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Appendix A

## Arrowhead Marsh

### Introduction

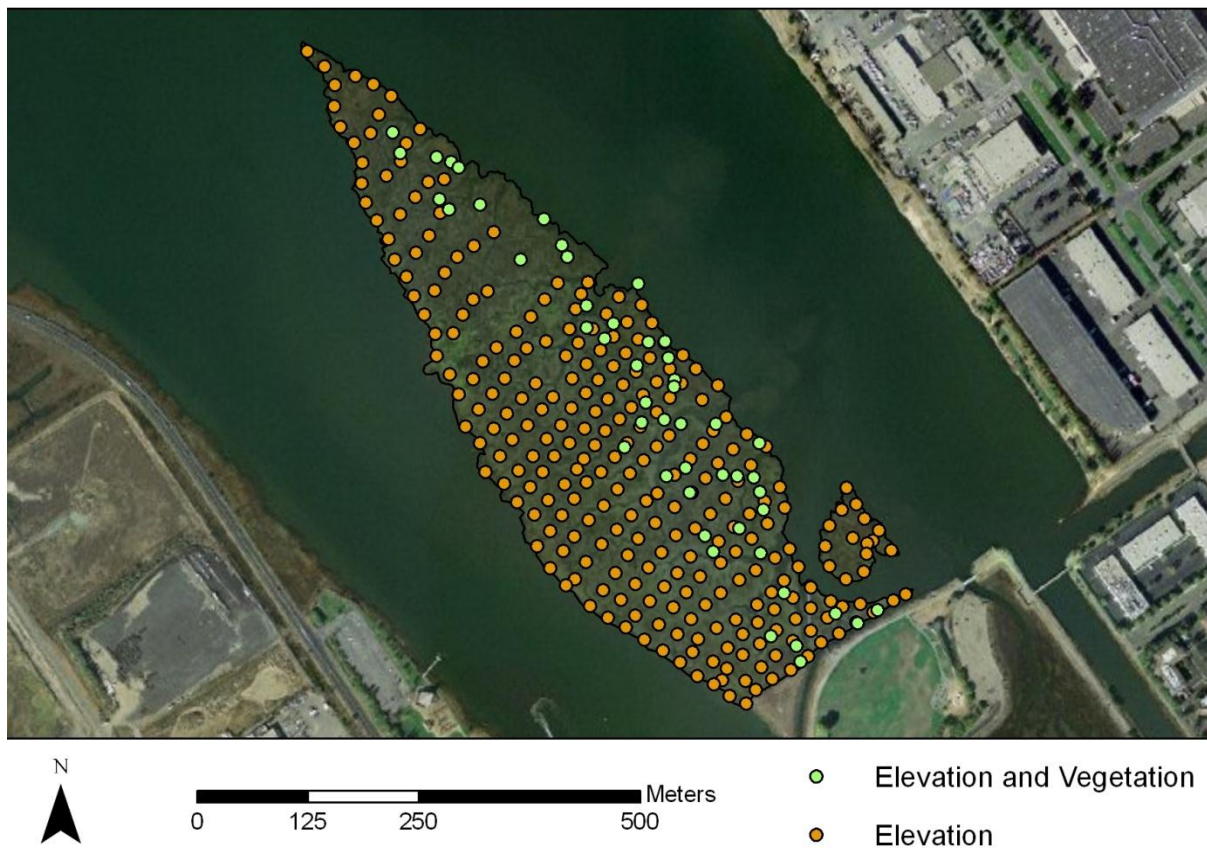
Located in central San Francisco Bay, Arrowhead Marsh (hereafter Arrowhead) is a tidal salt marsh which is owned by Oakland Port Authority and managed by East Bay Regional Parks as part of the 741 acre Martin Luther King Jr. Regional Park. Arrowhead is recognized as an important stopover on the Pacific Flyway and is part of the Western Shorebird Reserve Network. Arrowhead is also home to the federally-endangered California clapper rail (*Rallus longirostris obsoletus*) which occupies the low intertidal habitat dominated by cordgrass (*Spartina spp.*)

This study focused on 17.0 hectares of Arrowhead. Elevation and vegetation surveys were conducted in the winter of 2009 using an RTK GPS. To monitor tidal inundation, two water level loggers were deployed from 2009 - 2010. Beginning in 2006, a chemical herbicide (chemical mow) was applied to the western half of the marsh in an attempt to control the invasive *Spartina densiflora* and the *S. densiflora* x *S. foliosa* hybrid. Due to the treatment, vegetation was not surveyed in the western portion of Arrowhead.

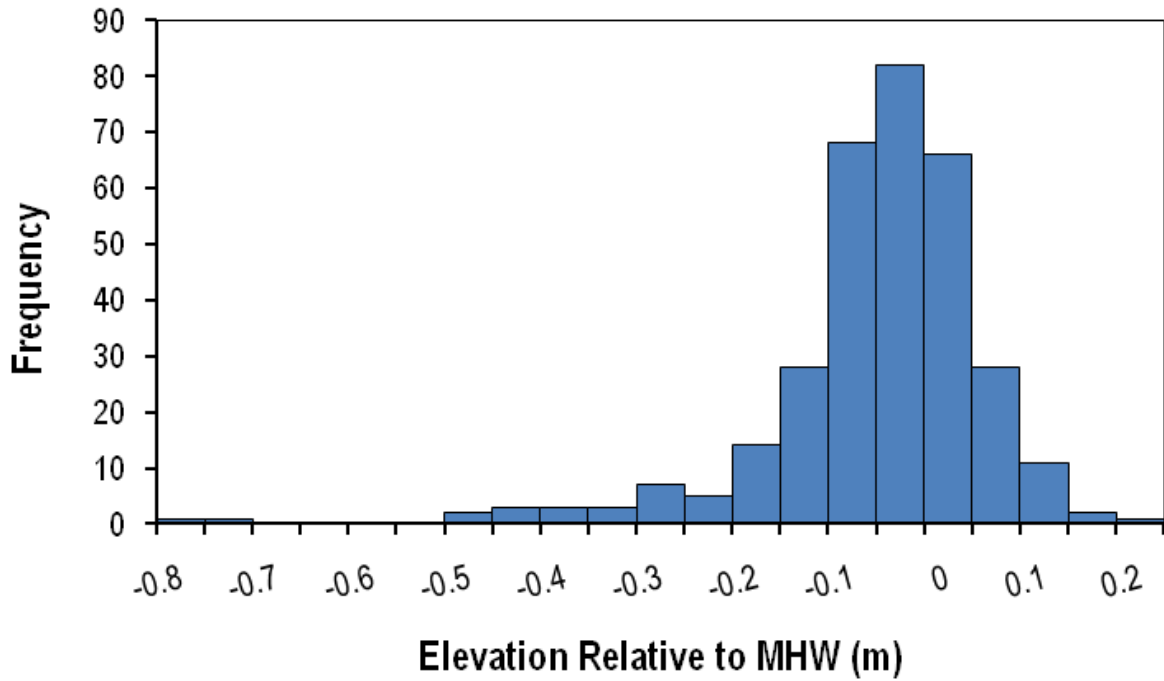
### Results

#### ***Elevation surveys***

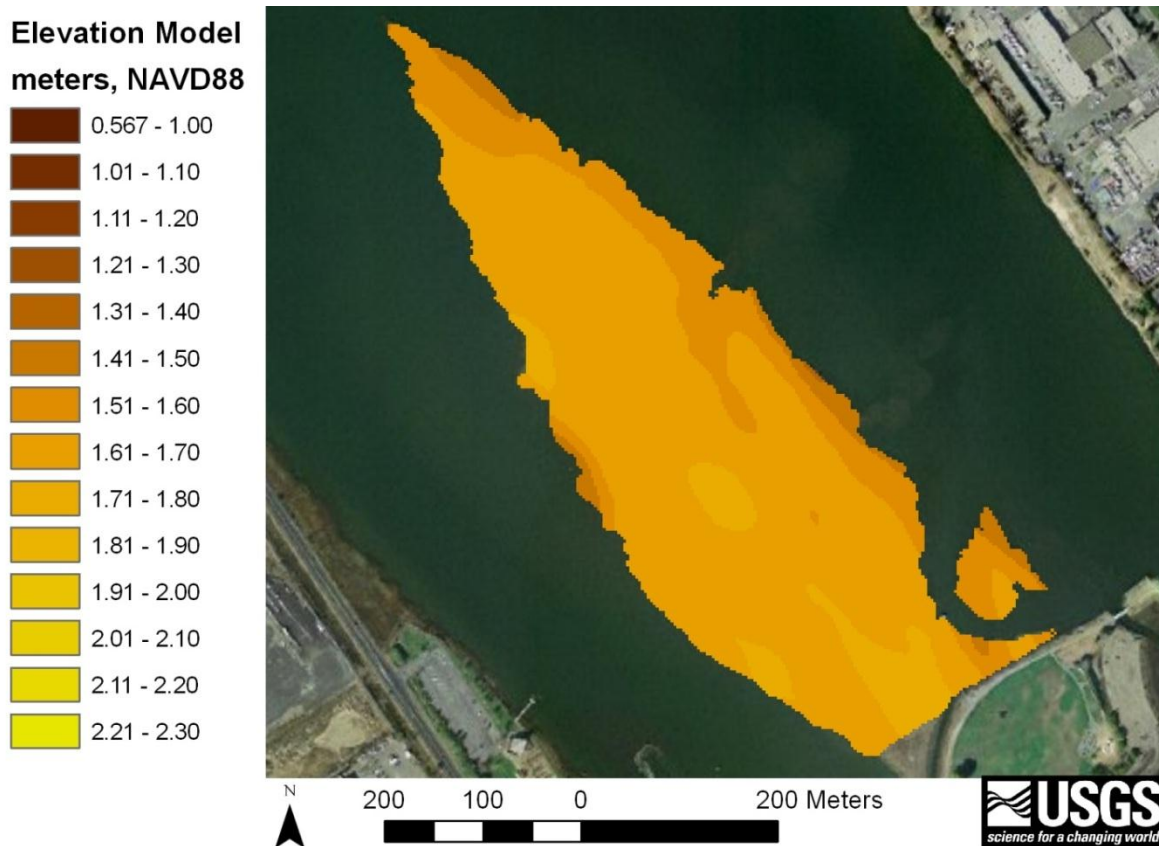
A total of 274 elevation measurements were taken at Arrowhead (Fig. A-1). The elevation range was 0.87 - 1.84 m with a mean of 1.62 m (NAVD88). Over half (65%) of the survey points fell within 1.55 - 1.70 m, with a 0.15 m range. Arrowhead was the second lowest marsh surveyed in this study with 87% of the elevation points taken located below mean high water (MHW; Fig A-2). Only 13% of survey points were located at elevations above MHW. A 3-m resolution elevation model was developed in ArcGIS 9.3 (ESRI, Redlands, CA) Spatial Analyst using the Kriging method (Fig. A-3). This baseline elevation model was used as the initial elevation in the WARMER sea-level rise (SLR) model.



**Figure A-1.** Arrowhead Marsh with elevation and vegetation survey points collected in 2009.



**Figure A-2.** Distribution of elevation relative to local mean high water (MHW) at Arrowhead Marsh.



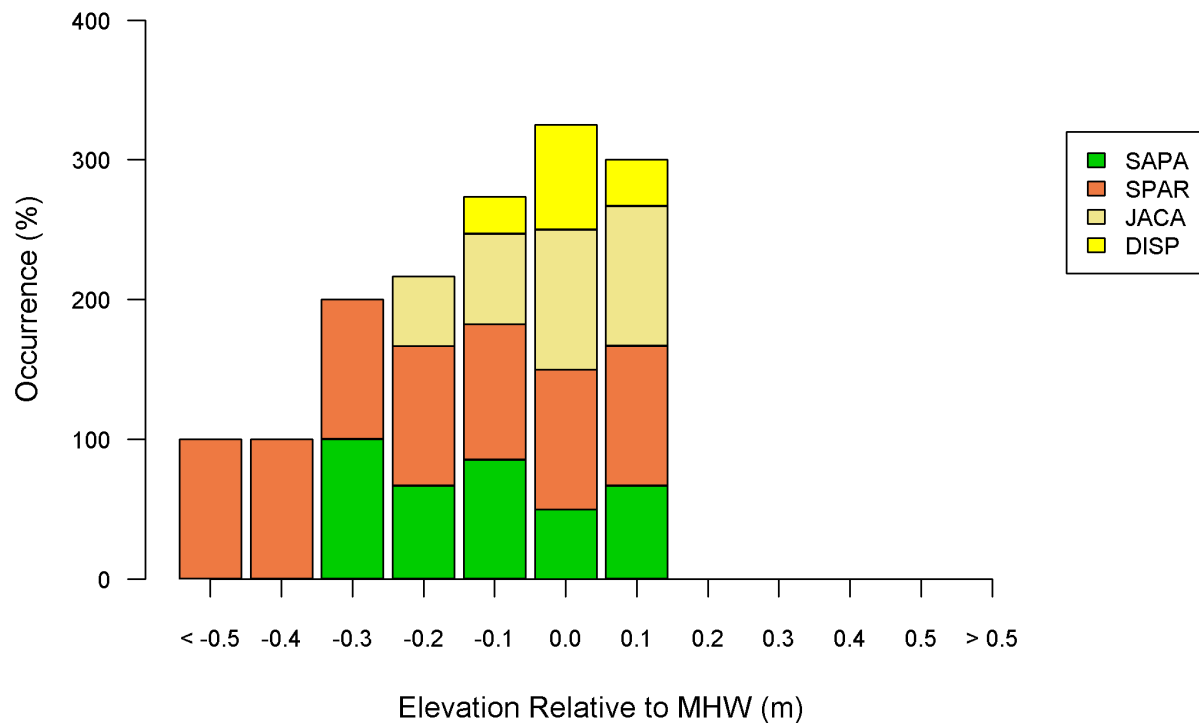
**Figure A-3.** Elevation model (3-m resolution) developed from ground RTK GPS elevation data.

### Vegetation surveys

Vegetation surveys were done concurrently with elevation surveys in December of 2009. A total of 50 locations (Fig. A-1) were measured for vegetation composition, height (cm), and percent cover (Table A-1).

We did not distinguish between invasive and native *Spartina spp.* and *Scirpus spp.* in the survey.

Vegetation in marshes is sensitive to soil salinity, inundation patterns and disturbance. Therefore, a stratification of vegetation species relative to MHW (Fig. A-4) was observed within this low slope marsh.



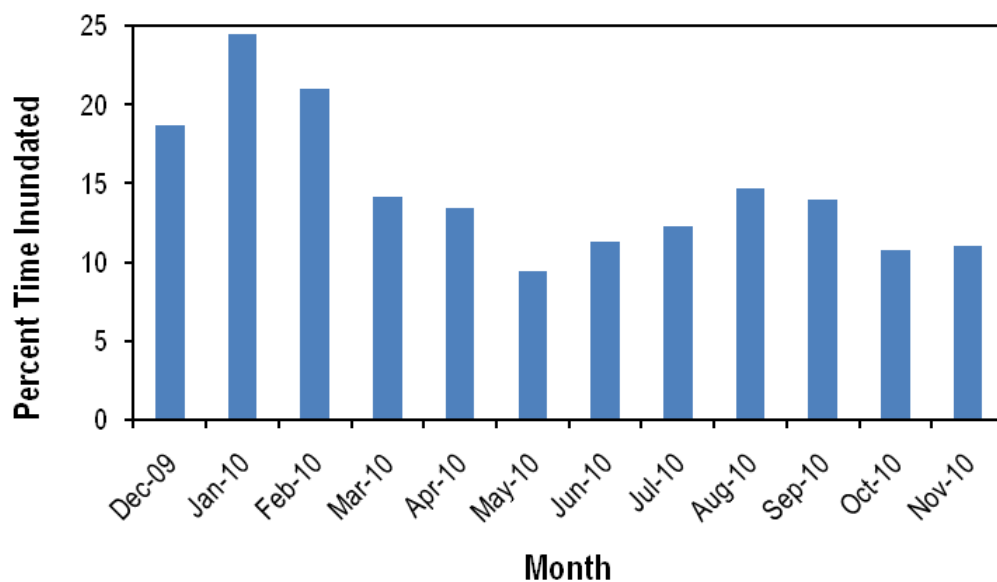
**Figure A-4.** Stratification of vegetation species was observed relative to MHW. Species codes: SAPA = *Sarcocornia pacifica*; SPAR = *Spartina spp.*; JACA = *Jaumea carnosa*; DISP = *Distichlis spicata*.

**Table A-1.** Mean marsh elevation, avg. and max height (cm), percent cover with standard deviations (SD), and presence by species in Arrowhead Marsh.

<b>Species</b>	<b>Elevation (MHW, m)</b>	<b>Elevation SD (MHW, m)</b>	<b>Avg, Height (cm)</b>	<b>Avg. Height SD (cm)</b>	<b>Max Height (cm)</b>	<b>Max Height SD (cm)</b>	<b>% Cover</b>	<b>% Cover SD</b>	<b>n</b>	<b>% Presence</b>
<i>Sarcocornia pacifica</i>	-0.15	0.07	21.63	16.40	25.97	18.88	22.18	17.05	38	76.00
<i>Spartina spp.</i>	-0.17	0.13	41.61	26.40	53.57	33.47	44.86	32.42	49	98.00
<i>Jaumea carnosa</i>	-0.13	0.07	11.88	7.25	14.47	8.58	31.38	25.40	32	64.00
<i>Distichlis spicata</i>	-0.11	0.06	17.00	10.10	19.69	11.46	13.00	13.92	13	26.00

### **Water level monitoring**

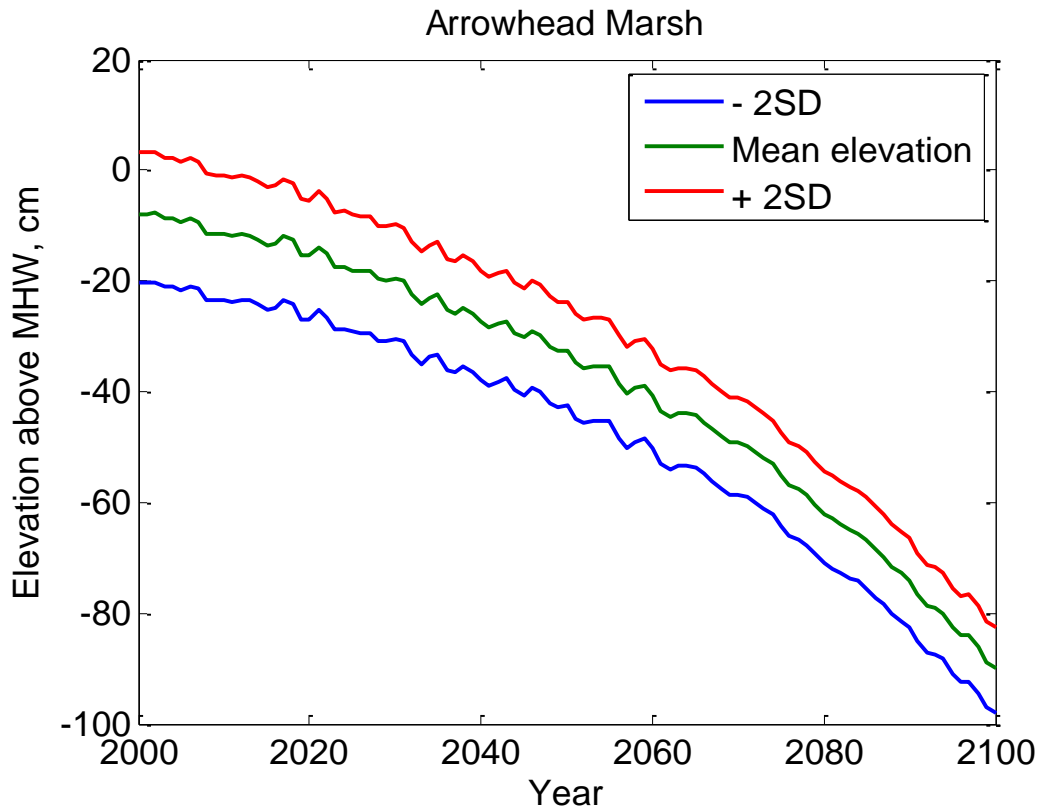
Site-specific water level was monitored at Arrowhead for one year from December 2009 – May 2011. Water level was measured using two data loggers deployed at the mouth of a second order channel and in the marsh interior. During 2010, MHW was 1.72 m and MHHW was 1.91 m for the site (NAVD88). Water levels throughout the year were recorded to evaluate seasonal patterns in tides. The marsh platform (defined as mean elevation) was inundated most often from December 2009 through February 2010 (Fig. A-5). Those months recorded above average water levels due to several record breaking storms that brought low air pressure and substantial rainfall, resulting in higher than predicted tides. The cumulative rainfall in January 2010 was above average throughout the SFBE and daily rainfall records were broken in some locations (NOAA). This resulted in longer inundation periods of the marsh platform.



**Figure A-5.** Percent of time Arrowhead was inundated monthly, based on the mean elevation of the marsh platform.

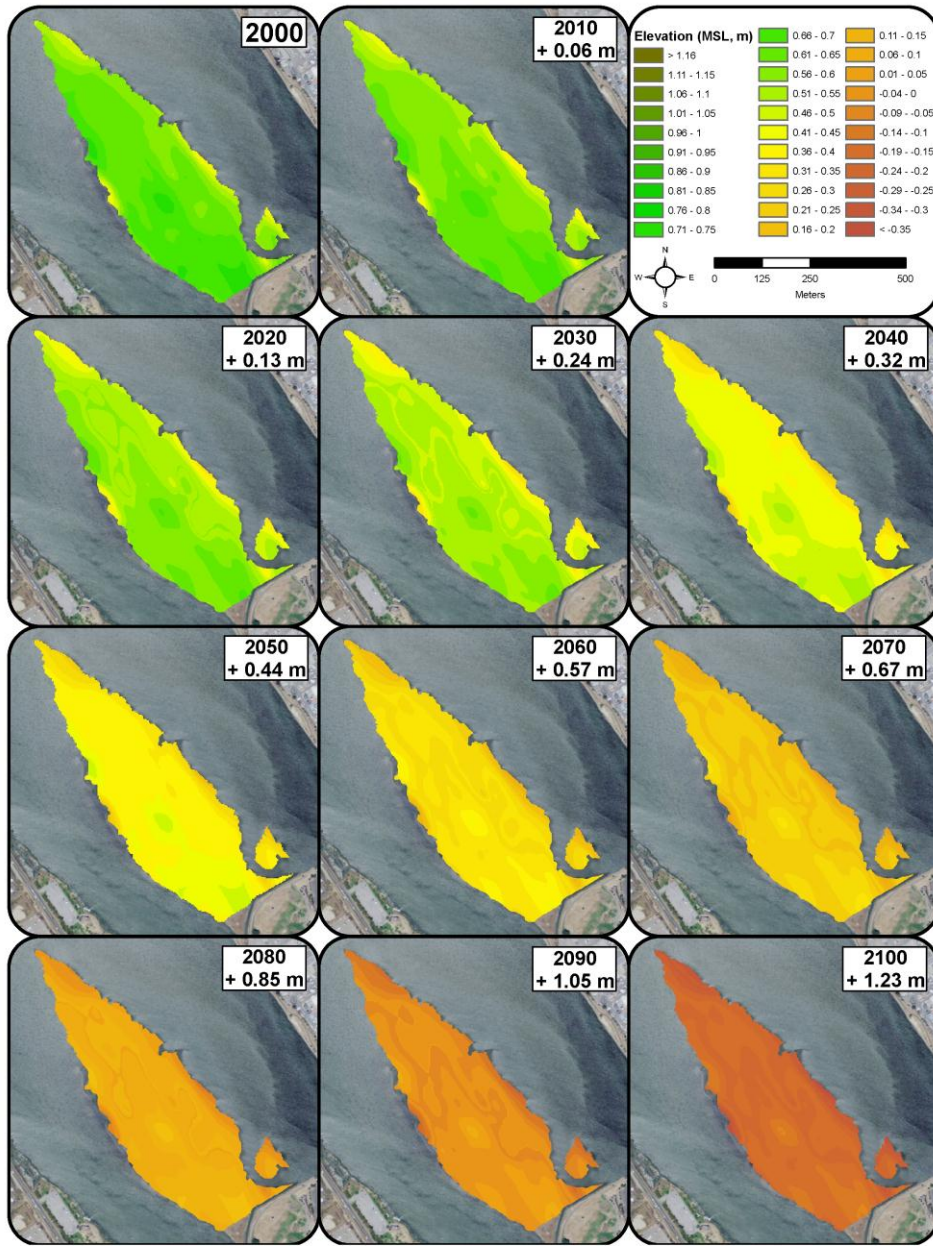
**Marsh elevation modeling**

Arrowhead had a low starting elevation and was located low in the tidal range, relative to our other study sites. The WARMER model results indicated that Arrowhead will not keep pace with SLR through this century. WARMER results show a gradual reduction in elevation relative to MHW over time, with a more dramatic decline after 2060 (Fig A-6). By 2080 the marsh is projected to be below MSL and therefore functionally a mudflat (Fig. A-7).



**Figure A-6.** WARMER scenarios for Arrowhead elevation change. Elevation above MHW is plotted versus model year with two standard deviations (SD).



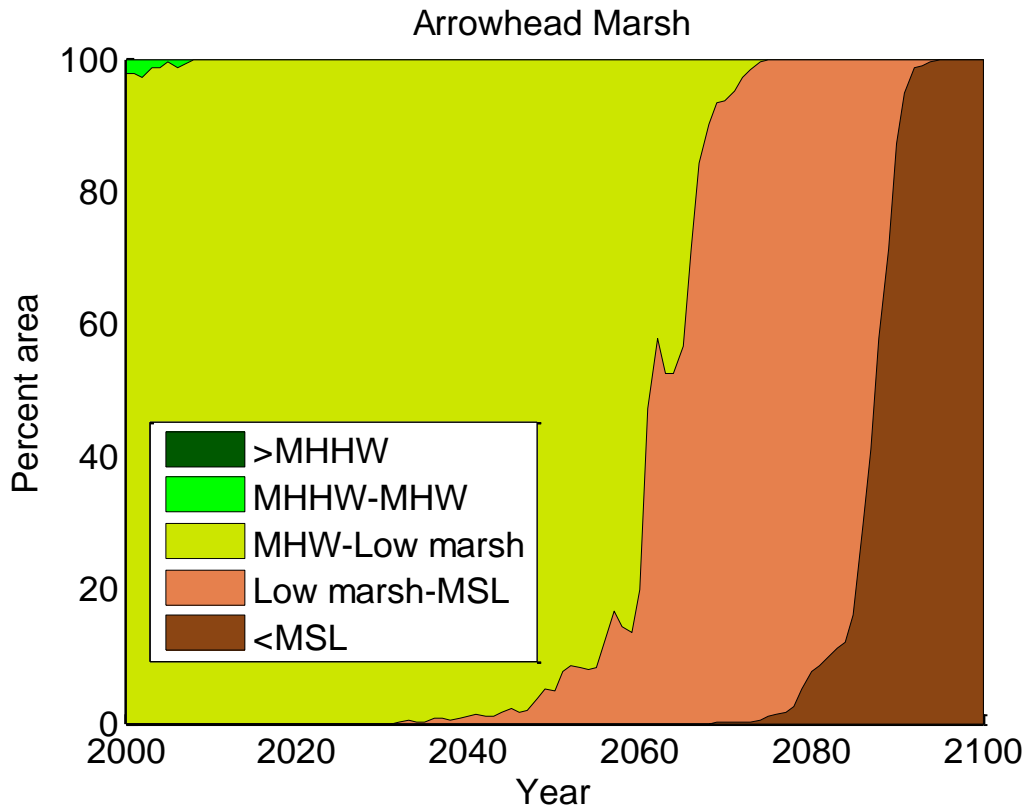


**Figure A-7.** Spatial WARMER results for Arrowhead. WARMER accounts for changes in relative sea level, subsidence, inorganic sediment accumulation, above/below ground organic matter productivity, compaction, and decay. Non-linear sea-level rise projections for California were used (Cayan *et al.* 2009).

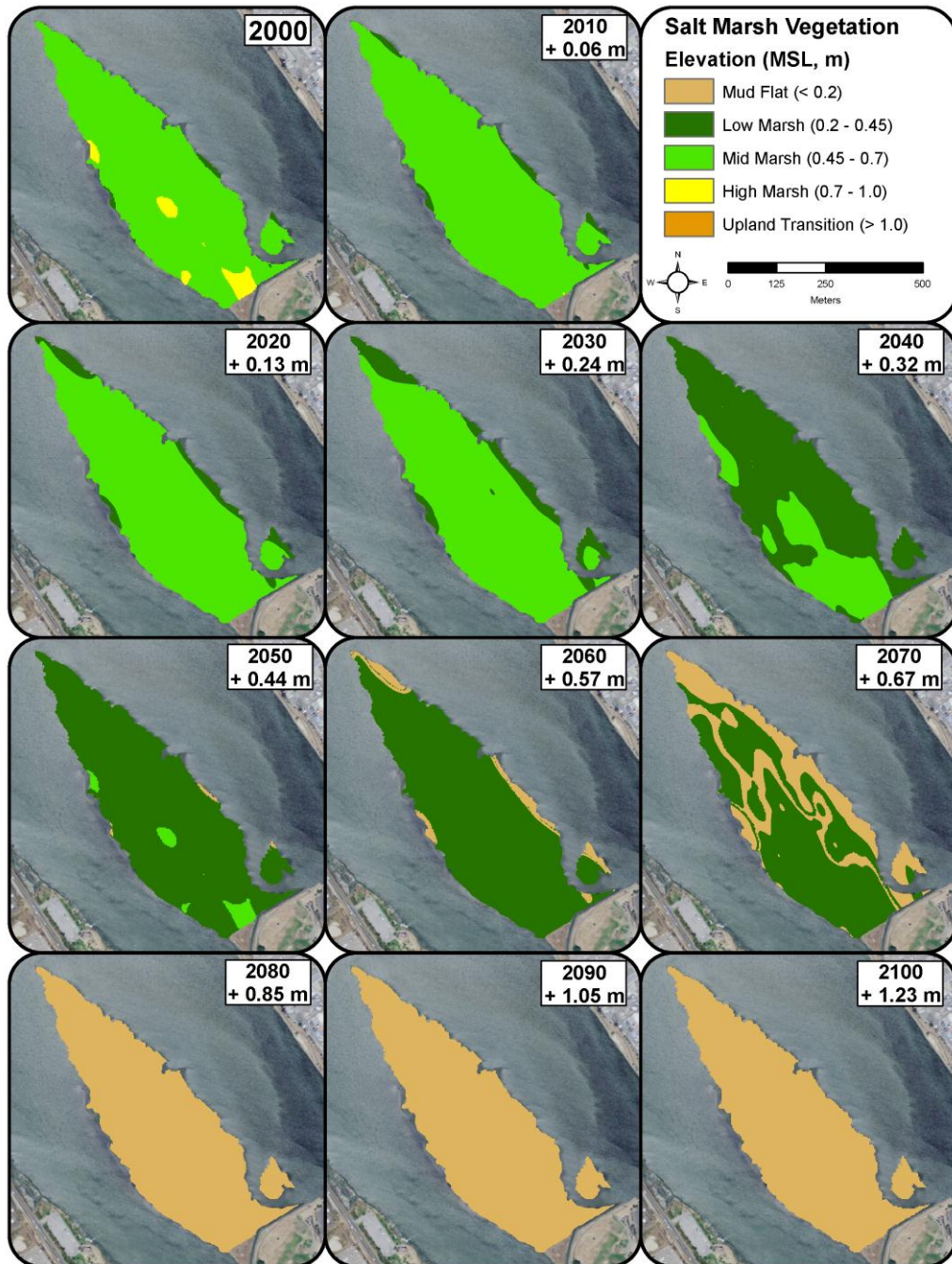


Elevation relative to the local tidal datum can be tied to vegetation observations (see methods). Vegetation data were categorized as mudflat, low, mid, high marsh, or upland transition plant communities (Table 4) and used to interpret the WARMER SLR results (Figs. A-8 – A-9). Upland transition (> 1.0 m MSL), is characterized by coyote bush (*Baccharis pilularis*). High marsh (0.7 – 1.0 m MSL), is characterized by *Frankenia salina* and *Jaumea carnosa*, while mid marsh (0.45 – 0.7 m MSL), is dominated by *Sarcocornia pacifica*. Low marsh (0.2 – 0.45 m MSL), is characterized by *Spartina spp.* or *Scirpus spp.* in brackish areas. Mudflat habitat (< 0.2 m MSL), is unvegetated or sparsely covered with *Spartina spp.* Currently vegetation at Arrowhead is primarily categorized as mid marsh with a little high marsh vegetation. All high marsh vegetation is projected to disappear with a + 0.06 m SLR. The largest transition occurred around 2040 (+ 0.32 m SLR), with a projected change from mid to low marsh vegetation. A transition to complete mudflat was projected by 2080 (+ 0.85 m SLR).

The WARMER model parameters for Arrowhead were extrapolated using sediment core data from China Camp marsh; thus, SLR projections should be interpreted with caution as local sedimentation processes may be quite different. To improve results, local site-specific sediment core data should be collected, along with suspended sediment concentration data to characterize sediment deposition potential.



**Figure A-8.** Area of Arrowhead Marsh within a given tidal range for the duration of the simulation period.



**Figure A-9.** Arrowhead WARMER results in terms of plant communities: mudflat, low, mid, or high marsh, or upland transition.