Weeding out the invaders:
Lessons learned from 5 years of hyperspectral weed detection in a highly altered estuary

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Background and Objectives

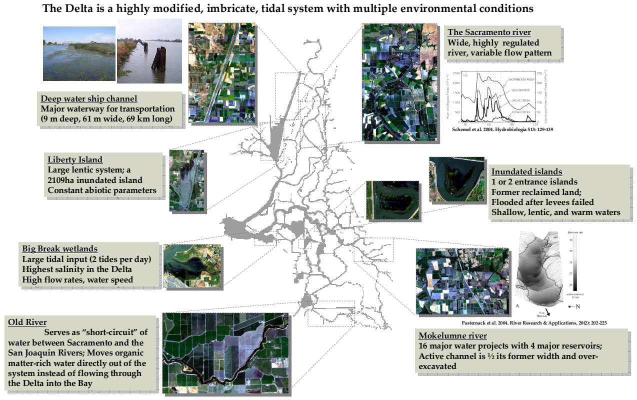
The spread of invasive plant species poses a significant threat to biological diversity and ecosystem functioning. Compared to terrestrial weeds, invasive aquatic vascular plants are more difficult to control and manage because they grow submerged in water, float on the water surface, or have inundated basal portions with emergent foliage and upper canopy. Of particular concern in the Sacramento-San Joaquin Delta Region are Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*), which are well known for their ability to alter physical and biological functions of aquatic systems. A fundamental need for invasive aquatic plant management is to develop a cost-effective, non-intrusive, large scale monitoring method.

Objectives

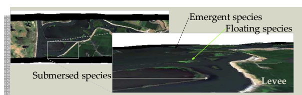
- **Produce annual maps of the areal distribution of emergent (e.g., tule), and floating (e.g., water hyacinth) species**
- **Produce annual maps of the areal distribution of submerged aquatic vegetation (lifeform classification)**
- **Analysis of the change in areal coverage (change detection)**
- **Relate water quality with submerged aquatic vegetation distribution**
- **Assess habitat quality for threatened and endangered pelagic organisms**

Environmental context

The Delta is a highly modified, imbricate, tidal system with multiple environmental conditions



Aquatic plant communities



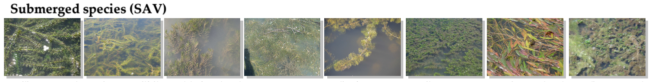
Emergent species

Tule *Schoenoplectus acutus* · Common reed *Phragmites spp.* · Cattail *Typha latifolia* · Blackberry *Rubus spp.* · Giant reed *Arundo donax* · Pepperweed *Lepidium latifolium*

Floating species

Water hyacinth *Eichhornia crassipes* · Primrose *Ludwigia peploides* · Pennywort *Hydrocotyle ranunculoides*

Submerged species (SAV)



Brazilian waterweed *Egeria densa* · Eurasian watermilfoil *Myriophyllum spicatum* · Curlyleaf pondweed *Potamogeton crispus* · Sago *Stuckenia pectinata* · Carolina fanwort *Cabomba caroliniana* · Coontail *Ceratophyllum demersum* · American pondweed *Potamogeton nodosus* · Canadian waterweed *Elodea canadensis*

Challenges:

Spatial extent:
Largest area
(2600km² waterways);
Single consistent method;
High spatial resolution data set;
Good accuracy (>80%);
Wall-to-wall sampling.

Temporal extent:
Multiple years (2003 - 2007);
Ongoing management activities.

Spectral extent:
High dimensional data.

Remote sensing of aquatic vegetation requires:

- High spatial and spectral resolution imagery, collected at specific times (tidal and sun angle)
- Classification must account for varying water conditions (for SAV), confounding factors (tree canopy), phenological heterogeneity, and dynamics of the system
- Multiple inputs considered simultaneously, and large training and testing data sets

Sensor Choice and Flight Planning

Sensor Choice

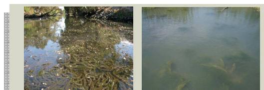
Challenges:
We need a **large spatial extent** at **high spatial resolution**
Hyperspectral data to discriminate spectrally similar species
Short-wave infrared bands (SWIR) are needed to perform atmospheric correction and differentiating plants with a column of water from those at the surface

Solutions:
Air-borne hyperspectral sensors (e.g. AVIRIS, Hymap and SpecTIR) are the only sensors that meet both the spectral and spatial resolution requirements.
We acquired 64-67 flightlines each year collected from HyVista's Hymap sensor, which has 3m ground resolution and 128 bands from 0.45 µm to 2.5 µm

Flight Planning

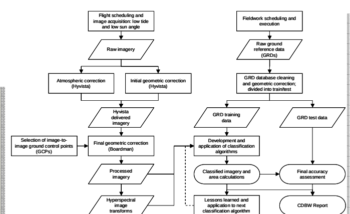
Challenges:
Specular reflection from water surface
Depth of water column above targets affects signal

Solutions:
Image acquisition during the **late morning** and **early afternoon** avoids specular reflection
Image acquisition during **low tide** minimizes the depth of the water column over submerged plants
Image acquisition in **low wind conditions** minimizes speckling caused by specular reflection off of waves

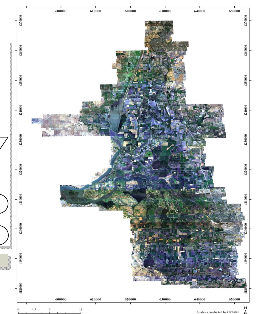


Specular reflection over *E. densa* · Turbid water column over *E. densa*

Processing and analysis



Flowchart of project imagery processing and analysis



Radiometric

Challenges:
Our system (and classification effort) has both aquatic and terrestrial components
No vendor currently performs atmospheric corrections designed for water

Solutions:
Training data for classifiers and spectral unmixing algorithms must be **extracted from the images themselves**.
Field spectra for submerged cover classes do not match in-scene spectra
Investigate **TAFKAA and radiative transfer models** (e.g., Hydrolight, Biopti)

Geometric

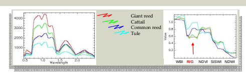
Challenges:
Vendor provided geometric corrections to aerial imagery are usually +/- 2-5 pixels off, even after manual image-to-image georegistration

Solutions:
Joseph Boardman's **orthorectification software has resulted in +/- 1 pixel misregistration errors** using approximately 50% of the original image-to-image tie points that a standard polynomial warp would require

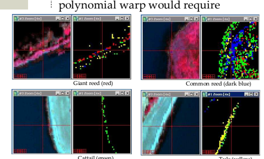
Classification

Emergent

Challenges:
Spectral signatures similar to submerged species



Solutions:
Emergent species identified using **red/green ratio**
Merge LiDAR with Hyperspectral to improve classification

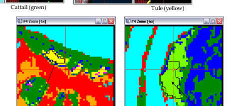


Giant reed (red) · Common reed (dark blue) · Cattail (green) · Tule (yellow)

Floating

Challenges:
Water hyacinth is **spectrally similar** to co-occurring floating and emergent species and sunlit portions of tree crowns
Water hyacinth has **multiple phenologies** at any acquisition time

Solutions:
Application of **decision trees** with multiple inputs (**SAM, LSU, continuum removal, indexes, band averages**, etc.)
Training data collected for **all common species** and their **phenologic stages**
Sunlit tree crowns were distinguished from floating vegetation by **LiDAR and height**



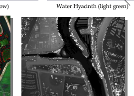
Pennywort (yellow) · Water Hyacinth (light green)

Submerged

Challenges:
Submerged spectral signature is highly dependent on the local water conditions
Tree shadows cast on water are confused with submerged species

Solutions:
Submerged species were distinguished from water and turbid water using **chlorophyll features**
Tree crowns shade were distinguished from SAV by **LiDAR and ray-tracing techniques**
Submerged species at surface easily distinguished from water

Submerged species



LiDAR imagery used for tracing shadows

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Future Directions

- Assess relationship between climate and species abundance using time-series
- Relate management activities with invasive species distributions
- Relate invasive species distribution trends with habitat quality