Limonium ramosissimum Treatment Pilot & Development of a Marsh Vulnerability Index for San Francisco Bay

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San Francisco Estuary tidal marshes serve many important functions, including providing habitat for endangered plants and animals. However, more than 85% of the Estuary's marshes have been lost to various forms of development, and the remaining marshes are often fragmented from one another and lack a significant high marsh component and estuarine-terrestrial transition zone. These anthropogenic impacts increase the vulnerability of these systems to further degradation by invasive species, and loss of marsh acreage from sea level rise.

Aside from the Invasive *Spartina* Project's cordgrass eradication effort, there has not been a coordinated regional program to address invasive plants in the Estuary's tidal marshes. Our two-year pilot project funded by a grant from the National Fish & Wildlife Foundation (NFWF) has two primary activities: (1) removing high-priority populations of invasive sea lavender and (2) assessing the vulnerability of the Estuary's tidal marshes to invasive plant damage.

Algerian sea lavender, *Limonium ramosissimum* (Poir.) Maire, as well as *Limonium duriusculum* (Girard) Fourr., are invasive plants spreading in the tidal marshes of both northern and southern California. *Limonium ramosissimum* was identified as one of three "Highest Concern" invasive plants by Don Edwards National Wildlife Refuge and the South Bay Salt Ponds Restoration project. In the summer of 2016, *Limonium* was treated at 12 sites in Alameda, Marin, and San Mateo Counties using chemical and manual methods, with follow-up treatment planned for 2017.

In a complementary effort, a team of local marsh ecologists utilized the USFWS Invasive Plant Inventory and Early Detection Tool (IPIEDT) developed by Giselle Block and her colleagues to assess the vulnerability of 40 large marshes based on current invasive plant presence, ecological integrity, and vectors of invasive plant dispersal. Rankings were used to prioritize weed mapping at ten sites (two of which were completed in September 2016). Initial results from mapping will be used to test and refine our IPIEDT criteria, while providing a baseline evaluation and template for future assessments. Our results benefit Estuary management through systematic prioritization, allowing for regional coordination of invasive plant treatment to maximize benefits to high-value tidal marshes.

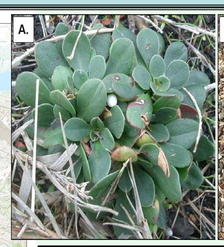
During planning for treatment implementation, several experts were consulted that have experimented with herbicide on invasive *Limonium* around California. Based on their experiences, a mixture of 3% imazapyr (Polaris®) and 2% glyphosate (Rodeo®) was selected for this pilot year of treatment in the San Francisco Estuary, with the lecithin-based surfactant Liberate® added at 1%, along with a blue marker dye. Two sites (Sanchez Marsh and Coyote Point Marina) with extensive *Limonium ramosissimum* infestations were selected for a study to evaluate and compare the efficacy of three herbicide treatments. Short PVC poles were used to delineate the 1 meter X 1 meter plots in dense infestation sectors. Each study plot group received the four treatments: a mixture of 3% imazapyr and 2% glyphosate, 4% glyphosate alone, 3% imazapyr alone, and an untreated control plot. While all three herbicide trials at Sanchez Marsh test plots showed high efficacy (around 85-95%) at the one month evaluation, efficacy at the Coyote Point plots was much more variable.

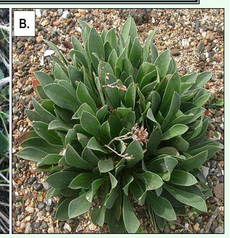
Backpack treatment at Ideal Marsh South including extensive *Limonium ramosissimum* infestation along channel banks

Flowering rosettes of *Limonium duriusculum* growing amongst the rare native hemiparasite *Chloropyron maritimum* ssp. *palustre* at Strawberry Marsh in Marin Co.

Backpack treatment of *Limonium ramosissimum* monoculture on the rare oyster-shell beach in Foster City

Band of treated *Limonium ramosissimum* in the estuarine-terrestrial transition zone at Coyote Creek Lagoon





Invasive sea lavender in San Francisco Estuary marshes: (A.) *Limonium duriusculum* (B.) *Limonium ramosissimum* subsp. *Provinciale*. Photos by Gavin Archbald from Archbald & Boyer 2014

Limonium ramosissimum exploiting a crack in the concrete adjacent to Sanchez Marsh

Twelve invasive *Limonium* infestation sites were selected for treatment in the first pilot year of the project in 2016. Many of these are large infestations of near monocultures of LIRA located around the "epicenter" for this invasion along the Burlingame and San Mateo shorelines of the West Bay, stretching from Oyster Point Marina down to Seal Slough. Due to the relatively large size of these infestations, herbicide was selected as the most cost-effective treatment method for the majority of the pilot sites.

At two Marin County infestations that also contain the rare annual plant *Chloropyron maritimum ssp. palustre* (Point Reyes bird's beak), treatment was conducted manually to reduce potential impacts to the native vegetation. This rare native is a hemiparasite, and appears to have formed a haustorial connection to either the roots of LIDU or LIRA or to native marsh vegetation, allowing these plants to provide host subsidies. Careful manual removal around the rare plant was very tedious and time consuming, but succeeded in preserving many of the rare individuals that can contribute to the seed bank, which will help with re-establishment after the LIDU/LIRA is eradicated.

Approximately 6 acres (23,874 m^2) of invasive *Limonium* (LIRA at all sites and LIDU at Strawberry Marsh) was treated across the 12 sites in this first season of the project. All sites treated with herbicide utilized backpack sprayers as the delivery system, but a heavily-infested portion of Sanchez Marsh was treated by truck and hose for efficiency. In the case of manual removal, all LIDU/LIRA was bagged and disposed off-site as garbage (not composted out of concern that seeds may survive and spread the infestation).

Limonium ramosissimum one month post-treatment at Coyote Point with greater than 90% efficacy

Area Description

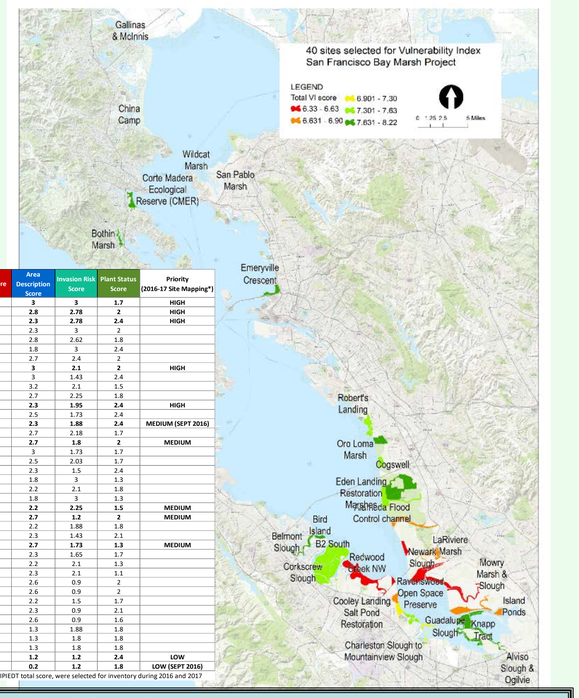
- **Ecological Integrity —** The structure, composition, and functions of ecological communities within the bounds of natural or historic disturbance regimes.
- **Innate Resistance to Invasion —** The innate capacity of an ecosystem to resist establishment and spread of invasive plant species.
- **Importance to Federal or State-listed Species —** The relative importance of the area to federal or state listed endangered or threatened species as it relates to the presence or proximity of a species or its habitat.
- **Importance to Other Priority Natural Resources of Conservation Concern —** The relative importance of the area to other natural resources (species, communities or ecosystems) of priority conservation concern as it relates to the presence or proximity of a natural resource.

Invasion Risk

- **Terrestrial pathways —** The distribution and density of terrestrial pathways such as roads, trails, levees, berms, parking areas.
- **Aquatic pathways —** The distribution and density of aquatic pathways such as rivers, sloughs, streams, lakes and reservoirs.
- **Transport vectors —** The presence, frequency, and duration of human-mediated transport vectors in the area.
- **Anthropogenic disturbances —** The intensity, duration, and frequency of human-caused disturbance events.

Invasive Plant Status

- **Inventory and monitoring —** The status of invasive plant inventories or monitoring in the area.
- **Infestation level** — The status of invasive plant infestations in the area based upon area-specific knowledge or past inventory data.
- **Number of Invasive Species —** The approximate number of invasive plant species infesting the area based upon area-specific knowledge or past inventory data.



San Francisco Estuary Marsh Site (bold=selected for weed inventory)	Total Score	Area Description Score	Invasion Risk Score	Plant Status Score	Priority (2016-17 Site Mapping*)
Faber / Laumeister Marsh	**7.7**	**3**	**3**	**1.7**	**HIGH**
Bothin Marsh	**7.58**	**2.8**	**2.78**	**2**	**HIGH**
Inner Bair Island Restoration	**7.48**	**2.3**	**2.78**	**2.4**	**HIGH**
Eden Landing Restoration Marshes	7.3	2.3	3	2	
Alameda Flood Control channel	7.22	2.8	2.62	1.8	
Corkscrew Slough	7.2	1.8	3	2.4	
Corte Madera Ecological Reserve (CMER)	7.1	2.7	2.4	2	
Palo Alto Baylands	**7.1**	**3**	**2.1**	**2**	**HIGH**
Calaveras Marsh	6.83	3	1.43	2.4	
B2 North	6.8	3.2	2.1	1.5	
Whale's Tail Complex & OAC	6.75	2.7	2.25	1.8	
Charleston Slough to Mountainview Slough	**6.65**	**2.3**	**1.95**	**2.4**	**HIGH**
Mowry Marsh & Slough	6.63	2.5	1.73	2.4	
Emeryville Crescent	**6.58**	**2.3**	**1.88**	**2.4**	**MEDIUM (SEPT 2016)**
Cooley Landing Salt Pond Restoration	6.58	2.7	2.18	1.7	
LaRiviere Marsh	**6.5**	**2.7**	**1.8**	**2**	**MEDIUM**
Greco Island	6.43	3	1.73	1.7	
Dumbarton/Audubon & Railroad	6.23	2.5	2.03	1.7	
Oro Loma Marsh	6.2	2.3	1.5	2.4	
Belmont Slough	6.1	1.8	3	1.3	
Newark Slough	6.1	2.2	2.1	1.8	
Alviso Slough & Ogilvie	6.1	1.8	3	1.3	
Ravenswood Slough	**5.95**	**2.2**	**2.25**	**1.5**	**MEDIUM**
San Pablo Marsh	**5.9**	**2.7**	**1.2**	**2**	**MEDIUM**
Island Ponds	5.88	2.2	1.88	1.8	
Redwood Creek NW	5.83	2.3	1.43	2.1	
Ideal Marsh	**5.73**	**2.7**	**1.73**	**1.3**	**MEDIUM**
Guadalupe Slough	5.65	2.3	1.65	1.7	
Cogswell	5.6	2.2	2.1	1.3	
Robert's Landing	5.5	2.3	2.1	1.1	
Wildcat Marsh	5.5	2.6	0.9	2	
Gallinas & McInnis	5.5	2.6	0.9	2	
Deepwater Slough	5.4	2.2	1.5	1.7	
B2 South	5.3	2.3	0.9	2.1	
China Camp	5.1	2.6	0.9	1.6	
Knapp Tract	4.98	1.3	1.88	1.8	
Central Bair	4.9	1.3	1.8	1.8	
Pond B3 - Middle Bair Island Restoration	4.9	1.3	1.8	1.8	
Bird Island	**4.8**	**1.2**	**1.2**	**2.4**	**LOW**
Ravenswood Open Space Preserve	**3.2**	**0.2**	**1.2**	**1.8**	**LOW (SEPT 2016)**

*12 of the 40 marshes, ranging from high to low priority in IPIEDT total score, were selected for inventory during 2016 and 2017

Pilot weed mapping at Emeryville Crescent and Ravenswood Open Space

Biologists used a 20m X 20m grid system to map the coverage of seven weed species:

Lepidium latifolium L. (perennial pepperweed, tall whitetop)
Limonium duriusculum (Girard) Fourr. (European sea lavender)
Limonium ramosissimum (Poir.) Maire (Algerian sea lavender)
Limonium perezii (Stapf) Hubb. (Perez's sea lavender)
Phragmites australis (Cav.) Steudel (common reed)
Puccinellia maritima (Huds.) Parl. (seaside alkali grass)
Salsola soda L. (oppositeleaf Russian thistle, glasswort)

Presence of an additional five species was also recorded:
Arundo donax L. (giant reed)
Conium maculatum L. (poison-hemlock)
Dittrichia graveolens (L.) Greuter (stinkwort)
Elymus elongatus (Host) Greuter var. *ponticus* (Podp.) Dorn (tall wheat grass)
Symphyotrichum subulatum (Michx.) G.L.Nesom var. *squamatum* (Spreng.) S.D.Sundb. (Bahamian slim aster)

Mapping resulted in an increase in the number of known weed species at both pilot sites (Emeryville Crescent: from 3 to 7; Ravenswood Open Space: from 3 to 5), as well as far better understanding of the distribution and cover of these species.

IPIEDT and San Francisco Estuary Tidal Marshes

How applicable to this ecosystem?

Ten of the eleven criteria from the three IPIEDT categories were applicable to the Estuary's tidal marshes. For "Importance to Other Priority Natural Resources of Conservation Concern", there were simply too few designated resources to inform the ecologists and provide useful separation of scoring between marshes, so this criterion was often nulled out. The other ten criteria contributed to score separation for the 40 sites that were assessed.

Unique considerations within the criteria

Area Description:

For "Ecological integrity", the ecologists focused on marsh hydrology and channelization, and considered sediment dynamics, compaction of ground, and fragmentation by levees and other solid pathways, in addition to impact from invasives and the diversity of native plants and animals. For "Innate Resistance to Invasion", ecologists considered relative species richness, but also examined frequency of disturbance with respect to marsh age, accretion rates, and wrack scouring, in order to approximate the amount of invasible bare ground. Finally, the ecologists looked at number of listed species (California Ridgway's rail, salt marsh harvest mouse, California black rail, and *Chloropyron* spp.) at each site to score its "Importance to Federal or State-listed Species."

Invasion Risk:

In tidal marshes, "Terrestrial Pathways" included levees, trails, roads, railroads, and perimeter-to-area ratios at landlocked sites, while PG&E boardwalks were considered negligible. "Aquatic Pathways" included channels, flood control waterways, outer shorelines, and perimeter-to-area ratios for island sites. Flooding was only considered if marsh elevations were known, and was used to infer flooding frequency. For "Transport Vectors" ecologists considered public visitation, hunting, and fishing, either by boats, bikes, or on foot, as well as dredging and construction activities nearby. Lastly, "Anthropogenic Disturbances" in marshes included revegetation efforts, invasive cordgrass treatment, mosquito abatement, and breaching/restoration activities.

Invasive Plant Status:

This category had the fewest resources to inform scoring. Unless a site had been recently breached to restore tidal exchange, knowledge for "Inventory and Monitoring" was limited to *Spartina* spp., as well as *Lepidium latifolium* within Don Edwards National Wildlife Refuge. The "Infestation Level" was only grossly estimated, along with the "Number of Invasive Species." Initial mapping confirmed gaps in our knowledge of the distribution and abundance of the weeds.