Antioch Dunes National Wildlife Refuge
2023 Vegetation Inventory
Final Report

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Cover Photo: Antioch Dunes evening primrose (*Oenothera deltoides* ssp. *howellii*), Stamm Unit, Management Area 1 (Photograph Alice Miller, May 2023)

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Abbreviations

ADB	Antioch Dunes buckwheat
ADP	Antioch Dunes evening primrose
CAL-IPC	California Invasive Plant Council
CCP	Comprehensive Conservation Plan
CCW	Contra Costa wallflower
CDFA	California Department of Food and Agriculture
CDFW	California Department of Fish and Wildlife
CDFG	California Department of Fish and Game
Complex	San Francisco Bay National Wildlife Refuge Complex
EDRR	Early detection and rapid response
GLMM	Generalized Linear Mixed Model
KEA	Key Ecological Attribute
LMB	Lange's metalmark butterfly
MA	Management Area
NRMP	Natural Resource Management Plan
PBC	Pyramid Botanical Consultants
PG&E	Pacific Gas and Electric
Refuge	Antioch Dunes National Wildlife Refuge
SMART	Specific, Measurable, Attainable, Results-oriented, Time-bound

USFWS United States Fish and Wildlife Service

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Chapter 1—Introduction

1.1 Refuge setting

Antioch Dunes National Wildlife Refuge (Refuge) is one of seven refuges in the San Francisco Bay National Wildlife Refuge Complex (Complex) managed by the U.S. Fish and Wildlife Service (USFWS) (Figure 1). The Refuge is located along the south shore of the San Joaquin River on the northern border of the City of Antioch in Contra Costa County, California (Figures 1, 2). The Refuge was established in 1980 under the authority of the Federal Endangered Species Act (ESA) of 1973 to provide critical habitat for the federally endangered Lange's metalmark butterfly (LMB; *Apodemia mormo langei*) and two federally endangered plants, Antioch Dunes evening primrose (ADP; *Oenothera deltoides* ssp. *howellii*), and Contra Costa wallflower (CCW; *Erysimum capitatum* var. *angustatum*) (USFWS 2002, USFWS 2019). The Refuge vision is based on conserving endangered wildlife and plant species and the dune ecosystems that support them: 'endangered species management will be incorporated into the overall management of the riverine sand dune ecosystem. Using management actions that mimic natural processes, the Refuge will support self-sustaining populations of Lange's, wallflower, primrose, and other native species' (USFWS 2002).

The 67 acre Refuge is comprised of two disjunct units, the westernmost Stamm Unit (41 acres) and the easternmost Sardis Unit (26 acres) (Figure 2). The original designated area included 55 acres and 12 adjacent acres owned by Pacific Gas and Electric (PG&E) on the east and west boundary of the Sardis Unit (USFWS 2002), but the PG&E properties have recently been added to the Refuge. For Refuge management, the Stamm Unit is divided into five Management Areas (MAs) and the Sardis Unit into six MAs (Figure 2, Table 1), based on similar topographic features and/or species abundance.

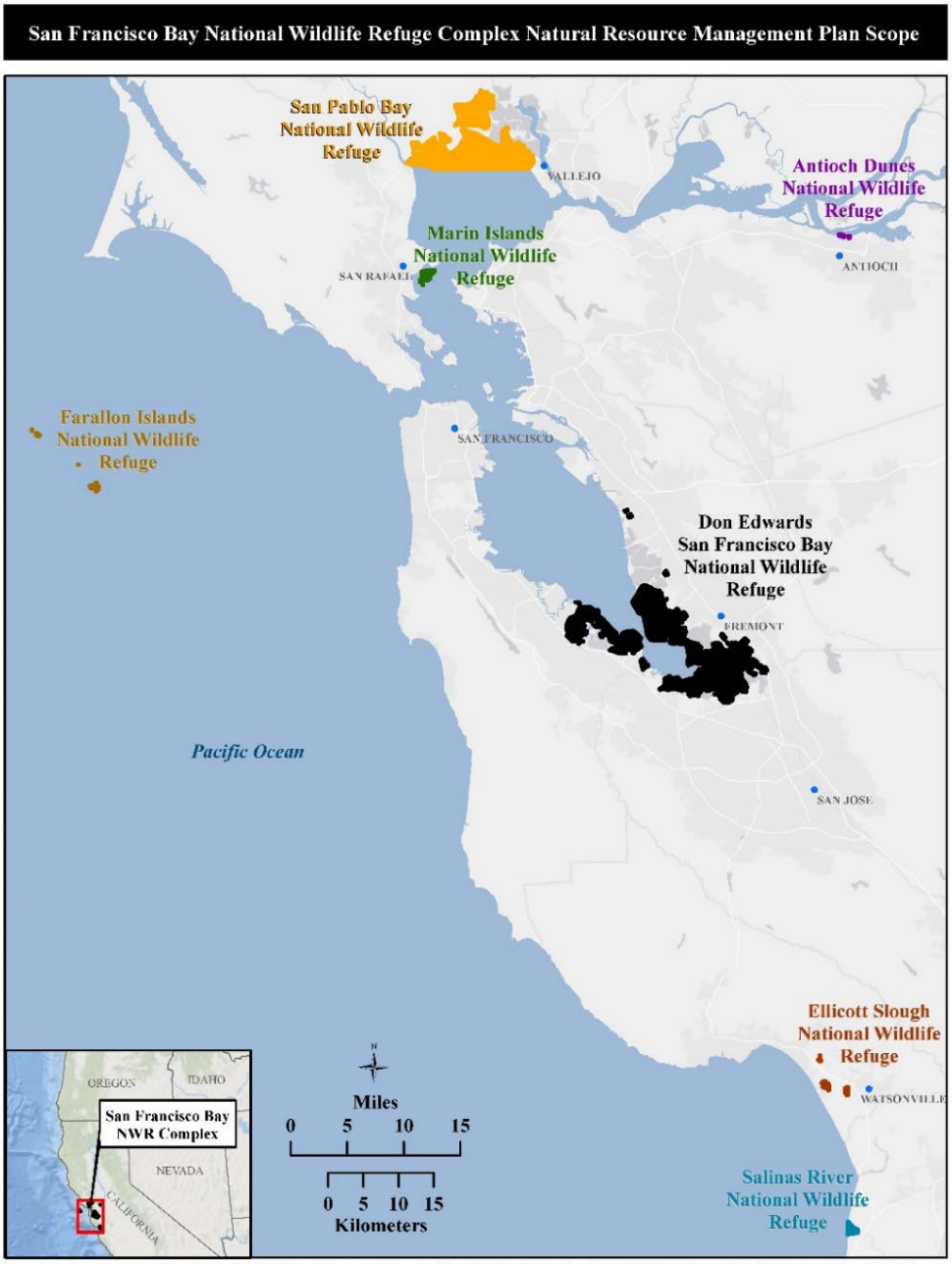

Figure 1. Geographic setting of the seven refuges of the San Francisco Bay National Wildlife Refuge Complex, including Antioch Dunes National Wildlife Refuge. Source: U.S. Fish and Wildlife Service.

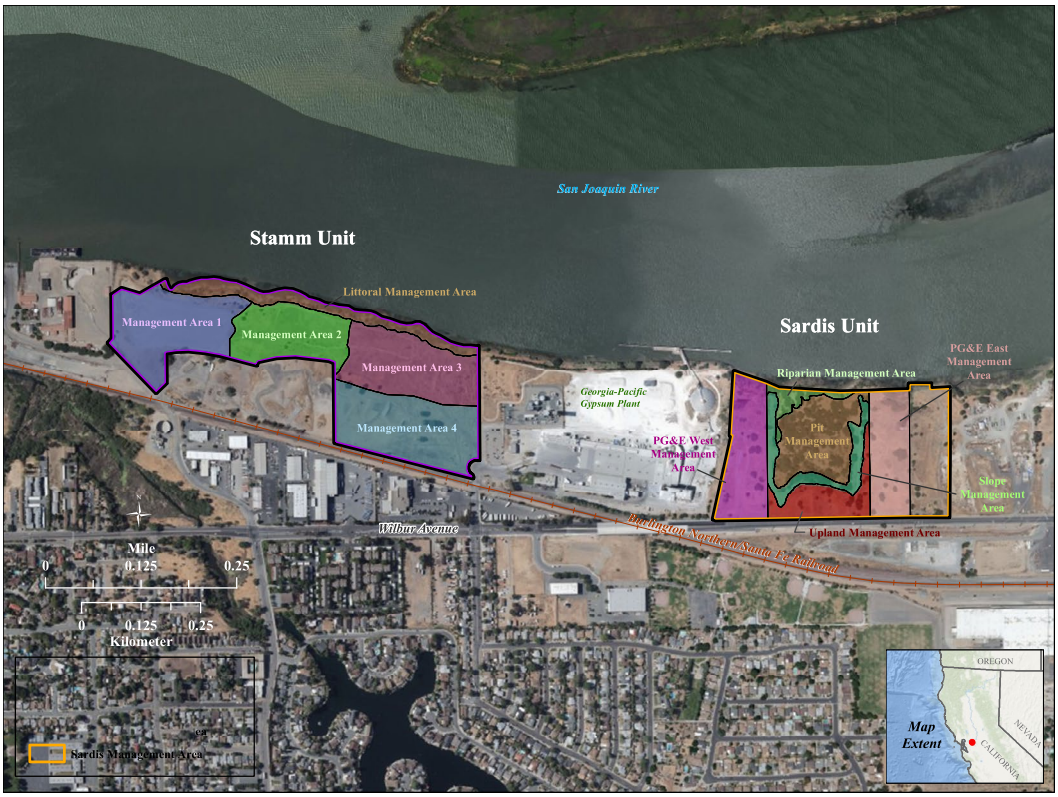

Figure 2. Antioch Dunes National Wildlife Refuge, with Stamm and Sardis Units, and Management Areas within each unit.

Table 1. Management Areas with priority for survey, Antioch Dunes National Wildlife Refuge.

Management Unit	Management Area	Approximate size (acres)	Priority
Stamm	MA1	9	High
	MA2	7	High
	MA3	11	Low
	MA4	11	Low
	Littoral	3	Low
Sardis	Pit	6	High
	PG&E East	6	High
	Slope	3	Low
	Upland	3	Low
	Riparian	2	Low
	PG&E West	6	Low

1.2 Refuge conservation goals and objectives

The overarching conservation goal of Antioch Dunes National Wildlife Refuge is to protect the three federally endangered species endemic to the Refuge (LMB, ADP and CCW), and their critical habitat provided by the riverine dune system.

Specific vegetation related management goals identified in the Comprehensive Conservation Plan (CCP) (USFWS 2002) include:

1. To protect, enhance and maintain habitat for threatened and endangered species, emphasizing species known to inhabit the Refuge, including LMB, CCW and ADP.
2. To protect, restore and manage the Antioch Dune ecosystem for a diversity of native plant and animal species.

The Natural Resource Management Plan (NRMP) for the Complex (USFWS 2019) is a step-down plan of the CCP that helps focus limited resources by identifying priority resources of conservation concern, identifying the most critical threats, refining goals and objectives, and focusing management strategies to address the most critical threats to achieve conservation goals and objectives. The NRMP identified two Key Ecological Attributes (KEAs) on the Refuge, including:

1) Lange's metalmark butterfly population size
2) Sand dune vegetation cover and composition

Sand dune vegetation cover and composition is indicated by 1) percent cover of non-vegetated open sand, and 2) percent cover of dune-associated and beneficial to LMB native plant species (USFWS 2019). Native dune vegetation status and trends includes the endangered species ADP and CCW, as well as host, nectar and perch plants of LMB. Antioch Dunes buckwheat (ADB; *Eriogonum nudum* var. *psychicola*) is the only larval food source for LMB. ADB is endemic to the Antioch Dunes, and requires sandy, well-drained soils and soil disturbance for seedling establishment (USFWS 2020). Adult females lay eggs on the lower stems of ADB where foliage is withered in summer, and eggs hatch when new growth appears during the rainy season (USFWS 2002, McNally 2014). LMB also uses nectar plants such as hairy gumweed (*Grindelia hirsutula*), telegraphweed (*Heterotheca grandiflora*), shrubby butterweed (*Senecio flaccidus* var. *douglasii*), and California matchweed (*Gutierrezia californica*) for food, and perch plants including deerweed (*Acmispon glaber* var. *glaber*). Relevant management goals outlined in the NRMP include:

> RDE_O02. Over the next 15 years (2018–2032), invasive plants occupy <5% of the landcover where sand placement has occurred in the Stamm Unit of Antioch Dunes NWR.
>
> RDE_O03. Contra Costa wallflower and Antioch Dunes evening primrose occupy ≥20% of the vegetative cover and naked stem buckwheat composes at least 20% of the vegetative cover at the Stamm Unit once desired sand depths are attained in dune restoration areas (per Antioch Dunes NWR sand dune management plan).
>
> RDE_O09. By 2033, cover of ripgut brome (annual grass), vetch, yellow starthistle, and Russian thistle is reduced by at least 50% and Himalayan blackberry is reduced by at least 80% (baseline = 2017 inventory) at the Stamm Unit of Antioch Dunes NWR.

RDE_O10. By 2033, cover of tree of heaven is reduced by 75% (baseline = 2017 inventory) at the Sardis and PG&E West Units of Antioch Dunes NWR.

RDE_O11. By 2033, oak cover is <20% at the Sardis Unit of Antioch Dunes NWR.

In accordance with Service policy, a Habitat Management Plan (HMP), a step-down plan to the CCP (USFWS 2002) and NRMP (USFWS 2019), is being prepared to describe the details of actions to manage riverine sand dune (RDE) and vegetation on the Refuge (USFWS in prep.). This HMP further refines Refuge goals and objectives to focus on asset based protection for listed species, and Refuge monitoring will be focused on tracking progress toward these goals and objectives. HMP goals and objectives will be assessed using data collected from SOP, including this inventory. This report, and associated geodatabase and maps, will enable the Refuge to assess the following goals and objectives:

RDE_Goal 1. By FY 2028, Management Area 1 and 2 of the Stamm Unit of Antioch Dunes NWR contains greater than 50 percent open sand and at least 46% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Mathers and USFWS 2018, and Arnold and Powell 1983, Mathers and USFWS 2018). (This report includes a direct assessment of RDE Goal 1 in Table 32).

RDE_Goal 2. By FY 2031, the priority areas in the Pit and PG&E East Management Areas of the Sardis Unit of Antioch Dunes NWR contains at least 20% open sand (<80% vegetated) and at least 21% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Arnold and Powell 1983, Mathers and USFWS 2018, Arnold and Powell 1983). (This report includes a direct assessment of RDE Goal 2 in Table 32).

RDE_Objective 1. By FY 2032, increase percent cover of CCW and ADP in current priority grids by 10 years from 2023 Inventory numbers.

RDE_Objective 3. By 2027, reduce or eradicate priority invasive plants (Table 3) in priority grids for the Lange's metalmark butterfly, Antioch Dunes evening primrose, and Contra Costa wallflower from 2023 Inventory numbers.

Invasive plants pose a critical threat to the health of the riverine dune system and the plants and wildlife that depend on them at Antioch Dunes National Wildlife Refuge by direct competition for resources with native plants, stabilization of a dynamic dune system to one that is unsuitable for threatened plants (ADB and other native dune species), nutrient enrichment of the infertile sand environment, alteration of microhabitat around ADB to the detriment of LMB larvae, and increasing risk and intensity of wildfire (USFWS 2002, McNally 2014, USFWS 2019, 2020a,b, 2021). Invasive plants are one of the most pervasive threats to biological integrity, diversity, and environmental health in the National Wildlife Refuge System (Block and Overbay 2019, USFWS 2019). Invasive plants can alter ecosystem function and structure and change the distribution, abundance, and diversity of native species (e.g., D'Antonio and Vitousek 1992, Vitousek et al. 1997, Mack et al. 2000, Seabloom et al. 2006).

The Refuge implements conservation strategies including enhancement and restoration of a dynamic dune environment through placement of dredged sand and restoration of the native dune plant community, and invasive plant prevention, containment, and control to improve the ecological health of the two KEAs (USFWS 2019). The success of these strategies should be evaluated with comprehensive vegetation inventories conducted every 5 years (USFWS 2019, USFWS in prep).

To provide quantitative baseline data on the status of priority native dune species, priority invasive plants, and landcover attributes relevant to conservation management goals, such as annual grass cover, a

baseline vegetation inventory was conducted in 2017 (Mathers and USFWS 2018). The current inventory is a 5-year remeasurement and refinement of the 2017 inventory, with analyses including a comparison of vegetation attributes from 2017 to 2023, and assessment of how Refuge management is progressing in terms of conservation objectives.

1.3 Purpose

In support of the above goals, Pyramid Botanical Consultants (PBC) was contracted to conduct a field-based inventory of select landcover types and native and nonnative plant species, using and refining the protocol developed in 2017 (Mathers and USFWS 2018). Field surveys were completed in May 2023. This report summarizes the results of this inventory and compares 2023 data with 2017 data. These results provide a quantitative assessment of management activities conducted to support LMB, ADB, ADP, and CCW and the riverine dune system habitat, as well as provide an assessment of the current distribution and abundance of priority native dune species, invasive species and landcover types within the Refuge, and provide data to track progress toward NRMP and HMP goals and objectives. Together, these results can be used to inform and prioritize future management decisions, assess long-term vegetation trends, and serve as a monitoring point for evaluating the effectiveness of vegetation management projects in future.

1.4 Environmental Setting

The Antioch Dunes were once a large, ancient, aeolian dune system extending along the southern bank of the San Joaquin River just east of the town of Antioch, within the San Francisco Bay Delta Watershed (Powell 1983, USFWS 2002, McNally 2014). The dunes historically occurred along a two-mile stretch of river, averaging approximately one-sixth of a mile wide and occupying an area of approximately 190 acres, with heights up to 120 feet (Howard and Arnold 1980, USFWS 2002, McNally 2014). These dunes are found nowhere else within the Delta ecoregion, and isolation of the dune system led to evolution of a unique suite of plant and wildlife species, with 8 insect taxa, including LMB, endemic to the Antioch Dunes (USFWS 2002, McNally 2014).

In the early 1900s, development of the dunes, including sand mining and brick manufacturing, began to destroy the dune system, fragmenting and shrinking the dune habitat (USFWS 2002, McNally 2014). When the Refuge was established in 1980, only a few acres of dune habitat, containing the last populations of ADP, CCW and LMB remained, and these few acres were degraded by invasive nonnative plants (USFWS 2002, McNally 2014). At the time of establishment, the Refuge was open to the public, but was closed in 1986 due to trampling of endangered plants and wildfires (USFWS 2002, McNally 2014). It has remained closed to the public since.

Historically, vegetation on the Refuge was dominated by scattered oaks among rolling dunes (USFWS 2002, McNally 2014, USFWS 2019). The current ecological setting of the Refuge is isolated habitat surrounded by industrial development (USFWS 2002, McNally 2014). Existing vegetation includes a Littoral Zone, a Riparian Zone, and an upland area of ‘unique stands at Antioch Dunes’ which are stabilized and semi-stabilized dunes with grasses and forbs, Antioch Dunes rare endemic species, and native dune shrubs and forbs (Sawyer and Keelor-Wolf 1995, USFWS 2002). The Littoral zone includes beach and wetland species such as cattail (*Typha angustifolia*) within the river’s tidal zone. Four rare species occur in this area, including Suisun marsh aster (*Aster lentus*), Delta mudwort (*Limosella subulata*), Delta tule pea (*Lathyrus jepsonii* var. *jepsonii*), and Mason’s lilaeopsis (*Lilaeopsis masonii*) (USFWS 2002). The Riparian Zone occurs adjacent to the Littoral Zone and along a typically steep bank from the river to upland habitats, and includes coast live oak (*Quercus agrifolia*), willow (*Salix*) species, and coastal scrub. Today, invasive annual grasses and forbs dominate stabilized dunes.

1.4.1 Stamm Unit

Topography in the Stamm Unit consists of rolling dunes up to 50 feet high above the river surface. Management Area 3 (MA3) in the Stamm Unit historically contained the best representation of the 'unique stands at Antioch Dunes' vegetation and supported the greatest concentration of endangered plants and a population of LMB. Today the Stamm Unit remains the stronghold for ADP, but a wildfire in 1999 destroyed much of the LMB and native dune habitat in the MA3 area (USFWS 2002). Recent dune restoration projects include a 2014-2015 sand deposition in Management Area 1 (MA1), and a 2020-2021 sand deposition in Management Area 2 (MA2) (Map 1-1). ADB was seeded into plots in the MA1 2014-2015 sand deposition area in 2019 and nectar plants were seeded in 2020 (Map 1-18). Current vegetation consists of semi-stabilized small dunes from the 2014-2015 and 2020-2021 deposition treatments, older stabilized dunes dominated by annual grasses, open oak woodlands concentrated along the river, and shore strand vegetation in the Riparian MA.

1.4.2 Sardis Unit

The smaller, eastern Sardis Unit is more diverse topographically, with steep slopes from Upland and PG&E MAs to the Pit and Littoral MAs, and dunes extending up to 80 feet above the water surface elevation in the PG&E Units. The PG&E Units were not mined for sand, so likely are more similar to the native topography prior to extensive disturbance of the dune system (USFWS 2002). The Sardis Unit is downwind of a gypsum manufacturing plant, and plants and soils within the Sardis unit are often coated with a fine layer of gypsum dust (USFWS 2002, McNally 2014, Spada et al. 2023). The Sardis Unit has higher tree and shrub cover than the Stamm Unit, with a dense coast live oak and coastal scrub community in portions of the Pit, Slope and Riparian MAs. The Sardis Unit contains the only known remaining LMB population, and ADB and nectar plant restoration activities have occurred here, with seeding trials for nectar plants in the Pit MA in 2020, and ADB seedings in the Pit MA in 2019 and 2020 (Map 2-1). CCW is more abundant and widespread in the Sardis Unit (Mather and USFWS 2018, USFWS 2021), and restoration of CCW has been focused on this Unit, with experimental and non-experimental seeding plots established in 2021 in the PG&E East and Slope MAs (Map 2-1).

1.5 Threatened and Endangered species habitat needs and threats

1.5.1 Lange's metalmark butterfly

Lange's metalmark butterfly was one of the first insects to be listed under the ESA, and was the reason Antioch Dunes National Wildlife Refuge was established (USFWS 2002, McNally 2014). At the time of Refuge establishment, LMB populations were known from the Pit MA in the Sardis Unit and MA3 in the Stamm Unit (USFWS 2002, McNally 2014). A 1999 fire destroyed most of the Stamm population, and since then the population has been in severe decline, with an estimated abundance of 8 individuals in 2018 (USFWS 2020). LMB is dependent on ADB – the only larval food source for this species. ADB is endemic to the Antioch Dunes, and requires sandy, well-drained soils and soil disturbance for seedling establishment (USFWS 2020). Adult females lay eggs on the lower stems of ADB where foliage is withered in summer, and eggs hatch when new growth appears during the rainy season (USFWS 2002, McNally 2014). ADB are also the preferred perch and nectar plant for LMB. Smothering of ADB plants and habitat by dense weeds can alter the microhabitat for LMB larvae (USFWS 2002, USFWS 2020). Invasive annual plants can stabilize dune soils, removing the soil disturbance necessary for ADB seedling establishment, and directly compete with ADB seedlings for light and moisture. LMB also depends on other native dune species such as California matchweed, hairy gumweed, shrubby butterweed and telegraphweed for nectar and perching.

1.5.2 Antioch Dunes evening primrose

ADP was federally listed as endangered in 1978, and the Refuge and a small area of adjacent property provides habitat for the only naturally occurring populations of this species. Preferred habitat for ADP is dynamic, semi-stabilized open sand (Pavlik and Manning 1993, Greene 1995, Evans et al. 2005, 2009, USFWS 2020). Invasive plants have been shown to reduce seedling establishment and survival by competition for light and moisture, and by stabilizing the soil (Pavlik and Manning 1993, Greene 1995, Thompson 2005a,b, Jones et al. 2021). ADP was monitored annually from 1985 to 2019, and every three years after 2019 (USFS 2020). Monitoring shows decline in the Stamm Unit from 1985 through 2005, a period of relative stability through 2015, and population growth after 2015, while abundance in the Stamm unit has remained low, apart from an increase in the 1990s (USFWS 2020). The recent sand deposition treatments in the Stamm Unit have caused the recent increase (USFWS 2020, Jones et al. 2021).

1.5.3 Contra Costa wallflower

Contra costa wallflower was listed as endangered in 1978, and is also endemic to the Antioch Dunes, with the only natural population of the species found on the Refuge and adjacent properties (USFWS 2002, USFS 2021). CCW tends to be found on wind-blown sand on north-facing slopes (USFWS 2002, Pavlik and Manning 1993, USFS 2021). CCW is more abundant in the Sardis Unit than the Stamm Unit, and while abundance fluctuates from year to year, possibly in response to variation in moisture availability, it has generally declined since 1984 (USFWS 2021). Invasive plants can outcompete CCW seedlings (USFWS 2019). Management activities include seed collection and seeding, which have appeared to increase CCW abundance (USFWS 2021).

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Chapter 2—Survey Protocol

2.1 Survey Objectives and Scope

The objectives for the 2023 vegetation inventory were:

Protocol Objective 1: Document the distribution and abundance of priority invasive plant species on the Refuge. Priority invasive plants were identified by the Refuge in advance of the inventory (Table 2). These are species that cause (or could cause) harm to Refuge conservation targets and their habitats, particularly LMB, ADP, CCW, and the dune ecosystem.

Protocol Objective 2: Document the distribution and abundance of native plant species of conservation concern on the Refuge. Native plants of conservation concern were identified by the Refuge in advance of the inventory and include plant species that are native to the Antioch Dunes ecosystem, have special status designation (such as Endangered, Threatened, or Rare), or provide habitat for sand-dune associated wildlife species (such as LMB) (Table 3).

Protocol Objective 3: Document the distribution and abundance of landcover types that are relevant to Refuge conservation targets and their habitats, particularly LMB, ADP, CCW, and the dune ecosystem (Table 4).

Protocol Objective 4: Provide summaries of the current status of priority invasive and native species and landcover types for each Management Unit, the Refuge overall, and by Refuge Management Area, and use the current status to assess NRMP goals RDE_G01, RDE_G02, RDE_O02, RDE_O03, RDE_O09, RDE_O10, RDE_O11(USFWS 2019) and HMP goals and objectives RDE_G01, RDE_G02, RDE_Objective_1, RDE_Objective_3 (USFWS in prep.). Analyze data from the 2017 and 2023 inventories to determine trends in priority vegetation attributes on the Refuge, and effects of sand deposition and seeding treatments on priority vegetation attributes (other relevant management activities that are well documented may be added in the future).

2.1.1 Target Species for Inventory

The 2017 targeted species included 13 native plant species or groups, 22 invasive plant species known to occur on the refuge and 6 early detection species. Based on results and recommendations from the 2017 survey (Mathers and USFWS 2018), and current Refuge management and vegetation trends, target species and landcover types were modified for the 2023 inventory. Modifications to the native plant target list for 2023 included removing three rare species (Delta tule pea, Mason's lilaeopsis, and Suisun marsh aster) that are tracked and managed using other methods, and adding an oak (*Quercus*) species group (including coast live oak, valley oak [*Quercus lobata*] and hybrids) because oak encroachment into dune habitat and subsequent habitat stabilization is a management concern. The 2023 target native plant list (Table 2) includes 11 species or groups, and is primarily focused on federally listed plant species (ADP, CCW), host, nectar and perch species important for LMB, or species otherwise important for management of LMB habitat (oak group). Modifications to the invasive species list for the 2023 survey included deleting giant reed (*Arundo donax*), iceplant (*Carpobrotus edulis*), Uruguayan pampas grass (*Cortaderia selloana*), and Cape-ivy (*Delairea odorata*) from the target invasive plant list; adding a mallow species group (*Malva parviflora*, *Malva* ssp.), white sweet clover (*Melilotus albus*) and puncture vine (*Tribulus*

terrestris); and grouping black mustard (*Brassica nigra*) with summer mustard (*Hirschfeldia incana*) and yellow star thistle (*Centaurea solstitialis*) with tocalote (*C. melitensis*). The 2023 target invasive plant list included 24 species or groups, which included 4 early detection species (Table 3).

Table 2. Native plant species targeted for inventory at Antioch Dunes National Wildlife Refuge in 2023.

Scientific name	Common name	Family	Life cycle	Special designation status	Identifiable Period (O = identifiable, X = possibly blooming)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acmispon glaber var. *glaber*	deerweed	Fabaceae	subshrub	N/A	O	O	X	X	X	X	X	X	O	O	O	O
Baccharis pilularis	coyote brush	Asteraceae	shrub	N/A	X	O	O	O	O	O	O	O	X	X	X	X
Eriogonum nudum var. *psychicola*	Antioch Dunes buckwheat	Polygonaceae	perennial herb	CNPS List 1B; Host plant for LMB	O	O	O	O	O	O	O	X	X	X	O	O
Erysimum capitatum var. *angustatum*	Contra Costa wallflower	Brassicaceae	perennial herb	Federal Endangered, State Endangered, CNPS List 1B			X	X	X	X	X	O				
Grindelia hirsutula	hairy gumweed	Asteraceae	perennial herb	Nectar plant for LMB	O	O	O	O	O	X	X	X	X	O	O	O
Gutierrezia californica	California matchweed	Asteraceae	subshrub	Nectar plant for LMB	O	O	X	X	X	X	X	X	X	X	O	O
Heterotheca grandiflora	telegraphweed	Asteraceae	annual	Nectar plant for LMB	X	X	X	X	X	X	X	X	X	X	X	X
Lupinus albifrons	silver bush lupine	Fabaceae	shrub	N/A	O	O	O	X	X	X	X	O	O	O	O	O
Oenothera deltoides ssp. *howellii*	Antioch Dunes evening primrose	Onagraceae	perennial herb	Federal Endangered, State Endangered, CNPS List 1B												
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	Oak group (Coast live oak, Valley oak, hybrids)	Fagaceae	Tree	Encroaching on LMB habitat	O	X	X	X	O	O	O	O	O	O	O	O
Senecio flaccidus var. *douglasii*	shrubby butterweed	Asteraceae	shrub	Nectar plant for LMB			X	X	X	X	X	X	X			

Table 3. Invasive plant species targeted for inventory at Antioch Dunes National Wildlife Refuge in 2023.

Scientific name(s)/Group	Common name or Group label	Family	Life cycle	CAL-IPC invasive ranking	Identifiable Period (O = identifiable, X = possibly blooming)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SPECIES PREVIOUSLY RECORDED IN REFUGE																
Ailanthus altissima	tree of heaven	Simaroubaceae	Tree	moderate	O	O	O	O	X	X	O	O	O	O	O	O
Brassica nigra, Hirschfeldia incana	mustard group (black mustard, summer mustard)	Brassicaceae	annual herb	moderate		X	X	X	X	X	X	O				
Carduus pyncocephalus	Italian thistle	Asteraceae	annual herb	moderate		X	X	X	X	X	X	O				
Centaurea group (*C. melitensis, C. solstitialis*)	Star thistle group (tocalote, yellow star thistle)	Asteraceae	annual herb	moderate, high				X	X	X	X	O				
Cynodon dactylon	Bermuda grass	Poaceae	perennial grass	moderate	O	O	O	X	X	O	O	O	O	O	O	O
Dittrichia graveolens	stinkwort	Asteraceae	annual herb	moderate						O	O	O	X	X	X	
Erodium cicutarium	redstem stork's bill	Geraniaceae	annual herb	limited		X	X	X	X	O						
Genista monpessulana	French broom	Fabaceae	shrub	high	O	O	X	X	X	O	O	O	O	O	O	O
Lepidium latifolium	perennial pepperweed	Brassicaceae	perennial herb	high	O	O	O	O	X	X	X	O	O	O	O	O
Malva group (*Malva parviflora*, *Malva* ssp.)	mallow species group (cheeseweed mallow, mallow species)	Malvaceae	annual/perennial herb	N/A		O	X	X	X	X	X	X	X	X	O	
Melilotus albus	white sweet clover	Fabaceae	annual herb	N/A				O	X	X	X	X	X	O		
Nicotiana glauca	tree tobacco	Solanaceae	tree or shrub	moderate	O	O	X	X	X	X	X	X	X	O	O	O
Raphanus sativus	wild radish	Brassicaceae	annual or biennial herb	Limited		X	X	X	X	X	X	O				
Robinia pseudoacacia	black locust	Fabaceae	tree	limited	O	O	X	X	X	X	O	O	O	O	O	O
Rubus armeniacus	Himalayan blackberry	Roasaceae	shrub/vine	high	O	O	O	X	X	X	X	X	O	O	O	O
Salsola tragus	Russian thistle	Chenopodiaceae	annual herb	limited						O	X	X	X	X		
Tribulus terrestris	puncture vine	Zygophyllaceae	annual herb	limited					O	X	X	X	X	X	O	
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	Tamarisk group (smallflower tamarisk, tamarisk)	Tamaricaceae	tree or shrub	high	O	O	O	X	X	O	O	O	O	O	O	O

Scientific name(s)/Group	Common name or Group label	Family	Life cycle	CAL-IPC invasive ranking	Identifiable Period (O = identifiable, X = possibly blooming)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vicia sativa	spring vetch	Fabaceae	annual vine	N/A		X	X	X	X	X	O	O				
Vicia villosa	winter/hairy vetch	Fabaceae	annual vine	N/A		X	X	X	O	O	O	O				
EARLY DETECTION SPECIES (not known to occur, according to Refuge managers)																
Aegilops triuncialis	goatgrass	Poaceae	annual grass	high					X	X	X	X				
Ammophila arenaria	European beachgrass	Poaceae	perennial grass	high	O	O	X	X	X	O	O	O	O	O	O	O
Bromus tectorum	cheatgrass	Poaceae	annual grass	high				O	X	X	X	X				
Taeniatherum caput-medusae	medusahead	Poacaeae	annual grass	high	O	O	O	X	X	X	O	O	O	O	O	O

2.1.2 Landcover types and other attributes

Landcover types important for supporting and evaluating dune ecosystem and invasive species conservation management goals were included in the vegetation inventory in 2017; these were modified in 2023 to include tree cover and shrub cover, and bare ground cover was refined to include only the area of the grid covered by bare soil or sand, and not roads/railways or other Refuge infrastructure, which were lumped with bare ground in the 2017 inventory (Table 4).

Table 4. Landcover types selected for survey in the Antioch Dunes National Wildlife Vegetation Inventory, 2023.

Landcover	Description
Annual grass	Cover of all annual grasses alive during the survey year (including early season grasses that may have already cured, or that were recently mowed)
Thatch	Cover of all plant debris from previous years' dead annual vegetation, leaf litter, fallen branches
Total vegetation	Cover of all live vegetation, including grasses, and including annuals from current survey year that have already senesced
Bare ground	Cover of sand or soil not covered in thatch or live vegetation
Water	Cover of open water and adjacent un-vegetated sandy or rocky beach areas that appear to be frequently flooded
Tree	Cover of all trees alive or dead during the survey year
Shrub	Cover of all shrubs alive or dead during the survey year
Refuge Infrastructure	Cover of infrastructure occurring within the Refuge other than roads/railways
Off Refuge Infrastructure	Cover of infrastructure occurring within the grid cell but outside of Refuge boundaries

The 2017 inventory identified cells where more than 10% of the cell area appeared to have been impacted by management activities with a yes/no attribute (Mathers and USFWS 2018). Since accurately identifying or being able to observe management activities (e.g., weeding, spraying, mowing) becomes increasingly difficult with increasing time after the activity occurs, management activity was not recorded during the 2023 inventory. Instead, a management layer that included management activities as a feature class (weeding, spraying, mowing, seeding, sand deposition) was added to the geodatabase to allow for an assessment of the effects of management activity on target species and landcover attributes. Since most of the documented management activities occurred after the inventory, only sand deposition and seeding trials could be evaluated.

2.1.3 Management Areas

Prior to the 2017 inventory, a workshop prioritized Refuge Management Areas for inventory (Table 1). All areas were surveyed in 2017 and in 2023. Future inventories that may be constrained by time or

budget should likely follow the area prioritization scheme laid out in Table 1, but consult with the Refuge and Complex to determine if priority changes have been made.

2.2 Survey Design

A survey grid consisting of 20 x 20 m (400-m^2) grid cells for each Refuge Management Unit, with a 100-foot buffer around Refuge boundaries, was established prior to the 2017 survey; the same grid system was used for 2023, except that grid cells were renumbered so that there were no duplicate grid cell numbers. In 2017, grid cells were numbered independently for each of the Stamm and Sardis Units, resulting in duplicate grid cell numbers. In 2023 grid cells were re-numbered with 2 digit alphanumeric identification numbers, with rows beginning at A to the north and going sequentially to the south, and columns starting with 001 at Stamm and numbering sequentially through Sardis, so that each grid cell in the survey had a unique identification number. Cells were cross-walked to allow for a comparison of results between 2017 and 2023 (Appendix A). Grid cell size was based on suggestions by USFWS Inventory and Monitoring staff and test surveys conducted by Shelterbelt to determine a size that worked best for an efficient survey but still allowed for accurate cover estimation (Mathers and USFWS 2018). Grid cells that occurred partly on Refuge lands were estimated across property boundaries.

An ESRI ArcGIS Field Maps project was developed for electronic data collection for the 2023 vegetation inventory.

2.3 Field Methods

2.3.1 Survey Timing

The inventory was conducted between May 8th and 14th 2023. Timing was based on peak reproductive phenology of target species to enable maximum levels of detection.

2.3.2 Field Preparation

Prior to beginning fieldwork, we created a target species identification guide with photographs, key features, taxonomic keys, and similar species for all target species. All surveyors reviewed this guide.

Mobile data collecting devices paired via Bluetooth with BadElf GNSS external GPS receivers with an accuracy of 3 meters were loaded with the Antioch Dunes NWR Vegetation Inventory Field Maps project. Background layers included in the project were grid cells, Management Areas, land ownership, and aerial imagery. Maps were downloaded onto devices to allow for offline data collection if cellular service was not available and to conserve battery life.

All reference materials (Target Species Identification Guide, taxonomic keys, Inventory SOP, etc.) were loaded onto our mobile data collecting devices to allow for digital access.

Equipment utilized during the field inventory included:

- Pinflags
- Data collection device (iPhone, Android, iPad, other tablet) with Field Maps Antioch Dunes National Wildlife Refuge Vegetation Inventory project

- Bad Elf GNSS Surveyor GPS
- External battery charger and cords for data collection device and BadElf
- Target species identification guide
- Antioch Dunes National Wildlife Refuge Vegetation Inventory SOP (Appendix A)
- Jepson Manual of Vascular Plants of California, Second Edition (Baldwin et al. 2012)
- Field notebook, pencils, lead
- Camera (used data collecting device)

2.3.3 Grid Cell Demarcation and Survey

Surveyors calibrated with each other on cover estimates at the beginning of the survey and when a new surveyor joined the team by each recording all data within the grid cell and comparing and discussing values recorded until each surveyor was recording within 10% on species and landcover estimates for each cell, and observing all target species. Grid cells corners were located using BadElf GPS devices paired with an iPhone or Tablet, and using the Field Maps project, and temporarily marked with pinflags. Following calibration, surveyors worked in adjacent rows, utilizing the same marked corners. Once the grid cell corners were located, surveyors typically worked individually to survey the cell, walking a zigzagging path that traversed the width of the cell for a minimum of 1 minute to document target species/groups cover, ADB points, and landcover throughout the cell. Increasing vegetation or topographic complexity, and/or greater target species diversity required a longer search time. The minimum sampling intensity was valid only for flat grid cells with low species diversity and excellent visibility, such as bare sand. Increasing vegetation density and complexity, increasing target species abundance and richness, and complex topography present in a cell required longer times for observation, and sites with abundant ADB could take 30 to 60 minutes. When ADB was abundant, two surveyors worked together, with one surveyor mapping ADB, and the other documenting target plant and landcover covers.

Once the cell had been walked through, and ADB points marked if present, target species and landcover cover classes were recorded in the Field Maps project and the Grid Cell was marked as “Surveyed”.

2.3.4 Geodatabase Attributes

Geodatabase attributes of the final inventory geodatabase are presented in Table 5. For each 20 x 20 meter grid cell, observers recorded percent cover class (Table 5) of each target species (Tables 2,3) and landcover type (Table 4) occurring in the cell. For both target species and landcovers, absolute cover was recorded, meaning total cover in a cell could add up to over 100 percent. For each cell, each ADB individual was marked as a point location in the Field Maps project, with date auto filled. Density of ADB in seeding trials in the Sardis Unit was very high, making point locations of individual plants impossible. For these areas, the number of individual plants corresponding to a point was recorded, and for two locations, polygons were mapped with an estimated count of ADB.

Table 5. Summary of final geodatabase attributes for the 2023 vegetation inventory, Antioch Dunes National Wildlife Refuge.

Attribute	Field Description	Domain/Format
LIT*	USFWS 3-character code of the National Wildlife Refuge, used as a unique identifier.	ATD
Cmplx_Name*	Name of National Wildlife Refuge Complex the unit is associated with.	San Francisco Bay National Wildlife Refuge Complex
OrgName*	Official name of the National Wildlife Refuge.	Antioch Dunes National Wildlife Refuge
Unit_Name*	Name of the individual unit or discrete area associated with the refuge	List of Refuge Management Units (Stamm, Sardis)
Management_Area*	Name of management area	List of Refuge Management Areas (MA1, MA2, MA3, MA4, Littoral, PG&E East, PG&E West, Pit, Riparian, Slope, Upland)
GridCell_ID	Grid cell identifier	Alphanumeric
Observer	First and last name of the person performing the observation	Alice Miller, Marchel Munnecke, Wendy Boes
Obs_Date	Date that the observation was made by the Observer.	YYYY-MM-DD
Cover_Class	Class of each target species and landcover type absolute canopy cover estimated as a percent of the search area.	0 (not detected), > 0-1%, 1-10%, 11-25%, 26-50%, 51-75%, 76-100%
Cover*	Midpoint value of each target species and landcover type cover class	0, 0.5, 4.5, 18, 38, 63, 88
Net_Infested_Area*	The approximate net area in acres occupied by each target species and landcover type, calculated as the cover midpoint * size of grid cell in meters * meters/acres conversion	Numerical acres
Native Species Richness*	Sum of the number of target native species present in grid cell	Numerical
Invasive Species Richness*	Sum of the number of target invasive species present in grid cell	Numerical
Target invasive plant total cover	Sum of all target invasive plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres
Target native plant total cover	Sum of all target native plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres
Nectar plant total cover	Sum of all Langes nectar plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres

Attribute	Field Description	Domain/Format
Antioch Dunes buckwheat abundance	Number Antioch Dunes buckwheat individuals present in a cell	Numerical
Start_Date*	Identifies the date that surveying was initiated.	YYYY-MM-DD
End_Date*	Identifies the date that surveying was completed.	YYYY-MM-DD
Surv_Yr*	Identifies the year the survey was conducted.	YYYY
Area_Surveyed*	Identifies area surveyed in acres	Numerical acres
Comments	Describes any additional information important to the associated record not contained within the existing fields	String
X_Coordinate*	Longitude of grid polygon centroids.	NAD83 UTM Zone 10N
Y_Coordinate*	Latitude of grid polygon centroids.	NAD83 UTM Zone 10N
LandcoverType	Target Landcover type encountered	Annual grass, thatch, total vegetation, bare ground, water/beach, tree, shrub, Refuge infrastructure, Off Refuge infrastructure
Surveyed	Indicates if grid cell has been surveyed. Default value is "No."	No, Yes, Unknown

*Data were calculated post-processing.

2.3.5 Post data collection daily tasks

At the end of each field day, mobile data collecting devices were synced with the geodatabase if data were collected offline. A record of the number of grid cells completed per day, completion progress of each priority area, average sampling times/cell/vegetation type, as well as other pertinent notes that came up during sampling were documented after each day of data collection.

2.3.6 Sources of Error

Sources of error could include observers missing target plants within the survey grid, mis-estimating cover, observer bias in estimating cover within and between inventories, or GPS error causing grid cells to be mislocated. It is common to assume observer differences in cover estimation of at least 20% (Wiser and Rose 1997); however, calibration and continuous communication between observers may reduce differences, and both were done in 2023 to minimize both observer error in missing target plants and observer bias in estimating cover. Calibration between 2017 observers and 2023 observers was not possible, and observer bias in cover estimation could influence results. GPS units with at least 3 meter accuracy were used for data collection to reduce GPS errors, but grid cell locations will never be exactly the same since they are not permanently marked, which could cause differences in cover estimates and ADB abundance counts within cells between inventory years.

Phenology of target species during the survey may impact detectability and cover estimates. For example, winter vetch was beginning to senesce in the Sardis Unit towards the end of the survey, which made it much less visible than at peak bloom. Survey conducted even 1-2 weeks later could have underestimated winter vetch cover. Telegraphweed was typically beginning to bolt during the 2023 survey, and cover estimates were based on the abundance of rosettes and seedlings, as well as persistent stalks from last year's plants; since the full current year's growth was not present, cover may have been underestimated for this species.

Invasive plant management treatments could impact cover estimates (Mathers and USFWS 2018). In 2023, areas that had been mowed were assessed as if they had been live, i.e., annual grass and forb material that had been recently mowed was treated as live, rather than thatch.

Antioch Dunes buckwheat plants and seedlings were very abundant in some areas, especially in seed treatment areas, which made delineating each individual plant as a point location difficult or impossible. In areas where density was too high to mark individuals, points represented a particular number of individuals, or a polygon was created with an estimate of individuals within the polygon. In these high density areas, abundance should be considered an estimate. Dense annual grasses and thatch covered ADB in some areas, which also made locating smaller individuals difficult, and it is likely that some individuals were missed; this likely also occurred in the 2017 inventory, so the trend in ADB abundance (count) between survey should be accurate.

2.4 Data Processing and Analysis

2.4.1 Grid Cell Data

The geodatabase resulting from data collection was quality control checked for errors. Post-processing fields were filled to populate the final geodatabase, using RStudio (RStudio 2023). A cover field, which

represented the midpoint of the cover class (Table 5) was created. The approximate net area of each target species or landcover type within a cell was calculated using the formula:

$$\text{Area (acres)} = [\text{cover midpoint}] \times [\text{grid cell area (400 m}^2\text{)}] / [100] \times [4046.86\ \text{m}^2/\text{acre}]$$

Total native and invasive species cover, and nectar plant cover were calculated for each grid cell. A native and invasive species richness column was calculated as the number of target native and invasive species occurring in the cell. Antioch Dunes buckwheat abundance was calculated as the sum of ADB individuals occurring in the cell.

2.4.2 Distribution and abundance visualization

Maps showing cover of each landcover type, cover of each target species, invasive and native plant richness, total invasive plant cover, total native plant cover, a heat map of nectar plant cover with ADB points, and a heat map of rare dune species were prepared (Appendix C). Landcover type and target species distribution and abundance were visualized by mapping cover within each surveyed grid cell for each Management Unit. Grid cells were symbolized utilizing a graduated color scheme to produce a separate heat map of each target species and each landcover type (Appendix C).

2.4.3 Comparison with 2017 results

The change in number and proportion of cells occupied, and change in net acres for each target species and landcover type between 2017 and 2023 for each Management Unit, Refuge total area, and Management Area was calculated. Since each survey was an inventory in which the entire refuge area was surveyed, changes between the two years do not need statistical analysis to determine if changes are significant; they represent the entire area and are not a sample.

To examine how management activities influenced changes in rare dune species and LMB nectar plant species abundance and bare ground, annual grass and thatch cover between 2017 and 2023, we tested for differences in attributes in 2017 and 2023, and changes in attributes between 2017 and 2023 among Management Areas using one way Anova, or a Kruskal-Wallis test, when data were non-normal. These analyses can be expanded to examine additional target species or landcovers as desired. We examined how recent sand deposition treatments (no sand, 2014-2015 sand deposition, and 2020-2021 sand deposition) had impacted relevant target species (species where a change in cover had occurred, and that were potentially impacted by sand deposition treatments) within the Stamm Unit (since recent deposition treatments had only occurred in this unit), using generalized linear mixed models (glmmTMB library; Brooks et al. 2017) with the change in attribute cover from 2017 to 2023 as the response, deposition treatment, MA, annual grass and bare ground cover as potential fixed effects, and unspecified zero inflation or zero-inflation specified as a random effect of MA. Zero-inflation models account for overinflated zero data, where differences in fixed or random effects on the presence or absence of a species (zero or non-zero) may be difference than effects on non-zero abundance (Brooks et al. 2017). The Littoral MA was removed for species that rarely, if at all, occurred in this area, such as ADP. Models fit with all potential variables, and with variables successively removed were compared using the information criterion AIC, and the model with the lowest AIC was selected as the best fitting. The effect of sand deposition treatment on annual grass and bare ground cover was examined with cover as a fixed effect, and sand deposition treatment and MA as potential fixed effects. Annual grass cover was not zero-inflated and was modelled without a zero inflation term. We examined how seeding treatments had impacted cover of seeded species (CCW, ADB, nectar plants) before and after seeding using a Wilcoxan rank sum test.

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Chapter 3—Results

3.1 Overview

A total of 175 person hours was spent surveying the 67 acres of the Refuge plus 3.5 acres of land outside of Refuge boundaries where grid cells intersected Refuge boundaries. The total 70.5 acres included 41.9 acres in the Stamm Unit and 28.6 acres in the Sardis Unit (Maps 1-1, 2-1). The 2023 inventory included the entire Littoral Management Area, and all outside Refuge areas where any portion of a grid cell that occurred within Refuge boundaries intersected; thus, the 2023 survey covered more grid cells than the 2017 survey (Maps 1-2, 2-2). In 2023, 779 total grids were surveyed (464 in the Stamm Unit and 315 in the Sardis Unit) compared to 713 total in 2017 (424 in the Stamm Unit and 289 in the Sardis Unit). Because of this small difference in area surveyed, and since both target species and landcovers were refined between the two inventories, we present results tables showing 2023 data only, including all 2023 areas surveyed and 2023 target species and landcovers, followed by a comparison of 2023 and 2017 results, with the 2023 area clipped to match the 2017 area, and comparing only the target species and landcovers that were measured in both inventories. For both sets of results we first present a summary of the Stamm and Sardis Units and Refuge overall, and then present results for each Management Area within the Stamm and Sardis Units.

3.2 Landcover

3.2.1 2023 Inventory Summary

Annual grasses were found in 94% of grid cells surveyed, and covered nearly 29 acres of the Refuge area, with 15.6 acres in the Stamm Unit and 13.35 acres in the Sardis Unit (Table 6, Maps 1-3, 2-3). Thatch cover, predominately from persistent dead annual species, was also prevalent, covering an estimated 31.72 acres of the Refuge, with 12.58 acres in the Stamm Unit and 19.14 acres in the Sardis Unit, with cover and distribution mirroring annual grass cover patterns (Tables 6-10, Maps 1-4, 2-4).

Bare ground covered an estimated 9.27 acres, with the majority of this found in the sand deposition treatments in the Stamm Unit (MA1 and MA2), with bare ground typically less than 10% in the rest of the Refuge (Tables 6-10, Maps 1-5, 2-5). Vegetation cover was high over the majority of the Refuge, occupying nearly 48 acres (Table 6, Maps 1-6, 2-6). Trees were found in 58% of grid cells, covering an estimated 9.33 acres, with trees much more abundant in the Sardis Unit than the Stamm Unit (Tables 6-10, Maps 1-7, 2-7). Shrub cover was relatively low, with shrubs found in 50% of surveyed grids and covering 3.29 acres, with shrubs proportionally more common in the Sardis Unit than the Stamm Unit (Tables 6-8, Maps 1-8, 2-8). Water and beach covered 4.54 acres of the Refuge, with proportionally more water/beach area in the Stamm Unit than the Sardis Unit (Tables 6-8, Maps 1-9, 2-9). Refuge infrastructure covered approximately 2.24 acres (Table 6, Maps 1-10, 2-10), and Off Refuge infrastructure approximately 4.66 acres (Table 6, Maps 1-11, 2-11).

Table 6. Summary of target landcovers observed in each Management Unit and overall, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)			Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)		
	Sardis	Stamm	Total	Sardis	Stamm	Total
Landcover Types						
Annual grass	302 (96%)	430 (93%)	732 (94%)	13.35 (43%)	15.60 (34%)	28.96 (38%)
Bare ground	291 (92%)	419 (90%)	710 (91%)	1.68 (5%)	7.59 (17%)	9.27 (12%)
Off Refuge infrastructure	29 (9%)	74 (16%)	103 (13%)	1.58 (5%)	3.08 (7%)	4.66 (6%)
Refuge infrastructure	94 (30%)	120 (26%)	214 (27%)	1.14 (4%)	1.09 (2%)	2.24 (3%)
Shrub cover	180 (57%)	213 (46%)	393 (50%)	1.50 (5%)	1.78 (4%)	3.29 (4%)
Thatch	306 (97%)	435 (94%)	741 (95%)	19.14 (62%)	12.58 (27%)	31.72 (42%)
Total vegetation	309 (98%)	452 (97%)	761 (98%)	21.95 (71%)	25.99 (57%)	47.94 (62%)
Tree cover	273 (87%)	178 (39%)	451 (58%)	7.80 (25%)	1.53 (3%)	9.33 (12%)
Water, beach cover	26 (8%)	66 (14%)	92 (12%)	1.30 (4%)	3.24 (7%)	4.54 (6%)
Total Grid Cells /Acres Surveyed 2023	**315**	**464**	**779**	**31**	**46**	**77**

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

3.2.1A Stamm Unit

Management Areas 3 and 4 in the Stamm Unit were dominated by annual grasses and thatch (Tables 7-8, Map 1-3, Map 1-4), while bare ground dominated in MA1 and MA2 with a large area of semi-stabilized and sparsely vegetated sand from the 2020-2021 sand deposition treatment in MA2, and semi-stabilized, vegetated dunes from the 2014-2015 sand deposition treatment in MA1 (Tables 7-8, Figure 3, Map 1-3). Tree cover frequency and extent was highest in MA1 (Table 7), where oak seedlings were common throughout, and mature trees occurred on MA edges (Map 1-7). While proportionally tree and shrub cover were not high in the Littoral MA relative to other Stamm Unit MAs (Table 7), the Littoral MA supported a concentration of riparian trees and shrubs such as willow and California walnut (*Juglans californica*) (Figure 4). Shrub cover was highest in MA1, with moderate shrub cover in MA3 and part of MA4 (Table 7, Map 1-8, Figure 4). Refuge infrastructure included dirt roads and boundary fences, with these areas relatively small (Tables 7-8, Map 1-10). Off Refuge infrastructure included dirt and paved roads, buildings, and railroads, and occupied 3.08 acres (Table 8, Map 1-11).

Table 7. Summary of target landcovers observed in each Management Area, Stamm Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)					Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)				
	MA1	MA2	MA3	MA4	Littoral	MA1	MA2	MA3	MA4	Littoral
Annual grass	122 (98%)	65 (93%)	92 (100%)	112 (97%)	34 (59%)	2.40 (19%)	0.84 (12%)	6.01 (66%)	5.97 (52%)	0.38 (1%)
Bare ground	121 (97%)	70 (100%)	76 (83%)	109 (95%)	42 (72%)	3.01 (24%)	3.74 (54%)	0.29 (3%)	0.36 (3%)	0.18 (0.4%)
Off refuge infrastructure	32 (26%)	8 (11%)	3 (3%)	31 (27%)	0	1.09 (9%)	0.34 (5%)	0.07 (1%)	1.58 (14%)	0
Refuge infrastructure	53 (42%)	23 (33%)	15 (16%)	18 (16%)	11 (19%)	0.71 (6%)	0.19 (3%)	0.06 (1%)	0.08 (1%)	0.06 (0.1%)
Shrub cover	76 (61%)	13 (19%)	51 (55%)	35 (30%)	37 (64%)	0.77 (6%)	0.03 (0.4%)	0.19 (2%)	0.12 (1%)	0.67 (1%)
Thatch	122 (98%)	65 (93%)	92 (100%)	112 (97%)	43 (74%)	1.61 (13%)	0.46 (7%)	4.69 (52%)	5.13 (45%)	0.69 (1%)
Total vegetation	122 (98%)	70 (100%)	92 (100%)	114 (99%)	54 (93%)	6.52 (53%)	2.10 (30%)	7.19 (79%)	7.75 (68%)	2.44 (4%)
Tree cover	81 (65%)	20 (24%)	22 (24%)	23 (20%)	32 (55%)	0.45 (4%)	0.11 (2%)	0.14 (2%)	0.32 (3%)	0.51 (1%)
Water, beach cover	7 (6%)	4 (6%)	0	0	51 (88%)	0.29 (2%)	0.08 (1%)	0	0	2.53 (4%)
Total Grid Cells Surveyed 2023	**125**	**70**	**92**	**115**	**58**	12.35	6.91	9.1	11.4	5.7

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Table 8. Summary of target landcover abundance, Stamm Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge (N=464).

	Number of Grids Containing Cover Type by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Landcover Type								
Annual grass	34	31	103	71	56	125	44	15.60
Bare ground	45	137	137	50	35	29	31	7.59

	Number of Grids Containing Cover Type by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Off Refuge infrastructure	390	2	18	16	7	11	20	3.08
Refuge infrastructure	344	27	68	17	6	1	1	1.09
Shrub cover	251	66	101	33	10	3	0	1.78
Thatch	29	41	117	96	68	90	23	12.58
Total vegetation	12	10	35	38	67	149	153	25.99
Tree cover	286	81	52	32	9	3	1	1.53
Water, beach cover	398	5	11	7	10	8	25	3.24

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

Figure 3. TOPLEFT. Annual grass dominated dunes, Stamm Unit, Management Area 3. TOPRIGHT. Semi stabilized, unvegetated dunes, 2020-2021 sand deposition treatment, Stamm Unit Management Area 1. BOTTOMLEFT. Colonization of new sand deposits in foreground, with more stabilized, older dunes in background, Stamm Unit, Management Area 2. BOTTOMRIGHT. Semi stabilized, vegetated dunes (2014-2015 sand deposition treatment) with abundant ADP, Stamm Unit, Management Area 1.

Figure 4. LEFT: California walnut and coast live oak in the Littoral Management Area, Stamm Unit. RIGHT: Deerbrush with ADP, Stamm Unit, Management Area 1.

3.2.1B Sardis Unit

Dense annual grasses dominated by ripgut brome (*Bromus diandrus*) were abundant in the Sardis Unit, covering 13.35 acres and present in all but 13 grid cells surveyed (Tables 9-10, Figure 5, Map 2-3). Annual grass extent was similar in the PG&E East, PG&E West, Slope and Upland MAs, with lower extent in the Pit and Riparian MAs (Table 9).Thatch cover dominated by herbaceous annual material was also abundant (Tables 9-10, Map 2-4). Bare ground covered only 1.68 acres in the Sardis Unit, with no large unvegetated areas present (Tables 9-10, Map 2-5). Vegetation cover was high in the Sardis Unit, with 76-100% vegetation cover in more than half of all grid cells (Tables 9-10, Map 2-6). Trees, dominated by oaks, were abundant in the Sardis Unit, covering 7.8 acres, and present in all but 42 grid cells; by extent, tree cover was highest in the Pit and Riparian MAs (Tables 9-10, Map 2-7). Shrubs were more frequent in the Sardis Unit, with a greater diversity of native shrub species present, including blue elderberry (*Sambucus neomexicana*) and toyon (*Heteromeles arbutifolia*) (Map 2-8). Water and beach covered 1.3 acres in the Sardis Unit (Table 10, Map 2-9). Refuge infrastructure included dirt roads, radio towers, and fences, and occupied 1.14 acres (Table 10, Map 2-10). Off Refuge infrastructure included dirt and paved roads, fences, and railroads, and occupied 1.58 acres (Table 10, Map 2-11).

Table 9. Summary of target landcovers observed in each Management Area, Sardis Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)					
	PG&E East	PG&E West	Pit	Riparian	Slope	Upland	PG&E East	PG&E West	Pit	Riparian	Slope	Upland
Annual grass	67 (96%)	71 (93%)	63 (98%)	20 (100%)	35 (100%)	45 (98%)	3.61 (52%)	3.21 (43%)	2.26 (36%)	0.67 (34%)	1.55 (44%)	2.06 (46%)
Bare ground	66 (94%)	67 (88%)	62 (97%)	20 (100%)	33 (94%)	41 (89%)	0.41 (6%)	0.63 (8%)	0.22 (3%)	0.10 (5%)	0.15 (4%)	0.16 (4%)
Off refuge infrastructure	4 (6%)	9 (12%)	0	0	0	16 (35%)	0.01 (0.2%)	0.64 (9%)	0	0	0	0.93 (21%)
Refuge infrastructure	7 (10%)	38 (50%)	14 (22%)	0	12 (34%)	23 (50%)	0.01 (0.2%)	0.50 (7%)	0.35 (6%)	0	0.10 (3%)	0.18 (4%)
Shrub cover	43 (61%)	23 (30%)	62 (97%)	17 (85%)	21 (60%)	12 (26%)	0.31 (4.5%)	0.10 (1%)	0.80 (16%)	0.14 (7%)	0.10 (3%)	0.03 (1%)
Thatch	69 (99%)	73 (96%)	63 (98%)	19 (95%)	35 (100%)	45 (98%)	4.48 (65%)	3.95 (53%)	4.64 (73%)	1.08 (55%)	2.56 (73%)	2.42 (54%)
Total vegetation	69 (99%)	74 (97%)	64 (100%)	20 (100%)	35 (100%)	45 (98%)	5.29 (76%)	4.39 (58%)	5.32 (84%)	1.42 (72%)	2.82 (81%)	2.68 (60%)
Tree cover	61 (87%)	62 (82%)	63 (98%)	20 (100%)	32 (91%)	32 (70%)	0.95 (13.7%)	1.06 (14%)	2.94 (46%)	0.99 (50%)	1.21 (34%)	0.63 (14%)
Water, beach cover	7 (10%)	4 (5%)	1 (2%)	10 (50%)	0	0	0.36 (5%)	0.25 (3%)	0.01 (0.09%)	0.34 (17%)	0	0
Total Grid Cells Surveyed 2023	**70**	**76**	**64**	**20**	**35**	**46**	6.92	7.51	6.33	1.98	3.50	4.50

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Table 10. Summary of landcover type abundance, Sardis Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge (N=315).

	Number of Grids Containing Cover Type by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Landcover Type								
Annual grass	13	10	40	43	59	118	32	13.35
Bare ground	24	103	153	30	5	0	0	1.68
Off Refuge infrastructure	286	3	6	1	2	1	16	1.58
Refuge infrastructure	221	28	42	11	8	2	3	1.14
Shrub cover	135	51	88	32	8	0	1	1.50
Thatch	9	4	19	24	32	95	132	19.14
Total vegetation	6	1	15	7	23	81	182	21.95
Tree cover	42	27	62	67	67	26	24	7.80
Water, beach cover	289	0	5	3	4	6	8	1.30

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

Figure 5. LEFT: Dense ripgut brome and thatch, with coast live oak in background, Sardis Unit, PG&E East Management Area. RIGHT: California walnut and coast live oak with annual grass understory, Sardis Unit, Slope Management Area.

3.2.2 Changes from 2017 to 2023

Changes observed between the 2017 and 2023 inventory years are presented here, for analysis of differences among Management Areas, see section 3.2. Annual grasses covered 7 fewer acres in 2023 than 2017 (Table 11); mostly a result of 2020-2021 sand deposition in MA2, which resulted in a 55% reduction in annual grass cover and a 9% reduction in thatch cover (Table 13). Despite the sand deposition treatment, total bare ground overall declined by 4 acres, with proportionally more bare ground loss in the Stamm Unit (Table 11). All MAs except for MA1, MA2 and the Pit lost bare ground between 2017 and 2023 (Tables 13, 15). However, the 2017 inventory lumped infrastructure with bare ground (Mathers and USFWS 2018), which makes a comparison between the two inventories difficult. With Refuge infrastructure added to bare ground there was still a 2 acre overall difference between 2017 and 2023. Annual grass cover declined in extent between 2017 and 2023 in MA4 and the Littoral MA in the Stamm Unit, and in the PG&E West, Pit, and the Slope MA, but thatch cover increased significantly in all of these MAs except the Littoral MA (Tables 13, 15). Thatch cover increased overall by 21.6 acres in 2023 relative to 2017, with increases measured in both units, but greater in the Sardis Unit than the Stamm Unit (Table 11). Total vegetation declined by 2.2 acres, with the majority of this decline in the Stamm Unit due to the 2020-2021 sand deposition (Tables 11, 13).

Table 11. Summary of target landcovers observed in each Management Unit and overall, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres*					
	Sardis		Stamm		Total		Sardis		Stamm		Total	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Landcover Types												
Annual grass	286 (99%)	-2 (-1%)	415 (98%)	13 (3%)	701 (98%)	11 (1%)	13.25	-0.7	15.57	-6.5	28.83	-7.1
Bare ground	269 (93%)	-14 (-5%)	402 (85%)	-12 (-13%)	671 (84%)	-26 (-14%)	1.56	-1.7	7.52	-90.5	9.08	-4.0
Thatch	285 (99%)	-1 (0%)	415 (98%)	3 (1%)	700 (98%)	2 (0%)	18.92	14.1	12.51	7.5	31.43	21.6
Total vegetation	288 (100%)	-1 (0%)	423 (100%)	0	711 (100%)	-1 (0%)	21.65	0.8	25.59	-3.0	47.25	-2.2
Water, beach cover	17 (6%)	-3 (-1%)	41 (10%)	7 (2%)	58 (8%)	4 (0%)	0.63	0.1	1.19	0.0	1.82	0.1
Total Grid Cells/Acres	**289**		**424**		**713**		**28.6**		**41.9**		**70.5**	

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres

Table 12. Summary of target landcover frequency in grid cells by Management Area, Stamm Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Annual grass	113 (99%)	9 (8%)	68 (100%)	0	92 (100%)	0	109 (98%)	0	33 (85%)	4 (10%)
Bare ground	114 (100%)	1 (1%)	68 (100%)	0	76 (82%)	-16 (-17%)	107 (96%)	-4 (-4%)	37 (95%)	7 (18%)
Thatch	114 (100%)	10 (9%)	63 (92%)	-5 (-7%)	92 (100%)	0	109 (98%)	-1 (-1%)	37 (95%)	-1 (-3%)
Total vegetation	114 (100%)	1 (1%)	68 (100%)	0	92 (100%)	0	111 (100%)	0	38 (97%)	-1 (-3%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Water, beach cover	5 (4%)	2 (2%)	4 (6%)	4 (6%)	0	0	0	0	32 (82%)	1 (3%)
Total Grid Cells Surveyed 2017	114		68		92		111		39	

Table 13. Summary of target landcovers net acres covered by Management Area, Stamm Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown.

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Annual grass	2.390 (21%)	3.583 (32%)	0.838 (12%)	-3.733 (-55%)	6.014 (66%)	0.124 (1%)	5.959 (54%)	-1.354 (-12%)	0.375 (10%)	-0.303 (-8%)
Bare ground	2.981 (26%)	5.416 (48%)	3.732 (56%)	3.057 (45%)	0.287 (2%)	-0.942 (-10%)	0.361 (3%)	-1.887 (-17%)	0.157 (4%)	-0.072 (-2%)
Thatch	1.583 (14%)	0.664 (6%)	0.457 (7%)	-0.576 (-9%)	4.690 (52%)	3.310 (36%)	5.117 (47%)	3.864 (35%)	0.664 (17%)	-0.063 (-2%)
Total vegetation	6.454 (57%)	5.183 (46%)	2.077 (31%)	-3.393 (-50%)	7.187 (79%)	-0.124 (-1%)	7.717 (70%)	-0.569 (-5%)	2.157 (56%)	-0.151 (-4%)
Water, beach cover	0.136 (1%)	0.125 (1%)	0.079 (1%)	0.079 (1%)	0	0	0	0	0.975 (25%)	-0.121 (-3%)
Total Acres Surveyed 2017	11.27		6.72		9.09		10.97		3.85	

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres

Table 14. Summary of target landcovers frequency in grid cells by Management Area, Sardis Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Annual grass	66 (100%)	0	67 (98%)	-1 (-1%)	63 (98%)	-1 (-2%)	20 (100%)	1 (5%)	35 (100%)	0	35 (100%)	0
Bare ground	64 (97%)	-1 (-2%)	59 (87%)	-9 (-13%)	62 (97%)	1 (2%)	20 (100%)	0	33 (94%)	-1 (-3%)	31 (89%)	-3 (-9%)
Thatch	66 (100%)	0	67 (98%)	-1 (-1%)	63 (98%)	-1 (-2%)	19 (95%)	-1 (-5%)	35 (100%)	1 (3%)	35 (100%)	2 (6%)
Total vegetation	66 (100%)	0	68 (100%)	0	64 (100%)	0	20 (100%)	0	35 (100%)	0	35 (100%)	0
Water, beach cover	3 (5%)	-1 (-2%)	3 (4%)	-3 (-4%)	1 (2%)	0	10 (50%)	1 (5%)	0	0	0	0
Total Grid Cells Surveyed 2017	66		68		64		20		35		35	

Table 15. Summary of target landcovers net acres covered by Management Area, Sardis Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown.

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Annual grass	3.594 (55%)	-0.245 (-4%)	3.170 (47%)	-0.423 (-6%)	2.255 (36%)	-0.152 (-2%)	0.674 (34%)	0.227 (11%)	1.548 (45%)	-0.341 (-10%)	2.001 (58%)	0.299 (9%)
Bare ground	0.407 (6%)	-0.118 (-2%)	0.570 (8%)	-0.529 (-8%)	0.217 (3%)	-0.291 (-5%)	0.098 (5%)	-0.039 (-2%)	0.154 (4%)	-0.259 (-7%)	0.112 (3%)	-0.389 (-11%)
Thatch	4.397 (67%)	3.308 (51%)	3.887 (58%)	2.759 (41%)	4.642 (73%)	3.236 (51%)	1.080 (55%)	0.722 (36%)	2.555 (74%)	2.101 (61%)	2.360 (68%)	1.975 (57%)
Total vegetation	5.148 (79%)	0.148 (2%)	4.331 (64%)	-0.427 (-6%)	5.32 (84%)	0.489 (8%)	1.423 (72%)	0.0741 (4%)	2.822 (82%)	0.299 (9%)	2.609 (75%)	0.252 (7%)
Water, beach cover	0.118 (2%	0.0257 (0.4%)	0.167 (2%)	0	0.0059 (0.1%)	0	0.335 (17%)	0.0756 (4%)	0	0	0	0
Total Acres Cells Surveyed 2017	6.52		6.72		6.33		1.98		3.46		3.46	

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres

3.3 Target Species

3.3.1 Native Species

3.3.1A 2023 Survey

Native target species were present in 87% of all surveyed grid cells, and occupied a total of 11.92 acres (Table 16, Maps 1-12, 2-12). Native target species were more likely to be found, and typically had higher cover, in the Stamm Unit than the Sardis Unit (Table 16, Maps 1-12, 2-12). Coast live oak was the only oak species observed, and was the most abundant native target species, covering 7.82 acres, with the majority mapped in the Sardis Unit (Table 16, Maps 1-24, 2-24). Coyote brush (*Baccharis pilularis*) was rare, observed in only 4% of grid cells and occupying 0.10 acres total, with the majority of occurrences in the Sardis Unit (Table 16, Maps 1-17, 2-17). Silver bush lupine (*Lupinus albifrons*) was found in 24% of grid cells, and occupied an estimated 1 acre, with abundance much higher in the Stamm Unit (Table 16, Maps 1-23, 2-23). Deerweed was present in 20% of grids cells and occupied 0.47 acres, with greater abundance in the Stamm Unit (Table 16, Maps 1-16, 2-16).

Rare dune species occupied 4.1 acres total, with 3.1 acres in the Stamm Unit and 1 acre in the Sardis Unit (Table 16, Maps 1-15, 2-15). ADP was the most abundant rare dune plant, occupying 1.21 acres in 2023 and present in 27% of grid cells surveyed, with the vast majority of this in the Stamm Unit (Table 16, Maps 1-25, 2-25). ADB was present in 28% of grid cells surveyed, and occupied at total 0.57 acres; more ADB occurred in the Sardis Unit, but the species was well represented in both units (Table 16, Maps 1-18, 2-18). A total 10,713 ADB individuals were mapped in the refuge, with 7,604 in Sardis and 3,109 in Stamm (Table 16). CCW was observed in 30% of grid cells, with greater frequency and abundance in the Sardis Unit; total cover was 0.08 acres (Table 16, Maps 1-19, 2-19).

Nectar plants were found in 44% of grid cells, with 0.66 total acres, and greater abundance and frequency in the Stamm Unit (Table 16). Telegraphweed was present in 40% of grids surveyed, and occupied 0.57 acres. This species was more abundant and prevalent in the Stamm Unit (Table 16, Map 1-22, 2-22). Hairy gumweed and California matchweed were both rare, found in 6% and 4% of grid squares respectively (Table 16, Map 1-22, 2-22). Shrubby butterweed was very rare, found in only five grid cells, four of which were in the Sardis Unit, and occupying only 0.01 acre (Table 16, Map 1-26, 2-26).

Table 16. Summary of native and invasive target species in each Management Unit and overall, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)			Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)		
	Sardis	Stamm	Total	Sardis	Stamm	Total
Native species	293 (93%)	384 (83%)	677 (87%)	7.54 (24%)	4.38 (10%)	11.92 (15%)
Nectar plants	109 (35%)	238 (51%)	347 (44%)	0.14 (0%)	0.53 (1%)	0.66 (1%)
Invasive species	305 (97%)	435 (94)	740 (95%)	4.69 (15%)	6.62 (14%)	11.31 (15%)
ADP Abundance (count of individuals)	NA			7,604	3,109	10,713
Native Species						
Acmispon glaber var. *glaber*	50 (16%)	104 (22%)	154 (20%)	0.11 (0%)	0.36 (1%)	0.47 (1%)
Baccharis pilularis	26 (8%)	5 (1%)	31 (4%)	0.08 (0%)	0.02 (0%)	0.10 (0%)
Eriogonum nudum var. *psychicola*	119 (38%)	123 (27%)	236 (30%)	0.35 (1%)	0.22(0%)	0.57 (1%)
Erysimum capitatum var. *angustatum*	59 (19%)	44 (9%)	103 (13%)	0.06 (0%)	0.02(0%)	0.08 (0%)
Grindelia hirsutula	22 (7%)	26 (6%)	48 (6%)	0.03 (0%)	0.02(0%)	0.06 (0%)
Gutierrezia californica	24 (8%)	6 (1%)	30 (4%)	0.02 (0%)	0.01(0%)	0.03 (0%)
Heterotheca grandiflora	81 (26%)	224 (48%)	306 (40%)	0.08 (0%)	0.50 (1%)	0.57 (1%)
Lupinus albifrons	53 (17%)	131 (28%)	184 (24%)	0.22 (1%)	0.78 (2%)	1.0 (1%)
Oenothera deltoides ssp. *howellii*	22 (7%)	185 (40%)	207 (27%)	0.02 (0%)	1.20 (3%)	1.21 (2%)
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	255 (81%)	166 (36%)	421 (54%)	6.58 (21%)	1.25 (3%)	7.82 (10%)
Senecio flaccidus var. *douglasii*	4 (1%)	1 (0%)	5 (1%)	0.01 (0%)	0	0.01 (0%)
Invasive Species						
Ailanthus altissima	54 (17%)	7 (2%)	61 (8%)	0.81 (3%)	0.03 (0%)	0.85 (1%)
Brassica nigra, Hirschfeldia incana	48 (15%)	216 (46%)	264 (34%)	0.03 (0%)	0.46 (1%)	0.49 (1%)
Carduus pyncocephalus	51 (16%)	4 (1%)	55 (7%)	0.07 (0%)	0.01 (0%)	0.08 (0%)
Centaurea group (*C. melitensis, C. solstitialis*)	151 (48%)	203 (44%)	354 (45%)	0.53 (2%)	0.30 (1%)	0.83 1%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)			Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)		
	Sardis	Stamm	Total	Sardis	Stamm	Total
Cynodon dactylon	5 (2%)	52 (11%)	57 (7%)	0.04 (0%)	0.22 (0%)	0.26 (0%)
Dittrichia graveolens	0	1 (0%)	1 (0%)	0	0.01 (0%)	0.01 (0%)
Erodium cicutarium	152 (48%)	276 (59%)	428 (55%)	0.95 (3%)	2.02 (4%)	2.96 (4%)
Genista monpessulana	14 (4%)	0	14 (2%)	0.07 (0%)	0	0.07 (0%)
Lepidium latifolium	17 (5%)	13 (3%)	30 (4%)	0.06 (0%)	0.03 (0%)	0.09 (0%)
Malva group (*Malva parviflora*, *Malva* ssp.)	45 (14%)	123 (26%)	168 (22%)	0.08 (0%)	0.60 (1%)	0.68 (1%)
Melilotus albus	0	0	0	0	0	0
Nicotiana glauca	5 (2%)	3 (1%)	8 (1%)	0.01 (0%)	0.01 (0%)	0.01 (0%)
Raphanus sativus	8 (3%)	10 (2%)	18 (2%)	0	0.01 (0%)	0.01 (0%)
Robinia pseudoacacia	27 (9%)	2 (0%)	29 (4%)	0.31 (1%)	0.02 (0%)	0.34 (0%)
Rubus armeniacus	34 (11%)	54 (12%)	88 (11%)	0.25 91%)	0.61 (1%)	0.86 (1%)
Salsola tragus	14 (4%)	42 (9%)	56 (7%)	0.01 (0%)	0.05 (0%)	0.06 (0%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	2 (1%)	0	2 (0%)	0.001 (0%)	0	0.001 (0%)
Tribulus terrestris	0	11 (2%)	11 (1%)	0	0.01 (0%)	0.01 (0%)
Vicia sativa	12 (4%)	21 (5%)	33 (4%)	0.01 (0%)	0.04 (0%)	0.04 (0%)
Vicia villosa	237 (75%)	379 (82%)	616 (79%)	1.46 (5%)	2.21 (5%)	3.67 (5%)
Early Detection Species						
Aegilops triuncialis	0	0	0	0	0	0
Ammophila arenaria	0	0	0	0	0	0
Bromus tectorum	0	0	0	0	0	0
Taeniatherum caput-medusae	0	0	0	0	0	0
Total Grid Cells Surveyed 2023	**315**	**464**	**779**	**31**	**46**	**77**

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Stamm Unit

All target native species were found in the Stamm Unit in at least one grid cell, with the highest frequency and extent in MA1 (Tables 17-18). The 2014-2015 sand deposition area in MA1 provided the highest concentration of nectar and perch plants for LMB, with an establishing population of ADB (Table 17, Map 1-14). Target native species richness was highest in MA1 in the Stamm Unit; native richness was generally higher where invasive plant richness was lower (Map 1-13). Oaks had the highest cover of native target species, at 1.25 acres (Table 18). Oak frequency was highest in MA1, extent highest in the Littoral MA, and frequency lower in MA2, MA3 and MA4, with the majority of occurrences consisting of seedlings with less than 1% cover (Figure 6, Tables 17-18, Map 1-24). Only five grid cells of coyote bush occurred in the Stamm Unit; in MA1, MA4 and the Littoral MA (Table 17, Map 1-16).

ADP was abundant in the Stamm Unit, covering 1.2 acres, with abundance highest in MA1 and MA2 in the sand deposition treatment areas (Figure 6, Table 17, Map 1-25). ADB covered 0.22 acres in the Stamm Unit, with all occurrences less than 10% cover, and found predominately around known populations in MA3 and MA4, on the edge of MA2, and a new population in the MA1 2014-2015 sand deposition treatment area (Figure 6, Tables 17-18, Map 1-18). CCW occurred in 44 grid cells in the Stamm Unit, occurring on shaded slopes in the Littoral MA, and in steeper sand deposits along the southern boundary of the Refuge in MA2 and backslopes of hummocks in MA3 and MA4 (Figure 6, Table 17, Map 1-19).

Silver bush lupine covered 0.78 acres in the Stamm Unit, and was most abundant in more hummocked sand deposits in MA1 and MA3 (Tables 17-18, Map 1-23). Deerbrush covered 0.36 acres, with distribution concentrated in the 2014-2015 sand deposition treatment area in MA1 and in the center of MA4 (Table 17, Map 1-16). Telegraphweed covered 0.50 acres, and was widely distributed throughout upland MAs in the Stamm Unit, with highest cover in the MA1 sand deposition treatment (Tables 17-18, Map 1-22). Hairy gumweed was most often found on the west side of the Stamm Unit in MA1, with an additional population between the two sand deposition treatments in MA2 (Table 17, Map 1-20). Only six occurrences of California matchweed occurred in the Stamm Unit, with most occurrences on the east side of the unit (Table 17, Map 1-21), and shrubby butterweed was found in one grid cell in MA4 (Table 17, Map 1-26).

Figure 6. TOPLEFT: Oak seedling among ADP, Stamm Unit, Management Area 1. TOPRIGHT: Abundant robust ADP, 2014-2015 sand deposition treatment, Stamm Unit, Management Area 1. BOTTOMLEFT: CCW on shaded bank, Stamm Unit, Littoral Management Area. BOTTOMRIGHT: New population of ADB in the 2014-2015 sand deposition treatment, Stamm Unit, Management Area 1.

Table 17. Summary of native and invasive target species by Management Area, Stamm Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)					Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)				
	MA1	MA2	MA3	MA4	Littoral	MA1	MA2	MA3	MA4	Littoral
Native species	116 (93%)	62 (89%)	85 (92%)	86 (75%)	35 (60%)	2.50 (15%)	0.31 (4%)	0.51 (2.8%)	0.57 (2.7%)	0.47 (6.3%)
Nectar plants	88 (71%)	45 (64%)	45 (49%)	49 (43%)	11 (19%)	0.37 (2%)	0.08 (1%)	0.05 (0.3%)	0.03 (0.1%)	0.01 (0.07%)
Invasive species	120 (96%)	65 (93%)	92 (100%)	114 (99%)	43 (74%)	1.75 (10%)	2.34 (30%)	1.02 (5.2%)	0.78 (3.4%)	0.73 (9.8%)
ADP Abundance (count of individuals)	NA					420	47	1532	1092	18
Native species										
Acmispon glaber var. *glaber*	51 (41%)	7 (10%)	10 (11%)	32 (28%)	4 (7%)	0.235 (1.4%)	0.014 (0.2%)	0.010 (0.06%)	0.098 (0.5%)	0.002 (0.03%)
Baccharis pilularis	2 (2%)	0	0	1 (1%)	2 (3%)	0.006 (0.04%)	0	0	0.006 (0.03%)	0.006 (0.09%)
Eriogonum nudum var. *psychicola*	21 (17%)	6 (9%)	53 (58%)	39 (34%)	4 (7%)	0.038 (0.2%)	0.003 (0.04%)	0.102 (0.5%)	0.068 (0.3%)	0.007 (0.1%)
Erysimum capitatum var. *angustatum*	0	7 (10%)	16 (17%)	4 (3%)	17 (29%)	0	0.003 (0.04%)	0.008 (0.04%)	0.002 (0.009%)	0.008 (0.1%)
Grindelia hirsutula	20 (16%)	6 (9%)	0	0	0	0.021 (0.1%)	0.003 (0.04%)	0	0	0
Gutierrezia californica	1 (1%)	0	1 (1%)	1 (1%)	3 (2%)	0.006 (0.03%)	0	0.006 (0.03%)	0.001 (0.007%)	0.000494 (0.007)
Heterotheca grandiflora	79 (63%)	43 (61%)	45 (49%)	47 (41%)	10 (17%)	0.347 (2.1%)	0.077 (1%)	0.044 (0.2%)	0.023 (0.1%)	0.005 (0.07%)
Lupinus albifrons	55 (44%)	9 (13%)	49 (53%)	11 (10%)	7 (12%)	0.505 (3%)	0.021 (0.3%)	0.206 (1.1%)	0.039 (0.2%)	0.014 (0.2%)
Oenothera deltoides ssp. *howellii*	98 (78%)	52 (74%)	22 (24%)	9 (8%)	4 (7%)	1.084 (6.4%)	0.096 (1.2%)	0.011 (0.06%)	0.004 (0.02%)	0.002 (0.03%)
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	73 (58%)	19 (27%)	22 (24%)	24 (21%)	28 (48%)	0.267 (1.6%)	0.095 (1.2%)	0.126 (0.7%)	0.331 (1.6%)	0.427 (5.7%)
Senecio flaccidus var. *douglasii*	0	0	0	0	0	0	0	0	0	0
Invasive species										
Ailanthus altissima	1 (1%)	1 (1%)	1 (1%)	0	4 (7%)	0.006 (0.04%)	0.006 (0.08%)	0.006 (0.03%)	0	0.013 (0.2%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)					Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)				
	MA1	MA2	MA3	MA4	Littoral	MA1	MA2	MA3	MA4	Littoral
Brassica nigra, Hirschfeldia incana	74 (59%)	51 (73%)	31 (34%)	47 (41%)	13 (22%)	0.213 (1.3%)	0.179 (2.3%)	0.026 (0.1%)	0.034 (0.2%)	0.006 (0.09%)
Carduus pyncocephalus	1 (1%)	0	0	4 (3%)	1 (2%)	0	0	0	0.006 (0.03%)	0
Centaurea group (*C. melitensis, C. solstitialis*)	57 (46%)	46 (66%)	36 (39%)	54 (47%)	10 (17%)	0.066 (0.4%)	0.050 (0.6%)	0.061 (0.3%)	0.115 (0.5%)	0.005 (0.07%)
Cynodon dactylon	44 (35%)	3 (4%)	2 (2%)	1 (1%)	2 (3%)	0.205 (1.2%)	0.001 (0.02%)	0.006 (0.03%)	0	0.006 (0.09%)
Dittrichia graveolens	1 (1%)	0	0	0	0	0	0.006 (0.08%)	0	0	0
Erodium cicutarium	82 (66%)	30 (43%)	59 (64%)	95 (83%)	10 (17%)	0.70 (4.2%)	0.086 (1.1%)	0.248 (1.3%)	0.955 (4.5%)	0.0267 (0.4%)
Genista monpessulana	0	0	0	0	0	0	0	0	0	0
Lepidium latifolium	6 (5%)	6 (9%)	0	0	1 (2%)	0.006 (0.04%)	0.019 (0.2%)	0.003 (0.02%)	0	0
Malva group (*Malva parviflora*, *Malva* ssp.)	63 (50%)	42 (60%)	2 (2%)	11 (10%)	5 (7%)	0.235 (1%)	0.351 (4%)	0.001 (0.005%)	0.005 (0.02%)	0.006 (0.08%)
Melilotus albus	0	0	0	0	0	0	0	0	0	0
Nicotiana glauca	3 (2%)	0	0	0	0	0	0.007 (0.09%)	0	0	0
Raphanus sativus	7 (6%)	3 (4%)	0	0	0	0	0.009 (0.1%)	0.001 (0.008%)	0	0
Robinia pseudoacacia	2 (2%)	0	0	0	0	0.024 (0.1%)	0	0	0	0
Rubus armeniacus	9 (7%)	1 (1%)	2 (2%)	0	41 (71%)	0.089 (0.5%)	0.0049 (0.06%)	0.012 (0.06%)	0	0.511 (7%)
Salsola tragus	3 (2%)	24 (34%)	1 (1%)	14 (12%)	0	0	0.007 (0.09%)	0.028 (0.2%)	0	0.012 (0.2%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	0	0	0	0	0	0	0	0	0
Tribulus terrestris	6 (5%)	4 (6%)	0	0	1 (2%)	0.003 (0.02%)	0.002 (0.03%)	0	0	0.0005 (0.007%)
Vicia sativa	1 (1%)	7 (10%)	5 (5%)	6 (5%)	2 (3%)	0.009 (0.05%)	0.008 (0.1%)	0.014 (0.07%)	0.001 (0.005%)	0.006 (0.08%)
Vicia villosa	104 (83%)	51 (73%)	86 (93%)	105 (91%)	33 (57%)	0.744 (4.4%)	0.301 (3.8%)	0.410 (2.2%)	0.616 (2.9%)	0.137 (1.8%)
Early Detection										

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)					Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)				
	MA1	MA2	MA3	MA4	Littoral	MA1	MA2	MA3	MA4	Littoral
Aegilops triuncialis	0	0	0	0	0	0	0	0	0	0
Ammophila arenaria	0	0	0	0	0	0	0	0	0	0
Bromus tectorum	0	0	0	0	0	0	0	0	0	0
Taeniatherum caput-medusae	0	0	0	0	0	0	0	0	0	0
Total Grid Cells Surveyed 2023	**125**	**70**	**92**	**115**	**58**	16.85	7.89	18.63	21.31	7.45

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Table 18. Summary of target native and invasive species abundance, Stamm Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge (N=464).

Species	Number of Grids Containing Target Species by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Native Species								
Acmispon glaber var. *glaber*	360	61	40	1	2	0	0	0.36
Baccharis pilularis	459	2	3	0	0	0	0	0.02
Eriogonum nudum var. *psychicola*	341	94	29	0	0	0	0	0.22
Erysimum capitatum var. *angustatum*	420	44	0	0	0	0	0	0.02
Grindelia hirsutula	438	24	2	0	0	0	0	0.02
Gutierrezia californica	458	5	1	0	0	0	0	0.01
Heterotheca grandiflora	240	175	39	10	0	0	0	0.5
Lupinus albifrons	333	51	61	16	3	0	0	0.78
Oenothera deltoides ssp. *howellii*	279	100	44	33	8	0	0	1.2
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	301	91	40	24	7	0	1	1.25
Senecio flaccidus var. *douglasii*	463	1	0	0	0	0	0	0

Species	Number of Grids Containing Target Species by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Invasive Species								
Ailanthus altissima	457	2	5	0	0	0	0	0.03
Brassica nigra, Hirschfeldia incana	248	162	49	5	0	0	0	0.46
Carduus pyncocephalus	460	3	1	0	0	0	0	0.01
Centaurea group (*C. melitensis, C. solstitialis*)	261	169	33	1	0	0	0	0.30
Cynodon dactylon	412	25	23	4	0	0	0	0.22
Dittrichia graveolens	463	0	1	0	0	0	0	0.01
Erodium cicutarium	188	107	128	22	15	4	0	2.02
Genista monpessulana	464	0	0	0	0	0	0	0.0
Lepidium latifolium	451	9	4	0	0	0	0	0.03
Malva group (*Malva parviflora*, *Malva* ssp.)	341	68	43	7	5	0	0	0.60
Melilotus albus	464	0	0	0	0	0	0	0.0
Nicotiana glauca	461	2	1	0	0	0	0	0.01
Raphanus sativus	454	9	1	0	0	0	0	0.01
Robinia pseudoacacia	462	0	1	1	0	0	0	0.02
Rubus armeniacus	410	14	21	13	5	1	0	0.61
Salsola tragus	422	37	5	0	0	0	0	0.05
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	464	0	0	0	0	0	0	0
Tribulus terrestris	453	11	0	0	0	0	0	0.01
Vicia sativa	443	16	5	0	0	0	0	0.04
Vicia villosa	85	118	224	30	6	1	0	2.21

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

Sardis Unit

All native target species were observed in the Sardis Unit, with native target species frequency and extent lowest in the PG&E West MA (Tables 19-20). Nectar and perch plants had the highest frequency in the PG&E East and West MAs (Table 19, Map 2-14). Native target species richness was highest in the PG&E East MA and western Slope and Pit MAs in areas where invasive plant target species richness was lower (Map 2-13). Oaks were the most abundant of native target species, occupying 6.58 acres and present in 81% of grid cells (Tables 19-20, Map 2-24). Coyote bush was more prevalent in the Sardis Unit than in the Stamm Unit, but was still rare, occupying 0.08 acres, occurring typically at low cover, and restricted to the Pit, Riparian and Slope MAs (Tables 19-20, Map 2-17).

ADB was the most abundant rare dune species, occupying an estimated 0.35 acres, and occurring in each MA, but with abundance much higher in the Pit and PG&E East MAs (Table 19, Map 2-18). Many seedlings and small plants of ADB were observed in seeding trial areas in the Pit MA (Figure 7, Map 2-18). Most ADB areas were overwhelmed with annual grasses, with plants surrounded and partially submerged by grass and winter vetch cover (Figure 7); nevertheless, ADB seedlings were observed establishing in deep annual grass and thatch cover (Figure 7).

Figure 7. LEFT: ADB population with dense annual grasses and winter vetch, Sardis Unit, Pit Management Area. RIGHT: ADB seedlings among annual grasses and thatch, Sardis Unit, Pit Management Area.

CCW was more widespread and abundant in the Sardis Unit, found in 59 grid cells, and each MA, but with abundance highest in the PG&E East and Slope MAs (Figure 8, Table 19, Map 2-19). ADP was observed in 22 grid cells, typically at very low cover, with abundance highest in the Upland and PG&E East MA (Figure 8, Tables 19-20, Map 2-25).

Figure 8. LEFT: Patch of flowering CCW in seeding trial plot, Sardis Unit, PG&E East Management Area. RIGHT: ADP with CCW, PG&E East Management Area.

Silver bush lupine occupied 0.22 acres, occurring generally at low cover, with distribution centered in PG&E East MA (Table 19, Map 2-23). Telegraphweed was widespread at low cover throughout the PG&E East, Upland and PG&E West MAs (Table 19, Map 2-22). Hairy gumweed and California matchweed were found at low cover in all MAs except the Riparian MA, and were most frequent in the Pit MA (Table 19, Maps 2-20, 2-21). Shrubby butterweed was observed in four grid cells with two each the Slope and PG&E East MA (Table 19, Map 2-26).

Table 19. Summary of native and invasive target species by Management Area, Sardis Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)					
	PG&E East	PG&E West	Pit	Riparian	Slope	Upland	PG&E East	PG&E West	Pit	Riparian	Slope	Upland
Native species	69 (99%)	61 (80%)	64 (100%)	20 (100%)	31 (89%)	45 (98%)	1.34 (19%)	0.81 (11%)	3.01 (48%)	0.64 (32%)	1.11 (32%)	0.63 (14%)
Nectar plants	30 (43%)	31 (41%)	18 (28%)	2 (10%)	8 (23%)	20 (43%)	0.041 (1%)	0.03 (0.4%)	0.04 (1%)	0	0.01 (0.2%)	0.02 (0.4%)
Invasive species	65 (93%)	74 (97%)	64 (100%)	20 (100%)	33 (94%)	46 (100%)	0.57 (8%)	1.7 (23%)	0.73 (12%)	0.63 (32%)	0.63 (18%)	0.4 (9%)
ADP Abundance (count of individuals)	NA						1875	423	4861	121	311	13
Native species												
Acmispon glaber var. *glaber*	13 (19%)	17 (22%)	6 (9%)	3 (15%)	6 (17%)	5 (11%)	0.0282 (0.4%)	0.0519 (1%)	0.0030 (0.05%)	0.0015 (0.07%)	0.0138 (0.4%)	0.0079 (0.2%)
Baccharis pilularis	0	0	23 (40%)	1 (5%)	2 (6%)	0	0	0	0.0776 (1%)	0.0059 (0.3%)	0.0010 (0.03%)	0
Eriogonum nudum var. *psychicola*	43 (61%)	21 (28%)	33 (52%)	4 (20%)	13 (37%)	5 (11%)	0.17 (2%)	0.0321 (0.4%)	0.0924 (1%)	0.0183 (1%)	0.0336 (1%)	0.0025 (0.05%)
Erysimum capitatum var. *angustatum*	24 (34%)	1 (1%)	15 (23%)	4 (20%)	11 (31%)	4 (9%)	0.039 (1%)	0.005 (0.007%)	0.0074 (0.1%)	0.0020 (0.1%)	0.0054 (0.2%)	0.0020 (0.04%)
Grindelia hirsutula	2 (3%)	1 (1%)	14 (22%)	0	1 (3%)	4 (9%)	0.001 (0.01%)	0.005 (0.007%)	0.0287 (0.5%)	0	0.005 (0.01%)	0.0020 (0.04%)
Gutierrezia californica	9 (13%)	3 (4%)	7 (11%)	0	4 (11%)	1 (2%)	0.0044 (0.06%)	0.0015 (0.02%)	0.0089 (0.1%)	0	0.0020 (0.06%)	0.005 (0.01%)
Heterotheca grandiflora	26 (37%)	30 (39%)	0	2 (10%)	5 (14%)	11 (23%)	0.0292 (0.4%)	0.0311 (0.4%)	0	0.0010 (0.05%)	0.0025 (0.07%)	0.0143 (0.3%)
Lupinus albifrons	31 (44%)	7 (9%)	3 (5%)	2 (10%)	6 (17%)	4 (9%)	0.149 (2%)	0.0252 (0.3%)	0.0015 (0.02%)	0.0064 (0.3%)	0.0247 (1%)	0.0128 (0.3%)
Oenothera deltoides ssp. *howellii*	8 (11%)	1 (1%)	0	0	4 (11%)	8 (20%)	0.004 (0.06%)	0.005 (0.007%)	0	0	0.0020 (0.06%)	0.0099 (0.2%)
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	60 (86%)	50 (66%)	63 (98%)	19 (95%)	26 (74%)	34 (74%)	0.907 (13%)	0.663 (9%)	2.79 (44%)	0.60 (30%)	1.021 (29%)	0.575 (13%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)					
	PG&E East	PG&E West	Pit	Riparian	Slope	Upland	PG&E East	PG&E West	Pit	Riparian	Slope	Upland
Senecio flaccidus var. *douglasii*	2 (3%)	0	0	0	2 (6%)	0	0.0064 (0.09%)	0	0	0	0.001 (0.03%)	0
Invasive species												
Ailanthus altissima	0	33 (53%)	3 (5%)	9 (45%)	9 (25%)	0	0	0.39 (5%)	0.06 (1%)	0.21 (10%)	0.16 (5%)	0
Brassica nigra, Hirschfeldia incana	5 (7%)	19 (25%)	8 (13%)	1 (5%)	6 (17%)	9 (20%)	0	0.01 (0.2%)	0.004 (0.06%)	0.0023 (0.02%)	0.0023 (0.08%)	0.00444 (0.1%)
Carduus pyncocephalus	8 (11%)	5 (7%)	19 (30%)	6 (30%)	6 (17%)	7 (15%)	0.01 (0.2%)	0.01 (0.2%)	0.01 (0.2%)	0.02 (1%)	0.01 (0.2%)	0.00346 (0.08%)
Centaurea group (*C. melitensis, C. solstitialis*)	26 (47%)	44 (58%)	37 (58%)	8 (40%)	19 (54%)	17 (40%)	0.03 (0.4%)	0.27 (4%)	0.12 (2%)	0.01 (1%)	0.08 (2%	0.01 (0.3%)
Cynodon dactylon	0	5 (7%)	0	0	0	0	0	0.04 (0.4%)	0	0	0	0
Dittrichia graveolens	0	0	0	0	0	0	0	0	0	0	0	0
Erodium cicutarium	3 (44%)	4 (58%)	1 (27%)	3 (15%)	18 (51%)	39 (85%)	0.22 (3%)	0.36 (5%)	0.08 (1%)	0.01 (0.3%)	0.08 (2%)	0.20 (4%)
Genista monpessulana	0	0	1 (20%)	1 (5%)	0	0	0	0	0.06 (1%)	0.01 (0.3%)	0	0
Lepidium latifolium	0	0	1(25%)	0	1 (3%)	0	0	0	0.06 (1%)	0	0	0
Malva group (*Malva parviflora*, *Malva* ssp.)	2(3%)	(12%)	(14%)	1 (5%)	1 (3%)	2 (50%)	0	0	0	0	0.000494 (0.01%)	0.07 (2%)
Melilotus albus	0	0	0	0	0	0	0	0	0	0	0	0
Nicotiana glauca	0	2 (3%)	0	1 (5%)	2 (6%)	0	0	0.01 (0.09%)	0	0	0.001 (0.03%)	0
Raphanus sativus	1 (1%)	1 (1%)	0	1 (5%)	0	5 (11%)	0	0	0	0	0	0.00247 (0.05%)
Robinia pseudoacacia	0	10 (13%)	5 (8%)	11 (55%)	1 (3%)	0	0	0.09 (1%)	0.05 (1%)	0.17 (8%)	0.01 (0.2%)	0
Rubus armeniacus	8 (11%)	1 (1%)	7 (11%)	14 (70%)	0	0	0.07 (1%)	0.01 (0.2%)	0.07 (1%)	0.07 (4%)	0	0
Salsola tragus	1 (1%)	3 (4%)	3 (5%)	0	0	7 (15%)	0	0	0	0	0.00148 (0.04%)	0.01 (0.2%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	2 (3%)	0	0	0	0	0	0	0	0	0	0
Tribulus terrestris	0	0	0	0	0	0	0	0	0	0	0	0

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)					
	PG&E East	PG&E West	Pit	Riparian	Slope	Upland	PG&E East	PG&E West	Pit	Riparian	Slope	Upland
Vicia sativa	0	0	9 (14%)	1 (5%)	2 (6%)	0	0	0	0	0.00049 (0.02%)	0.00099 (0.03%)	0
Vicia villosa	52 (74%)	63 (83%)	49 (77%)	14 (70%)	32 (91%)	27 (59%)	0.23 (3%)	0.50 (7%)	0.21 (3%)	0.14 (7%)	0.28 (8%)	0.10 (2%)
Early Detection												
Aegilops triuncialis	0	0	0	0	0	0	0	0	0	0	0	0
Ammophila arenaria	0	0	0	0	0	0	0	0	0	0	0	0
Bromus tectorum	0	0	0	0	0	0	0	0	0	0	0	0
Taeniatherum caput-medusae	0	0	0	0	0	0	0	0	0	0	0	0
Total Grid Cells Surveyed 2023	**70**	**76**	**64**	**20**	**35**	**46**	6.92	7.51	6.33	1.98	3.50	4.50

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Table 20. Summary of target native and invasive species abundance, Sardis Unit, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge (N=315).

Species	Number of Grids Containing Target Species by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Native Species								
Acmispon glaber var. *glaber*	265	35	15	0	0	0	0	0.11
Baccharis pilularis	289	15	10	1	0	0	0	0.08
Eriogonum nudum var. *psychicola*	196	70	47	2	0	0	0	0.35
Erysimum capitatum var. *angustatum*	256	54	5	0	0	0	0	0.06
Grindelia hirsutula	293	18	4	0	0	0	0	0.03
Gutierrezia californica	291	23	1	0	0	0	0	0.02
Heterotheca grandiflora	234	74	7	0	0	0	0	0.08
Lupinus albifrons	262	24	26	3	0	0	0	0.22
Oenothera deltoides ssp. *howellii*	293	21	1	0	0	0	0	0.02

Species	Number of Grids Containing Target Species by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	60	33	64	65	51	22	20	6.58
Senecio flaccidus var. *douglasii*	311	3	1	0	0	0	0	0.01
Invasive Species								
Ailanthus altissima	261	11	15	18	9	1	0	0.81
Brassica nigra, Hirschfeldia incana	267	47	1	0	0	0	0	0.03
Carduus pyncocephalus	264	43	8	0	0	0	0	0.07
Centaurea group (*C. melitensis, C. solstitialis*)	164	91	49	11	0	0	0	0.53
Cynodon dactylon	310	1	3	1	0	0	0	0.04
Dittrichia graveolens	315	0	0	0	0	0	0	0.0
Erodium cicutarium	163	54	76	18	4	0	0	0.95
Genista monpessulana	301	5	8	1	0	0	0	0.07
Lepidium latifolium	298	8	9	0	0	0	0	0.06
Malva group (*Malva parviflora*, *Malva* ssp.)	270	34	11	0	0	0	0	0.08
Melilotus albus	315	0	0	0	0	0	0	0.0
Nicotiana glauca	310	4	1	0	0	0	0	0.01
Raphanus sativus	307	8	0	0	0	0	0	0.0
Robinia pseudoacacia	288	3	13	9	2	0	0	0.31
Rubus armeniacus	281	12	16	4	2	0	0	0.25
Salsola tragus	301	13	1	0	0	0	0	0.01
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	313	2	0	0	0	0	0	0.001
Tribulus terrestris	315	0	0	0	0	0	0	0.0

Species	Number of Grids Containing Target Species by Percent Cover Class							
	0%	>0-1%	1-10%	11-25%	26-50%	51-75%	76-100%	Extent (acres)*
Vicia sativa	303	12	0	0	0	0	0	0.01
Vicia villosa	78	81	126	23	7	0	0	1.46

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

3.3.1B Changes from 2017 to 2023

Changes observed between the 2017 and 2023 inventory years are presented here, for analysis of differences among Management Areas, see section 3.2. Most target native species measured in both inventories declined in frequency and abundance from 2017 to 2023, except for ADP, which increased substantially (Table 21). Target native species and nectar species frequency declined in most MAs from 2017 to 2023 (Tables 22, 24). Greater declines were observed in the Stamm Unit for deerweed, ADB, hairy gumweed, and telegraphweed (Table 21). Coyote bush declines were greater in the Sardis Unit, but the species was also more prevalent in that Unit (Table 21, Maps 1-17, 2-17). Silver bush lupine declined in frequency in both units, but while it declined in abundance in the Sardis Unit, abundance increased in the Stamm Unit, especially in MA1 (Tables 21-25). ADP declined in frequency and abundance in the Sardis unit, while frequency and abundance increased significantly in the Stamm Unit (Tables 21-25). CCW increased in frequency in most MAs in the Stamm Unit, but declined in the Sardis Unit and declined in extent in most MAs in both units (Table 21).

Although the frequency and extent of ADB declined in both units, the total number of ADB individuals mapped increased by 483, with an increase of 2,244 individuals in the Sardis Unit and a decline of 1,761 individuals in the Stamm Unit (Table 21), most of which were lost from the 2020-2021 sand deposition treatment in MA2 (Tables 22-25). However, 331 new individuals of ADB colonized the 2014-2015 sand deposition treatment in MA1 between 2017 and 2023 with many small plants observed around larger adults (Figure 9, Tables 22-23, Map 1-17).

Figure 9. ADB colonization of 2014-2015 sand deposition treatment, Stamm Unit, Management Area 1.

Table 21. Summary of native and invasive target species in each Management Unit and overall, 2023 Vegetation Inventory, Antioch Dunes National Wildlife Refuge, with changes from 2017 survey. Note: Only species and grid cells measured in both inventory years are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres*					
	Sardis		Stamm		Total		Sardis		Stamm		Total	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Summary Values												
Native species	212 (73%)	-66 (-23%)	366 (86%)	22 (5%)	563 (79%)	-59 (-8%)	0.97	-1.46	3.12	-0.26	4.08	-1.71
Nectar plants	109 (38%)	-78 (-27%)	238 (56%)	-78 (-19%)	333 (47%)	-170 (-24%)	0.13	-0.39	0.53	-0.48	0.65	-0.88
Invasive species	283 (98%)	-22 (1%)	415 (98%)	25 (6%)	698 (98%)	3 (1%)	4.45	-3.01	5.95	-5.41	10.40	-8.4
ADP Abundance (individual count)	NA						7,604	2,244	3,109	-1,761	10,713	483
Native Species												
Acmispon glaber var. *glaber*	50 (17%)	-48 (-17%)	103 (24%)	-62 (-15%)	153 (21%)	-110 (-16%)	0.11	-0.25	0.36	-0.44	0.47	-0.69
Baccharis pilularis	26 (9%)	-17 (-6%)	4 (1%)	-2 (0%)	30 (4%)	-19 (-3%)	0.08	-0.29	0.01	-0.02	0.10	-0.30
Eriogonum nudum var. *psychicola*	119 (41%)	-8(-3%)	123 (29%)	-46 (-11%)	242 (34%)	-54 (-8%)	0.35	-0.27	0.22	-0.50	0.57	-0.77
Erysimum capitatum var. *angustatum*	59 (20%)	-3 (-1%)	44 (10%)	23 (5%)	103 (14%)	20 (2%)	0.06	-0.04	0.02	-0.01	0.08	-0.05
Grindelia hirsutula	20 (7%)	-2 (-14%)	24 (6%)	-13 (-3%)	44 (6%)	-15 (-2%)	0.03	0.002	0.02	-0.06	0.05	-0.06
Gutierrezia californica	24 (8%)	9 (3%)	6 (1%)	-11 (-3%)	30 (4%)	-2 (0%)	0.02	0.01	0.01	0.0	0.03	0.01
Heterotheca grandiflora	72 (25%)	-103 (-37%)	221 (52%)	-85 (-20%)	293 (41%)	-188 (-26%)	0.08	-0.40	0.49	-0.42	0.57	-0.82
Lupinus albifrons	53 (18%)	-4 (-2%)	131 (31%)	-25 (-6%)	184 (26%)	-29 (-4%)	0.22	-0.17	0.78	0.08	1.0	-0.09
Oenothera deltoides ssp. *howellii*	21 (7%)	-18 (-6%)	184 (43%)	98 (23%)	205 (29%)	80 (11%)	0.02	-0.02	1.20	1.10	1.21	1.07
Senecio flaccidus var. *douglasii*	4 (1%)	2 (0%)	1 (0%)	0	5 (1%)	2 (1%)	0.01	0.0	0.0	0.0	0.01	0.0
Invasive Species												
Ailanthus altissima	54 (19%)	7 (3%)	7 (2%)	7 (2%)	61 (9%)	14 (2%)	0.81	0.21	0.03	0.03	0.85	0.25

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres*					
	Sardis		Stamm		Total		Sardis		Stamm		Total	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Brassica nigra, Hirschfeldia incana	47 (16%)	-29 (-10%)	210 (50%)	-64 (-15%)	257 (36%)	-93 (14%)	0.03	-0.11	0.46	-0.26	0.49	-0.37
Carduus pyncocephalus	51 (18%)	27 (8%)	4 (1%)	1 (0%)	55 (8%)	28 (4%)	0.07	0.0	0.01	0.01	0.08	0.01
Centaurea group (*C. melitensis, C. solstitialis*)	150 (52%)	-27 (-11%)	194 (46%)	-20 (-4%)	344 (48%)	-47 (-7%)	0.53	-0.06	0.29	-0.38	0.82	-0.44
Cynodon dactylon	3 (1%)	1 (0%)	47 (11%)	22 (5%)	50 (7%)	23 (3%)	0.01	0.0	0.22	0.15	0.23	0.15
Dittrichia graveolens	0	0	1 (0%)	-2 (-1%)	1 (0%)	-2 (0%)	0.0	0.0	0.01	0.0	0.01	0.01
Erodium cicutarium	137 (47%)	2 (0%)	268 (63%)	-1 (0%)	405 (57%)	1 (0%)	0.0	-1.20	2.01	0.04	2.01	-1.16
Genista monpessulana	14 (5%)	5 (2%)	0	0	14 (2%)	5 (4%)	0.07	0.02	0.0	0.0	0.07	0.02
Lepidium latifolium	17 (6%)	6 (4%)	13 (3%)	5 (1%)	30 (4%)	11 (8%)	0.06	0.02	0.03	0.02	0.09	0.04
Nicotiana glauca	4 (1%)	-8 (-3%)	3 (1%)	2 (1%)	7 (1%)	-6 (-1%)	0.01	0.0	0.01	0.01	0.01	0.0
Raphanus sativus	8 (3%)	-8 (-3%)	9 (2%)	0	17 (2%)	-8 (-2%)	0.0	-0.02	0.02	0.01	0.01	-0.01
Robinia pseudoacacia	25 (9%)	0	1 (0%)	0	26 (4%)	0	0.30	0.01	0.02	0.01	0.32	0.02
Rubus armeniacus	29 (10%)	-5 (-2%)	47 (11%)	5 (1%)	76 (11%)	0	0.22	-0.16	0.60	0.02	0.81	-0.15
Salsola tragus	10 (3%)	-91 (-32%)	39 (9%)	-38 (-20%	49 (7%)	-129 (-18%)	0.0	-0.25	0.04	-0.04	0.04	-0.29
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	2 (1%)	2 (1%)	0	-1 (0%)	2 (0%)	1 (0%)	0.0	0.001	0	-0.010	0.001	-0.01
Vicia sativa	12 (4%)	-44 (-15%)	21 (5%)	21 (5%)	33 (5%)	-23 (-3%)	0.01	-0.52	0.04	0.04	0.04	-0.49
Vicia villosa	231 (80%)	34 (12%)	373 (88%)	27 (6%)	604 (85%)	61 (9%)	1.45	-1.84	2.19	-5.04	3.65	-6.87
Early Detection Species												
Aegilops triuncialis	0	0	0	0	0	0	0	0	0	0	0	0
Ammophila arenaria	0	0	0	0	0	0	0	0	0	0	0	0
Bromus tectorum	0	0	0	0	0	0	0	0	0	0	0	0

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)						Extent of Cover Type in Acres*					
	Sardis		Stamm		Total		Sardis		Stamm		Total	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Taeniatherum caput-medusae	0	0	0	0	0	0	0	0	0	0	0	0
Total Grid Cells Surveyed 2017	**289**		**424**		**713**		**28.6**		**41.9**		**70.5**	

* Extent calculation (midpoint percent cover class * grid cell area m2 * 0247105 acres).

Table 22. Summary of native and invasive target species frequency in grid cells by Management Area, Stamm Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown. Note: Only species and grid cells measured in both inventory years are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Native species	109 (96%)	-1 (-1%)	59 (87%)	-8 (-12%)	84 (91%)	-1 (-1%)	80 (72%)	-21 (-19%)	29 (74%)	6 (15%)
Nectar plants	86 (75%)	-20 (-18%)	45 (66%)	-10 (-15%)	45 (49%)	-22 (-24%)	47 (42%)	-22 (-20%)	11 (28%)	-8 (-21%)
Invasive species	112 (98%)	3 (3%)	62 (91%)	-6 (-9%)	92 (100%)	0	111 (100%)	0	38 (97%)	4 (10%)
Native species										
Acmispon glaber var. *glaber*	51 (45%)	6 (5%)	7 (10%)	-7 (-10%)	10 (11%)	-50 (-54%)	31 (28%)	-10 (-9%)	4 (10%)	-1 (-3%)
Baccharis pilularis	1 (1%)	-1 (-1%)	0	-1 (-1%)	0	-3 (-3%)	1 (1%)	1 (1%)	2 (5%)	2 (5%)
Eriogonum nudum var. *psychicola*	21 (18%)	9 (8%)	6 (9%)	-43 (-63%)	53 (58%)	-12 (-13%)	39 (35%)	-3 (-3%)	4 (10%)	3 (8%)
Erysimum capitatum var. *angustatum*	7 (3%)	3 (3%)	16 (24%)	12 (18%)	4 (4%)	0	4 (4%)	2 (2%)	17 (44%)	10 (26%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Grindelia hirsutula	18 (16%)	-16 (-14%)	6 (9%)	5 (7%)	0	-1 (-1%)	0	0	0	-1 (-3%)
Gutierrezia californica	1 (1%)	1 (1%)	0	-6 (-9%)	1 (1%)	-6 (-7%)	3 (3%)	3 (3%)	1 (3%)	-3 (-8%)
Heterotheca grandiflora	78 (68%)	-24 (-21%)	43 (63%)	8 (12%)	45 (49%)	-20 (-22%)	45 (41%)	-24 (-22%)	10 (26%)	-7 (-8%)
Lupinus albifrons	55 (48%)	8 (7%)	9 (13%)	-32 (-47%)	49 (53%)	-4 (-4%)	11 (10%)	4 (4%)	7 (8%)	-1 (-3%)
Oenothera deltoides ssp. *howellii*	98 (86%)	54 (47%)	51 (75%)	46 (68%)	22 (24%)	10 (11%)	9 (8%)	-16 (-14%)	4 (10%)	4 (10%)
Senecio flaccidus var. *douglasii*	0	0	0	0	0	-1 (-1%)	0	0	1 (3%)	1 (3%)
Invasive species										
Ailanthus altissima	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	0	0	0	0
Brassica nigra, Hirschfeldia incana	69 (61%)	-20 (-18%)	51 (75%)	19 (28%)	31 (34%)	-47 (-51%)	46 (41%)	-32 (-29%)	13 (33%)	4 (10%)
Carduus pyncocephalus	1 (1%)	1 (1%)	0	0	0	-1 (-1%)	4 (4%)	3 (3%)	1 (3%)	1 (3%)
Centaurea group (*C. melitensis, C. solstitialis*)	53 (46%)	-16 (-14%)	44 (65%)	-10 (-15%)	36 (39%)	-1 (-1%)	51 (46%)	14 (13%)	10 (26%)	-3 (-8%)
Cynodon dactylon	39 (34%)	27 (24%)	3 (4%)	3 (4%)	2 (2%)	1 (1%)	1 (1%)	0	3 (8%)	-8 (-21%)
Dittrichia graveolens	1 (1%)	1 (1%)	0	-1 (-1%)	0	-1 (-1%)	0	-1 (-1%)	0	-1 (-3%)
Erodium cicutarium	76 (67%)	32 (28%)	30 (44%)	-15 (-22%)	59 (64%)	-33 (-36%)	93 (84%)	1 (1%)	10 (26%)	3 (8%)
Genista monpessulana	0	0	0	0	0	0	0	0	0	0
Lepidium latifolium	6 (5%)	1 (1%)	6 (9%)	4 (6%)	0	0	0	0	1 (3%)	0
Nicotiana glauca	3 (3%)	2 (2%)	0	0	0	0	0	0	0	0
Raphanus sativus	6 (5%)	1 (1%)	3 (4%)	1 (1%)	0	0	0	0	0	-1 (-3%)
Robinia pseudoacacia	1 (1%)	0	0	0	0	0	0	0	0	0

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Rubus armeniacus	7 (6%)	2 (2%)	1 (1%)	-1 (-1%)	2 (2%)	2 (2%)	0	0	37 (95%)	7 (18%)
Salsola tragus	3 (3%)	-4 (-4%)	22 (32%)	12 (18%)	1 (1%)	-32 (35%)	13 (12%)	-20 (-18%)	0	-1 (-3%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	-1 (-1%)	0	0	0	0	0	0	0	0
Vicia sativa	7 (6%)	7 (6%)	5 (7%)	5 (7%)	6 (7%)	6 (7%)	2 (2%)	2 (2%)	1 (3%)	1 (3%)
Vicia villosa	100 (88%)	40 (35%)	50 (74%)	-17 (-25%)	86 (93%)	-14 (-15%)	105 (95%)	5 (5%)	32 (82%)	4 (10%)
Total Grid Cells Surveyed 2017	114		68		92		111		39	

Table 23. Summary of native and invasive target species extent of cover type by Management Area, Stamm Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown. Note: Only species and grid cells measured in both inventory years are shown.

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Native species	2.229 (20%)	1.234 (11%)	0.217 (3.2%)	-0.343 (-5.1%)	0.387 (4.3%)	-0.787 (-8.7%)	0.241 (2.2%)	-0.320 (-2.9%)	0.046 (1.2%)	-0.047 (-1.2%)
Nectar plants	0.367 (3.3%)	-0.221 (-2%)	0.080 (1.2%)	-0.059 (-0.9%)	0.050 (0.5%)	-0.091 (-1%)	0.024 (0.2%)	-0.070 (-0.6%)	0.005 (0.1%)	-0.043 (-1.1%)
Invasive species	2.064 (18.3%)	0.184 (1.6%)	0.657 (9.8%)	-2.075 (-30.1%)	0.783 (8.6%)	-2.526 (-27.8%)	1.731 (15.8%)	-0.822 (-7.5%)	0.715 (18.6%)	-0.180 (-4.7%)

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Native species										
Acmispon glaber var. *glaber*	0.235 (2.1%)	0.109 (1%)	0.014 (0.2%)	-0.014 (-0.2%)	0.010 (0.1%)	-0.476 (-5.2%)	0.098 (0.9%)	-0.047 (-0.4%)	0.002 (0.05%)	-0.011 (-0.3%)
Baccharis pilularis	0	0	0	-0.006 (-0.09%)	0	0	0.006 (0.05%)	-0.013 (-0.1%)	0.006 (0.2%)	0.006 (0.2%)
Eriogonum nudum var. *psychicola*	0.038 (0.3%)	0.010 (0.09%)	0.003 (0.04%)	-0.192 (-2.9%)	0.102 (1.1%)	-0.202 (-2.2%)	0.068 (0.6%)	-0.126 (-1.1%)	0.007 (0.2%)	0.007 (0.2%)
Erysimum capitatum var. *angustatum*	0	-0.007 (-0.07%)	0.003 (0.05%)	-0.004 (-0.06%)	0.008 (0.09%)	-0.005 (-0.05%)	0.002 (0.02%)	0.001 (0.009%)	0.008 (0.2%)	0.005 (0.1%)
Grindelia hirsutula	0.020 (0.2%)	-0.057 (-0.5%)	0.003 (0.04%)	0.002 (0.04%)	0	0	0	0	0	-0.006 (-0.2%)
Gutierrezia californica	0	0	0	-0.003 (-0.04%)	0.006 (0.07%)	-0.003 (-0.03)	0.001 (0.01%)	0.001 (0.01%)	0	-0.001 (-0.04%)
Heterotheca grandiflora	0.346 (3.1%)	-0.165 (-1.5%)	0.077 (1.1%)	-0.058 (-0.9%)	0.044 (0.5%)	-0.087 (-1%)	0.022 (0.2%)	-0.072 (-0.7%)	0.005 (0.1%)	-0.036 (-0.9%)
Lupinus albifrons	0.505 (4.5%)	0.325 (2.9%)	0.021 (0.3%)	-0.162 (-2.4%)	0.206 (2.3%)	-0.018 (-0.2%)	0.039 (0.4%)	-0.046 (-0.4%)	0.014 (0.4%)	-0.012 (-0.3%)
Oenothera deltoides ssp. *howellii*	1.084 (9.6%)	1.019 (9%)	0.096 (1.4%)	0.093 (1.4%)	0.011 (0.1%)	0.005 (0.05%)	0.004 (0.04%)	-0.019 (-0.2%)	0.002 (0.05%)	0.002 (0.05%)
Senecio flaccidus var. *douglasii*	0	0	0	0	0	0	0	0	0	0
Invasive species										
Ailanthus altissima	0.006 (0.05%)	0.006 (0.05%)	0.006 (0.1%)	0.006 (0.1%)	0.006 (0.07%)	0.006 (0.07%)	0	0	0.013 (0.3%)	0.013 (0.3%)
Brassica nigra, Hirschfeldia incana	0.211 (1.9%)	-0.004 (-0.04%)	0.179 (2.7%)	0.136 (2%)	0.026 (0.3%)	-0.211 (-2.3%)	0.034 (0.3%)	-0.190 (-1.7%)	0.006 (0.2%)	0.002 (0.05%)
Carduus pyncocephalus	0	0	0	0	0	-0.001 (-0.01%)	0.006 (0.06%)	0.006 (0.05%	0.0005 (0.01%)	0
Centaurea group (*C. melitensis, C. solstitialis*)	0.064 (0.6%)	-0.165 (-1.5%)	0.049 (0.7%)	-0.081 (-1.2%)	0.061 (0.7%)	-0.047 (-0.5%)	0.108 (1%)	-0.048 (-0.4%)	0.005 (0.1%)	-0.046 (-1.2%)
Cynodon dactylon	0.203 (1.8%)	0.146 (1.3%)	0.001 (0.02%)	0.001 (0.02%)	0.006 (0.07%)	0.006 (0.07%)	0	0	0.006 (0.2%)	-0.010 (-0.3%)
Dittrichia graveolens	0.006 (0.05%)	0.006 (0.05%)	0	0	0	0	0	0	0	0
Erodium cicutarium	0.697 (6.2%)	0.486 (4.3%)	0.086 (1.3%)	-0.146 (-2.2%)	0.248 (2.7%)	-0.555 (-6.1%)	0.954 (8.7%)	0.264 (2.4%)	0.027 (0.7%)	-0.009 (-0.2%)

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)									
	MA1		MA2		MA3		MA4		Littoral	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Genista monpessulana	0	0	0	0	0	0	0	0	0	0
Lepidium latifolium	0.019 (0.2%)	0.006 (0.05%)	0.003 (0.04%)	0.002 (0.03%)	0	0	0	0	0.006 (0.2%)	0.005 (0.1%)
Nicotiana glauca	0.007 (0.06%)	0.006 (0.06%)	0	0	0	0	0	0	0	0
Raphanus sativus	0.008 (0.07%)	0.006 (0.06%)	0.001 (0.007%)	0.002 (0.03%)	0	0	0	0	0	0
Robinia pseudoacacia	0.018 (0.2%)	0.012 (0.1%)	0	0	0	0	0	0	0	0
Rubus armeniacus	0.077 (0.7%)	0.017 (0.2%)	0	0	0.012 (0.1%)	-0.061 (-0.7%)	0	0	0.509 (13.2%)	0.063 (1.6%)
Salsola tragus	0.007 (0.06%)	0.003 (0.03%)	0.022 (0.3%)	0.017 (0.3%)	0.0005 (0.005%)	-0.023 (-0.3%)	0.012 (0.1%)	-0.037 (-0.3%)	0	0
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	-0.006 (-0.05%)	0	0	0	0	0	0	0	0
Vicia sativa	0.009 (0.08%)	0.009 (0.08%)	0.008 (0.1%)	0.008 (0.1%)	0.014 (0.2%)	0.014 (0.2%)	0.001 (0.009 %)	0.001 (0.009%)	0.006 (0.2%)	0.006 (0.2%)
Vicia villosa	0.731 (6.5%)	-0.344 (-3.1%)	0.300 (4.5%)	-2.018 (-30%)	0.410 (4.5%)	-1.654 (-18.2%)	0.616 (5.6%)	-0.817 (-7.5%)	0.136 (3.5%)	-0.203 (-5.3%)
Total Acres Surveyed 2017	11.27		6.72		9.09		10.97		3.85	

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

Table 24. Summary of native and invasive target species frequency in grid cells by Management Area, Sardis Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown. Note: Only species and grid cells measured in both inventory years are shown.

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Native species	54 (82%)	-2 -(3%)	45 (66%)	-11 (-16%)	50 (78%)	-8 (-13%)	7 (35%)	2 (10%)	25 (71%)	-6 (-17%)	21 (60%)	-8 (-23%)
Nectar plants	30 (45%)	-21 (-32%)	29 (43%)	-25 (-37%)	18 (28%)	-7 (-11%)	2 (10%)	-2 (-10%)	8 (23%)	-18 (-51%)	12 (34%)	10 (29%)
Invasive species	63 (95%)	-1 -(2%)	68 (100%)	10 (15%)	64 (100%)	1 (2%)	20 (100%)	0	33 (94%)	2 (6%)	35 (100%)	1 (3%)
Native species												
Acmispon glaber var. *glaber*	13 (20%)	-22 (-33%)	17 (25%)	-5 (-7%)	6 (9%)	-12 (-19%)	3 (15%)	0	6 (17%)	-4 (-11%)	5 (14%)	-5 (-14%)
Baccharis pilularis	0	0	0	-1 (-1%)	23 (36%)	-14 (-22%)	1 (5%)	1 (5%)	2 (6%)	-3 (-9%)	0	0
Eriogonum nudum var. *psychicola*	43 (65%)	-3 (-5%)	21 (31%)	-1 (-1%)	33 (52%)	-6 (-9%)	4 (20%)	2 (10%)	13 (37%)	-1 (-3%)	5 (14%)	1 (3%)
Erysimum capitatum var. *angustatum*	24 (36%)	-2 (-3%)	1 (1%)	1 (1%)	15 (23%)	-4 (--6%)	4 (20%)	0	11 (31%)	0	4 (11%)	2 (6%)
Grindelia hirsutula	2 (3%)	-4 (-6%)	1 (1%)	-2 (-3%)	14 (22%)	4 (6%)	0	0	1 (3%)	0	2 (6%)	0
Gutierrezia californica	9 (14%)	0	3 (4%)	1 (1%)	7 (11%)	6 (9%)	0	0	4 (11%)	2 (6%)	1 (3%)	0
Heterotheca grandiflora	26 (39%)	-22 (-33%)	28 (41%)	-25 (-37%)	0	-18 (-28%)	2 (10%)	-2 (-10%)	5 (12%)	-20 (-57%)	11 31%)	-15 (-43%)
Lupinus albifrons	31 (47%)	1 (2%)	7 (10%)	0	3 (5%)	-4 (-6%)	2 (10%)	-1 (-5%)	6 (17%)	-1 (-3%)	4 (11%)	1 (3%)
Oenothera deltoides ssp. *howellii*	8 (12%)	-13 (-20%)	1 (1%)	-3 (-4%)	0	-1 (-2%)	0	-1 (-5%)	4 (11%)	1 (-3%)	8 (23%)	-1 (-3%)
Senecio flaccidus var. *douglasii*	2 (3%)	1 (2%)	0	0	0	0	2 (10%)	2 (10%)	0	0	0	-1 (-3%)
Invasive species												
Ailanthus altissima	0	0	33 (49%)	4 (6%)	3 (5%)	0	9 (45%)	3 (15%)	9 (26%)	0	0	0
Brassica nigra, Hirschfeldia incana	5 (8%)	-11 (-17%)	18 (26%)	0	8 (13%)	-9 (-14%)	1 (5%)	-4 (-20%)	6 (17%)	-2 (-6%)	9 (26%)	-2 (-6%)
Carduus pyncocephalus	8 (8%)	4 (6%)	5 (7%)	5 (7%)	19 (30%)	11 (17%)	6 (30%)	0	6 (17%)	5 (14%)	7 (20%)	2 (6%)

Cover Type	Number of Grid Cells Containing Cover Type (Proportion of Grids Containing Cover Type)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Centaurea group (*C. melitensis, C. solstitialis*)	26 (39%)	-10 (15%)	44 (65%)	9 (13%)	37 (58%)	-11 (-17%)	8 (40%)	-6 (-30%)	19 (54%)	2 (6%)	16 (46%)	-5 (-14%)
Cynodon dactylon	0	-2 (-3%)	3 (4%)	3 (4%)	0	0	0	0	0	0	0	0
Dittrichia graveolens	0	0	0	0	0	0	0	0	0	0	0	0
Erodium cicutarium	31 (47%)	-10 (-15%)	40 (59%)	14 (21%)	17 (27%)	-11 (-17%)	3 (15%)	2 (10%)	18 (51%)	1 (3%)	28 (80%)	7 (20%)
Genista monpessulana	0	0	0	0	13 (20%)	5 (8%)	1 (5%)	0	0	0	0	0
Lepidium latifolium	0	0	0	0	16 (25%)	6 (9%)	0	0	1 (3%)	1 (3%)	0	-1 (-3%)
Nicotiana glauca	0	0	1 (1%)	-9 (-13%)	0	0	1 (5%)	0	2 (6%)	2 (6%)	0	-1 (3%)
Raphanus sativus	1 (2%)	-3 (-5%)	1 (1%)	-2 (-3%)	0	0	1(5%)	1 (5%)	0	0	5 (14%)	-4 (-11%)
Robinia pseudoacacia	0	0	8 (12%)	-3 (-4%)	5 (8%)	2 (3%)	11 (55%)	0	1 (3%)	1 (3%)	0	0
Rubus armeniacus	6 (9%)	-1 (-2%)	2 (3%)	-2 (-3%)	7 (11%)	-4 (-6%)	14(75%)	2 (10%)	0	0	0	0
Salsola tragus	1 (2%)	-24 (-36%)	3 (4%)	-45 (-66%)	0	0	0	-1 (-5%)	3 (9%)	-7 (-20%)	3 (9%)	-14 (-40%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	0	2 (3%)	2 (3%)	0	0	0	0	0	0	0	0
Vicia sativa	0	-6 (-9%)	0	-1 (-1%)	9 (14%)	-24 (-38%)	1 (5%)	-4 (-20%)	2 (6%)	-7 (-20%)	0	-2 (-6%)
Vicia villosa	52 (79%)	8 (12%)	61 (90%)	10 (15%)	49 (77%)	5 (8%)	14 (70%)	1 (5%)	32 (91%)	7 (20%)	23 (66%)	3 (9%)
Total Grid Cells Surveyed 2017	66		68		64		20		35		35	

Table 25. Summary of native and invasive target species extent of cover type by Management Area, Sardis Unit, Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory, with difference from 2017 inventory. Note: Only species and grid cells measured in both inventories are shown. Note: Only species and grid cells measured in both inventory years are shown.

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Native species	0.431 (6.6%)	-0.553 (-8.5%)	0.142 (2.1%)	-0.267 (-4%)	0.219 (3.5%)	-0.381 (-6%)	0.0351 (1.8%)	-0.0059 (-0.3%)	0.0865 (2.5%)	-0.127 (-3.7%)	0.0415 (1.2%)	-0.125 (-3.6%)
Nectar plants	0.041 (0.6%)	-0.132 (-2%)	0.032 (0.5%)	-0.174 (-2.6%)	0.0376 (0.6%)	0.0232 (0.4%)	0.0010 (0.05%)	-0.0010 (-0.05%)	0.0059 (0.2%)	-0.0351 (-1%)	0.0069 (0.2%)	-0.0796 (-2.3%)
Invasive species	0.563 (8.6%)	-1.292 (-19.8%)	1.635 (24.3%)	-0.152 (-2.3%)	0.7250 (11.5%)	-0.7670 (-12.1%)	0.634 (32%)	-0.0010 (-0.05%)	0.629 (18.2%)	-0.54 (-15.6%)	0.262 (7.6%)	-0.206 (-5.9%)
Native species												
Acmispon glaber var. *glaber*	0.0282 (0.4%)	-0.1334 (-2%)	0.0519 (0.8%)	-0.0133 (-0.2%)	0.0030 (0.05%)	-0.0277 (-0.4%)	0.0015 (0.08%)	-0.0163 (-0.8%)	0.0138 (0.4%)	-0.0247 (-0.7%)	0.0079 (0.2%)	-0.0415 (-1.2%)
Baccharis pilularis	0	0	0	-05 (0.007%)	0.0776 (4.6%)	-0.292 (-4.6%)	0.0059 (0.3%)	0.0059 (0.3%)	0.0010 (0.03%)	-0.0069 (-0.2%)	0	0
Eriogonum nudum var. *psychicola*	0.1700 (2.6%)	-0.1834 (-2.8%)	0.0321 (0.5%)	-0.0331 (-0.5%)	0.0924 (01.5%)	-0.0583 (-0.9%)	0.0183 (0.9%)	0.0064 (0.3%)	0.0336 (1%)	-05 (-0.01%)	0.0025 (0.07%)	05 (0.01%)
Erysimum capitatum var. *angustatum*	0.0390 (0.6%)	-0.0227 (-0.3%)	05 (0.007%)	05 (0.007%)	0.0074 (0.1%)	-0.0128 (-0.2%)	0.0020 (0.1%)	0	0.0054 (0.2%)	-0.0054 (-0.2%)	0.0020 (0.06%	0.0010 (0.03%)
Grindelia hirsutula	0.0010 (0.02%)	-0.0128 (-0.2%)	05 (0.007%)	-0.0010 (-0.01%)	0.0287 (0.5%)	0.0237 (0.4%)	0	0	05 (0.01%)	0	0.0010 (0.03%)	-0.0054 (-0.2%)
Gutierrezia californica	0.0044 (0.07%)	0	0.0015 (0.02%)	05 (0.007%)	0.0089 (0.1%)	0.0084 (0.1%)	0	0	0.0020 (0.06%)	0.0010 (0.03%)	05 (0.01%)	0
Heterotheca grandiflora	0.0292 (0.4%)	-0.1196 (-1.8%)	0.0301 (0.4%)	-0.1730 (-2.6%)	0	-0.0089 (-0.1%)	0.0010 (0.05%)	-0.0010 (-0.05%)	0.0025 (0.07%)	-0.0371 (-1.1%)	0.0054 (0.2%)	-0.0736 (-2.1%)
Lupinus albifrons	0.1488 (2.3%)	-0.0697 (1.1%)	0.0252 (0.4%)	-0.0292 (-0.4%)	0.0015 (0.02%)	-0.0128 (-0.2%)	0.0064 (0.3%)	-05 (-0.02%)	0.0247 (0.7%)	-0.0549 (-1.6%)	0.0128 (0.4%)	-0.0049 (-0.1%)
Oenothera deltoides ssp. *howellii*	0.0040 (0.06%)	-0.0119 (-0.2%)	05 (0.007%)	-0.0178 - (0.3%)	0	-05 (-0.008%)	0	-05 (-0.05%)	0.0020 (0.06%)	05 (0.01%)	0.0094 (0.3%)	-05 (-0.01%)
Senecio flaccidus var. *douglasii*	0.0064 (0.1%)	05 (0.008%)	0	0	0	0	0	0	0.0010 (0.03%)	0.0010 (0.03%)	0	-05 (-0.01%)
Invasive species												
Ailanthus altissima	0	0	0.3894 (2.6%)	0.1779 (2.6%)	0.0613 (1%)	-0.0198 (-0.3%)	0.206 (10.4%)	0.0954 (4.8%)	0.159 (4.6%)	-0.0371 (-1.1%)	0	0

Cover Type	Extent of Cover Type in Acres* (Percent Cover in Area Surveyed**)											
	PG&E East		PG&E West		Pit		Riparian		Slope		Upland	
	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017	2023	Change from 2017
Brassica nigra, Hirschfeldia incana	0.0025 (0.04%)	-0.0163 (-0.3%)	0.0143 (0.2%)	-0.0109 (-0.2%)	0.0040 (0.06%)	-0.0371 (-0.6%)	05 (0.02%	-0.0183 (-0.9%)	0.0030 (0.09%)	-0.0119 (-0.3%)	0.0044 (0.1%)	-0.0119 (-0.3%)
Carduus pyncocephalus	0.0148 (0.2%)	0.0020 (0.03%)	0.0079 (0.1%)	0.0079 (0.1%)	0.015 (0.2%)	0	0.0193 (1%)	0	0.0084 (0.2%)	0.0079 (0.2%)	0.0035 (0.1%)	-0.0217 (-0.6%)
Centaurea group (*C. melitensis, C. solstitialis*)	0.0292 (0.4%)	-0.0722 (-1.1%)	0.2733 (2.9%)	0.1962 (2.9%)	0.117 (1.9%)	-0.0751 (-1.2%)	0.0148 (0.7%	-0.0301 (-1.5%)	0.083 (2.4%)	-0.0287 (-0.8%)	0.0133 (0.4%)	-0.0405 (-1.2%)
Cynodon dactylon	0	-0.0064 (-0.1%)	0.0124 (0.2%)	0.0124 (0.2%)	0	0	0	0	0	0	0	0
Dittrichia graveolens	0	0	0	0	0	0	0	0	0	0	0	0
Erodium cicutarium	0.2244 (3.4%)	-0.1651 (-2.5%)	0.3445 (0.02%)	-0.0015 (-0.02%)	0.0781 (1.2%)	-0.0890 (-1.4%)	0.0069 (0.3%	-0.0109 (-0.5%)	0.084 (2.4%)	-0.0143 (-0.4%)	0.143 (4.1%)	-0.0020 (-0.06%)
Genista monpessulana	0	0	0	0	0.0618 (1%)	0.0297 (0.5%)	0.0059 (0.3%)	-0.0119 (-0.6%)	0	0	0	0
Lepidium latifolium	0	0	0	0	0.0568 (0.9%)	0.0237 (0.4%)	0	0	05 (0.01%)	05 (0.01%)	0	-05 (-0.01%)
Nicotiana glauca	0	0	05 (0.007%)	-0.0099 (0.1%)	0	0	05 (0.02%)	0	0.0010 (0.03%)	0.0010 (0.03%)	0	-05 (-0.01%)
Raphanus sativus	05 (0.008%)	-0.0069 (-0.1%)	05 (0.007%)	-0.0010 (0.01%)	0	0	05 (0.02%)	05 (0.02%)	0	0	0.0025 (0.07%)	-0.0074 (-0.2%)
Robinia pseudoacacia	0	0	0.0801 (1.2%)	-0.0415 (0.6%)	0.0479 (0.8%)	0.0237 (0.4%)	0.168 (8.5%)	0.0227 (1.1%)	0.0059 (0.2%)	0.0059 (0.2%)	0	0
Rubus armeniacus	0.0628 (1%)	-0.0578 (0.9%)	0.0119 (0.2%)	-0.0010 (0.01%)	0.0677 (1.1%)	-0.0539 (-0.9%)	0.0741 (3.7%)	-0.0524 (-2.6%)	0	0	0	0
Salsola tragus	05 (0.008%)	-0.0499 (0.8%)	0.0015 (0.02%)	-0.1557 (2.3%)	0	0	0	-05 (0.02%)	0.0015 (0.04%)	-0.0252 (-0.7%)	0.0015 (0.04%)	-0.0124 (-0.4%)
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	0	0	0.0010 (0.01%)	0.0010 (0.01%)	0	0	0	0	0	0	0	0
Vicia sativa	0	-0.0756 (1.6%)	0	-05 (-0.007%)	0.0044 (0.07%)	-0.276 (-4.4%)	05 (0.02%)	-0.0420 (-1.1%)	0.0010 (0.03%)	-0.109 (-3.1%)	0	-0.0183 (-0.5%)
Vicia villosa	0.2288 (3.5%)	-0.844 (12.9%)	0.498 (7.4%)	-0.329 (-4.9%)	0.211 (3.3%)	-0.294 (-4.6%)	0.137 (6.9%)	0.0465 (2.7%)	0.282 (8.1%)	-0.329 (-9.5%)	0.0939 (2.7%)	-0.0904 (-2.6%)
Total Acres Cells Surveyed 2017	6.52		6.72		6.33		1.98		3.46		3.46	

* Extent calculation (Midpoint percent cover class * grid cell area m2 * 0247105 acres)

** Percent cover in area surveyed calculation (Extent/area surveyed*100)

3.3.2 Invasive Species

3.3.3A 2023 Survey

Invasive target species were found in 95% of surveyed grid cells at Antioch Dunes National Wildlife Refuge, ranging from 94% in the Stamm Unit to 97% in the Sardis Unit (Table 16). None of the Early Detection species were observed (Table 16). All remaining target invasive species were observed except for white sweetclover (*Melilotus albus*). Tree of heaven (*Ailanthus altissima),* mustards (*Brassica nigra, Hirschsfeldia incana*), *Centaurea* group (*Centaurea melitensis, C. solstitialis*) Italian thistle (*Carduus pycnocephalus*), bermudagrass (*Cynodon dactylon*), redstem stork's bill (*Erodium cicutarium*), perennial pepperweed (*Lepidium latifolium*), malva group (*Malva parviflora*, *Malva* ssp.), tobaccobrush (*Nicotiana glauca*), radish (*Raphanus sativus*), black locust (*Robinia pseudoacacia*), Himalayan blackberry (*Rubus armeniacus*), Russian thistle (*Salsola tragus*), winter vetch and spring vetch (*V. sativa*) were found in both units (Table 16). Stinkweed (*Dittrichia graveolens*) and puncturevine (*Tribulus terrestris*) were found only in the Stamm Unit, and French broom (*Genista monpessulana)* and tamarix group (*Tamarix parviflora, T. ramosissima*) species were observed only in the Sardis Unit (Table 16).

Winter vetch was by far the most widespread invasive target species, found in 79% of grid cells, and occupying 3.67 acres; this species was prevalent in both Units (Table 20). Redstem stork's bill was also widespread, found in 55% of grid cells and occupying 2.96 acres; this species was more abundant in the Stamm Unit, but was prevalent in both Units (Table 16). Two additional invasive annual *Erodium* species were observed, including longbeak stork's bill (*E. botrys*), and short fruited filaree (*E. brachycarpum*); these were noted as 'Other species', and may have occasionally been lumped with *E. cicutarium. Centaurea* group species were found in 45% of grid cells and occupied 0.83 acres; these species were prevalent in both Units (Table 16). Mustard group species were found in 34% of grid cells, occupying 0.49 acres; these species were significantly more abundant in the Stamm Unit (Table 16). *Malva* group species were found in 22% of grid squares, and occupied 0.68 acres; this species was more prevalent in the Stamm Unit (Table 16).

The remaining target invasive species occurred within less than 10% of grid squares surveyed (Table 16).The invasive trees, tree of heaven and black locust, were much more prevalent in the Sardis Unit, with tree of heaven found in 17% of Sardis grid cells relative to 2% in Stamm Unit cells, and black locust found in 9% of grid cells in Sardis and less than 1% in Stamm (Table 16). Italian thistle and perennial pepperweed were more frequent and abundant in the Sardis Unit (Table 16). Russian thistle, bermudagrass, and Himalayan blackberry were more frequent and abundant in the Stamm Unit (Table 16), and spring vetch, radish, and tree tobacco cover and frequency were similar in both Units (Table 16). Only one occurrence of stinkwort was found (Table 16).

Several invasive plant species not included on the target list for this inventory, but that have invasive potential were observed. A patch of sweet fennel (*Foeniculum vulgare*), a California invasive plant pest council (CAL-IPC) Moderate species, was found in a moist area in the Sardis Unit. A single individual of rush skeletonweed (*Chondrilla juncea*) was observed in the Sardis Unit in grid cell I62. This individual was pulled. While white sweetclover was not observed, yellow sweetclover (*Melilotus officinalis*) was observed at low abundance, typically in more disturbed areas like roads and boundaries. Bird of paradise (*Caesalpinia gilliesii*) was observed in two grid cells in the Sardis Unit.

Stamm Unit

Invasive target plant richness was highest on Refuge boundaries, in the area of MA2 not treated by sand deposition, and the riverside area of MA1 (Maps 1-13, 2-13). Winter vetch was the dominant target invasive plant in terms of area infested and number of grid cells occupied in this unit (Figure 10, Tables 16-18, Map 1-44). This species can completely grow over and bury ADP, ADB and CCW, creating hummocks of thatch over the dead or barely living plants. Redstem stork's bill, with other annual *Erodium* species, was also widespread in the Stamm Unit, covering 2.02 acres (Table 18, Map 1-33). Redstem stork's bill frequency, extent and cover was highest in southern areas of the Stamm Unit in MA1 MA3 and MA4, and this species was not observed in large areas of the MA1 and MA2 in sand deposition treatments (Tables 17-18, Map 1-33).

Himalayan blackberry was the third most abundant target invasive species in the Stamm Unit in terms of acres infested (0.61), but was strongly concentrated in the Littoral MA and areas in MA1, MA2 and MA3 near the river (Figure 10, Table 17, Map 1-40). *Malva* group species covered 0.60 acres in the Stamm Unit, occurred in all MAs, but had highest abundance in disturbed areas near roads, Refuge boundaries, and an excavated area between MA1 and MA2 (Figure 10, Table 17, Map 1-36). Mustard group species covered 0.60 acres in the Stamm Unit, occurred in all MAs, and were also more prevalent near disturbed areas such as roads and Refuge boundaries (Table 17, Map 1-28). *Centaurea* group species covered 0.30 acres in the Stamm Unit, were abundant in all MAs except the Littoral MA, and also had highest cover in disturbed areas such as roads and Refuge boundaries (Table 17, Map 1-30).

Bermudagrass had large populations on the west side of the Stamm Unit in MA1 (Table 17, Map 1-31). Smaller populations of this species were also found in MA2, MA3 and MA4 and the east side of the Littoral MA (Table 17, Map 1-31).

Figure 10. TOPLEFT: Winter vetch with ripgut brome, ADP and ADB, Stamm Unit, Management Area 2. TOPRIGHT: Himalayan blackberry with winter vetch and willow, Stamm Unit, Littoral Management Area. BOTTOMLEFT: Malva *in road along southern refuge boundary, Stamm Unit, Management Area 1. BOTTOMRIGHT: Bermudagrass with ripgut brome and ADP and ADB, Stamm Unit, Management Area 1.*

Tree of heaven was scattered in the Stamm Unit, predominately in the Littoral MA, but also near the Refuge boundary in MA2 and MA3 (Table 17, Map 1-27). Italian thistle was found in only four grid cells in the Stamm Unit, with four occurrences under oak canopy in MA4 and one occurrence each on the west side of the Littoral MA and MA1 (Table 17, Map 1-29). Stinkwort was found in only one grid cell in MA1 (Table 17, Map 1-32).

Perennial pepperweed was found in three locations, with a growing population in a disturbed area near the road on the northwestern boundary of MA1, a population of scattered individuals near the seasonal pond in MA2, and a small population in one grid cell on the east side of the Littoral MA (Table 17, Map 1-35). Three small occurrences of tree tobacco were found, all in MA1 on the edge of the Littoral MA (Tables 17-18, Map 1-37). Radish was found in 10 grid cells, with distribution centered near the river in MA1, and in disturbed areas in MA1 and MA2 with most occurrences at less than 1% cover (Tables 17-18, Map 1-38).

Black locust was found in only two grid cells in the Stamm Unit on the southern Refuge boundary in MA1 (Table 17, Map 1-39). Puncture vine was found in 17 grid cells in the Stamm Unit, with most associated with the road near the river in MA1, one occurrence in the Littoral MA, and two grid cells in disturbed areas near the boundary in MA2 (Table 17, Map 1-42). Twenty-one occurrences of spring vetch were found in the Stamm Unit, with low frequency in all MAs (Table 17, Map 1-43).

Sardis Unit

All target invasive species except for white sweetclover, stinkwort and puncture vine were observed in the Sardis Unit (Table 16). As in the Stamm Unit, winter vetch was the most abundant and widespread of target invasive species present, with cover lowest under tree and shrub canopy (Table 16, Maps 2-43). Redstem stork's bill was the second most widespread species in the Sardis Unit, but was absent from much of the Pit MA, Riparian MA and northern parts of the PG&E MAs (Map 2-32). *Erodium brachycarpum* was present in several grid cells on the west side of the Pit MA, but does not appear on the map. *Centaurea* group species were the third most widespread invasive species, with abundance highest in the PG&E West MA, and with several dense populations near ADB populations (Figure 11, Table 19, Map 2-30).

A large population of tree of heaven occurred in the PG&E West, Riparian and Slope MAs (Figure 11, Table 19, Map 2-27). A population of black locust occurred in the northwest corner of the Sardis Unit, occurring primarily in the PG&E West and Riparian MAs, but extending into the Slope and Pit MAs (Figure 11, Table 19, Map 2-38). French broom was found in 14 grid cells within shaded coast live oak forest and shrublands on the west side of the Pit MA, with one grid cell in the Riparian MA (Figure 11, Table 19, Map 2-33). Himalayan blackberry occupied approximately 0.25 acres, predominately in the Riparian MA, but also on north facing slopes in the PG&E East MA, moist areas in the Pit MA, and one grid cell in the PG&E West MA (Table 19, Map 2-39).

Figure 11. TOPLEFT: Yellow star thistle population with ADB, Sardis Unit, PG&E West Management Area. TOPRIGHT: Tree of heaven, Sardis Unit, PG&E West Management Area. BOTTOMLEFT: Black locust with tree of heaven, Sardis Unit, PG&E West Management Area. BOTTOMRIGHT: French broom with winter vetch and yellow sweetclover, Sardis Unit, Pit Management Area.

Perennial pepperweed was found in the Pit MA and one grid cell in the Slope MA in shaded, moist forest (Figure 12, Table 19, Map 2-34). A sweet fennel infestation was observed in this area (Figure 12). Bermudagrass was found in disturbed areas in the PG&E West MA (Table 19, Map 2-31). *Malva* group species occurred in all MAs, but were most abundant in disturbed areas on the southern side of the Sardis Unit (Table 19-20, Map 2-35).

Figure 12. LEFT: Perennial pepperweed population in coast live oak forest, Sardis Unit, Pit Management Area. RIGHT: Sweet fennel infestation, Sardis Unit, Pit Management Area.

Tree tobacco was found in five widely scattered grid cells in the Sardis Unit in the PG&E West, Riparian and Slope MAs (Table 19, Map 2-36). Radish was centered in disturbed areas in the Upland MA, with a single grid cell in each of the Littoral, PG&E West, and PG&E East MAs (Table 19, Map 2-37). Russian thistle was sparse in the Sardis Unit, with most occurrences associated with disturbed habitat on the southern boundary and in the Upland MA (Table 19, Map 2-40). Spring vetch was observed in 12 grid cells, largely confined to the Pit MA, but also observed in the Riparian and Slope MAs (Table 19, Map 2-42). *Tamarix* group species was observed in four grid cells in the PG&E West MA, within the tree of heaven infestation (Table 19, Map 2-41).

3.3.3B Changes from 2017 to 2023

Three of the invasive target species or groups observed in both 2017 and 2023 declined in frequency and abundance throughout the Refuge from 2017 to 2023, including mustard group species, *Centaurea* group species, and Russian thistle (Table 21). Mustards were observed in 93 fewer grid cells (14% less), and declined in cover by 0.37 acres (Table 21). Mustards declined in frequency and extent in MA1, MA3 and MA4, but increased in MA2 and the Littoral MA in the Stamm Unit, and decreased in frequency and extent in all Sardis MAs (Tables 17-20). *Centaurea* group species were observed in 47 fewer cells (7% less), and declined in cover by 0.44 acres (Table 21). *Centaurea* group species declined in frequency and extent in all Stamm Unit MAs, except for MA4 where extent increased, and in all Sardis Unit MAs except for PG&E West, and an increase in frequency in the Slope MA (Tables 17-20). Russian thistle was observed in 129 fewer cells (18% less), and declined in cover by 0.29 acres (Table 21). Russian thistle increased in frequency in MA1 and MA2 and increased in extent in MA2, but declined or did not change in all Sardis MAs (Tables 17-20). Since the 2023 survey occurred at an earlier date than the 2017 survey, *Centaurea* and Russian thistle were likely at an earlier stage of maturity; while we attempted to estimate cover assuming the size of mature plants, cover of these species could have been estimated lower overall in 2023 relative to 2017. However, mustard species were at peak reproductive maturity and highly visible, and *Centaurea* and Russian thistle were both readily detectable, and it is unlikely that reduced detection in a grid cell could have reduced the frequency of these species to the extent measured.

Tree of heaven, Italian thistle, bermudagrass, French broom, and perennial pepperweed increased in both frequency and abundance from 2017 to 2023 (Table 21). Tree of heaven was found in 61 more grid cells in 2023 than in 2017, with the majority of this in the PG&E West MA in the Sardis Unit, where it was well established in 2017 (Tables 21-25). Bermudagrass was found in 23 more grid cells in 2023 than in 2017 (3% more), with an increase in area occupied of 0.15 acres; the most growth and spread occurred in MA1 in the Stamm Unit (Tables 21-25). French broom was only found in the Sardis Unit, and increased by five grid cells (2% more), with a small increase in cover, with growth confined to the Pit MA where it increased in frequency and extent (Tables 21, 24-25). Perennial pepperweed frequency increased by 11 grid cells (8% more), with a 0.04 acre increase, with increases occurring in both the Sardis and Stamm Units in most MAs in which it had been recorded in 2017, except for the Upland MA where it was not observed in 2023 (Tables 21-25).

Winter vetch was found in 61 more grid cells (9% more) in 2023 than 2017, but the area occupied decreased by 6.87 acres; increases in frequency were seen in both units, and declines in cover were seen in both units (Table 21). Winter vetch increased in frequency but declined in extent in all MAs in both Units, except for an increase in extent in the Riparian MA (Tables 21-25), Spring vetch declined in frequency and extent in all MAs in the Sardis Unit, but increased in the Stamm Unit (Tables 21-25).

Tamarix was found in the Sardis Unit in 2023, where it was not present in 2017, but was not found in the Stamm Unit, where it was present in 2017 (Table 21). Tree tobacco declined in frequency in the Sardis Unit, but increased in the Stamm Unit; cover was low in both years (Table 21). Himalayan blackberry increased in frequency and abundance in most MAs in the Stamm Unit, with growth greatest in the Littoral MA (Tables 17-18). In the Sardis Unit, Himalayan blackberry increased in frequency in the Riparian MA, but declined in PG&E East, West and the Pit MAs, and declined in extent in all MAs (Tables 19-20). Radish declined in frequency and abundance in the Sardis Unit, which was consistent across MAs except for a new observation in the Riparian MA, with small increases in frequency and abundance in the Stamm Unit (Tables 21-25). Black locust did not change in overall frequency, but cover slightly increased in both the Sardis and Stamm Units (Table 21). Black locust increased in extent in the Pit, Riparian and Slope MAs, increased in frequency in the Pit and Slope MAs, and declined in frequency and extent in the PG&E West MA (Tables 22-25). Stinkwort was only observed in one grid cell in the Stamm Unit in 2023, down from three grid cells in 2017 (Table 21).

3.4 Analysis of vegetation attributes by Management Area and management activities

3.4.1 Native dune and LMB important plant cover by Management Area

Cover of rare dune species was affected by MA in both 2017 and 2023 (Table 26). Between 2017 and 2023, ADP cover increased in all MAs in the Stamm Unit except for MA4, and declined or did not change in all Sardis MAs (Table 26). The change in ADP cover from 2017 to 2023 was significant by MA with the large increase in MA1 different from all other MAs (Table 26). ADB cover declined more in the PG&E East MA than all other Sardis MAs, and more in MA3 and MA4 than MA1 in the Stamm Unit (Table 25). Changes in CCW cover by MA between 2017 and 2023 was not significant (Table 26).

Nectar plant cover was also affected by MA in both 2017 and 2023 (Table 27). Hairy gumweed cover declined more in MA1 than all other MAs (Table 27). California matchweed cover increased in the Pit MA, while declining in MA2 and MA3 (Table 27). Telegraphweed cover in PG&E West declined more than declines measured in MA3, MA4 and the Pit MA (Table 27). Shrubby butterweed was not tested statistically due to very low occurrences of this species. Overall nectar plant cover declined in all MAs except for the Pit and Riparian MAs in the Sardis Unit (Table 27). Management Area was a highly significant predictor of pooled nectar plant cover change, with nectar plant cover increasing in the Pit MA and declining in MA3 and MA4 (Table 27).

Table 26. Mean cover (midpoint of cover class) of rare dune species in 2017[1], 2023[2], and mean change[3] between 2017 and 2023 in each Management Area.

Management Unit	Management Area	*Oenothera deltoides* ssp. *howellii*			*Eriogonum nudum* var. *psychicola*			*Erysimum capitatum* var. *angustatum*		
		2017	2023	Change	2017	2023	Change	2017	2023	Change
Stamm	Littoral	0.0	0.01	0.03	0.0	0.16	0.33	0.11	0.05	-0.06
	Management Area 1	0.54	8.24	8.43	0.33	0.29	-0.02	0.07	0.01	-0.06
	Management Area 2	0.03	1.20	1.19	2.64	0.26	-2.37	0.10	0.08	-0.02
	Management Area 3	0.07	0.10	0.03	3.35	1.01	-2.35	0.17	0.11	-0.06
	Management Area 4	0.19	0.04	-0.15	1.70	0.57	-1.11	0.01	0.02	0.01
Sardis	PG&E East	0.25	0.05	-0.20	5.56	2.39	-3.02	0.97	0.57	-0.4
	PG&E West	0.23	0.02	-0.21	0.82	0.38	-0.40	0.01	0.01	0
	Pit	0.02	0.01	-0.01	2.09	1.61	-0.47	0.35	0.15	-0.2
	Riparian	0.0	0.0	0.0	0.0	0.06	0.06	0.06	0.13	0.07
	Slope	0.13	0.0	-0.13	0.0	0.0	0.0	0.13	0.13	0
	Upland	0.26	0.21	0.0	0.37	0.18	-0.14	0.06	0.07	0.01

[1]Difference by Management Area significant, Kruskal-Wallis Test P < 01.
[2]Difference by Management Area significant, Kruskal-Wallis Test P < 01.
[3]ADP: Change by Management Area Anova with TukeysHSD Test, P < 01; MA1 significantly different from all other Mas.
ADB: Change by Management Area Anova with TukeysHSD Test P < 01; PG&E East – Littoral P<0.05, PG&E East – MA1 P<01, PG&E West – PG&E East P < 0.01, PG&E East – Pit, P<0.01, PG&E East– Upland P<0.05, MA1– MA2 P<0.01, MA1 – MA3 P<0.01.
CCW: Change by Management Area Anova NS, P > 0.05

Table 27. Mean cover (midpoint of cover class) of LMB nectar plant species in 2017[1], 2023[2], and mean change[3] between 2017 and 2023 in each Management Area.

Management Unit	Management Area	*Grindelia hirsutula*			*Gutierrezia californica*			*Heterotheca grandiflora*			*Senecio flaccidus* var. *douglasii*			Nectar plants total		
		2017	2023	Change	2017	2023	Change	2017	2023	Change	2017	2023	Change	2017	2023	Change
Stamm	Littoral	0.33	0.0	-0.33	0.0	0.0	0.0	0.69	0.03	-0.64	0.0	0.0	0.0	1.03	0.03	-0.97
	Management Area 1	0.63	0.16	-0.46	0.0	0.0	0.0	4.41	2.63	-1.55	0.0	0.0	0.0	5.04	2.79	-2.01
	Management Area 2	0.01	0.03	0.02	0.05	0.0	-0.05	2.19	1.16	-1.0	0.0	0.0	0.0	2.25	1.19	-1.03
	Management Area 3	0.0	0.0	0.0	0.12	0.08	-0.04	1.15	0.37	-0.79	0.01	0.0	-0.01	1.28	0.45	-0.84
	Management Area 4	0.0	0.0	0.0	0.0	0.01	0.01	0.84	0.21	-0.64	0.0	0.0	0.0	0.84	0.22	-0.62
Sardis	PG&E East	0.22	0.01	-0.21	0.07	0.06	-0.008	2.29	0.43	-1.83	0.10	0.09	0.0	2.67	0.58	-2.06
	PG&E West	0.02	0.01	-0.01	0.02	0.02	0.006	3.06	0.35	-2.69	0.0	0.0	0.0	3.10	0.38	-2.70
	Pit	0.05	0.32	0.27	0.01	0.11	0.10	0.24	0.02	-0.22	0.0	0.01	0.01	0.31	0.47	0.16
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0	0.06	0.06	0.0	0.0	0.0	0.0	0.06	0.06	0.0
	Slope	0.0	0.0	0.0	0.0	0.13	0.13	1.50	0.13	-1.38	0.0	0.13	0.13	1.50	0.38	-1.13
	Upland	0.17	0.04	-0.14	0.01	0.01	0.0	1.62	0.32	-1.44	0.01	0.0	-0.01	1.81	0.37	-1.59

[1]Difference by Management Area significant, Kruskal-Wallis Test P < 01.
[2]Difference by Management Area significant, Kruskal-Wallis Test P < 01.
[3]*Grindelia hirsutula*: Change by Management Area Anova with TukeysHSD Test, P < 01; MA1 – MA2 P, 0.05, MA1 – MA3 P < 0.05, MA1 – MA4 P < 0.01, MA1 – PG&E West P < 0.05, MA1 – Pit P < 01
Gutierrezia californica: Change by Management Area Anova with TukeysHSD Test, P < 0.01; Pit – MA2 P < 0.001, Pit – MA3 P < 0.01
Heterotheca grandiflora: Change by Management Area Anova with TukeysHSD Test, P < 0.001; PG&E West – MA3 P < 0.05, PG&E West – MA4 P < 0.01, PG&E West – Pit P < 0.001
Nectar plants total cover: Change by Management Area Anova with TukeysHSD Test, P < 01; Pit – MA1 < 0.001, Pit – PG&E East P < 0.01, Pit – PG&E West P < 0.001, PG&E West – MA3 P < 0.05, PG&E West – MA4 P < 0.01

3.4.2 Bare ground, annual grass and thatch cover by Management Area

Bare ground, annual grass and thatch cover were significantly different in MAs in both 2017 and 2023 (Table 28). The increase in bare ground in MA2 between 2017 and 203 was significant relative to all other MAs (Table 28). The decline in annual grass cover was significantly greater in MA2 and MA1 relative to changes in most other MAs (Table 28). The smaller changes in thatch cover in MA1, MA2 and the Littoral MA were significant relative to the large increases in thatch observed in other MAs (Table 28).

Table 28. Mean cover (midpoint of cover class) of bare ground, annual grass and thatch in 2017[1], 2023[2], and mean change[3] between 2017 and 2023 in each Management Area.

Management Unit	Management Area	Bare ground			Annual grass			Thatch		
		2017	2023	Change	2017	2023	Change	2017	2023	Change
Stamm	Littoral	5.9	4.1	-1.8	17.6	9.7	-7.9	18.9	17.2	-1.6
	Management Area 1	48.1	26.5	21.6	31.8	21.2	-10.6	5.9	14.1	8.2
	Management Area 2	10.0	55.5	45.5	68	12.5	-55.6	15.4	6.8	-8.6
	Management Area 3	13.5	3.2	-10.3	64.8	66.1	1.4	15.2	51.6	36.4
	Management Area 4	20.5	3.3	-17.2	66.7	54.3	-12.3	11.4	46.6	-35.2
Sardis	PG&E East	8.0	6.2	-1.8	58.9	55.1	-3.8	16.7	67.4	50.7
	PG&E West	16.3	8.5	-7.9	53.4	47.2	-6.4	16.8	46.6	41.0
	Pit	8.0	3.4	-4.9	48.1	35.6	-2.4	22.2	73.4	51.0
	Riparian	6.9	5.0	-2.0	22.6	34.1	11.5	18.1	54.7	36.5
	Slope	11.9	4.5	-7.5	54.6	44.7	-9.8	13.1	73.9	60.7
	Upland	14.5	3.2	-11.2	49.4	58.1	8.6	11.1	68.2	57.1

[1]Difference by Management Area significant, Kruskal-Wallis Test P< 0.001.
[2]Difference by Management Area significant, Kruskal-Wallis Test P < 0.001.
[3]Annual grass: Change by Management Area Anova with TukeysHSD Test, P < 0.001; MA2 – Littoral, P, 0.001, MA1 – Upland, P < 0.05, MA3 – MA2 P < 0.001, MA4 – MA2, P<0.001, Pit – MA2, P<0.001, PG&E East – MA2, P<0.001, PG&E West – MA2, p,0.001, Slope – MA2 P<0.001, Upland – MA2 p<0.001, MA4 – MA3, p<0.05, Riparian – MA4, P<0.05.
Bare ground: Change by Management Area Anova with TukeysHSD Test, P < 0.001; Littoral– MA1, P, 0.001, Littoral – MA2, P < 0.05, Littoral – MA4, P < 0.001, MA1 – MA2, P<0.001, MA1– MA3, P<0.05, MA1 – PG&E East, P<0.001, MA1 – PG&E West, P<0.001, MA1 – Pit, P<0.001, MA1 – Riparian, P<0.001, MA1 – Slope P<0.05, MA2 – all MAs, P<0.001, MA4 – PG&E East, P<0.001, MA4 – Pit, P<0.05, MA4 – Riparian, P<0.05.
Thatch: Change by Management Area Anova with TukeysHSD Test, P < 0.001; Littoral – all except MA1, MA2, P, 0.001, MA1 – all MAs P<0.001, MA2 – all MAs, P<0.001, MA3 – PG&E East, P<0.005, MA3 – Pit, P<0.005, MA3 – Slope P<0.001, MA3 – Upland, P<0.001, MA4 – PG&E East, P<0.001, MA4 – Pit, P<0.001, MA4 – Slope, P<0.001, MA4 – Upland, P<0.001, PG%E West – Slope, P<0.005, PG&E West – Upland, P<0.05, Riparian – Slope, P<0.05.

3.4.2 Sand Deposition

Sand deposition treatments increased cover of ADP; increases in ADP cover were highest in the 2014-2015 sand deposition treatment in MA1, followed by the 2020-2021 treatment in MA2, and lowest in areas that had not received treatment (Table 29). The best-fitting model included sand deposition treatment as a fixed effect and a non-significant zero inflation term on MA (Table A1), indicating that sand treatment is driving differences in cover of ADP, and MA is more important in determining whether ADB is present or not, but the latter was not statistically significant due to high variability in presence or absence within grid cells.

Sand deposition also had a positive effect on ADB abundance, with ADB cover highest in the 2014-2015 sand deposition treatment; however, there was a longer lag time for ADB to recolonize newly deposited sand with ADB cover lowest in the 2020-2021 sand deposition treatment in the Stamm Unit (Table 29). The best-fitting model for ADB included sand deposition treatment as a fixed effect and a non-significant zero inflation term on MA (Table A2), indicating that sand treatment is driving differences in cover of ADP and MA is more important in determining whether ADB is present or not, but the latter was not statistically significant due to high variability in presence or absence within grid cells. Sand deposition was not significant in explaining the change in CCW cover in 2023, with the best fitting model for CCW including only a nonsignificant effect of annual grass cover as a fixed effect and a significant zero-inflation term on MA (Table A3). Similarly, sand deposition treatment was not significant in explaining change in nectar plant cover in 2023, and the best fitting model for nectar plants included only a nonsignificant effect of annual grass cover as a fixed effect and a nonsignificant zero-inflation term on MA (Table A4), indicating that parameters included in the model for nectar plants are not capturing what is driving the change in nectar plant cover in the Stamm Unit.

Annual grass cover was much lower in the 2020-2021 sand deposition treatment, and remained lower in the 2014-2015 treatment area (Table 29). The best fit model for annual grass cover was a GLM with sand deposition treatment and MA as fixed effects (Table A5). This model was not zero-inflated. The model indicated that mean annual grass cover in MA3 grid cells was highest, followed by MA4, with differences among the other MAs not significant. Bare ground cover was approximately 60% in the two years after sand deposition after both treatments (Table 29). Bare ground remained much higher eight years after treatment than in areas receiving no sand (Table 29). The best fit model for bare ground cover included sand deposition and MA as fixed effects, with a significant zero inflation term on MA (Table A6). Each sand deposition treatment had significantly different bare ground cover, as did each MA, with MA2 highest, followed by MA1, MA3 and MA4. The significant zero inflation term indicates that MA is also important in determining whether bare ground is present or not.

Table 29. Mean cover (midpoint of cover class) of ADP and ADB, and annual grass and bare ground cover in grid cells with sand deposition treatments and grid cells with no sand deposition treatment, Stamm Unit, and mean change in cover between 2017 and 2023 in sand treatments.

Deposition Treatment	*Oenothera deltoides* ssp. *howellii*			*Eriogonum nudum* var. *psychicola*			*Erysimum capitatum* var. *angustatum*		
	2017	2023	Change	2017	2023	Change	2017	2023	Change
2014-2015	0.74	13.56	0.27	0.30	0.47	0.17	0.02	0	-0.02
2020-2021	0.04	1.55	3.36	3.36	0.37	-2.99	0.13	0.07	-0.06
No sand	0.15	0.13	1.99	1.99	0.89	-1.1	0.21	0.13	-0.08
	Nectar Plant Cover			**Target Desirable Native Plant Cover**			**Bare Ground Cover**		
2014-2015	6.02	4.58	-1.44	8.92	25.59	16.67	34.32	-26.46	2.46
2020-2021	2.66	1.63	-1.03	10.25	4.31	-6.94	59.27	47.93	-55.83
No sand	1.6	0.37	-1.23	7.96	3.27	-4.69	5.91	-7.50	-8.03
	Annual Grass Cover			**Target Invasive Plant Cover**					
2014-2015	20.78	23.24	60.78	15.02	12.12	-2.9			
2020-2021	67.91	12.07	11.34	40.43	10.37	-30.13			
No sand	53.55	45.52	13.41	25.29	14.12	-11.27			

3.4.3 Seeding Trials

Grid cells that had been seeded with ADB and nectar plants typically had greater cover of these species in 2023 relative to 2017 (Table 30). In grid cells that had been seeded with CCW cover, CCW cover typically did not change, or decreased, though in one case (H69), cover increased (Table 30). Cover of CCW is typically low, as this species is delicate and sparsely distributed, so it is likely that the grid scale of this inventory, with cover class estimated over a large relatively large area, is not fine enough to detect changes in cover from CCW seeding. The fact that CCW remained at a similar cover or decreased, indicates supplemental seeding may be necessary to prevent additional steeper declines.

Table 30. Mean cover (midpoint of cover class) of ADB, CCW, and nectar plants in grid cells with seeding treatments in 2017 (before seeding) and 2023 (after seeding).

Eriogonum nudum* var. *psychicola			***Erysimum capitatum* var. *angustatum***			**Nectar Plants**		
	Cover			**Cover**			**Year**	
Grid Cell	2017	2023	Grid Cell	2017	2023	Grid Cell	2017	2023
F7	0	0	E66	0.5	0.5	F10	6	6
F9	0	0.5	E67	0.5	0.5	F11	0.5	6
G10	0	0.5	F66	0.5	0.5	G10	0.5	0.5
G11	0	0.5	F67	0.5	0.5	G11	0.5	6
G7	0	0.5	F68	0.5	0.5	G7	0.5	6
G8	0	0.5	G66	0	0	G8	0.5	6
H7	0	0.5	G67	6	6			
H8	0	6	G68	6	6			
I64	0	6	G69	6	0.5			
J61	6	6	G70	6	0.5			
J64	6	6	H67	0.5	0.5			
K61	18	6	H68	0.5	6			
K62	6	0.5	H69	6	6			
K63	6	6	H70	6	0.5			
L57	0	6	I69	0.5	0.5			
L58	6	6						
L62	6	6						
L63	6	6						
M57	6	6						
M62	6	0.5						
M63	6	0.5						

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Chapter 4—Discussion and Recommendations

The distribution and abundance of priority native species/groups of concern, priority invasive species/groups, and landcover types relevant to management of Refuge resources were quantified within 20 x 20 meter grid cells for two Management Units of Antioch Dunes National Wildlife Refuge. Changes in frequency and cover of these species and landcovers relative to 2017 inventory were assessed, the impact of management activities on observed changes was analyzed, and current status in terms of NRMP (USFWS 2019) and HMP (USFWS in prep.) goals were assessed.

4.1 Conservation goals

The 2023 inventory showed mixed result in terms of NRMP and HMP goals, with some conservation targets showing significant improvement, e.g., increases in ADP cover and frequency, increase in bare unvegetated sand, and declines in annual grass and target invasive plant cover with sand deposition treatments in the Stamm Unit. There were overall reductions in cover of many target invasive plants, including mustards, *Centaurea*, redstem stork's bill, radish, winter and spring vetch, Russian thistle, and Himalayan blackberry. There was an increase in nectar plants and an increase in CCW and ADB cover and abundance where seeding treatments had occurred. CCW increased in frequency in the Stamm Unit. However, overall declines in most native dune species, including declines in LMB nectar plant species in all areas except where they were seeded, were observed across the Refuge, as well as increases in several target invasive plants, including tree of heaven, Italian thistle, bermudagrass, French broom and perennial pepperweed. Oak seedlings were found to be widespread across the Refuge, and especially in the 2014-2015 sand deposition treatment in MA1, posing a future threat to maintenance of a dynamic dune ecosystem and HMP RDE_goal_1 targets. The declines in priority native species are unlikely to be directly related to the expansions in tree of heaven, Italian thistle, French broom and perennial pepperweed, which are generally expanding outwards from existing population centers where native target species are not present or present only at low abundance in 2017. The bermudagrass populations in MA1 however, are likely causing a reduction in habitat quality for ADP, ADB and native dune species.

Progress was made in meeting Refuge conservation goals for several metrics (Table 31). HMP RDE_goal _1 is currently being met in terms of bare sand for MA2, but is not being met for bare sand in MA1 or for native dune species composition in either MA (Table 32). The current status of bare sand and native dune species composition in the PG&E and Pit MAs are well short of RDE goal 2 (Table 32); sand deposition treatments has not yet occurred in these MAs, so this result is not unexpected. NRMP KEA indicators are still in poor status for the Refuge overall (Table 33).

Bare ground covered an estimated 14% of the total area of the Refuge, well below the greater than 40% open, non-vegetated sand desired for the Refuge (USFWS 2019). However, in recent sand deposition treatments in the Stamm Unit, bare ground was much higher, together averaging over 46% cover, which exceeds the desired conditions goal. Native dune plant species comprised approximately 4.1 acres or 6.1% of the land cover on the Refuge. In the Stamm Unit, native dunes species comprised 7.5% cover and

in the Sardis Unit only 3.4% cover. Sand deposition treatments had extremely positive effects on ADP cover, and while the initial effects of deposition on ADB were negative with a loss in cover in the 2020-2021 sand treatment, ADB increased in the 2014-2015 treatment, with numerous small plants and robust adults observed. Sand deposition treatments had a positive effect on nectar plant abundance, with telegraphweed and hairy gumweed cover highest in sand deposit areas in the Stamm Unit. It did not have an effect on other LMB nectar plants, which declined throughout the Refuge. CCW cover declined in both sand treatment areas, but the rate of decline was lower than in areas of the Stamm Unit not treated with sand.

Table 31. Current status and desired future state (goals) of the riverine dune ecosystem at Antioch Dunes National Wildlife Refuge in terms Refuge management strategies and associated objectives defined in the NRMP (USFWS 2019).

Strategy Title	Expected Outcome (Objective)	Current Status 2023
Sand dune restoration and management	RDE_O02. Over the next 15 years (2018–2032), invasive plants occupy <5% of the landcover where sand placement has occurred in the Stamm Unit of Antioch Dunes NWR.	• Mean invasive annual grass cover is 23.2% in 2014-2015 sand deposition treatment and 12.07% in 2020-2021 sand deposition treatment • Mean total target invasive plant cover is 12.12% in 2014-2015 sand deposition treatment and 10.37% cover in 2020-2021 sand deposition treatment
Sand dune restoration and management and native plant restoration	RDE_O03. Contra Costa wallflower and Antioch Dunes evening primrose occupy ≥20% of the vegetative cover and naked stem buckwheat composes at least 20% of the vegetative cover at the Stamm Unit once desired sand depths are attained in dune restoration areas (per Antioch Dunes NWR sand dune management plan).	• CCW and ADP cover is 13.56% in 2014-2015 sand deposition and 1.62% in 2020-2021 sand deposition. ADP increased significantly in sand deposition treatments, and CCW increased in frequency in the Stamm Unit • ADB cover is 0.47% in 2014-2015 sand deposition and 0.37% in 2020-2021 sand deposition with increasing trend in 2014-2015 treatment
Invasive plant management	RDE_O09. By 2033, cover of ripgut brome (annual grass), vetch, yellow starthistle, and Russian thistle is reduced by at least 50% and Himalayan blackberry is reduced by at least 80% (baseline = 2017 inventory) at the Stamm Unit of Antioch Dunes NWR.	• Annual grass cover decreased by 19.7% of 2017 baseline • Winter vetch cover decreased by 65.7% of 2017 baseline • Russian thistle cover decreased by 86.3% of 2017 baseline • Himalayan blackberry decreased by 15.1% of 2017 baseline
Invasive plant management	RDE_O10. By 2033, cover of tree of heaven is reduced by 75% (baseline = 2017 inventory) at the Sardis and PG&E West Units of Antioch Dunes NWR.	• Tree of heaven cover increased by 40.9% of 2017 baseline
Invasive plant management	RDE_O11. By 2033, oak cover is <20% at the Sardis Unit of Antioch Dunes NWR.	• Oak cover in the Sardis Unit is 21.2% in 2023

Table 32. Current status and desired future state (goals) of the riverine dune ecosystem at Antioch Dunes National Wildlife Refuge in terms Refuge management strategies and associated objectives defined in the HMP (USFWS *in prep.*).

Goal	Expected Outcome (Objective)	Current Status 2023
RDE_Goal_1	By FY 2028, Management Area 1 and 2 of the Stamm Unit of Antioch Dunes NWR contains greater than 50 percent open sand and at least 46% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Mathers and USFWS 2018, and Arnold and Powell 1983, Mathers and USFWS 2018).	• Open sand cover in MA1 is 24% and MA2 is 54%. • Native dune associated species comprises 34% of vegetative cover in MA1 and 10% in MA2.
RDE_Goal_2	By FY 2031, the priority areas in the Pit and PG&E East Management Areas of the Sardis Unit of Antioch Dunes NWR contains at least 20% open sand (<80% vegetated) and at least 21% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Arnold and Powell 1983, Mathers and USFWS 2018, Arnold and Powell 1983).	• Open sand cover in the PG&E East MA is 6% and Pit MA is 3%. • Native dune associated species comprises 8% of vegetative cover in the PG&E East MA and 3% in Pit MA.
RDE_Objective_1	By FY 2032, increase percent cover of CCW and ADEP in current priority grids by 10 years from 2023 Inventory numbers.	• Not relevant 2023
RDE_Objective_3	By 2027, reduce or eradicate priority invasive plants (Table 3) in priority grids for the Lange's metalmark butterfly, Antioch Dunes evening primrose, and Contra Costa wallflower from 2023 Inventory numbers.	• Not relevant 2023

Table 33. Current status and desired future state (goals) of the riverine dune ecosystem at Antioch Dunes National Wildlife Refuge in terms of key ecological attributes and indicators.

Key Ecological Attribute	*Indicator*	*Status: Measure (Trend) 2017*	*Status: Measure (Trend) 2023*	*Goal*
Sand dune vegetation cover and composition	% cover open sand (non-vegetated)	Poor: Stamm Unit = 23.4% bare ground, Sardis Unit = 11.4% bare ground[2] (decreasing)	Poor: Stamm Unit = 17.9% bare ground, Sardis Unit = 5.5% bare ground[2] (decreasing)	RDE_G01. By FY 2028, the Stamm Unit of Antioch Dunes NWR contains at least 30% open sand (or <70% vegetated) and at least 46% of the vegetative cover comprises native dune-associated plant species. RDE_G02. By FY 2031, the Sardis Unit of Antioch Dunes NWR contains at least 20% open sand (<80% vegetated) and at least 21% of the vegetative cover comprises native dune-associated plant species.

Key Ecological Attribute	*Indicator*	*Status: Measure (Trend) 2017*	*Status: Measure (Trend) 2023*	*Goal*
Sand dune vegetation cover and composition	% cover native desirable plant species (beneficial to Lange's metalmark butterfly)	Poor: Stamm Unit = 8.5% sand dune native plants, Sardis Unit = 8.1% sand dune native plants[2] (decreasing)	Poor: Stamm Unit = 7.5% sand dune native plants, Sardis Unit = 3.4% sand dune native plants[2] (decreasing)	See above: RDE_G01, RDE_G02

Green = within target, Yellow = below target, within NRMP estimate, Red = below target and below NRMP estimate

4.2 Target Native species

Sand deposition treatments have been very effective for improving ADP, with cover of ADP much higher in areas with sand deposition, and rapid colonization of new sand treatments. While we did not measure plant size, anecdotal observations were that ADP individuals were much larger in the 2014-2015 treatment than in areas without new sand and with high invasive plant cover, and compared to the 2020-2021 treatment, where most individuals appeared young. Jones et al. (2021) found ADP most abundant on restored dunes in the Stamm Unit, with declining abundance as annual grass cover increased on areas with no sand deposition.

ADB cover declined across the Refuge, except for the Riparian and Littoral MAs, where ADB was recorded in 2023 but not in 2017, and in the 2014-2015 sand deposition treatment, where 331 new individuals colonized between 2017 and 2023. There appears to be a greater lag time for ADB to colonize sand deposition treatments, but anecdotal observations found more robust seedlings and adults in this area than in areas with dense annual grass cover. Seedlings were found within annual grass and thatch dominated areas but appeared etiolated and small. Seeding was beneficial for ADB, with abundance very high in recently seeded areas in most seeding trials in the Sardis Unit, and with seeding on flat areas more effective than sloped areas. Annual grasses and winter vetch are negatively impacting ADB, with individuals in some areas almost completely submerged.

CCW cover had small declines overall, with frequency increasing in the Stamm Unit and decreasing in the Sardis Unit. CCW cover declined in all Stamm MAs and in the PG&E East and Pit MAs of the Sardis Unit, but increased in the Littoral and Slope MAs and did not change in the Riparian and Upland MAs in the Sardis Unit. The steep slopes, with natural disturbance from erosion, and higher tree and shrub cover of the Littoral, Slope and Riparian MAs reduce cover and vigor of invasive annual grasses, which may be why CCW has trended better in these areas. CCW cover increased with supplemental seeding, but this did not prevent overall declines in cover in the areas in which seeding occurred.

LMB nectar and perch plants declined throughout the Refuge between 2017 and 2023, except for increases in nectar cover in the Pit MA, where nectar plants increased, probably in part due to seeding. California experienced exceptional drought during 2018-2022, which could have caused mortality of adults and a lack of recruitment. Widespread mortality of adult chaparral shrubs in response to drought has been observed in the last two decades in California (e.g., McAuliffe and Hamerlynck 2010, Jacobson and Pratt 2013).

4.3 Target invasive species

Refuge conservation goals related to invasive plant management are trending in the right direction, and even exceeding objectives for some species, including winter vetch and Russian thistle (Table 19). However, other target invasive plants have increased since 2017. A brief discussion of patterns of each target invasive plant follows.

Tree of heaven (*Ailanthus altissima*)

Tree of heaven is a Cal-IPC Moderate species that was introduced as an ornamental landscape plant, and has escaped into disturbed and semi-natural habitats along coastal California, the Sierra foothills, and other western states. It is a fabaceous tree that may spread by seeds and suckering roots which may form thickets (DiTomaso and Healy 2007). Fruits mature in late summer that disperse throughout fall, winter and into the following spring, germinating if moist conditions exist (DiTomaso and Healy 2007). This tree is mostly confined to the PG&E West and Slope MAs of the Sardis Unit, but has spread between 2017 and 2023, increasing its extent by 40%. ADB occurs within the infestation, and the infestation is moving towards larger ADB populations. The tree of heaven population in the western Slope MA is very dense, with thick winter vetch in the understory, and it is unlikely that any native dune species could persist or establish in this area.

Mustard group (*Brassica nigra, Hirschfeldia incana*)

Mustard group species, black mustard and summer mustard, decreased throughout the Refuge. Both species are Cal-IPC Moderate species. Black mustard has allelopathic chemicals that can inhibit germination of native plants, and increase fire frequency in invaded areas. Summer mustard establishes in disturbed soils and can outcompete native species. These species were widespread on the Refuge, especially in areas of recent sand deposition and where disturbance is maintained such as roads, but typically only abundant on disturbed Refuge edges, and not within the dunes.

Italian thistle (*Carduus pyncocephalus)*

Italian thistle is a Cal-IPC Moderate species that is widespread in coastal California. It may become dominant in grassland communities, outcompeting more desirable vegetation, and it does especially well in wet years (Cowan 2000). This species has increased on the Refuge, and was often seen in the shade of oak canopy and on north-facing slopes in the Sardis Unit, where it poses a threat to CCW.

Centaurea group (*C. melitensis, C. solstitialis)*

Yellow star thistle is a Cal-IPC High species found in chaparral, coastal prairie, grassland and riparian areas throughout California. Tocalote is a Cal-IPC Moderate species, also found throughout most of California. Yellow starthistle was considered a severe threat to health of Refuge habitats in 2002, and intensive herbicide treatments, burning, mechanical control and restoration were applied to control it and other invasive species (USFWS 2002). *Centaurea* group species, while still one of the more abundant target invasive plants/groups on the Refuge, declined significantly from 2017 to 2023. However, several dense stands were documented close to ADB populations in the Sardis Unit, and should be targeted for treatment.

Bermudagrass (*Cynodon dactylon)*

Bermudagrass is a Cal-IPC Moderate species that is fast growing and can form dense carpets that can outcompete native species. It has spread significantly on the Refuge, especially on the Stamm Unit, where several dense populations were mapped on the 2014-2015 sand deposition areas. These occurrences directly threaten ADP and ADB, and other native dune species. Dense infestations were also mapped in the Riparian MA and Littoral MA.

Stinkwort (*Dittrichia graveolens)*

Stinkwort is a Cal-IPC Moderate – Alert species that occurs in disturbed habitats below 700 m throughout northern California (Rosatti 2014). It was observed in one grid cell in 2013 and three in 2017. This species has peak reproduction in the fall, so both inventories could have underestimated cover due to low detectability, but regardless, this species is not widespread on the Refuge.

Redstem stork's bill (*Erodium cicutarium)*

Redstem stork's bill is a Cal-IPC Limited species. It was the second most abundant and frequent invasive plant on the Refuge in 2023. This species was noted to have increased after prescribed burning reduced starthistle cover, but perhaps be less competitive or soil stabilizing than other invasive plants (USFWS 2002). Other annual *Erodium* species were also present, but not as extensive.

French broom (*Genista monpessulana)*

French broom is a Cal-IPC High shrub that is found in the Coast Ranges, Sierra Nevada foothills, Transverse Ranges, Channel Islands and coastal areas in California. Broom species seeds may persist in the seed bank for up to 100 years, to emerge and dominate following a disturbance event such as fire. This makes management very difficult once these species are well established. French broom has spread from its 2017 footprint in the Pit MA in the Sardis Unit, occurring along the firebreak trail in this unit and within and along the edge of coast live oak woodlands. The population is expanding towards an ADB population, including two of the seeding trials. Since this population is still relatively small, and not currently within sensitive species habitat, it should be targeted for control.

Perennial pepperweed (*Lepidium latifolium*)

Perennial pepperweed is a Cal-IPC High species that is typically associated with wetlands and disturbed sites. This plant may resprout from root fragments and produces abundant seeds. Perennial pepperweed has spread from existing sites in the western Riparian MA in the Stamm Unit and moist soils in the Pit MA in the Sardis Unit, increasing in both cover and frequency. Scattered individuals occurred around the seasonal pond in the Stamm Unit. While this plant is not likely to impact native dune species due to its affinity for moist soils, it does pose a threat to the state listed rare plants that occur in the strand area of the Refuge, and control while populations remain small is recommended.

Mallow group (*Malva parviflora*, *Malva spp.)*

Malva parviflora and other invasive annual mallows, are not rated by Cal-IPC. This group of species is associated with disturbed areas and waste places throughout California (Baldwin et al. 2012). Mallow species were abundant in hard, disturbed soils along refuge boundaries, roads, and in excavated soils in MA3 in the Stamm Unit, but was never observed as abundant within dune soils, and does not appear to pose a threat to native dune vegetation.

White sweetclover (*Melilotus albus*)

White sweetclover is not rated by Cal-IPC. This species was added to the target invasive plant list on the recommendation of Mather and USFWS (2018), after it was observed frequently in dune habitats in the 2017 inventory. White sweetclover was not observed on the Refuge in 2023. Yellow sweetclover was observed relatively frequently, but always at very low cover, and did not appear to be a threat to either dune or riparian vegetation.

Tree tobacco (*Nicotiana glauca*)

Tree tobacco is a Cal-IPC Moderate shrub or small tree known from open disturbed areas at elevations below 1,100 meters in California. This species was limited on the Refuge in both 2017 and 2023, and overall cover and frequency remained similar between the two inventories. While this species does not

appear to be spreading, removing existing occurrences while they remain small is recommended to prevent future spread.

Radish (*Raphanus sativus*)

Radish is a Cal-IPC Limited species that can become abundant in grasslands, wet areas and open disturbed areas. They may become abundant enough to exclude native vegetation. At Antioch Dunes National Wildlife Refuge, radish was observed mostly in the strand areas, within steeper dunes on the southern boundary of the Stamm Unit, and disturbed areas in the Sardis Unit, and always at very low cover. This species has declined since 2017. While this species does not appear to be posing an imminent threat to native dune species or LMB, it should continue to be monitored.

Black locust (*Robinia pseudoacacia*)

Black locust is a Cal-IPC Limited species that has escaped from cultivation to naturalize throughout California. It is mostly confined to the PG&E West MA in Sardis, with occasional individuals also found in the Littoral MA. This species has not spread since the 2017 survey. It poses the most threat to CCW, which occurs on steep slopes in the black locust infestation.

Puncturevine (*Tribulus terrestris*)

Puncturevine is a Cal-IPC Limited species that is found invading grasslands and dunes throughout California. This species was confined to the road along the Littoral MA and two other disturbed areas in the Stamm Unit, and only one to several individuals were observed in any grid cell. Since this species is capable of invading dunes, it should be controlled before it establishes in the dune habitat, and continue to be monitored.

Spring vetch (*Vicia sativa*)

Spring vetch is not rated by Cal-IPC. This trailing herb occurs throughout coastal California in disturbed areas, grasslands, oak and riparian woodland. This species declined overall on the Refuge from 2017 to 2023, but increased on the Stamm Unit, where it was not recorded in 2017. This species does not appear to be as vigorous or problematic as winter vetch, but should continue to be monitored and treated with winter vetch.

Winter vetch (*Vicia villosa*)

Winter vetch is not rated by Cal-IPC, but is especially detrimental to the native dune species of the Refuge and the dune ecosystem due to its ability to degrade habitat by stabilizing dynamic soils, as well as by its aggressive smothering. ADP appears tolerant of soil disturbance and some mechanical damage when winter vetch is removed (USFWS 2002), but extreme care must be taken when removing winter vetch from ADB, due to the possibility of disturbing LMB. Yet, removing winter vetch from ADB is critical, because it can completely bury ADB plants, making them unfindable for LMB adults, and making microhabitat unsuitable for LMB larvae. Controlling winter vetch on the Refuge will remain a high priority.

4.4 Pathways and vectors

Antioch Dunes National Wildlife Refuge is so small, and has been so extensively disturbed and heavily invaded, that invasion pathways into the Refuge from roads and trails are not as relevant as larger, more intact areas. Nevertheless, Refuge boundary areas and roads are demonstrated by these inventory results to be a source of invasive plants, such as Russian thistle, starthistles, mustards, mallow, and puncturevine, which had greater abundance and frequency in these areas.

Small, isolated populations of invasive species are practically much easier to control than large populations. More importantly, the impacts of invasive species may be negligible with only a few plants, but can be ecosystem altering when an invasive species is dominant (e.g., D'Antonio and Vitousek 1999, Lambrinos 2002). Passive restoration after removal of small populations may be the only necessary treatment, while intensive restoration is probably necessary following removal of dense infestations. Infilling and rates of spread of invasive species also occurs much faster the greater the number of source populations (Moody and Mack 1998). For these reasons, early detection and rapid response is widely accepted as the most effective management strategy for controlling invasive species (e.g., Simberloff 2003, Westbrooks 2004, Abella et al. 2008, Davies and Johnson 2011). Existing occurrences within and adjacent to the Refuge provide seed sources for additional spread. While most target invasive species are already widespread, controlling small populations while they are small, such as puncturevine and tree tobacco, is important to reduce future impacts and to increase feasibility of control.

Oaks are currently present as scatted adults in the Stamm Unit and upland areas of the Sardis Unit, and are more abundant in the Riparian, Littoral and Pit MAs. Oak seedlings were frequent in dune habitats, especially in sand deposition treatments in the Stamm Unit. Oaks are a natural component of the Refuge ecosystem, but oak colonization of the dunes is a threat to maintaining a dynamic dune system. These seedlings should be removed while they are small and easily pulled, and regular (~ every 2-3 years) monitoring and removal should maintain oaks at low abundance in dune areas.

Dominant vectors for new infestations are Refuge staff and cooperators, vehicles, equipment for dune restoration, imported sand, and trespassers. Standard operating procedures for vigilant examination of clothing, vehicles and equipment for invasive plant propagules prior to visiting the Refuge minimizes introduction of new species or new populations.

4.5 Future surveys

This vegetation inventory provides an assessment of management activities conducted to support conservation goals for KEAs on Antioch Dunes National Wildlife Refuge, and provides a data point from which future conditions and activities can be assessed. We recommend refining objectives of dune restoration success to be specific for ADP and CCW (Table 18). CCW does not appear to be responding to the sand deposition treatments, perhaps because the sand deposition is not occurring in areas where CCW is particularly abundant, or is not creating suitable habitat, as CCW appears to favor slightly more stabilized, finer soils than ADP and ADB. We recommend adding invasive plant objectives to the invasive plant conservation management strategy (Table 18), particularly for eradication of puncturevine, tree tobacco and perennial pepperweed, which all currently have low distribution on the Refuge. We recommend adding sweet fennel to the target invasive plant list, as this species is prevalent in the Pit Area, and capable of spreading further where it may begin to threaten CCW and ADB. We recommend observing yellow sweetclover, and if it still appears to be present as a waif with minor impacts by the time of the next inventory, remove it from the target invasive species list. We recommend creating an *Erodium* group that includes *E. cicutarium*, *E. botrys*, and *E. brachycarpum*, all of which were observed on the Refuge and have similar ecology and management.

Multivariate modelling could be used to examine patterns in target native and nonnative species distribution and abundance, and additional statistical models could be built for any of the target species, groups or landcovers. For the current report, statistical modelling focused on sand deposition treatments in the Stamm Unit, since this is where sand treatment occurred, and since dune and native dune community restoration is a KEA for the Refuge. As additional inventories and management activities occur, statistical power will increase.

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Chapter 5—References

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Appendix A

Antioch Dunes National Wildlife SOP

U.S. Fish and Wildlife Service
U.S. Department of the Interior

Pyramid Botanical Consultants

Standard operating procedure for Antioch Dunes National Wildlife Refuge vegetation inventory

December 2023

ON THE COVER: Antioch Dunes buckwheat (*Eriogonum nudum var. psychicola)*

Survey Protocol Summary

This vegetation inventory protocol for vegetation inventory at Antioch Dunes National Wildlife Refuge *describes the rationale, methods, and analysis to compare time series results for a grid-based invasive plant, key native species, and landcover inventory for the Sardis and Stamm units of the Antioch Dunes National Wildlife Refuge, Antioch, California. Under the protocol, the following vegetation attributes are inventoried in a 20 meter by 20 meter grid overlain in GIS over the entire refuge; cover of priority invasive species or groups of species, native species of conservation concern (endemic to the Antioch dune ecosystem), species with special status designation (Endangered, Threatened, or Rare) or that provide habitat or modify habitat for Federally Listed wildlife species such as Lange's metalmark butterfly (*Apodemia mormo langei*), and landcover types relevant to management of Federally Listed wildlife species. In addition, within each grid square, each individual of Antioch Dunes buckwheat (*Eriogonum nudum *var.* psychicola*) is mapped as a point location. These data and analyses provide the current status of vegetation attributes relevant to priority conservation management goals on the Antioch Dunes National Wildlife Refuge, allow assessment of conservation management goals, provide trends in vegetation attributes, and help agency staff evaluate past management, and prioritize future management actions.*

The general objective of this protocol is to provide standardized methods to complete grid-based vegetation inventory of Antioch Dunes National Wildlife Refuge, with analysis and reporting of current status and trends.

This survey is implemented over the entire Antioch Dunes National Wildlife Refuge area. The survey effort can be adjusted to allow for budget and time constraints, or to address specific management questions.

Suggested citation:

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Abbreviations

ADB	Antioch Dunes buckwheat
ADP	Antioch Dunes evening primrose
CAL-IPC	California Invasive Plant Council
CCP	Comprehensive Conservation Plan
CCW	Contra Costa wallflower
CDFA	California Department of Food and Agriculture
CDFW	California Department of Fish and Wildlife
CDFG	California Department of Fish and Game
Complex	San Francisco Bay National Wildlife Refuge Complex
EDRR	Early detection and rapid response
GLMM	Generalized Linear Mixed Model
KEA	Key Ecological Attribute
LMB	Lange's metalmark butterfly
MA	Management Area
NRMP	Natural Resource Management Plan
PBC	Pyramid Botanical Consultants
PG&E	Pacific Gas and Electric
Refuge	Antioch Dunes National Wildlife Refuge
SMART	Specific, Measurable, Attainable, Results-oriented, Time-bound

USFWS United States Fish and Wildlife Service

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Narrative

Element 1: Introduction

Background

This protocol prescribes methods for collecting data on the abundance and distribution of priority invasive and native species and landcover types at Antioch Dunes National Wildlife Refuge (Refuge), reporting on current status with evaluation of Refuge management goals and trends between 2017 and 2023 inventories, and analyzing data to interpret trends of priority attributes between survey intervals and the effects of management activities on priority attributes.

Antioch Dunes National Wildlife Refuge is one of seven refuges in the San Francisco Bay National Wildlife Refuge Complex managed by the U.S. Fish and Wildlife Service (USFWS). The Refuge is located along the south shore of the San Joaquin River on the northern border of the City of Antioch in Contra Costa County, California (Figure 1). The Refuge was established in 1980 to provide critical habitat for the Endangered Lange's metalmark butterfly (LMB; *Apodemia mormo langei*) and two Endangered plants, Antioch Dunes evening primrose (ADP; *Oenothera deltoides* ssp. *howellii*), and Contra Costa wallflower (CCW; *Erysimum capitatum* var. *angustatum*) (USFWS 2002). The 67 acre refuge is comprised of two units, the Stamm Unit (41 acres) and the Sardis Unit (26 acres) (Figure 1). For Refuge management, the Stamm Unit is divided into five Management Areas and the Sardis Unit into six Management Areas (Figure 1, Table 1).

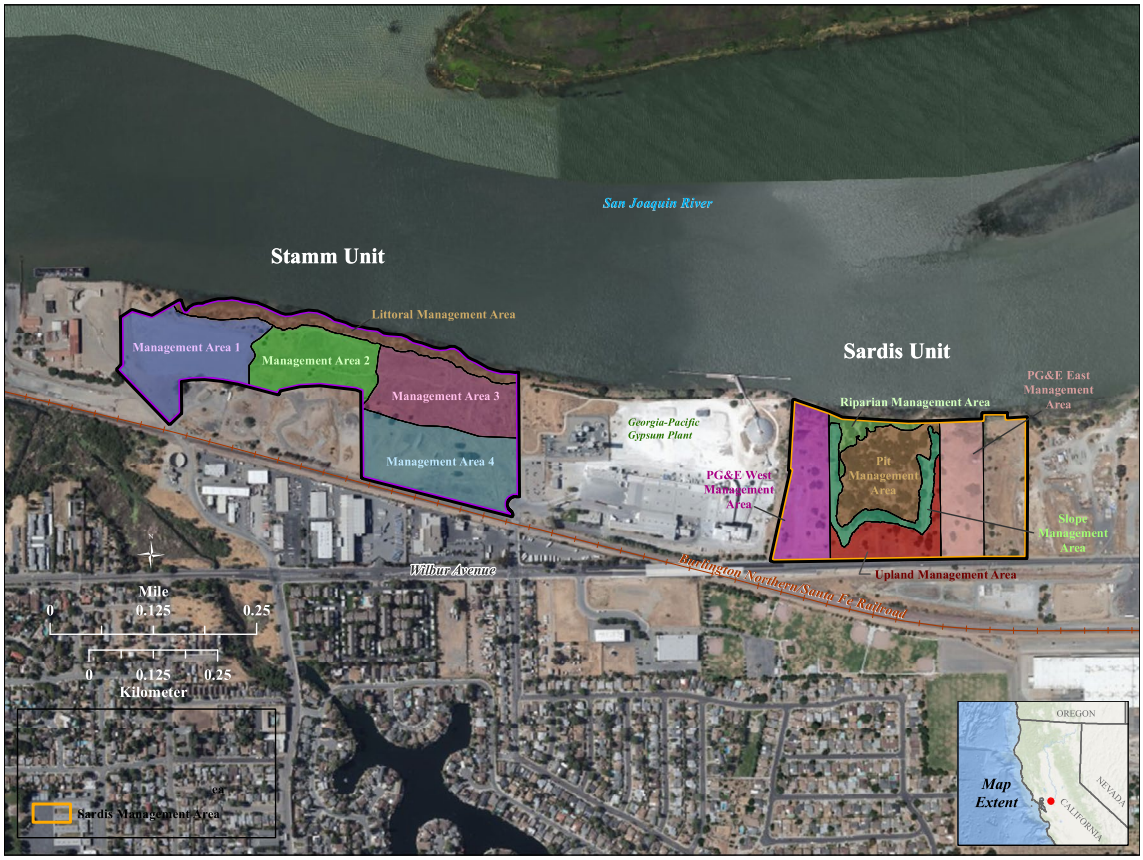

Figure 1. Antioch Dunes National Wildlife Refuge, with Stamm and Sardis Units, and Management Areas within each unit.

The Refuge was established under the authority of the Federal Endangered Species Act of 1973 and was established to protect a unique riverine dune ecosystem, including designated "critical habitat" of the three endangered species (USFWS 2002). The initial Refuge included 55-acres and 12 adjacent acres owned by PG&E (USFWS 2002), but the PG&E properties have recently been added to the Refuge.

Ecological Setting

The Antioch Dunes were once a large, ancient, aeolian dune system extending along the southern bank of the San Joaquin River just east of the town of Antioch (Powell 1983). The dunes historically occurred along a two-mile stretch of river, averaging approximately one-sixth of a mile wide and occupying an area of approximately 190 acres, with heights up to 120 feet (Howard and Arnold 1980, USFWS 2002). Isolation of the dune system led to evolution of a unique suite of plant and wildlife species, with 29 new insect taxa discovered in the dunes (USFWS 2002). In the early 1900s development of the dunes, including sand mining and brick manufacturing, began to destroy the dune system, fragmenting and shrinking the dune habitat (USFWS 2002). When the Refuge was established in 1980, only a few acres of dune habitat, containing the last populations of ADP, CCW and LMB remained, and these few acres were degraded by invasive weeds (USFWS 2002). At the time of establishment, the Refuge was open to the public, but was closed in 1986 due to trampling of endangered plants and wildfires (USFWS 2002). It has remained closed to the public since.

The current ecological setting of the Refuge is isolated habitat surrounded by industrial development (USFWS 20002). Existing vegetation includes upland habitat dominated by coast live oak (*Quercus*

agrifolia), coastal scrub, invasive annual grass dominated areas, dunes, and small sections of shore strand habitat along the river in both units (Mathers and USFWS 2018).

Management objectives and goals

The overarching conservation goal of Antioch Dunes National Wildlife Refuge is to protect the three federally endangered species endemic to the Refuge, and critical habitat provided by the riverine dune system.

Specific vegetation related management goals identified in the Comprehensive Conservation Plan (CCP) (USFWS 2002) include:

1. To protect, enhance and maintain habitat for threatened and endangered species, emphasizing species known to inhabit the Refuge, including LMB, CCW and ADP.

2. To protect, restore and manage the Antioch Dune ecosystem for a diversity of native plant and animal species.

The Natural Resource Management Plan (NRMP) for the Complex (USFWS 2019) is a step-down plan of the CCP that helps focus limited resources by identifying priority resources of conservation concern, identifying the most critical threats, refining goals and objectives, and focusing management strategies to address the most critical threats to achieve conservation goals and objectives. The NRMP identified two Key Ecological Attributes (KEAs) on the Refuge, including:

1. Lange's metalmark butterfly population size

2. Sand dune vegetation cover and composition

Sand dune vegetation cover and composition is indicated by 1) percent cover of non-vegetated open sand, and 2) percent cover of dune-associated and beneficial to LMB native plant species (USFWS 2019). Native dune vegetation status and trends includes the endangered species ADP and CCW, as well as host, nectar and perch plants of LMB. Antioch Dunes buckwheat (ADB; *Eriogonum nudum* var. *psychicola*) is the only larval food source for LMB. ADB is endemic to the Antioch Dunes, and requires sandy, well-drained soils and soil disturbance for seedling establishment (USFWS 2020). Adult females lay eggs on the lower stems of ADB where foliage is withered in summer, and eggs hatch when new growth appears during the rainy season (USFWS 2002, McNally 2014). LMB also uses nectar plants such as hairy gumweed (*Grindelia hirsutula*), telegraphweed (*Heterotheca grandiflora*), shrubby butterweed (*Senecio flaccidus* var. *douglasii*), and California matchweed (*Gutierrezia californica*), for food, and perch plants including deerweed (*Acmispon glaber* var. *glaber*). Specific relevant management goals outlined in the NRMP include:

RDE_O02. Over the next 15 years (2018–2032), invasive plants occupy <5% of the landcover where sand placement has occurred in the Stamm Unit of Antioch Dunes NWR.

RDE_O03. Contra Costa wallflower and Antioch Dunes evening primrose occupy ≥20% of the vegetative cover and naked stem buckwheat composes at least 20% of the vegetative cover at the Stamm Unit once desired sand depths are attained in dune restoration areas (per Antioch Dunes NWR sand dune management plan).

RDE_O09. By 2033, cover of ripgut brome (annual grass), vetch, yellow starthistle, and Russian thistle is reduced by at least 50% and Himalayan blackberry is reduced by at least 80% (baseline = 2017 inventory) at the Stamm Unit of Antioch Dunes NWR.

RDE_O09. By 2033, cover of ripgut brome (annual grass), vetch, yellow starthistle, and Russian thistle is reduced by at least 50% and Himalayan blackberry is reduced by at least 80% (baseline = 2017 inventory) at the Stamm Unit of Antioch Dunes NWR.
RDE_O10. By 2033, cover of tree of heaven is reduced by 75% (baseline = 2017 inventory) at the Sardis and PG&E West Units of Antioch Dunes NWR.

RDE_O11. By 2033, oak cover is <20% at the Sardis Unit of Antioch Dunes NWR.

In accordance with Service policy, a Habitat Management Plan (HMP), a step-down plan to the CCP (USFWS 2002) and the NRMP (USFWS 2019), is being prepared to describe the details of actions to manage riverine sand dune (RDE) and vegetation on the Refuge (USFWS in prep.). This HMP further refines refuge goals and objectives to focus on asset based protection for listed species, and refuge monitoring will be focused on tracking progress toward these goals and objectives:

RDE_Goal 1. By FY 2028, Management Area 1 and 2 of the Stamm Unit of Antioch Dunes NWR contains greater than 50 percent open sand and at least 46% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Mathers and USFWS 2018, and Arnold and Powell 1983, Mathers and USFWS 2018).

RDE_Goal 2. By FY 2031, the priority areas in the Pit and PG&E East Management Areas of the Sardis Unit of Antioch Dunes NWR contains at least 20% open sand (<80% vegetated) and at least 21% of the vegetative cover comprises native dune-associated plant species (Miller 2023, Arnold and Powell 1983, Mathers and USFWS 2018, Arnold and Powell 1983).

RDE_Objective 1. By FY 2032, increase percent cover of CCW and ADEP in current priority grids by 10 years from 2023 Inventory numbers.

RDE_Objective 3. By 2027, reduce or eradicate priority invasive plants (Table 3) in priority grids for the Lange's metalmark butterfly, Antioch Dunes evening primrose, and Contra Costa wallflower from 2023 Inventory numbers.

These goals and objectives will be assessed using data collected from SOP, including this inventory. This inventory will enable the Refuge to assess the above CCP (USFWS 2002), NRMP (USFWS 2019) and HMP (USFWS in prep.) goals and objectives.

Protocol development

This protocol was developed as part of a contract (140F0522P0278) to Pyramid Botanical Consultants to refine the protocol developed for the 2017 vegetation inventory (Mathers and USFWS 2018), implement a new vegetation inventory of the Refuge, and analyze vegetation inventory data to compare results from 2017 to 2023.

This inventory protocol is based on the methods developed for the 2017 inventory by Shelterbelt Builders Inc and USFWS. The 2017 Antioch Dunes vegetation inventory objectives were developed over a two-day workshop held by the USFWS Pacific Southwest Region Inventory and Monitoring Program (I&M) in 2016. The workshop was attended by I&M staff, Refuge staff and Mark Heath of Shelterbelt Builders Inc. The invasive plant inventory and early detection prioritization tool (IPIEDT) was used to prioritize invasive plant species and areas to survey (Mathers and USFWS 2018). Refinements to the 2017 protocol were developed based on recommendations from the 2017 inventory (Mathers and USFWS 2018), and consultation with the Refuge and Complex staff. Refinements included updates to target species lists and landcover attributes, an ArcGIS online Field Maps app electronic data collection system,

and protocols for data analysis to compare 2017 and 2023 results. This protocol will be used to guide future inventory, with revisions as necessary.

Survey objectives

Protocol Objective 1: Document the distribution and abundance of priority invasive plant species on the Refuge. Priority invasive plants were identified by the Refuge in advance of the inventory (Table 4). These are species that cause (or could cause) harm to the Refuge conservation targets and their habitats, particularly LMB, ADP, CCW, and the dune ecosystem.

Protocol Objective 2: Document the distribution and abundance of native plant species of conservation concern on the Refuge. Native plants of conservation concern were identified by the Refuge in advance of the inventory and include plant species that are native to the Antioch Dunes ecosystem, have special status designation (such as Endangered, Threatened, or Rare), or provide habitat for sand-dune associated wildlife species (such as LMB) (Table 3). This objective was expanded in 2022 to include cover of oak species (*Quercus* sp.), which appear to be expanding into the dune ecosystem to the detriment of managed species.

Protocol Objective 3: Document the distribution and abundance of landcover types that are relevant to Refuge conservation targets and their habitats, particularly LMB, ADP, CCW, and the dune ecosystem (Table 2).

Protocol Objective 4: Provide summaries of the current status of priority invasive and native species and landcover types for each Management Unit, the Refuge overall, and by Refuge Management Area, and use the current status to assess the NRMP goals RDE_G01, RDE_G02, RDE_O02, RDE_O03, RDE_O09, RDE_O10, RDE_O11(USFWS 2019) and HMP goals and objectives RDE_G01, RDE_G02, RDE_Objective_1, RDE_Objective_3 (USFWS in prep.). Analyze data from the 2017 and 2023 inventories to determine trends in priority vegetation attributes on the Refuge, and effects of sand deposition and seeding treatments on priority vegetation attributes (other relevant management activities that are well documented may be added in the future).

Element 2: Survey design

Sampling units, sample frame, and target universe

The target universe is the vegetation community of Antioch Dunes National Wildlife Refuge, specifically the presence, abundance, and distribution of native, invasive, and invasive plant species (see Tables 2-3). A 2016 workshop prioritized Management Areas for inventory (Table 1). All areas were surveyed in 2017 and 2023. A 2023 workshop prioritized MA1, MA2, Pit and PG&E East for survey in 2023, and future inventories that may be constrained by time or budget should follow that prioritization scheme. Inventory to evaluate NRMP goals should be done every 5 years (USFWS 2019).

Table 1. Target area priority for vegetation inventory at Antioch Dunes National Wildlife Refuge.

Refuge Unit	Management Area	Approximate size (acres)	Priority
Stamm	MA1	9	High
	MA2	7	High
	MA3	11	Low
	MA4	11	Low

	Littoral	3	Low
Sardis	Pit	6	High
	PG&E East	6	High
	Slope	3	Low
	Upland	3	Low
	Riparian	2	Low
	PG&E West	6	Low

A survey grid consisting of 20 x 20 m (400-m^2) grid cells for each Refuge unit, with a 100-foot buffer around Refuge boundaries, was established prior to the 2017 survey; the same grid system was used for 2023, except that grids were renumbered so that there were no duplicate grid numbers. In 2017 grid cells were numbered independently for each of the Stamm and Sardis unit, resulting in duplicate grid cell numbers. In 2023 grid cells were re-numbered with 2-digit alphanumeric identification numbers, with rows beginning at A to the north and going sequentially to the south, and columns starting with 001 at Stamm and numbering sequentially through Sardis, so that each cell in the survey had a unique identification number. Cells were cross walked to allow for a comparison of results between 2017 and 2023 (Appendix A). Grid cell size was based on suggestions by USFWS NWRS Region 8 Inventory and Monitoring staff, and test surveys conducted by Shelterbelt to determine a size that worked best for an efficient survey but still allowed for accurate cover estimation. Cells that fell entirely outside of fence lines and/or property boundaries or consisted entirely of unvegetated open water were not surveyed. Cells that occurred partly on Refuge lands were estimated across property boundaries.

Landcover types, other attributes

Landcover types important for management of species of conservation concern and invasive plants were included in the vegetation inventory in 2017; these were modified in 2023 to include tree cover and shrub cover, and bare ground cover defined to include only the area of the grid covered by bare soil or sand, and not include roads/railways or other Refuge infrastructure, which were included with bare ground in the 2017 survey (Table 2). Cover of Refuge roads, Refuge infrastructure, and off Refuge infrastructure were determined from Refuge GIS layers post-processing.

Table 2. Landcover types selected for survey in the Antioch Dunes National Wildlife Vegetation Inventory, 2023.

Landcover	Description
Annual grass	Cover of all annual grasses alive during the survey year (including early season grasses that may have already cured, or that were recently mowed)
Thatch	Cover of all plant debris from previous years' dead annual vegetation, leaf litter, fallen branches
Total vegetation	Cover of all live vegetation, including grasses, and including annuals from current survey year that have already senesced
Bare ground	Cover of sand or soil not covered in thatch or live vegetation

Water	Cover of open water and adjacent un-vegetated sandy or rocky beach areas that appear to be frequently flooded
Tree	Cover of all trees alive or dead during the survey year
Shrub	Cover of all shrubs alive or dead during the survey year
Refuge Road	Cover of roads/railways
Refuge Infrastructure	Cover of infrastructure occurring within the Refuge other than roads/railways
Off Refuge Infrastructure	Cover of infrastructure occurring within the grid cell but outside of Refuge boundaries

The 2017 survey identified cells where more than 10% of the cell area appeared to have been impacted by management activities with a yes/no attribute (Mathers and USFWS 2018). Since accurately identifying or being able to observe management activities (e.g., weeding, spraying, mowing) becomes increasingly difficult with increasing time after the activity occurs, management activities were not recorded during the 2023 survey. Instead, Refuge staff mapped management activities as polygons as they occurred, and management layers (weeding, spraying, mowing or other, and sand deposition) were added to the project geodatabase to allow for an assessment of the effects of management activities on priority vegetation attributes.

Target species

The 2017 targeted species included 13 native plant species or groups, 22 invasive plant species known to occur on the Refuge and 6 early detection species. The target native species list for 2023 was modified based on discussion by Refuge and Complex staff, with modifications including removal of three rare species (Delta tule pea [*Lathyrus jepsonii* var. *jepsonii*], Mason's lilaeopsis [*Lilaeopsis masonii*], and Suisun marsh aster [*Symphyotrichum lentum*] that are tracked and managed using other methods, and addition of an oak species group (including coast live oak, valley oak [*Quercus lobata*] and hybrids) because oak encroachment into Listed species habitat and subsequent habitat modification is a management concern. The 2023 target native plant list (Table 3) included 11 species or groups, and was primarily focused on nectar and habitat species important for LMB, Federally listed plant species (ADP, CCW), or species otherwise important for management of LMB habitat (oak species group, coyote bush (*Baccharis pilularis).* The invasive species list was modified for the 2023 survey following recommendations in Mather and USWSW (2018), and discussion by Refuge and Complex staff. Changes included removal of giant reed (*Arundo donax*), iceplant (*Carpobrotus edulis*), Uruguayan pampas grass (*Cortaderia selloana*), and Cape-ivy (*Delairea odorata*) from the target invasive plant list; addition of a mallow species group (*Malva parviflora*, *Malva* spp.), white sweet clover (*Melilotus albus*) and puncture vine (*Tribulus terrestris*); and grouping black mustard (*Brassica nigra*) with summer mustard (*Hirschfeldia incana*) and yellow star thistle (*Centaurea solstitialis*) with tocalote (*C. melitensis*). The 2023 target invasive plant list included 24 species or groups, which included 4 early detection species (Table 4).

Table 3. Native plant species targeted for inventory at Antioch Dunes National Wildlife Refuge in 2023.

Scientific name	Common name	Family	Life cycle	Special designation status; Rational for inclusion	Identifiable Period (O = identifiable, X = possibly blooming)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acmispon glaber var. *glaber*	deerweed	Fabaceae	subshrub	N/A; Perching plant for LMB	O	O	X	X	X	X	X	X	O	O	O	O
Baccharis pilularis	coyote brush	Asteraceae	shrub	N/A; Perching plant for LMB	X	O	O	O	O	O	O	O	X	X	X	X
Eriogonum nudum var. *psychicola*	Antioch Dunes buckwheat	Polygonaceae	perennial herb	CNPS List 1B; Host plant for LMB	O	O	O	O	O	O	O	X	X	X	O	O
Erysimum capitatum var. *angustatum*	Contra Costa wallflower	Brassicaceae	perennial herb	Federal Endangered, State Endangered, CNPS List 1B			X	X	X	X	X	O				
Grindelia hirsutula	hairy gumweed	Asteraceae	perennial herb	Nectar plant for LMB	O	O	O	O	O	X	X	X	X	O	O	O
Gutierrezia californica	California matchweed	Asteraceae	subshrub	Nectar plant for LMB	O	O	X	X	X	X	X	X	X	X	O	O
Heterotheca grandiflora	telegraphweed	Asteraceae	annual	Nectar plant for LMB	X	X	X	X	X	X	X	X	X	X	X	X
Lupinus albifrons	silver bush lupine	Fabaceae	shrub	N/A; Perching plant for LMB	O	O	O	X	X	X	X	O	O	O	O	O
Oenothera deltoides ssp. *howellii*	Antioch Dunes evening primrose	Onagraceae	perennial herb	Federal Endangered, State Endangered, CNPS List 1B												
Quercus ssp. (*Quercus agrifolia*, *Q. lobata*, *Q. agrifolia* x *lobata*)	Oak group (Coast live oak, Valley oak, hybrids)	Fagaceae	Tree	N/A; Encroaching on LMB habitat	O	X	X	X	O	O	O	O	O	O	O	O
Senecio flaccidus var. *douglasii*	shrubby butterweed	Asteraceae	shrub	Nectar plant for LMB			X	X	X	X	X	X	X			

Table 4. Invasive plant species targeted for inventory at Antioch Dunes National Wildlife Refuge in 2023.

Scientific name(s)/Group	Common name or Group label	Family	Life cycle	Invasive ranking	Identifiable Period (O = identifiable, X = possibly blooming)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SPECIES PREVIOUSLY RECORDED IN REFUGE																
Ailanthus altissima	tree of heaven	Simaroubaceae	Tree	moderate	O	O	O	O	X	X	O	O	O	O	O	O
Brassica nigra, Hirschfeldia incana	mustard group (black mustard, summer mustard)	Brassicaceae	annual herb	moderate		X	X	X	X	X	X	O				
Carduus pyncocephalus	Italian thistle	Asteraceae	annual herb	moderate		X	X	X	X	X	X	O				
Centaurea group (*C. melitensis, C. solstitialis*)	Star thistle group (tocalote, yellow star thistle)	Asteraceae	annual herb	Moderate, high				X	X	X	X	O				
Cynodon dactylon	Bermuda grass	Poaceae	perennial grass	moderate	O	O	O	X	X	O	O	O	O	O	O	O
Dittrichia graveolens	stinkwort	Asteraceae	annual herb	moderate						O	O	O	X	X	X	
Erodium cicutarium	redstem stork's bill	Geraniaceae	annual herb	limited		X	X	X	X	O						
Genista monpessulana	French broom	Fabaceae	shrub	high	O	O	X	X	X	O	O	O	O	O	O	O
Lepidium latifolium	perennial pepperweed	Brassicaceae	perennial herb	high	O	O	O	O	X	X	X	O	O	O	O	O
Malva group (*Malva parviflora*, *Malva* ssp.)	mallow species group (cheeseweed mallow, mallow species)	Malvaceae	annual/perennial herb	N/A		O	X	X	X	X	X	X	X	X	O	
Melilotus albus	white sweet clover	Fabaceae	annual herb	N/A				O	X	X	X	X	X	O		
Nicotiana glauca	tree tobacco	Solanaceae	tree or shrub	moderate	O	O	X	X	X	X	X	X	X	O	O	O
Raphanus sativus	wild radish	Brassicaceae	annual or biennial herb	Limited		X	X	X	X	X	X	O				
Robinia pseudoacacia	black locust	Fabaceae	tree	limited	O	O	X	X	X	X	O	O	O	O	O	O
Rubus armeniacus	Himalayan blackberry	Roasaceae	shrub/vine	high	O	O	O	X	X	X	X	X	O	O	O	O
Salsola tragus	Russian thistle	Chenopodiaceae	annual herb	limited						O	X	X	X	X		
Tribulus terrestris	puncture vine	Zygophyllaceae	annual herb	limited					O	X	X	X	X	X	O	
Tamarix group *(Tamarix parviflora, Tamarix ramosissima*)	Tamarisk group (smallflower tamarisk, tamarisk)	Tamaricaceae	tree or shrub	high	O	O	O	X	X	O	O	O	O	O	O	O
Vicia sativa	spring vetch	Fabaceae	annual vine	N/A		X	X	X	X	X	O	O				
Vicia villosa	winter/hairy vetch	Fabaceae	annual vine	N/A		X	X	X	O	O	O	O				

EARLY DETECTION SPECIES (not known to occur, according to Refuge managers)																	
Aegilops triuncialis	goatgrass	Poaceae	annual grass	high					X	X	X	X					
Ammophila arenaria	European beachgrass	Poaceae	perennial grass	high	O	O	X	X	X	O	O	O	O	O	O	O	
Bromus tectorum	cheatgrass	Poaceae	annual grass	high				O	X	X	X	X					
Taeniatherum caput-medusae	medusahead	Poacaeae	annual grass	high	O	O	O	X	X	X	O	O	O	O	O	O	

Target areas

Survey timing

For maximum efficiency and to minimize impacts to threatened wildlife, plants and habitat, the survey should occur over a time period when the most target species are identifiable, which is May and June (Tables 3-4). No single time period will capture the optimum phenological period for identification for all target species, for example, stinkwort (*Dittrichia graveolens*), emerges and blooms much later than most other target species (Table 4). However, most species are identifiable in May and June, and because the grid survey approach requires intensive survey over all areas of the Refuge, a single survey effort is preferable to reduce impacts, and manage budget and time constraints. Grid cells with plants with potential target species that are not yet identifiable can be marked to return to later, or notes can be made that identification is uncertain or that cover may be higher at peak reproduction.

Sources of error

Sources of error could include observers missing target plants within the survey grid, mis-estimating cover, or GPS error causing grid cells to be mislocated. Missing target species and mis-estimating cover errors may be significantly reduced by quality assurance procedures. Ensuring that observers are well-trained on target species detection, and are thoroughly traversing each grid cell, and timing the survey to maximize detectability of target species will reduce the likelihood that target species are missed. A May to June survey will capture the most species, but refinement of the inventory window in the inventory year will be necessary based on winter and spring weather patterns. Inventory planners should follow weather patterns and phenology in the general area and communicate with Refuge and Complex staff to fine-tune inventory dates. Even with these procedures, it is likely that some target species individuals will be missed when they occur at very low cover, especially within dense vegetation; this may result in small underestimates of target species distribution when they are present at low cover classes, and an underestimate of Antioch Dunes buckwheat count. Calibration of observers is necessary for consistency in observer cover estimates, and reduction of cover estimation errors due to observer bias; this is achieved by observers completing data collection within the same grid cell and comparing results until observers are within 10% on species and landcover cover estimates for each cell and observing all target species. Calibration within an inventory year cannot control for errors that could have occurred in the past, or may occur in the future, and surveys conducted at different phenological windows may result in different estimates of cover. Analysis of inventory trends may be impacted by observer cover estimation error, which could inflate or obscure changes in cover. An examination of conditions in which the inventories occurred should be considered when interpreting trends, and ensuring that observers are well-calibrated for each inventory will help reduce bias, but differences in observer bias between inventories cannot be completely controlled for. Invasive plant management treatments such as mowing could impact cover estimates of annual grass, thatch and bare ground, as well as any target species that were treated (Mathers and USFWS 2018). Observers should calibrate within treated grid cells to ensure that they are consistent. Management activity GIS layers may help with interpretation of cover estimates within treated areas, for example cover estimates in treated cells can be compared with cover estimates in untreated cells. Since grid cells are not permanently marked, GPS errors will always mean that grid cells are not exactly the same between inventory years; using GPS units with at least 3-meter accuracy will reduce GPS errors, but GPS errors cannot be removed.

Element 3: Field Methods

Pre-survey logistics and preparation

Prior to beginning fieldwork, observers must be trained on target species identification, habitat and phenology characteristics using resources such as the Jepson Manual (Baldwin et al. 2012), Calflora (*https://www.calflora.org/*) and Cal-IPC (*https://www.cal-ipc.org/*).

Mobile data collecting devices that can be paired with ArcGIS Field Maps and an external GPS receiver such as a BadElf GNSS Surveyor must be loaded with the Antioch Dunes Vegetation Inventory Field Maps project. The Field Maps project includes grid square layers, land ownership, and aerial imagery as well as data collection forms for target native species, target invasive species, and landcover types. In case of a loss of cellular service, offline maps of the Field Maps project should be downloaded for data collection prior to beginning the survey. Offline maps should be synced with AGOL at the end of every field day.

Prior to initiating the survey, observers must meet with Refuge staff to: 1) Ensure required access is provided, 2) identify safety hazards, and 3) review sensitive resource areas and agree upon measures to minimize disturbance to sensitive natural resources.

Field equipment and supplies (for each observer)

- Antioch Dunes National Wildlife Refuge Vegetation Inventory SOP (may be electronic)
- Target species identification resources (may be electronic)
- Antioch Dunes National Wildlife Refuge plant list (may be electronic)
- Data collection device (iPhone, Android, iPad, other tablet) with Field Maps app and Antioch Dunes National Wildlife Refuge Vegetation Inventory project
- Bad Elf GNSS Surveyor GPS
- External battery charger and cords for data collection device and Bad Elf
- Percent cover diagrams to aid in estimating percent cover (CNPS 2019)
- *Gate key for Refuge access*
- *Pin flags with 2 colors (minimum of 50 each)*
- Field notebook and pencils
- Camera (may use data collecting device)

Grid cell demarcation and data collection procedures

Grid cell corners are located using BadElf GPS receivers paired with a data collection device and using the Field Maps project. Using the location provided on the grid cell with aerial imagery to identify significant features on the landscape (trees, etc.), grid cell corners should be located to an accuracy of 2.5 meters. Corners are temporarily marked with pin flags while the survey is occurring, and removed when no longer necessary (i.e., when all grid cells with a corner marked by the pin flag are completed). Following calibration, surveyors should work in adjacent rows, one surveyor per grid cell, utilizing the same marked corners. If marking ADB points and recording target species and landcover covers is too time consuming for a single observer, observers may need to work together in a single grid square in areas where ADB is abundant.

Once the grid cell corners are located, observers walk a meandering path that traverses the width of the cell for a minimum of 1 minute to document target plant species/groups cover, ADB points, and

landcover throughout the cell. Increasing vegetation or topographic complexity, and/or greater target species diversity will require a longer search time.

Grid cell attributes

Grid cell attributes to be collected in the field are presented in Table 5. For each 20 x 20 meter grid cell, observers will record percent cover class (Table 6) of each target species and landcover type (annual grass, thatch, total vegetation, bare ground, tree cover, shrub cover) occurring in the cell. The Field Maps project defaults to zero, so only species or landcovers observed need to be recorded. For both target species and landcovers, absolute cover is recorded (not relative cover), meaning total cover in a cell may add up to over 100 percent. For each cell, each ADB individual is marked as a point location in the Field Maps project, with date auto filled.

Table 5. Summary of grid cell attributes collected for the Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory.

Attribute	Description
Grid cell ID number	The number of the grid cell being surveyed; will autofill based on location in the field
Surveyed	Yes/No
Date	Auto filled when surveyed is changed to yes
Surveyor	First initial and last name of surveyor (Choose from drop-down)
Species scientific name or group code	Scientific name of target species or group. The taxonomic standard is International Taxonomic Information Standard (ITIS)
Species cover	Percent cover class of each target species or species group within the cell
Landcover cover class	Percent cover class of landcover type occurring within the cell
Notes	Miscellaneous notes, e.g., herbivory, drought impacts, disturbance

Table 6. Cover classes used for the Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory.

Cover class number	Range of percent cover	Cover class midpoint
1	< 1%	0.5%
2	1 – 10%	6%
3	11 – 25%	18%
4	26 – 50%	38%
5	51 – 75%	63%
6	76 – 100%	88%

ADB mapping

In addition to the attributes described above, for each grid cell, each individual of ADB is mapped using a point feature layer in the Field Maps project, which records the location of each individual, the grid cell number and the date. This high level of spatial detail was requested in 2017 because ADB is the host plant for LMB larvae and is critical to LMB recovery (Mathers and USFWS 2018). The 2023 inventory only had a point feature class to map ADB; areas where ADB had been seeded had very high abundance of small individuals where accurately mapping each individual was not possible. In these cases, we used

each point to estimate an abundance range or created a polygon using another mapping source and estimated abundance within the polygon, and added the abundance to the ADB count per grid cell. For future inventories we recommend including both an ADB point and polygon feature class.

Prior to finishing a grid cell, attributes should be double-checked for accuracy and completeness.

Element 4: Data Management and Analysis

The geodatabase resulting from data collection must be quality control checked for errors. Post-processing will result in the following attributes populating the final geodatabase (Table 7):

Table 7. Summary of final geodatabase attributes for the 2023 vegetation inventory, Antioch Dunes National Wildlife Refuge.

Attribute	Field Description	Domain/Format
LIT*	USFWS 3-character code of the National Wildlife Refuge, used as a unique identifier.	ATD
Cmplx_Name*	Name of National Wildlife Refuge Complex the unit is associated with.	San Francisco Bay National Wildlife Refuge Complex
OrgName*	Official name of the National Wildlife Refuge.	Antioch Dunes National Wildlife Refuge
Unit_Name*	Name of the individual unit or discrete area associated with the Refuge	List of Refuge management units (Stamm, Sardis)
Management_Area*	Name of management area	List of Refuge Management Areas (MA1, MA2, MA3, MA4, Littoral, PG&E East, PG&E West, Pit, Riparian, Slope, Upland)
GridCell_ID	Grid cell identifier	Alphanumeric
Observer	First and last name of the person performing the observation	String
Obs_Date	Date that the observation was made by the Observer.	YYYY-MM-DD
Cover_Class	Class of each target species and landcover type absolute canopy cover estimated as a percent of the search area.	0 (not detected), > 0-1%, 1-10%, 11-25%, 26-50%, 51-75%, 76-100%
Cover*	Midpoint value of each target species and landcover type cover class	0, 0.5, 4.5, 18, 38, 63, 88
Net_Infested_Area*	The approximate net area in acres occupied by each target species and landcover type, calculated as the cover midpoint * size of grid cell in meters * meters/acres conversion	Numerical acres
Native Species Richness*	Sum of the number of target native species present in grid cell	Numerical
Invasive Species Richness*	Sum of the number of target invasive species present in grid cell	Numerical
Target invasive plant total cover	Sum of all target invasive plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres
Target native plant total cover	Sum of all target native plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres
Nectar plant total cover	Sum of all Langes nectar plant species cover present in a cell, calculated as the sum of all cover midpoints * size of grid cell in meters * meters/acres conversion	Numerical acres

Attribute	Field Description	Domain/Format
Antioch Dunes buckwheat abundance	Number Antioch Dunes buckwheat individuals present in a cell	Numerical
Start_Date*	Identifies the date that surveying was initiated.	YYYY-MM-DD
End_Date*	Identifies the date that surveying was completed.	YYYY-MM-DD
Surv_Yr*	Identifies the year the survey was conducted.	YYYY
Area_Surveyed*	Identifies area surveyed in acres	Numerical acres
Comments	Describes any additional information important to the associated record not contained within the existing fields	String
X_Coordinate*	Longitude of grid polygon centroids.	NAD83 UTM Zone 10N
Y_Coordinate*	Latitude of grid polygon centroids.	NAD83 UTM Zone 10N
LandcoverType	Target Landcover type encountered	Annual grass, thatch, total vegetation, bare ground, water/beach, tree, shrub, Refuge infrastructure, Off Refuge infrastructure
Surveyed	Indicates if grid cell has been surveyed. Default value is "No."	No, Yes, Unknown

*Data calculated post-processing.

Data are to be entered in the field electronically. If devices fail and paper datasheets have to be used, paper data forms will be scanned to data collection devices daily using an app such as Genius Scan and entered into the geodatabase in the week after the survey period.

A cover field for target species and landcover will be created from the cover classes that represented the midpoint of each cover class. The approximate net area of each target species or landcover type within each cell will be calculated using the formula:

$$\text{Area (acres)} = [\text{cover midpoint}] \times [\text{grid cell area } (m^2)] / [100] \times [4046.86\ m^2/\text{acre}]$$

An invasive species richness column will be calculated as the sum of target invasive species occurring in the cell.

Landcover type and target species distribution and abundance will be visualized by mapping cover within each surveyed grid cell for each management unit. Grid cells will be symbolized utilizing a graduated color scheme to produce a separate "heat map" of each target species and each landcover type. To visualize target species richness, a similar heat map will be created utilizing the number of species per grid cell. Both a native and invasive species richness map will be created for each unit.

Analysis methods

Descriptive results

Inventory data will be summarized with tables showing the number and proportion of grid cells occupied, extent of area occupied by each target species and landcover type overall and for each inventory unit (Sardis or Stamm) in 2023, and for each Management area in each unit, and the change in number, proportion and cover in 2023 relative to 2017. When a grid cell contains multiple Management areas, the grid cell should be assigned to the dominant (highest cover) Management area within the grid cell. Maps showing dominant landcover types, cover of each landcover type, cover of each target species, invasive plant richness, total invasive plant cover, total native plant cover, management activity, and a heat map of nectar plant cover with ADB points, as well as a heat map of ADB cover and ADB points will be prepared.

Assessment of Management Goals and Objectives

The current inventory data should be used to evaluate NRMP goals RDE_G01, RDE_G02, RDE_O02, RDE_O03, RDE_O09, RDE_O10, RDE_O11(USFWS 2019) and HMP goals and objectives RDE_G01, RDE_G02, RDE_Objective_1, RDE_Objective_3 (USFWS in prep.). To evaluate the composition of native dune species within the MA1, MA2, PG&E East and Pit Management areas (HMP RDE_G01 and RDE_G02), the sum of the extent of each native dune species divided by the extent of total vegetation within the relevant Management area will provide the percent of the vegetation provided by native dune species. Remaining goals and objectives are straightforward to assess.

Data analysis

Since both 2017 and 2023 are inventories, changes recorded over Refuge areas represent actual changes, i.e., they are not samples requiring statistical analysis. Because Management Areas have different priorities and management actions, differences in target species and landcovers covers and changes from 2017 to 2023 were tested using Anova or Kruskal-Wallis tests for non-normal data. The effect of sand deposition treatments on changes in target species and landcovers covers from 2017 to 2023 were tested with Generalized Linear Mixed Models (GLMM) with zero-inflation terms, and annual grass cover and Management area added as covariates. Models were evaluated using Akaike's Information Criterion (AIC). Analyses should be refined as conservation management goals are refined and as management activities are added.

Software

All analyses and graphics are accomplished using custom scripts written in the open-source R language and environment for statistical computing (RStudio 2023). At least intermediate experience in R is necessary to attain robust results with the greatest efficiency.

Element 5: Reporting

The final report should include a description of the rationale and field methods of the inventory including a description of the environment setting; results including tables of number and proportion of grid cells occupied and area occupied by each target species and landcover type overall and by Management area for each Unit, as well as changes in number, proportion and acres occupied from 2017 to 2023, photographs of common and important vegetation communities and infestations, and heat maps of each landcover type and target species within each Unit, with additional maps as described in the Analysis methods section; discussion including recommendations; and references. Refuge staff should be consulted for additional guidance on the content of the report for each inventory year, e.g., when conservation goals have been refined, new goals have been added, or changes in management activities have occurred.

Element 6: Personnel Requirements and Training

Roles and responsibilities

There are three roles necessary to implement this protocol: lead biologist, crew team member, and GIS specialist.

Lead biologist

This monitoring protocol must be conducted under the guidance of a lead biologist with experience in botany, field monitoring, analyses, interpretation, and reporting in order to ensure its success, reliability, and ability to inform the management objectives. This lead biologist:

- oversees the field effort including survey implementation and staff training
- can act as the crew leader in the field and for data entry and analysis components of the protocol
- receives the entered and verified electronic data and conducts the data analysis
- formulates interpretation
- completes survey and final reports

Crew team members

Crew, team members implement the field survey and data management methods as directed by the lead biologist. Ideally the inventory should be completed by 2-3 team members including the lead biologist.

GIS specialist

The GIS specialist is responsible for trouble-shooting Field Maps project problems, for post-processing collected data, and for preparing results maps.

Qualifications

All field staff must have the physical and mental ability to work in potentially challenging field conditions and must be skilled in plant identification.

Lead biologist

Skills of a qualified lead biologist include:

- field survey experience in California coastal ecosystems
- team leadership experience
- data management skills
- ability to interpret vegetation inventory data
- sufficient skills in R to construct GLMMs to analyze inventory data
- sufficient proficiency in GIS to manage Field maps app and data

Crew team members

A qualified crew team member should be an experienced botanist with experience in the California coastal vegetation and invasive plants of California, excellent observational skills, field surveying experience or other experience collecting biological or ecological data, and the ability to enter data digitally into Field Maps. Crew team members must be able to follow detailed instructions in the protocol, or verbal instructions from the lead biologist under field conditions. Attention to detail and an ability to keep meticulous records are required.

Crew team members

The GIS specialist must be experienced with Field Maps, data processing in ArcGIS Pro, and in map production.

Element 7: Operational Requirements

Budget

The budget will vary according to the survey effort in a given year. To survey the entire Refuge, the budget must be enough to support approximately 10 days of field data collection with travel and accommodation for two observers, data analysis and reporting.

Schedule

The vegetation inventory will coincide with peak reproduction of the greatest number of target species, which typically occurs in May to June, with specific timing varying with precipitation conditions in a given year. Data analysis and reporting timelines will depend on the entity conducting the survey (e.g., contractors or agency staff), and goals and funding constraints.

Coordination

Coordination between the lead biologist, crew team, and Antioch Dunes National Wildlife Refuge staff is necessary to complete this survey successfully. Coordination will include communication about phenology, management, access and safety within the proposed inventory window.

Element 8: References

Mathers, J. and U.S. Fish and Wildlife Service. 2018. Antioch Dunes National Wildlife Refuge: 2017 Vegetation Inventory. Unpublished report, Shelterbelt Builders Inc., San Francisco CA; U.S. Fish and Wildlife Service, San Francisco Bay National Wildlife Complex, Fremont, CA; U.S. Fish and Wildlife Service, Pacific Southwest Region Refuges Inventory and Monitoring Program, Sacramento, CA. 114pp.

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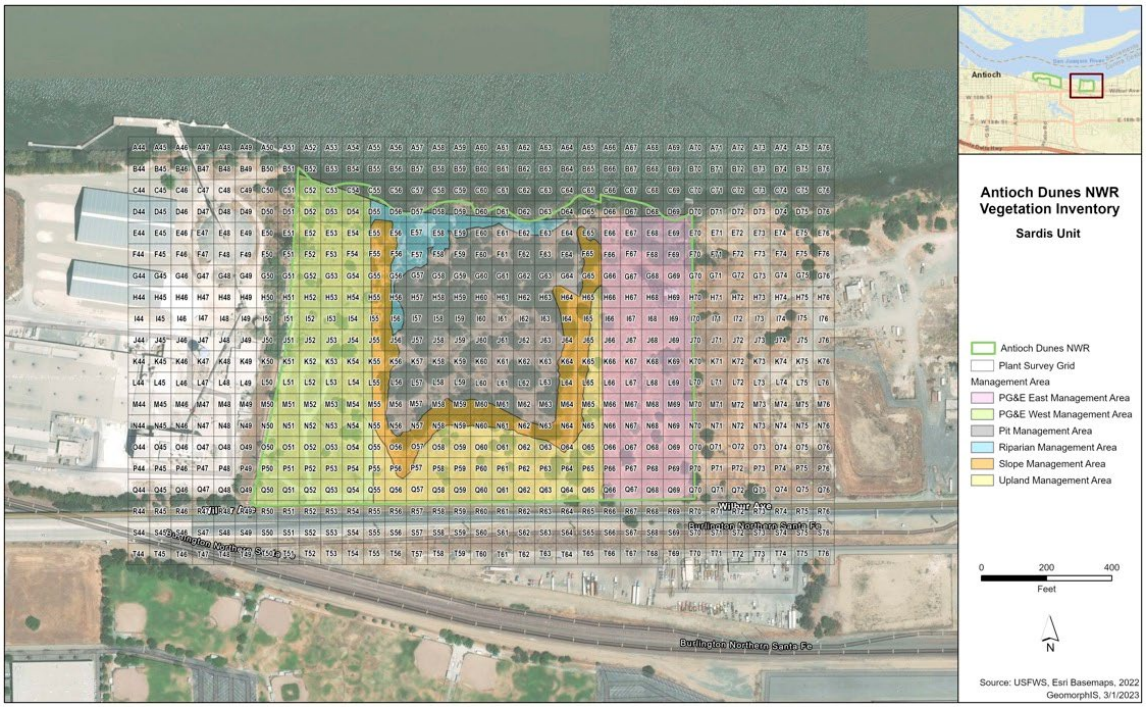
USFWS. 2013. How to develop survey protocols: a handbook. Version 1.0. 44.

[USFWS] U.S. Fish and Wildlife Service. 2002. Antioch Dunes National Wildlife Refuge Comprehensive Conservation Plan. U.S. Fish and Wildlife Service, Region 1, California/Nevada Refuge Planning Office, Sacramento, CA, San Francisco Bay National Wildlife Refuge Complex, Newark, CA.

[USFWS] U.S. Fish and Wildlife Service. 2019. Natural Resource Management Plan for the San Francisco Bay National Wildlife Complex. National Wildlife System. Pacific Southwest Region. Sacramento, CA.

[USFWS] U.S. Fish and Wildlife Service. [in prep]. *Habitat Management Plan for Antioch Dunes National Wildlife Refuge*. U.S. Fish and Wildlife Service, National Wildlife Refuge System, Department of the Interior Unified Regions 8 & 10 (Legacy Region 8, Pacific Southwest Region), Fremont, CA.

APPENDIX A. STAMM AND SARDIS UNIT MAPS WITH GRID SQUARE IDENTIFICATION NUMBERS USED IN THE 2023 INVENTORY


Antioch
Antioch Dunes NWR
Vegetation Inventory
Sardis Unit
Antioch Dunes NWR
Plant Survey Grid
Management Area
PG&E East Management Area
PG&E West Management Area
Pit Management Area
Riparian Management Area
Slope Management Area
Upland Management Area
0
200
400
Feet
N
Wilbur Ave
Burlington Northern Santa Fe
Source: USFWS, Esri Basemaps, 2022
GeomorphIS, 3/1/2023

APPENDIX B. CROSS WALK OF GRID CELL NUMBERS USED IN 2017 AND 2023

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	A44	0
Sardis	A45	1
Sardis	A46	2
Sardis	A47	3
Sardis	A48	4
Sardis	A49	5
Sardis	A50	6
Sardis	A51	7
Sardis	A52	8
Sardis	A53	9
Sardis	A54	10
Sardis	A55	11
Sardis	A56	12
Sardis	A57	13
Sardis	A58	14
Sardis	A59	15
Sardis	A60	16
Sardis	A61	17
Sardis	A62	18
Sardis	A63	19
Sardis	A64	20
Sardis	A65	21
Sardis	A66	22
Sardis	A67	23
Sardis	A68	24
Sardis	A69	25
Sardis	A70	26
Sardis	A71	27
Sardis	A72	28
Sardis	A73	29
Sardis	A74	30
Sardis	A75	31
Sardis	A76	32
Sardis	B44	33
Sardis	B45	34
Sardis	B46	35
Sardis	B47	36
Sardis	B48	37
Sardis	B49	38
Sardis	B50	39
Sardis	B51	40

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	B52	41
Sardis	B53	42
Sardis	B54	43
Sardis	B55	44
Sardis	B56	45
Sardis	B57	46
Sardis	B58	47
Sardis	B59	48
Sardis	B60	49
Sardis	B61	50
Sardis	B62	51
Sardis	B63	52
Sardis	B64	53
Sardis	B65	54
Sardis	B66	55
Sardis	B67	56
Sardis	B68	57
Sardis	B69	58
Sardis	B70	59
Sardis	B71	60
Sardis	B72	61
Sardis	B73	62
Sardis	B74	63
Sardis	B75	64
Sardis	B76	65
Sardis	C44	66
Sardis	C45	67
Sardis	C46	68
Sardis	C47	69
Sardis	C48	70
Sardis	C49	71
Sardis	C50	72
Sardis	C51	73
Sardis	C52	74
Sardis	C53	75
Sardis	C54	76
Sardis	C55	77
Sardis	C56	78
Sardis	C57	79
Sardis	C58	80
Sardis	C59	81
Sardis	C60	82
Sardis	C61	83

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	C62	84
Sardis	C63	85
Sardis	C64	86
Sardis	C65	87
Sardis	C66	88
Sardis	C67	89
Sardis	C68	90
Sardis	C69	91
Sardis	C70	92
Sardis	C71	93
Sardis	C72	94
Sardis	C73	95
Sardis	C74	96
Sardis	C75	97
Sardis	C76	98
Sardis	D44	99
Sardis	D45	100
Sardis	D46	101
Sardis	D47	102
Sardis	D48	103
Sardis	D49	104
Sardis	D50	105
Sardis	D51	106
Sardis	D52	107
Sardis	D53	108
Sardis	D54	109
Sardis	D55	110
Sardis	D56	111
Sardis	D57	112
Sardis	D58	113
Sardis	D59	114
Sardis	D60	115
Sardis	D61	116
Sardis	D62	117
Sardis	D63	118
Sardis	D64	119
Sardis	D65	120
Sardis	D66	121
Sardis	D67	122
Sardis	D68	123
Sardis	D69	124
Sardis	D70	125
Sardis	D71	126

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	D72	127
Sardis	D73	128
Sardis	D74	129
Sardis	D75	130
Sardis	D76	131
Sardis	E44	132
Sardis	E45	133
Sardis	E46	134
Sardis	E47	135
Sardis	E48	136
Sardis	E49	137
Sardis	E50	138
Sardis	E51	139
Sardis	E52	140
Sardis	E53	141
Sardis	E54	142
Sardis	E55	143
Sardis	E56	144
Sardis	E57	145
Sardis	E58	146
Sardis	E59	147
Sardis	E60	148
Sardis	E61	149
Sardis	E62	150
Sardis	E63	151
Sardis	E64	152
Sardis	E65	153
Sardis	E66	154
Sardis	E67	155
Sardis	E68	156
Sardis	E69	157
Sardis	E70	158
Sardis	E71	159
Sardis	E72	160
Sardis	E73	161
Sardis	E74	162
Sardis	E75	163
Sardis	E76	164
Sardis	F44	165
Sardis	F45	166
Sardis	F46	167
Sardis	F47	168
Sardis	F48	169

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	F49	170
Sardis	F50	171
Sardis	F51	172
Sardis	F52	173
Sardis	F53	174
Sardis	F54	175
Sardis	F55	176
Sardis	F56	177
Sardis	F57	178
Sardis	F58	179
Sardis	F59	180
Sardis	F60	181
Sardis	F61	182
Sardis	F62	183
Sardis	F63	184
Sardis	F64	185
Sardis	F65	186
Sardis	F66	187
Sardis	F67	188
Sardis	F68	189
Sardis	F69	190
Sardis	F70	191
Sardis	F71	192
Sardis	F72	193
Sardis	F73	194
Sardis	F74	195
Sardis	F75	196
Sardis	F76	197
Sardis	G44	198
Sardis	G45	199
Sardis	G46	200
Sardis	G47	201
Sardis	G48	202
Sardis	G49	203
Sardis	G50	204
Sardis	G51	205
Sardis	G52	206
Sardis	G53	207
Sardis	G54	208
Sardis	G55	209
Sardis	G56	210
Sardis	G57	211
Sardis	G58	212

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	G59	213
Sardis	G60	214
Sardis	G61	215
Sardis	G62	216
Sardis	G63	217
Sardis	G64	218
Sardis	G65	219
Sardis	G66	220
Sardis	G67	221
Sardis	G68	222
Sardis	G69	223
Sardis	G70	224
Sardis	G71	225
Sardis	G72	226
Sardis	G73	227
Sardis	G74	228
Sardis	G75	229
Sardis	G76	230
Sardis	H44	231
Sardis	H45	232
Sardis	H46	233
Sardis	H47	234
Sardis	H48	235
Sardis	H49	236
Sardis	H50	237
Sardis	H51	238
Sardis	H52	239
Sardis	H53	240
Sardis	H54	241
Sardis	H55	242
Sardis	H56	243
Sardis	H57	244
Sardis	H58	245
Sardis	H59	246
Sardis	H60	247
Sardis	H61	248
Sardis	H62	249
Sardis	H63	250
Sardis	H64	251
Sardis	H65	252
Sardis	H66	253
Sardis	H67	254
Sardis	H68	255

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	H69	256
Sardis	H70	257
Sardis	H71	258
Sardis	H72	259
Sardis	H73	260
Sardis	H74	261
Sardis	H75	262
Sardis	H76	263
Sardis	I44	264
Sardis	I45	265
Sardis	I46	266
Sardis	I47	267
Sardis	I48	268
Sardis	I49	269
Sardis	I50	270
Sardis	I51	271
Sardis	I52	272
Sardis	I53	273
Sardis	I54	274
Sardis	I55	275
Sardis	I56	276
Sardis	I57	277
Sardis	I58	278
Sardis	I59	279
Sardis	I60	280
Sardis	I61	281
Sardis	I62	282
Sardis	I63	283
Sardis	I64	284
Sardis	I65	285
Sardis	I66	286
Sardis	I67	287
Sardis	I68	288
Sardis	I69	289
Sardis	I70	290
Sardis	I71	291
Sardis	I72	292
Sardis	I73	293
Sardis	I74	294
Sardis	I75	295
Sardis	I76	296
Sardis	J44	297
Sardis	J45	298

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	J46	299
Sardis	J47	300
Sardis	J48	301
Sardis	J49	302
Sardis	J50	303
Sardis	J51	304
Sardis	J52	305
Sardis	J53	306
Sardis	J54	307
Sardis	J55	308
Sardis	J56	309
Sardis	J57	310
Sardis	J58	311
Sardis	J59	312
Sardis	J60	313
Sardis	J61	314
Sardis	J62	315
Sardis	J63	316
Sardis	J64	317
Sardis	J65	318
Sardis	J66	319
Sardis	J67	320
Sardis	J68	321
Sardis	J69	322
Sardis	J70	323
Sardis	J71	324
Sardis	J72	325
Sardis	J73	326
Sardis	J74	327
Sardis	J75	328
Sardis	J76	329
Sardis	K44	330
Sardis	K45	331
Sardis	K46	332
Sardis	K47	333
Sardis	K48	334
Sardis	K49	335
Sardis	K50	336
Sardis	K51	337
Sardis	K52	338
Sardis	K53	339
Sardis	K54	340
Sardis	K55	341

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	K56	342
Sardis	K57	343
Sardis	K58	344
Sardis	K59	345
Sardis	K60	346
Sardis	K61	347
Sardis	K62	348
Sardis	K63	349
Sardis	K64	350
Sardis	K65	351
Sardis	K66	352
Sardis	K67	353
Sardis	K68	354
Sardis	K69	355
Sardis	K70	356
Sardis	K71	357
Sardis	K72	358
Sardis	K73	359
Sardis	K74	360
Sardis	K75	361
Sardis	K76	362
Sardis	L44	363
Sardis	L45	364
Sardis	L46	365
Sardis	L47	366
Sardis	L48	367
Sardis	L49	368
Sardis	L50	369
Sardis	L51	370
Sardis	L52	371
Sardis	L53	372
Sardis	L54	373
Sardis	L55	374
Sardis	L56	375
Sardis	L57	376
Sardis	L58	377
Sardis	L59	378
Sardis	L60	379
Sardis	L61	380
Sardis	L62	381
Sardis	L63	382
Sardis	L64	383
Sardis	L65	384

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	L66	385
Sardis	L67	386
Sardis	L68	387
Sardis	L69	388
Sardis	L70	389
Sardis	L71	390
Sardis	L72	391
Sardis	L73	392
Sardis	L74	393
Sardis	L75	394
Sardis	L76	395
Sardis	M44	396
Sardis	M45	397
Sardis	M46	398
Sardis	M47	399
Sardis	M48	400
Sardis	M49	401
Sardis	M50	402
Sardis	M51	403
Sardis	M52	404
Sardis	M53	405
Sardis	M54	406
Sardis	M55	407
Sardis	M56	408
Sardis	M57	409
Sardis	M58	410
Sardis	M59	411
Sardis	M60	412
Sardis	M61	413
Sardis	M62	414
Sardis	M63	415
Sardis	M64	416
Sardis	M65	417
Sardis	M66	418
Sardis	M67	419
Sardis	M68	420
Sardis	M69	421
Sardis	M70	422
Sardis	M71	423
Sardis	M72	424
Sardis	M73	425
Sardis	M74	426
Sardis	M75	427

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	M76	428
Sardis	N44	429
Sardis	N45	430
Sardis	N46	431
Sardis	N47	432
Sardis	N48	433
Sardis	N49	434
Sardis	N50	435
Sardis	N51	436
Sardis	N52	437
Sardis	N53	438
Sardis	N54	439
Sardis	N55	440
Sardis	N56	441
Sardis	N57	442
Sardis	N58	443
Sardis	N59	444
Sardis	N60	445
Sardis	N61	446
Sardis	N62	447
Sardis	N63	448
Sardis	N64	449
Sardis	N65	450
Sardis	N66	451
Sardis	N67	452
Sardis	N68	453
Sardis	N69	454
Sardis	N70	455
Sardis	N71	456
Sardis	N72	457
Sardis	N73	458
Sardis	N74	459
Sardis	N75	460
Sardis	N76	461
Sardis	O44	462
Sardis	O45	463
Sardis	O46	464
Sardis	O47	465
Sardis	O48	466
Sardis	O49	467
Sardis	O50	468
Sardis	O51	469
Sardis	O52	470

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	O53	471
Sardis	O54	472
Sardis	O55	473
Sardis	O56	474
Sardis	O57	475
Sardis	O58	476
Sardis	O59	477
Sardis	O60	478
Sardis	O61	479
Sardis	O62	480
Sardis	O63	481
Sardis	O64	482
Sardis	O65	483
Sardis	O66	484
Sardis	O67	485
Sardis	O68	486
Sardis	O69	487
Sardis	O70	488
Sardis	O71	489
Sardis	O72	490
Sardis	O73	491
Sardis	O74	492
Sardis	O75	493
Sardis	O76	494
Sardis	P44	495
Sardis	P45	496
Sardis	P46	497
Sardis	P47	498
Sardis	P48	499
Sardis	P49	500
Sardis	P50	501
Sardis	P51	502
Sardis	P52	503
Sardis	P53	504
Sardis	P54	505
Sardis	P55	506
Sardis	P56	507
Sardis	P57	508
Sardis	P58	509
Sardis	P59	510
Sardis	P60	511
Sardis	P61	512
Sardis	P62	513

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	P63	514
Sardis	P64	515
Sardis	P65	516
Sardis	P66	517
Sardis	P67	518
Sardis	P68	519
Sardis	P69	520
Sardis	P70	521
Sardis	P71	522
Sardis	P72	523
Sardis	P73	524
Sardis	P74	525
Sardis	P75	526
Sardis	P76	527
Sardis	Q44	528
Sardis	Q45	529
Sardis	Q46	530
Sardis	Q47	531
Sardis	Q48	532
Sardis	Q49	533
Sardis	Q50	534
Sardis	Q51	535
Sardis	Q52	536
Sardis	Q53	537
Sardis	Q54	538
Sardis	Q55	539
Sardis	Q56	540
Sardis	Q57	541
Sardis	Q58	542
Sardis	Q59	543
Sardis	Q60	544
Sardis	Q61	545
Sardis	Q62	546
Sardis	Q63	547
Sardis	Q64	548
Sardis	Q65	549
Sardis	Q66	550
Sardis	Q67	551
Sardis	Q68	552
Sardis	Q69	553
Sardis	Q70	554
Sardis	Q71	555
Sardis	Q72	556

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	Q73	557
Sardis	Q74	558
Sardis	Q75	559
Sardis	Q76	560
Sardis	R44	561
Sardis	R45	562
Sardis	R46	563
Sardis	R47	564
Sardis	R48	565
Sardis	R49	566
Sardis	R50	567
Sardis	R51	568
Sardis	R52	569
Sardis	R53	570
Sardis	R54	571
Sardis	R55	572
Sardis	R56	573
Sardis	R57	574
Sardis	R58	575
Sardis	R59	576
Sardis	R60	577
Sardis	R61	578
Sardis	R62	579
Sardis	R63	580
Sardis	R64	581
Sardis	R65	582
Sardis	R66	583
Sardis	R67	584
Sardis	R68	585
Sardis	R69	586
Sardis	R70	587
Sardis	R71	588
Sardis	R72	589
Sardis	R73	590
Sardis	R74	591
Sardis	R75	592
Sardis	R76	593
Sardis	S44	594
Sardis	S45	595
Sardis	S46	596
Sardis	S47	597
Sardis	S48	598
Sardis	S49	599

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	S50	600
Sardis	S51	601
Sardis	S52	602
Sardis	S53	603
Sardis	S54	604
Sardis	S55	605
Sardis	S56	606
Sardis	S57	607
Sardis	S58	608
Sardis	S59	609
Sardis	S60	610
Sardis	S61	611
Sardis	S62	612
Sardis	S63	613
Sardis	S64	614
Sardis	S65	615
Sardis	S66	616
Sardis	S67	617
Sardis	S68	618
Sardis	S69	619
Sardis	S70	620
Sardis	S71	621
Sardis	S72	622
Sardis	S73	623
Sardis	S74	624
Sardis	S75	625
Sardis	S76	626
Sardis	T44	627
Sardis	T45	628
Sardis	T46	629
Sardis	T47	630
Sardis	T48	631
Sardis	T49	632
Sardis	T50	633
Sardis	T51	634
Sardis	T52	635
Sardis	T53	636
Sardis	T54	637
Sardis	T55	638
Sardis	T56	639
Sardis	T57	640
Sardis	T58	641
Sardis	T59	642

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Sardis	T60	643
Sardis	T61	644
Sardis	T62	645
Sardis	T63	646
Sardis	T64	647
Sardis	T65	648
Sardis	T66	649
Sardis	T67	650
Sardis	T68	651
Sardis	T69	652
Sardis	T70	653
Sardis	T71	654
Sardis	T72	655
Sardis	T73	656
Sardis	T74	657
Sardis	T75	658
Sardis	T76	659
Stamm	A1	0
Stamm	A2	1
Stamm	A3	2
Stamm	A4	3
Stamm	A5	4
Stamm	A6	5
Stamm	A7	6
Stamm	A8	7
Stamm	A9	8
Stamm	A10	9
Stamm	A11	10
Stamm	A12	11
Stamm	A13	12
Stamm	A14	13
Stamm	A15	14
Stamm	A16	15
Stamm	A17	16
Stamm	A18	17
Stamm	A19	18
Stamm	A20	19
Stamm	A21	20
Stamm	A22	21
Stamm	A23	22
Stamm	A24	23
Stamm	A25	24
Stamm	A26	25

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	A27	26
Stamm	A28	27
Stamm	A29	28
Stamm	A30	29
Stamm	A31	30
Stamm	A32	31
Stamm	A33	32
Stamm	A34	33
Stamm	A35	34
Stamm	A36	35
Stamm	A37	36
Stamm	A38	37
Stamm	A39	38
Stamm	A40	39
Stamm	A41	40
Stamm	A42	41
Stamm	A43	42
Stamm	B1	43
Stamm	B2	44
Stamm	B3	45
Stamm	B4	46
Stamm	B5	47
Stamm	B6	48
Stamm	B7	49
Stamm	B8	50
Stamm	B9	51
Stamm	B10	52
Stamm	B11	53
Stamm	B12	54
Stamm	B13	55
Stamm	B14	56
Stamm	B15	57
Stamm	B16	58
Stamm	B17	59
Stamm	B18	60
Stamm	B19	61
Stamm	B20	62
Stamm	B21	63
Stamm	B22	64
Stamm	B23	65
Stamm	B24	66
Stamm	B25	67
Stamm	B26	68

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	B27	69
Stamm	B28	70
Stamm	B29	71
Stamm	B30	72
Stamm	B31	73
Stamm	B32	74
Stamm	B33	75
Stamm	B34	76
Stamm	B35	77
Stamm	B36	78
Stamm	B37	79
Stamm	B38	80
Stamm	B39	81
Stamm	B40	82
Stamm	B41	83
Stamm	B42	84
Stamm	B43	85
Stamm	C1	86
Stamm	C2	87
Stamm	C3	88
Stamm	C4	89
Stamm	C5	90
Stamm	C6	91
Stamm	C7	92
Stamm	C8	93
Stamm	C9	94
Stamm	C10	95
Stamm	C11	96
Stamm	C12	97
Stamm	C13	98
Stamm	C14	99
Stamm	C15	100
Stamm	C16	101
Stamm	C17	102
Stamm	C18	103
Stamm	C19	104
Stamm	C20	105
Stamm	C21	106
Stamm	C22	107
Stamm	C23	108
Stamm	C24	109
Stamm	C25	110
Stamm	C26	111

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	C27	112
Stamm	C28	113
Stamm	C29	114
Stamm	C30	115
Stamm	C31	116
Stamm	C32	117
Stamm	C33	118
Stamm	C34	119
Stamm	C35	120
Stamm	C36	121
Stamm	C37	122
Stamm	C38	123
Stamm	C39	124
Stamm	C40	125
Stamm	C41	126
Stamm	C42	127
Stamm	C43	128
Stamm	D1	129
Stamm	D2	130
Stamm	D3	131
Stamm	D4	132
Stamm	D5	133
Stamm	D6	134
Stamm	D7	135
Stamm	D8	136
Stamm	D9	137
Stamm	D10	138
Stamm	D11	139
Stamm	D12	140
Stamm	D13	141
Stamm	D14	142
Stamm	D15	143
Stamm	D16	144
Stamm	D17	145
Stamm	D18	146
Stamm	D19	147
Stamm	D20	148
Stamm	D21	149
Stamm	D22	150
Stamm	D23	151
Stamm	D24	152
Stamm	D25	153
Stamm	D26	154

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	D27	155
Stamm	D28	156
Stamm	D29	157
Stamm	D30	158
Stamm	D31	159
Stamm	D32	160
Stamm	D33	161
Stamm	D34	162
Stamm	D35	163
Stamm	D36	164
Stamm	D37	165
Stamm	D38	166
Stamm	D39	167
Stamm	D40	168
Stamm	D41	169
Stamm	D42	170
Stamm	D43	171
Stamm	E1	172
Stamm	E2	173
Stamm	E3	174
Stamm	E4	175
Stamm	E5	176
Stamm	E6	177
Stamm	E7	178
Stamm	E8	179
Stamm	E9	180
Stamm	E10	181
Stamm	E11	182
Stamm	E12	183
Stamm	E13	184
Stamm	E14	185
Stamm	E15	186
Stamm	E16	187
Stamm	E17	188
Stamm	E18	189
Stamm	E19	190
Stamm	E20	191
Stamm	E21	192
Stamm	E22	193
Stamm	E23	194
Stamm	E24	195
Stamm	E25	196
Stamm	E26	197

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	E27	198
Stamm	E28	199
Stamm	E29	200
Stamm	E30	201
Stamm	E31	202
Stamm	E32	203
Stamm	E33	204
Stamm	E34	205
Stamm	E35	206
Stamm	E36	207
Stamm	E37	208
Stamm	E38	209
Stamm	E39	210
Stamm	E40	211
Stamm	E41	212
Stamm	E42	213
Stamm	E43	214
Stamm	F1	215
Stamm	F2	216
Stamm	F3	217
Stamm	F4	218
Stamm	F5	219
Stamm	F6	220
Stamm	F7	221
Stamm	F8	222
Stamm	F9	223
Stamm	F10	224
Stamm	F11	225
Stamm	F12	226
Stamm	F13	227
Stamm	F14	228
Stamm	F15	229
Stamm	F16	230
Stamm	F17	231
Stamm	F18	232
Stamm	F19	233
Stamm	F20	234
Stamm	F21	235
Stamm	F22	236
Stamm	F23	237
Stamm	F24	238
Stamm	F25	239
Stamm	F26	240

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	F27	241
Stamm	F28	242
Stamm	F29	243
Stamm	F30	244
Stamm	F31	245
Stamm	F32	246
Stamm	F33	247
Stamm	F34	248
Stamm	F35	249
Stamm	F36	250
Stamm	F37	251
Stamm	F38	252
Stamm	F39	253
Stamm	F40	254
Stamm	F41	255
Stamm	F42	256
Stamm	F43	257
Stamm	G1	258
Stamm	G2	259
Stamm	G3	260
Stamm	G4	261
Stamm	G5	262
Stamm	G6	263
Stamm	G7	264
Stamm	G8	265
Stamm	G9	266
Stamm	G10	267
Stamm	G11	268
Stamm	G12	269
Stamm	G13	270
Stamm	G14	271
Stamm	G15	272
Stamm	G16	273
Stamm	G17	274
Stamm	G18	275
Stamm	G19	276
Stamm	G20	277
Stamm	G21	278
Stamm	G22	279
Stamm	G23	280
Stamm	G24	281
Stamm	G25	282
Stamm	G26	283

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	G27	284
Stamm	G28	285
Stamm	G29	286
Stamm	G30	287
Stamm	G31	288
Stamm	G32	289
Stamm	G33	290
Stamm	G34	291
Stamm	G35	292
Stamm	G36	293
Stamm	G37	294
Stamm	G38	295
Stamm	G39	296
Stamm	G40	297
Stamm	G41	298
Stamm	G42	299
Stamm	G43	300
Stamm	H1	301
Stamm	H2	302
Stamm	H3	303
Stamm	H4	304
Stamm	H5	305
Stamm	H6	306
Stamm	H7	307
Stamm	H8	308
Stamm	H9	309
Stamm	H10	310
Stamm	H11	311
Stamm	H12	312
Stamm	H13	313
Stamm	H14	314
Stamm	H15	315
Stamm	H16	316
Stamm	H17	317
Stamm	H18	318
Stamm	H19	319
Stamm	H20	320
Stamm	H21	321
Stamm	H22	322
Stamm	H23	323
Stamm	H24	324
Stamm	H25	325
Stamm	H26	326

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	H27	327
Stamm	H28	328
Stamm	H29	329
Stamm	H30	330
Stamm	H31	331
Stamm	H32	332
Stamm	H33	333
Stamm	H34	334
Stamm	H35	335
Stamm	H36	336
Stamm	H37	337
Stamm	H38	338
Stamm	H39	339
Stamm	H40	340
Stamm	H41	341
Stamm	H42	342
Stamm	H43	343
Stamm	I1	344
Stamm	I2	345
Stamm	I3	346
Stamm	I4	347
Stamm	I5	348
Stamm	I6	349
Stamm	I7	350
Stamm	I8	351
Stamm	I9	352
Stamm	I10	353
Stamm	I11	354
Stamm	I12	355
Stamm	I13	356
Stamm	I14	357
Stamm	I15	358
Stamm	I16	359
Stamm	I17	360
Stamm	I18	361
Stamm	I19	362
Stamm	I20	363
Stamm	I21	364
Stamm	I22	365
Stamm	I23	366
Stamm	I24	367
Stamm	I25	368
Stamm	I26	369

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	I27	370
Stamm	I28	371
Stamm	I29	372
Stamm	I30	373
Stamm	I31	374
Stamm	I32	375
Stamm	I33	376
Stamm	I34	377
Stamm	I35	378
Stamm	I36	379
Stamm	I37	380
Stamm	I38	381
Stamm	I39	382
Stamm	I40	383
Stamm	I41	384
Stamm	I42	385
Stamm	I43	386
Stamm	J1	387
Stamm	J2	388
Stamm	J3	389
Stamm	J4	390
Stamm	J5	391
Stamm	J6	392
Stamm	J7	393
Stamm	J8	394
Stamm	J9	395
Stamm	J10	396
Stamm	J11	397
Stamm	J12	398
Stamm	J13	399
Stamm	J14	400
Stamm	J15	401
Stamm	J16	402
Stamm	J17	403
Stamm	J18	404
Stamm	J19	405
Stamm	J20	406
Stamm	J21	407
Stamm	J22	408
Stamm	J23	409
Stamm	J24	410
Stamm	J25	411
Stamm	J26	412

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	J27	413
Stamm	J28	414
Stamm	J29	415
Stamm	J30	416
Stamm	J31	417
Stamm	J32	418
Stamm	J33	419
Stamm	J34	420
Stamm	J35	421
Stamm	J36	422
Stamm	J37	423
Stamm	J38	424
Stamm	J39	425
Stamm	J40	426
Stamm	J41	427
Stamm	J42	428
Stamm	J43	429
Stamm	K1	430
Stamm	K2	431
Stamm	K3	432
Stamm	K4	433
Stamm	K5	434
Stamm	K6	435
Stamm	K7	436
Stamm	K8	437
Stamm	K9	438
Stamm	K10	439
Stamm	K11	440
Stamm	K12	441
Stamm	K13	442
Stamm	K14	443
Stamm	K15	444
Stamm	K16	445
Stamm	K17	446
Stamm	K18	447
Stamm	K19	448
Stamm	K20	449
Stamm	K21	450
Stamm	K22	451
Stamm	K23	452
Stamm	K24	453
Stamm	K25	454
Stamm	K26	455

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	K27	456
Stamm	K28	457
Stamm	K29	458
Stamm	K30	459
Stamm	K31	460
Stamm	K32	461
Stamm	K33	462
Stamm	K34	463
Stamm	K35	464
Stamm	K36	465
Stamm	K37	466
Stamm	K38	467
Stamm	K39	468
Stamm	K40	469
Stamm	K41	470
Stamm	K42	471
Stamm	K43	472
Stamm	L1	473
Stamm	L2	474
Stamm	L3	475
Stamm	L4	476
Stamm	L5	477
Stamm	L6	478
Stamm	L7	479
Stamm	L8	480
Stamm	L9	481
Stamm	L10	482
Stamm	L11	483
Stamm	L12	484
Stamm	L13	485
Stamm	L14	486
Stamm	L15	487
Stamm	L16	488
Stamm	L17	489
Stamm	L18	490
Stamm	L19	491
Stamm	L20	492
Stamm	L21	493
Stamm	L22	494
Stamm	L23	495
Stamm	L24	496
Stamm	L25	497
Stamm	L26	498

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	L27	499
Stamm	L28	500
Stamm	L29	501
Stamm	L30	502
Stamm	L31	503
Stamm	L32	504
Stamm	L33	505
Stamm	L34	506
Stamm	L35	507
Stamm	L36	508
Stamm	L37	509
Stamm	L38	510
Stamm	L39	511
Stamm	L40	512
Stamm	L41	513
Stamm	L42	514
Stamm	L43	515
Stamm	M1	516
Stamm	M2	517
Stamm	M3	518
Stamm	M4	519
Stamm	M5	520
Stamm	M6	521
Stamm	M7	522
Stamm	M8	523
Stamm	M9	524
Stamm	M10	525
Stamm	M11	526
Stamm	M12	527
Stamm	M13	528
Stamm	M14	529
Stamm	M15	530
Stamm	M16	531
Stamm	M17	532
Stamm	M18	533
Stamm	M19	534
Stamm	M20	535
Stamm	M21	536
Stamm	M22	537
Stamm	M23	538
Stamm	M24	539
Stamm	M25	540
Stamm	M26	541

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	M27	542
Stamm	M28	543
Stamm	M29	544
Stamm	M30	545
Stamm	M31	546
Stamm	M32	547
Stamm	M33	548
Stamm	M34	549
Stamm	M35	550
Stamm	M36	551
Stamm	M37	552
Stamm	M38	553
Stamm	M39	554
Stamm	M40	555
Stamm	M41	556
Stamm	M42	557
Stamm	M43	558
Stamm	N1	559
Stamm	N2	560
Stamm	N3	561
Stamm	N4	562
Stamm	N5	563
Stamm	N6	564
Stamm	N7	565
Stamm	N8	566
Stamm	N9	567
Stamm	N10	568
Stamm	N11	569
Stamm	N12	570
Stamm	N13	571
Stamm	N14	572
Stamm	N15	573
Stamm	N16	574
Stamm	N17	575
Stamm	N18	576
Stamm	N19	577
Stamm	N20	578
Stamm	N21	579
Stamm	N22	580
Stamm	N23	581
Stamm	N24	582
Stamm	N25	583
Stamm	N26	584

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	N27	585
Stamm	N28	586
Stamm	N29	587
Stamm	N30	588
Stamm	N31	589
Stamm	N32	590
Stamm	N33	591
Stamm	N34	592
Stamm	N35	593
Stamm	N36	594
Stamm	N37	595
Stamm	N38	596
Stamm	N39	597
Stamm	N40	598
Stamm	N41	599
Stamm	N42	600
Stamm	N43	601
Stamm	O1	602
Stamm	O2	603
Stamm	O3	604
Stamm	O4	605
Stamm	O5	606
Stamm	O6	607
Stamm	O7	608
Stamm	O8	609
Stamm	O9	610
Stamm	O10	611
Stamm	O11	612
Stamm	O12	613
Stamm	O13	614
Stamm	O14	615
Stamm	O15	616
Stamm	O16	617
Stamm	O17	618
Stamm	O18	619
Stamm	O19	620
Stamm	O20	621
Stamm	O21	622
Stamm	O22	623
Stamm	O23	624
Stamm	O24	625
Stamm	O25	626
Stamm	O26	627

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	O27	628
Stamm	O28	629
Stamm	O29	630
Stamm	O30	631
Stamm	O31	632
Stamm	O32	633
Stamm	O33	634
Stamm	O34	635
Stamm	O35	636
Stamm	O36	637
Stamm	O37	638
Stamm	O38	639
Stamm	O39	640
Stamm	O40	641
Stamm	O41	642
Stamm	O42	643
Stamm	O43	644
Stamm	P1	645
Stamm	P2	646
Stamm	P3	647
Stamm	P4	648
Stamm	P5	649
Stamm	P6	650
Stamm	P7	651
Stamm	P8	652
Stamm	P9	653
Stamm	P10	654
Stamm	P11	655
Stamm	P12	656
Stamm	P13	657
Stamm	P14	658
Stamm	P15	659
Stamm	P16	660
Stamm	P17	661
Stamm	P18	662
Stamm	P19	663
Stamm	P20	664
Stamm	P21	665
Stamm	P22	666
Stamm	P23	667
Stamm	P24	668
Stamm	P25	669
Stamm	P26	670

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	P27	671
Stamm	P28	672
Stamm	P29	673
Stamm	P30	674
Stamm	P31	675
Stamm	P32	676
Stamm	P33	677
Stamm	P34	678
Stamm	P35	679
Stamm	P36	680
Stamm	P37	681
Stamm	P38	682
Stamm	P39	683
Stamm	P40	684
Stamm	P41	685
Stamm	P42	686
Stamm	P43	687
Stamm	Q1	688
Stamm	Q2	689
Stamm	Q3	690
Stamm	Q4	691
Stamm	Q5	692
Stamm	Q6	693
Stamm	Q7	694
Stamm	Q8	695
Stamm	Q9	696
Stamm	Q10	697
Stamm	Q11	698
Stamm	Q12	699
Stamm	Q13	700
Stamm	Q14	701
Stamm	Q15	702
Stamm	Q16	703
Stamm	Q17	704
Stamm	Q18	705
Stamm	Q19	706
Stamm	Q20	707
Stamm	Q21	708
Stamm	Q22	709
Stamm	Q23	710
Stamm	Q24	711
Stamm	Q25	712
Stamm	Q26	713

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	Q27	714
Stamm	Q28	715
Stamm	Q29	716
Stamm	Q30	717
Stamm	Q31	718
Stamm	Q32	719
Stamm	Q33	720
Stamm	Q34	721
Stamm	Q35	722
Stamm	Q36	723
Stamm	Q37	724
Stamm	Q38	725
Stamm	Q39	726
Stamm	Q40	727
Stamm	Q41	728
Stamm	Q42	729
Stamm	Q43	730
Stamm	R1	731
Stamm	R2	732
Stamm	R3	733
Stamm	R4	734
Stamm	R5	735
Stamm	R6	736
Stamm	R7	737
Stamm	R8	738
Stamm	R9	739
Stamm	R10	740
Stamm	R11	741
Stamm	R12	742
Stamm	R13	743
Stamm	R14	744
Stamm	R15	745
Stamm	R16	746
Stamm	R17	747
Stamm	R18	748
Stamm	R19	749
Stamm	R20	750
Stamm	R21	751
Stamm	R22	752
Stamm	R23	753
Stamm	R24	754
Stamm	R25	755
Stamm	R26	756

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	R27	757
Stamm	R28	758
Stamm	R29	759
Stamm	R30	760
Stamm	R31	761
Stamm	R32	762
Stamm	R33	763
Stamm	R34	764
Stamm	R35	765
Stamm	R36	766
Stamm	R37	767
Stamm	R38	768
Stamm	R39	769
Stamm	R40	770
Stamm	R41	771
Stamm	R42	772
Stamm	R43	773
Stamm	S1	774
Stamm	S2	775
Stamm	S3	776
Stamm	S4	777
Stamm	S5	778
Stamm	S6	779
Stamm	S7	780
Stamm	S8	781
Stamm	S9	782
Stamm	S10	783
Stamm	S11	784
Stamm	S12	785
Stamm	S13	786
Stamm	S14	787
Stamm	S15	788
Stamm	S16	789
Stamm	S17	790
Stamm	S18	791
Stamm	S19	792
Stamm	S20	793
Stamm	S21	794
Stamm	S22	795
Stamm	S23	796
Stamm	S24	797
Stamm	S25	798
Stamm	S26	799

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	S27	800
Stamm	S28	801
Stamm	S29	802
Stamm	S30	803
Stamm	S31	804
Stamm	S32	805
Stamm	S33	806
Stamm	S34	807
Stamm	S35	808
Stamm	S36	809
Stamm	S37	810
Stamm	S38	811
Stamm	S39	812
Stamm	S40	813
Stamm	S41	814
Stamm	S42	815
Stamm	S43	816
Stamm	T1	817
Stamm	T2	818
Stamm	T3	819
Stamm	T4	820
Stamm	T5	821
Stamm	T6	822
Stamm	T7	823
Stamm	T8	824
Stamm	T9	825
Stamm	T10	826
Stamm	T11	827
Stamm	T12	828
Stamm	T13	829
Stamm	T14	830
Stamm	T15	831
Stamm	T16	832
Stamm	T17	833
Stamm	T18	834
Stamm	T19	835
Stamm	T20	836
Stamm	T21	837
Stamm	T22	838
Stamm	T23	839
Stamm	T24	840
Stamm	T25	841
Stamm	T26	842

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	T27	843
Stamm	T28	844
Stamm	T29	845
Stamm	T30	846
Stamm	T31	847
Stamm	T32	848
Stamm	T33	849
Stamm	T34	850
Stamm	T35	851
Stamm	T36	852
Stamm	T37	853
Stamm	T38	854
Stamm	T39	855
Stamm	T40	856
Stamm	T41	857
Stamm	T42	858
Stamm	T43	859
Stamm	U1	860
Stamm	U2	861
Stamm	U3	862
Stamm	U4	863
Stamm	U5	864
Stamm	U6	865
Stamm	U7	866
Stamm	U8	867
Stamm	U9	868
Stamm	U10	869
Stamm	U11	870
Stamm	U12	871
Stamm	U13	872
Stamm	U14	873
Stamm	U15	874
Stamm	U16	875
Stamm	U17	876
Stamm	U18	877
Stamm	U19	878
Stamm	U20	879
Stamm	U21	880
Stamm	U22	881
Stamm	U23	882
Stamm	U24	883
Stamm	U25	884
Stamm	U26	885

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	U27	886
Stamm	U28	887
Stamm	U29	888
Stamm	U30	889
Stamm	U31	890
Stamm	U32	891
Stamm	U33	892
Stamm	U34	893
Stamm	U35	894
Stamm	U36	895
Stamm	U37	896
Stamm	U38	897
Stamm	U39	898
Stamm	U40	899
Stamm	U41	900
Stamm	U42	901
Stamm	U43	902
Stamm	V1	903
Stamm	V2	904
Stamm	V3	905
Stamm	V4	906
Stamm	V5	907
Stamm	V6	908
Stamm	V7	909
Stamm	V8	910
Stamm	V9	911
Stamm	V10	912
Stamm	V11	913
Stamm	V12	914
Stamm	V13	915
Stamm	V14	916
Stamm	V15	917
Stamm	V16	918
Stamm	V17	919
Stamm	V18	920
Stamm	V19	921
Stamm	V20	922
Stamm	V21	923
Stamm	V22	924
Stamm	V23	925
Stamm	V24	926
Stamm	V25	927
Stamm	V26	928

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	V27	929
Stamm	V28	930
Stamm	V29	931
Stamm	V30	932
Stamm	V31	933
Stamm	V32	934
Stamm	V33	935
Stamm	V34	936
Stamm	V35	937
Stamm	V36	938
Stamm	V37	939
Stamm	V38	940
Stamm	V39	941
Stamm	V40	942
Stamm	V41	943
Stamm	V42	944
Stamm	V43	945
Stamm	W1	946
Stamm	W2	947
Stamm	W3	948
Stamm	W4	949
Stamm	W5	950
Stamm	W6	951
Stamm	W7	952
Stamm	W8	953
Stamm	W9	954
Stamm	W10	955
Stamm	W11	956
Stamm	W12	957
Stamm	W13	958
Stamm	W14	959
Stamm	W15	960
Stamm	W16	961
Stamm	W17	962
Stamm	W18	963
Stamm	W19	964
Stamm	W20	965
Stamm	W21	966
Stamm	W22	967
Stamm	W23	968
Stamm	W24	969
Stamm	W25	970
Stamm	W26	971

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	W27	972
Stamm	W28	973
Stamm	W29	974
Stamm	W30	975
Stamm	W31	976
Stamm	W32	977
Stamm	W33	978
Stamm	W34	979
Stamm	W35	980
Stamm	W36	981
Stamm	W37	982
Stamm	W38	983
Stamm	W39	984
Stamm	W40	985
Stamm	W41	986
Stamm	W42	987
Stamm	W43	988
Stamm	X1	989
Stamm	X2	990
Stamm	X3	991
Stamm	X4	992
Stamm	X5	993
Stamm	X6	994
Stamm	X7	995
Stamm	X8	996
Stamm	X9	997
Stamm	X10	998
Stamm	X11	999
Stamm	X12	1000
Stamm	X13	1001
Stamm	X14	1002
Stamm	X15	1003
Stamm	X16	1004
Stamm	X17	1005
Stamm	X18	1006
Stamm	X19	1007
Stamm	X20	1008
Stamm	X21	1009
Stamm	X22	1010
Stamm	X23	1011
Stamm	X24	1012
Stamm	X25	1013
Stamm	X26	1014

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	X27	1015
Stamm	X28	1016
Stamm	X29	1017
Stamm	X30	1018
Stamm	X31	1019
Stamm	X32	1020
Stamm	X33	1021
Stamm	X34	1022
Stamm	X35	1023
Stamm	X36	1024
Stamm	X37	1025
Stamm	X38	1026
Stamm	X39	1027
Stamm	X40	1028
Stamm	X41	1029
Stamm	X42	1030
Stamm	X43	1031
Stamm	Y1	1032
Stamm	Y2	1033
Stamm	Y3	1034
Stamm	Y4	1035
Stamm	Y5	1036
Stamm	Y6	1037
Stamm	Y7	1038
Stamm	Y8	1039
Stamm	Y9	1040
Stamm	Y10	1041
Stamm	Y11	1042
Stamm	Y12	1043
Stamm	Y13	1044
Stamm	Y14	1045
Stamm	Y15	1046
Stamm	Y16	1047
Stamm	Y17	1048
Stamm	Y18	1049
Stamm	Y19	1050
Stamm	Y20	1051
Stamm	Y21	1052
Stamm	Y22	1053
Stamm	Y23	1054
Stamm	Y24	1055
Stamm	Y25	1056
Stamm	Y26	1057

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	Y27	1058
Stamm	Y28	1059
Stamm	Y29	1060
Stamm	Y30	1061
Stamm	Y31	1062
Stamm	Y32	1063
Stamm	Y33	1064
Stamm	Y34	1065
Stamm	Y35	1066
Stamm	Y36	1067
Stamm	Y37	1068
Stamm	Y38	1069
Stamm	Y39	1070
Stamm	Y40	1071
Stamm	Y41	1072
Stamm	Y42	1073
Stamm	Y43	1074
Stamm	Z1	1075
Stamm	Z2	1076
Stamm	Z3	1077
Stamm	Z4	1078
Stamm	Z5	1079
Stamm	Z6	1080
Stamm	Z7	1081
Stamm	Z8	1082
Stamm	Z9	1083
Stamm	Z10	1084
Stamm	Z11	1085
Stamm	Z12	1086
Stamm	Z13	1087
Stamm	Z14	1088
Stamm	Z15	1089
Stamm	Z16	1090
Stamm	Z17	1091
Stamm	Z18	1092
Stamm	Z19	1093
Stamm	Z20	1094
Stamm	Z21	1095
Stamm	Z22	1096
Stamm	Z23	1097
Stamm	Z24	1098
Stamm	Z25	1099
Stamm	Z26	1100

Unit Name	Grid Cell Number 2023	Grid Cell Number 2017
Stamm	Z27	1101
Stamm	Z28	1102
Stamm	Z29	1103
Stamm	Z30	1104
Stamm	Z31	1105
Stamm	Z32	1106
Stamm	Z33	1107
Stamm	Z34	1108
Stamm	Z35	1109
Stamm	Z36	1110
Stamm	Z37	1111
Stamm	Z38	1112
Stamm	Z39	1113
Stamm	Z40	1114
Stamm	Z41	1115
Stamm	Z42	1116
Stamm	Z43	1117

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Appendix B

Data Dictionary

Feature Classes Created for Antioch Dunes National Wildlife Refuge 2023 Vegetation Inventory

Associated Tables:

- Target native species
- Target invasive species
- Landcover

Data fields included in Target native plants Cover Table:
Definition: The Native plants table was designed to hold survey data linked to the Plant_Survey_Grids polygons, via the GridCellID key. The table provides details for grid cells that have been surveyed, with attributes such as percent cover class, cover midpoint, net acres infested, total target native plant cover, nectar plant cover, and native plant richness.

0 Field Name: GlobalID
Alias: Global ID
Type: String
Length: 3
Definition: Unique identifier calculated in Esri ArcGIS software

1 Field Name: LIT
Alias: Station Literal
Type: String
Length: 8
Definition: USFWS 3-character code of the National Wildlife Refuge, used as a unique identifier. Example: AND

2 Field name: Cmplx_Name
Alias: Complex Name
Type: String
Length: 85
Definition: Name of National Wildlife Refuge Complex the unit is associated with.
Example: San Francisco Bay National Wildlife Refuge Complex

4 Field Name: OrgName
Alias: Organization Name
Type: String

Length: 75
Definition: Official name of the National Wildlife Refuge.
Example: Antioch Dunes National Wildlife Refuge

5 Field Name: Unit_Name
Alias: Unit Name
Type: String
Length: 75
Definition: Name of the individual unit or discrete area associated with the refuge
Example: List of refuge management units

6 Field Name: GridCellID
Alias: Grid Cell ID
Type: String
Length: 10
Definition: Grid cell identifier - alphanumeric

7 Field Name: Area_Surveyed
Alias: Area Surveyed in Meters
Type: Double
Length: 8
Definition: Identifies area surveyed for target plants and landcovers in acres

8 Field Name: Start_Date
Alias: Start Date
Type: Date/Time
Length: 8
Definition: Identifies the date that surveying was initiated. Date format: YYYY-MM-DD

9 Field Name: End_Date
Alias: End Date
Type: Date/Time
Length: 8
Definition: Identifies the date that surveying was completed. Date format: YYYY-MM-DD

10 Field Name: Surv_Yr
Alias: Survey Year
Type: Integer
Length: 4
Definition: Identifies the year the survey was conducted. Year format: YYYY

11 Field Name: Observer
Alias: Observer
Type: String
Length: 50

Definition: First and last name of the person performing the observation

12 Field Name: Comments
Alias: Comments
Type: String
Length: 254
Definition: Describes any additional information important to the associated record that is not contained within the existing fields

13 Field Name: X_Coordinate
Alias: X Coordinate
Type: Real
Length: 10
Definition: Longitude of point coordinates or polygon centroids. NAD83 UTM Zone 10N or 11N

14 Field Name: Y_Coordinate
Alias: Y Coordinate
Type: Latitude of point coordinates or polygon centroids.
Length: 10
Definition: Preferred projected coordinate system: NAD83 UTM Zone 10N or 11N

15 Field Name: SHAPE_length
Alias: Shape length
Type: Double
Length: 20
Definition: Length in meters

16 Field Name: SHAPE_AREA
Alias: Shape length
Type: Double
Length: 20
Definition: area in meters

For each target native plant species

17 – 27 Field Name: [Name of Target native species]
Alias: [Name of target species] Percent Cover Class
Type: String
Length: 12
Definition: For each target native species, identifies cover estimated as a percent of the search area or mapped infestation. Default value is 0% (not detected). 0-1%, 1-10%, 11-25%, 26-50%, 51-75%, 76-100%.

28 – 38 Field Name: [Name of Target native species] Cover
Alias: [Name of target species] Cover

Type: Integer
Length: 3
Definition: For each target species, identifies plant species cover estimated as a percent of the search area or mapped infestation. If only recording cover classes, this value is designated as the mid-point of the cover class.

39 – 49 Field Name: [Name of Target native species] Net infested acres
Alias: [Name of target species] Net infested area
Type: Double
Length: 8
Definition: Calculated as (gross infested area)*(% cover of plant species within area). If only recording cover class, use mid-point for calculation. Acres

50 Field Name: Other
Alias: other
Type: Text
Length: 254
Definition: Other notable native species present comments

50 Field Name: Target native plant total cover
Alias: Native total cover
Type: Double
Length: 8
Definition: Sum of target native species net cover present in a grid cell

51 Field Name: Target nectar plant total cover
Alias: Nectar total cover
Type: Double
Length: 8
Definition: Sum of nectar plant species (*Heterotheca grandiflora*, *Grindelia hirsutula, Gutierrezia californica*, *Senecio flaccidus* var. *douglasii*) net cover present in a grid cell

52 Field Name: Target native plant richness
Alias: Native richness
Type: Double
Length: 2
Definition: Number of target native species present in a grid cell

Data fields included in Target invasive plants Cover Table:
Definition: The invasive plants table was designed to hold survey data linked to the Plant_Survey_Grids polygons, via the GridCellID key. The table provides details for grid cells that have been surveyed, with attributes such as percent cover class, cover midpoint, net acres infested, total target invasive plant cover, and invasive plant richness.

17 – 36 Field Name: [Name of Target invasive species]
Alias: [Name of target species] Percent Cover Class

Type: String
Length: 12
Definition: For each target invasive species, identifies cover estimated as a percent of the search area or mapped infestation. Default value is 0% (not detected). 0-1%, 1-10%, 11-25%, 26-50%, 51-75%, 76-100%.

37 – 56 Field Name: [Name of Target invasive species] Cover
Alias: [Name of target species] Cover
Type: Integer
Length: 3
Definition: For each target species, identifies plant species cover estimated as a percent of the search area or mapped infestation. If only recording cover classes, this value is designated as the mid-point of the cover class.

57 – 76 Field Name: [Name of Target invasive species] Net infested acres
Alias: [Name of target species] Net infested area
Type: Double
Length: 8
Definition: Calculated as (gross infested area)*(% cover of plant species within area). If only recording cover class, use mid-point for calculation. Acres

50 Field Name: Other
Alias: other
Type: Text
Length: 254
Definition: Other notable invasive species present comments

50 Field Name: Target invasive plant total cover
Alias: Native total cover
Type: Double
Length: 8
Definition: Sum of target invasive species net cover present in a grid cell

51 Field Name: Target invasive plant richness
Alias: Native richness
Type: Double
Length: 2
Definition: Number of target invasive species present in a grid cell

Data fields included in Landcover Cover Table:
Definition: The landcover table was designed to hold survey data linked to the Plant_Survey_Grids polygons, via the GridCellID key. The table provides details for grid cells that have been surveyed, with attributes such as percent cover class, cover midpoint, and net acres covered.

17 – 25 Field Name: [Name of landcover type]

Alias: [Name of landcover type] Percent Cover Class
Type: String
Length: 12
Definition: For each landcover type identifies cover estimated as a percent of the search area or mapped infestation. Default value is 0% (not detected). 0-1%, 1-10%, 11-25%, 26-50%, 51-75%, 76-100%.

26 – 34 Field Name: [Name of landcover type] Cover
Alias: [Name of landcover type] Cover
Type: Integer
Length: 3
Definition: For each target species, identifies plant species cover estimated as a percent of the search area or mapped infestation. If only recording cover classes, this value is designated as the mid-point of the cover class.

35 – 43 Field Name: [Name of landcover type] Net infested acres
Alias: [Name of landcover type] Net infested area
Type: Double
Length: 8
Definition: Calculated as (gross infested area)*(% cover of plant species within area). If only recording cover class, use mid-point for calculation. Acres

Definition: Identifies the year the survey was conducted. Year format: YYYY

11 Field Name: Other
Alias: other
Type: Text
Length: 254
Definition: Other comments

Appendix C

Maps

Stamm Unit Maps

Map 1-1 Stamm Unit Survey Grid
Map 1-2 Stamm Unit Grid Cells Surveyed 2017-2022
Map 1-3 Stamm Unit Annual Grass Cover
Map 1-4 Stamm Unit Thatch Cover
Map 1-5 Stamm Unit Bare Ground Cover
Map 1-6 Stamm Unit Total Vegetation Cover
Map 1-7 Stamm Unit Tree Cover
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Map 2-42 Sardis Unit *Vicia sativa*
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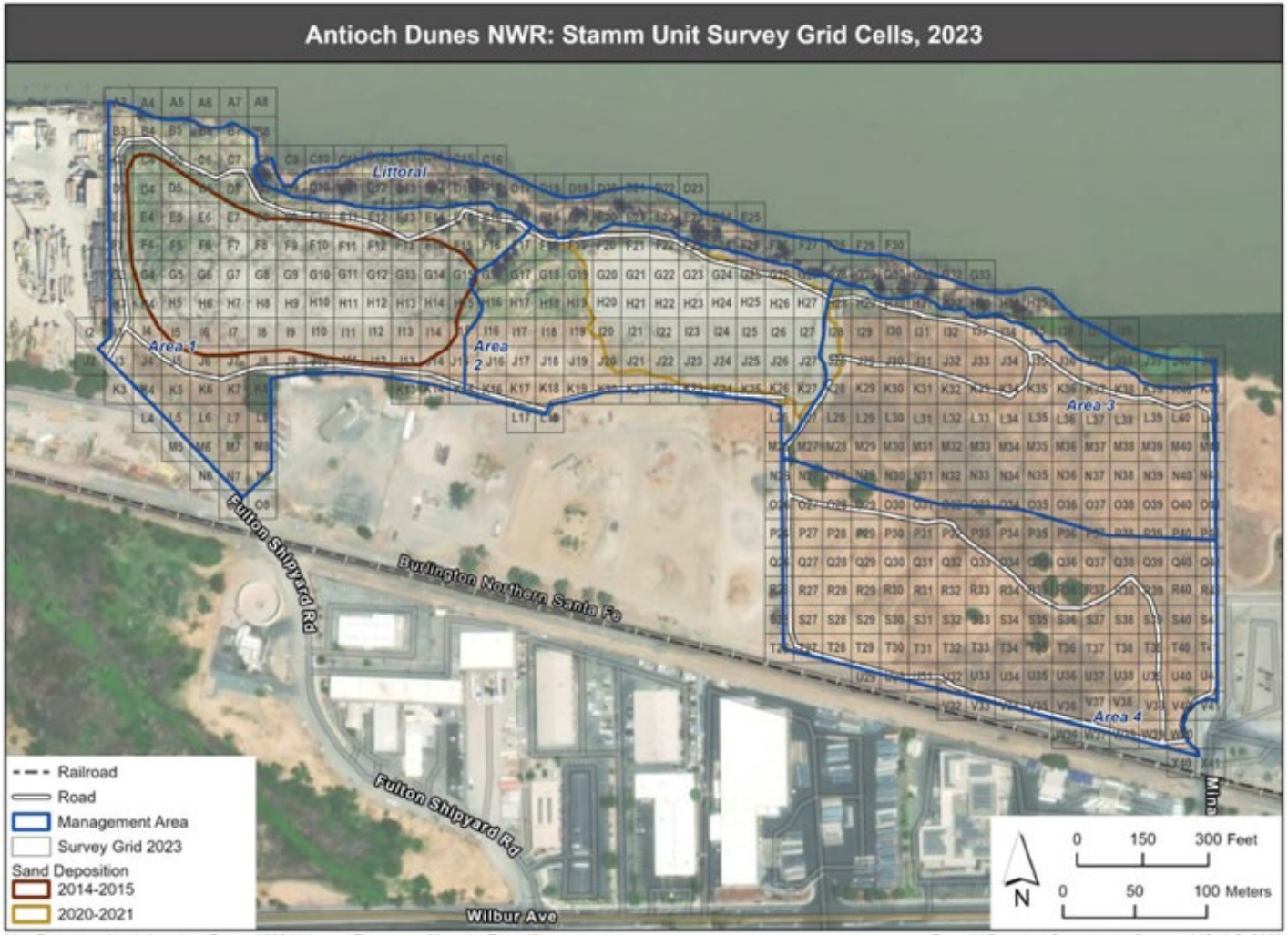
Map 1-1 Stamm Unit Survey Grid



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-2 Stamm Unit Grid Cells Surveyed 2017 and 2022

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
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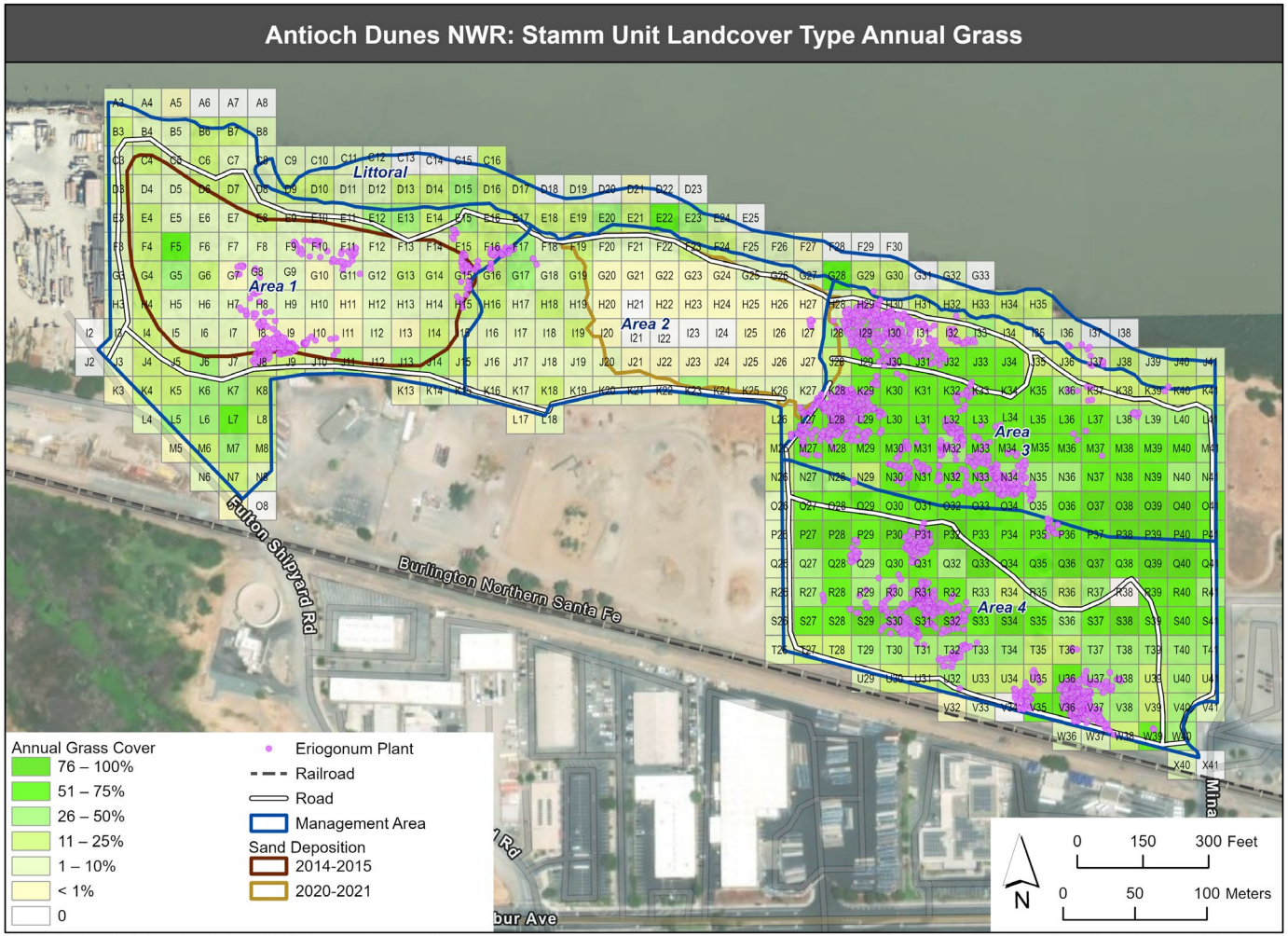
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-3 Stamm Annual Grass Cover



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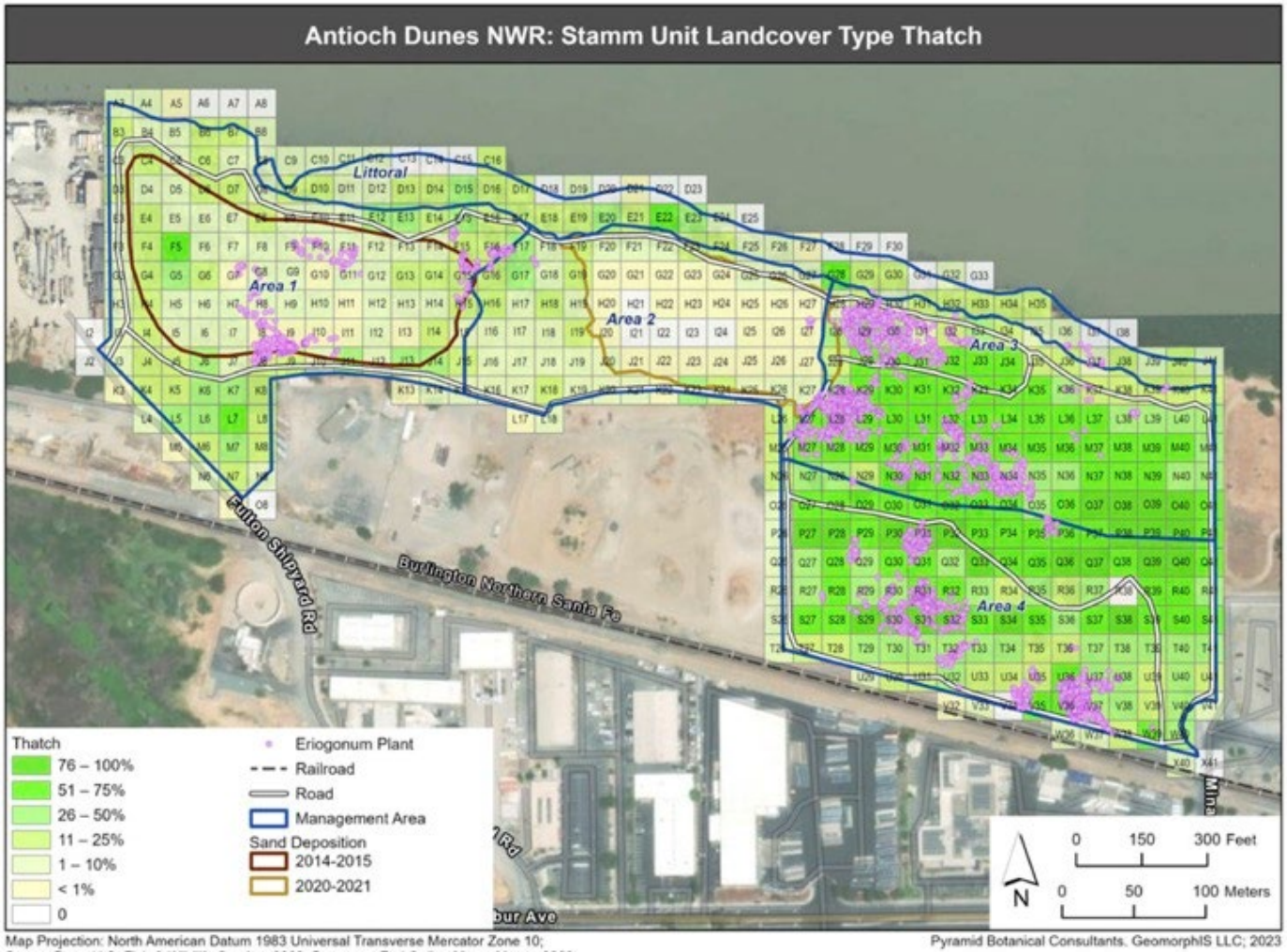
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-4 Stamm Thatch Cover



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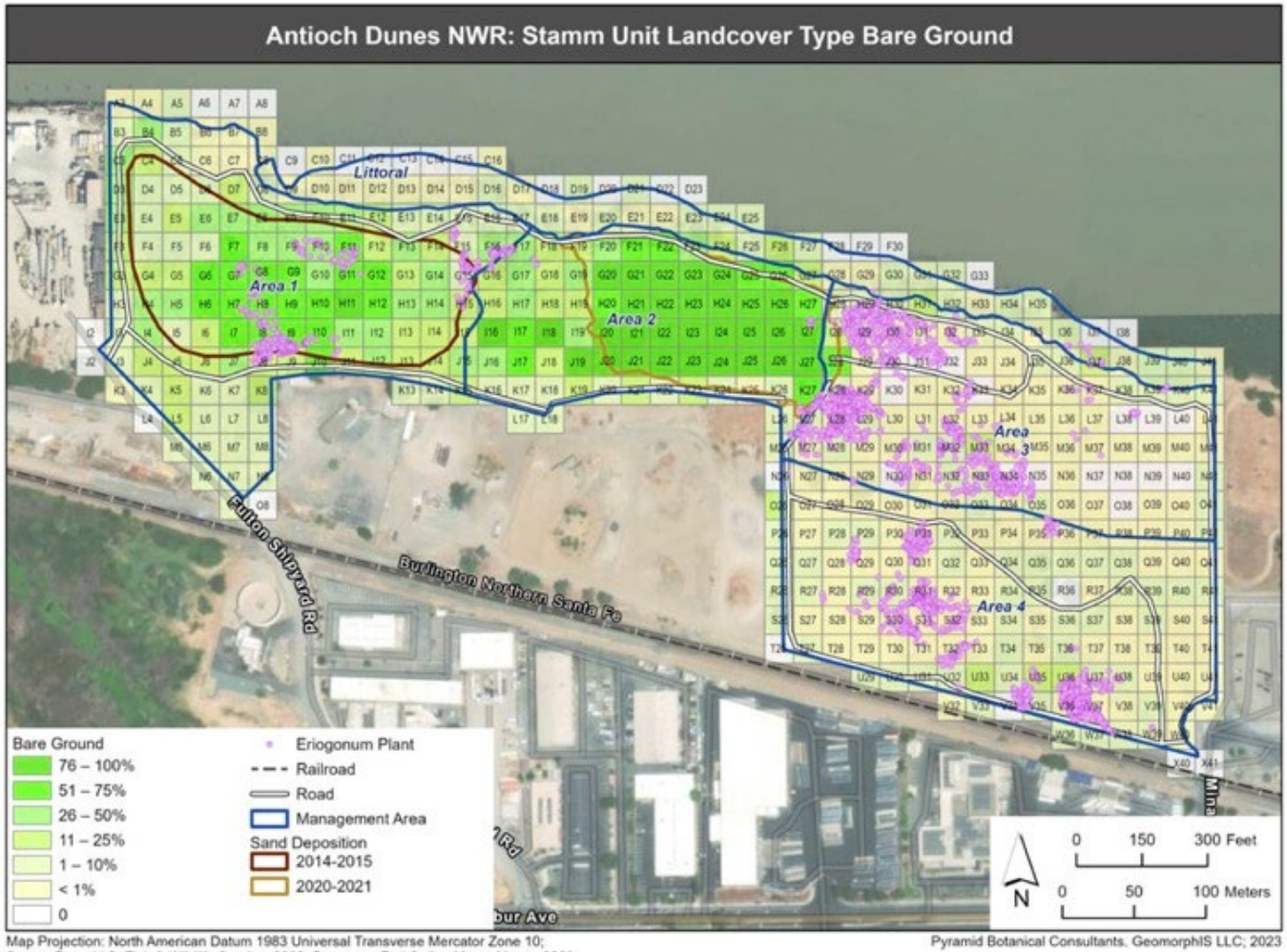
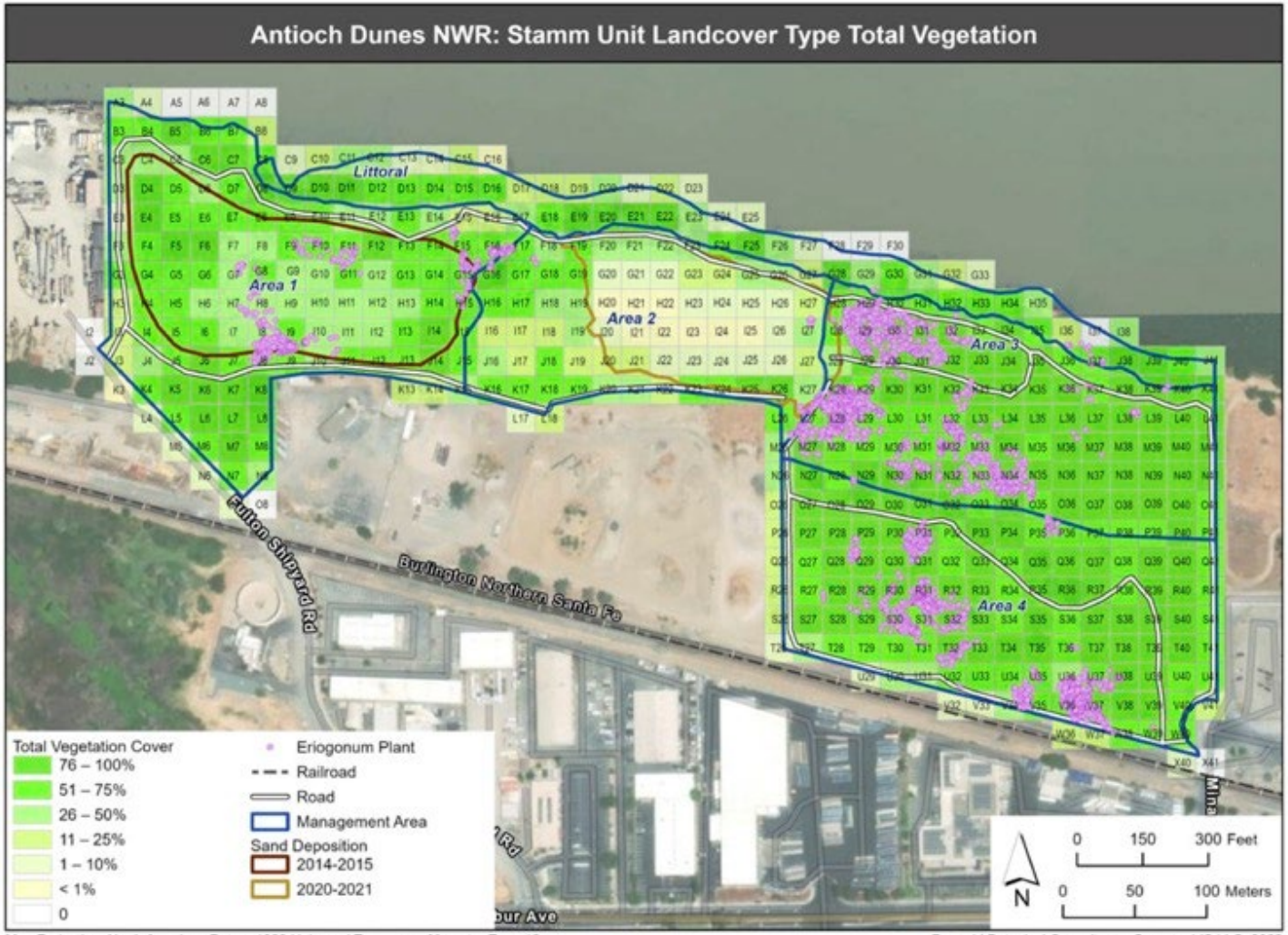
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-5 Stamm Unit Bare Ground Cover



Map 1-6 Stamm Unit Total Vegetation Cover



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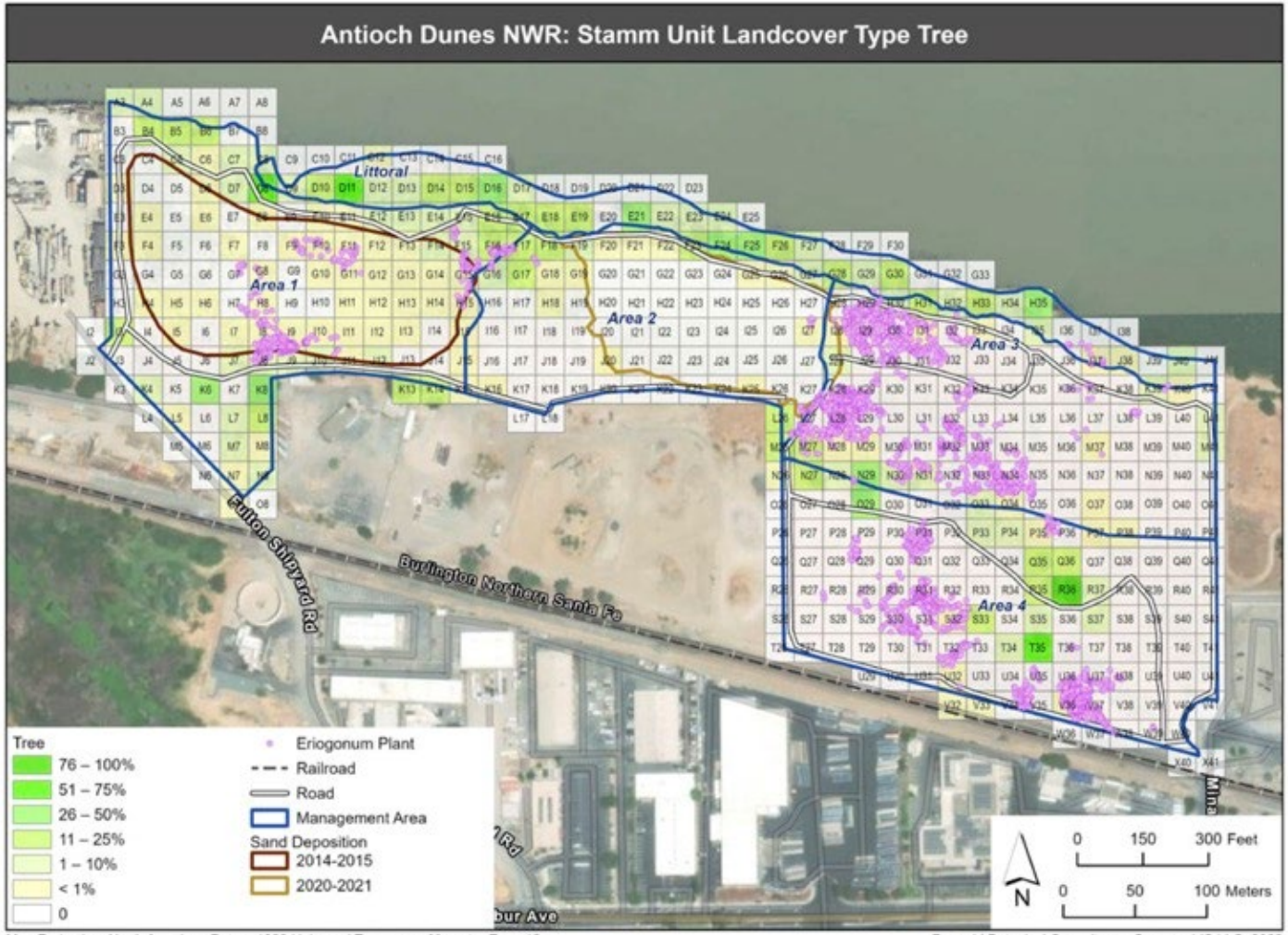
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-7 Stamm Unit Tree Cover



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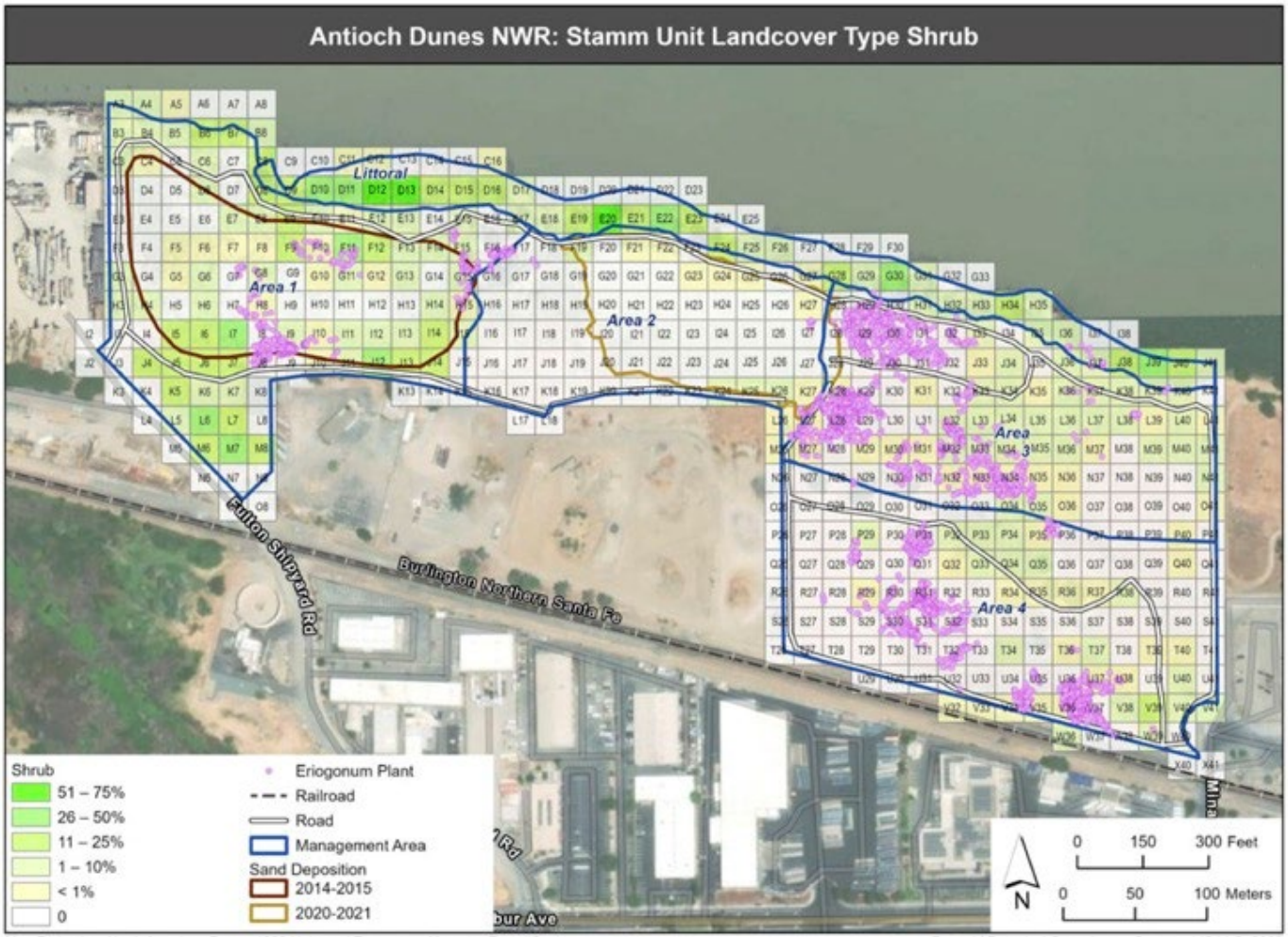
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-8 Stamm Unit Shrub Cover



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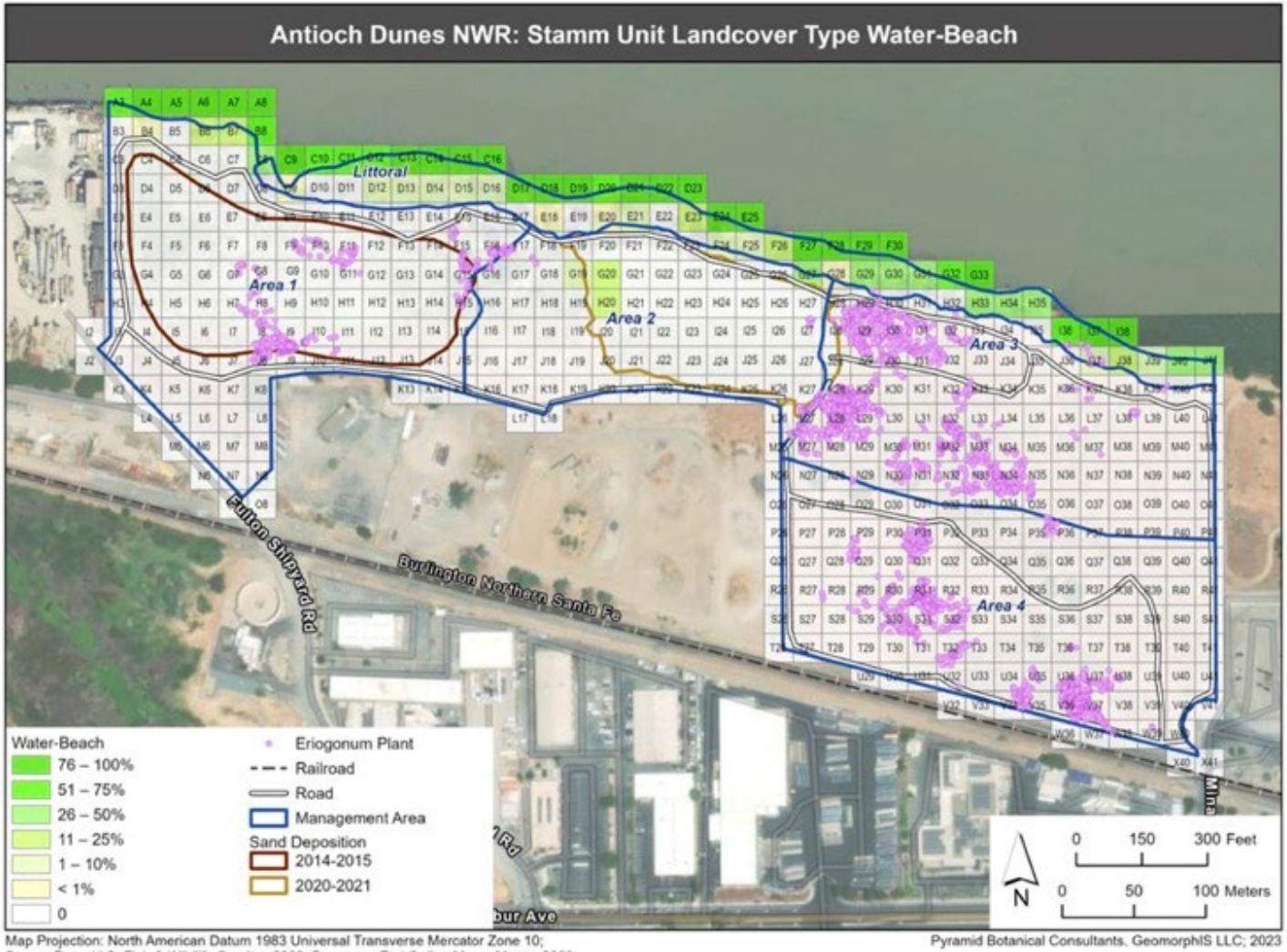
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-9 Stamm Unit Water/Beach Cover



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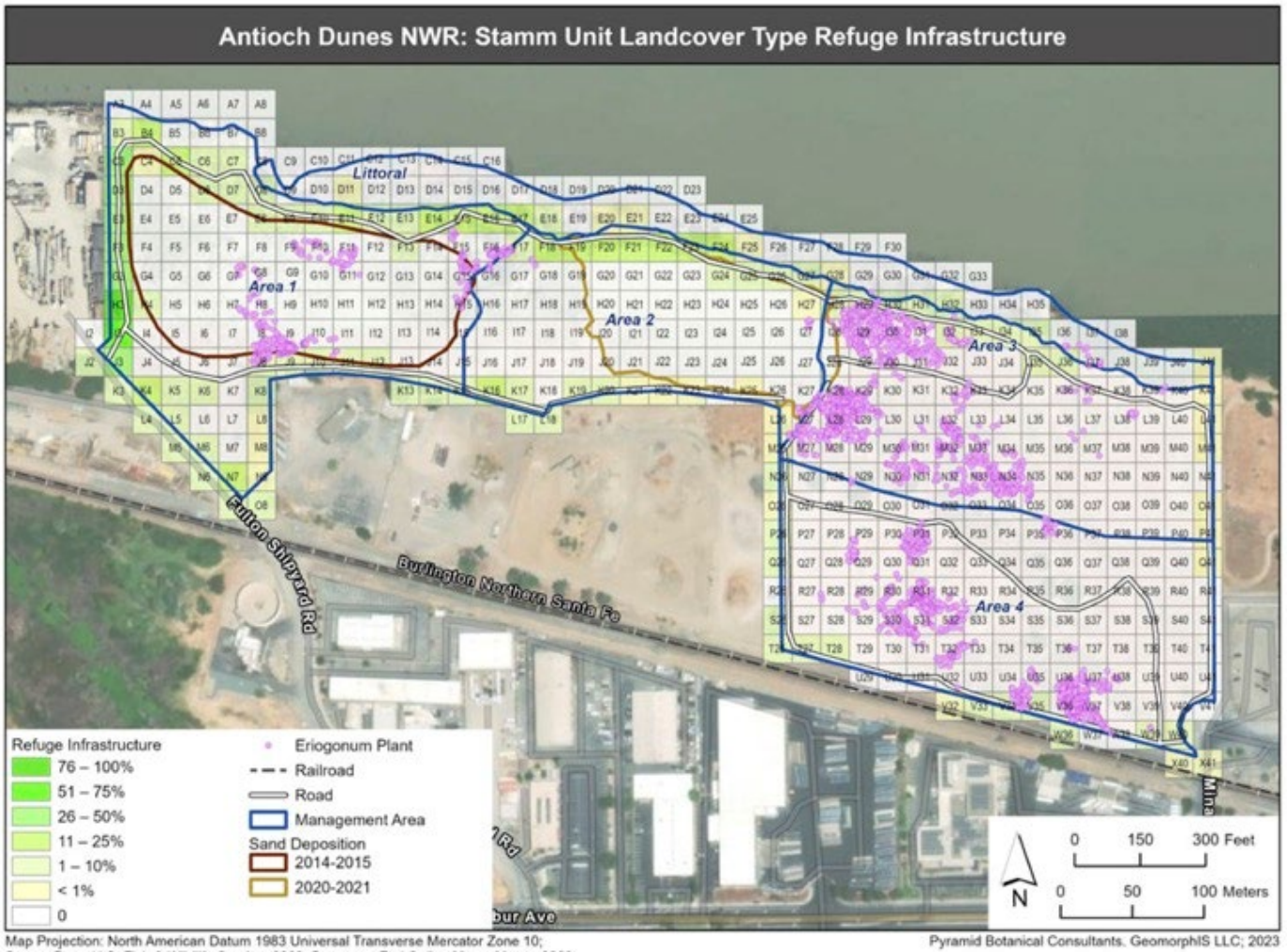
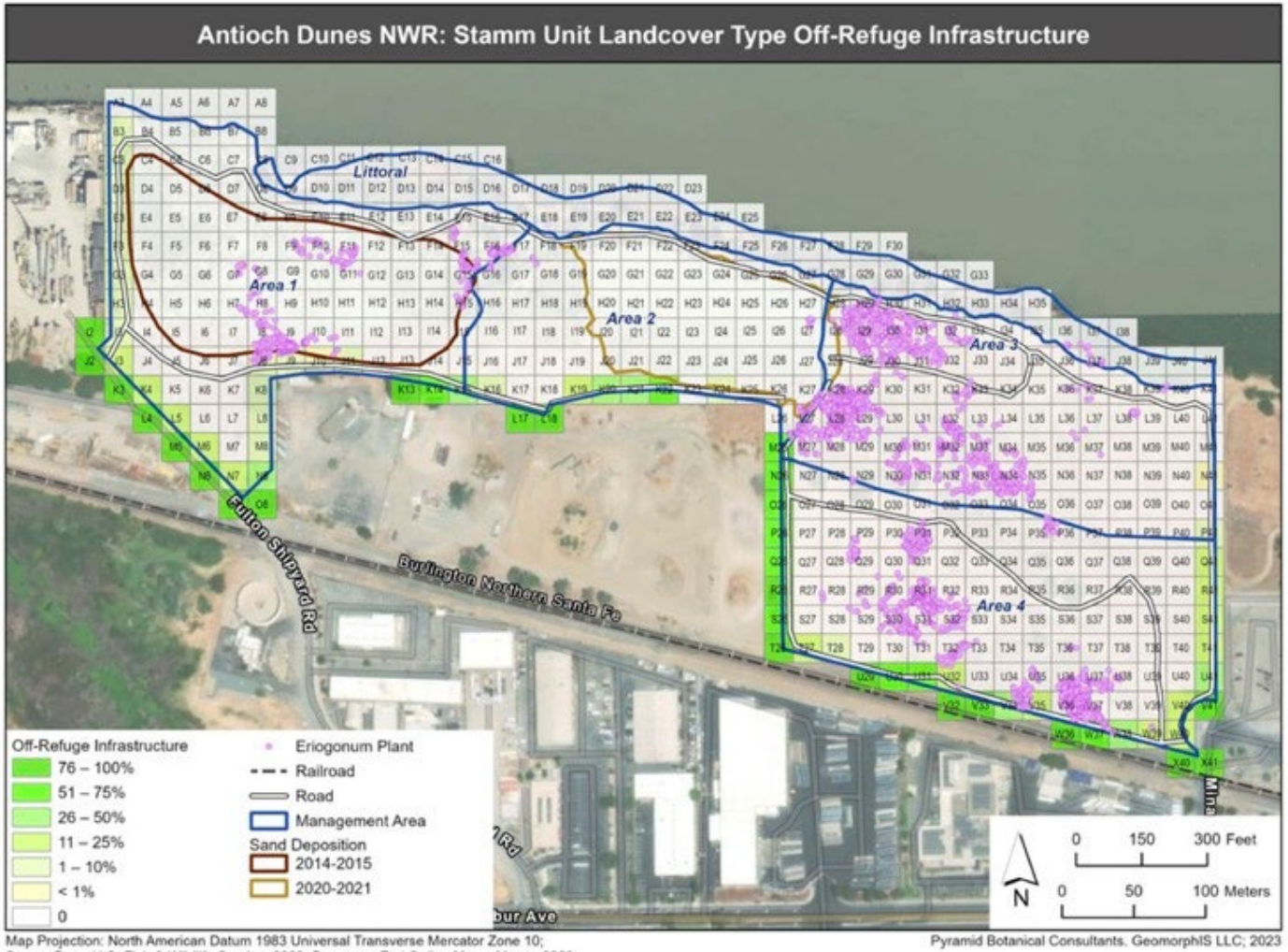
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-10 Stamm Unit Refuge Infrastructure



Map 1-11 Stamm Unit Off-Refuge Infrastructure



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Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

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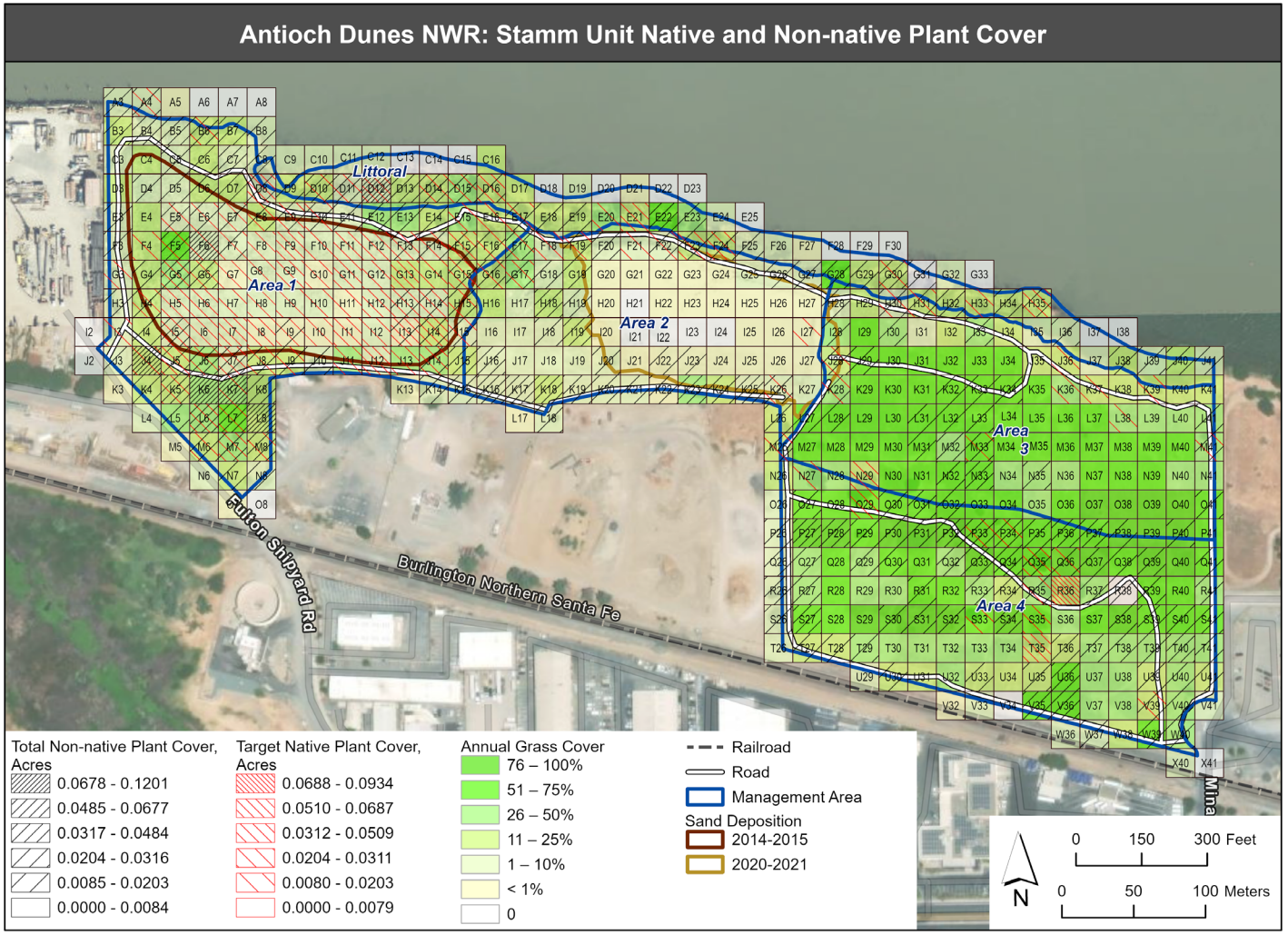
Map 1-12 Stamm Unit Total Target Native and Invasive Plant Cover



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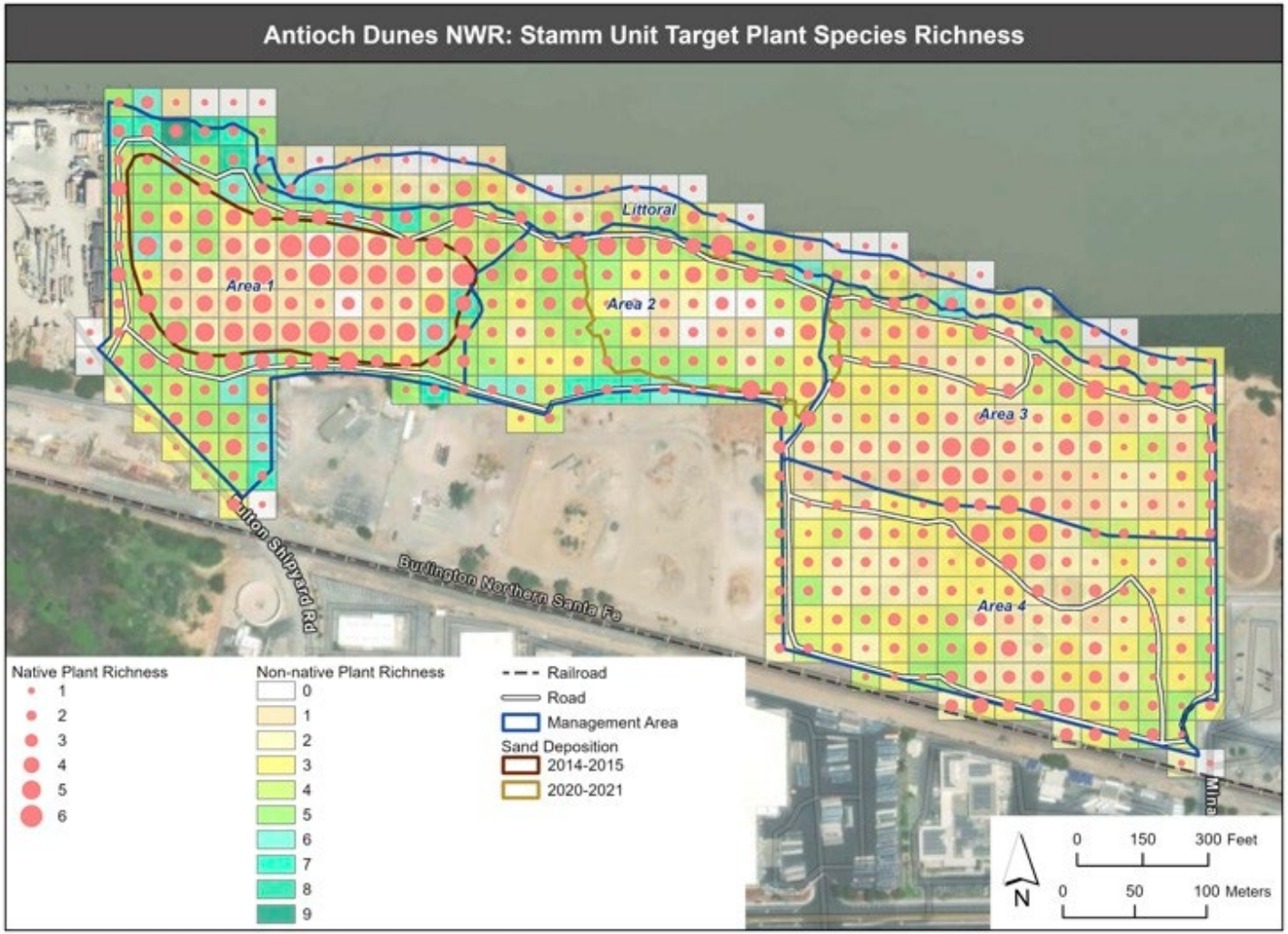
Map 1-13 Stamm Unit Target Plant Native Richness and Invasive Plant Richness



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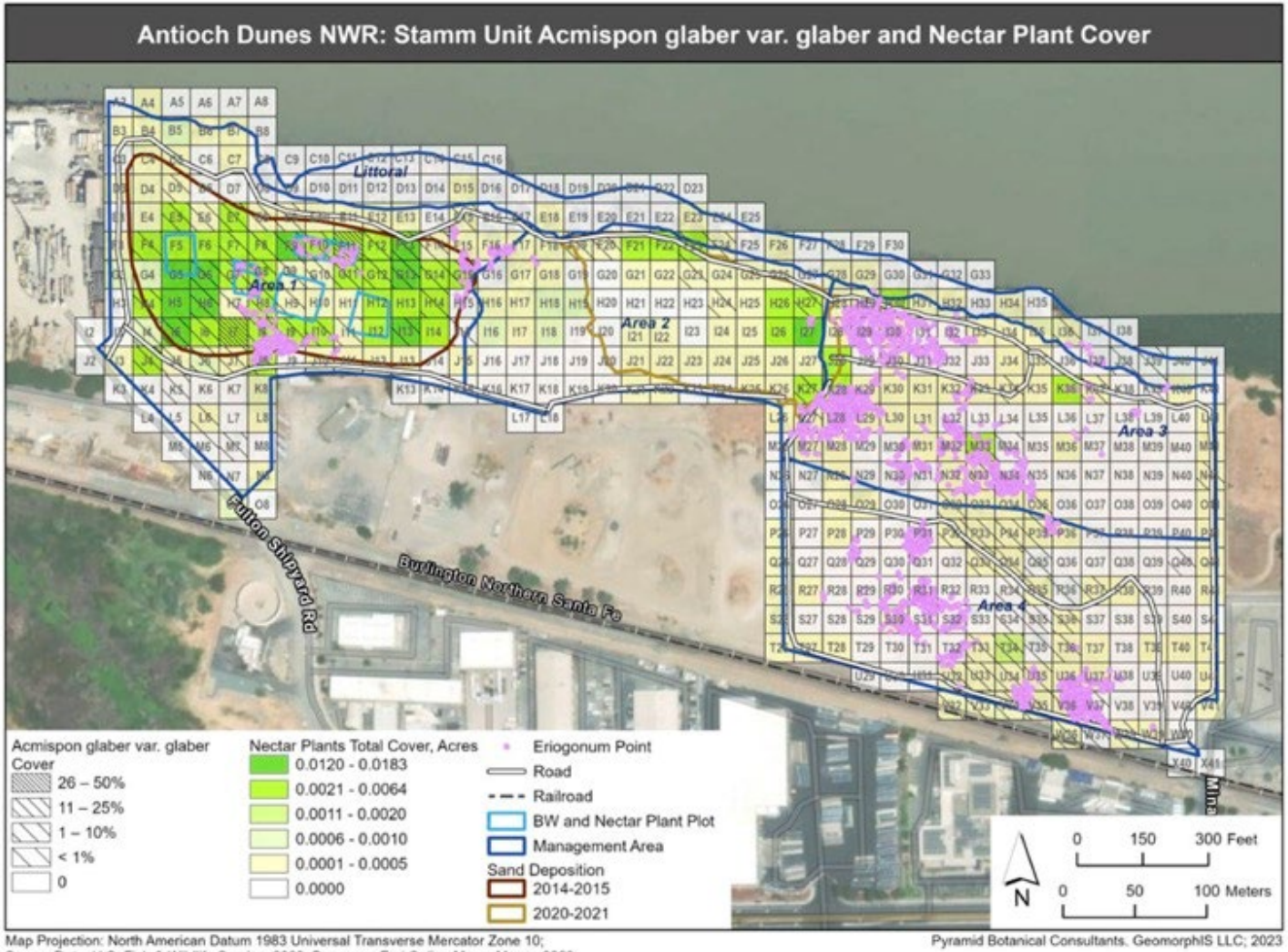
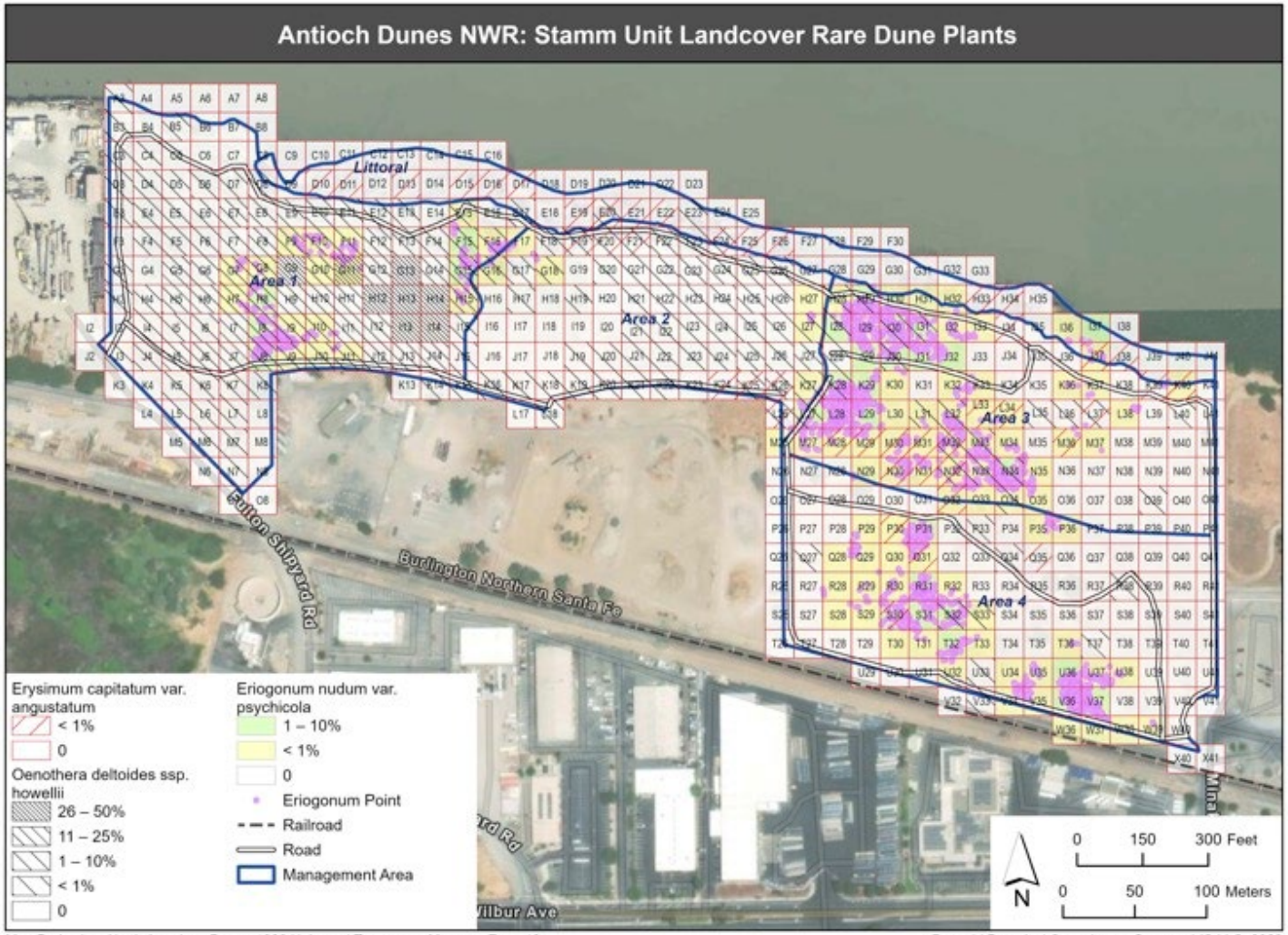
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

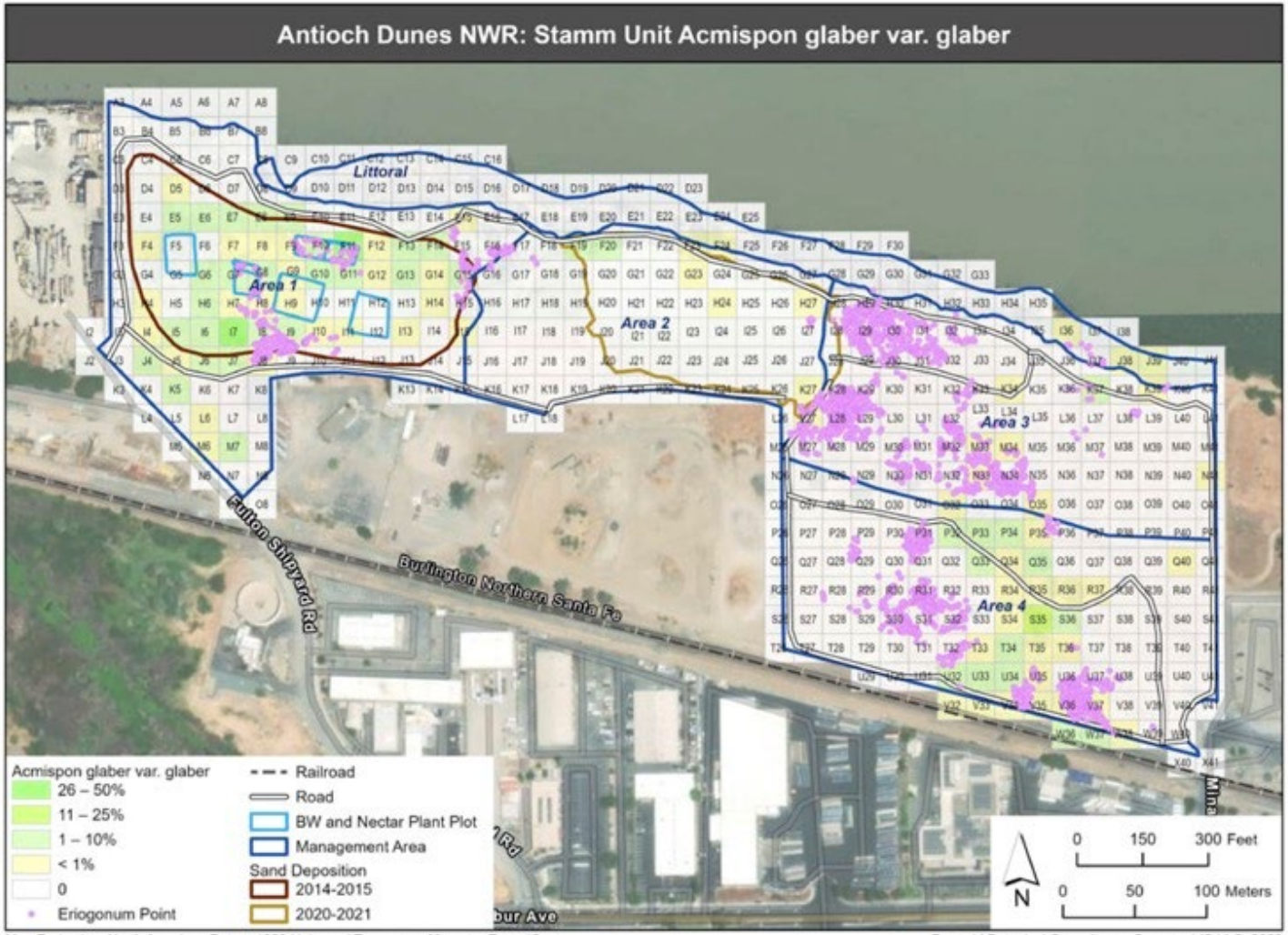
Map 1-14 Stamm Unit Nectar and Perch Plant Cover



Map 1-15 Stamm Unit Rare Dune Species Cover



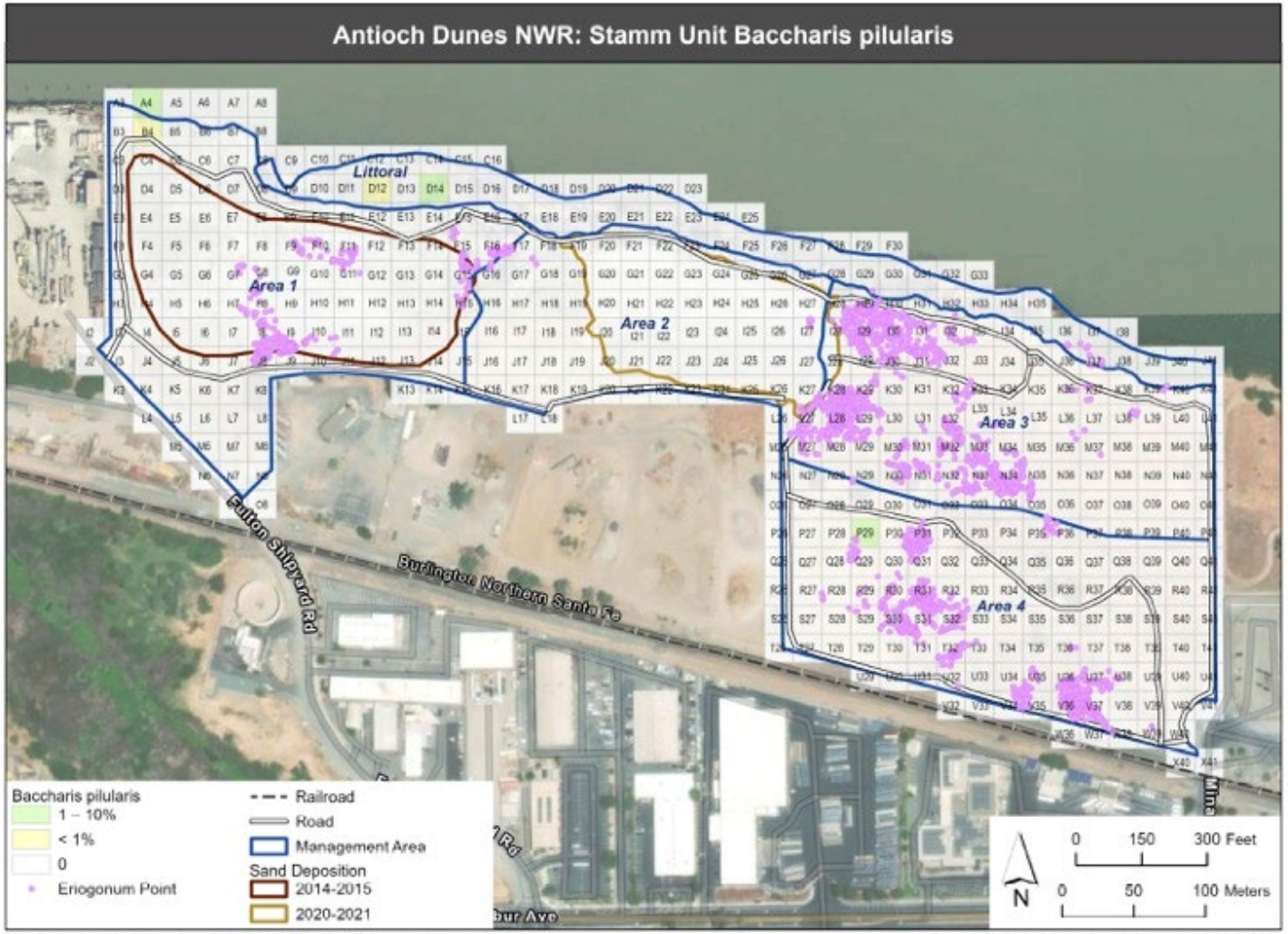
Map 1-16 Stamm Unit Stamm Unit *Acmispon glaber* var. *glaber*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-17 Stamm Unit *Baccharis pilularis*



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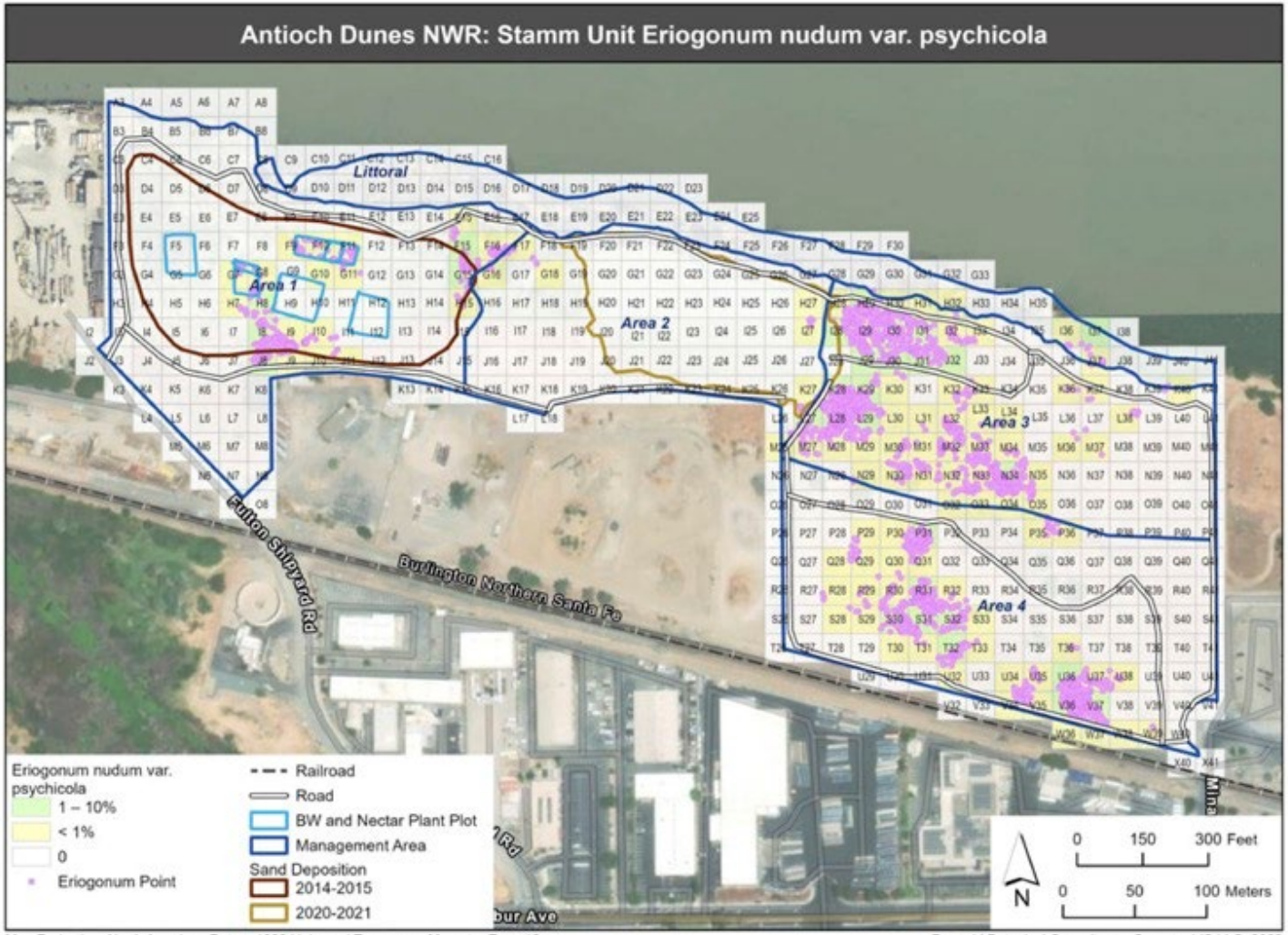
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-18 Stamm Unit *Eriogonum nudum var. psychicola*



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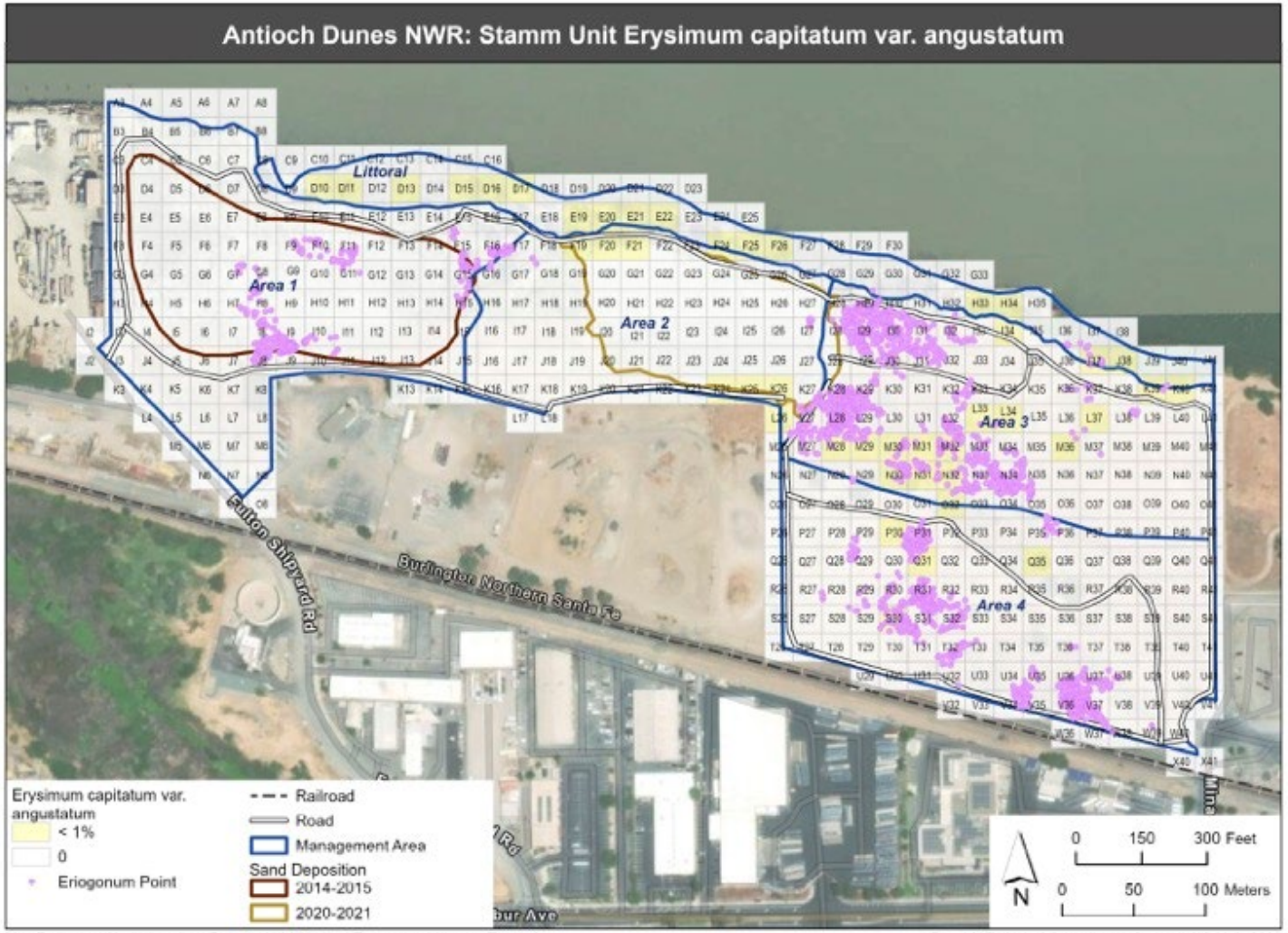
Map 1-19 Stamm Unit *Erysimum capitatum* var. *angustatum*



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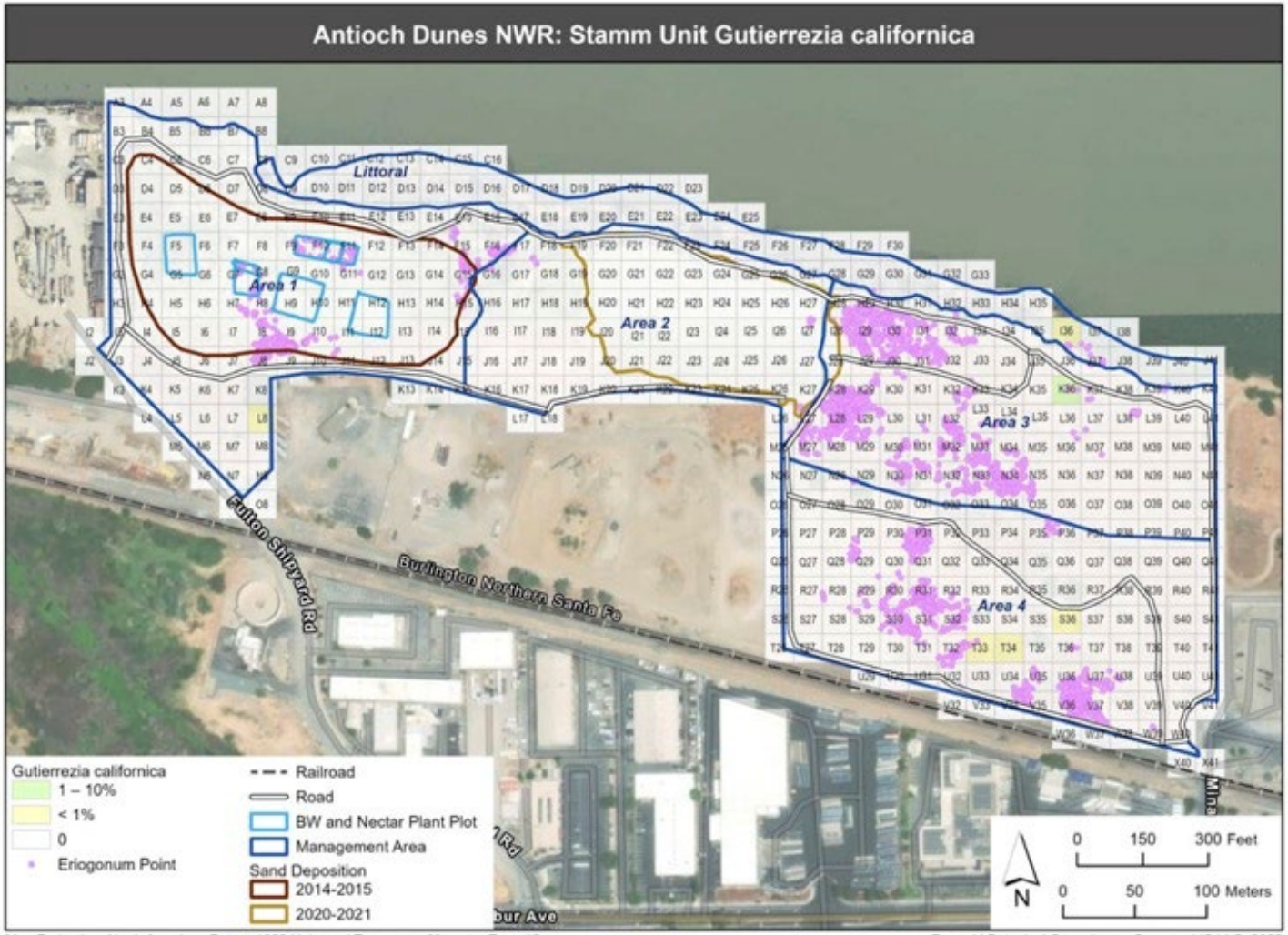
Map 1-20 Stamm Unit *Grindelia hirsutula*

Map 1-21 Stamm Unit *Gutierezzia californica*



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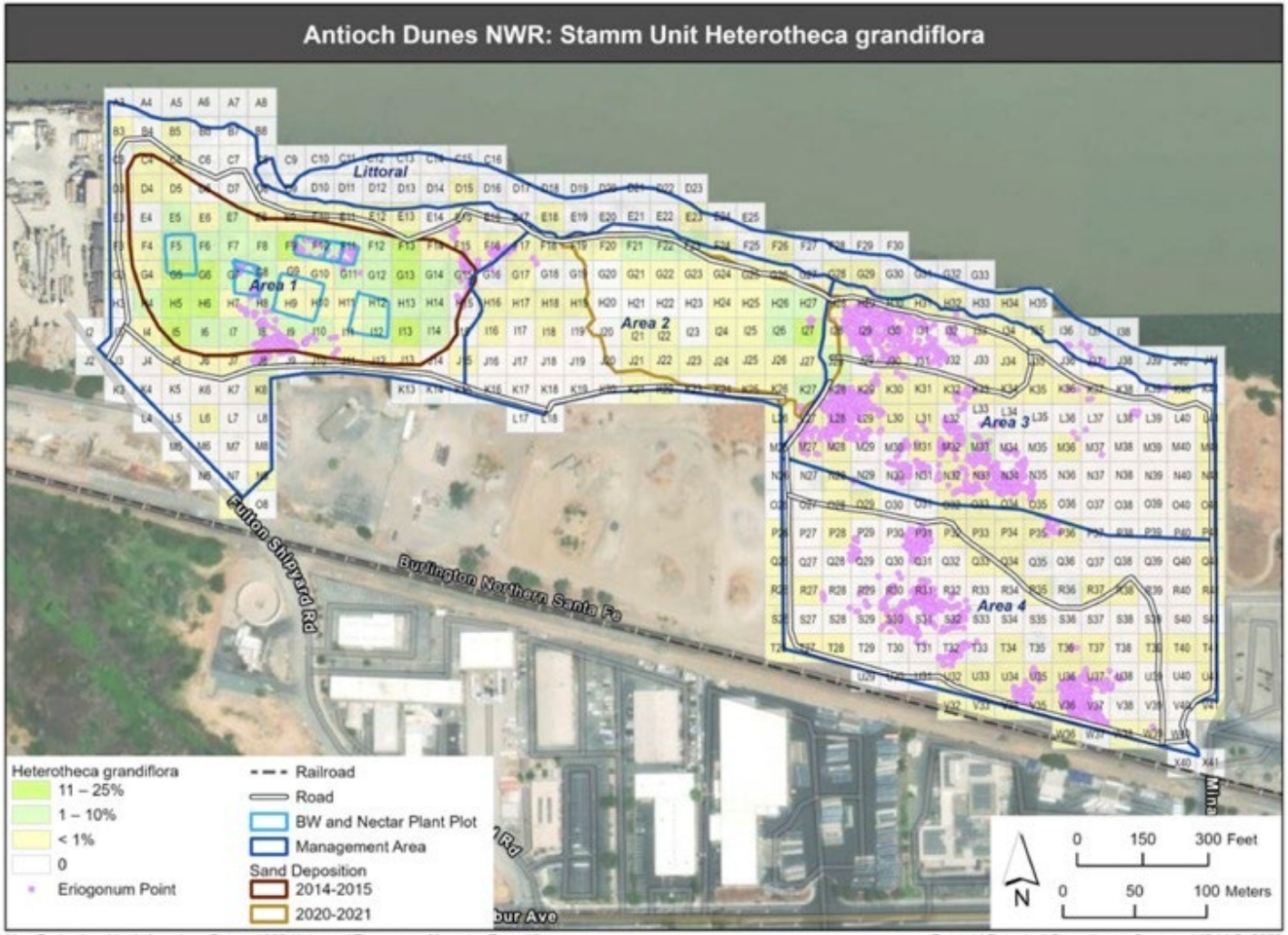
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-22 Stamm Unit *Heterotheca grandiflora*



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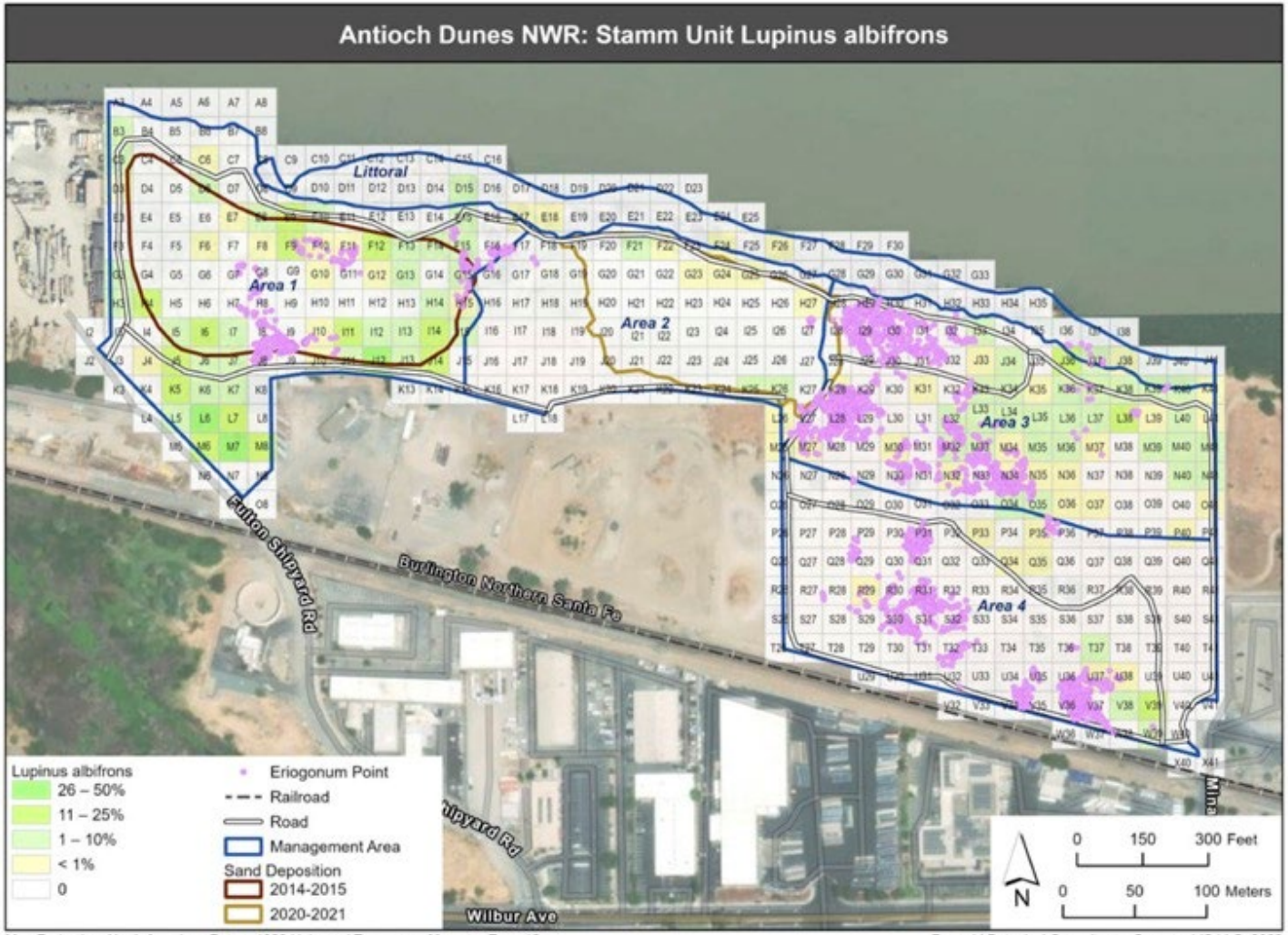
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-23 Stamm Unit *Lupinus albifrons*



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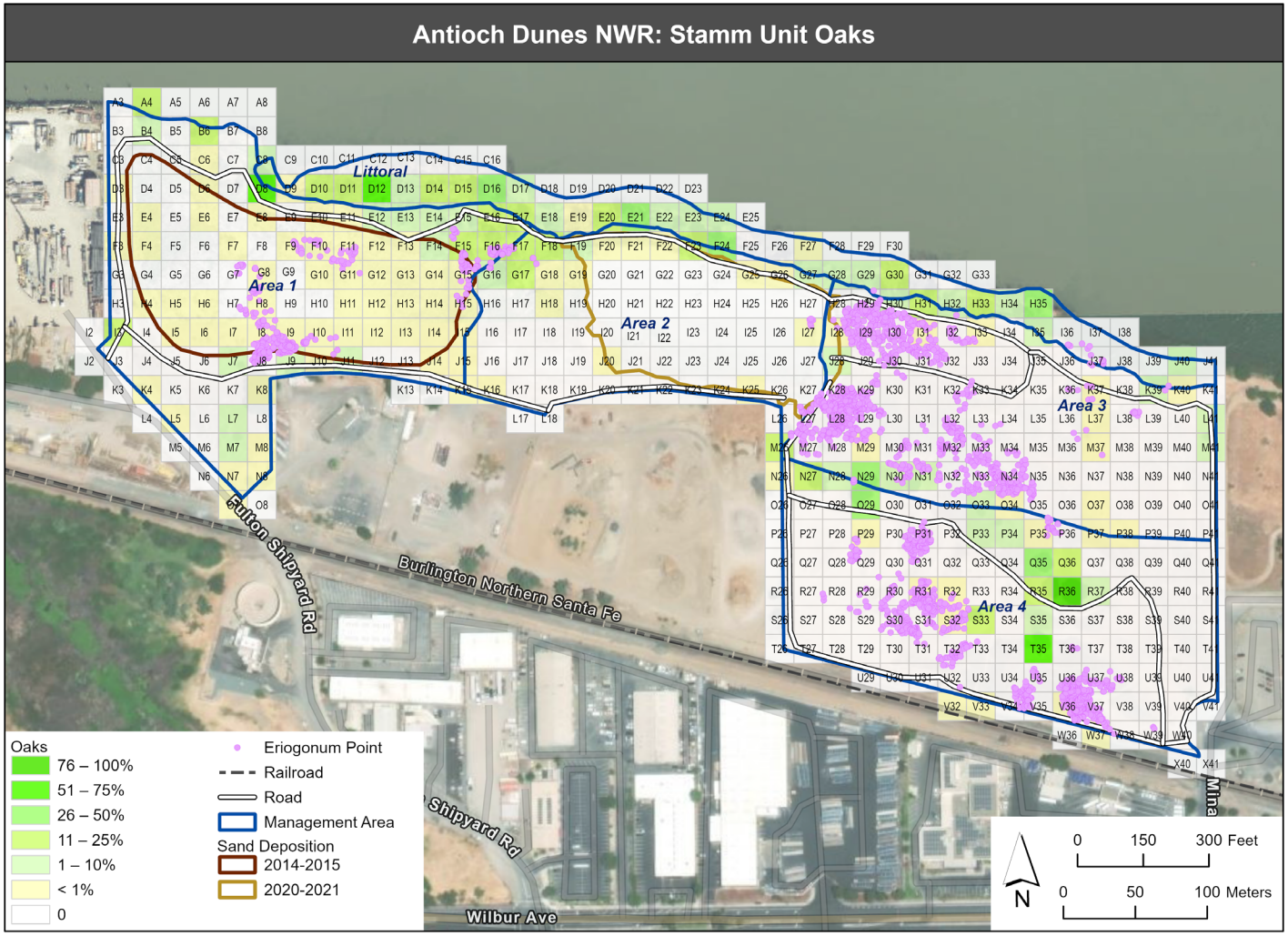
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-24 Stamm Unit *Quercus* subsp.



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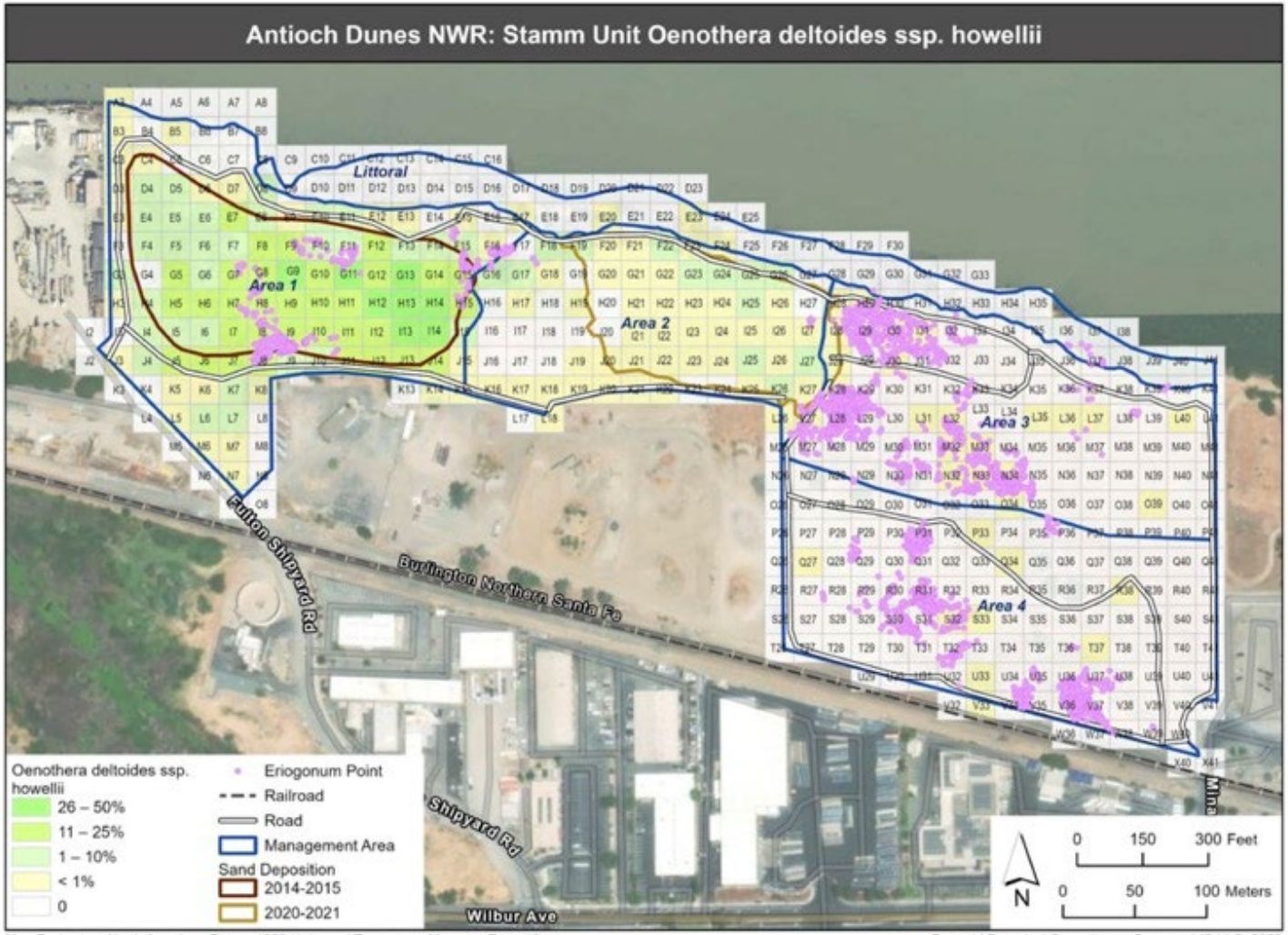
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-25 Stamm Unit *Oenothera deltoides ssp. howellii*



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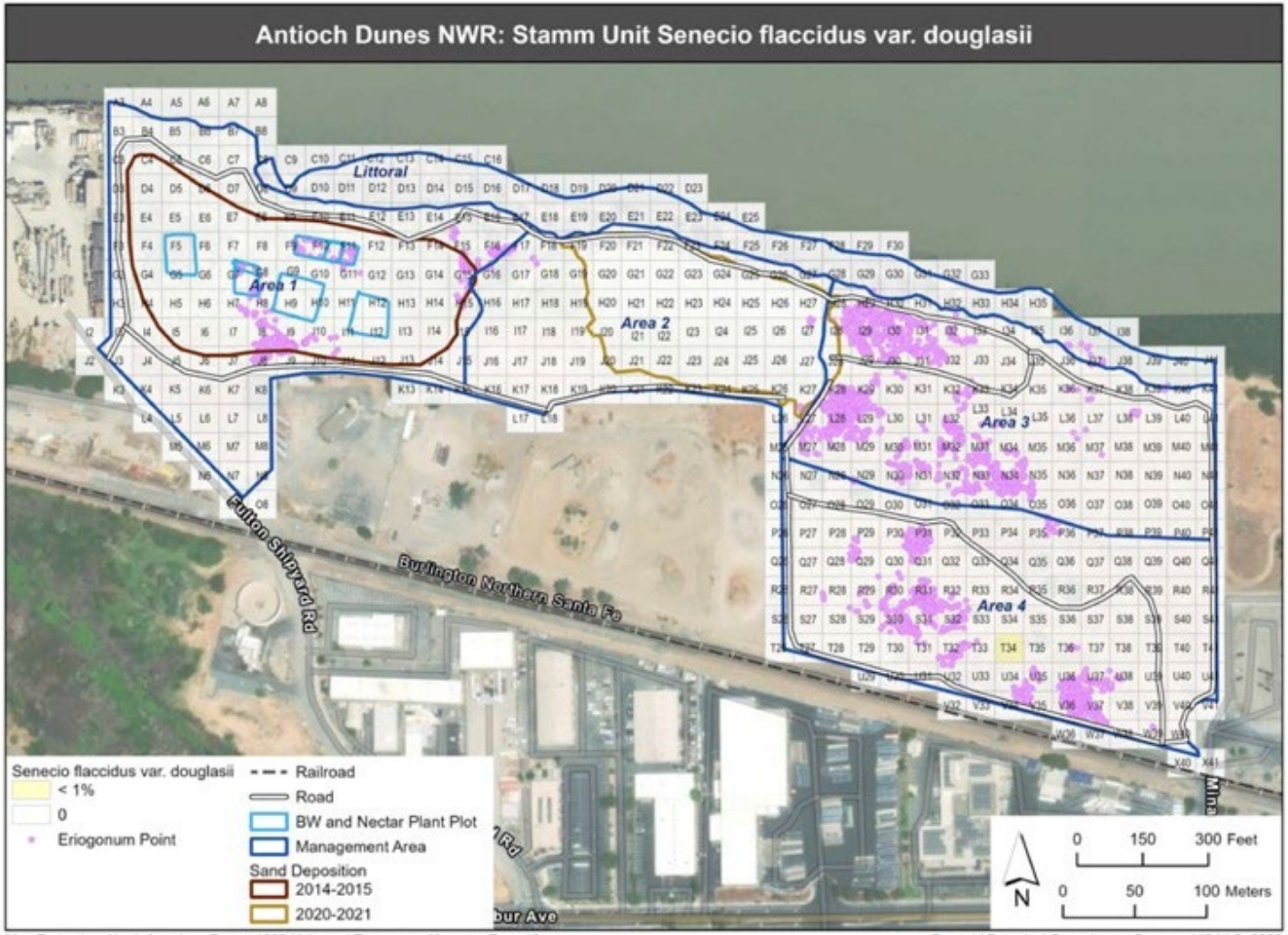
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-26 Stamm Unit *Senecio flaccidus var. douglasii*



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Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-27 Stamm Unit *Ailanthus altissima*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

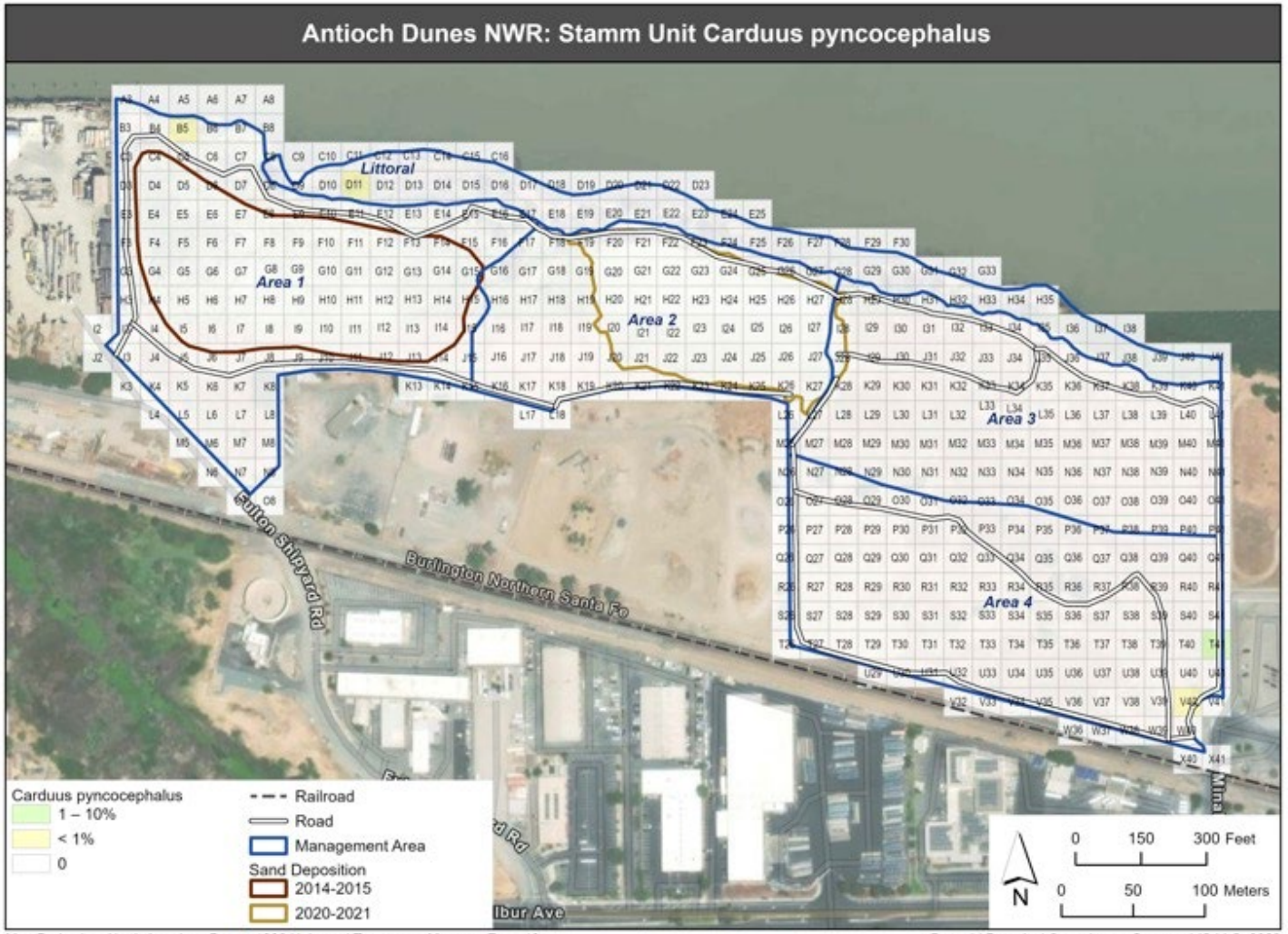
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-28 Stamm Unit *Brassica nigra, Hirschfeldia incana*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-29 Stamm Unit *Carduus pyncocephalus*



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Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

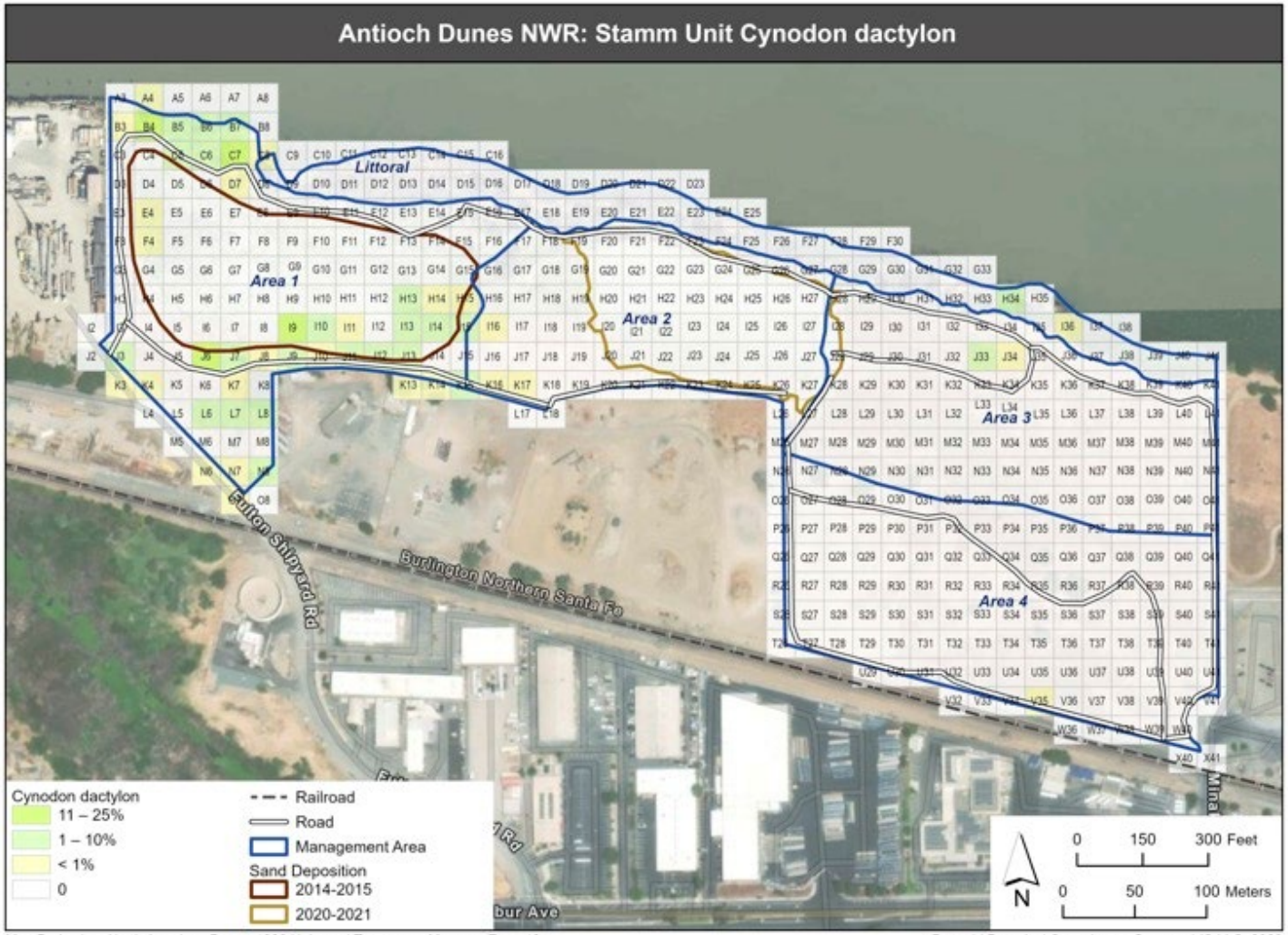
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-30 Stamm Unit *Centaurea* group (*C. melitensis, C. solstitialis*)

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-31 Stamm Unit *Cynodon dactylon*



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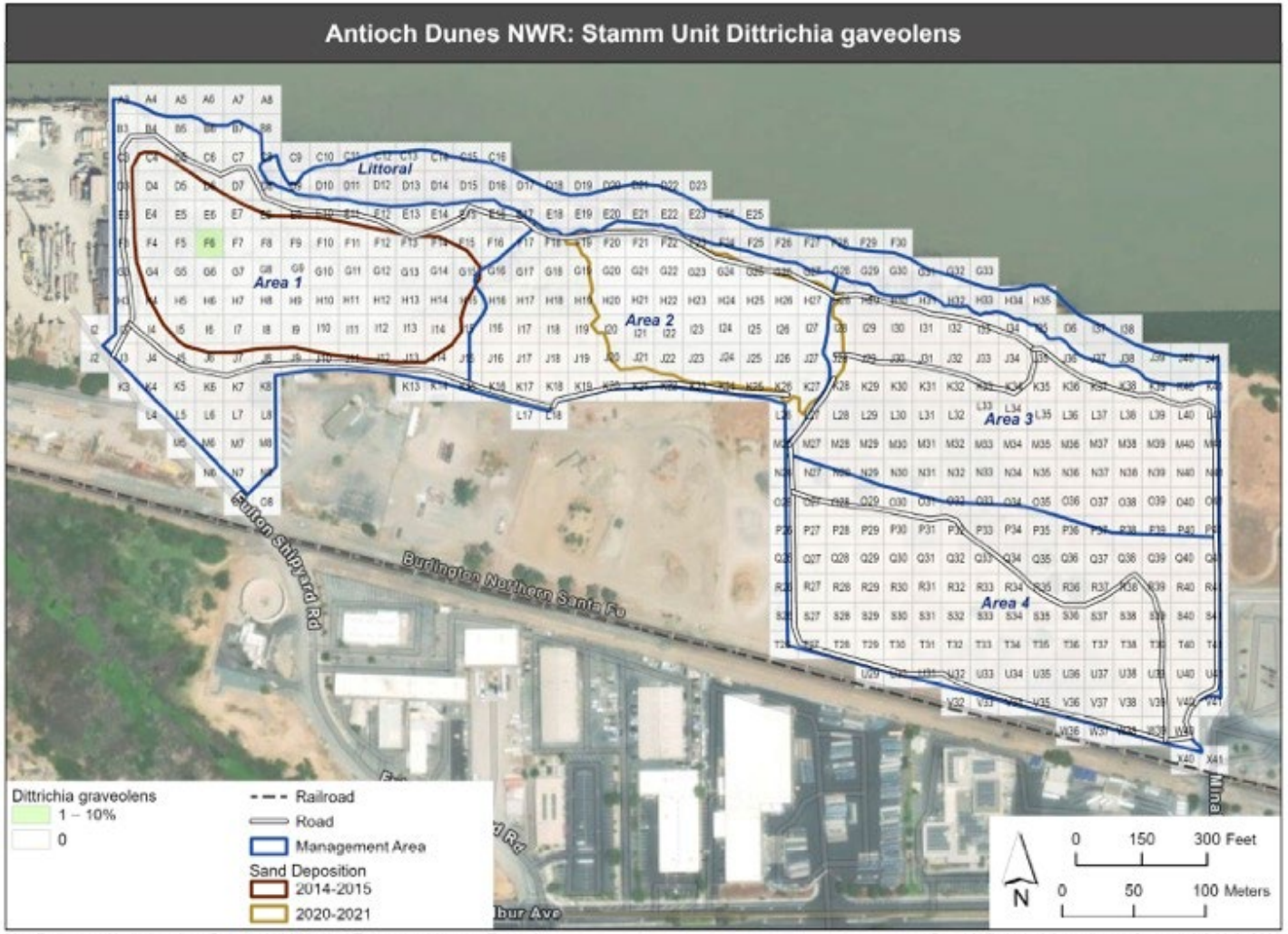
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-32 Stamm Unit *Dittrichia graveolens*



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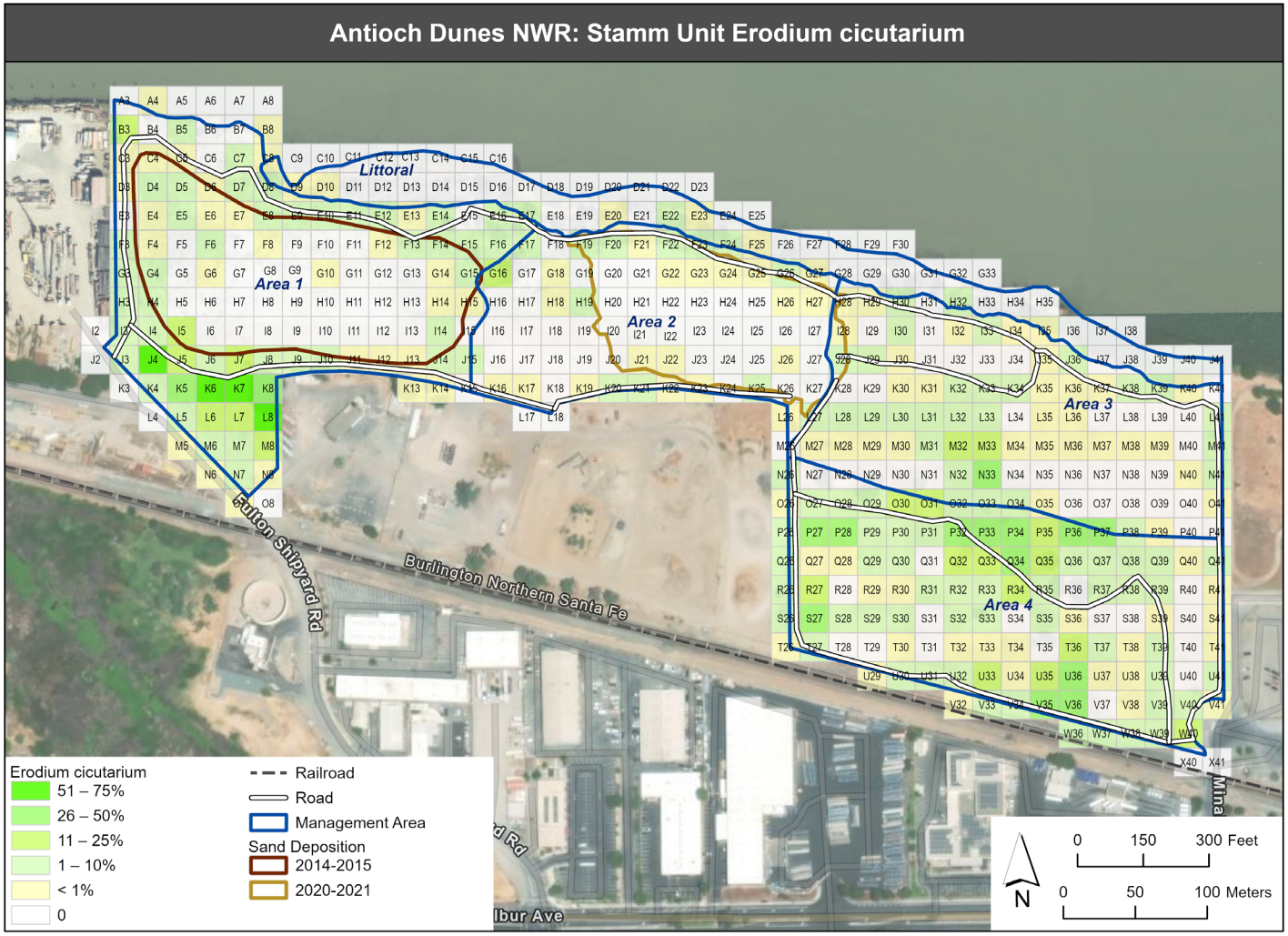
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-33 Stamm Unit *Erodium cicutarium*



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Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-34 Stamm Unit *Lepidium latifolium*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-36 Stamm Unit *Malva* group (*Malva* parviflora, *Malva* ssp.)

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-37 Stamm Unit *Nicotiana glauca*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

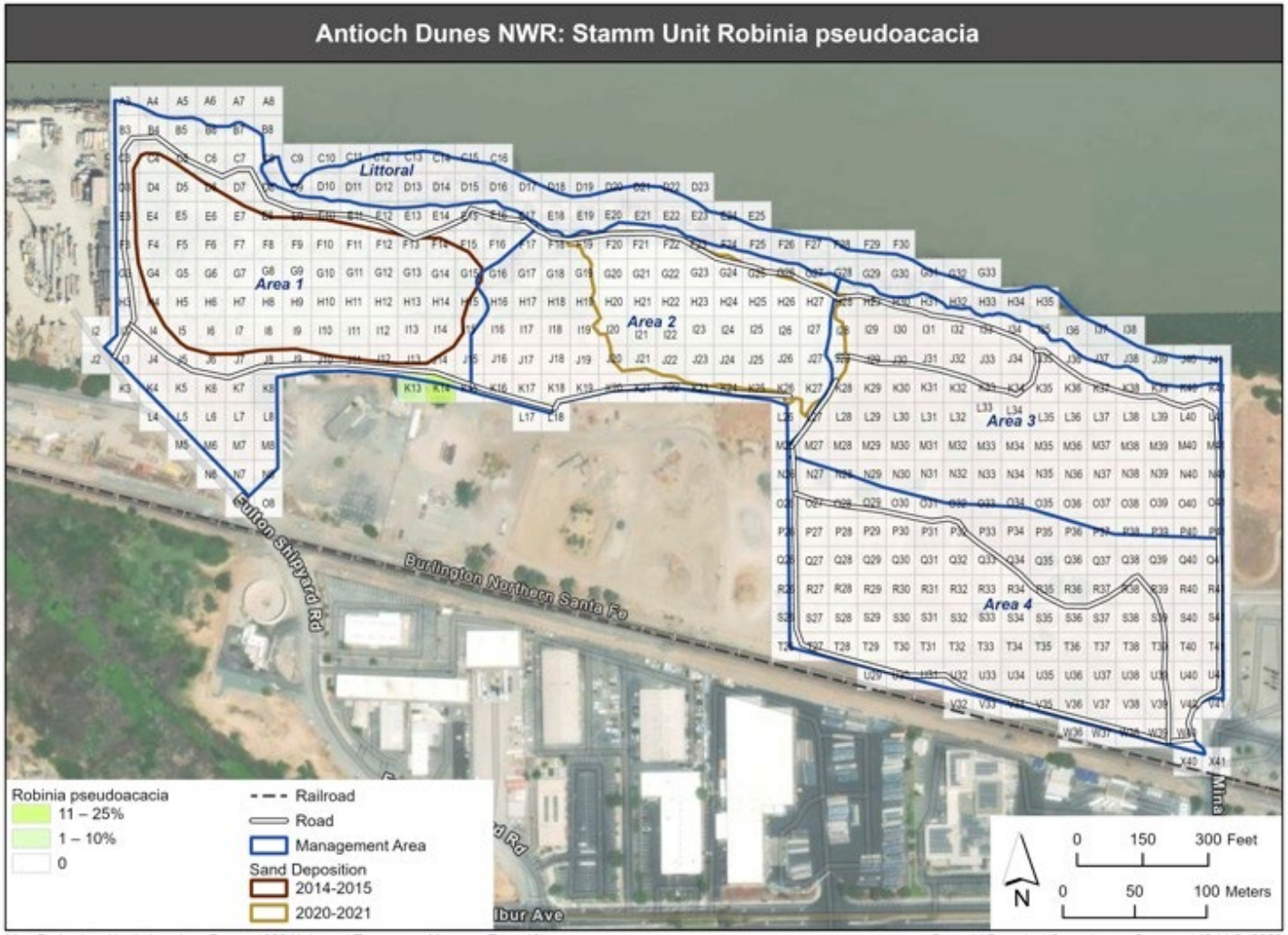
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

1-38 Stamm Unit *Raphanus sativus*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-39 Stamm Unit *Robinia pseudoacacia*



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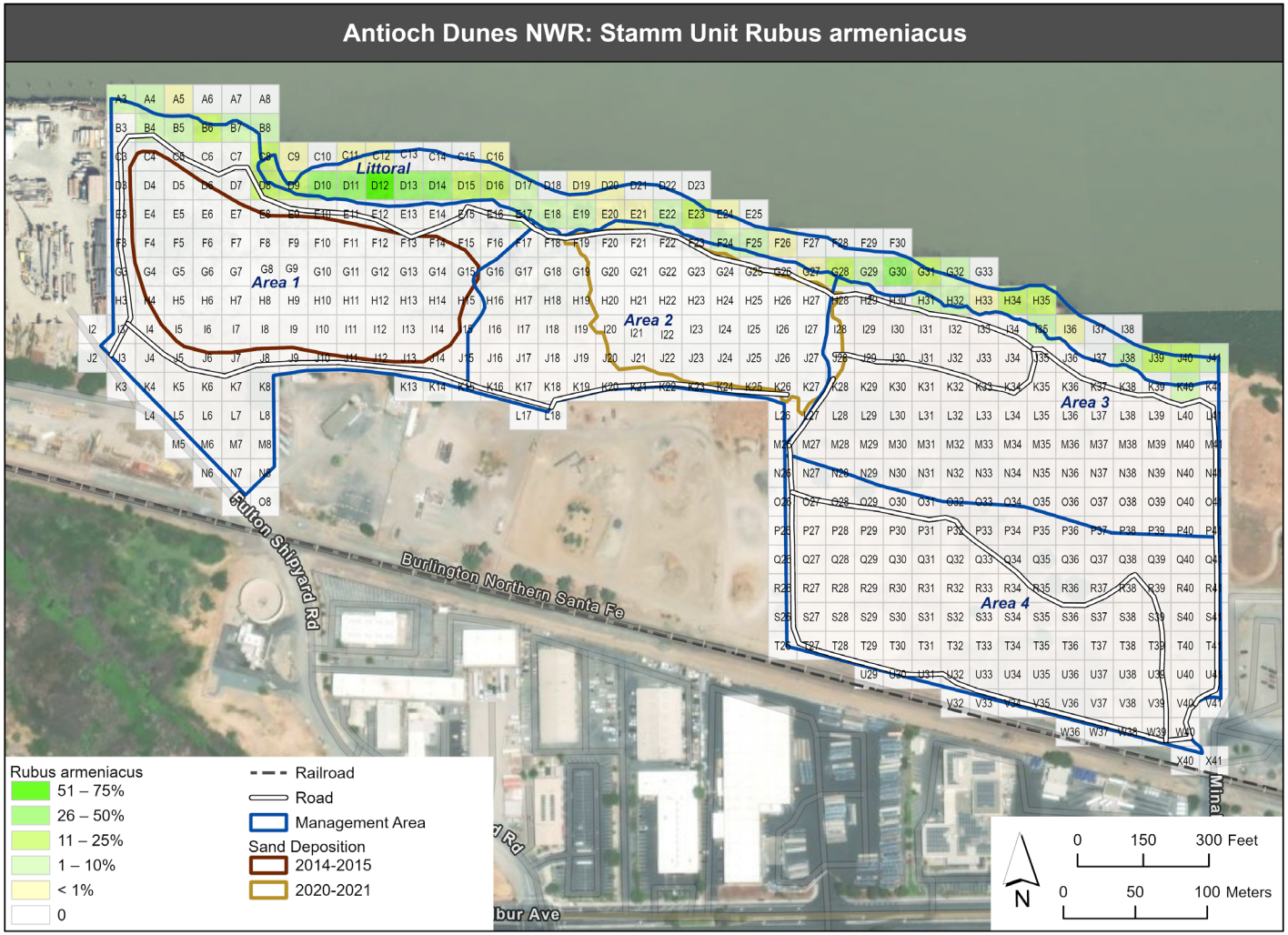
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

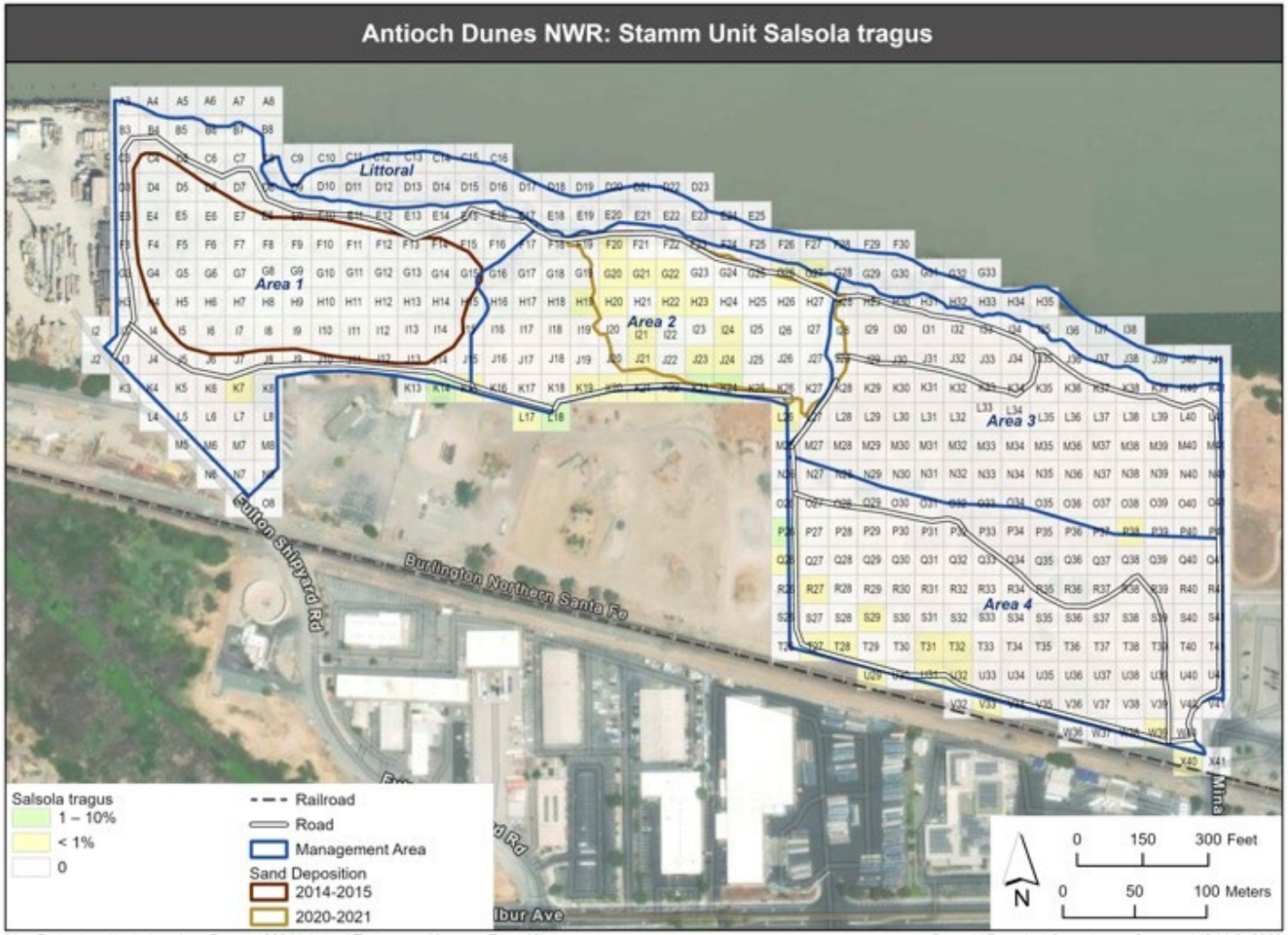
Map 1-40 Stamm Unit *Rubus armeniacus*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-41 Stamm Unit *Salsola tragus*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

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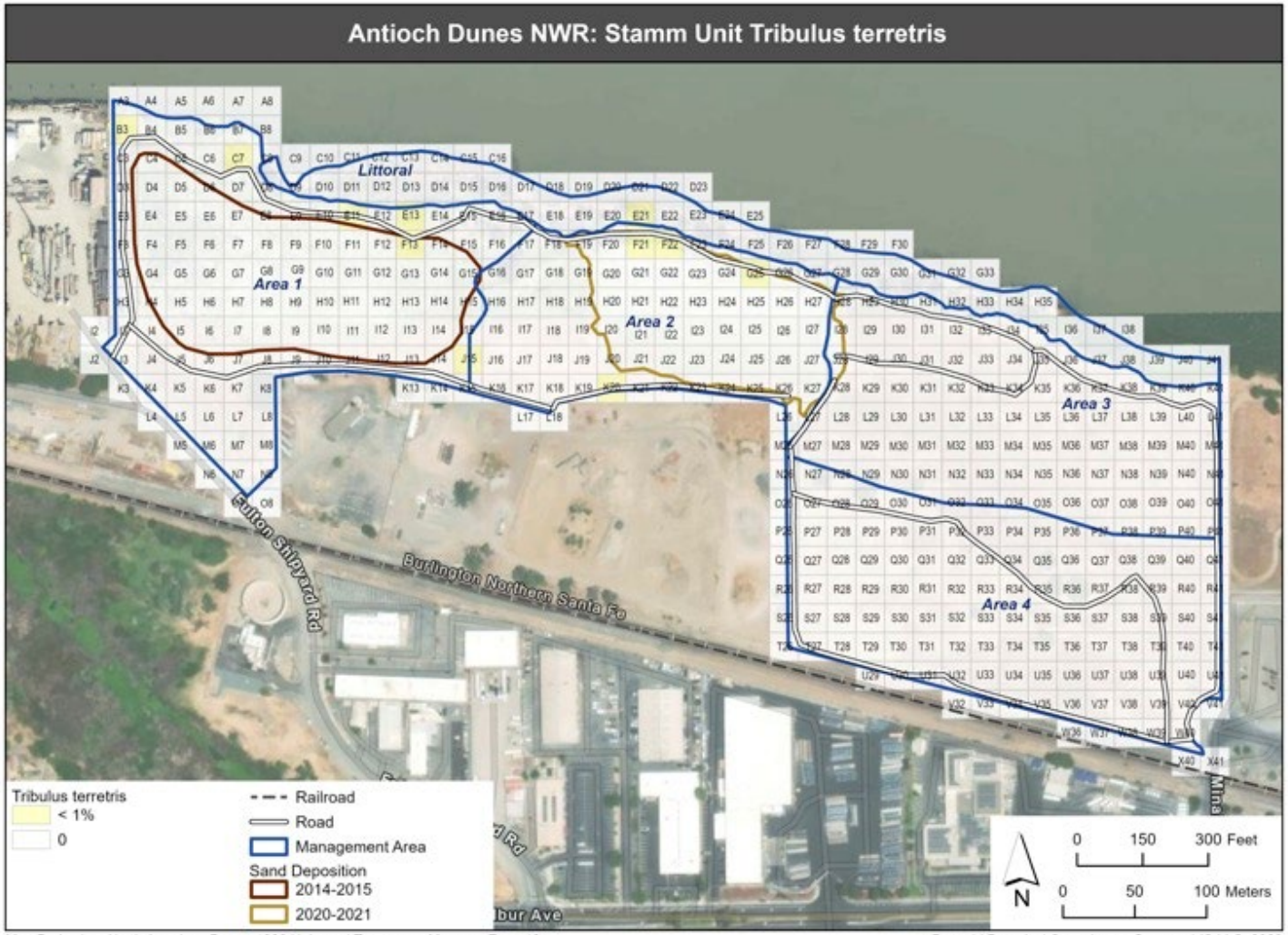
Map 1-42 Stamm Unit *Tribulus terrestris*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

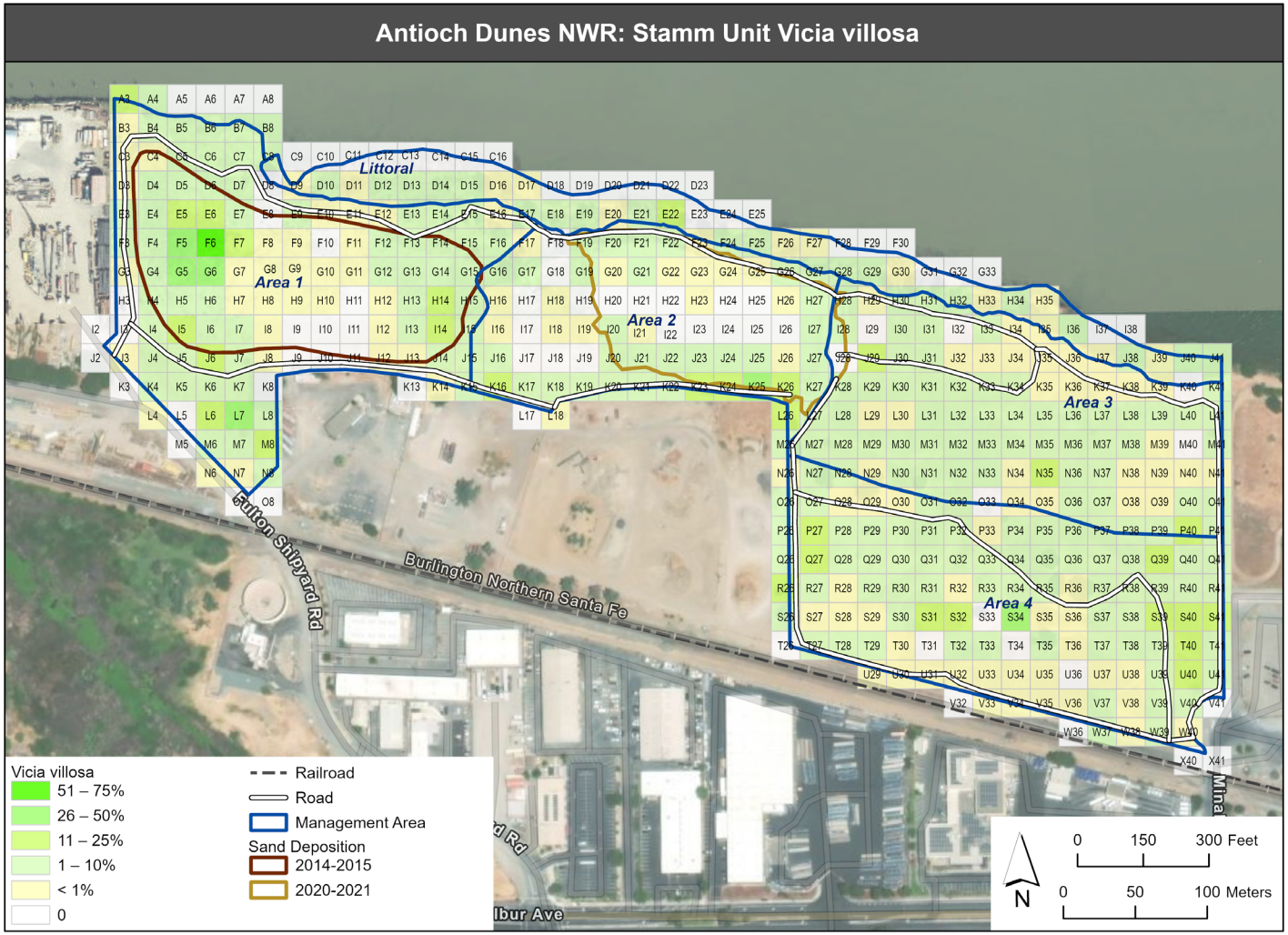
Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-43 Stamm Unit *Vicia sativa*

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 1-44 Stamm Unit *Vicia villosa*



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Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-1 Sardis Unit Survey Grid

Map 2-2 Map

Map 2-2 Sardis Unit Grid Cells Surveyed 2017 and 2022

Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

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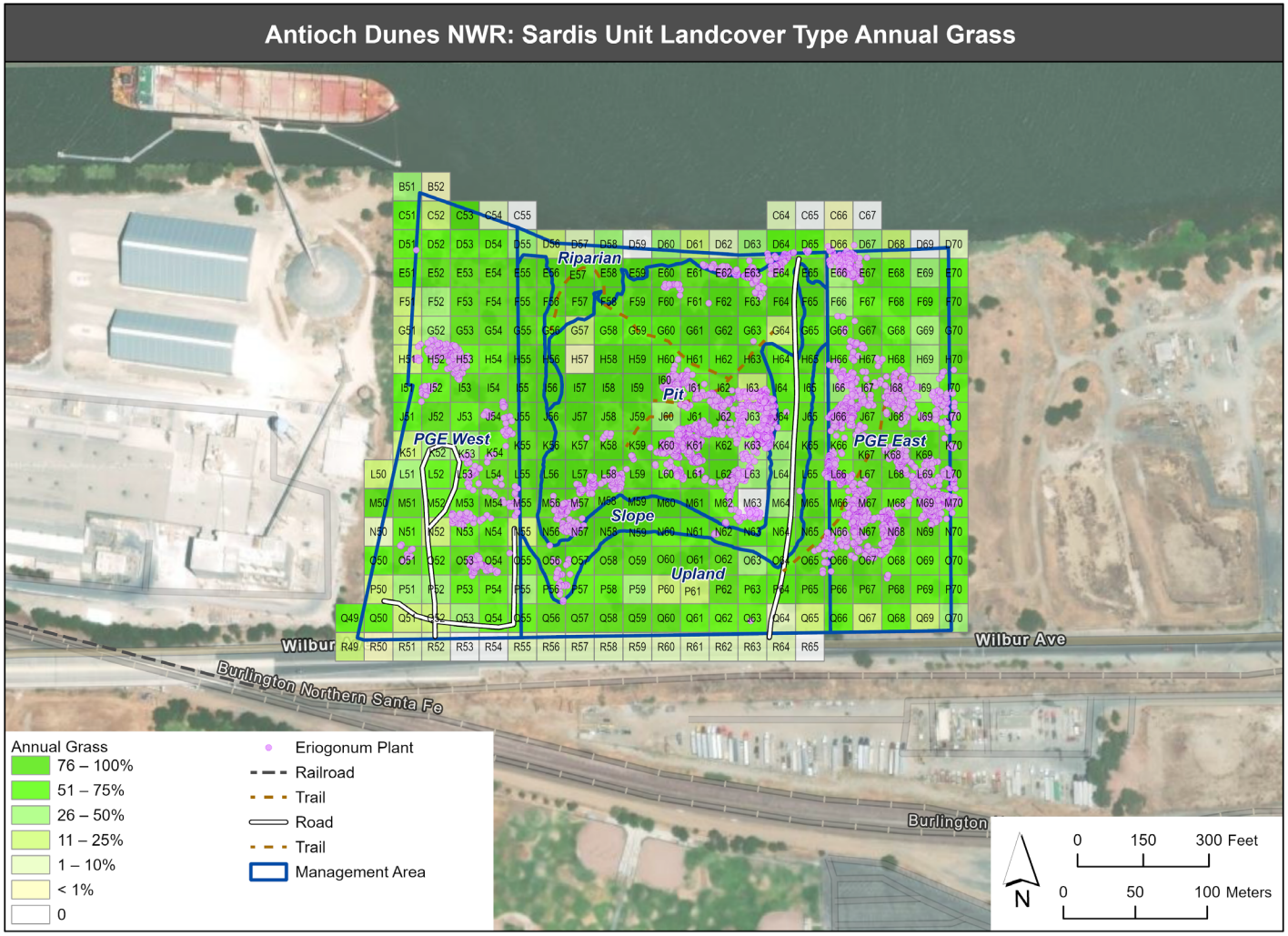
Map 2-3 Sardis Unit Annual Grass Cover



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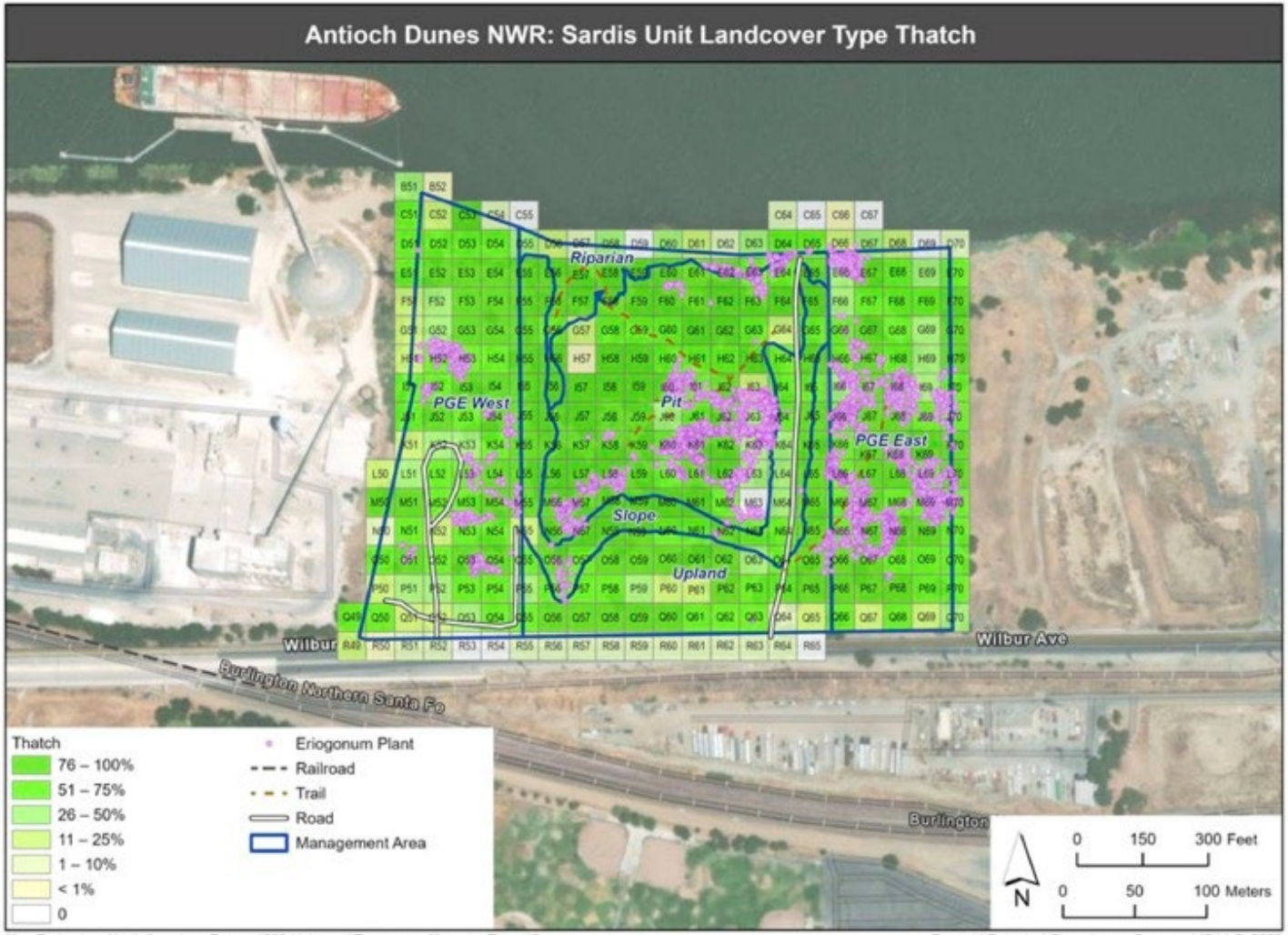
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

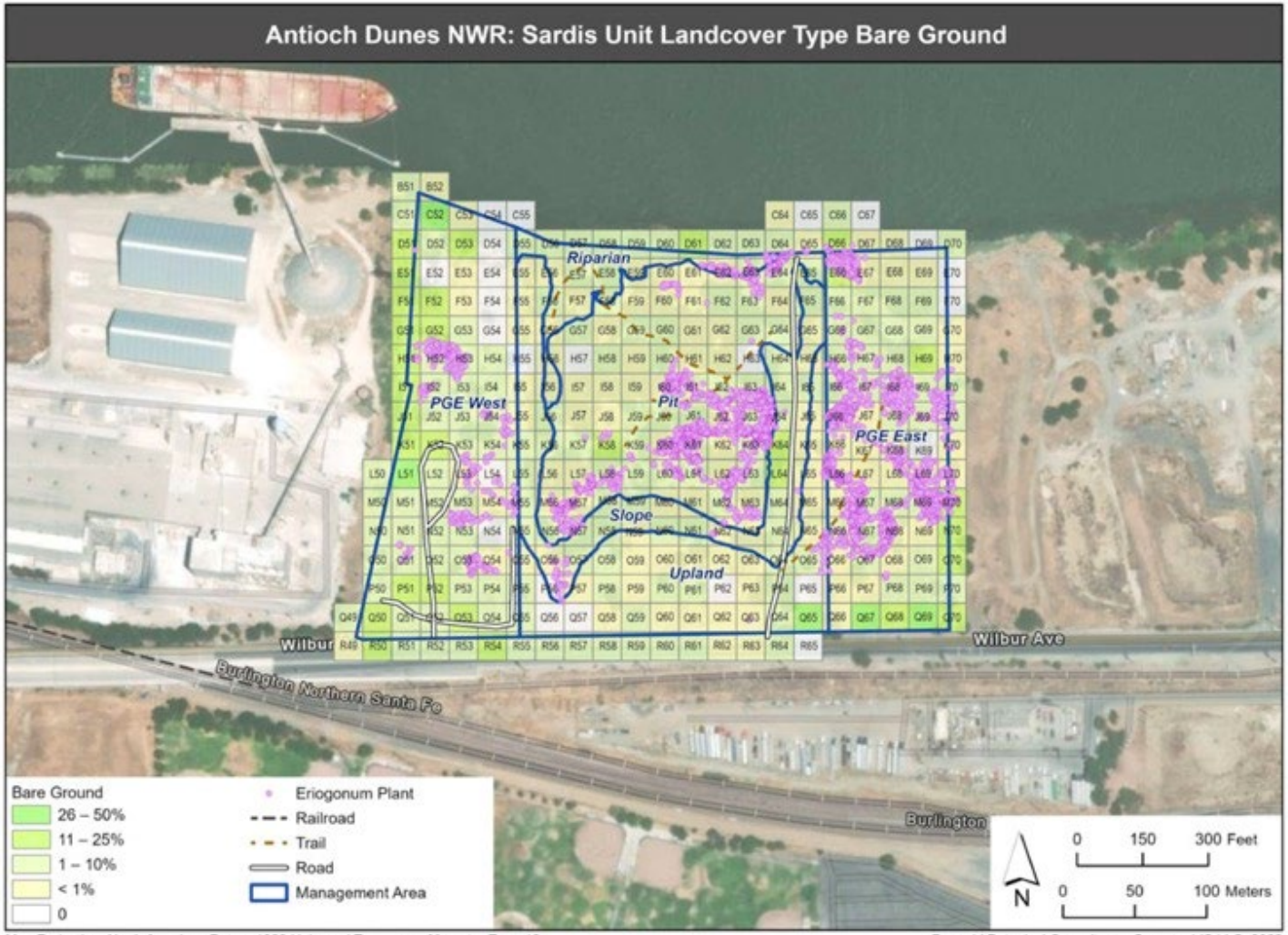
Map 2-4 Sardis Unit Thatch Cover



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-5 Sardis Unit Bare Ground Cover



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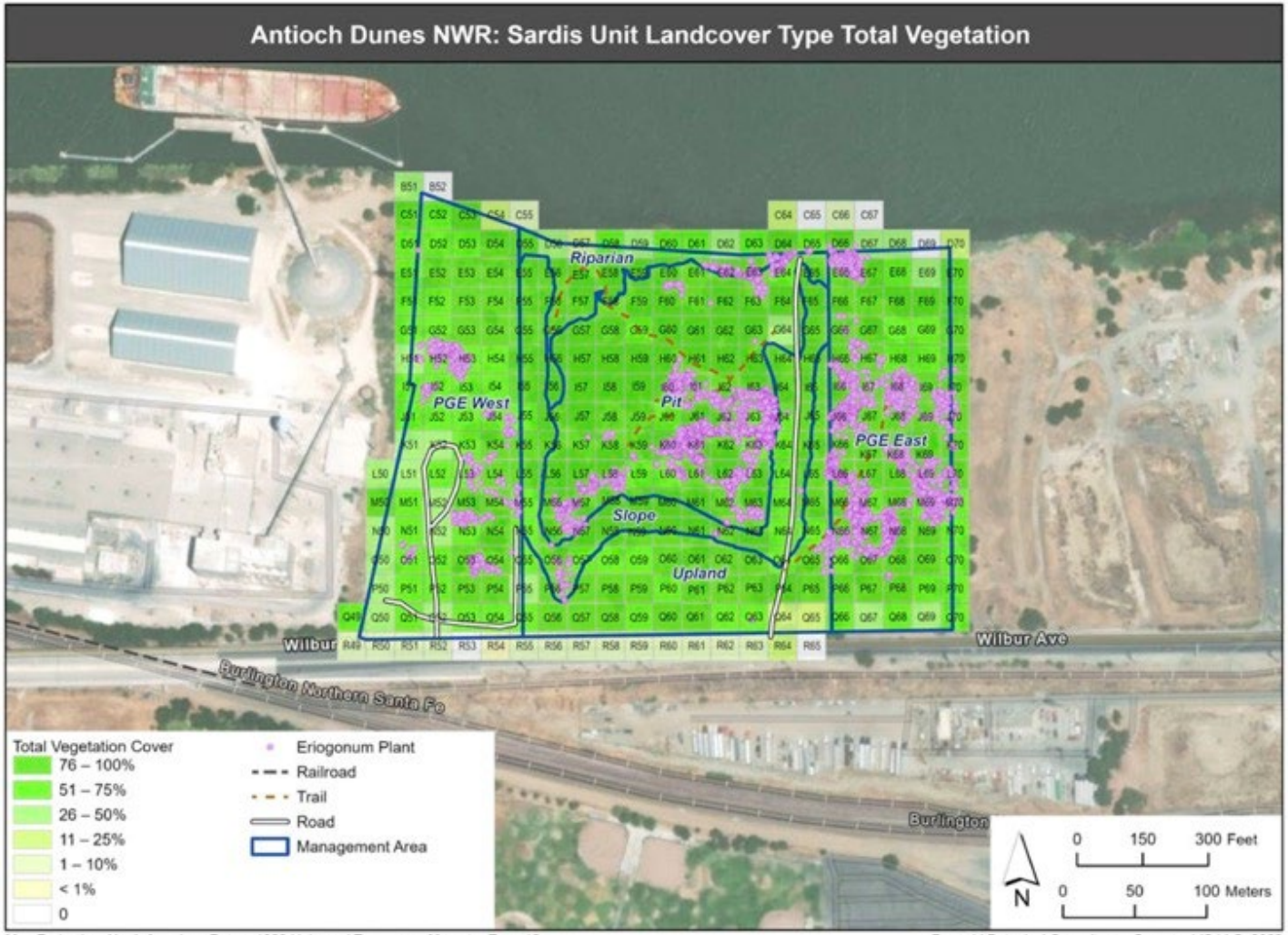
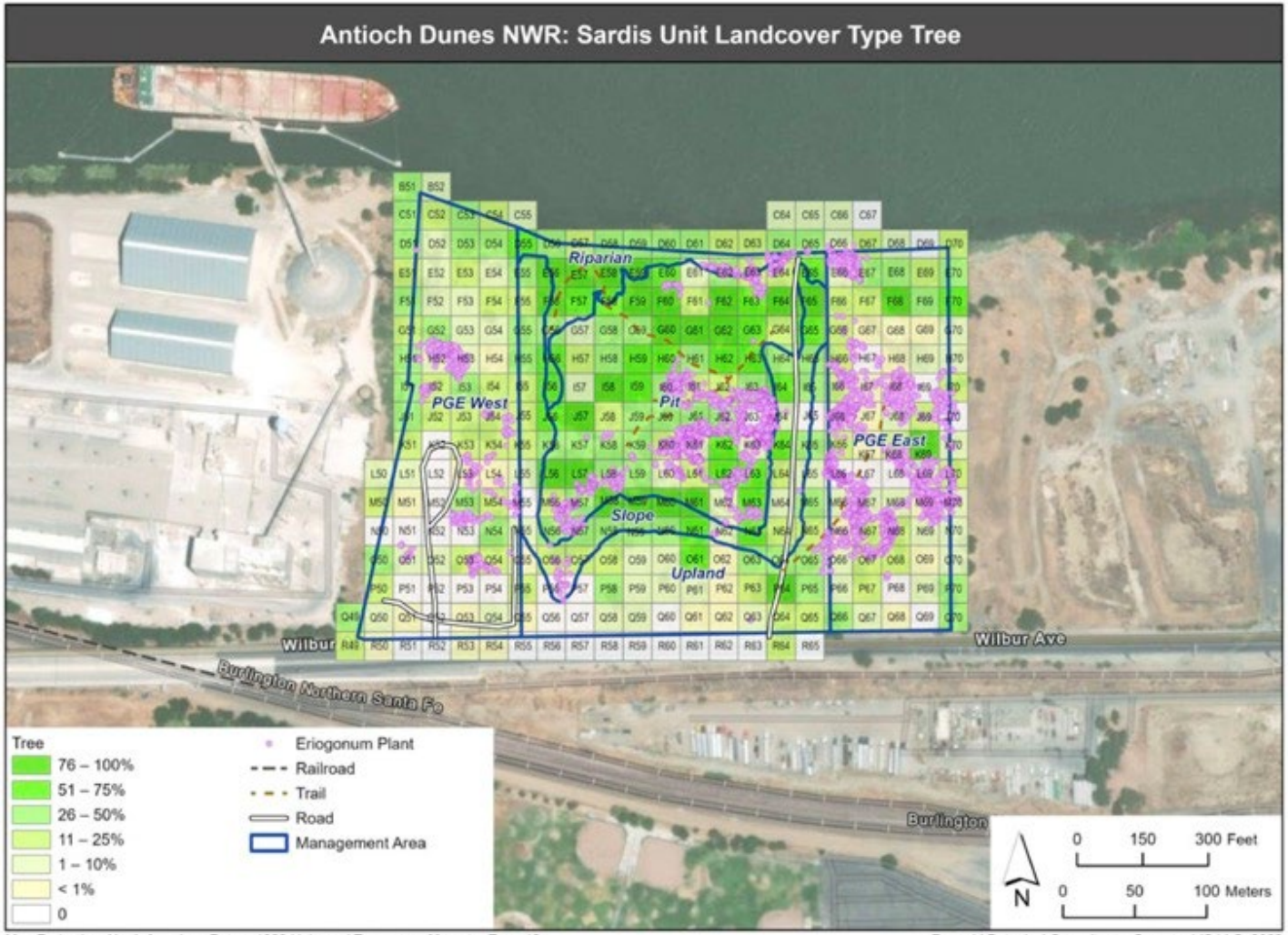
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-6 Sardis Unit Total Vegetation Cover



Map 2-7 Sardis Unit Tree Cover



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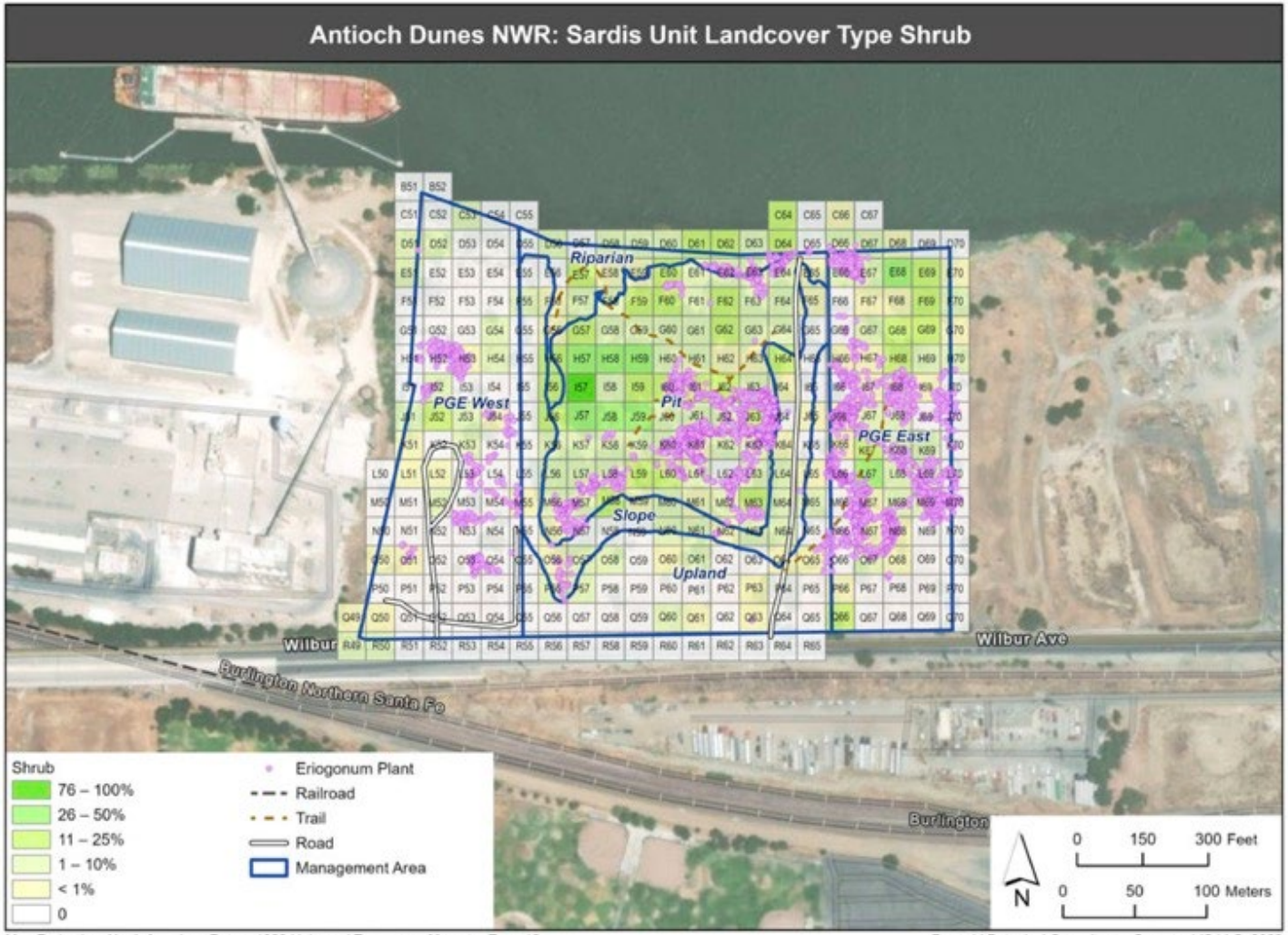
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-8 Sardis Unit Shrub Cover



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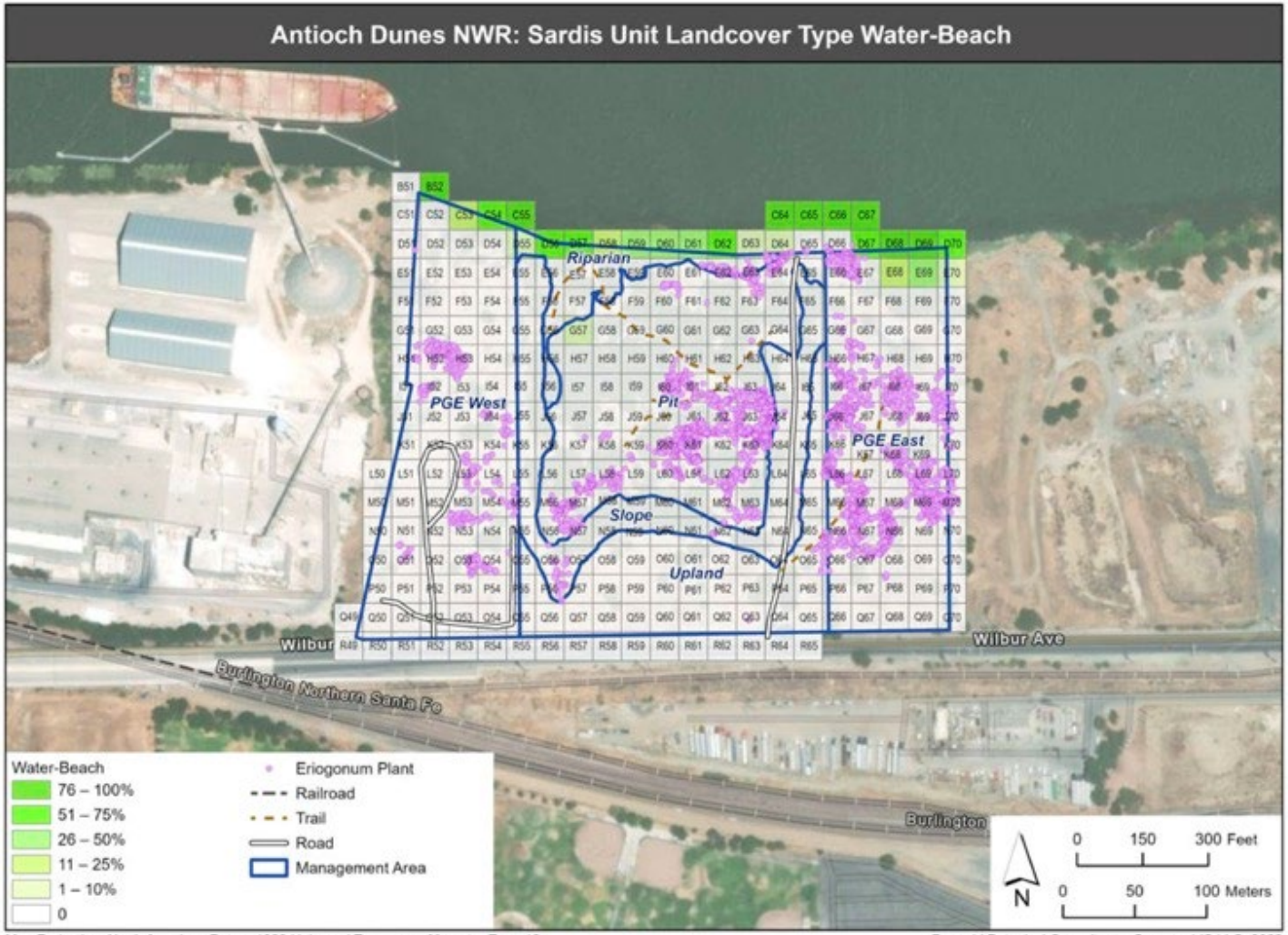
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

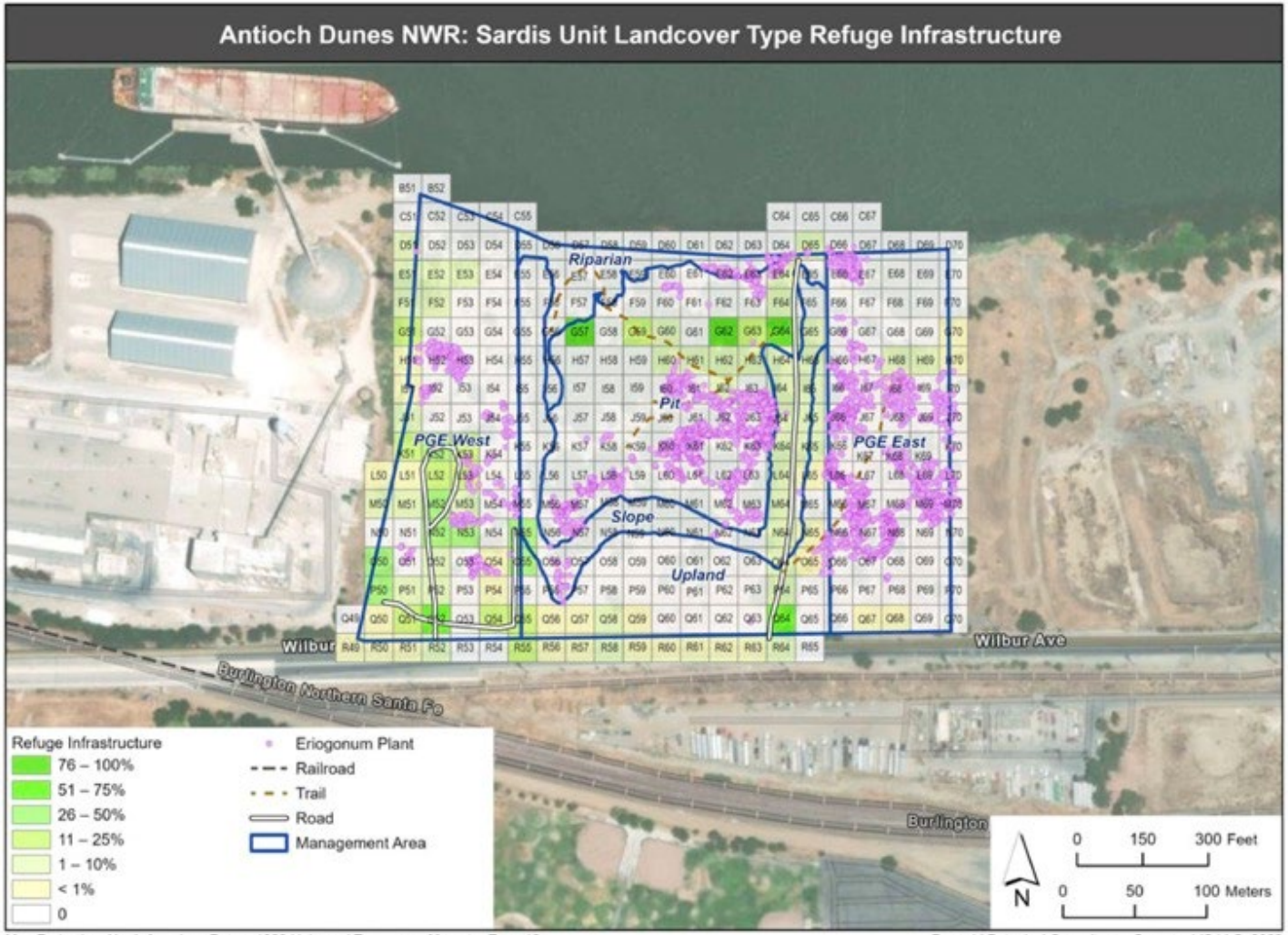
Map 2-9 Sardis Unit Water/Beach Cover



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

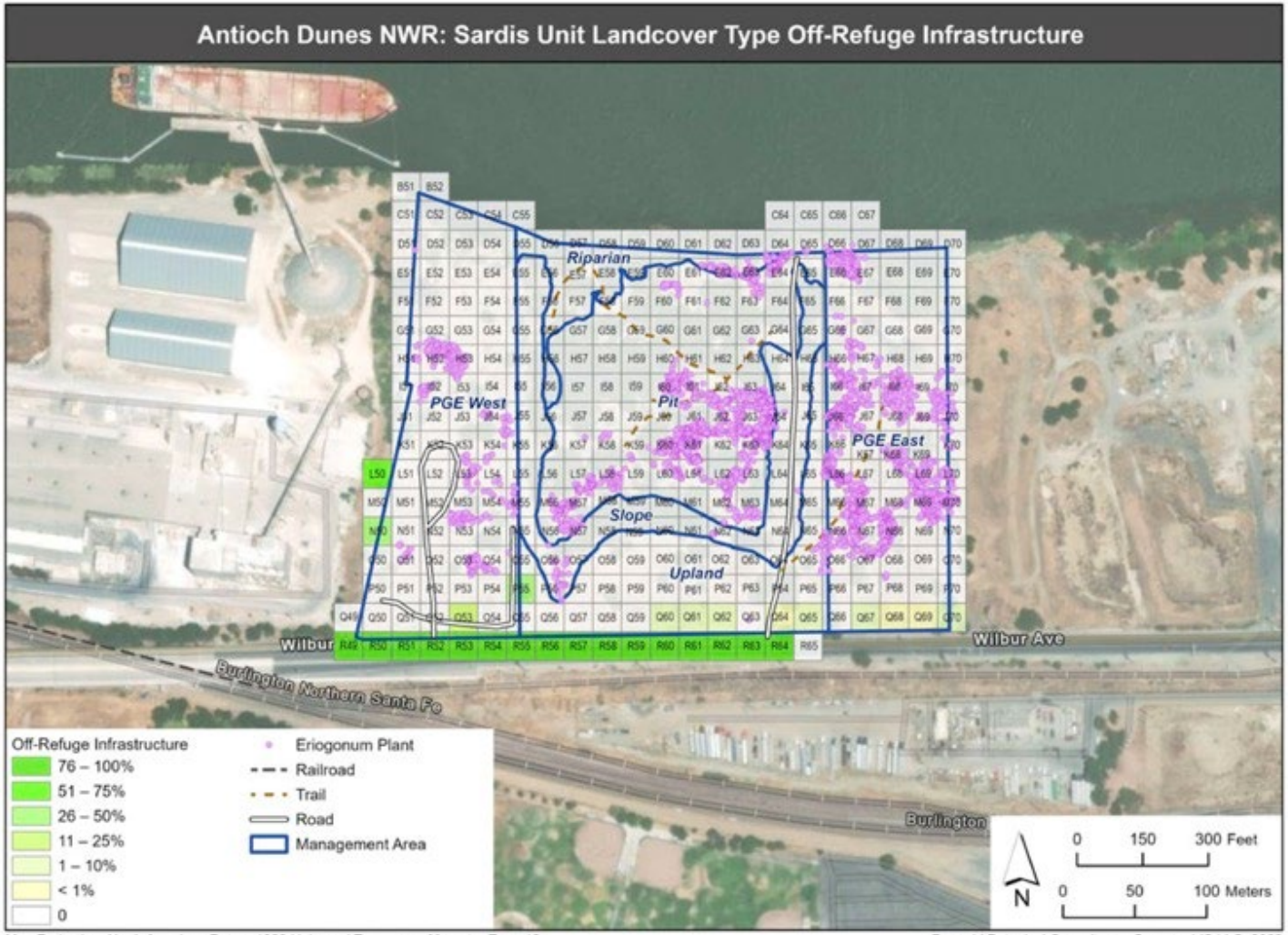
Map 2-10 Sardis Unit Refuge Infrastructure



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-11 Sardis Unit Off-Refuge Infrastructure



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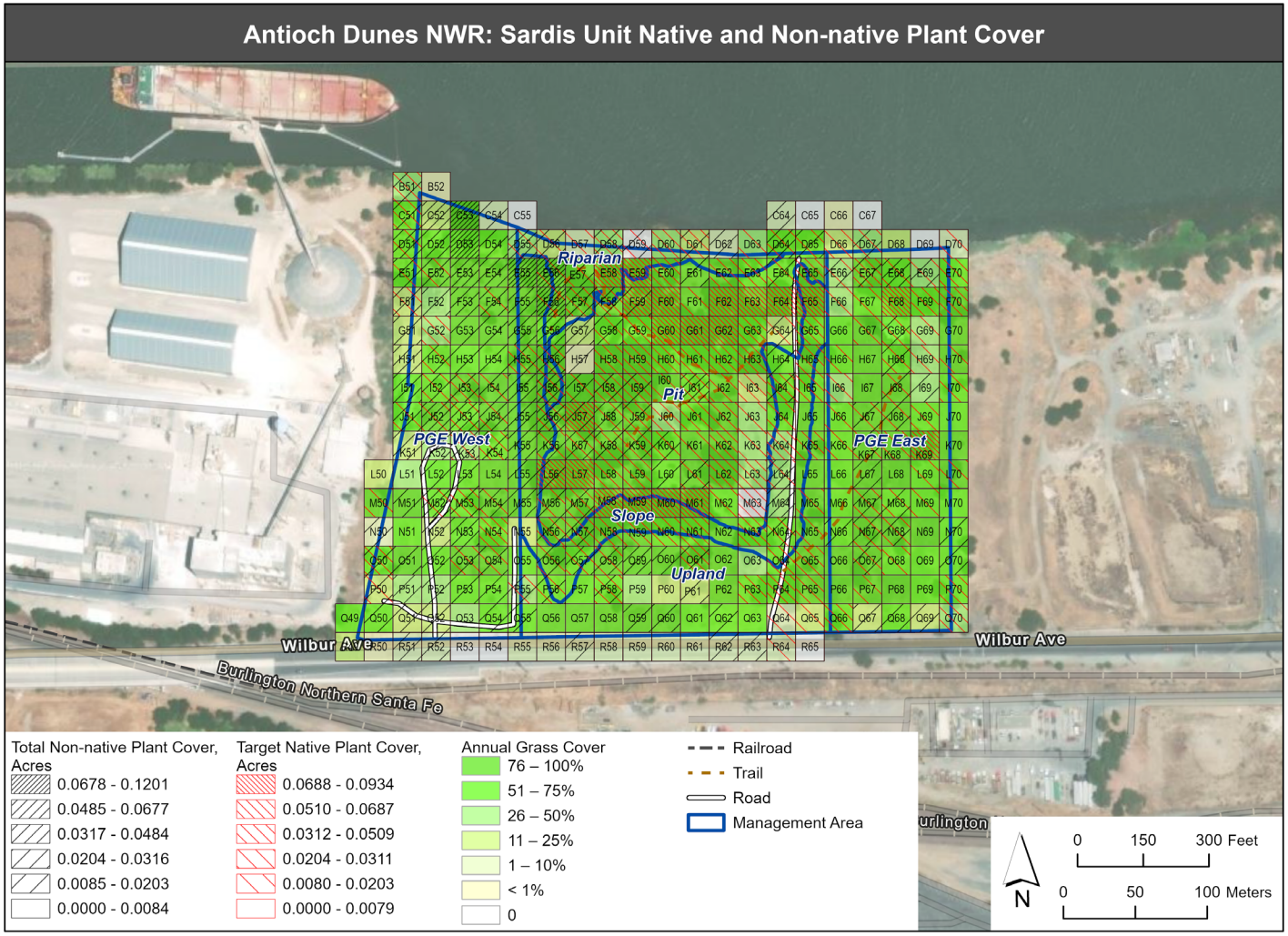
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-12 Sardis Unit Total Target Native and Invasive Plant Cover



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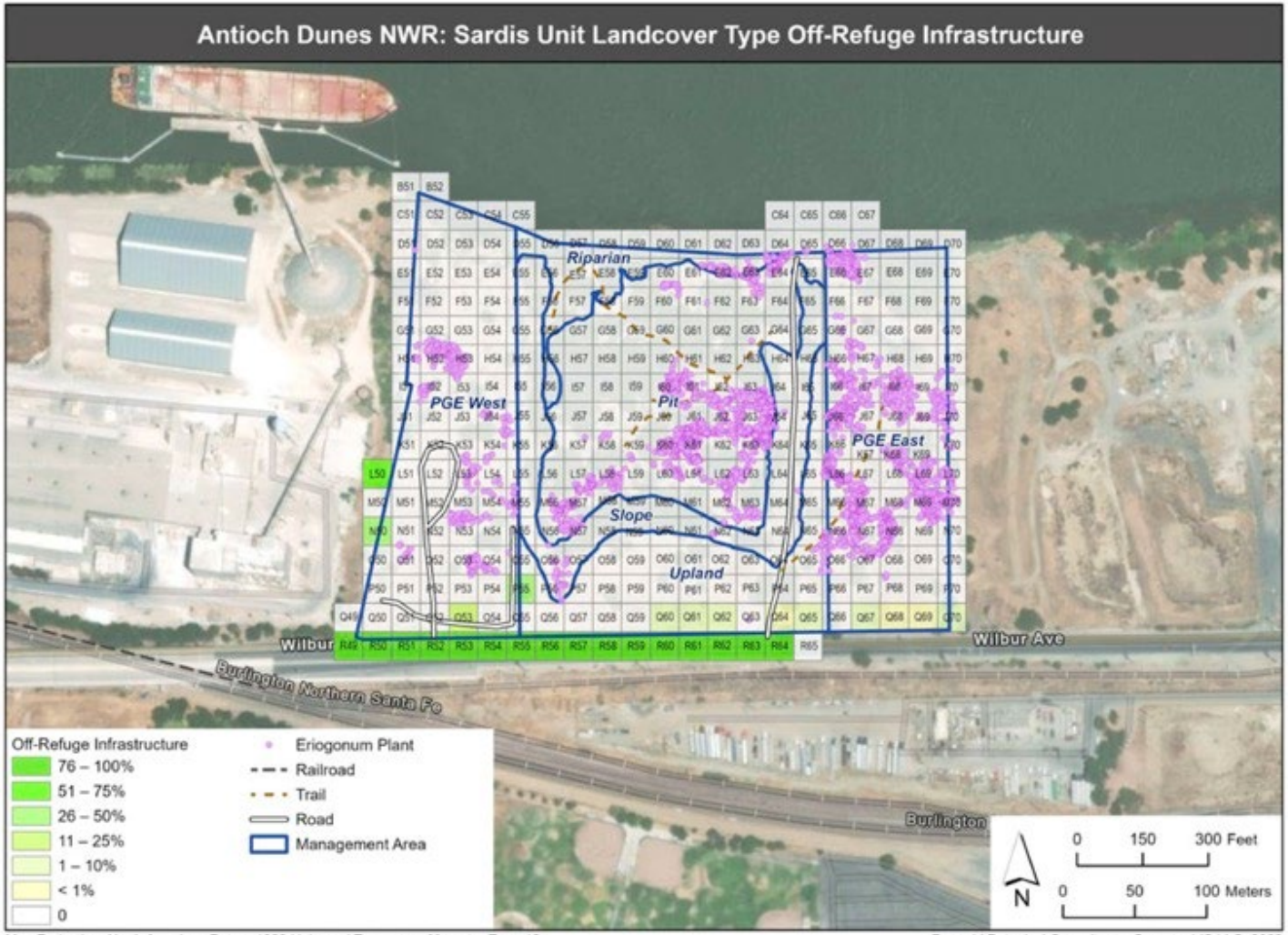
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

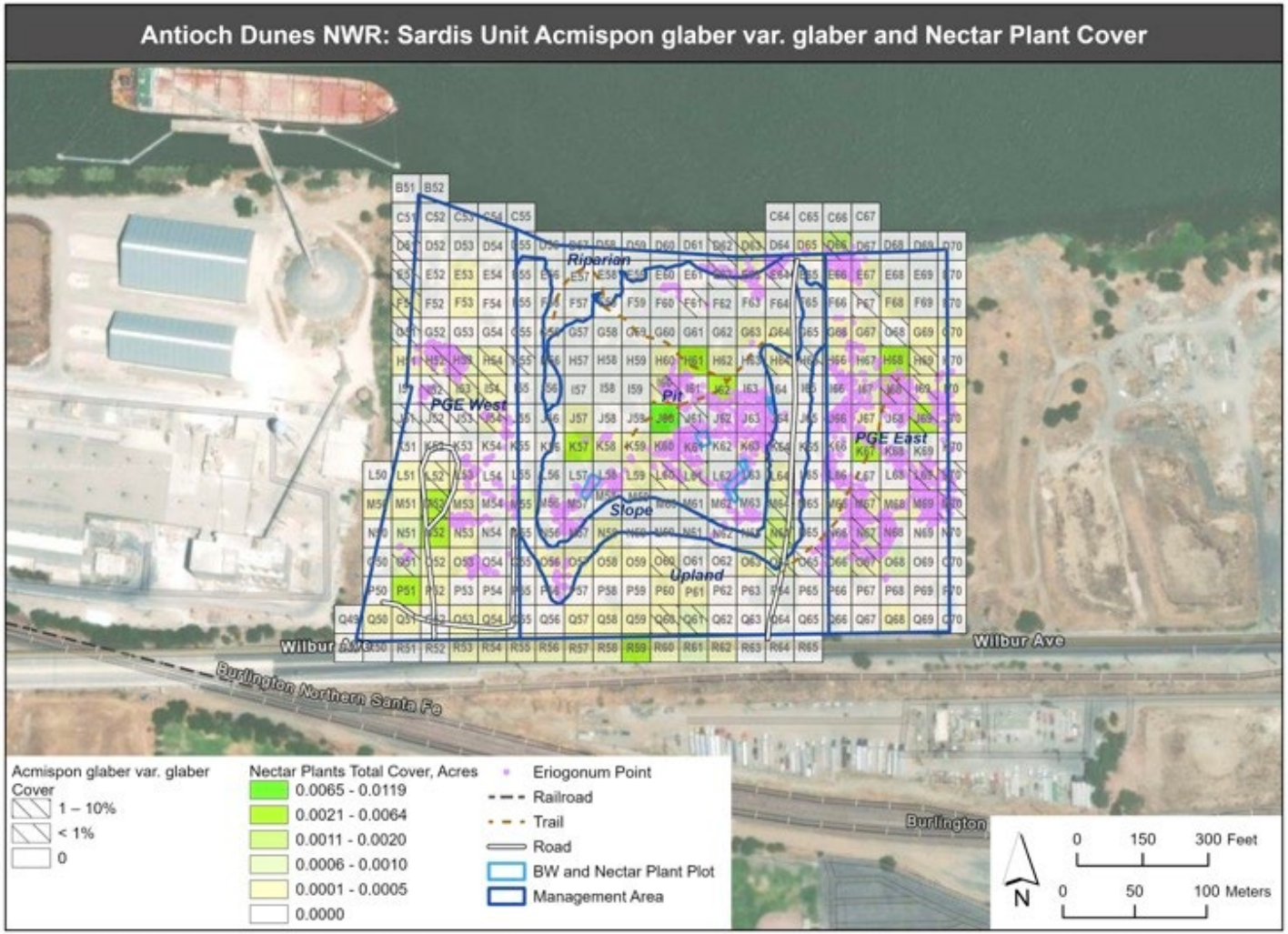
Map 2-13 Sardis Unit Target Native Plant Richness and Invasive Plant Richness



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

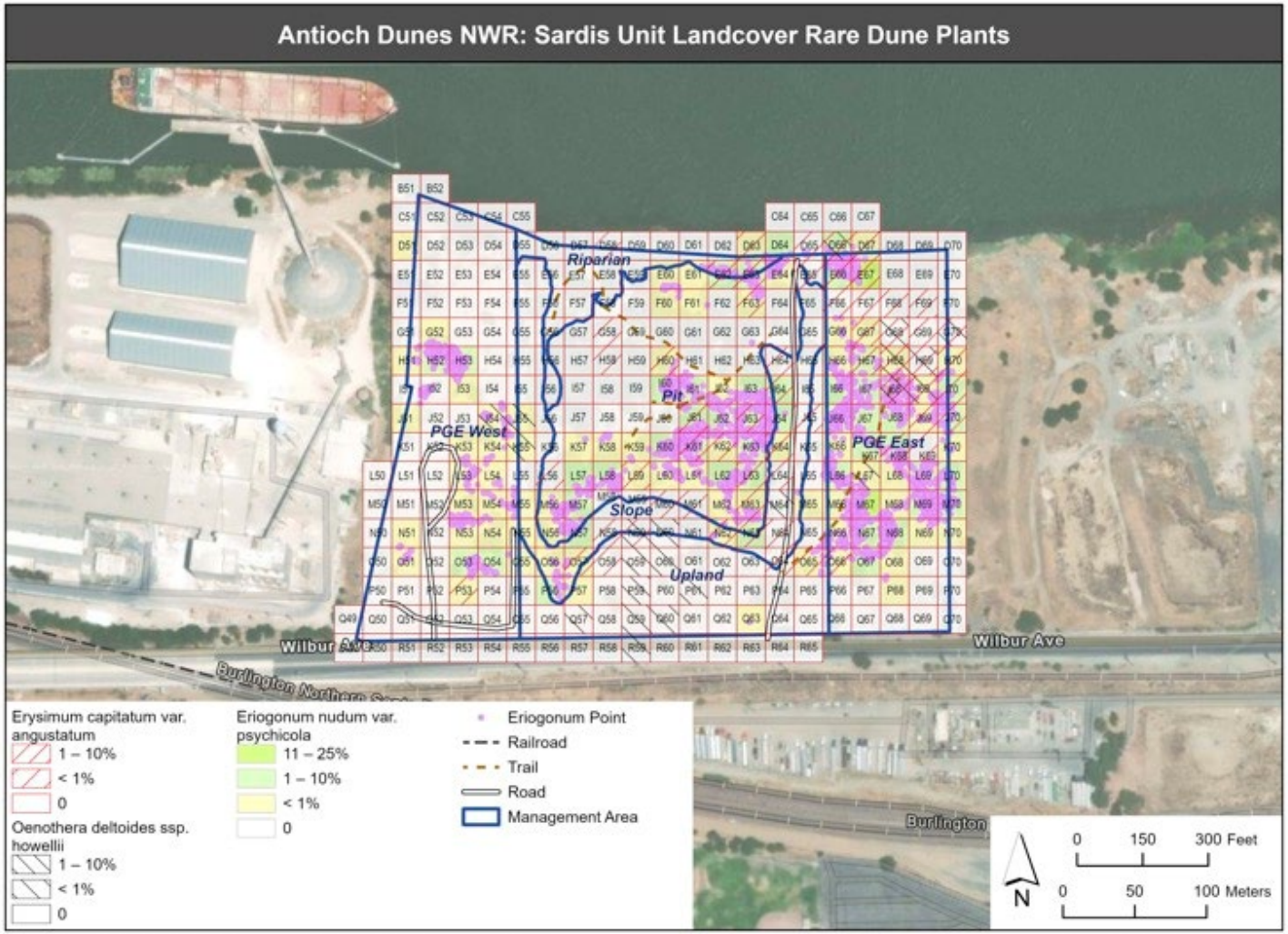
Map 2-14 Sardis Unit Nectar and Perch Plant Cover



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-15 Sardis Unit Rare Dune Plant Cover



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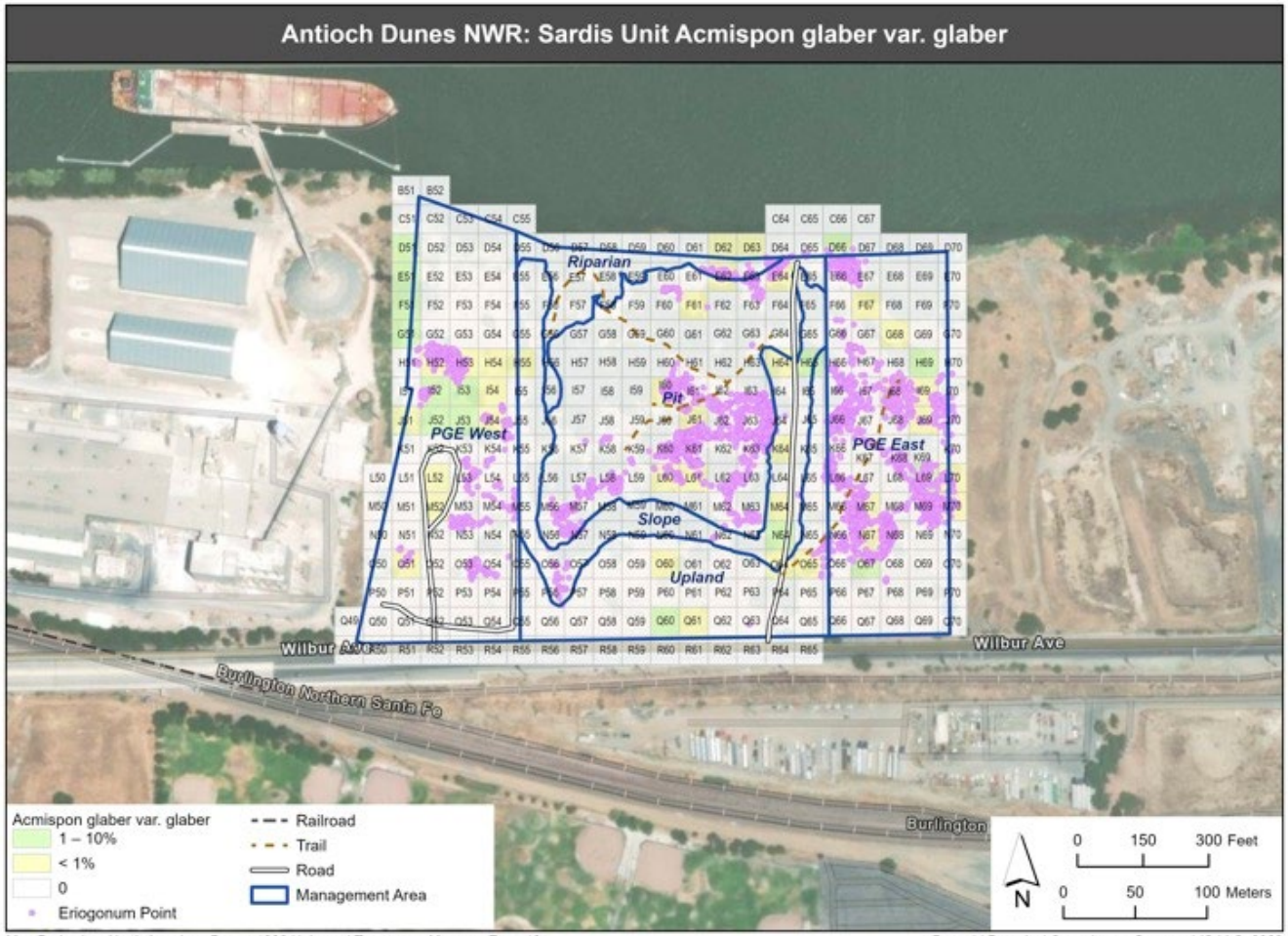
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

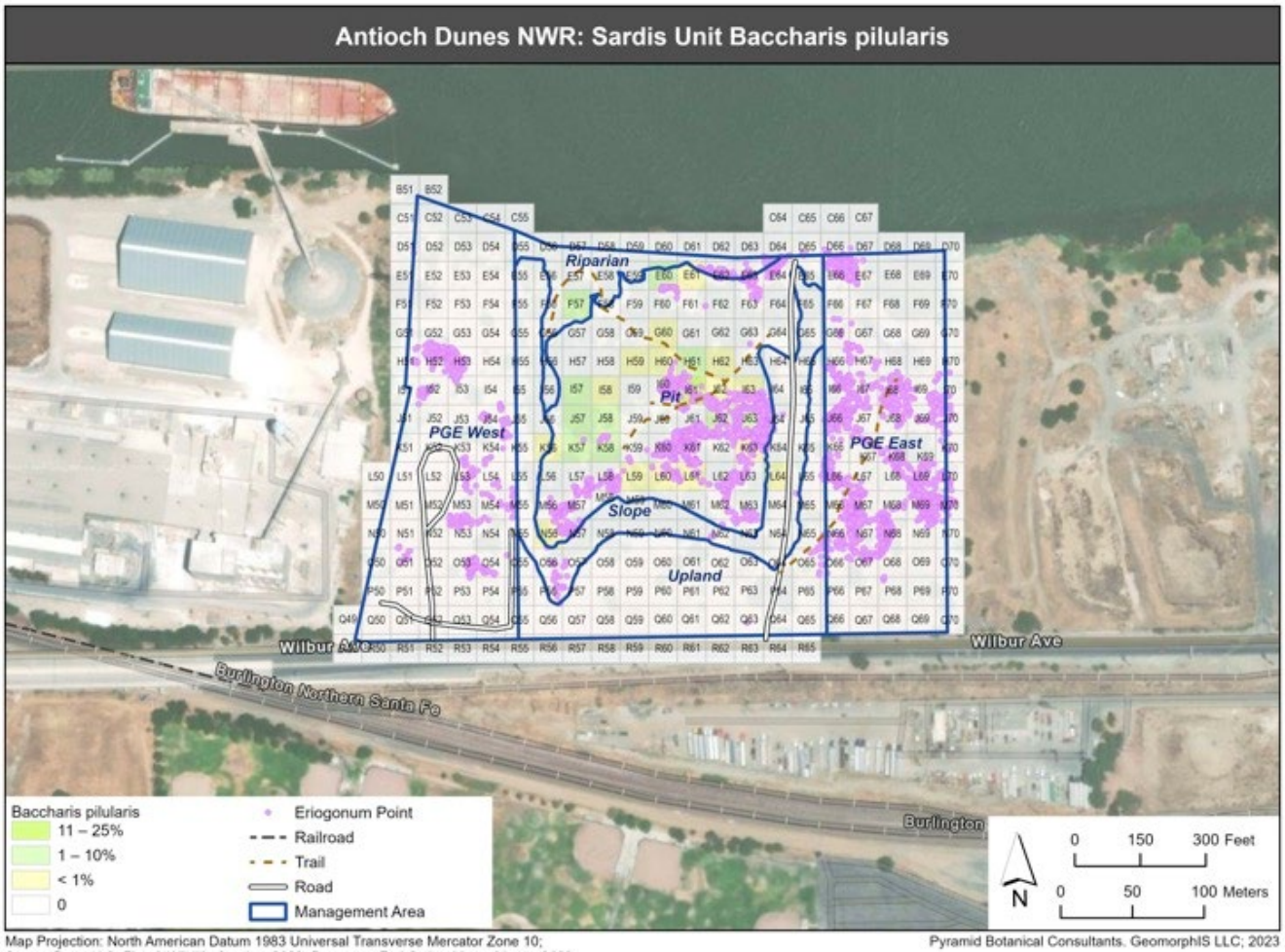
Map 2-16 Sardis Unit *Acmispon glaber* var. *glaber*



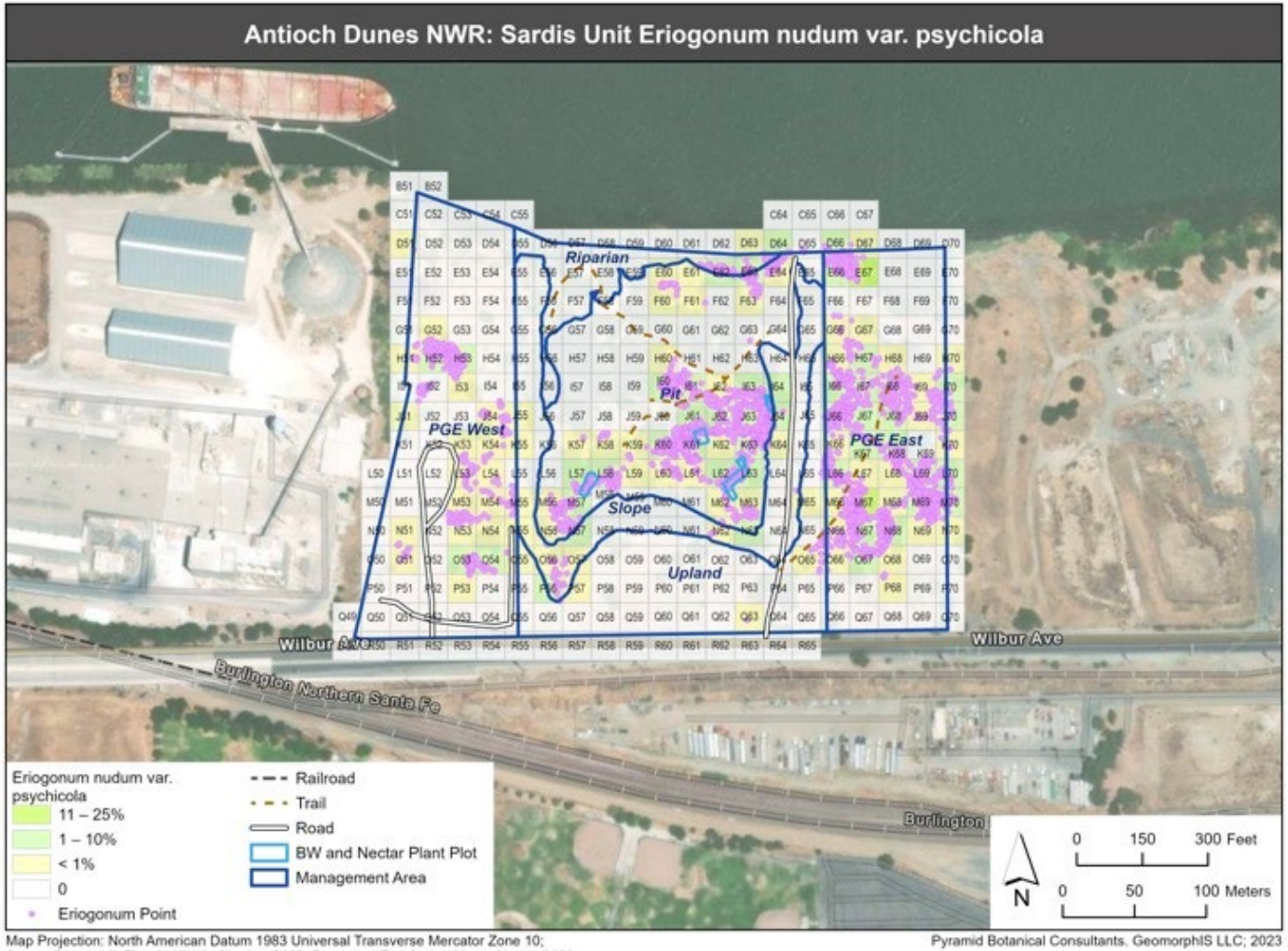
Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-17 Sardis Unit *Baccharis pilularis*



Map 2-18 Sardis Unit *Eriogonum nudum var. psychicola*



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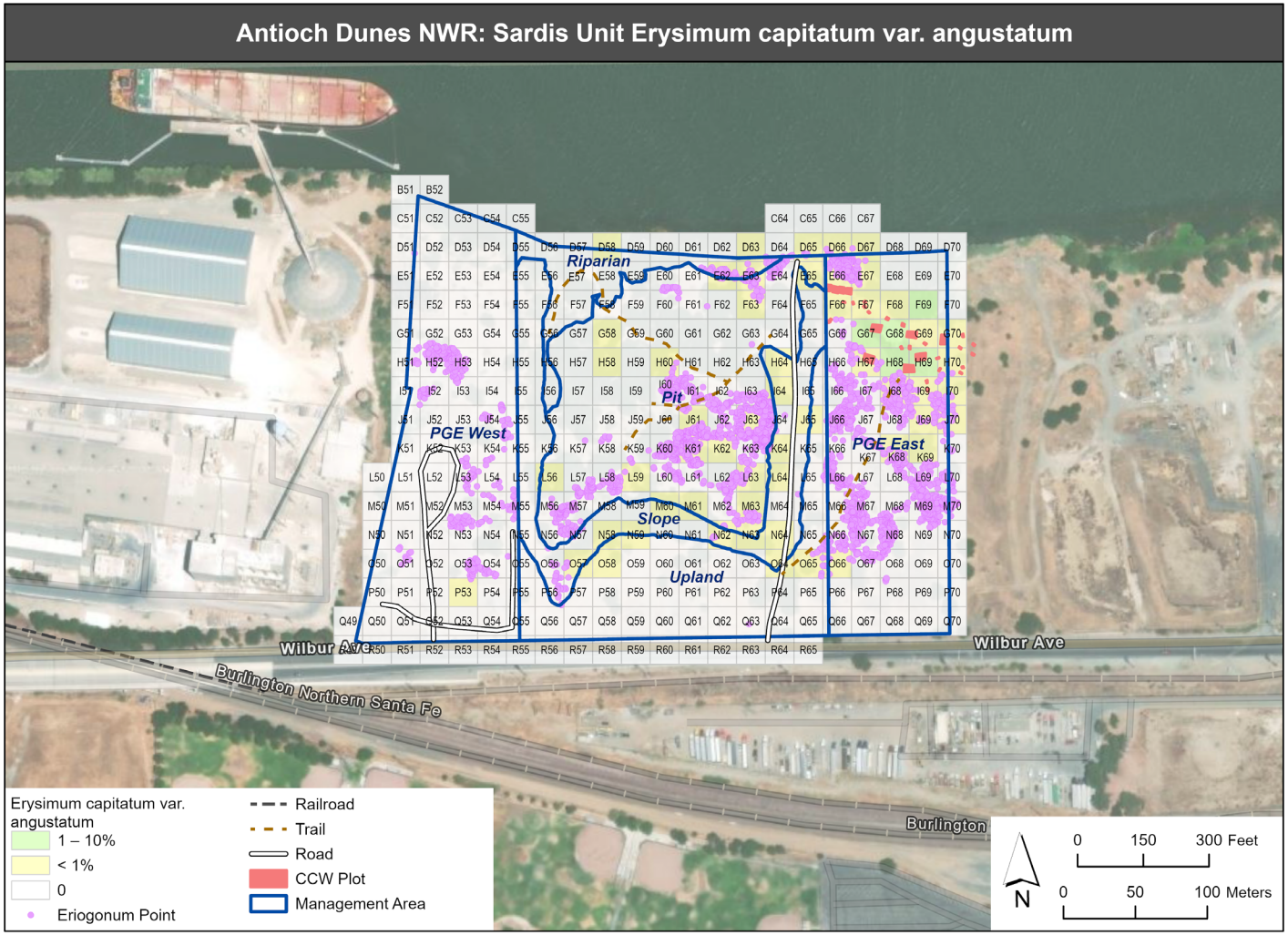
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-19 Sardis Unit *Erysimum capitatum* var. *angustatum*



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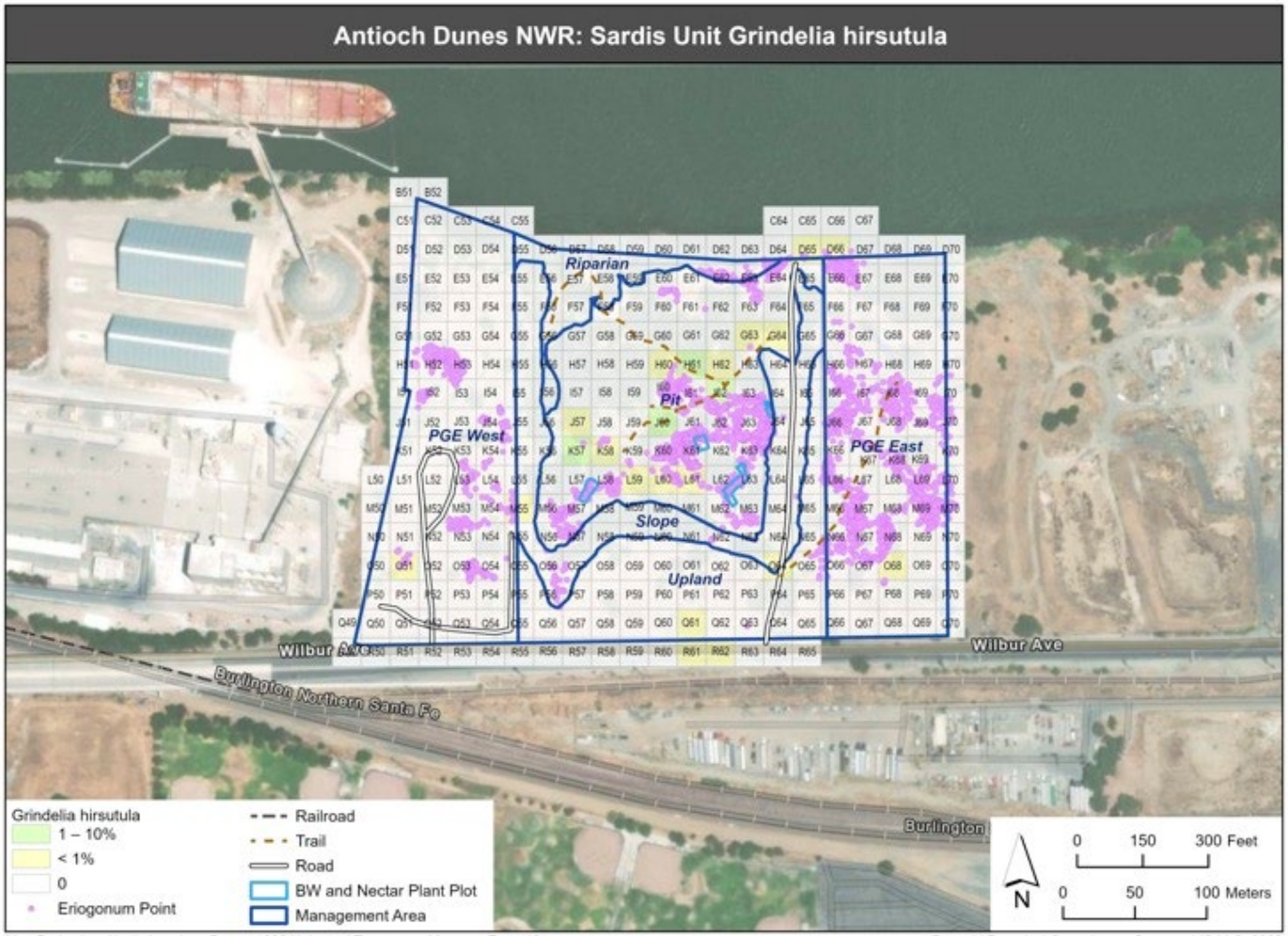
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-20 Sardis Unit *Grindelia hirsutula*



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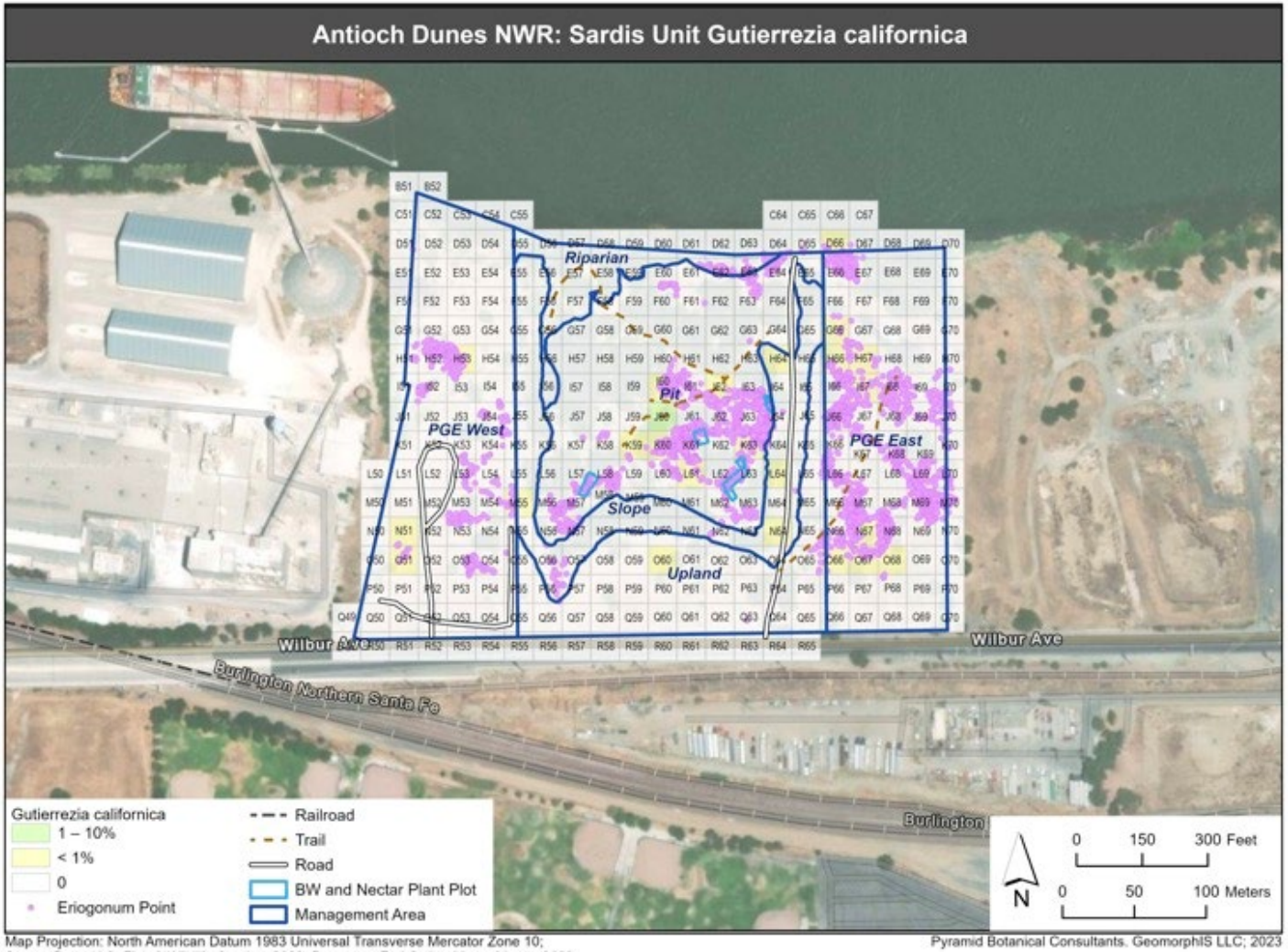
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-21 Sardis Unit *Gutierezzia californica*



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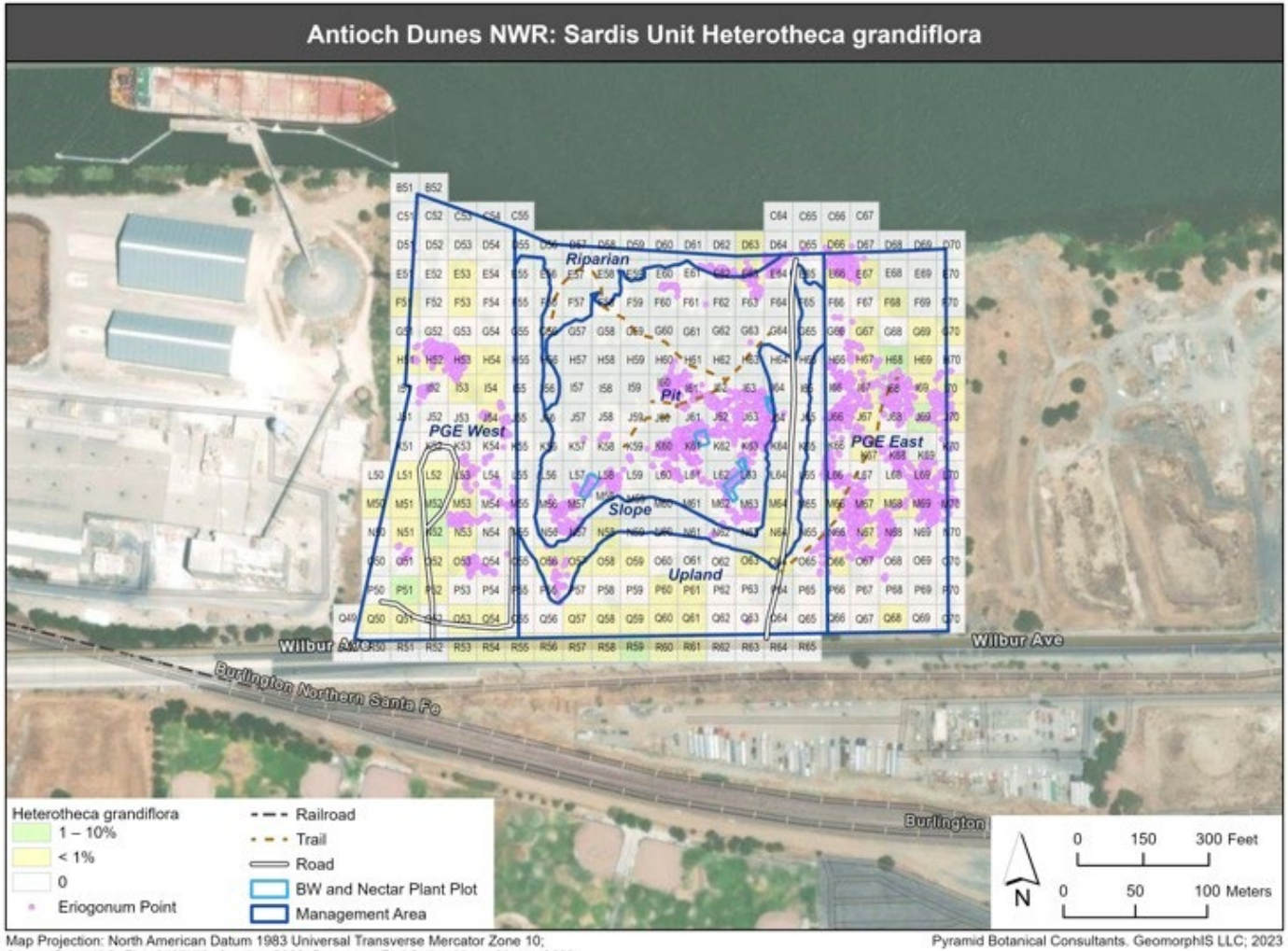
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-22 Sardis Unit *Heterotheca grandiflora*



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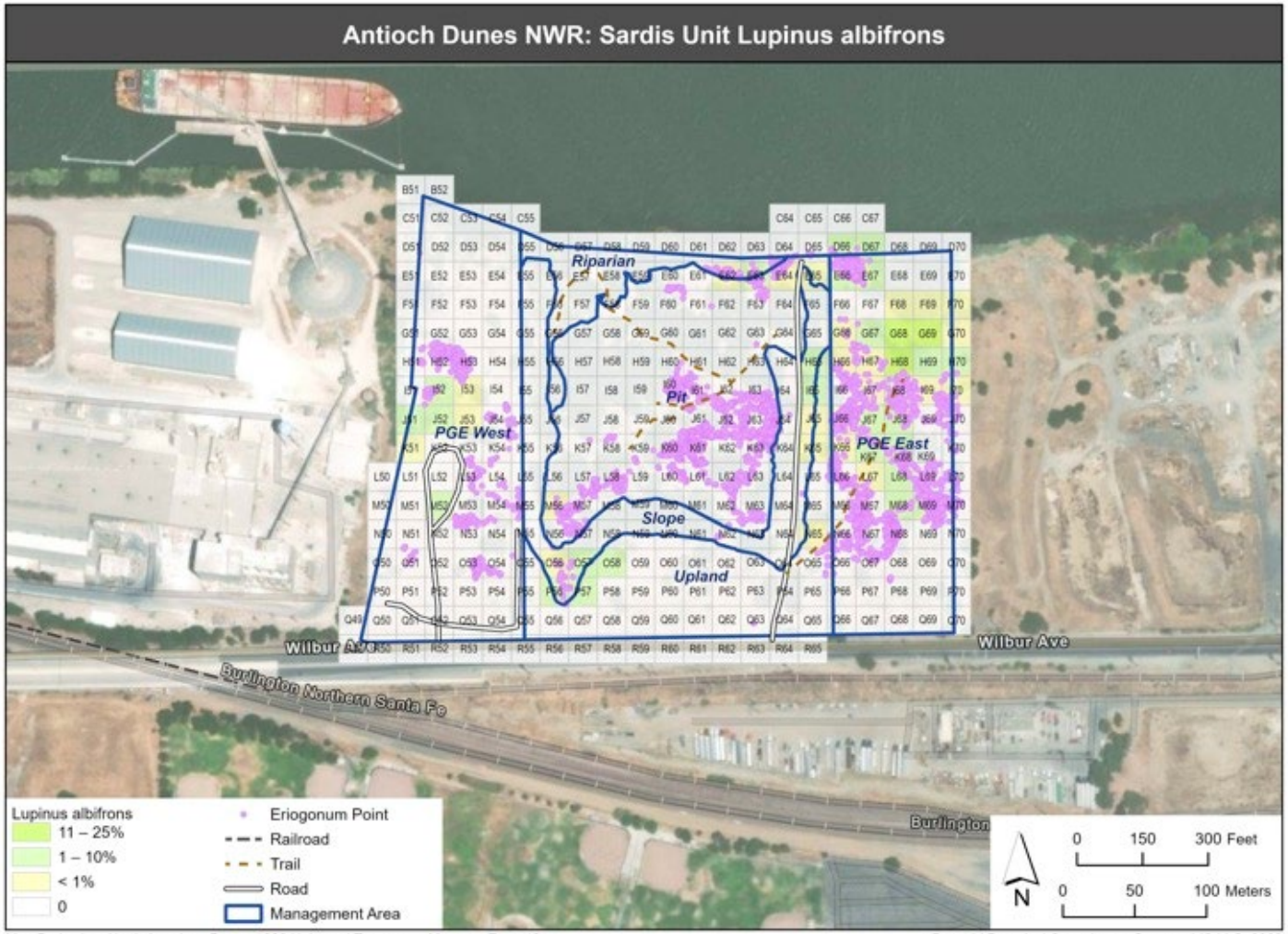
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-23 Sardis Unit *Lupinus albifrons*



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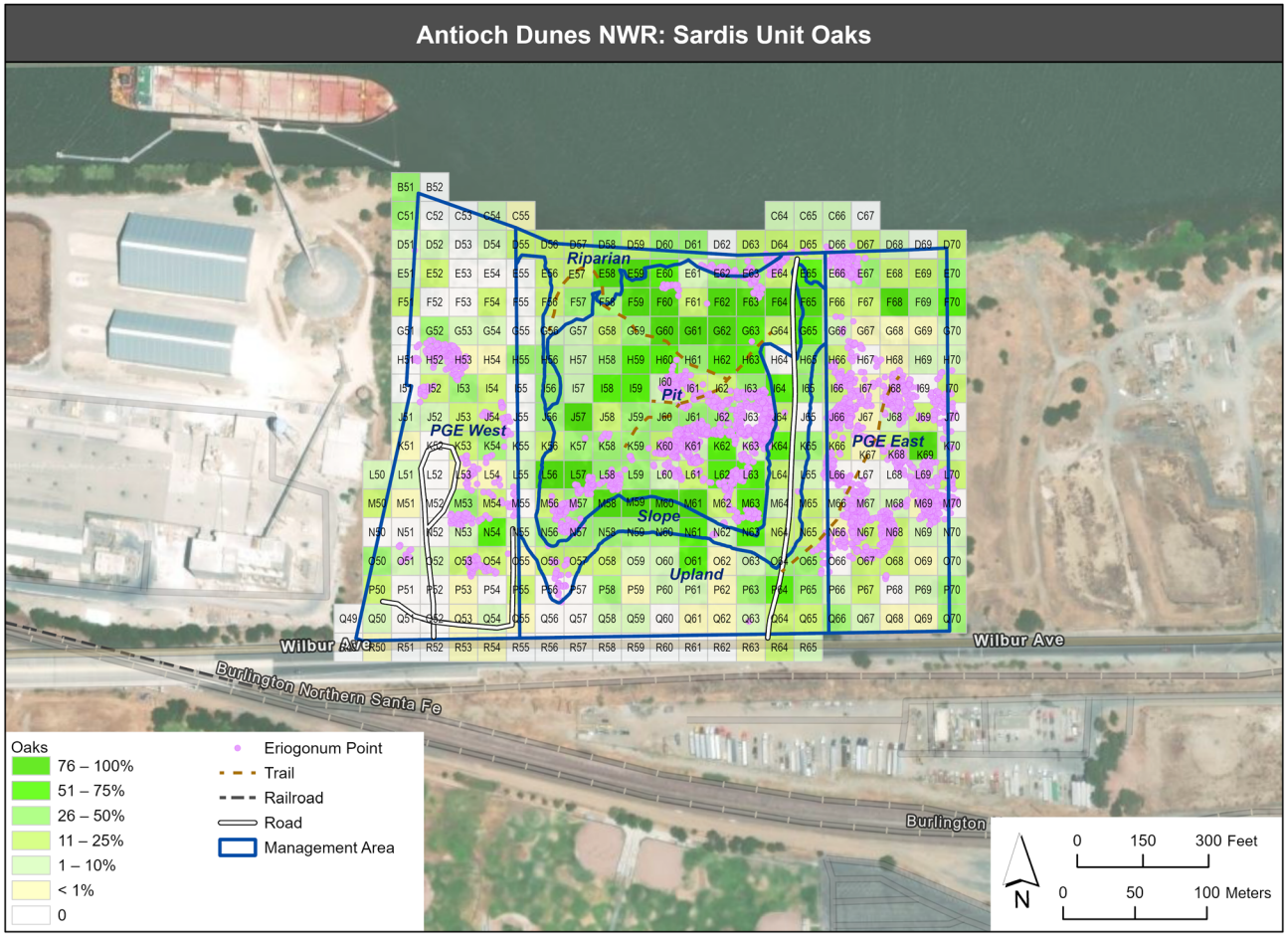
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-24 Sardis Unit *Quercus* subsp.



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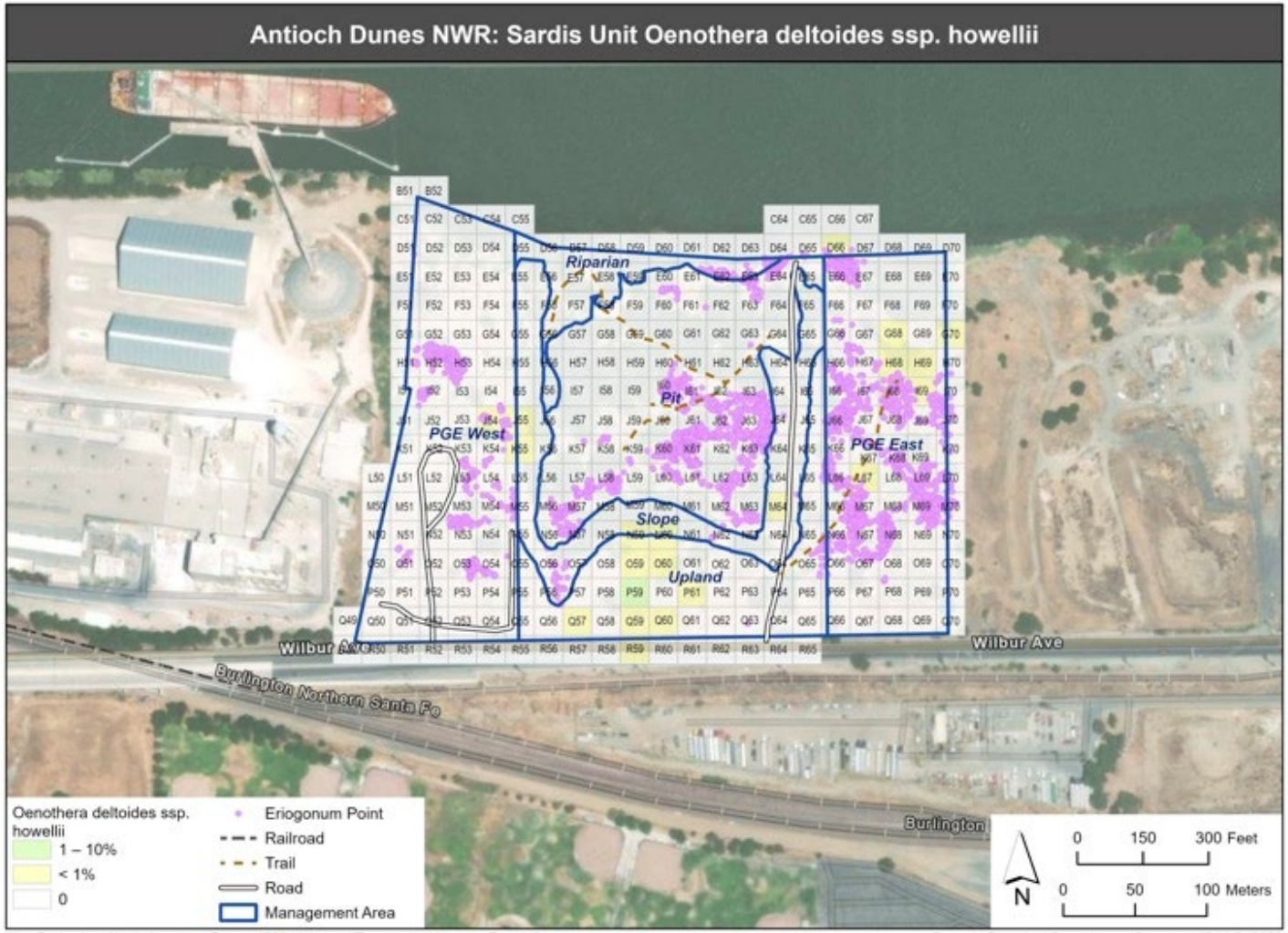
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-25 Sardis Unit *Oenothera deltoides ssp. howellii*



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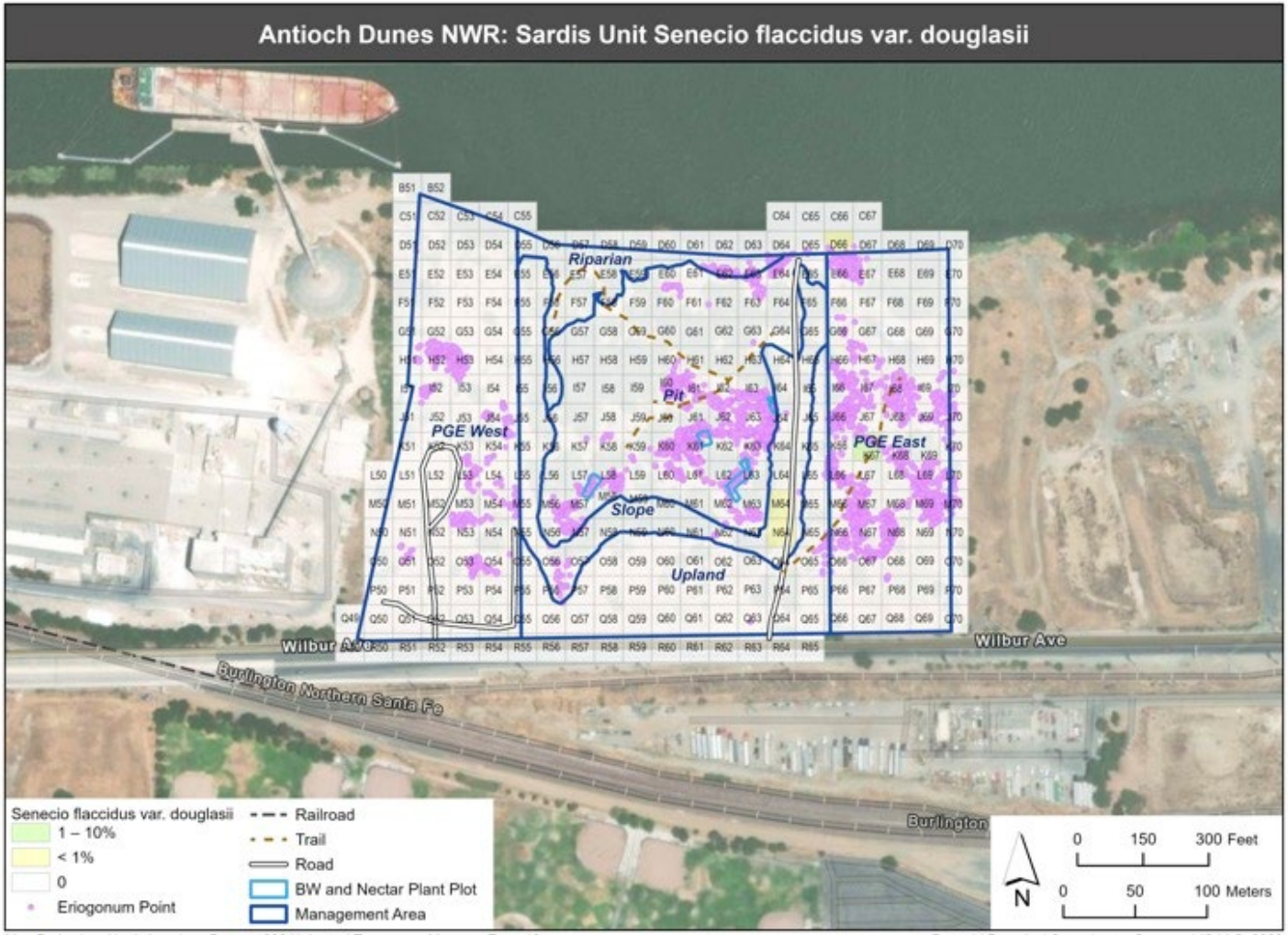
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-26 Sardis Unit *Senecio flaccidus var. douglasii*



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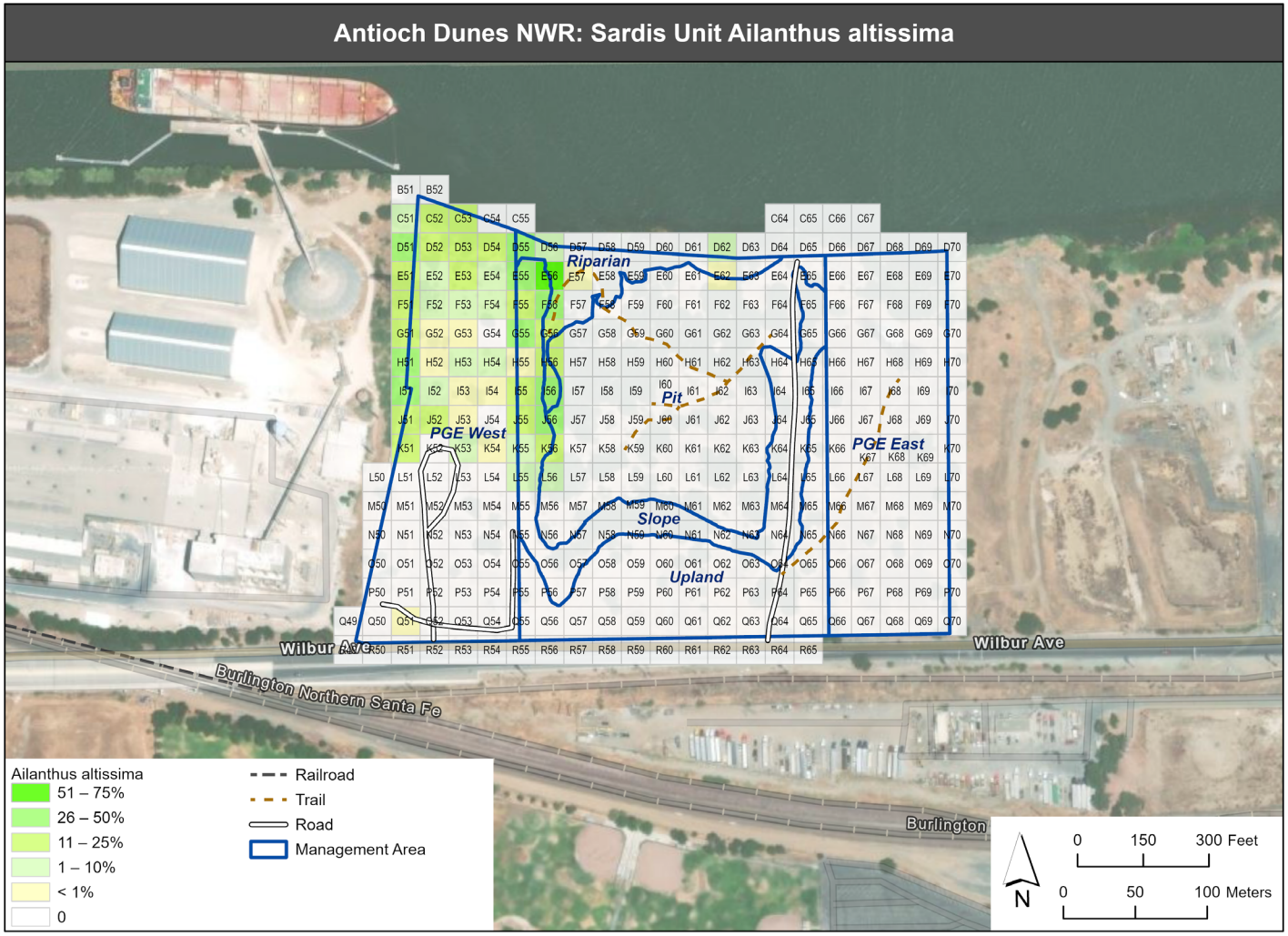
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-27 Sardis Unit *Ailanthus altissima*



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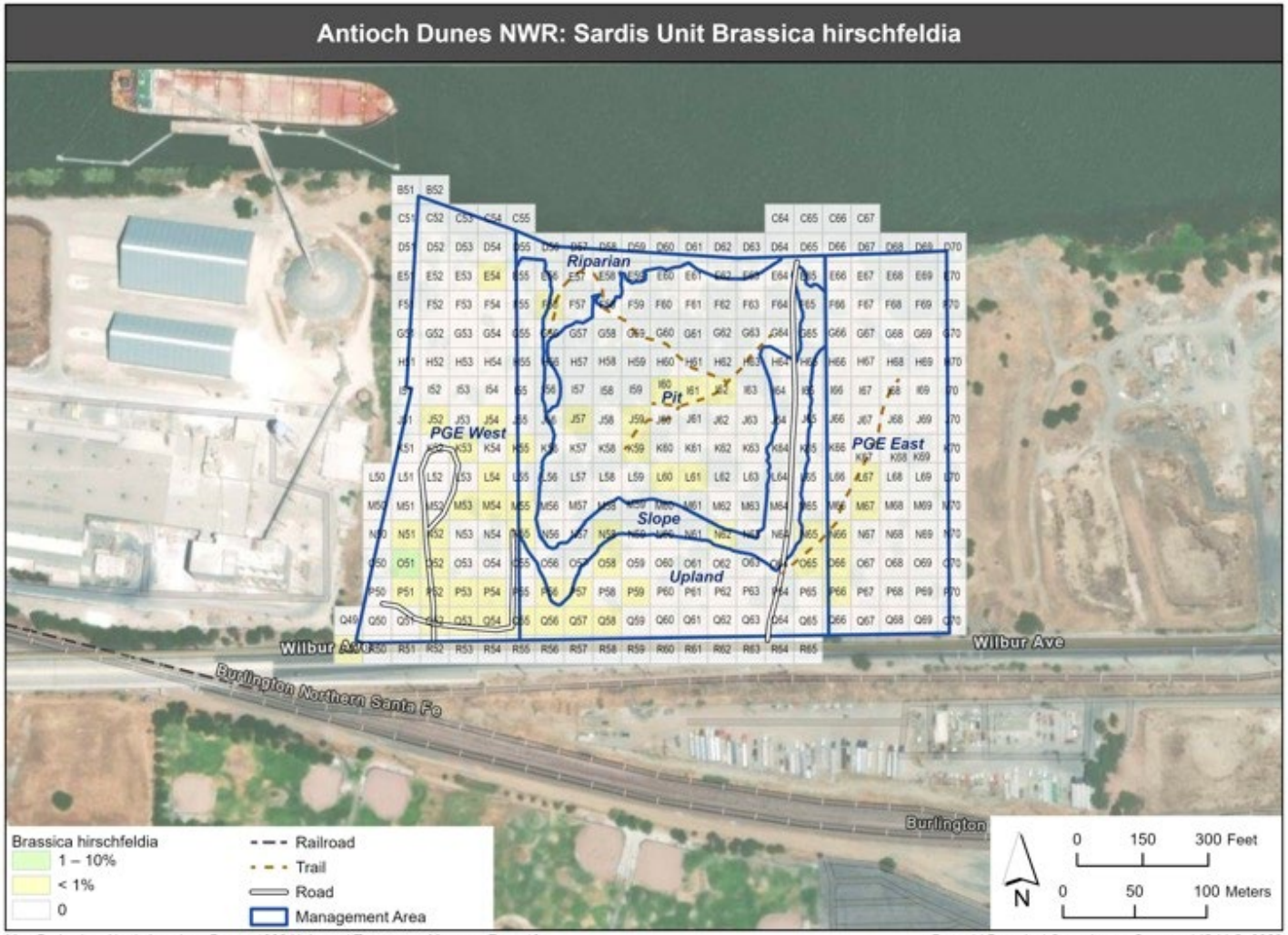
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-28 Sardis Unit *Brassica nigra, Hirschfeldia incana*



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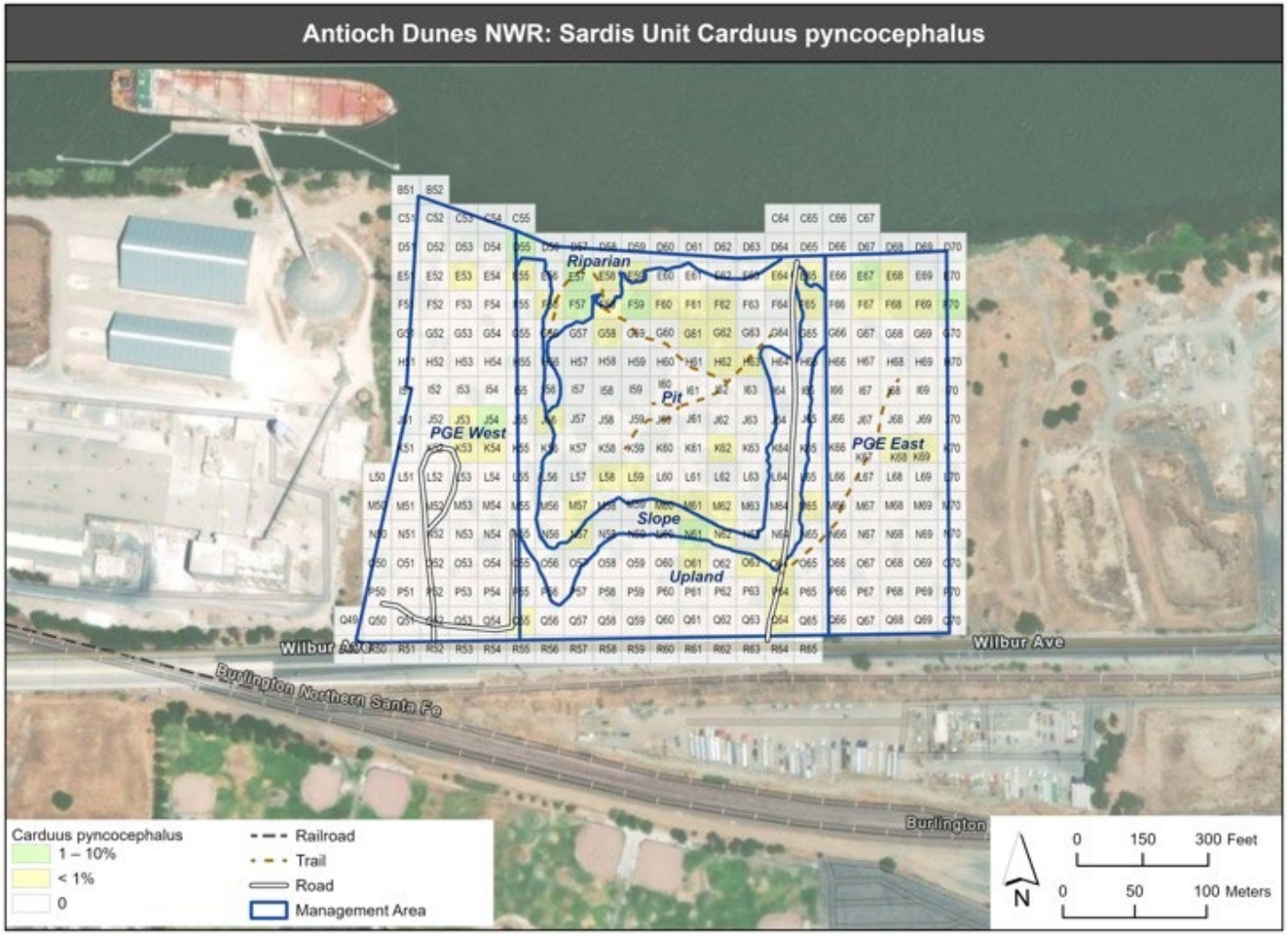
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-29 Sardis Unit *Carduus pyncocephalus*



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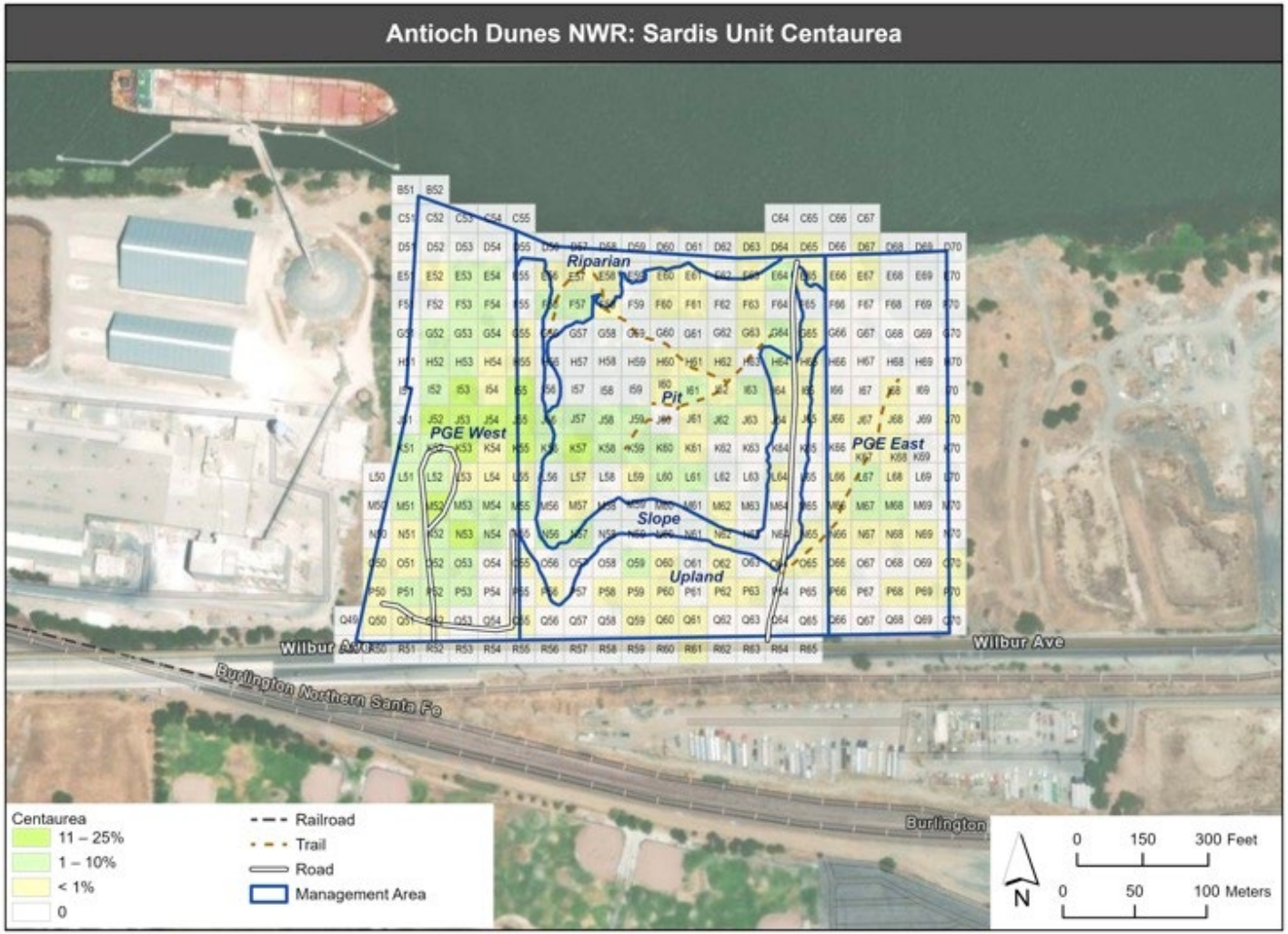
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-30 Sardis Unit *Centaurea* group (*C. melitensis, C. solstitialis*)



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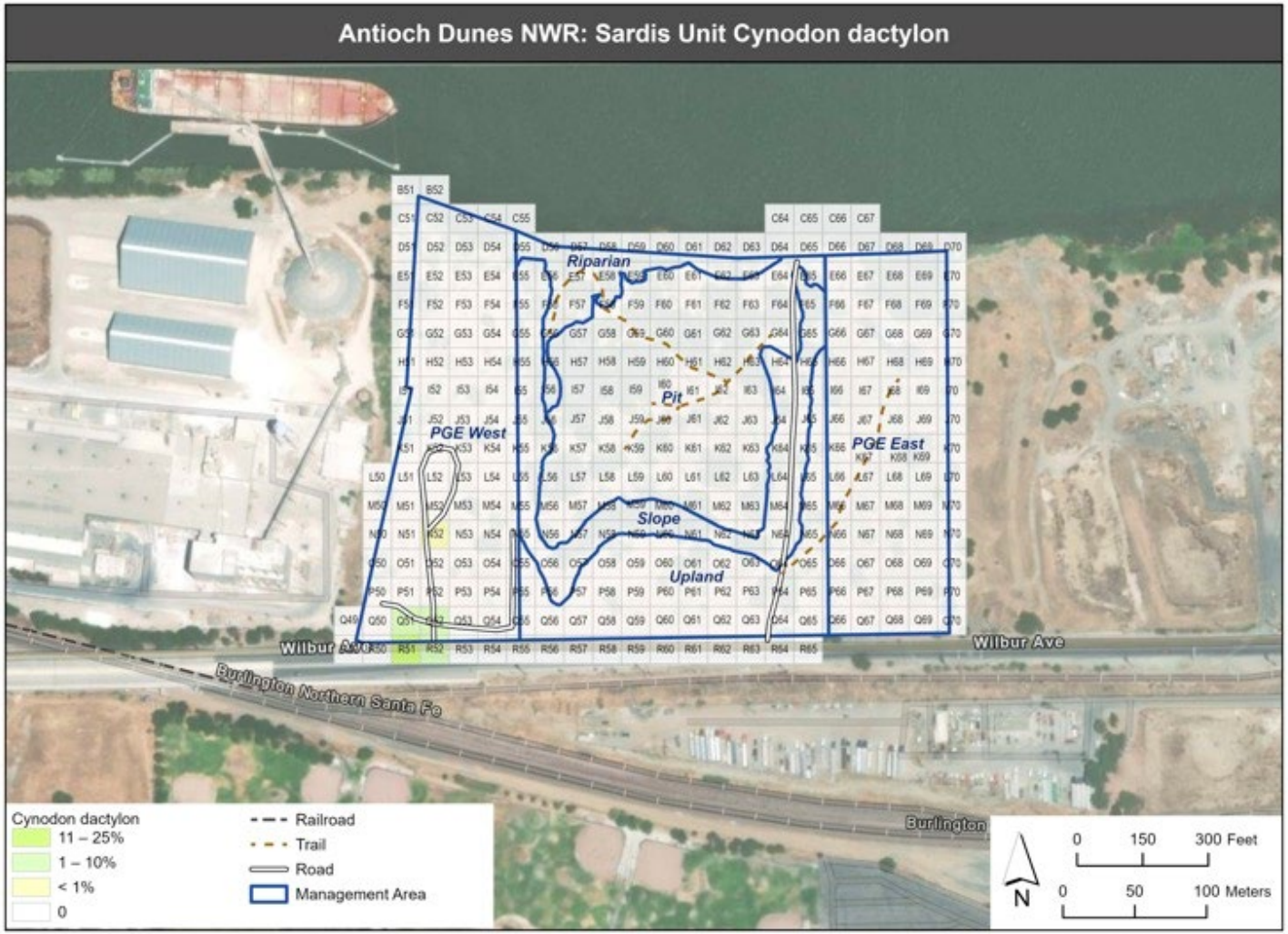
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

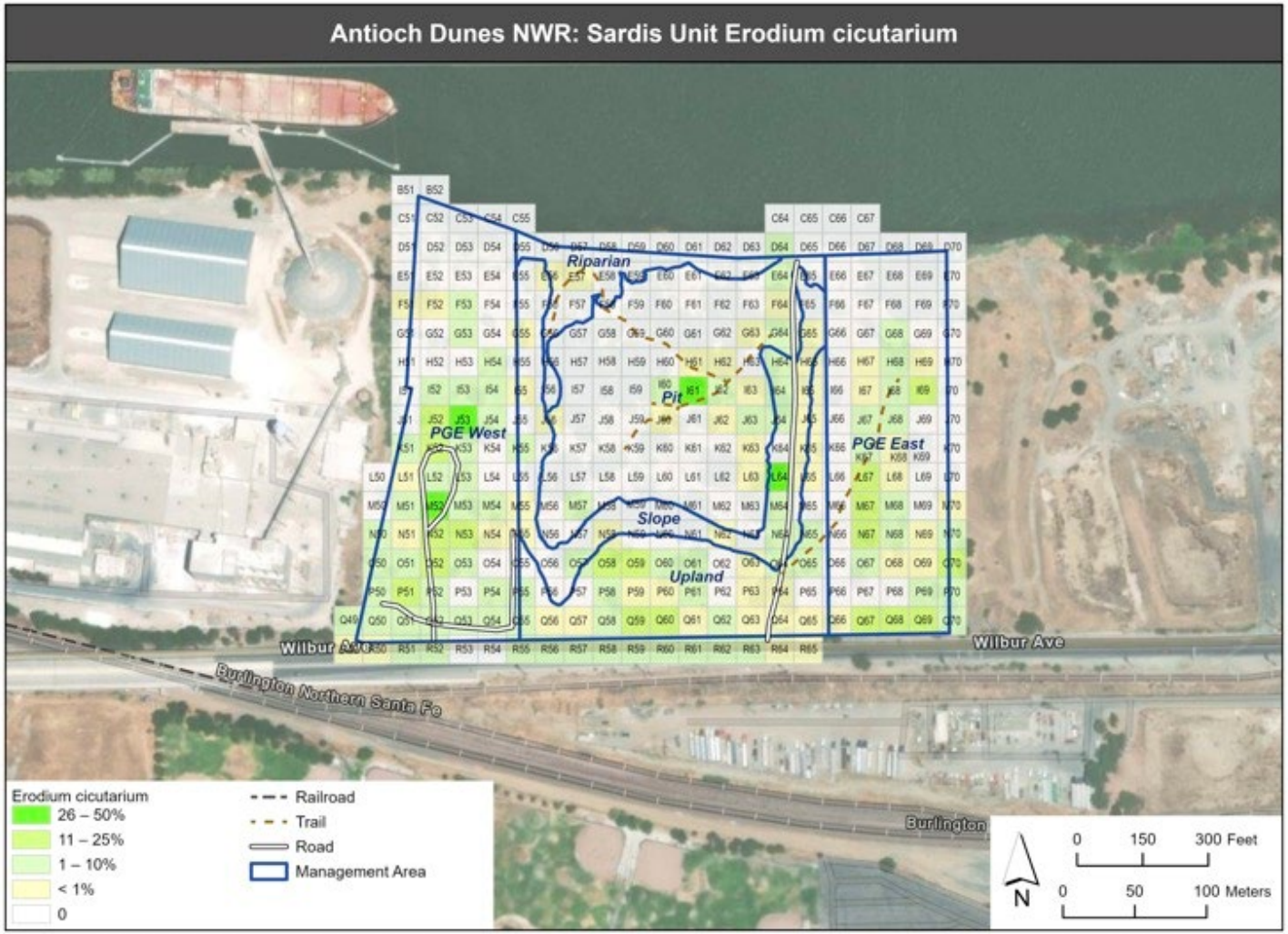
Map 2-31 Sardis Unit *Cynodon dactylon*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-32 Sardis Unit *Erodium cicutarium*



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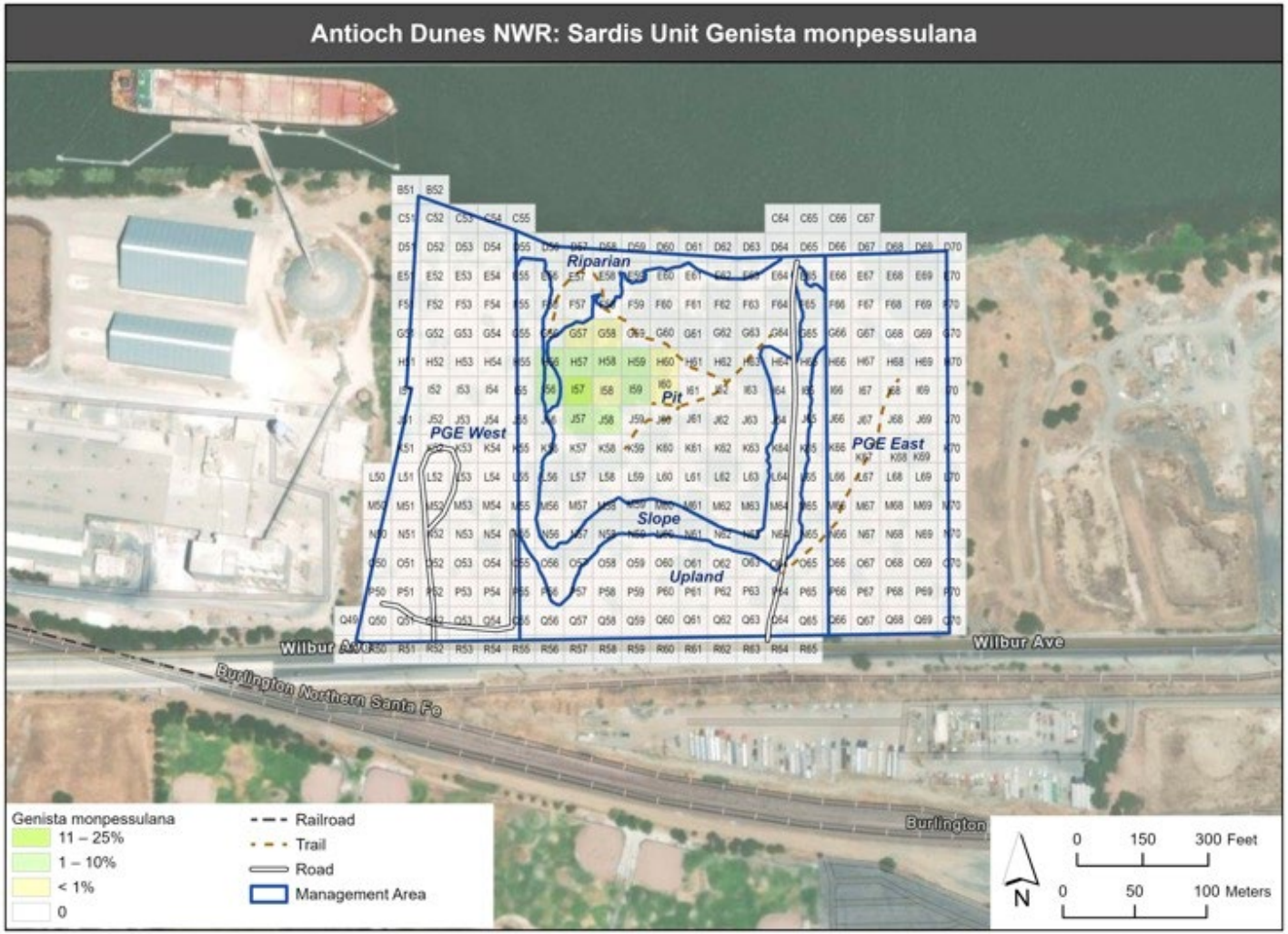
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-33 Sardis Unit *Genista monspessulana*



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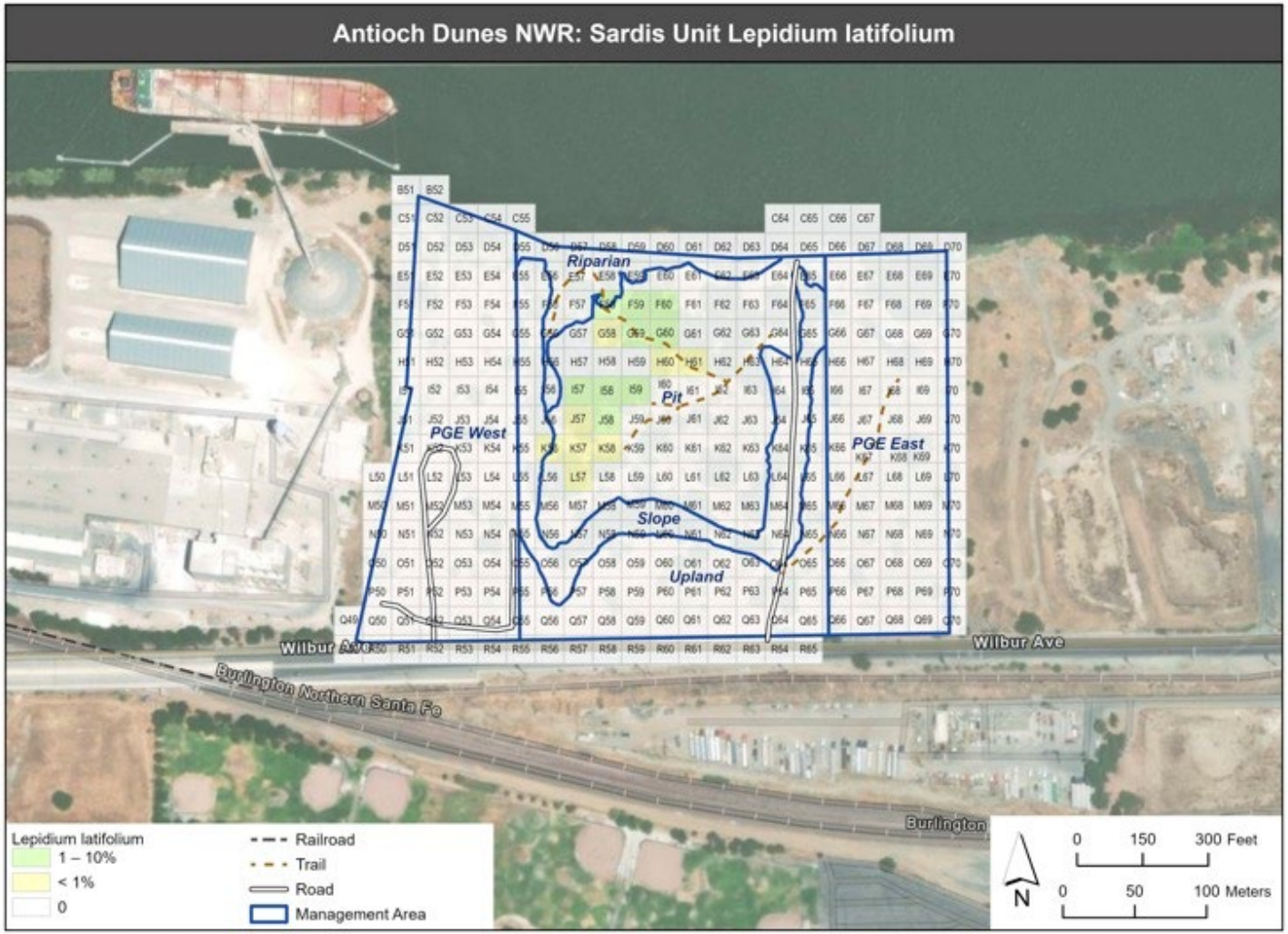
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

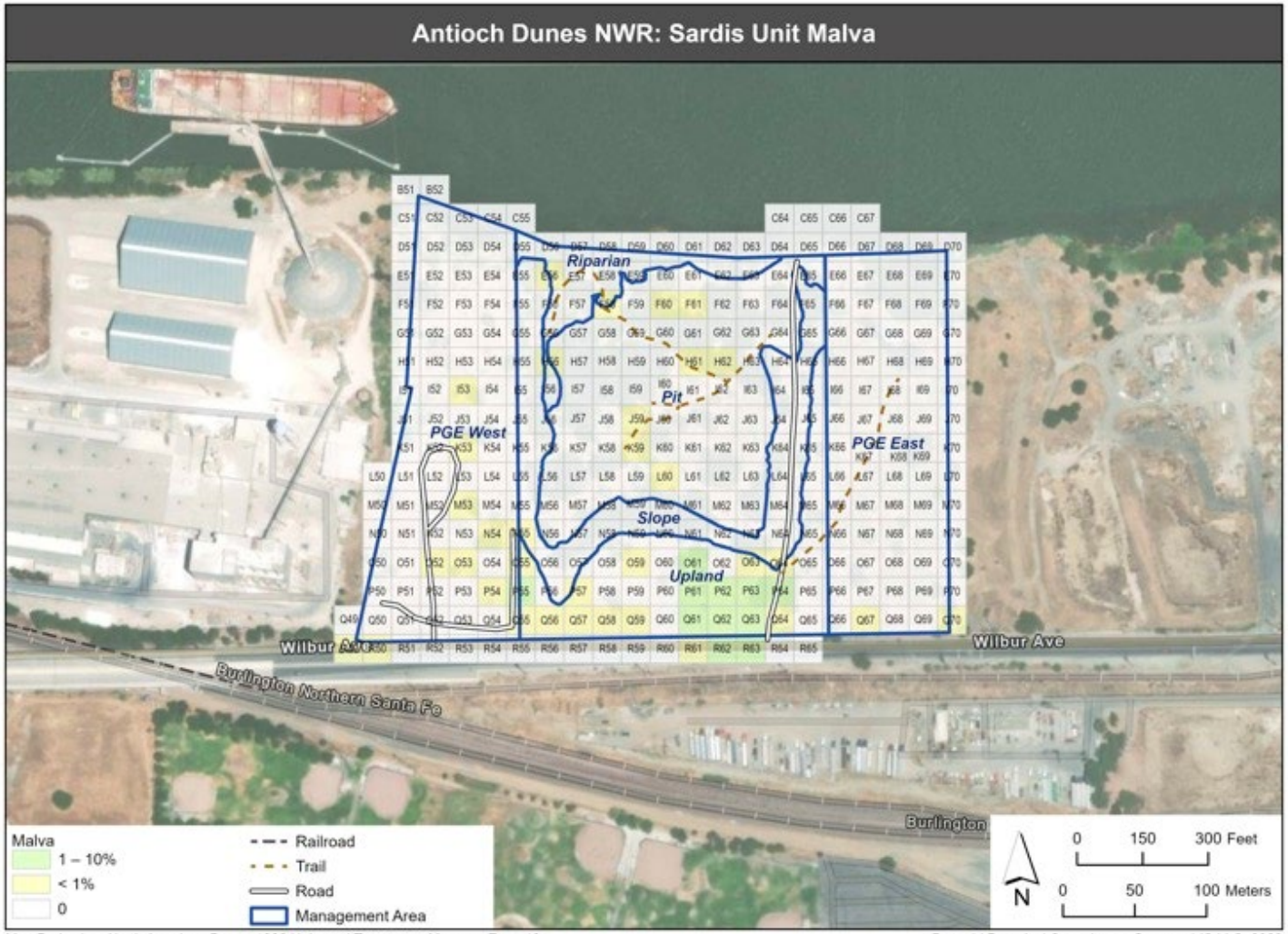
Map 2-34 Sardis Unit *Lepidium latifolium*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-35 Sardis Unit *Malva* group (*Malva* parviflora, *Malva* ssp.)



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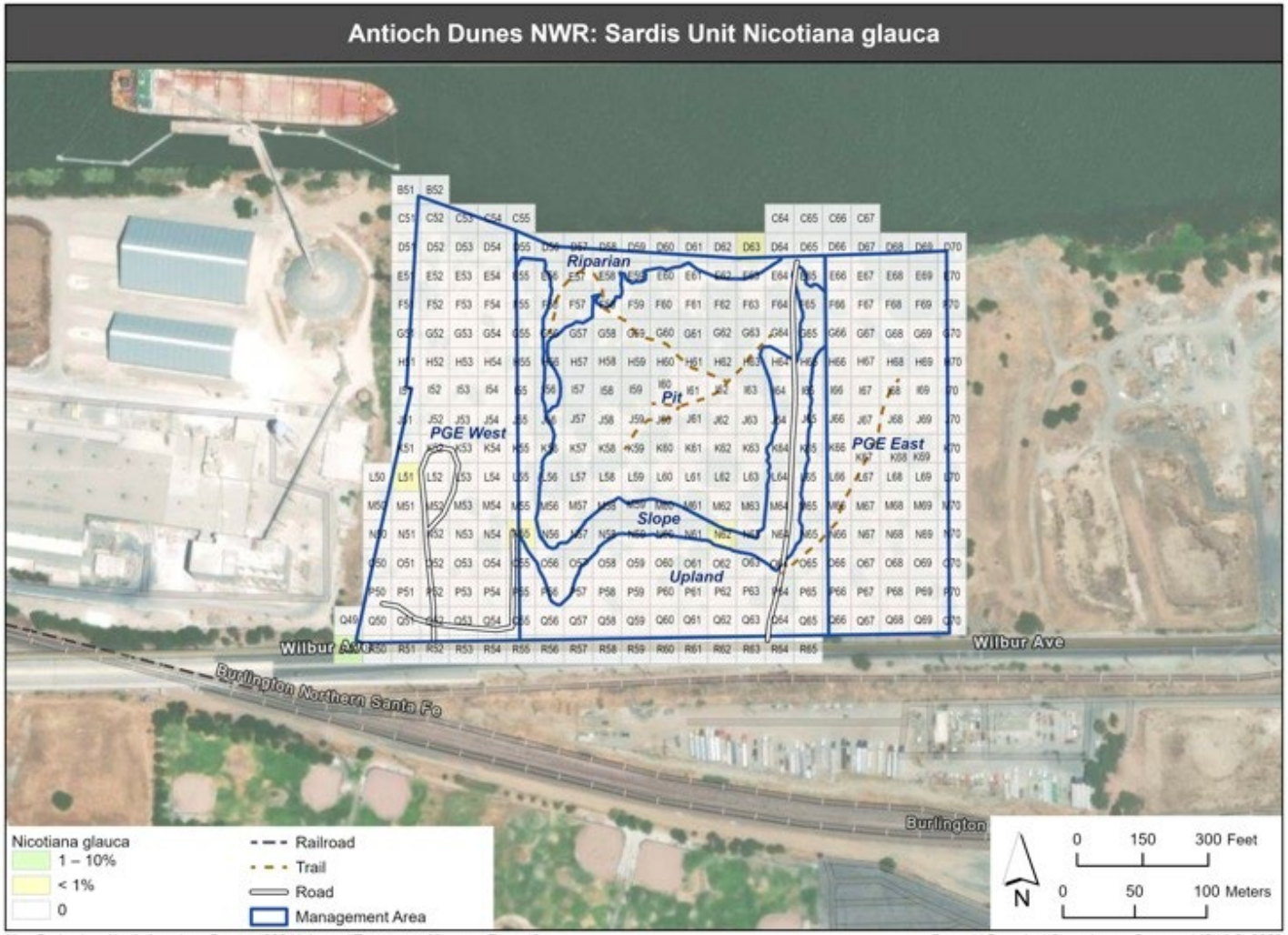
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

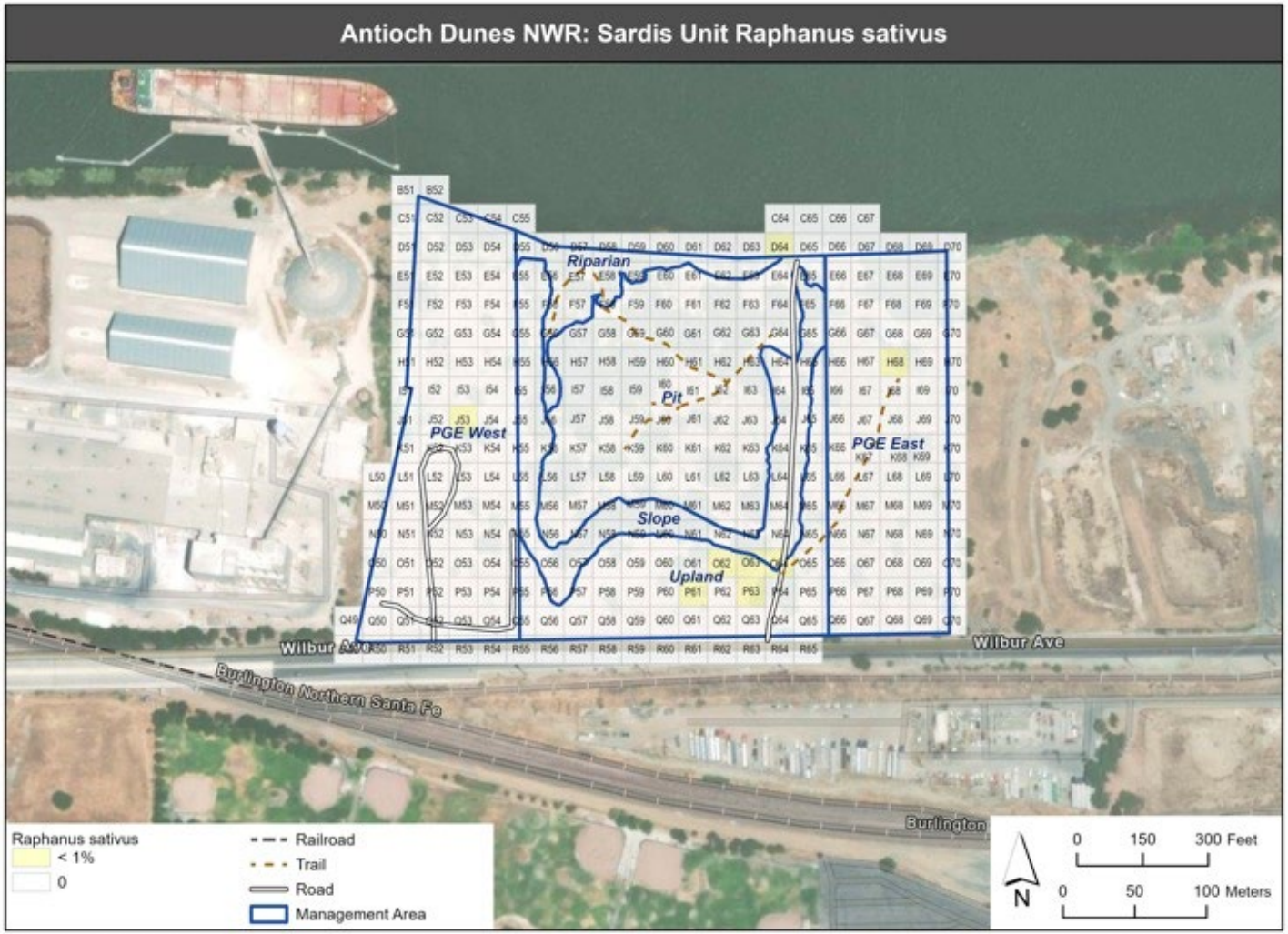
Map 2-36 Sardis Unit *Nicotiana glauca*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

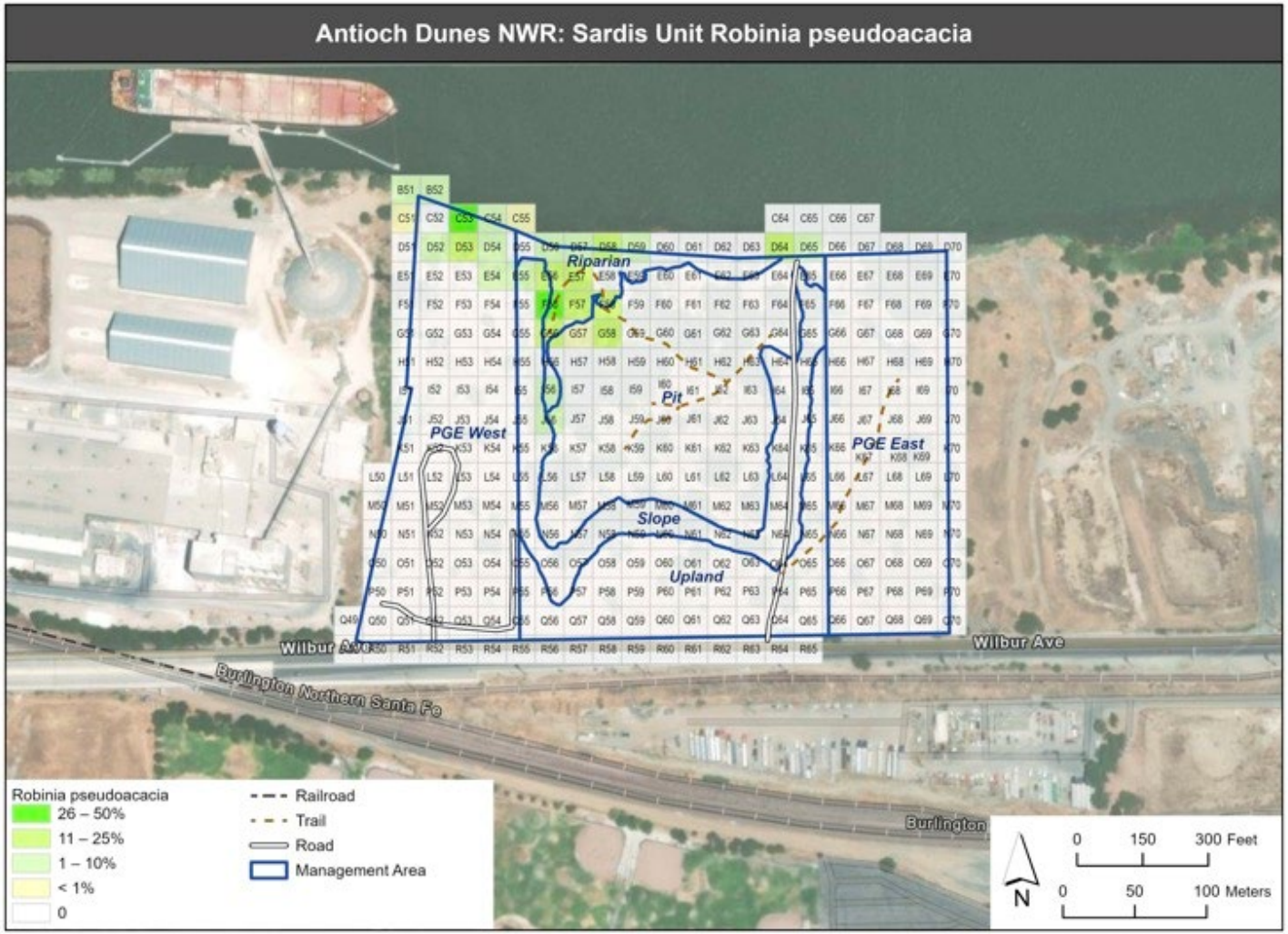
Map 2-37 Sardis Unit *Raphanus sativus*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

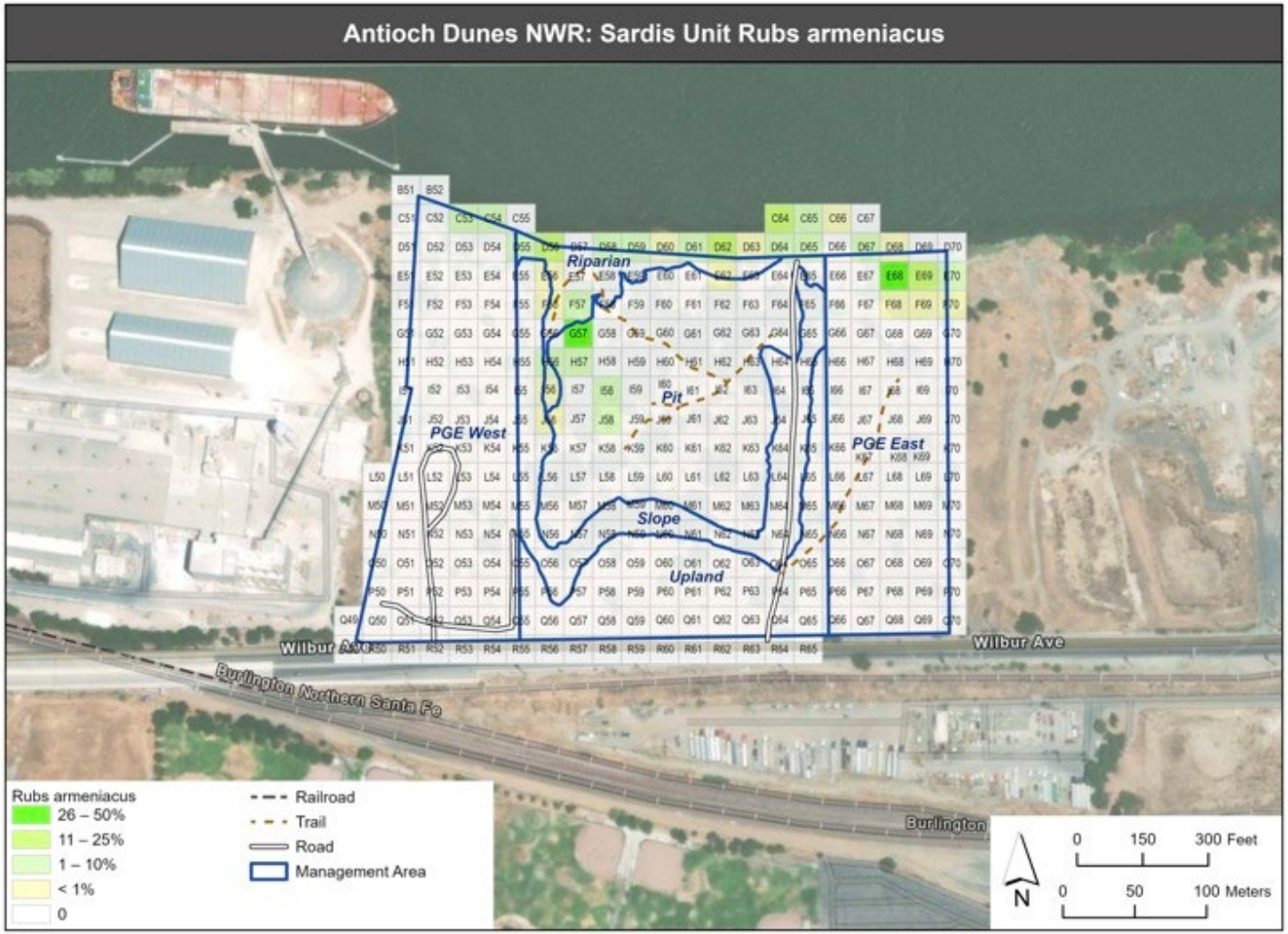
Map 2-38 Sardis Unit *Robinia pseudoacacia*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

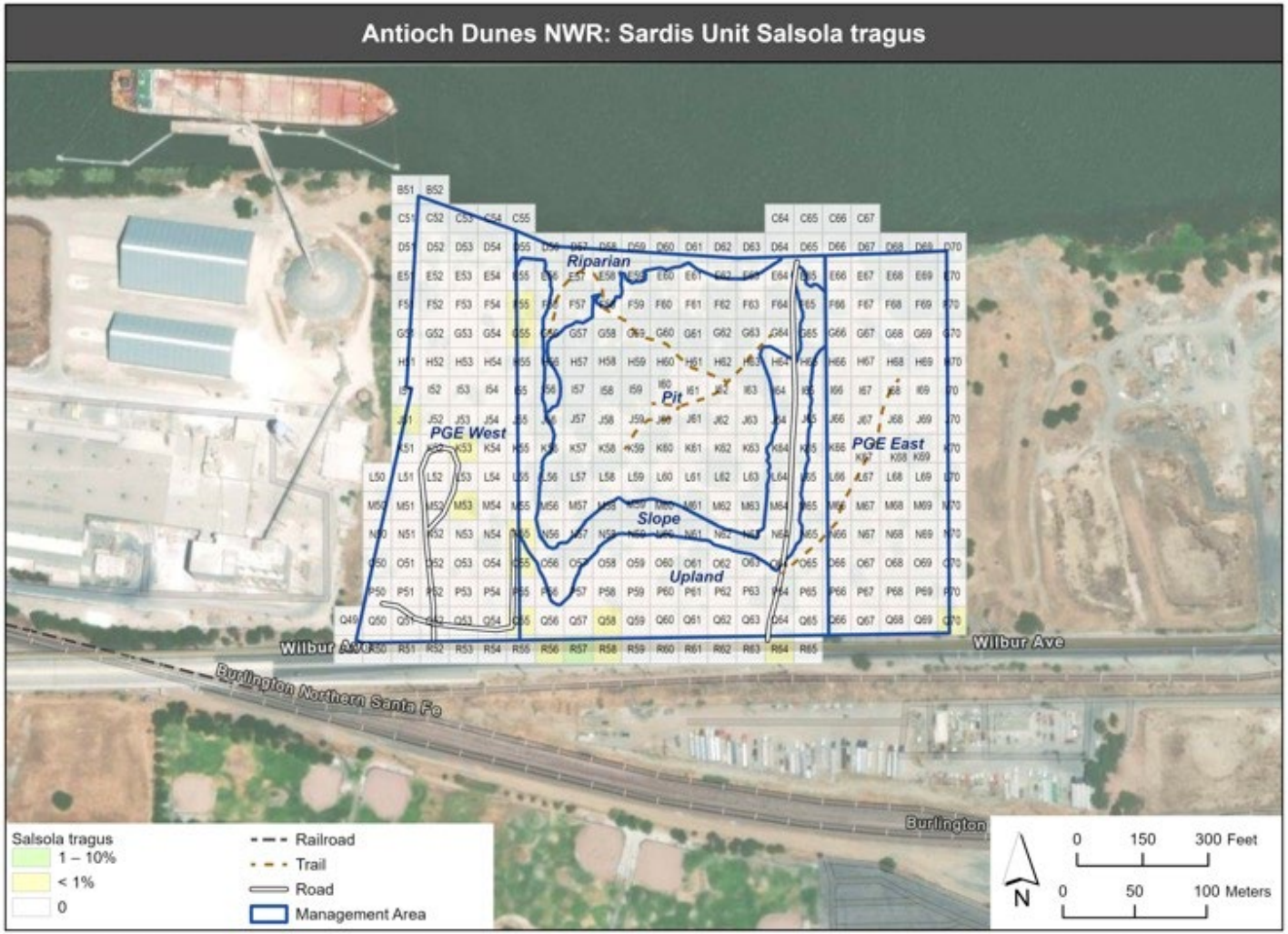
Map 2-39 Sardis Unit *Rubus armeniacus*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

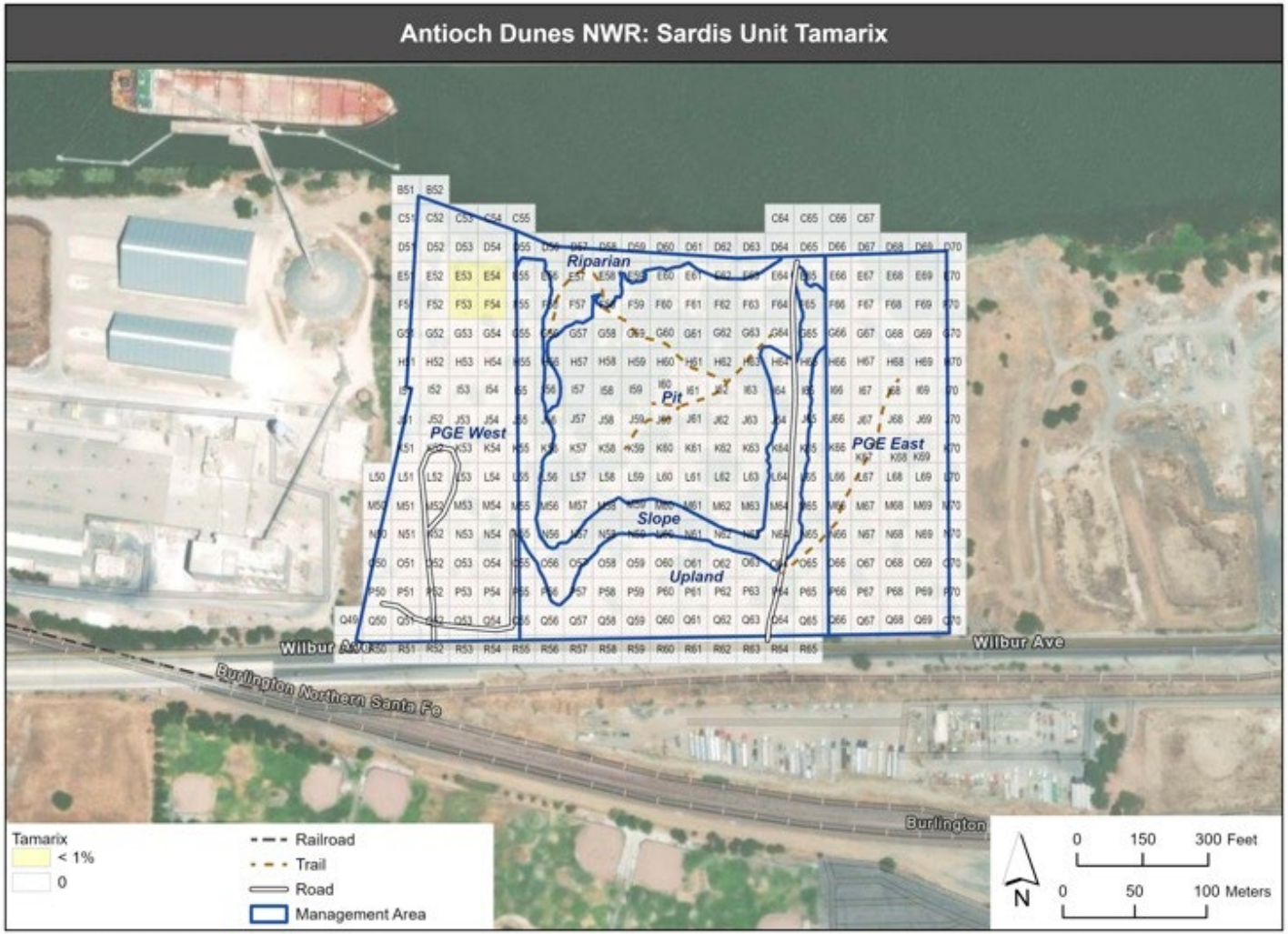
Map 2-40 Sardis Unit *Salsola tragus*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

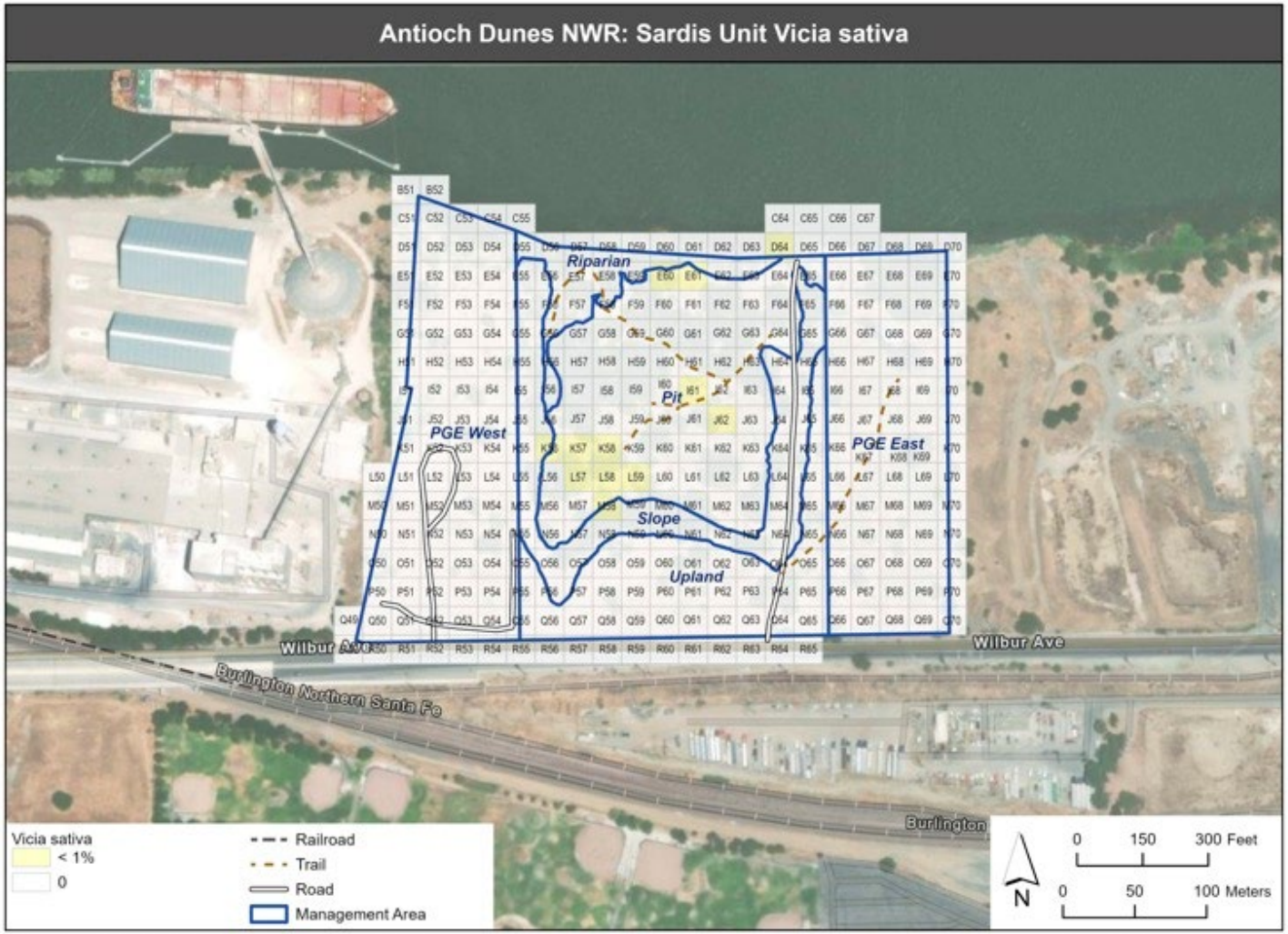
Map 2-41 Sardis Unit *Tamarix group (T. parviflora, T. ramosissima)*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

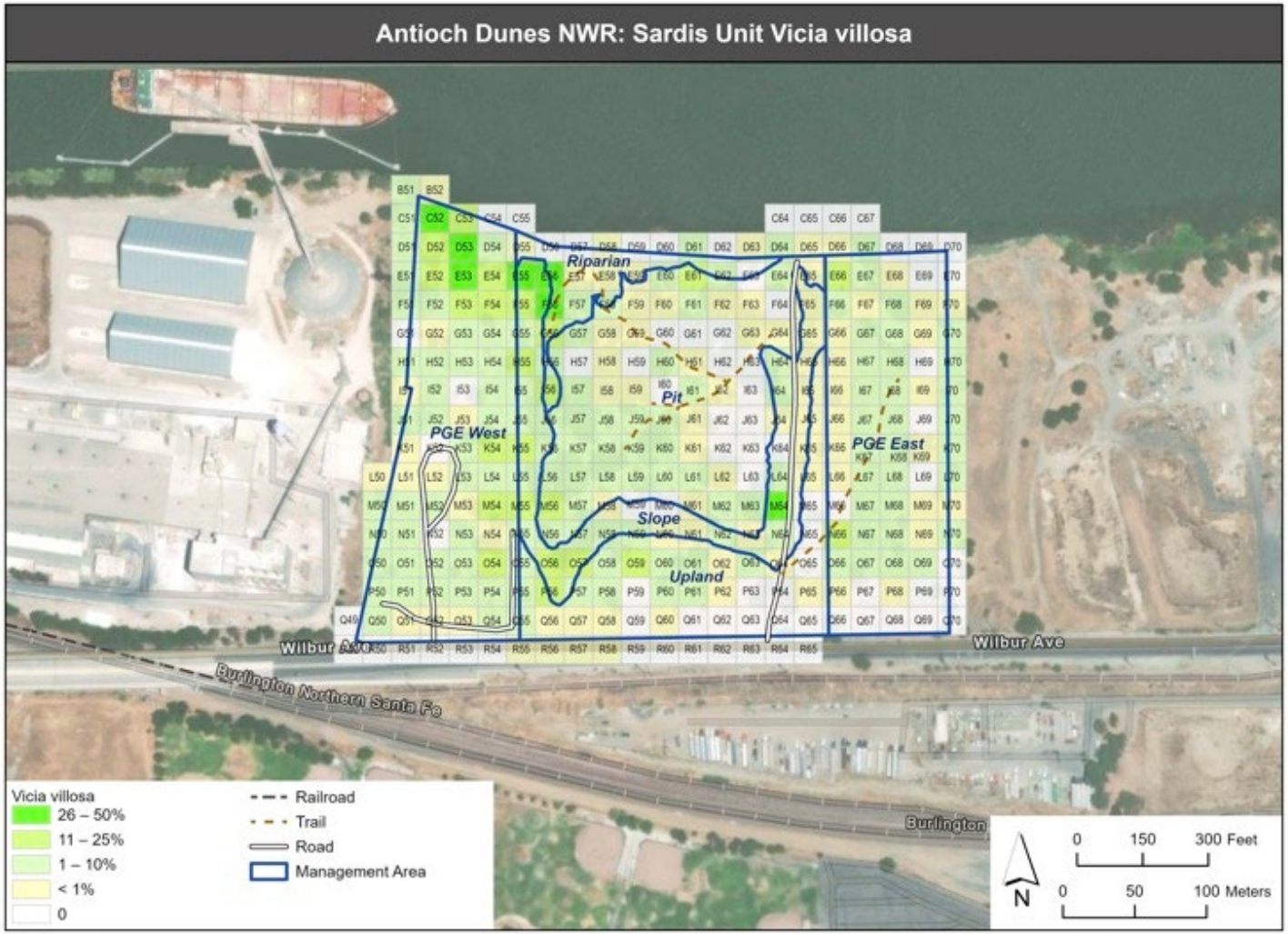
Map 2-42 Sardis Unit *Vicia sativa*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Map 2-43 Sardis Unit *Vicia villosa*



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10;
Source Data: U.S. Fish & Wildlife Service, 2023; Basemap: Esri Online Maps, Maxar, 2023

Pyramid Botanical Consultants. GeomorphIS LLC; 2023

Appendix D

Supplemental Results

Table A1. Best-fit model generalized linear model of changes in ADP estimated cover between 2017 and 2023 Stamm Unit. Note: The Littoral MA was excluded from analysis.

Table A2. Best-fit model generalized linear model of changes in ADB estimated cover between 2017 and 2023, Stamm Unit. Note: The Littoral MA was excluded from analysis.

Table A3. Best-fit model generalized linear model of changes in CCW estimated cover between 2017 and 2023, Stamm Unit.

Table A4. Best-fit model generalized linear model of changes in nectar plant estimated cover between 2017 and 2023, Stamm Unit.

Table A5. Best-fit model generalized linear model of changes in annual grass estimated cover between 2017 and 2023, Stamm Unit. Note: The Littoral MA was excluded from analysis.

Table A6. Best-fit model generalized linear model of changes in bare ground estimated cover between 2017 and 2023, Stamm Unit. Note: The Littoral MA was excluded from analysis.

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