring species were mapped by estimating ground cover within a 100-meter^2 pre-established grid system (Figure 6). Within each grid cell, additional population attribute information was collected (Table 3).

The 100-meter^2 grid size was selected because it is a cost-effective scale (allowing the entire survey to be completed in 6 days) for large property surveys while allowing for data resolution that is useful for weed population tracking and treatment planning. For example, a 50-meter grid size would provide a four-fold increase in grid mapping resolution. However, this increase in resolution comes at an approximately four-fold increase in cost. Scales greater than 100-meters are more cost effective to conduct, but difficult to fly at an altitude that allows for a view of the entire area while providing proper views to discern and assess the target plant.

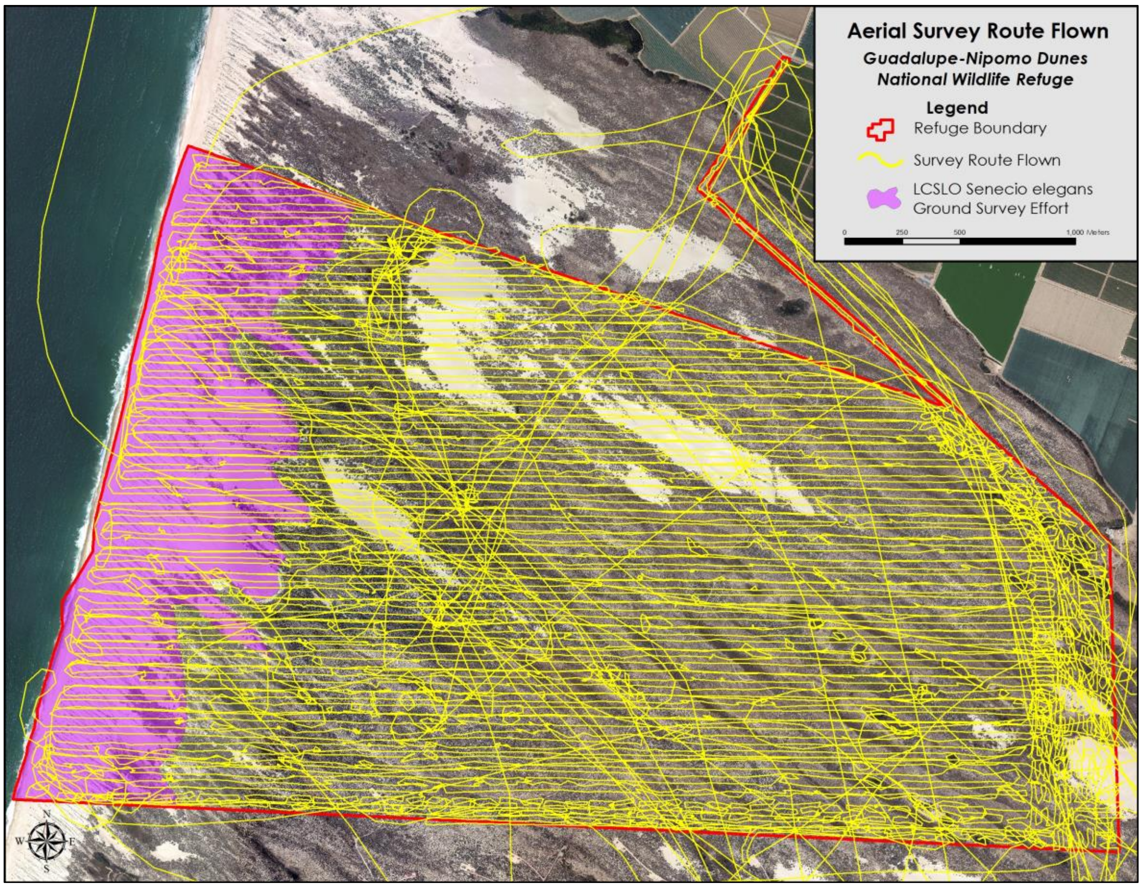

Figure 4 Digitally recorded aerial survey tracks following a serpentine transect pattern flown during the February 2016 surveys.

Figure 5. Example of the widespread and continual distribution of perennial veldt grass on GNDNWR.

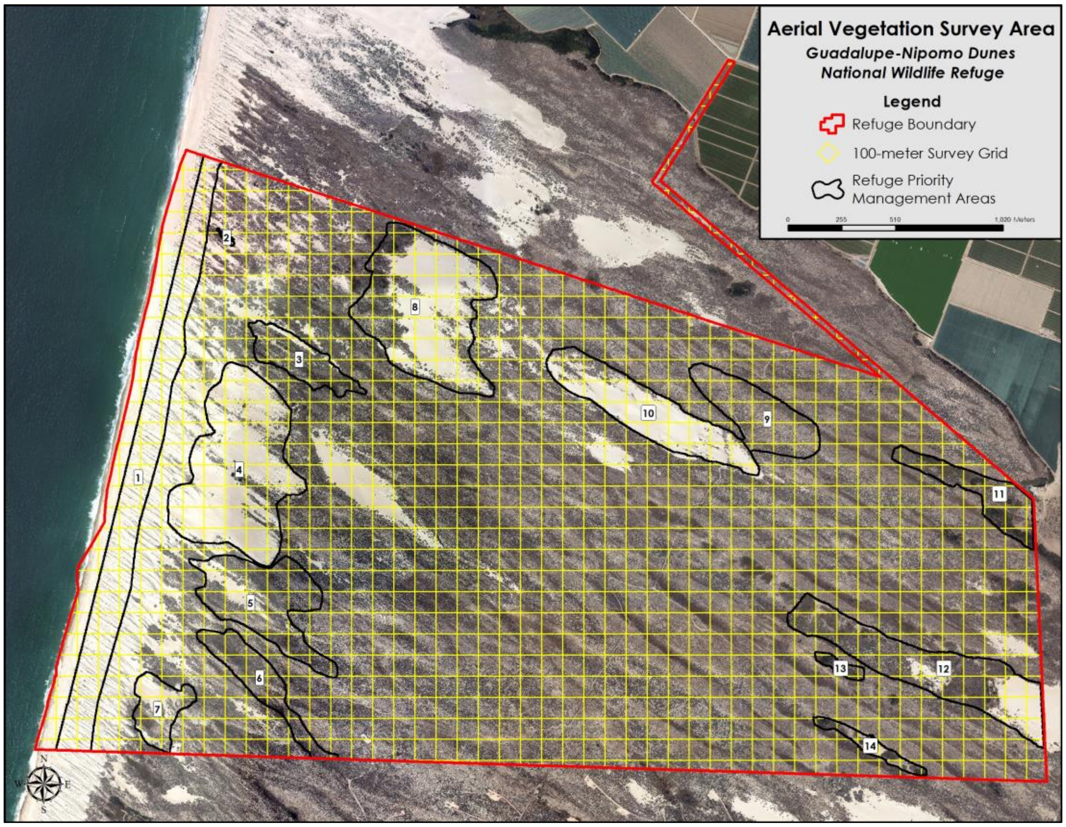

Figure 6. Map of the 100-meter^2 grid cell system and RPMAs within the boundaries of the Refuge. Each RPMA is labeled with an individual identification number that can be referenced in Table 5 (Section 4.0). This table provides summary information and area selection justification for each RPMA.

Table 2. Attribute field information associated with polygon data recorded during the GNDNWR aerial survey.

Field Name	***Attribute Description***
Stand_ID	Individual stand identification code.
Date_Range	Time period in which the survey was performed.
Com_Name	Common name of the documented population stand.
Species	Scientific name (conforming to ITIS 2016) of the documented population stand.
Num_Indv	Estimated number of plants within the documented population stand.
Pop_Dens	The vegetative cover of the documented invasive plant species within the mapped polygon. The cover-classes were used to visually estimate cover within the poygon. Value Ranges: **0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100**%.
Age_Class	The most common age of plants within the population stand. Age was divided into **seedlings, saplings, mature,** mixed age classes with more young plants than old (***MixedYoung***) and mixed age classes with more old plants than young (***MixedOld***).
ID_Confid	Confidence level (**High, Mod, Low**) that the survey team was able to identify the documented invasive plant to species from the air.
Photo_Take	A geocoded photo was taken of the documented population stand.
Surveyor	The name of the surveyors recording the data and helicopter pilot.
Comment	Miscellaneous note regarding the documented invasive plant population stand.
Gross_Acres	Total area (acres) of the polygon including the interstitial spaces between the documented invasive plants within a population.
Net_Acres	Net area (acres) covered by the documented invasive plants within the polygon, not including the interstitial spaces between plants. Calculated by multiplying the midpoint value of ***Pop_Dens*** x the **Gross_Acres** value.
CAL_IPC	Plant ranking for the documented invasive plant according to California Invasive Plant Council (*Cal-IPC 2006*).
POINT_X	X coordinate of the polygon centriod in NAD_1983_StatePlane_California_V_FIPS_0405_Feet.
POINT_Y	Y coordinate of the polygon centriod in NAD_1983_StatePlane_California_V_FIPS_0405_Feet.

Table 3. Attribute field information associated with grid data recorded during the GNDNWR aerial survey.

Field Name	***Attribute Description***
ID	Individual grid cell identification code.
Date_Range	Time period in which the survey was performed.
AMAR_Cover	The vegetative cover of European beachgrass of the documented invasive plant species within the mapped polygon. The cover-classes were used to visually estimate cover within the poygon. Value Ranges: **0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100**%.
CACH_Cover	The vegetative cover of hottentot fig iceplant within the mapped grid cell. The cover-classes were used to visually estimate cover within the poygon. Value Ranges: **0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100**%.
CAED_Cover	The vegetative cover of sea-fig iceplant within the mapped polygon. The cover-classes were used to visually estimate cover within the poygon. Value Ranges: **0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100**%.
EHCA_Cover	The vegetative cover of perennial veldt grass within the mapped polygon. The cover-classes were used to visually estimate cover within the poygon. Value Ranges: **0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100**%.
Gross_Acre	Total area (acres) of each mapped grid cell including the interstitial spaces between the documented invasive plants within a population.
AMAR_Acres	Net area (acres) covered by European beachgrass within a population stand, not including the interstitial spaces between plants. Calculated by multiplying the midpoint value of **AMAR_Cover** x the ***Gross_Acres*** value.
CACH_Acres	Net area (acres) covered by hottentot fig iceplant within a population stand, not including the interstitial spaces between plants. Calculated by multiplying the midpoint value of ***CACH_Cover*** x the ***Gross_Acres value.***
EHCA_Acres	Net area (acres) covered by perennial veldt grass within a population stand, not including the interstitial spaces between plants. Calculated by multiplying the midpoint value of ***EHCA_Cover*** x the ***Gross_Acres value.***
CAED_Acres	Net area (acres) covered by sea-fig iceplant within a population stand, not including the interstitial spaces between plants. Calculated by multiplying the midpoint value of ***CAED_Cover*** x the ***Gross_Acres value.***

3.0 Survey Results

3.1 Invasive Plant Survey Results

During the six-day survey period, WCS flew a total of 610.7 survey kilometers (379.4-miles), documented a total of 1,899 invasive plant stands accounting for 493.8 net acres of invasive plant cover within 2,253-acres of the GNDNWR (Table 4, Figure 8).

During the helicopter survey, five of the 16 invasive plant species slated for point and polygon mapping were documented on the Refuge (Table 4, Figure 8). Detection of plants with an annual growth habit were not easily discernible due to the early timing of the survey period. Thus, species such as red-purple ragwort (*Senecio elegans*), whitetop (*Cardaria draba*), heart-podded hoary cress (*Lepidium draba*), fennel (*Foeniculum vulgare*), and Bermuda buttercup (*Oxalis pes-caprae*) were not detected. To offset the deficiency in survey timing, the LCSLO performed four additional ground surveys for red-purple ragwort on 23 and 28 June and 2 and 4 August 2016 (Figure 4). During those surveys, they detected 41 stands accounting for 0.135 net acres of red-purple ragwort infestation within 8.02 gross acres of infested habitat (Table 4, Figure 8).

Limited amounts of black mustard (*Brassica nigra*), perennial mustard (*Hirschfeldia incana*), and London rocket (*Sisymbrium irio*) were observed on the Refuge. However, none were documented within the designated RPMAs and were therefore not mapped. However, it is highly likely that these species occur within at least some of the RPMAs because these are widely distributed species in this region with the ability to lay dormant within the seed bank. However, at the time of the survey annual broad leaves such as these were only beginning to emerge (Figure 7).

Figure 7. View of annual grasses and broadleaf plants [primarily poison hemlock (*Conium maculatum*)] emerging from the seed bank in mid-February 2016.

At the time of the survey, non-native grasses appeared to be further along in development than mustard species. As a result, 10 stands accounting for 1.60 net acres of non-native grasses were documented within 8.25 gross acres of infested RPMA habitat (Table 4, Figure 8). However, it is likely that this cover value is an underestimate due to the early timing of the helicopter survey relative to the phenology of non-native grasses at the Refuge.

Though none of the eight early detection species were observed on the Refuge, substantial amounts of Sahara mustard (*Brassica tournefortii*) were observed growing along the road margins of Oso Flaco Lake Road near the main access road entrance to the Refuge.

Of the four-species mapped using a 100-meter by 100-meter grid system, perennial veldt grass was by far the most extensive. In total, WCS mapped 335.39-acres of net perennial veldt grass within 1,615.49-acres of gross infested habitat. European beachgrass (94.53 net acres within 511.08-acres of gross infested habitat), was the next most common invasive plant species followed by sea-fig iceplant (58.68 net acres within 1,268.90-acres of gross infested habitat) and hottentot fig iceplant (0.6 net acres within 42.0-acres of gross infested habitat) respectively (Table 4, Figure 9).

As illustrated in Figure 9, European beachgrass is highly concentrated in the northwestern portion of the Refuge immediately inland of the foredune region. Whereas perennial veldt grass is largely absent from the foredune region but increases in density in the eastern portion of the Refuge where the dune structure is more stabilized. Conversely, sea-fig iceplant is more established along the coast. Hottentot fig iceplant appears to be more sporadic throughout the Refuge but occurs on average closer to the coast.

Narrow-leaved iceplant (0.75 net acres within 119.28 acres of gross infested habitat), a relatively small annual iceplant species, is the third most common invasive plant documented on the Refuge in terms of stand total yet sixth in terms of net acreage (Table 4, Figure 8). This species is extremely widespread throughout the Refuge; however, it was not observed with high groundcover densities at any of the documented 285 stand localities. It is probable that the narrow-leaved iceplant populations expanded substantially as the growing season progressed, though the likelihood of significant expansion is low due to the current drought conditions along the central coast of California. The distribution of these populations indicate that it is likely that the entire Refuge has a substantial latent seed bank of narrow-leaved iceplant that responds to favorable soil conditions and weather patterns on an annual basis.

Figures 10 and 11 display the net occurrence of each documented invasive plant species on the preserve relative to the underlying habitat type infested. These “coarse-grained” habitat types were mapped by Lindsey M. Whitaker during a previous study as partial fulfillment of a Master’s thesis to identify prime areas of high native biodiversity worthy of particular preservation and protection within the NDC (Whitaker 2016). Each of these habitat types was attributed a “Rarity Ranking” based on its global rarity and relative occurrence within the NDC.

Of the three most common invasive plants on the Refuge (perennial veldt grass, European beachgrass, and sea-fig iceplant), *Central Coast Dune Scrub/Sage Scrub* was the most commonly infested native habitat followed by *Active Dunes Central* and *Coastal Dune Swale* habitats. Whitaker designated *Central Coast Dune Scrub/Sage Scrub* and *Active Dunes Central* as intermediate ranked habitats (locally rare native vegetation type comprising 5% or less of a landscape unit), while *Coastal Dune Swale* is considered a high priority habitat (globally unique or highest priority locally rare native vegetation type; Whitaker 2016).

Of the ten documented invasive plants with net infestations of less than three acres, *Riparian Woodland/Scrub Central*, *Coast Dune Scrub/Sage Scrub*, and *Coastal Dune Swale* were the most infested native habitats. Per Whitaker 2016, *Riparian Woodland/Scrub Central* is also considered a high priority habitat.

Table 4. Summary of invasive and native plant populations stands documented during GNDNWR aerial surveys. Total stand count, gross acre, and net acre values provided with horizontal histograms illustrating the totals by species.

#	Method	Species	Common Name	# of Stands Total & Bar Graph	Gross Acreage Total & Bar Graph	Net Acreage Total & Bar Graph
1	**Documented Invasive Plants** *Mapped Using a Grid System* *(4 Species)*	*Ammophila arenaria*	European beachgrass	215	511.08	94.53
2		*Carpobrotus chilensis*	sea-fig iceplant	529	1268.90	58.68
3		*Carpobrotus edulis*	hottentot fig iceplant	17	42.01	0.61
4		*Ehrharta calycina*	perennial veldt grass	718	1615.49	335.39
5	**Documented Invasive Plants** *Mapped Using Points & Polygons* *(16 Species)*	*Cakile maritima*	European searocket	1	0.002	0.0003
6		*Cardaria draba*	whitetop	*Not Found*	*Not Found*	*Not Found*
7		*Cirsium vulgare*	bull thistle	14	1.21	0.02
8		*Conicosia pugioniformis*	narrow-leaved iceplant	285	119.28	0.75
9		*Conium maculatum*	poison hemlock	28	15.07	2.07
10		*Cortaderia jubata*	jubata grass	14	0.005	0.003
11		*Cynodon dactylon*	Bermuda grass	*Not Found*	*Not Found*	*Not Found*
12		*Foeniculum vulgare*	fennel	*Not Found*	*Not Found*	*Not Found*
13		*Lepidium draba*	heart-podded hoary cress	*Not Found*	*Not Found*	*Not Found*
14		*Mentha* sp.	mint	*Not Found*	*Not Found*	*Not Found*
15		*Nicotiana glauca*	tree tobacco	*Not Found*	*Not Found*	*Not Found*
16		*Oxalis pes-caprae*	Bermuda buttercup	*Not Found*	*Not Found*	*Not Found*
17		*Pinus radiata*	Monterey Pine	3	0.024	0.021
18		*Senecio elegans*	red-purple ragwort	41	8.02	0.135
19		*Silybum marianum*	milk thistle	1	0.001	0.0001
20		*Tamarix ramosissima*	tamarisk	*Not Found*	*Not Found*	*Not Found*
21	**Documented Invasive Plants** **Map in RPMAs Only *(Mustard)*** *Mapped Using Points & Polygons* *(3 Species)*	*Brassica nigra*	black mustard	*Not Found*	*Not Found*	*Not Found*
22		*Hirschfeldia incana*	perennial mustard			
23		*Sisymbrium irio*	London rocket			
24	**Documented Invasive Plants** **Map in RPMAs Only *(NNG)*** *Mapped Using Points & Polygons* *(5 Species)*	*Avena barbata*	slender wild oats	10	8.25	1.60
25		*Avena fatua*	common wild oats			
26		*Bromus diandrus*	ripgut brome			
27		*Bromus madritensis* ssp. *rubens*	red brome			
28		*Hordeum murinum*	foxtail barley			
29	**Early Detection Invasive Plants** **(Undocumented)** *Mapped Using Points & Polygons* *(8 Species)*	*Cirsium arvense*	Canada thistle	*Not Found*	*Not Found*	*Not Found*
30		*Cuscuta japonica*	Japanese dodder			
31		*Emex spinosa*	spiny emex			
32		*Euphorbia terracina*	carnation spurge			
33		*Limonium* sp.	Algerian sea lavender			
34		*Linaria dalmatica* ssp. *Dalmatica*	Dalmation toadflax			
35		*Thinopyrum junceiforme*	Russian wheatgrass			
36		*Brassica tournefortii*	Sahara mustard			
37	**Documented Special Status Native Plants** *Mapped Using Points & Polygons* *(3 Species)*	*Cirsium rhothophilum*	surf thistle	23	2.87	0.03
38		*Cirsium scariosum* var. *loncholepis*	La Graciosa thistle	*Not Found*	*Not Found*	*Not Found*
39		*Dithyrea maritima*	beach spectaclepod	*Not Found*	*Not Found*	*Not Found*
40	**Undocumented Special Status Native Plants** *Mapped Using Points & Polygons* *(1 Species)*	*Layia carnosa*	Beach layia	*Not Found*	*Not Found*	*Not Found*

BLACK TEXT= Species listed in the Statement of Work mapped during the survey TURQUOISE TEXT= Species listed in the Statement of Work NOT DETECTED during the survey
GREEN TEXT= Species NOT LISTED in the Statement of Work but mapped during the survey RED TEXT= Species listed in the Statement of Work NOT DETECTED during the helicopter survey but subsequently ground mapped by LCSLO staff

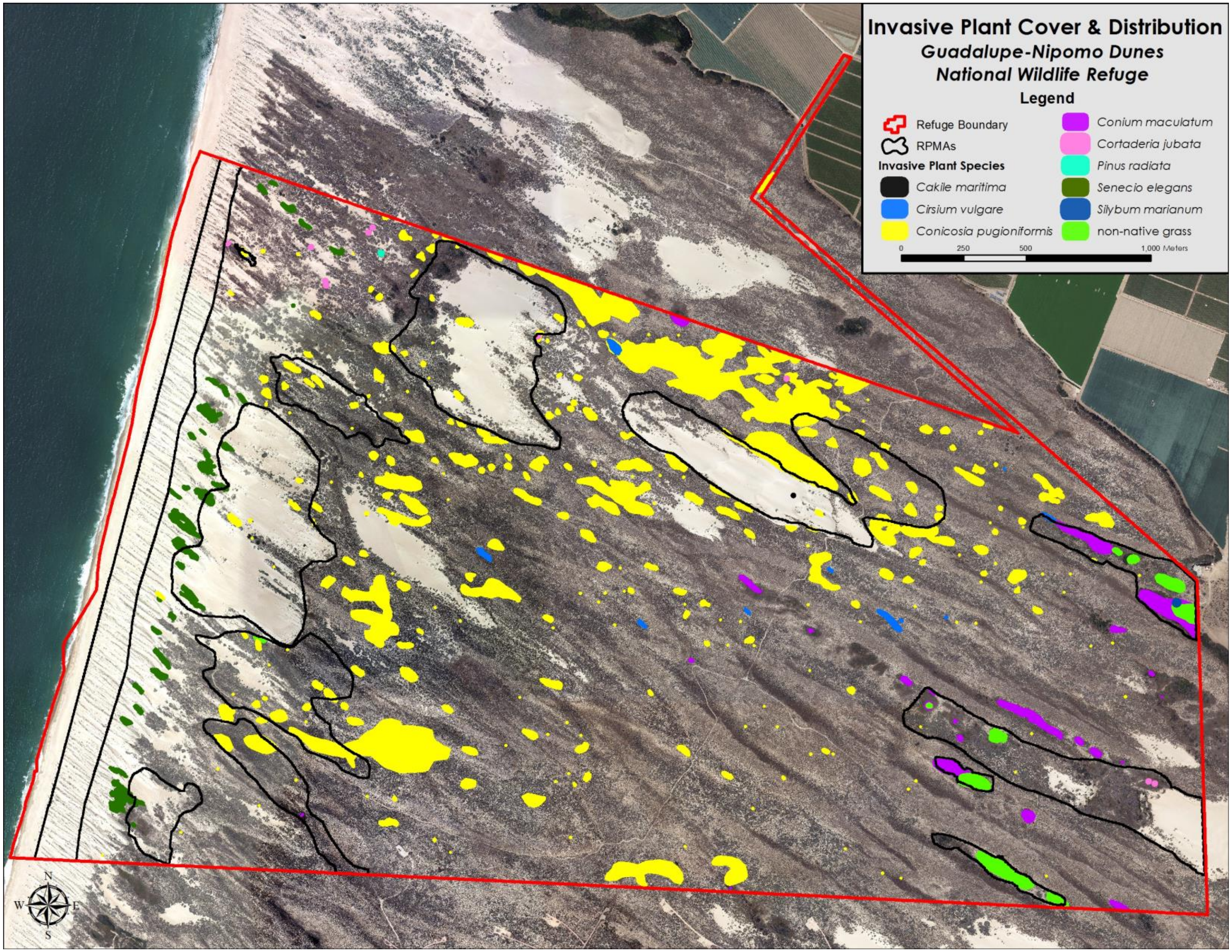

Figure 8. Map of invasive plant cover and distribution documented during February 2016 GNDNWR aerial surveys.

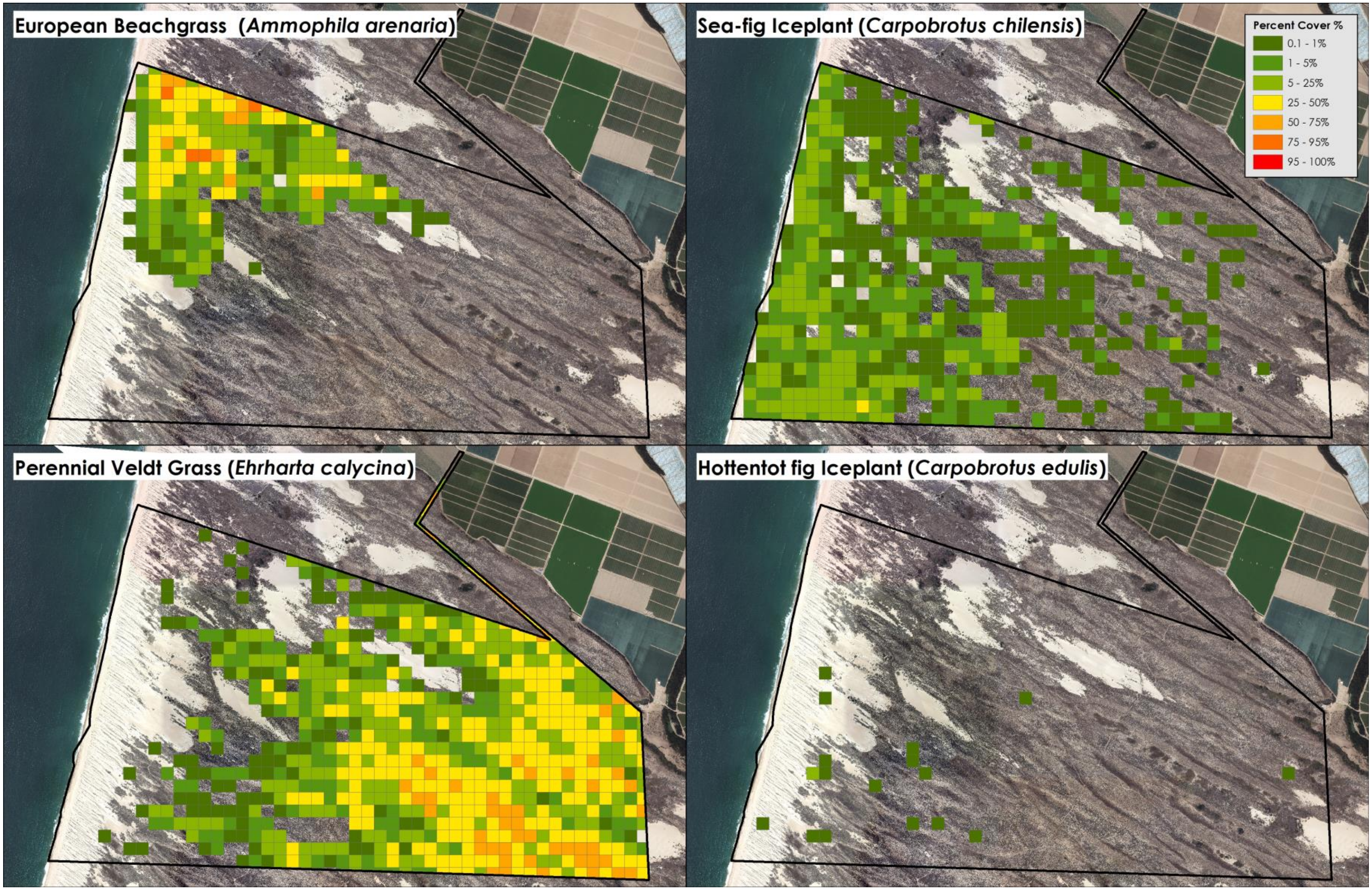

Figure 9. Distribution and percent cover of the invasive plant species mapped using a 100-m grid set atop the extent of GNDNWR.

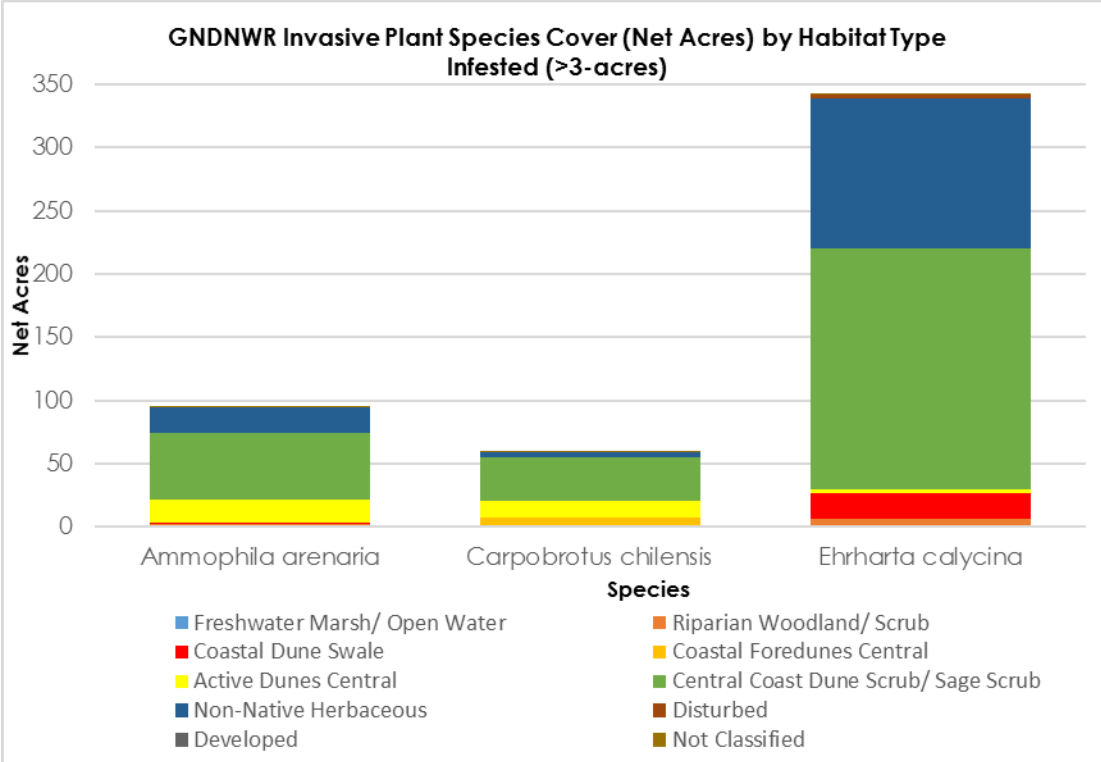

Figure 10. Invasive plant species occurring by habitat type occupying more than three net acres.

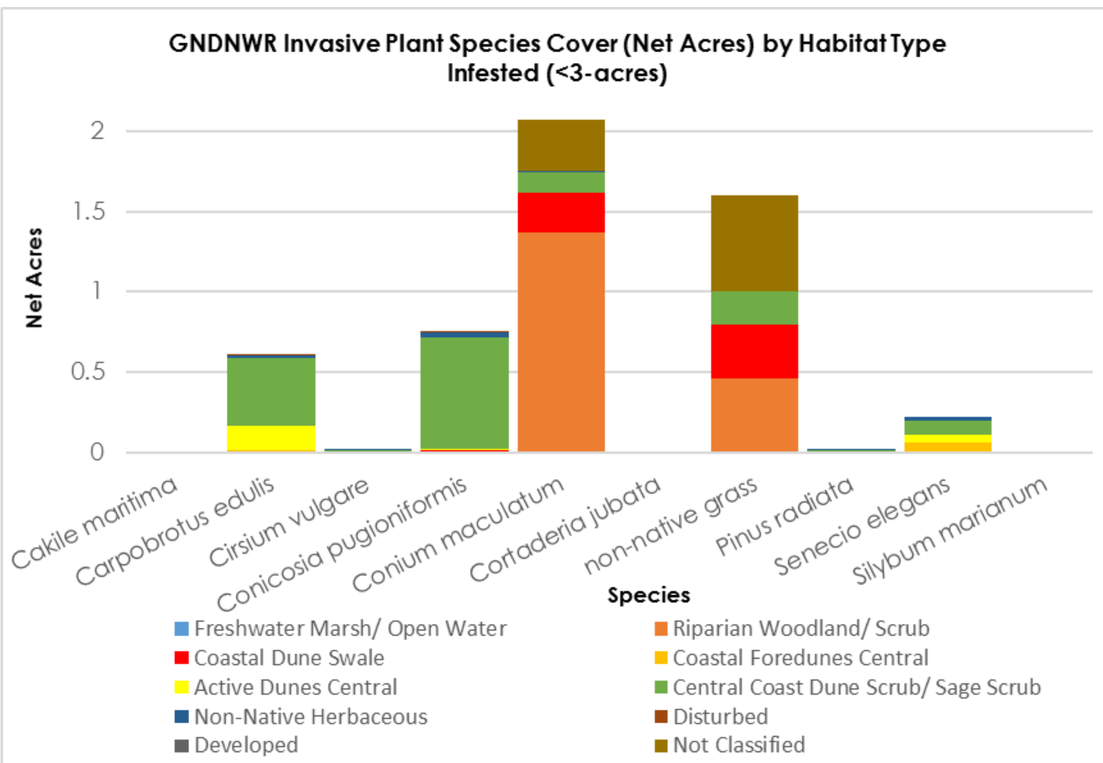

Figure 11. Invasive plant species occurring by habitat type occupying less than three net acres.

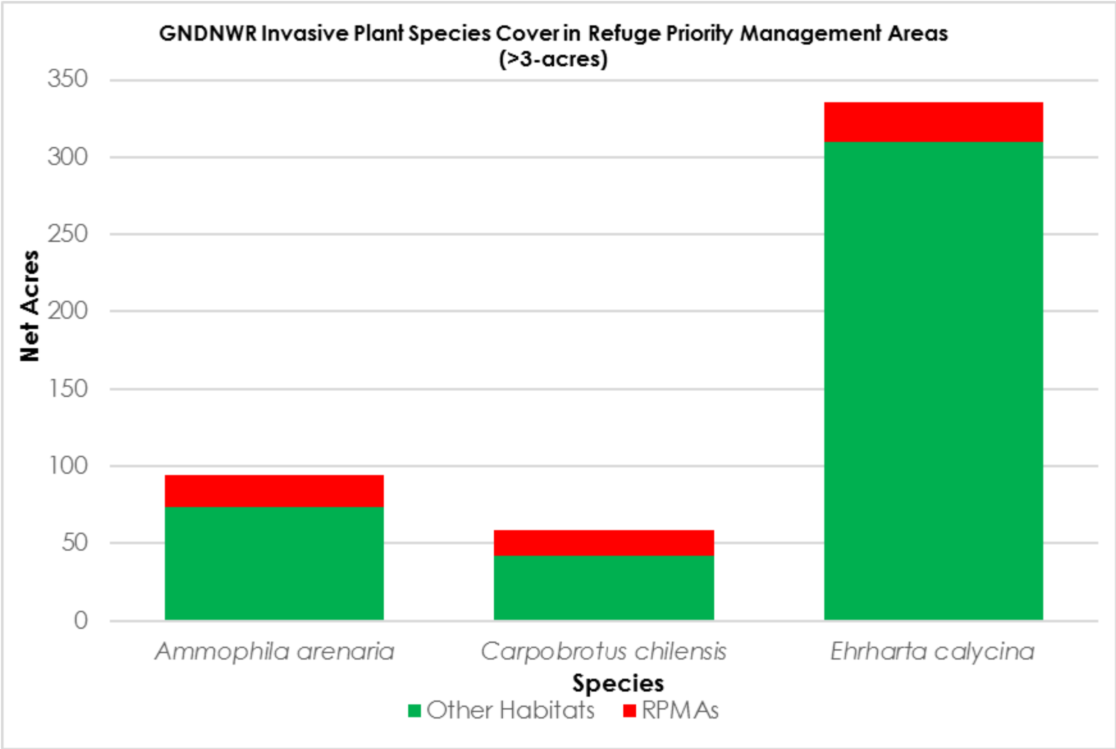

Figure 12. Invasive plant species' cover in RPMAs occupying areas greater than three net acres.

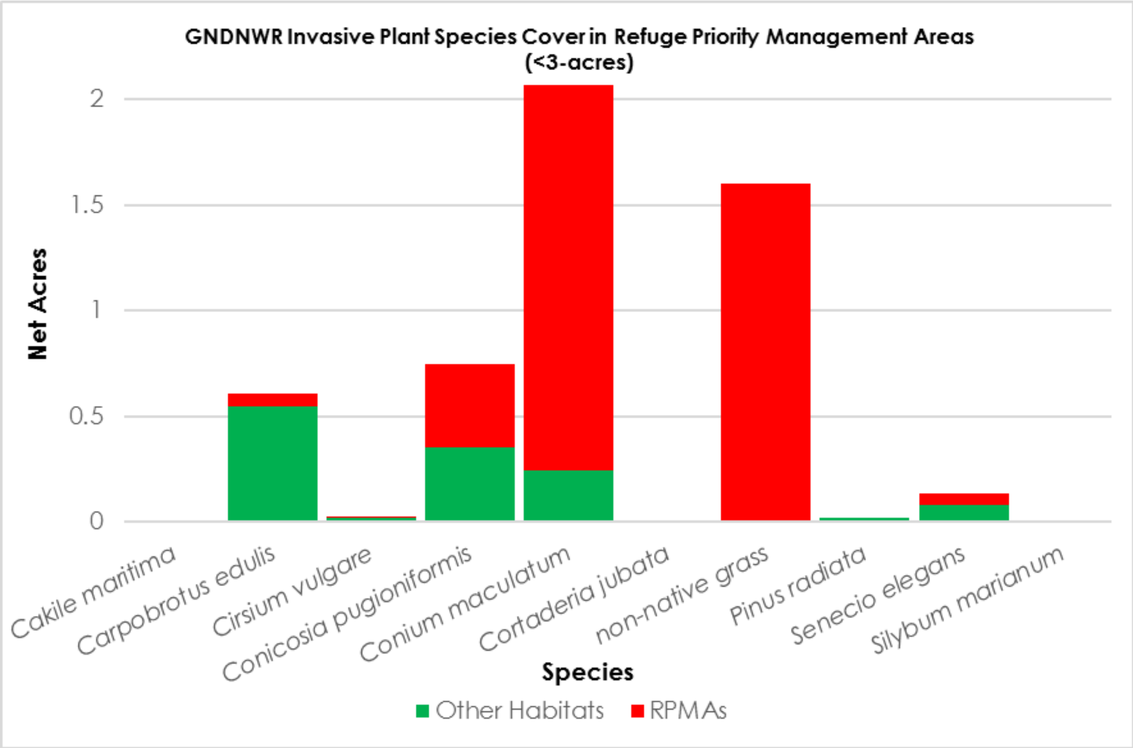

Figure 13. Invasive plant species' cover in RPMAs occupying areas less than three net acres.

In addition to habitat association, Figures 12 and 13 display the net occurrence of each documented invasive plant species occurring within and outside of RPMAs. Of the three most commonly occurring invasive plants on the refuge, perennial veldt grass (25.2 net acres) was documented infesting the largest amount of RPMAs followed by European beachgrass (21.3 net acres) and sea-fig iceplant (17.0 net acres). Of the 10 less common invasive plants on the Refuge, poison hemlock and non-native grasses occur in RPMAs at the highest frequency. Both species appear to occur in wetlands or dune swale settings (habitats typically designated as a sensitive resource within the NDC) more so than the surrounding upland habitats.

3.2 Special Status Plant Survey Results

Unfortunately, the late winter window for helicopter surveys was not optimal for detection of the three-special status native plant species known to occur on the Refuge. These species are perennials or biennials that undergo significant dieback in the winter months. Of the four species, only surf thistle was visible. However, all surf thistle was relatively small and non-flowering at the time of the survey. A total of twenty-three stands of surf thistle were documented, occupying a gross area of 2.87-acres and 0.03-net acres (Table 4, Figure 14). Subsequent follow-up ground surveys for red-purple ragwort in June and August 2016 detected more surf thistle stands, including additional plants outside the boundaries of WCS's defined polygons.

Beach spectaclepod and la Graciosa thistle were not detected during the February 2016 surveys because both species had not yet emerged.

Beach layia was also not detected during surveys. Although timing was poor for native biannual/annual species, the survey window was relatively optimal for beach layia because nearby populations to the south of GNDNWR were observed in a vegetative state on Vandenberg Air Force Base (Katrina Olthof, personal communication).

Given constraints associated with the Western snowy plover breeding season, it does not appear that use of low-flying helicopter is the appropriate tool for survey of these species.

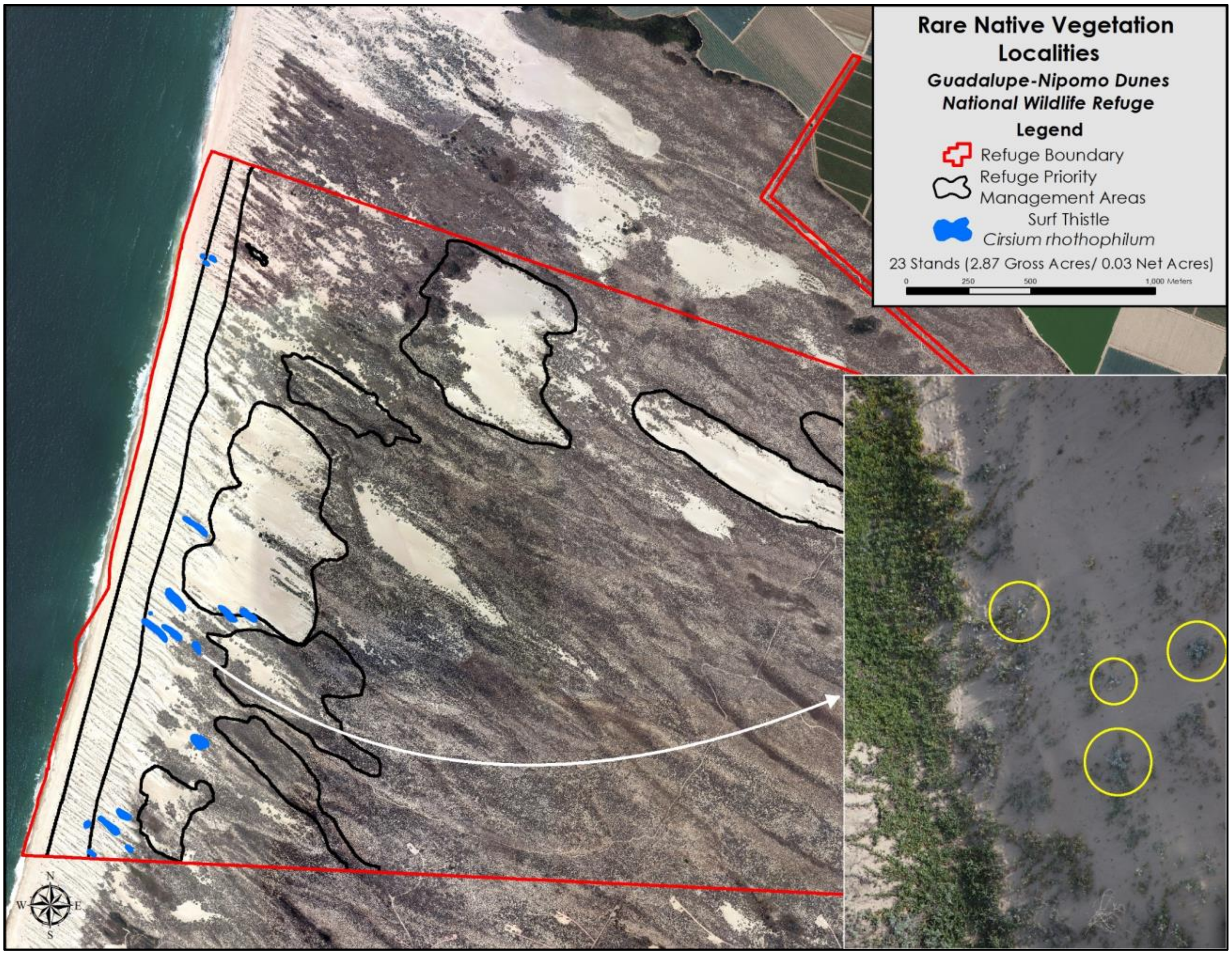

Figure 14. Distribution of 23 stands of surf thistle documented during the February 2016 GNDNWR aerial surveys. Yellow circles indicate surf thistle plants as seen from above.

3.3 Feral Pig Survey Results

While performing aerial plant surveys, WCS documented the presence of ten feral pigs (ranging from approximately 80 to 250 pounds) on GNDNWR. All pigs were observed inland of the primary dune ridge running north-south along the western one-third of the Refuge (Figure 15). This region of the preserve has numerous steep east-facing slopes where accreted sand spills off the primary dune ridge towards the back dunes to the east. These slopes are often covered in dense back dune vegetation with pockets of moisture dependent scrub vegetation such as poison oak (*Toxicodendron diversilobum*), California blackberry (*Rubus ursinus*) and arroyo willow (*Salix lasiolepis*; Figures 16 and 17). The feral pigs appear to utilize this dense vegetation for cover bedding. Routine use of these sites by feral pigs has resulted in disturbance to the soil crust and vegetation structure. Impacts such as this may upset bird breeding activities, limit available habitat for nesting, as well as reduce the biodiversity of the vegetation community (Browning 2008, Crooks 2006; Figure 17).

Pig rooting (ground disturbance caused by pigs tilling the soil in search of forage) was not easily documented in the loose substrate of the dunes and pigs were generally kept out of wetland sites by exclusionary wire fencing. However, pigs appeared to find a way through the fences at two dune swale wetlands in the southeastern portion of the Refuge (Figure 15). At each of these sites, pigs rooted up basin bottom vegetation around the lowest point of each wetland and excavated mud wallow holes.

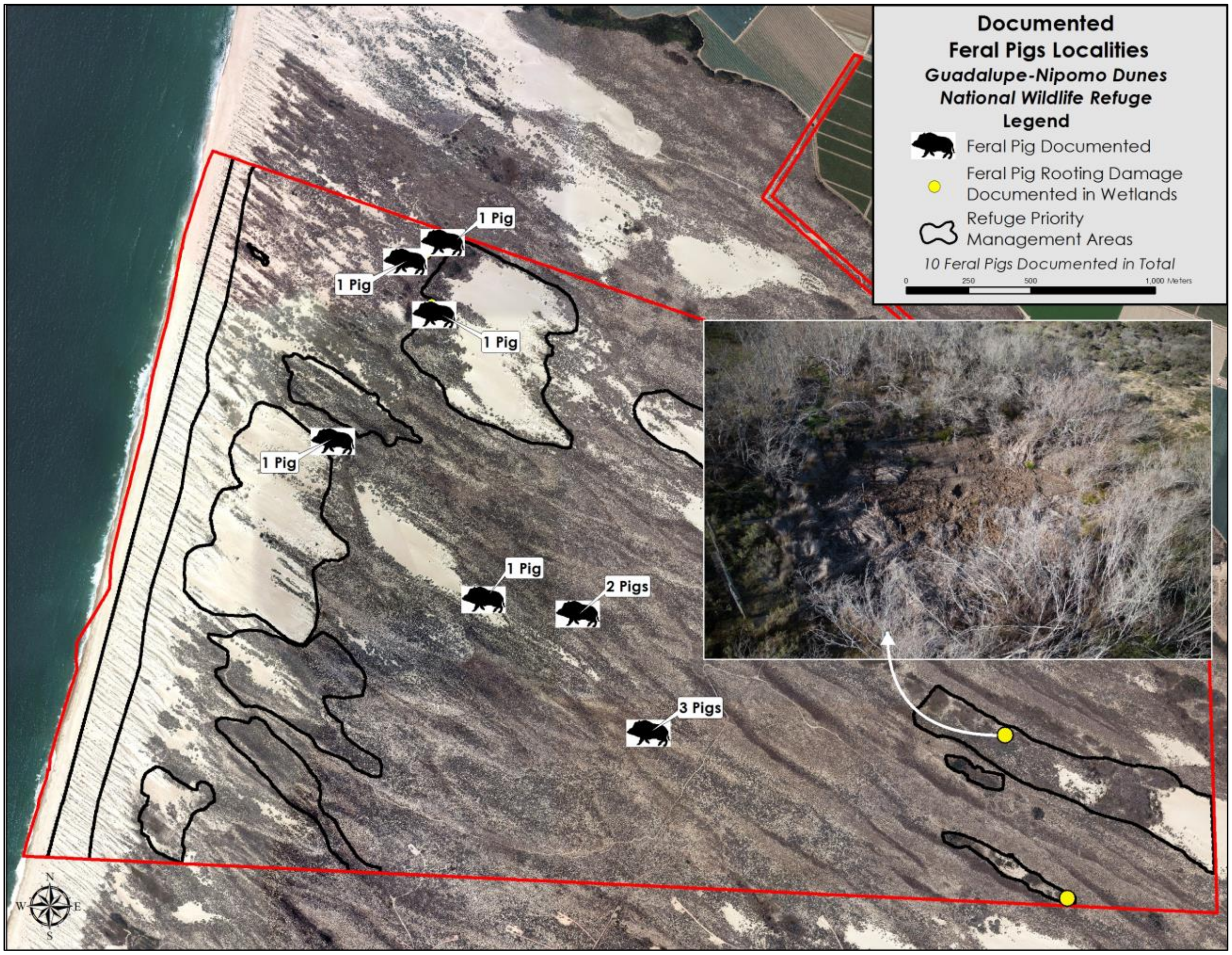

Figure 15. Map of documented feral pigs and rooting damage to wetland habitats on the GNDNWR.

Figure 16. A feral pig resting in the shade of an arroyo willow on GNDNWR.

Figure 17. Typical view of vegetation damage due to feral pig bedding on GNDNWR.

4.0 General Discussion

During the aerial survey, WCS identified several general topics that require additional discussion or future consideration. These topics are detailed below:

Detectability of Target Species

When conducting an invasive plant survey, it is important to select a methodology that effectively and efficiently documents the presence and extent of the target species. However, to date no research has been conducted to verify the effectiveness of helicopter survey relative to other methodologies such as ground survey. In fact, surprisingly little research has been conducted that validates the effectiveness of various ground survey techniques. To that end, WCS, The Nature Conservancy, the Irvine Ranch Conservancy, and the US Fish and Wildlife Service are currently collaborating to compare aerial and ground survey methodologies in a controlled field study. However, the exact techniques to be used to compare geospatial data and survey effort have yet to be established.

An anecdotal review of a preliminary ground to air survey comparison performed on Irvine Ranch in Spring 2016 suggest that there are pros and cons to either survey technique. Ground surveys appear superior under dense canopy environments in deep canyons with sparse understory vegetation, under power lines, near housing, horse stables or near roadways. A helicopter survey approach provided better data in dense canopy environments with dense understory vegetation, moderate to open ground, remote slopes, and areas away from roads or trails.

Identifying a simple metric that communicates a minimum mapping size for target species is not easily done. WCS has successfully surveyed from helicopter for Vandenberg monkeyflower (*Diplacus vandenbergensis*), a rare plant that is often smaller than a penny. However, this species occurs in niche habitats that are easily identified from the air. If Vandenberg monkeyflower were mixed in with dense vegetation, it would likely be overlooked.

In the end, helicopter-based survey detectability comes down to cost. Regardless of target size or habitat context, the slower and lower the helicopter flies, the more likely a surveyor will be able to detect a target. However, much like ground surveys, a minimum rate of speed is necessary to travel an entire refuge area while staying within budget. For this reason, helicopter survey methodologies are not much different from a ground approach. The difference is mostly a product of the angle of view and speed of movement. Observers are typically no further in the air from a target species than a typical ground surveyor would be horizontally from a target plant.

An additional limitation of the aerial survey approach was identified during this project. Unlike ground surveys, the helicopter is not permitted to access nesting habitat of western snowy plover and California least tern during their breeding season from 1 March to 30 September. For this reason, WCS and LCSLO opted to perform the invasive plant survey of the entire preserve in late February prior to the emergence or peak emergence of several invasive plants included on the target list.

As result, it is likely that the occurrence of surf thistle, European searocket, bull thistle, slender-leaved iceplant, poison hemlock, and milk thistle is underestimated on the Refuge, as these species reach peak emergence later in spring. Likewise, beach spectaclepod, red-purple ragwort, black mustard, perennial mustard, and London rocket were not detected during the aerial survey due to the later phenology of these species. Given this new understanding, future aerial survey efforts in the dunes should be split into two zones surveyed at different times of the year. The coastal strand nesting habitat should be surveyed during late February or early October, depending on rainfall and the phenology of the target survey species. This area may also be surveyed on the ground during the bird nesting season. However, access to these areas requires oversight by a federally permitted individual. The inland portions of the Dune Complex should be surveyed during late April to mid-June to coinciding with peak emergence for most invasive plant species occurring in coastal California.

Refuge Priority Management Areas (RPMAs) and Dune Protected Areas (DPAs)

Prior to the survey, refuge staff had identified important and unique sites called Refuge Priority Management Areas (RPMAs) where much of the limited management resources would be focused (Figure 6). The justification for each RPMA selection is detailed in Table 5 (USFWS 2016).

As illustrated in Figures 12 and 13, invasive plants are present in and around much of the existing RPMAs. Data collected during this survey will help identify the threats facing each of these RPMAs and allow for a more thorough prioritization of future management efforts.

These data have also proven useful in the development of the preliminary Dune Protected Areas (DPAs) for the GNDNWR portion of the Dune Complex (Figure 18). Unlike RPMAs, which prioritize resources that align with particular refuge management objectives, DPAs identify areas that possess high quality or unique native resources while lacking significant infestations of non-native invasive plants and/or animals. In many respects, the layout of the DPAs reflect the extent of many of the RPMAs. However, more weight was given in the Refuge CCP to the management of open sand sheets that support few sensitive resources.

Given the unique “big picture” perspective gained by having conducted an aerial survey of the Refuge, WCS would suggest considering the addition of the dune swale complex occurring on the east side of a large European beachgrass dominated retention ridge (Figure 18). This habitat appears relatively intact and functional. However, the site is threatened by nearby invasive plant infestations and regular visitation by feral pigs. In fact, three feral pigs were found utilizing this area during the survey (Figure 15).

Table 5. Descriptions, associated acreages, and sensitive resources contained within RPMAs. Table contents provided by Jon Hall LCSLO.

RPMA	Area (Acres)	Description
1	88	At least 95-percent of the Refuge's western snowy plover breeding activity occurs in RPMA 1. Coastal strand and dune mat vegetation communities are present, surf thistle is also present. However, this RPMA is threatened by beach grass, ice plant, and purple ragwort.
2	0.82	This RMPA is a hiking destination that provides habitat for California red-legged frog; western pond turtle, red-winged blackbirds and waterfowl. Documented flora include Myrtle Pond and Myrtle Marsh and outplantings of marsh sandwort and Gamble's watercress as well as seeds of La Graciosa thistle have been planted here. The perimeter of RPMA 2 is surrounded by European beachgrass.
3	18.56	The highest point on the Refuge, Oso Flaco Peak, occurs here. Coreopsis dune scrub also occurs here but this RPMA needs treatments for beach grass and ice plant.
4	91.21	The largest open sand sheet on the Refuge occurs here and periodically supports breeding western snowy plover.
5	44.65	This RPMA is predominantly characterized by an open sand sheet and coreopsis dune scrub. Beach spectacle-pod also occurs in RPMA 5.
6	20.24	The densest coreopsis dune scrub on the Refuge occurs here.
7	15.15	This RPMA contains open sand sheets, coastal dunes scrub, coastal dunes swale and supports one of the densest population of beach spectacle pod on the Refuge.
8	85.79	The number one hiking destination (Hidden Willow Valley) for the inland portion of Refuge occurs here. This RPMA contains several willow riparian communities, large *Juncus* and *Carex* wetlands, coastal dunes scrub. Habitats support neotropical migrant birds, owl and hawk roosting. This area is threatened by European beach grass.
9	51.60	The dynamic and scenic migrating sand sheet, Lunar Crater, is a popular hiking destination but is threatened by European beach grass that could stablize the sand sheet.
10	34.42	One of the most intact areas of coastal dunes scrub in the entire Dunes Complex (Phoebe Valley) occurs here. This habitat supports roosting Say's phoebes in the winter and mule deer year round. Veldt grass poses the greatest invasion but is still controllable.
11	25.26	The cottonwood-willow forest is the tallest forested area on the Refuge. The only Santa Barbara sedge wetland occupies 1.56 acres within this RPMA. Habitats include scattered willow wetlands and coastal dunes scrub which provide good owl and hawk roosting sites. Portions of this RPMA are threatened by veldt grass and poison hemlock.
12	60.27	Woodpecker Valley contains the largest continuous willow forest on the Refuge within RPMA 12. Habitats support California red-legged frog, neotropical avian migrants, and two-striped gartersnake in Snakebite Pond. Gambel's watercress and marsh sandwort have been planted at Snakebite Pond. Other habitats include dune swales and dune scrub but this RPMA is predominantly threated by veldt grass and feral swine.
13	4.21	The only known population of La Graciosa thistle on the Refuge occurs within this RPMA. Habitats include willow forest and provide owl and hawk roosting sites. However, this area is threatened by feral swine. Gambel's watercress and marsh sandwort have been planted here.
14	9.14	California red-legged frog breed at most of the ponds within Four Pond Valley (Colorada Pond, Icebox Pond, and East Pond) within RPMA 14. Gambel's watercress, marsh sandwort have been planted here as well as seeds for La Graciosa. thistle owl and hawk roosting; threatened by feral swine

Total Area: 549.32 acres (21-percent of Refuge)

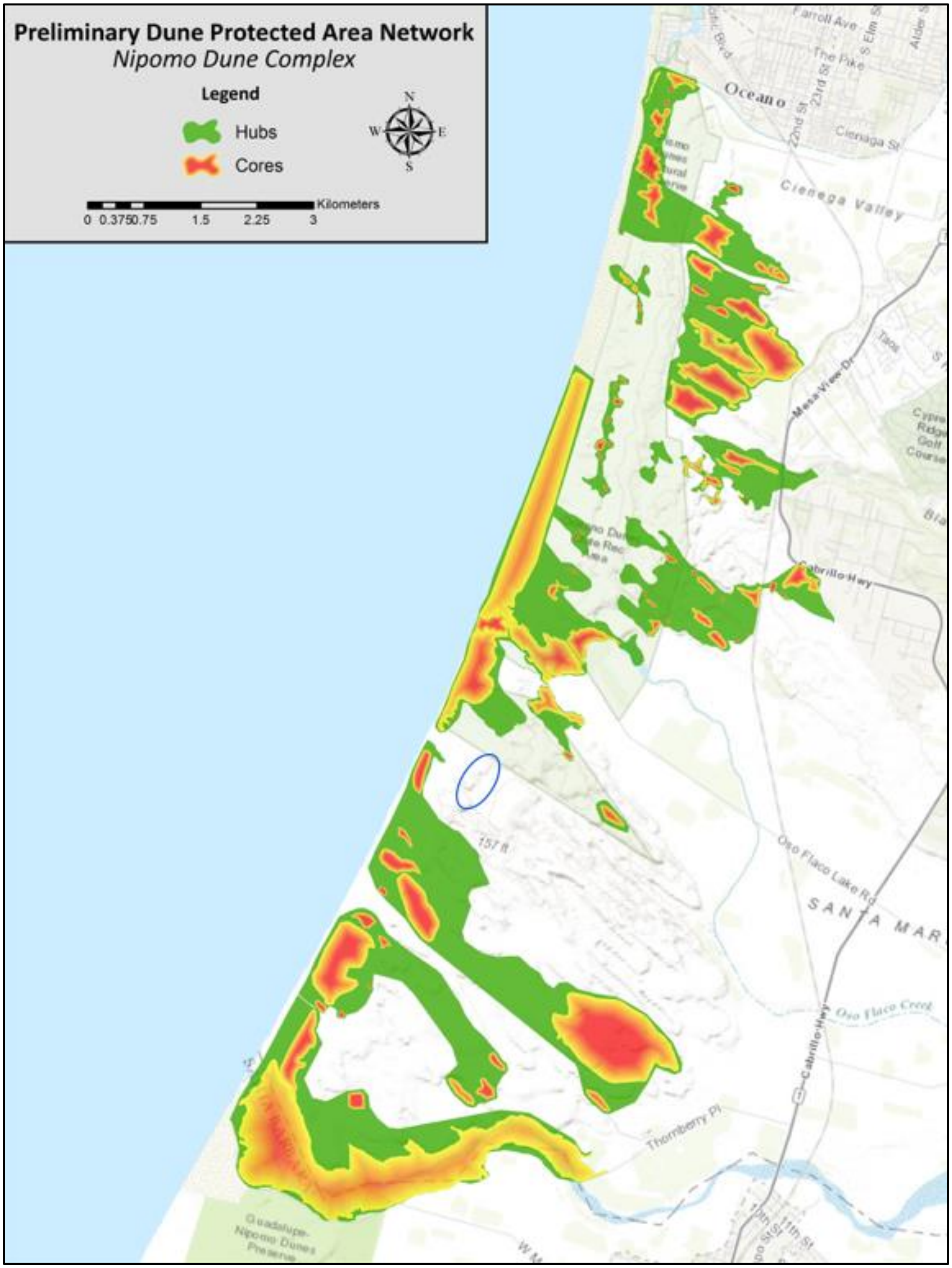

Figure 18. Map of the preliminary Dune Protected Areas Network for the northern Nipomo Dunes. The blue circle indicates the location of a dune wetland complex that may merit additional consideration for inclusion within the DPA network. Map courtesy of the LCSLO.

Feral Pigs

Based on results of the aerial survey, feral pigs play an active role in utilizing and inadvertently modifying dune habitats that they exploit. While the boundary of the Refuge is too porous to maintain a sustained feral pig eradication, efforts should be made to cull pigs on the Nipomo Dune Complex whenever possible. The current *Feral Swine Control and Monitoring Plan* within the GNDNWR CCP calls for a comprehensive ground-based management of feral pigs through maintenance of high quality resource exclusion fencing, targeted trapping, hunting with dogs and vigilant monitoring (USFWS 2016).

Neighboring property owners (California State Parks on the GNDNWR northern boundary and Chevron on the southern boundary) both utilize the United State Department of Agriculture-Wildlife Services to trap pigs. Both properties have well established infrastructure which makes trapping the preferred option. However, GNDNWR is not structured in a way that favors trapping as an optimal method for feral pig control. Rather, the open habitat on the Refuge is ideal for an aerial hunting approach like that which was performed on Santa Cruz Island in 2006 (Parkes et al. 2010). Regular culling events could be done in less than two hours from a low-flying helicopter. WCS's helicopter subcontractor, Native Range Inc., performed the feral pig eradication of Santa Cruz Island and their chief pilot is confident that feral pig numbers can be kept to a minimum on the Refuge if two to three culling events were to be performed on the Refuge each year. Results could be further enhanced if aerial culling efforts were conducted across most the greater Nipomo Dunes Complex and combined with persistent trapping efforts.

5.0 Development of an Invasive Plant Management Plan

The GNDNWR is bordered by the Callendar Dunes to the north, Santa Maria Valley agriculture to the east, and Chevron's Guadalupe Oil Field Restoration Area to the south. Many vectors exist for the transport of invasive species in this region, including agricultural activity, vehicle transport, coastal visitors, and natural systems such as wind or animal transport. Because of the persistence of invasive species common to the region, new incursions, and the risk of reinfestation, invasive plant management of the GNDNWR will require continual collaboration and oversight at a *regional scale*. Formation of a dune system-wide *Invasive Plant Management Plan* (IPMP) is the best way to achieve this goal. Such a plan would establish standard early detection and rapid response practices, institute effective biosecurity protocols, develop monitoring methodologies, and advance comprehensive restoration work plans that prioritize the most critically important habitats within the greater Nipomo Dunes Complex.

The process for developing a holistic IPMP for the Nipomo Dunes begins with the selection of a target invasive plant species list. This list was selected in 2015 using the IPIEDT (Olsen and Hall 2015). Prior to the aerial survey of GNDNWR, this species list was further refined by LCSLO and WCS staff to target the survey of species with the highest likelihood to negatively impact Refuge resources while executing limited funds to effectively survey the entire Refuge.

To date, WCS has collected geospatial invasive plant data from only the GNDNWR. However, the Refuge is but one area of the greater Nipomo Dune Complex. The remaining properties are scheduled for survey during the 2017/18 growing seasons. Once completed, the comprehensive dataset will be analyzed by the LCSLO to direct an IPMP that details objectives based off each species' unique ecology and distribution across the entire Complex. One of the first steps in this analysis requires comparison of these data to a geospatial distribution of priority resources and list of overall management objectives for the Dune Complex to establish a threat assessment of each target invasive plant species. In addition to identifying potential impacts of each invasive plant on the various resources of the Dune Complex, this assessment should identify constraints imposed upon potential management activities that may be used to control each target species. To that end, a detailed list of potential management actions for each target species should be researched for later comparison to these constraints.

Furthermore, the Dune Complex should conduct a thorough financial estimation of projected resources that will be allocated to invasive plant control activities moving forward. This estimation should consider options for supplemental grant funding in addition to existing programmatic allocations. Development of a projected budget is crucial because it identifies constraints imposed on potential management actions for each target species. It is essential that this estimation projects out at least five-years of future funding, as effective invasive plant management requires a sustained effort.

Once the threat assessment, constraints assessment, management action assessment, and financial projection have been completed, these factors should be analyzed holistically to prioritize the species to be targeted for various management goals ranging from limited containment to complete eradication. This prioritization should give urgency to those species that have been newly introduced so that they may be controlled before the species becomes entrenched and too costly to effectively control. "The Invasion Curve" is a concept in conservation biology that shows that eradication of an invasive species becomes less likely and control costs increase as an invasive species spreads over time (Figure 19). Prevention is the most cost-effective solution, followed by eradication if conducted in a timely manner. If a species is not detected and removed early, intense, and long-term control efforts become unavoidable. Identifying where a species falls on "The Invasion Curve" is the first step in identifying the management goal to be set for each invasive species.

After management goals have been established, a series of habitat-based or species-specific work plans should be developed that detail the actions to be taken to control priority target species. These work plans should provide all minimization measures to be enacted while conducting management activities that reduce or eliminate negative impacts to sensitive resources on the Dune Complex. Providing a detailed explanation of the proposed minimization measures is crucial when recommending actions in or around federally listed species habitat. This information is compulsory to acquire the necessary USFWS permits to conduct actions that may lead to "take" of listed species. Although invasive species management typically protects, creates, or enhances habitat for native species, control actions may impact individuals or modify habitat at a crucial life phase of the species. For this reason, final selection of proposed actions should be conducted in an open forum with review from federally listed species experts.

In addition to the proposed management activities, each work plan should state management success criteria and detail cost-effective monitoring methodologies to be used to determine if goals have been met. If not achieved, thresholds should be established to determine whether management actions should be continued or the program should be redesigned to better achieve stated goals. Thresholds can be based on an arbitrary population density, groundcover, or similar metrics. However, ecological thresholds that identify both effectiveness of control efforts and habitat sensitive resource response is preferred.

In addition to success criteria based monitoring, a semi-routine Dune Complex-wide survey should be maintained. Based on other long-term invasive species eradication projects occurring on Irvine Ranch and Santa Cruz Island, property-wide invasive plant surveys should be conducted on a five-year cycle. This time-period allows for treatment efforts to take effect while identifying new pioneer invasive plant populations before they become completely entrenched.

As stated above, development of a comprehensive IPMP should give the highest priority to the prevention of invasive plant introduction and establishment and spread on the Refuge. For this reason, a detailed audit of current and future GNDNWR management activities, equipment maintenance/transport, material procurement, and restoration methodologies employed on the property should be conducted. This assessment should be teamed with existing biosecurity "Best Management Practices" to develop a standard set of invasive organism prevention policies for all visitors, contractors, and GNDNWR staff.

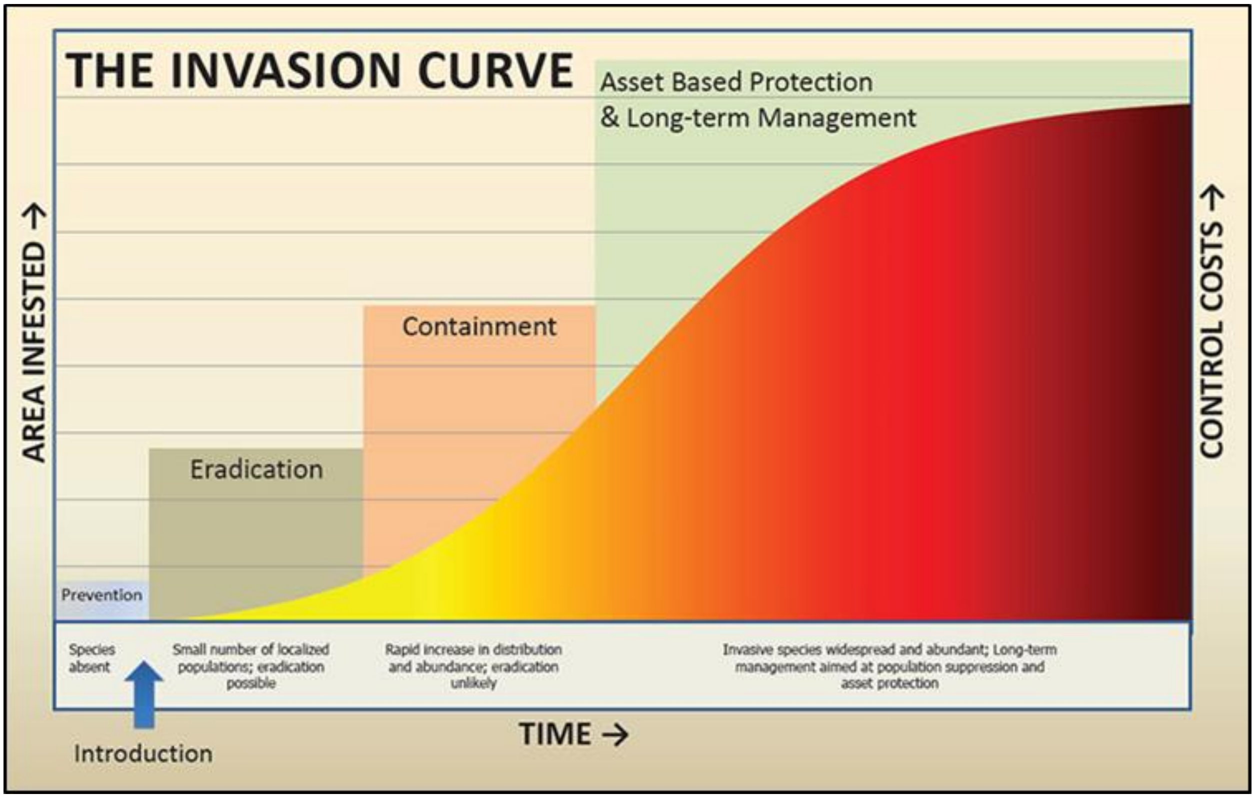

Figure 19. View of the classic *Invasion Curve* showing the relationship between invasive plant infestation "size" and control costs. Photo courtesy of the North American Invasive Species Network (http://www.naisn.org).

6.0 Interim Invasive Plant Prioritization

While the development of an *Invasive Plant Management Plan* allows for comprehensive decision making, the creation of such a program is time consuming. In the interim, resources are best directed towards "low hanging fruit" or species occurring toward the left side of the *Invasion Curve.* However, directing field treatments according to a species' *Invasion Curve* status alone is overly simplistic. Additional factors can easily be included in a preliminary review of the survey data such as the "invasiveness" of a species, the quality of habitat it is infesting and other life history factors that make the species harder to control over the long term.

To provide timely recommendations for those species that should be targeted while an IPMP is being developed, WCS created a customized interim prioritization system for eradication oriented treatment of the 13 detected invasive plant taxa documented at GNDNWR (Table 4). To create this prioritization, WCS reviewed all existing invasive plant species data and the habitat context in which they were found. Through this process, WCS identified eight variables to develop a customized treatment prioritization. These variables include:

1. The total number of stands of each invasive plant species;
2. The gross acres of habitat infested of each invasive plant species;
3. The net acres of each invasive plant species;
4. California Invasive Plant Council's Inventory Rating for each species ([Cal-IPC] 2006);
5. GNDNWR habitat conservation priorities;
6. The presence of invasive plant species within a RPMA;
7. The life cycle of each invasive plant species;
8. The fecundity of each invasive plant species;
9. The seed longevity of each invasive plant species.

Like most wildland areas in California, GNDNWR is infested with too many invasive species with varying ecologies to conveniently manage all invasives. Index ranking of invasive plants therefore provides a uniform methodology for interim prioritization which allows for 1) the highest ranked and manageable species to be controlled first, 2) limited resources to be used efficiently, and 3) management decisions based on defensible systematic rigor.

A series of index values ranging from 1 to 3 were developed for each prioritization variable. An index rank of 3 was assigned to variables that correlate with high priority treatment conditions such as small number and size of infestations; small net and gross acreages; Cal-IPC's inventory rating for ecological damage caused by each species; invasive plants infesting high quality or high priority habitat types; invasive plants with a short life cycle that are difficult to detect and respond to; highly fecund species that quickly spread; and finally, species with longer lived seed banks. An index ranking of 1 was designated for inverse conditions that correlate with low priority treatment conditions. These various index values were then compiled to develop an overall invasive plant priority ranking system to determine species from highest to lowest priority for eradication or control. These ranked species can be then cross-referenced with their location on the *Invasion Curve* so that treatment options can be realistically evaluated (Figure 19).

6.1 Interim Prioritization Indices

Stand Total Index

According to the concept expressed in the Invasion Curve, invasive species with small population sizes require less effort to control relative to larger and therefore more established populations (Figure 19). For this reason, invasive species infestations represented by few stands or are in the early stages of invasion should be prioritized with a *Stand Total Index* score of 3. Conversely, well-established or high numbers of invasive plant stands should be designated with a *Stand Total Index* score of 1 (Table 6).

As discussed in the section above and shown in Figure 19, eradication is most effective and less costly when the total number of invasive plant stands is low. The number of populations of a species is an indicator of the access time needed to eradicate that species. Traveling to many populations is much more time consuming and difficult than accessing one or few populations. The number of populations is also an effective way to determine which phase of invasion a species is in or how invasive it is, i.e. many small populations could mean the species is in an expansion phase of invasion. Typically, smaller populations have less seed in the soil, and are thus easier to eradicate. Therefore, a higher priority (*Stand Total Index* score of 3) was assigned to those invasive plant species with the lowest number of stand occurrences and an index score of 1 to those species with the most numerous stand totals.

To develop the *Stand Total Index*, the invasive plant stand total was tallied for each species. An 80-percent confidence interval was calculated to determine thresholds to attribute the *Stand Total Index* score from 1-3 (low-high priority; Table 6).

Table 6. Summary of invasive plant stand totals, invasive plant area in acres and associated index values including infested habitat acres by species.

Species	Stand Total	Stand Total Index	Total Gross Acres	Gross Area Index	Total Net Acres	Net Area Index
Ammophila arenaria	215	2	511.08	2	94.53	2
Cakile maritima	1	3	0.002	3	0.0003	3
Carpobrotus chilensis	529	1	1268.90	1	58.68	2
Carpobrotus edulis	17	3	42.01	3	0.61	3
Cirsium vulgare	14	3	1.21	3	0.02	3
Conicosia pugioniforn	285	2	119.28	2	0.75	3
Conium maculatum	28	3	15.07	3	2.07	3
Cortaderia jubata	14	3	0.005	3	0.003	3
Ehrharta calycina	718	1	1615.49	1	335.39	1
non-native grasses	10	3	8.25	3	1.60	3
Pinus radiata	3	3	0.02	3	0.02	3
Senecio elegans	41	3	8.02	3	0.14	3
Silybum marianum	1	3	0.0006	3	0.0001	3
Total	**1876**		**3589.32**		**493.80**	
Mean	*144.31*		*276.10*		*37.98*	
SD	*233.83*		*540.33*		*94.04*	
Lower 80% CI of mean	*79.45*		*126.24*		*11.90*	
Upper 80% CI of mean	*298.68*		*605.19*		*120.12*	

*Index Scores: **1** (Green)= Low Priority Rank, **2** (Yellow)= Intermediate Priority Rank, **3** (Red)= High Priority Rank.*

Gross Acre Index

Invasive species with small population areas require less effort to control relative to larger and therefore more established populations (Figure 19). However, gross area differs from net area in that gross area (acres) refers to the total area that the invasive plant occurs across the landscape including native habitat interspersed with invasive populations.

To develop an index of "area size" of each infestation specific to GNDNWR, the gross invasive plant acreage total (GIS attribute data field entitled "*Gross_Acres*") was tallied for each species. An 80-percent confidence interval was calculated to determine thresholds to attribute the *Gross Area Index* score from 1-3 (low-high priority; Table 6). Those species with moderate stand acreages that fell within the 80-percent confidence interval were assigned an index score of 2. Species with acreage values above and below the confidence interval were assigned index scores of 1 and 3 respectively.

Net Acre Index

Invasive species with small population areas require less effort to control relative to larger and therefore more established populations (Figure 19). However, net area differs from gross area in that net area (acres) refers to the concentrated area that the invasive plant inhabits, excluding interspersed landscapes.

To develop an index of "area size" of each infestation specific to GNDNWR, the net invasive plant acreage total (GIS attribute data field entitled "*Net_Acres*") was tallied for each species. An 80-percent confidence interval was calculated to determine thresholds to attribute the *Net Area Index* score from 1-3 (low-high priority; Table 6). Those species with moderate stand acreages that fell within the 80-percent confidence interval were assigned an index score of 2. Species with acreage values above and below the confidence interval were assigned index scores of 1 and 3 respectively.

Cal-IPC Ranking Index

Cal-IPC's Invasive Plant Inventory was used to determine the threat posed by each species across the state (Cal-IPC 2006). The Inventory was developed by individually ranking each species using a plant assessment form, which is separated into three subject sections that are composed of several sub-sections listed below:

Section 1- Ecological Impact
- 1.1- Impact on abiotic ecosystem processes
- 1.2- Impact on plant community composition, structure, and interactions
- 1.3- Impact on higher trophic levels
- 1.4- Impact on genetic integrity

Section 2- Invasive Potential
- 2.1- Role of anthropogenic and natural disturbance in establishment
- 2.2- Local rate of spread with no management
- 2.3- Recent trend in total area infested within California
- 2.4- Innate reproductive potential
- 2.5- Potential for human-caused dispersal
- 2.6- Potential for natural long-distance dispersal (>1 km)
- 2.7- Other regions invaded

Section 3- Ecological Amplitude and Distribution
- 3.1- Ecological amplitude
- 3.2- Distribution

Cal-IPC developed a matrix ranking system to compile and balance data gathered for each invasive plant species for all section scores to determine the species' overall score and rank. Ranking categories are as follows:

> **High**: These species have severe ecological impacts on ecosystems, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. These species are usually widely distributed ecologically, both among and within ecosystems.
>
> **Moderate**: These species have substantial and apparent but generally not severe ecological impacts on ecosystems, plant and animal communities, and vegetation structure. Their reproductive biology is conducive to moderate to high rates of dispersal, though establishment is generally dependent on ecological disturbance. Ecological amplitude and distribution may range from limited to widespread.
>
> **Limited**: The ecological impacts of these species are minor. Their reproductive biology and other invasiveness attributes result in low to moderate rates of invasion. Ecological amplitude and distribution tend to be generally limited (however, they may be locally persistent and problematic). These species may be more problematic than their rank reveals if there is a lack of published literature.

WCS incorporated the Cal-IPC Inventory ranking for each species whenever available. High, moderate and limited ranked species were designated *Cal-IPC Ranking Index* scores of 3-1 respectively (Table 7). Though the majority of invasive plants occurring on GNDNWR were included in the Cal-IPC Inventory and possessed ranking score values, two invasive plant species have not been assessed or ranked by Cal-IPC (Table 7). For those species, the *Cal-IPC Ranking Index* was inferred by WCS based on general knowledge of the invasive plant in coastal Central California.

Table 7. Summary of *Cal-IPC Ranking Index* scores for each invasive plant species based on each species' impacts, invasiveness, and range and frequency of habitat types invaded throughout California.

Species	Common Name	Cal-IPC Inventory Rating	Cal-IPC Rank Index
Cortaderia jubata	jubata grass	High	**3**
Carpobrotus edulis	hottentot fig iceplant	High	**3**
Conium maculatum	poison hemlock	Moderate	**2**
Cirsium vulgare	bull thistle	Moderate	**2**
Senecio elegans	red-purple ragwort	*not classified*	**2**
Pinus radiata	Monterey Pine	Limited	**1**
non-native grasses	non-native grasses	*not classified*	**2**
Silybum marianum	milk thistle	Limited	**1**
Cakile maritima	European searocket	Limited	**1**
Carpobrotus chilensis	sea-fig iceplant	Moderate	**2**
Ehrharta calycina	perennial veldt grass	High	**3**
Ammophila arenaria	European beachgrass	High	**3**
Conicosia pugioniformis	slender-leaved iceplant	Limited	**1**

Cal-IPC Rank Index values displayed in ***RED*** *are species that have yet to be assessed by Cal-IPC. Instead, the ranking value was inferred based on WCS observations on the GNNWR and the central coast region of California as a whole.*

Index Scores: ***1*** *(Green)= Low Priority Rank,* ***2*** *(Yellow)= Intermediate Priority Rank,* ***3*** *(Red)= High Priority Rank.*

Habitat Priority Index

Various habitats within the NDC including the Refuge were identified as prime areas of high native biodiversity worthy of substantial conservation actions and protections (Whitaker 2016). Habitat types were attributed "Rarity Rankings" based on global significance and relative occurrence with the NDC. These "Rarity Rankings" were subsequently assigned varying levels of management priority scores of one to three from low to high priorities respectively (Table 8).

Table 8. Summary of *Habitat Priority Index* scores for each species based on the associated land use, "exoticness", and disturbance level of the habitat that the invasive plant has infested.

Habitat Type	Habitat Managment Priority	Habitat Priority Value
Active Dunes Central	Intermediate	**2**
Central Coast Dune Scrub/ Sage Scrub	Intermediate	**2**
Coastal Dune Swale	High	**3**
Coastal Foredunes	Intermediate	**2**
Developed	Low	**1**
Disturbed	Low	**1**
Freshwater Marsh/ Open Water	High	**3**
Non-Native Herbaceous	Low	**1**
Riparian Woodland/ Scrub	High	**3**
Not Classified	Low	**1**

Index Scores: ***1*** *(Green)= Low Priority Rank,* ***2*** *(Yellow)= Intermediate Priority Rank,* ***3*** *(Red)= High Priority Rank.*

The overall Habitat Priority Index for each species was calculated using the relative frequency of net acres occurring within each habitat priority divided by the net acres infested into an additive cumulative index score between one and three (Equation 1; Figure 20, 21; Table 9). A species index score of 3 indicates that most of the stands occur in areas of high priority habitat whereas a score of 1 indicates that most stands occur in low priority habitat.

Table 9. Habitat priority indices for 13 documented invasive plant species at GNDNWR.

Species	Common Name	High Priority Acres	Intermediate Priority Acres	Low Priority Acres	Net Acres	Habitat Priority Index
Ammophila arenaria	European beachgrass	2.85	70.91	20.78	94.53	**1.81**
Cakile maritima	European searocket	-	0.0003	-	0.0003	**2.00**
Carpobrotus chilensis	sea-fig iceplant	0.86	54.51	3.31	58.68	**1.96**
Carpobrotus edulis	hottentot fig iceplant	-	0.59	0.01	0.61	**1.98**
Cirsium vulgare	bull thistle	0.0004	0.02	0.0002	0.02	**2.01**
Conicosia pugioniformis	slender-leaved iceplant	0.02	0.70	0.03	0.75	**1.98**
Conium maculatum	poison hemlock	1.62	0.13	0.32	2.07	**2.63**
Cortaderia jubata	jubata grass	0.001	0.002	0.0004	0.003	**2.07**
Ehrharta calycina	perennial veldt grass	26.07	193.86	121.84	341.77	**1.72**
non-native grasses	non-native grasses	0.79	0.21	0.60	1.60	**2.12**
Pinus radiata	Monterey Pine	0.01	0.01	0.00005	0.02	**2.51**
Senecio elegans	red-purple ragwort	0.001	0.20	0.02	0.22	**1.91**
Silybum marianum	milk thistle	0.0001	-	-	0.0001	**3.00**

*Index Scores: **1** (Green)= Low Priority Rank, **2** (Yellow-Orange)= Intermediate Priority Rank, **3** (Red)= High Priority Rank.*

Equation 1. Method of calculating the *Habitat Priority Index* for each invasive plant species.

$$\boldsymbol{HPI} = \left[\left(\frac{HPR\_1}{t}\times 1\right) + \left(\frac{HPR\_2}{t}\times 2\right) + \left(\frac{HPR\_3}{t}\times 3\right)\right]$$

HPI= Habitat priority index by species
HPR_x= Total area of gross habitat infested within a Habitat Priority Ranking of x (x=1, 2 or 3)
t = Total area of gross habitat infested

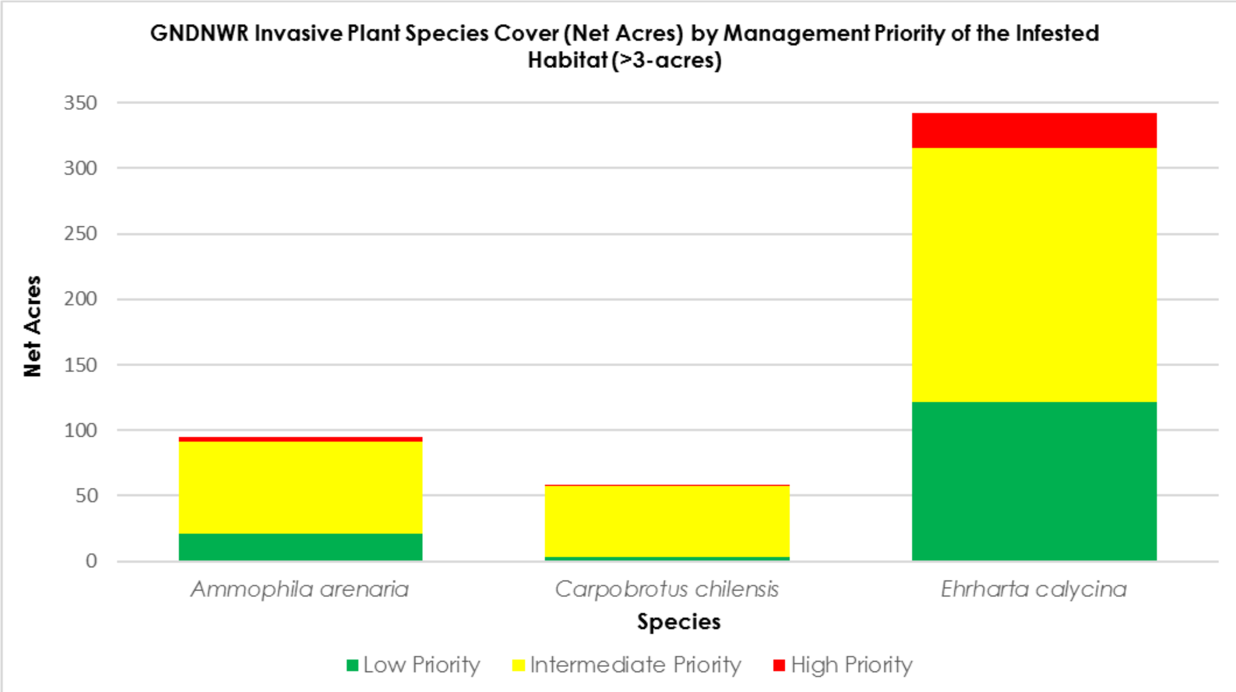

Figure 20. Invasive plant species occupying more than three net acres in high, intermediate, and low priority habitat types.

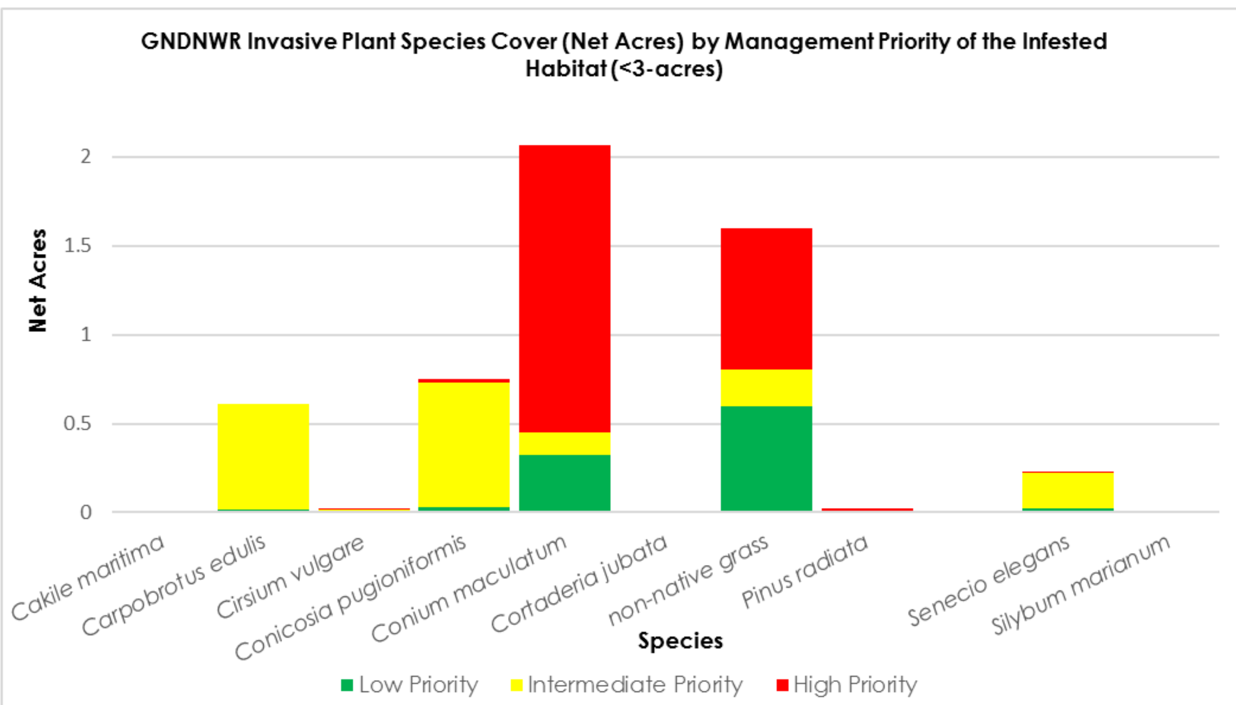

Figure 21. Total acres of each invasive species by the *Habitat Priority Index* score of the habitats that were infested by that species.

Life Cycle Index

Species detectability is key to management strategies. Because annual species have a shorter life cycle and therefore are ephemeral in nature, they become harder to monitor. Subsequently annual species are able to spread throughout wildlands and become entrenched. Species with annual life cycles received *Life Cycle Index* scores of 3 and conversely, perennial species, i.e. easier to detect species, received *Life Cycle Index* scores of 1 (Table 10).

Table 10. Life cycle and associated index for 13 documented invasive plant species at GNDNWR.

Species	Common Name	Life Cycle	Life Cycle Index
Ammophila arenaria	European beachgrass	Perennial	3
Cakile maritima	European searocket	Annual	1
Carpobrotus chilensis	sea-fig iceplant	Perennial	3
Carpobrotus edulis	hottentot fig iceplant	Perennial	3
Cirsium vulgare	bull thistle	Annual	1
Conicosia pugioniformis	slender-leaved iceplant	Annual	1
Conium maculatum	poison hemlock	Annual	1
Cortaderia jubata	jubata grass	Perennial	3
Ehrharta calycina	perennial veldt grass	Perennial	3
non-native grasses	non-native grasses	Annual	1
Pinus radiata	Monterey Pine	Perennial	3
Senecio elegans	red-purple ragwort	Annual	1
Silybum marianum	milk thistle	Annual	1

*Index Scores: **1** (Green)= Low Priority Rank, **2** (Yellow)= Intermediate Priority Rank, **3** (Red)= High Priority Rank.*

Fecundity Index

Fecundity refers to the ability to produce abundant fruits and is an apt characteristic of invasive plants with prolific propagule dissemination. Any species with higher abilities to produce more propagules received a *Fecundity Index* score of 3 whereas invasive species with lower fecundity received lower index scores (Table 11). Species with the ability to produce more propagules are more likely to spread and become entrenched quickly and should therefore be prioritized.

Table 11. Fecundity and associated index of 13 documented invasive plant species at GNDNWR.

Species	Common Name	Fecundity	Fecundity Index
Ammophila arenaria	European beachgrass	Low	1
Cakile maritima	European searocket	High	3
Carpobrotus chilensis	sea-fig iceplant	Moderate	2
Carpobrotus edulis	hottentot fig iceplant	Moderate	2
Cirsium vulgare	bull thistle	High	3
Conicosia pugioniformis	slender-leaved iceplant	Moderate	2
Conium maculatum	poison hemlock	High	3
Cortaderia jubata	jubata grass	High	3
Ehrharta calycina	perennial veldt grass	High	3
non-native grasses	non-native grasses	High	3
Pinus radiata	Monterey Pine	Low	1
Senecio elegans	red-purple ragwort	High	3
Silybum marianum	milk thistle	High	3

*Index Scores: **1** (Green)= Low Priority Rank, **2** (Yellow)= Intermediate Priority Rank, **3** (Red)= High Priority Rank.*

Seed Longevity

Seed longevity refers to the length of time that seeds remain dormant and viable in the soil. Seed longevity is wide-ranging amongst different species and therefore has significant management implications. Species with longer seed longevity should be prioritized for treatment because of their ability to over time become firmly ensconced on the landscape with little hope for eradication. Species with shorter seed longevity are not as pressing for management concerns and are therefore attributed lower scores on the *Seed Longevity Index* (Table 12). Because published literature is limited, WCS met with LCSLO's Jon Hall to collaboratively determine appropriate scores based on collective regional experience in coastal Central California.

Table 12. Seed longevity and associated index for 13 documented invasive plant species at GNDNWR.

Species	Common Name	Seed Longevity	Seed Longevity Index
Ammophila arenaria	European beachgrass	Short	1
Cakile maritima	European searocket	Moderate	2
Carpobrotus chilensis	sea-fig iceplant	Moderate	2
Carpobrotus edulis	hottentot fig iceplant	Moderate	2
Cirsium vulgare	bull thistle	Moderate	2
Conicosia pugioniformis	slender-leaved iceplant	Moderate	2
Conium maculatum	poison hemlock	Moderate	2
Cortaderia jubata	jubata grass	Short	1
Ehrharta calycina	perennial veldt grass	Moderate	2
non-native grasses	non-native grasses	Short	1
Pinus radiata	Monterey Pine	Short	1
Senecio elegans	red-purple ragwort	Moderate	2
Silybum marianum	milk thistle	Moderate	2

*Index Scores: **1** (Green)= Low Priority Rank, **2** (Yellow)= Intermediate Priority Rank, **3** (Red)= High Priority Rank.*

6.2 Interim Prioritization Ranking

Due to limited resources available for land stewardship, it is necessary to prioritize management objectives. For this reason, a systematic and transparent prioritization of objectives is necessary. Having developed the eight descriptive indices (ranked 1-3, low to high priority for control) discussed above, the objective of this project is to develop a quantitative invasive plant treatment prioritization ranking system.

The first and perhaps most logical way of utilizing these indices is to sum the index scores for each invasive plant species. This *Additive Priority Score* signifies a single value that identifies those species that are best suited for treatment due to their particularly small population and infestation area, occurrence in high quality and high priority habitats, ecological "impactfulness" and invasiveness within natural systems, invasive plants with a short life cycle that become nuisances to detect; highly fecund species that quickly spread; and finally, species with longer lived seed banks. (Equation 2; Table 13; Figure 22).

Equation 2. Method of calculating the *Additive Priority Score* for each invasive plant species.

$$\boldsymbol{APS} = STI + GAI + NAI + CRI + HPI + LCI + FI + SLI$$

APS= *Additive priority score for a species*
STI=Stand Total Index
GAI=Gross Area Index
NAI=Net Area Index
CRI=Cal-IPC Rank Index
HPI=Habitat Priority Index
LCI=Life Cycle Index
FI=Fecundity Index
SLI=Seed Longevity Index

While an additive priority system is effective, not all index factors represent topics that are of equal importance to land managers. After a detailed review of various quantitative prioritization options, WCS devised a modified additive priority system that allows particular indices to be given additional weight relative to others. This *Weighted Priority Score* was submitted to LCSLO Restoration Manager Jon Hall for review to determine which indices may deserve additional consideration. After review of the ranking system, it was determined that the *Cal-IPC Ranking Index* should be weighted by a multiplication factor of 2. This newly weighted prioritization score stresses ecological "impactfulness", invasiveness and regional saturation of each species relative to the other indices within the ranking system (Equation 3; Table 13; Figure 22).

Equation 3. Method of calculating the *Weighted Priority Score* for each invasive plant species.

$$\boldsymbol{WPS} = (STI \times w1) + (GAI \times w1) + (NAI \times w1) + (CRI \times w2) + (HPI \times w1) + (LCI \times w1) + (FI \times w1) + (SLI \times w1)$$

WPS= *Weighted priority score for a species*
w(#)=weighting factor by index

Table 13. Summary of the six variable index scores for each invasive plant species with calculated *Additive* and *Weighted Priority Scores* sorted from high to low ranking by the *Weighed Priority Score Index.*

Species Name	Common Name	Stand Total Index Weighting Factor	Stand Total Index	Gross Area Index Weighting Factor	Gross Area Index	Net Area Index Weighting Factor	Net Area Index	Cal-IPC Rank Index Weighting Factor	Cal-IPC Rank Index	Habitat Priority Index Weighting Factor	Habitat Priority Index	Life Cycle Index Weighting Factor	Life Cycle Index	Fecundity Index Weighting Factor	Fecundity Index	Seed Longevity Weighting Factor	Seed Longevity	Additive Priority Score	Weighted Priority Score
Cortaderia jubata	jubata grass		3		3		3		3		2.07		1		3		1	19.07	25.07
Carpobrotus edulis	hottentot fig iceplant		3		3		3		3		1.98		1		2		2	18.98	24.98
Conium maculatum	poison hemlock		3		3		3		2		2.63		3		3		2	21.63	23.63
Cirsium vulgare	bull thistle		3		3		3		2		2.01		3		3		2	21.01	23.01
Senecio elegans	red-purple ragwort		3		3		3		2		1.91		3		3		2	20.91	22.91
non-native grasses	non-native grasses		3		3		3		2		2.12		3		3		1	20.12	22.12
Silybum marianum	milk thistle		3		3		3		1		3.00		3		3		2	21.00	21.00
Cakile maritima	European searocket		3		3		3		1		2.00		3		3		2	20.00	20.00
Ammophila arenaria	European beachgrass		2		2		2		3		1.81		1		1		1	13.81	19.81
Ehrharta calycina	perennial veldt grass		1		1		1		3		1.72		1		3		2	13.72	19.72
Conicosia pugioniformis	slender-leaved iceplant		2		2		3		1		1.98		3		2		2	16.98	16.98
Pinus radiata	Monterey Pine		3		3		3		1		2.51		1		1		1	15.51	15.51
Carpobrotus chilensis	sea-fig iceplant		1		1		2		2		1.96		1		2		2	12.96	14.96

Cal-IPC Rank Index values displayed in ***RED*** *are species that have yet to be assessed by Cal-IPC. Instead, the ranking value was inferred based on WCS observations on the GNNWR and the central coast region of California as a whole.*

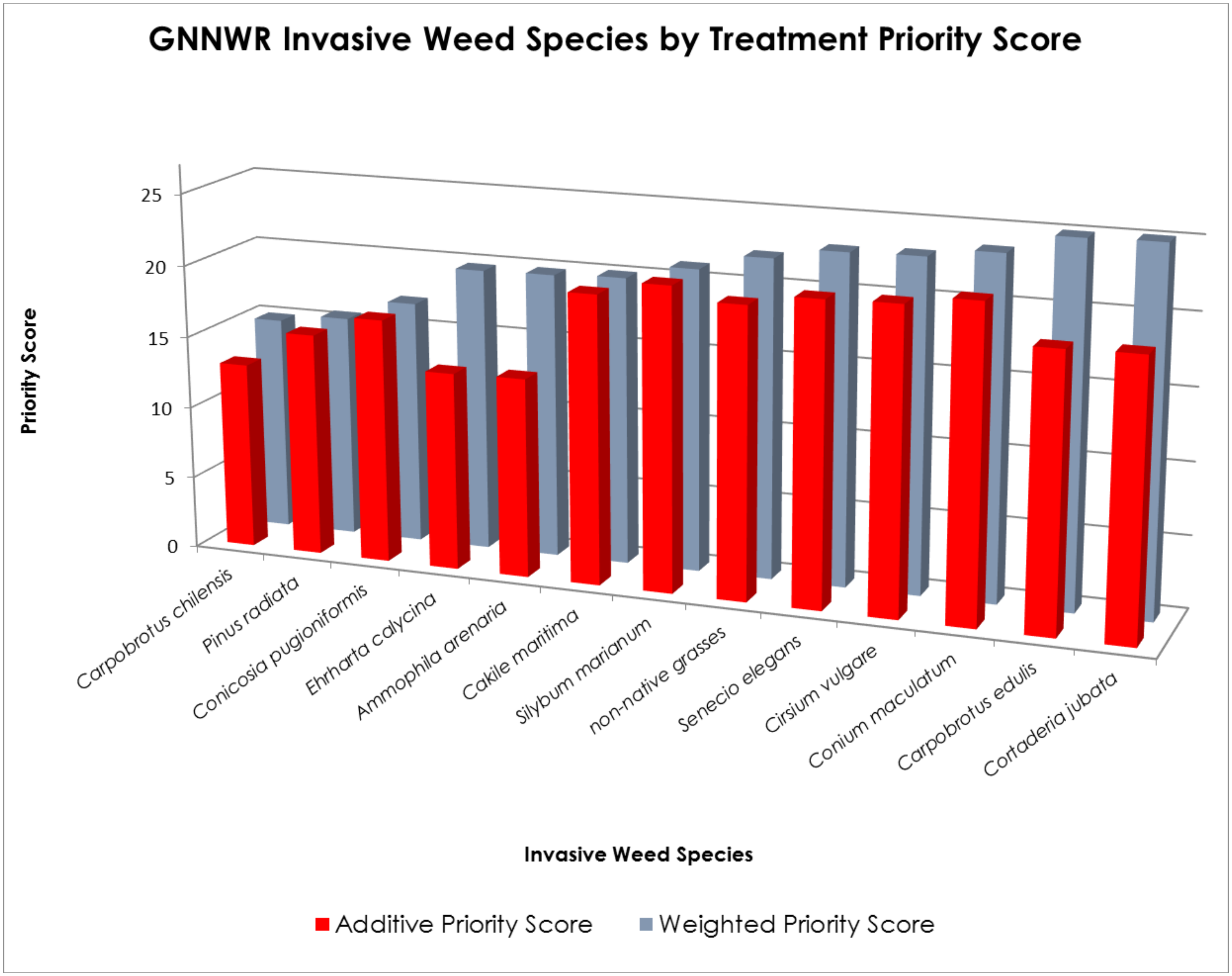

Figure 22. Bar chart summarizing the *Additive* and *Weighed Priority Scores* sorted from high to low ranking by the *Weighed Priority Score Index.*

According to the final weighted interim prioritization, jubata grass, hottentot fig iceplant, poison hemlock, bull thistle, and red-purple ragwort were ranked as the top five target treatment species. This ranking suggests that treatment efforts should be directed towards the eradication or control of these species until a more in-depth analysis can be performed that more critically reviews each species against the specific management goals of the refuge. For example, the interim prioritization places European beachgrass stands as a low-ranked species despite being historically targeted for treatment due to its impacts on western snowy plover and California least tern breeding habitat (Figure 23).

This ranking indicates that European beachgrass is not likely to be eradicated from the Refuge without a large expenditure of resources. However, well-established species occurring on the right side of the *Invasion Curve* (such as perennial veldt grass, sea-fig iceplant, and European beachgrass) currently represent 92.5-percent of the impacts to high priority habitats. Furthermore, a large portion of the European beachgrass infestation appears to be disrupting the natural transport of windblown sand from the coastal strand to the inland reaches of the Refuge (Figure 24). This species forms deep root systems that cause an overly developed foredune ridge resulting in the eventual stabilization of the back dune. This reduction in dune dynamism in turn supports conditions favorable for the establishment and expansion of perennial veldt grass (Figure 25).

This scale of habitat degradation should not be overlooked when developing a comprehensive *Invasive Plant Management Plan* for GNDNWR and the greater dune complex. To support such a plan, an in-depth prioritization should be conducted that identifies units of area infested by common invasive species relative to areas of sensitive natural resources and important regions that function to support essential dune processes.

Although this interim prioritization is only intended to direct treatment efforts until an *Invasive Plant Management Plan* is complete, this prioritization can be modified to include more factors that may influence relative species priority rankings. Information regarding wildlife use of target species, impacts to listed species, constraints to treatment, likelihood of treatment success, cost of treatment, habitat recovery following treatment, and treatment efficiency considerations (i.e. treatment of multiple species clusters to save time) could prove helpful in further refining the eradication prioritization over time.

It is our goal that data gathered during the February 2016 surveys will aid in the development of this prioritization and eventual comprehensive invasive plant management plan.

Figure 23. European beachgrass as seen from the coast stabilizing foredunes and limiting natural dune processes.

Figure 24. European beachgrass as seen from back dunes, creating an optimal environment for the encroachment of perennial veldt grass.

Figure 25. Example of stabilized back dune habitat heavily infested with perennial veldt grass on GNDNWR.

7.0 Acknowledgements

WCS would like to thank the Dunes Collaborative, including the California Department of Fish and Wildlife, Guadalupe-Nipomo Dunes National Wildlife Refuge and the Land Conservancy of San Luis Obispo County for providing financial support for the aerial surveys and subsequent prioritization. We are grateful for the opportunity to work with LCSLO helping to protect one of the few remaining intact dune ecosystems of California. Many thanks to Lindsey Whitaker for providing GIS support for this project. A very special thank you to Jon Hall for his support for the project, excellent coordination, and oversight.

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him

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