South Bay Salt Pond Restoration Project
Graduate Fellow Research Final Report

Research Topic:	Monitoring Invasive Algerian Sea Lavender Using Multispectral Satellite Imagery
Principle Investigator:	Gavin Archbald San Francisco State University
Time Period:	November 2009- December 2010

Summary of project:
The purpose of this project was to identify and map invasive Algerian sea lavender (*Limonium ramosissimum ssp provinciale*) populations in marshes south of the San Mateo Bridge in San Francisco Bay, and to develop remote sensing and GIS methods to identify and monitor populations. In addition, an investigation of tidal datums in the South Bay as they relate to these studies was developed to aid in habitat identification.

The project was broken into 5 key tasks:
Task 1 – Develop a GIS-based habitat suitability model for invasive Algerian sea lavender
Task 2 – Conduct GIS based field searches
Task 3 – Remote sensing analysis to detect invasive Algerian sea lavender
Task 4 – Compare Satellite and Aerial Imagery
Task 5 – Reporting and Presentations
Task 6* – Tidal datum analysis and write-up (*not in original Scope of Work)

Location of products:
The methods used and results produced may be found in the three following final report papers.

Paper 1: Identifying *Limonium ramosissimum* populations using a GIS based species distribution model and ground searches in tidal marshes of South San Francisco Bay

Paper 2 (with Appendix): Merging tidal datums and lidar elevation for species distribution modeling in South San Francisco Bay

Paper 3: An object based image analysis approach to testing the effect of flowering and patch size on *Limonium ramosissimum* detection using CIR and IKONOS imagery

Specific locations of key products, organized by products listed in the Scope of Work are below:

Expected Products from the Scope of Work	**Location of product delivered**
1) Habitat likelihood model and map.	Paper 1: pages 15-17, figures 12 -15.
2) A map and corresponding shapefiles of presence/absence of Algerian sea lavender in locations searched.	Paper 1: page 18, figure 16. Shapefiles to be transferred upon arrangement.
3) A comparison of pixel versus object based image analysis approaches for mapping selected vegetation classes chosen in coordination with Design, Community, & Environment.	Interim Report
4) A map of Algerian sea lavender in the 2010 satellite imagery coverage area.	Map of all known populations in paper 1, page 33, figure 31 are based on result of ground searches only because sea lavender was not able to be reliably detected with remote sensing methods (see paper 3).
5) A comparison of IKONOS satellite and high resolution aerial imagery for identifying small Algerian sea lavender populations.	Paper 3
6) Interpolation of tidal datums and exploration of their utility for species distribution modeling in conjunction with the 2004 lidar data set for S. San Francisco Bay.	Paper 2

Summary of Key Findings:

Paper 1: Identifying *Limonium ramosissimum* populations using a GIS based species distribution model and ground searches in tidal marshes of South San Francisco Bay:

- The species distribution model developed for this project based on lidar elevation, tidal datums, and other environmental variables, distinguished between suitable and unsuitable habitat for Algerian sea lavender in South Bay marshes with 68% accuracy (Cohen's Kappa statistic) based on a review of model classification using aerial imagery.

- The model assigned a 77% average probability of suitable Algerian sea lavender habitat in locations where the invader was found versus 24% average probability of suitable habitat in random locations that were searched and the invader was not found.

- 8 distinct Algerian sea lavender populations were identified within the study area and, with the exception of Plummer Creek Marsh, mapped with GPS.

- 3 of the Algerian sea lavender populations found were small enough to be pulled by hand and these were removed, slowing invasion at Greco Island, Bird Island and outside the Ravenswood Complex at Pond R1.

- 18 days of model based field searches covered 2.2 km^2 of marshes, mostly concentrated long shoreline and levy roads, but this only allowed 13% of highly suitable (>90% probability) habitat to be searched.

- Searches were biased towards habitats on Don Edwards Wildlife Refuge and other public lands, and in marshes near to levies and navigable sloughs. Therefore, undiscovered populations are most likely to be located inland from bay edges and in difficult to access, private, high marsh or seasonally flooded areas- particularly those with a history of disturbance, restoration, or riparian flooding.

Paper 2: Merging tidal datums and lidar elevation for species distribution modeling in South San Francisco Bay:

- Tidal datums from tidesandcurrents.noaa.gov translated to NAVD88 using a conversion table developed for the Foxgrover, 2005 hydrographic survey provides the best available data to predict tidal datums in South San Francisco Bay.

- Tidal datums interpolated using NOAA tide stations fit with independent tidal gauge measurements in the Coyote Creek/Guadalupe Slough area when the MLLW to NAVD88 conversion is made using Foxgrover et al, 2005 tables, but not when interpolation is based on a MLLW to NAVD88 conversion made using Vdatum software provided by NOAA.

- Interpolated tidal datum layers combined with lidar elevation provide an improvement over elevation data alone for species distribution models.

Paper 3: An object based image analysis approach to testing the effect of flowering and patch size on *Limonium ramosissimum* detection using CIR and IKONOS imagery

- Regardless of patch size, degree of flowering, or image analysis technique, neither CIR nor IKONOS imagery was able to detect Algerian sea lavender in isolation from other high marsh habitat at Sanchez Creek Marsh and Coyote Point Marina where this study was performed.

- Both imagery sources, however, were successfully used to map broad habitat classes including mudflats, low marsh, high marsh, and upland habitats at these marshes.

- Increased spectral range and resolution of hyperspectral imagery may provide a means to map Algerian sea lavender and this can be determined using inexpensive field surveys or previously collected hyperspectral imagery.

Management recommendations:

- Because without action Algerian sea lavender is highly likely to continue to spread to restored and disturbed high marsh and transition zone habitats within the South Bay Salt Pond project area, as part of a comprehensive weed management strategy we recommend the long-term goal of eradicating *Limonium ramosissimum* in San Francisco Bay and the local watershed in collaboration with multiple stakeholders.

- Immediate removal of the 5 known populations within the project area is recommended to slow spread by eliminating local seed sources.

- To coordinate long-term monitoring and removal of Algerian sea lavender we recommend collaborating with Don Edwards Wildlife Refuge, The Bay Area Early Detection Network and Cal Flora, The Bay Joint Venture, The Invasive *Spartina* Project, the California Invasive Plant Council, Save the Bay, local Native Plant Society local chapters, neighboring land holders and other stakeholders.

- To coordinate best practices for monitoring and removal with other restoration projects we recommend collaborating with the Bay Conservation and Development Commission, the Coastal Conservancy and the U.S. Army Corps of Engineers practitioners.

- We recommend collaboration with local colleges and universities to support eradication by providing research on removal methods and impacts, and by writing letters of support and justification to lawmakers.

- Monitoring of Algerian sea lavender and other invasive and rare species within the project area would benefit from the continued refinement of spatially explicit predictive models. These models should continue to be tested for their ability to guide field searches, reduce monitoring costs, and improve early detection.

- In order to integrate remote sensing into a comprehensive weed management plan, we recommend a review of the invasive species likely to invade the project area and a study of the scale at which these species are detectable with multispectral versus hyperspectral imagery.

- Installing tide stations in sloughs and channels in the South Bay, resurveying tidal benchmark elevations, and integrating these datasets using more accurate spatial reference systems would improve tidal datum reckoning in the South Bay and provide data needed to model species distributions, monitor sea level rise, evaluate flood risk, and determine how restoration actions affect the South Bay's tidal prism.