

This packet contains the additional resources shared during the May 2nd debrief meeting. Contact Sarah D. Ferner at daviess@sfsu.edu with questions.



Vegetation Data

Location of Vegetation Transects

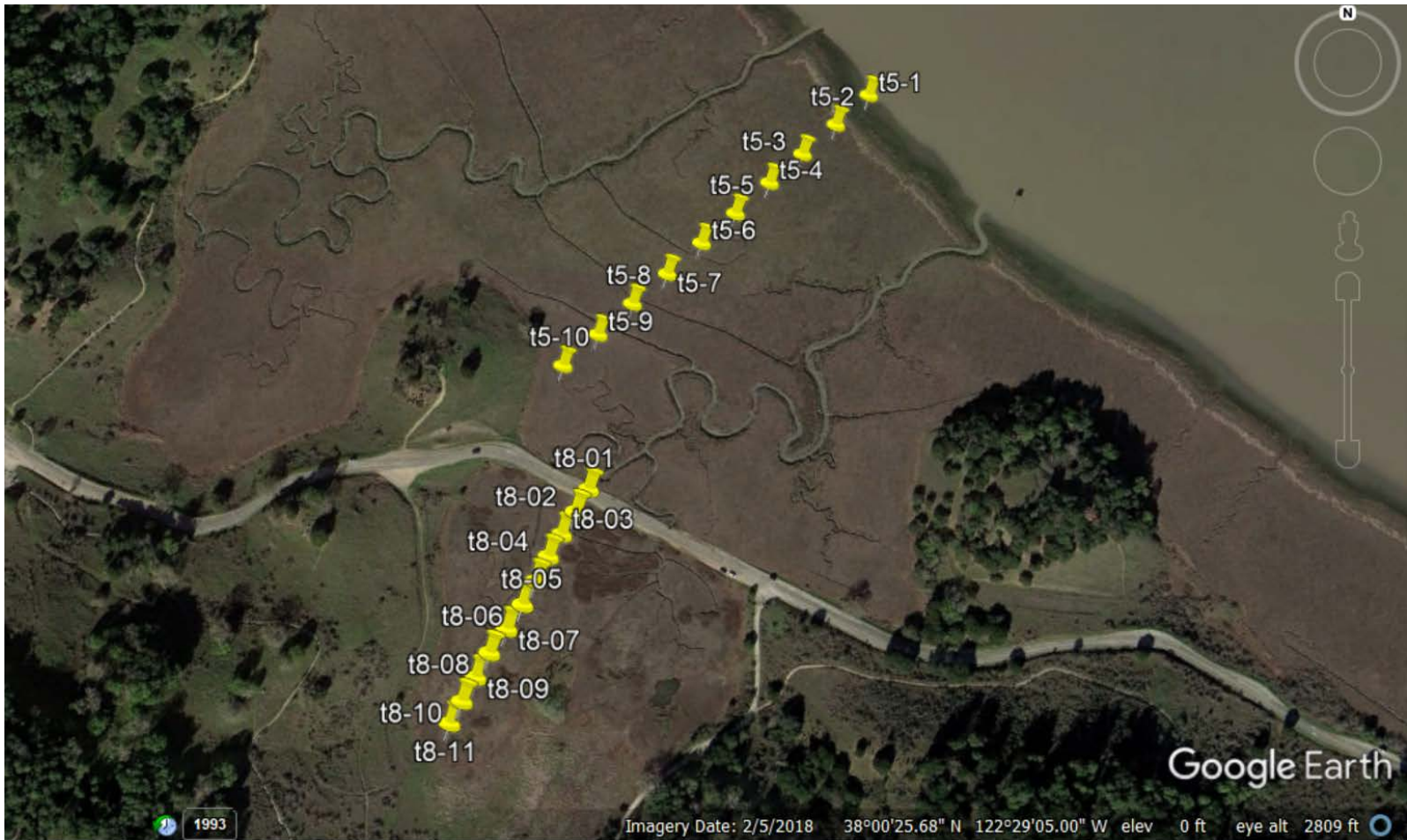
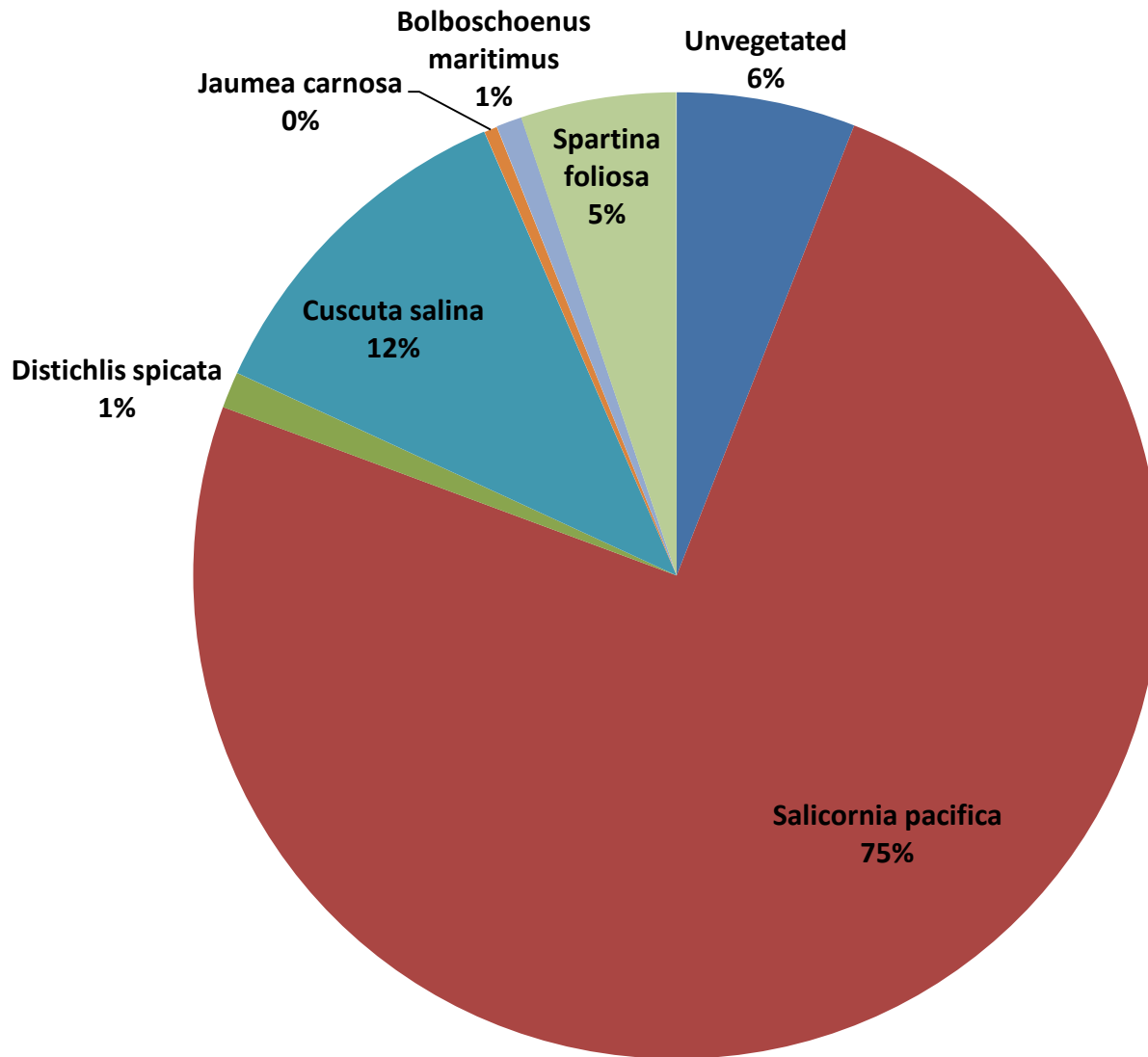




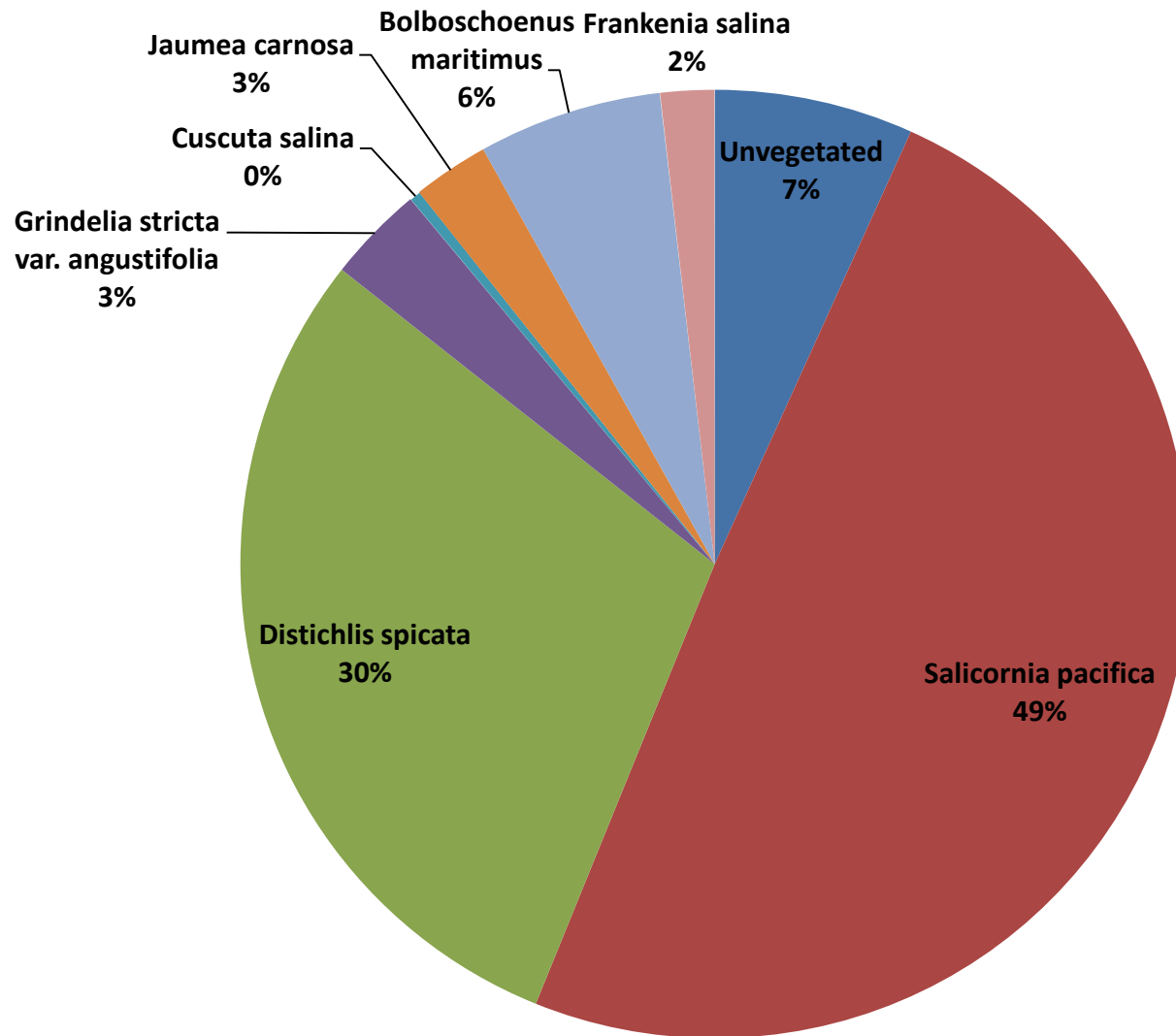
Photo from the top of Bullet Hill, looking across Miwok Meadows in late summer. The orange plant is Dodder (*Cuscuta*).



Average Percent Cover of Plots on Transect 5 - Bayland side of Road



Average Percent Cover of Plots on Transect 8 – Upland Side of Road



The next three pages are copied from Baye, 2007. Accessed at www.spartina.org



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**Selected Tidal Marsh Plant Species
of the San Francisco Estuary:**

A Field Identification Guide

Version 1.0 submitted July 2006
Printed March 2007

Prepared for the
San Francisco Estuary Invasive Spartina Project
(a project of the California State Coastal Conservancy)
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Pickleweed, perennial pickleweed

Salicornia virginica L.

Current Botanical name: *Sarcocornia pacifica* (Standley) A. J. Scott, in part; *S. perennis* (Miller) A. J. Scott, in part (northwest, possibly Central California).

Family: Amaranthaceae (Amaranth family; traditionally in Chenopodiaceae)

San Francisco Estuary range: Throughout.

Habitat: Middle and high tidal marsh zones, salt or brackish marshes; also diked nontidal seasonal saline wetlands.

Recognition characters: Succulent leafless cylindrical jointed stems, semi-woody base, shrubby erect irregular branches or creeping growth habit; gray-brown in winter, green spring-summer, drab reddish green in fall.

Similar species: *S. europaea* is annual with single trunk, geometric branching, bright crimson by mid-October; upper mudflats, often mixed with *Spartina*. *Arthrocnemum subterminale* has geometric branch patterns, vegetative shoot tips.

Comments: Native dominant or abundant in tidal marsh vegetation. Perennial/woody species of former *Salicornia* are now placed in *Sarcocornia* or *Arthrocnemum*.

DODDER FAMILY (Cuscutaceae)



Salt marsh dodder

Cuscuta salina Engelman var. *major*

Family: Cuscutaceae (dodder family)

San Francisco Estuary range: Throughout.

Habitat: High and middle tidal marsh zones, brackish or salt, associated with non-graminoid halophytes.

Recognition characters: Conspicuous orange-yellow to rich orange masses of tangled wire-like stems completely blanket host vegetation in patches ranging from less than a square foot to hundreds of acres of tidal marsh, visible from planes or aerial photos. Patches sometimes proliferate whitish bell-shaped small flowers.

Diagnostic (key) characters: Multiple varieties are recognized; var. *major* is expected in tidal salt marshes within San Francisco Estuary, distinguished by minor and variable floral characters.

Similar species: Other terrestrial *Cuscuta* species

Comments: Full parasite on stems of host plants, usually broadleaf halophyte forbs or shrubs. Pickleweed is most common host. Can become dominant over large areas of high marsh edges or marsh plains, and may cause dieback of host vegetation, vegetation gaps.

Grasses and Graminoids



Alkali-bulrush

Scirpus maritimus L.

Current Botanical name: *Bolboschoenus maritimus* (L.) Palla

Family: Cyperaceae (sedge family)

San Francisco Estuary range: Western Suisun Bay, San Pablo Bay, San Francisco Bay.

Habitat: Middle brackish tidal marsh zone; also non-tidal brackish marshes, intermittent lagoon edges.

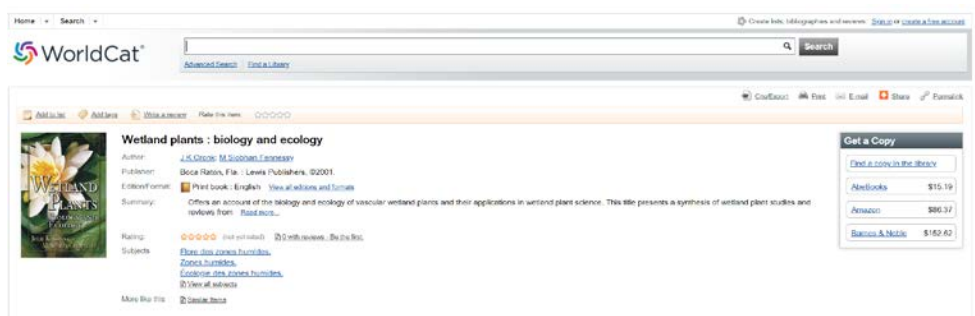
Recognition characters: Dense colonies from extensively creeping rhizomes, 3-angled stems; compact clusters of flowerheads subtended by three long leaf-like bracts; rhizomes bear hard "tubers". Often deciduous during periods of high summer marsh soil salinity in drought years.

Diagnostic (key) characters: Irregular V-shaped non-green and veinless membrane at top of sheath on side of culm opposite of blade juncture.

Similar species: *Scirpus* (*Schoenoplectus*) *robustus* is closely related and hybridizes, forming intermediates in some geographic areas; species boundaries vary in taxonomic treatments, further confused by misapplication of names in older floras and references.

Comments: Tubers may persist dormant for years during high-salinity phases of fluctuating brackish-salt marshes of San Pablo Bay (esp. Napa-Sonoma Marshes, Petaluma Marsh) during droughts, so marshes may rapidly fluctuate between pickleweed dominance and alkali-bulrush dominance (pickleweed understory) with short-term climate changes. Invades salt marsh during consecutive series of high rainfall years. Often out-competed by tules (*S. acutus*, *S. californicus*) or cattails (*Typha* spp.) in lower salinity brackish or fresh-brackish marshes.

The following excerpt is from page 138 of Cronk, J.K. and M. S. Fennessy. 2001 Wetland Plants: Biology and Ecology. CRC Press/Lewis Publishers. Boca Raton, FL. 440 pages.



The screenshot shows the WorldCat website interface. At the top, there is a search bar with the text "Search" and a magnifying glass icon. Below the search bar, the title "Wetland plants : biology and ecology" is displayed. The author is listed as "Cronk, J.K. and Fennessy, M.S.". The publisher is "Boca Raton, Fla. : Lewis Publishers, ©2001.". The summary states: "Offers an account of the biology and ecology of vascular wetland plants and their applications in wetland plant science. This site presents a synthesis of wetland plant studies and reviews from...". The rating is shown as five stars. The subjects are "Wetland plants", "Wetland ecology", and "Wetland plants - Florida". On the right side, there is a "Get a Copy" section with a table of prices:

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Summary

All plant cells require oxygen for aerobic respiration. When the sediments are flooded, very little or no oxygen is available to plant roots. Wetland plants have developed a number of adaptations to the lack of oxygen in the soil environment. These adaptations include the development of air spaces, called aerenchyma, that allow oxygen to move from aerial parts to belowground parts of the plant. Other adaptations include adventitious rooting, shallow rooting, and a variety of root structures known as pneumatophores (found on trees). Some mangrove species have aerial roots known as drop and prop roots. Stem adaptations include rapid underwater shoot extension, hypertrophy, and stem buoyancy.

Gases (oxygen, carbon dioxide, methane, and others) move through plants via diffusion. Some wetland plants also exhibit the capacity to move gases via pressurized ventilation, underwater gas exchange, and Venturi-induced convection. Oxygen diffuses from plant roots into the surrounding sediments (called radial oxygen loss) and the resulting oxygenated rhizosphere provides a habitat for aerobic microbes and an area within the otherwise saturated soil in which elements may become oxidized.

When plant cells are deprived of oxygen, anaerobic metabolism begins. With anaerobic metabolism, ATP production continues, although at a much decreased rate. An indicator that plant cells are undergoing anaerobic metabolism is increased ADH activity. Ethanol, the main product of alcoholic fermentation, may not be as toxic as originally thought. During the first minutes of anoxic conditions, the cytoplasmic pH decreases in most plants. This may be caused by the production of lactic acid or by the decrease in the amount of ATP to regulate pH. Some flood-tolerant plants appear to be able to avoid the decrease in pH. Metabolic responses to anoxia are also reflected in protein metabolism under different levels of oxygen availability. Mitochondrial adaptations may also play a role in flood tolerance.

Plants growing in saline environments must be able to acquire water without accumulating excess salt. The water potential of halophytes must be lower than the water potential of the surrounding medium. Salt-tolerant plants are able to increase their internal solute concentration by osmotic adjustment and thereby lower their water potential. Some halophytes are able to avoid salt toxicity through salt exclusion and excretion, by shedding salt-laden leaves, or by succulence. High sulfide levels in salt marshes and mangroves create a stressful environment for plant growth. Some of the adaptations for low oxygen levels also help plants avoid sulfide toxicity, such as adventitious and shallow rooting and radial oxygen loss.

Wetland plant adaptations to low

From PLANTS Factsheet: https://plants.usda.gov/plantguide/pdf/pg_scma8.pdf

Bolboschoenus maritimus

Description General: Sedge Family (Cyperaceae). Alkali bulrush is a native perennial, heavily rhizomatous, obligate, wetland plant that may reach 1.5 m (60 in) in height and form dense stands. The stems are upright and angular with several leaves, up to 1 cm (0.4 in) wide, along the lower two thirds of the plant. The flowers are borne in sessile spikelets, densely clustered at the tip of the stem, and nestled in 3 or more leafy bracts. Spikelets are 1.2-2 cm (0.5 to 0.8 in) long. The seeds are brown lenticular achenes, 2.5 to 4 mm (0.1 to 0.16 in) long (Cronquist et al., 1977).

Distribution: Cosmopolitan bulrush is found throughout North America with the exception of the Southeastern United States. For current distribution, consult the Plant Profile page for this species on the PLANTS Web site. **Habitat:** Cosmopolitan bulrush is found in areas with saturated soils including marshes, playas, ponds, streams and mud flats (Welsh et al., 2003). It is often found growing in association with other salt tolerant wetland species such as iodine bush (*Allenrolfea occidentalis*) inland saltgrass (*Distichlis spicata*) and seepweed (*Suaeda* spp.).

Adaptation Cosmopolitan bulrush is found at low to mid elevations from 850 to 2,100 m (2,800 to 6,900 ft). in marshes, transient wet spots, pond margins, and backwater areas. It forms large dense stands in alkaline or saline sites. It can handle a pH of up to 9.0 and will grow on soils from fine clay to silt loam to sand. Cosmopolitan bulrush can survive periods of total inundation of up to 1 m (3 ft) deep. It tends to spread and reproduce when the water table is within 10 cm (4 in) of the surface. This species can occur in freshwater sites, but is usually a pioneering species that will be replaced over time with more

Grass Shrimp



Check out this article in Bay Nature

<https://baynature.org/article/from-the-bottom-up/>

Bay Nature magazine • January-March 2002

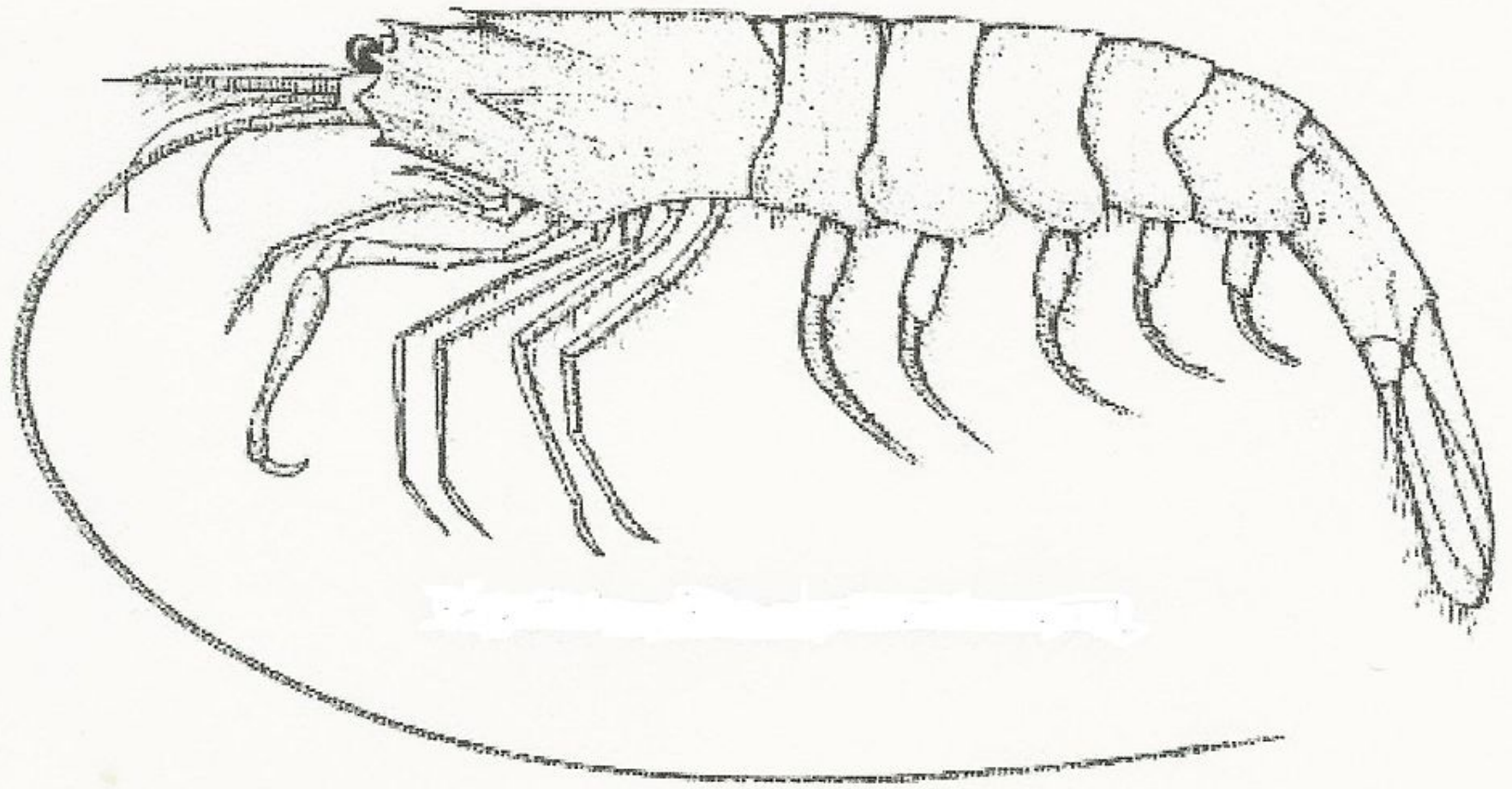
From the Bottom Up

by *Micky Ellinger*

January 1, 2002

SHARE THIS:   

It's an hour before dawn; the Dorothy Ann sways as the tide lifts her out of the mud. Bart Laine must navigate the Alviso Slough as soon as the tide is high enough to float his boat. The bait shop trucks will be waiting when he gets back; he doesn't waste a minute of his fishing day. "Your money's out there swimming around and you've got to go get it," he says. The slough is a black river, the tules a ten-foot-high tunnel. Airplanes from three airports wink like fireflies. We reach the open Bay, silent except for the throb of the giant diesel engine beneath our feet, as the horizon glows with the lights of San Jose, San Francisco, the East Bay. Laine's quarry is the bay



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Title

Distribution of Macroinvertebrates Across a Tidal Gradient, Marin County, California

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Distribution of Macroinvertebrates Across a Tidal Gradient, Marin County, California

April Robinson¹, Andrew N. Cohen², Brie Lindsey³, and Letitia Grenier¹

ABSTRACT

The distribution of macroinvertebrates across a tidal gradient is described from a study of invertebrate distribution across tidal marsh sub-habitats, a non-quantitative survey of epifauna on intertidal rocky substrate, and a few additional observations and records from China Camp State Park, Marin County, California. In the tidal marsh study, invertebrates were sampled from distinct sub-habitat types: high-order channels, low-order channels, vegetated marsh plain, and natural levees adjacent to channels. Invertebrates were collected using a variety of trapping methods to account for capture biases associated with any one method. All common invertebrate taxa were significantly more abundant in a particular sub-habitat, and within each trapping method a few species accounted for most of the biomass. On intertidal rocks, 79% of the taxa identified to species or genus were exotic, but a few native species were common.

KEY WORDS

Macroinvertebrate, intertidal, food web, tidal marsh, tidal gradient, salt marsh, exotic species, San Francisco Bay, China Camp State Park

INTRODUCTION

Intertidal habitats present a harsh physical environment for resident invertebrates. Twice daily tides subject terrestrial invertebrates to the risk of drowning, and aquatic invertebrates to the risk of desiccation. Inundation periods and sediment properties vary across the intertidal gradient, and environmental conditions change rapidly with inundation and exposure. Physical and biological conditions change over small spatial scales, because slight changes in elevation translate to large changes in hydrology, geomorphology, and vegetation (Collins and others 1986; Pennings and Callaway 1992).

Distribution of rocky intertidal invertebrates varies over both large and small spatial scales as a result of differences in dispersal, recruitment, and response to changes in microhabitat between species (Underwood and Chapman 1996). The small-scale zonation of rocky intertidal invertebrates results from a combination of physiological limitations and ecological interactions (Tomanek and Helmuth 2002).

Within tidal marshes, distinct sub-habitats—from large, high-order channels to small, low-order channels, to marsh plain and natural levee—are found adjacent to each other along the tidal gradient, sometimes changing abruptly from one meter to the next. Marsh invertebrate communities vary by sub-habitat, with many species showing a preference for particular elevations, vegetation zones or substrate types

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(Teal 1962; Davis and Grey 1966; Levin and Talley 2000).

Invertebrates constitute much of the secondary productivity in tidal marshes (Teal 1962), and play a critical role in transferring primary productivity up the food web, forming a substantial part of the diet of many resident marsh vertebrates (Grenier and Greenberg 2005). Because few seeds and fruits in the marsh are available for foraging terrestrial vertebrates (Greenberg and others 2006), the distribution and diversity of invertebrates largely determines the food resources available for secondary consumers, and influences their foraging behaviors. Invertebrates constitute a substantial portion of the diet of many common marsh fish species as well (Visintainer and others 2006).

This paper provides original data on the distribution of macroinvertebrates across a tidal gradient, and reviews what is known about the diversity, distribution, and abundance of intertidal invertebrates at China Camp State Park in Marin County, California, a National Estuarine Research Reserve Site.¹ In this paper, we present data from two studies, one of tidal marsh invertebrates and the other of rocky intertidal invertebrates. Most of the previously available invertebrate data from China Camp focus on predation of invertebrates (Dean and others 2005; Visintainer and others 2006) rather than on their diversity and distribution. We also briefly discuss the implications of invertebrate distribution and diversity on the behavioral ecology of their predators.

METHODS

Study Area

China Camp State Park contains 180 ha of tidal marsh, located on the western edge of San Pablo Bay in Marin County, CA (38°00'45" N, 122°29'25" W). San Pablo Bay is subject to semi-diurnal tides and has a Mediterranean climate with mild, wet winters and warm, dry summers. The upper part of the

¹ The material in this article is also being published in the San Francisco Bay National Estuarine Research Reserve's Site Profile, and in the book *Tidal Salt Marshes of the San Francisco Estuary: Ecology, Restoration, Conservation*.

intertidal zone, above roughly mean high water, is occupied by salt marsh, with mudflats below that. Rock outcrops and boulders are exposed on the low intertidal mudflats near a small island known as Rat Rock. The salt marsh is composed of a mix of ancient and centennial marsh, with the centennial marsh having accreted along the bayward edge over the last 150 years, likely due to the deposition of Gold Rush hydraulic mining sediments (Jaffe and others 2007).

The salt marsh at China Camp includes several distinct sub-habitats along a tidal gradient, each with distinct vegetation and hydrology (Figure 1). The dendritic tidal conveyance network comprises high-order channels that receive tides twice daily, and low-order channels that are smaller and at slightly higher elevation, and, thus, receive less frequent tidal inundation. Pacific cordgrass (*Spartina foliosa*) grows inside the banks of the high-order channels; the low-order channels are unvegetated (though they may be overhung by pickleweed, *Sarcocornia pacifica*, or other vegetation). Low-order channels peter out into the marsh plain, which, in turn, receives less frequent tidal inundation than the channels. Marsh plain is the most extensive sub-habitat in the marsh, extending from mean high water to slightly above mean higher high water, dominated by pickleweed, a low-growing succulent halophyte, with other common marsh plants interspersed (primarily *Jaumea carnosa*, *Distichlis spicata* and *Frankenia salina*; Goals Project 2000). Natural levees build up along the edge of channels as coarse sediments are deposited by over-

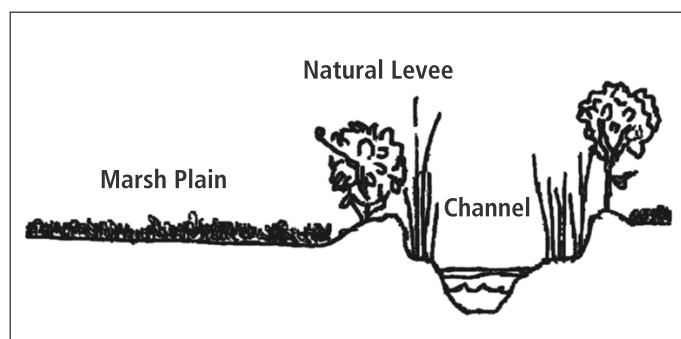


Figure 1 Sub-habitats of the China Camp tidal marsh. Channels are bordered by natural levees with vegetation dominated by *Grindelia stricta* and *Sarcocornia pacifica*. The marsh plain adjacent the natural levee is slightly lower in elevation and is dominated by *S. pacifica*.

banking tides (Collins and others 1986). These levees are dominated by gumplant (*Grindelia stricta*), a short woody shrub. Levees are higher and wider, and *Grindelia* is more abundant, along high-order channels. Consequently, flood tides overflow low-order channels first, wetting the marsh plain near small channels more frequently and for longer periods than near large channels (Collins and others 1986).

Tidal Marsh Invertebrate Study

Invertebrates at China Camp marsh were collected from the channels, marsh plain, and natural levees as part of a food web study reported in greater detail by Grenier (2004). Invertebrates were collected to investigate which taxa were available as potential prey items for the San Pablo Song Sparrow (*Melospiza melodia samuelis*), a tidal marsh obligate, and other marsh vertebrates; and to determine how macroinvertebrates were distributed across the tidal gradient. Because no single method was sufficient to account for all invertebrate locomotion types and habitat preferences, multiple trapping methods were used. We conducted the study in a 3.3-ha plot within the centennial portion of the marsh, which is characterized by the simple, less sinuous channels typical of a rapidly formed marsh.

Sample Collection

We conducted sampling at low tide from May to July, 2001, which consisted of five capture methods: pit trap, sweep net, snail count, mud core, and sticky trap. We expended equal sampling effort along high-order and low-order channels. For each channel type, we stratified random sampling locations across three sub-habitats: within the channel, on the natural levee adjacent to the channel, and on the nearby marsh plain. No samples were taken in standing water. We recorded the plant species within 10 cm of each trap.

We conducted pit trap, sweep net, and snail count methods with equal effort in each of the sub-habitats. Pit traps were cylindrical plastic containers, 11 cm in diameter and 11 cm deep, buried in the sediment, with the top of the trap level with the ground, and no space between the container and the surrounding

sediment. Traps were open for at least 3 hours. Sweep net sampling consisted of 10 strokes with a 15-inch diameter sailcloth net; each stroke sweeping new vegetation. Snail counts consisted of counting all snails within a 22-cm x 22-cm quadrat.

We used mud core and sticky trap methods only in the channels, because (1) on the natural levees and marsh plains, pilot mud core samples consisted of dry, hard-packed sediment devoid of macroinvertebrates, and (2) pilot sticky trap samples replicated results from pit traps and sweep nets in natural levee and marsh plain habitats. Cores were 7 cm in diameter and 10 cm deep, and we collected organisms from them with a 0.5-mm mesh sieve. For each core, we recorded the relative abundance of roots on a scale of 0 to 3, with 0 indicating no roots and 3 indicating very dense roots. Sticky traps were a thin layer of Tanglefoot adhesive spread onto sheets of plastic (20 x 10 cm) that were placed on the sediment. We set the traps for at least 3 hours and checked frequently as the tide rose; if the traps were in jeopardy of flooding, we moved them to adjacent higher ground.

Sample Processing

Common invertebrates were identified to the lowest feasible taxonomic level with assistance from experts (see "Acknowledgements"). We determined average biomass for large or common taxa (<10 individuals per trap method) by weighing between 9 and 115 individuals per taxon, after drying at 55 °C until we achieved a constant weight. Snails were weighed without their shells. Because planthoppers (*Prokelisia marginata*) had such low mass, they were weighed in groups of 10 individuals at a time. We estimated masses for araneid spiders from lycosid spiders of similar size.

Data Analysis

We calculated catch per unit effort (CPUE) as the number of invertebrates of the same taxon caught per trap hour for pit traps and sticky traps, and as invertebrates per trapping event for all other capture methods. We examined differences in CPUE among sub-habitats using non-parametric ANOVA

(Kruskal–Wallis), which was also used to determine the relationship between CPUE and presence of roots, and CPUE and plant community composition. The relationship between CPUE and plant community composition was examined separately for each of the sub-habitats along the tidal gradient, because vegetation varied dramatically among sub-habitats. We tested plant-invertebrate relationships in the channel sub-habitat separately for large and small channels, because *Spartina foliosa* was found only in large channels.

Rocky Intertidal Invertebrates

During low tide on November 15, 2005, A. Cohen collected by hand and identified organisms on and around a low intertidal rocky outcrop and boulders near Rat Rock at China Camp State Park with a 10-power hand lens. The sampling was conducted as a component of ongoing surveys for the State of California’s Marine Invasive Species Program, with the goal of characterizing and monitoring the

distribution and abundance of exotic species in California’s coastal waters. Some of these samples, along with quantitative samples from nearby quadrats, were preserved for identification in the laboratory. We report here only on the initial field identifications.

RESULTS

Tidal Marsh Invertebrates

A total of 4,597 invertebrates was captured in 787 trapping events, representing seven taxonomic classes and at least 14 orders (Table 1). Six of the seven taxa identified to species (85.7%) were exotic (most of the arthropods were not identified to species). As expected, community composition of invertebrates differed notably by capture method, and one taxon dominated captures for most trapping methods. The amphipod *Traskorchestia traskiana* comprised 77% of the individuals caught by pit trap; the planthopper *Prokelisia marginata* comprised 64% of the individu-

Table 1 Number of invertebrates collected in the tidal marsh study by each capture method

Phylum	Class	Order	Family	Genus and Species	Common Name	Mud Core	Pit Trap	Sweep Net	Snail Count	Sticky Trap	
Annelida	Oligochaeta				Oligochaete worm	655	–	–	–	–	
	Polychaeta	Phyllodocida	Nereididae	<i>Alitta succinea</i> ^a	Polychaete worm	2	–	–	–	–	
		Other Polychaetes				Polychaete worm	131	–	–	–	–
Mollusca	Gastropoda	Basommatophora	Ellobiidae	<i>Myosotella myosotis</i> ^a	European marsh snail	1	3	22	866	2	
	Bivalvia	Veneroida	Tellinidae	<i>Macoma petalum</i> ^a		39	–	–	–	–	
Arthropoda	Crustacea	Amphipoda	Corophiidae	<i>Corophium alienense</i> ^a	Aquatic amphipod	195	3	–	–	–	
			Corophiidae	<i>Grandidierella japonica</i> ^a	Aquatic amphipod	98	–	–	–	–	
			Talitridae	<i>Traskorchestia traskiana</i>		–	602	4	–	4	
Arachnida	Araneae		Araneidae		Orb spider	–	4	44	–	–	
			Lycosidae		Wolf spider	–	26	2	–	–	
			Other Arachnida			Spider	2	7	38	–	1
Insecta	Coleoptera		Heteroceridae		Mud-living beetle	41	3	–	–	–	
			Curculionidae		Weevil	–	–	7	–	–	
			Carabidae	<i>Bembidion sp.</i>	Ground beetle	–	65	1	–	–	
					Spotted cucumber beetle	–	–	13	–	–	
			Other Coleoptera			Beetle adult	1	5	17	–	–
						Beetle larvae	14	52	–	–	–
			Diptera	Dolichopodidae		Long-legged fly	–	–	116	–	544
				Ulidiidae		Picture-winged fly	–	–	25	–	–
				Other Diptera				–	–	86	–
			Homoptera	Delphacidae	<i>Prokelisia marginata</i> ^a	Planthopper	–	–	703	–	1
Other Homoptera				Leafhopper	–	1	11	–	–		
Hemiptera					–	–	9	–	–		
Lepidoptera				Moth	–	–	4	–	–		
Other Insecta				Insect	1	1	6	–	–		

^a Indicates an exotic species.

als caught by sweep net. Oligochaete and polychaete worms made up 67% of mud core captures and dolichopodid flies made up 83% of individuals caught by sticky trap.

Pit trap biomass was dominated by one species across all sub-habitats, while sweep net biomass was dominated by different taxa in each sub-habitat (Figures 2 and 3). Mass (± 1 SD) of common taxa ranged from 0.26 (± 0.07) mg/individual for *Prokelisia marginata* to 8.65 (± 6.70) mg per individual for *Traskorchestia traskiana* (Table 2). The mean biomass per quadrat for the snail *Myosotella myosotis* was 15.7 mg on the marsh plain, and 25.5 mg on the natural levee, with no snails observed in the channels.

The abundance of common taxa differed by sub-habitat (Table 3). Channel size also influenced inver-

tebrate community composition, with several common taxa being more abundant near either low-order or high-order channels (Table 4). The burrowing amphipod *Corophium alienense* was the only species whose abundance was related to the density of plant roots, being more abundant in areas with lower root density (Kruskal-Wallis; $H = 14.57$, $n = 72$, $p = 0.02$).

The abundance of *Corophium* amphipods, *Macoma petalum* clams, and *Prokelisia* planthoppers was related to plant distribution. The burrowing amphipods and clams were more likely to be found in large channels where *Spartina foliosa* was not present (*C. alienense*: Mann-Whitney $U = 223.5$, $n = 36$, $p < 0.001$; *M. petalum*: Mann-Whitney $U = 223$, $n = 36$, $p < 0.001$), while planthoppers were more likely to be found in channels where *S. foliosa* was present (Mann-Whitney $U = 94$, $n = 36$, $p < 0.001$).

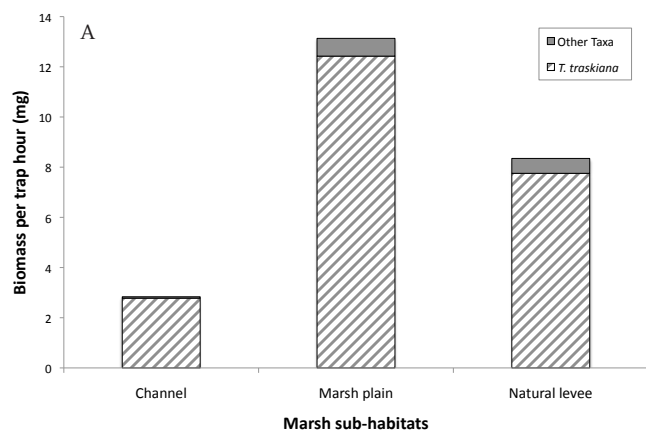


Figure 2 Mean biomass per trap hour for pit traps by (A) marsh sub-habitat and (B) channel order

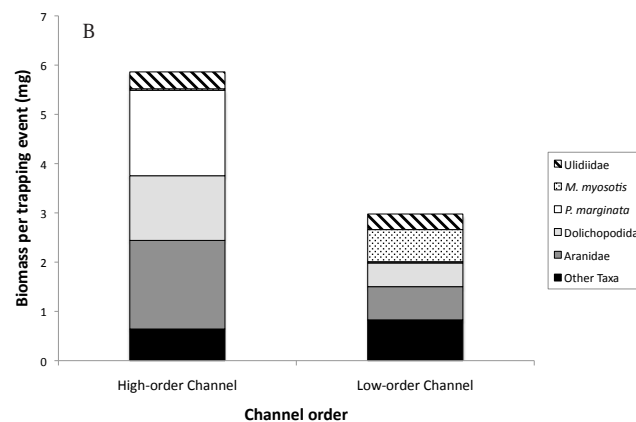
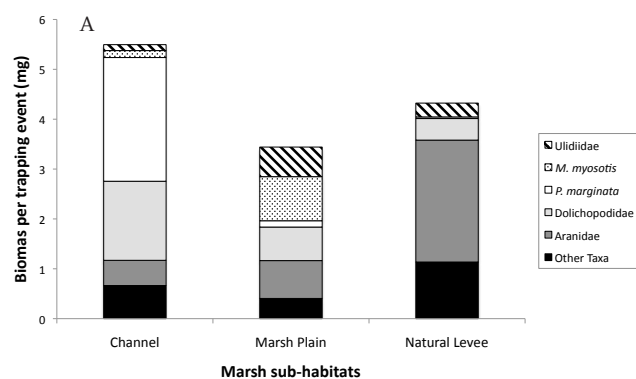


Figure 3 Mean biomass per trapping event from sweep netting by (A) marsh sub-habitat and (B) channel order

Table 2 Individual mass (+/- 1 SD) for common taxa caught by sweep net and pit trap

Taxon (Order)	n (Weighted)	Mean biomass	(mg)
<i>T. traskiana</i> (Amphipoda)	99	8.65	±6.70
Chrysomelidae (Coleoptera)	26	7.15	±2.06
Lycosidae (Araneae)	26	6.07	±4.20
<i>M. myosotis</i> (Basommatophora)	60	3.35	±1.44
Ulidiidae (Diptera)	25	2.85	±1.16
Curculionidae (Coleoptera)	9	2.49	±0.28
Heteroceridae (Coleoptera)	16	1.96	±0.75
Dolichopodidae (Diptera)	113	1.73	±0.61
<i>Bembidion</i> sp. (Coleoptera)	42	1.68	±0.42
Corophiidae (Amphipoda)	11	0.45	±0.25
<i>P. marginata</i> (Homoptera)	40	0.26	±0.07

Rocky Intertidal Invertebrates

Invertebrates from nine classes and at least 16 orders were observed in the epifaunal survey (Table 5). Of the 28 taxa identified to genus or species, 22 (78.6%) are known to be exotic.

Additional Records

In addition to the taxa above, several invertebrates that had been seen but not captured during the quantitative tidal marsh study were hand-collected for identification. These taxa included the European green crab (*Carcinus maenas*), the yellow shore crab (*Hemigrapsus oregonensis*), two species of shrimp (*Palaemon macrodactylus* and *Crangon franciscorum*), the Eastern mud snail (*Ilyanassa obsoleta*), stinkbugs in the family Pentatomidae, and mites in the family Tetranychidae.

Other invertebrates we commonly observed at China Camp include the isopod *Sphaeroma quoiana*, whose pencil-diameter burrows riddle the channel banks and may contribute to their slumping and erosion, and the small, commensal isopod *Iais californica*, which lives on *Sphaeroma*'s ventral surface. Both of these species are from Australia. The ribbed horse mussel *Geukensia demissa*, an import from the Atlantic, lives in the lower channels and at the marsh edge, attached by byssal threads to subsurface *Spartina* stems or other objects.

DISCUSSION

The data presented in this paper demonstrate the unequal distribution of invertebrates across intertidal sub-habitats at China Camp State Park in San Francisco Bay. Relatively few species made up the majority of the invertebrate biomass in the tidal marsh, and the majority of both the rocky intertidal invertebrates and the tidal marsh invertebrates identified to species level were exotic. The strong association of certain invertebrate groups to specific sub-habitats suggests that predators with different feeding specializations may forage primarily in one part of the marsh or another.

Invertebrate Diversity

Two general groups of intertidal invertebrates were collected at China Camp: those that belong to taxonomic groups that are primarily land-dwelling (terrestrial-derived invertebrates), and those belonging to taxonomic groups that are mostly marine-dwelling (marine-derived invertebrates). While only marine-derived invertebrates were found in the rocky intertidal habitat, both marine- and terrestrial-derived invertebrates were found in the tidal marsh. The terrestrial-derived invertebrates included spiders, insects, oligochaetes, and the pulmonate snail *Myosotella myosotis*; the marine-derived invertebrates included sponges, cnidarians, polychaete worms, opistho-

Table 3 Catch per unit effort (CPUE) by sub-habitat for pit trap and sweep net samples. *P*-values are from Kruskal–Wallis tests (alpha = 0.05). Bold text indicates the zone with the highest CPUE.

Capture method	Taxon (Order)	Total count (No. of trap hours to trapping events)			<i>p</i>
		Channel	Marsh plain	Natural levee	
Pit Trap	Lycosidae (Araneae)	0 (234)	13 (230)	13 (236)	0.001
	<i>Bembidion</i> sp. (Coleoptera)	0 (234)	44 (230)	21 (236)	< 0.001
	<i>T. traskiana</i> (Amphipoda)	69 (234)	318 (230)	215 (236)	< 0.001
	Heteroceridae larvae (Coleoptera)	52 (234)	0 (230)	0 (236)	< 0.001
Sweep Net	Chrysomelidae (Coleoptera)	1 (72)	3 (72)	9 (72)	0.014
	Aranidae (Araneae)	3 (72)	9 (72)	32 (72)	< 0.001
	Ulidiidae (Diptera)	2 (72)	15 (72)	7 (72)	0.002
	<i>P. marginata</i> (Homoptera)	689 (72)	5 (72)	9 (72)	< 0.001
	Dolichopodidae (Diptera)	70 (72)	28 (72)	18 (72)	0.016
Snail Count	<i>M. myosotis</i> (Basommatophora)	0 (72)	339 (72)	547 (72)	< 0.001

Table 4 Comparison of catch per unit effort (CPUE) of common taxa by channel order, summed across all sub-habitats. *P*-values are from Kruskal–Wallis tests (alpha = 0.05). Bold text indicates the channel size with the greatest CPUE, where results are significant.

Capture method	Taxon (Order)	Total Count (No. of Trap Hours to Trapping Events)		<i>p</i>
		Low-order Channel	High-order Channel	
Pit Trap	<i>T. traskiana</i> (Amphipoda)	418 (349)	187 (350)	< 0.001
	<i>Bembidion</i> sp. (Coleoptera)	37 (349)	28 (350)	0.673
	Lycosidae (Araneae)	12 (349)	14 (350)	0.91
Sweep Net	<i>M. myosotis</i> (Basommatophora)	21 (108)	1 (108)	0.01
	Aranidae (Araneae)	12 (108)	32 (108)	0.014
	<i>P. marginata</i> (Homoptera)	11 (108)	692 (108)	< 0.001
	Curculionidae (Coleoptera)	0 (108)	7 (108)	0.007
	Dolichopodidae (Diptera)	30 (108)	86 (108)	0.013
	Chrysomelidae (Coleoptera)	9 (108)	4 (108)	0.154
	Ulidiidae (Diptera)	12 (108)	13 (108)	0.827
Mud Core	Oligochaeta	108 (36)	19 (36)	0.001
	Polychaeta	424 (36)	231 (36)	0.011
	Heteroceridae (Coleoptera)	3 (36)	38 (36)	0.035
	<i>C. alienense</i> (Amphipoda)	26 (36)	72 (36)	0.801
	<i>M. petalum</i> (Veneroida)	13 (26)	26 (36)	0.822
	<i>G. japonica</i> (Amphipoda)	80 (36)	115 (36)	0.868
Sticky Trap	Dolichopodidae (Diptera)	278 (36)	266 (36)	0.83
Snail Count	<i>M. myosotis</i> (Basommatophora)	641 (108)	245 (108)	< 0.001

Table 5 Marine invertebrates collected on intertidal rocks at China Camp in November 2005 and identified in the field

Phylum	Class	Order	Family	Species	Common name	
Porifera	Desmospongiae	Halichondrida	Halichondriidae	<i>Halichondria</i> sp. ^{1,a}	sponge	
		Haplosclerida	Chalinidae	<i>Haliclona</i> sp. ^{1,a}	sponge	
		Other Desmospongiae			sponge	
Cnidaria	Hydrozoa				hydroid	
	Anthozoa	Actiniaria	Diadumenidae	<i>Diadumene</i> sp. ^{2,a}	anemone	
Diadumenidae			<i>Diadumene lineata</i> ^a	orange-lined anemone		
Annelida	Polychaeta	Phyllodocida	Nereididae	<i>Alitta succinea</i> ^a	pile worm	
			Polynoidae	<i>Harmothoe praeclara</i> ^{3,a}	scale worm	
		Other Polychaeta			polychaete worm	
Mollusca	Gastropoda	Cephalaspidea	Philinidae	<i>Philine</i> sp. ^{4,a}	tortellini snail	
		Other Opisthobranchia		unidentified opisthobranch	sea slug	
	Bivalvia	Ostreoida	Ostreidae	<i>Ostrea lurida</i>	Olympia oyster	
			Mytiloida	Mytilidae	<i>Geukensia demissa</i> ^a	ribbed horse mussel
		Mytiloida	Mytilidae	<i>Musculista senhousia</i> ^a	green bag mussel	
			Mytilidae	<i>Mytilus galloprovincialis</i> ^a / <i>trossulus</i> ⁵	bay mussel	
			Myoida	Corbulidae	<i>Corbula amurensis</i> ^a	overbite clam
		Veneroida	Myidae	<i>Mya arenaria</i> ^a	Atlantic softshell clam	
			Tellenidae	<i>Venerupis philippinarum</i> ^a	Japanese littleneck clam	
			Other Bivalvia		unidentified clam	clam
Arthropoda	Crustacea	Balanomorpha	Chthamalidae	<i>Chthamalus</i> sp. ⁶	barnacle	
			Balanidae	<i>Balanus glandula</i>	barnacle	
			Balanidae	<i>Balanus</i> sp.	barnacle	
		Isopoda	Sphaeromatidae	<i>Gnorimosphaeroma oregonensis</i>	isopod	
		Amphipoda	Gammaridae			amphipod
			Corophiidae or Aoridae		unidentified Corophiid or <i>Grandidierella japonica</i> ^{7,a}	amphipod
		Decapoda	Portunidae	<i>Carcinus maenas</i> ^a	green shore crab	
			Varunidae	<i>Hemigrapsus oregonensis</i>	yellow mud crab	
Bryozoa	Gymnolaemata	Ctenostomata	Nolellidae	<i>Anguinella palmata</i> ^a	bryozoan	
			Vesiculariidae	<i>Bowerbankia</i> sp. ^a	bryozoan	
		Cheilostomata	Membraniporidae	<i>Conopeum</i> sp. ^a	bryozoan	
			Cryptosulidae	<i>Cryptosula pallasiana</i> ^a	bryozoan	
			Schizoporellidae	<i>Schizoporella</i> sp. ^{8, a}	bryozoan	
Chordata	Ascidiacea	Pleurogona	Styelidae	<i>Botryllus schlosseri</i> ^a	seasquirt	
			Molgulidae	<i>Molgula manhattensis</i> ^a	seasquirt	

a exotic species

Taxonomic notes:

- 1 The sponges in San Francisco Bay in the genera *Halichondria* and *Haliclona* have been identified in many texts as the Atlantic species *Halichondria bowerbanki* and *Haliclona loosanoffi*, respectively, but some taxonomists have recently questioned these identifications.
- 2 Of the four exotic *Diadumene* species in San Francisco Bay, this is the orange- or salmon-colored one that has sometimes been listed as *D. cincta*, but according to Dr. Daphne Fautin of the University of Kansas is not that species.
- 3 Based on its abundance in other studies in San Francisco Bay, this is probably the Australian species *Harmothoe praeclara* and not the native (and primarily outer coast) species *H. imbricata*, but no morphological characters were examined that would distinguish the two.
- 4 At least four exotic *Philine* species have been reported in Central California: *P. auriformis* from New Zealand and *P. orientalis* from the Philippines and Hong Kong in San Francisco Bay and other waters; and *P. aperta* from South Africa and *P. japonica* from Japan in other Central California bays. This seems an unlikely convergence of multiple species in this one genus from distant corners of the world, and we consider the taxonomy of exotic *Philine* species on the west coast of North America to be yet unresolved.
- 5 The native species *Mytilus trossulus*, the Mediterranean species *M. galloprovincialis*, and hybrids of the two have all been reported in San Francisco Bay. Characters were not examined to distinguish among these. Based on the frequency of the exotic or hybrid forms in San Francisco Bay, these specimens were counted as exotic (see Results).
- 6 The native species *Chthamalus fissus* and *C. dalli* are both present in Central California; characters were not examined to distinguish between them.
- 7 The Corophiidae reported in San Francisco Bay west of the Carquinez Strait are *Corophium alienense*, *C. heteroceratum*, *Monocorophium acherusicum*, *M. insidiosum*, and *M. uenoi*—all of them exotic. The native Corophiidae reported in the San Francisco Bay watershed, *Americorophium spinicorne* and *A. stimpsoni*, are only found east of Carquinez Strait, usually in fresh water. The native *A. brevis*, once present in San Francisco Bay, is believed to be extinct south of Humboldt Bay. The Aoridae species *Grandidierella japonica*, from Japan, resembles the Corophiidae and is common in San Francisco Bay. Morphological characters were not examined to distinguish among these various species.
- 8 The *Schizoporella* species in San Francisco Bay was formerly identified in many texts as the Atlantic species *S. unicornis*, but may comprise more than one species. We consider the taxonomy of *Schizoporella* in San Francisco Bay to be unresolved.

branch snails, bivalves, crustaceans, bryozoans, and sea squirts (Tables 1 and 5). As is typical of San Francisco Bay, many of the marine-derived invertebrate species at China Camp have been introduced from other parts of the world, including the coasts of the North Atlantic Ocean, Pacific Asia, and Australia (Cohen and Carlton 1995).

Invertebrate Distribution

Tidal Marsh

Most taxa in this study showed a preference for a particular sub-habitat or channel order. In addition, one taxon dominated the catch for most trapping methods, reflecting whether the capture method was most likely to catch ground-crawling, flying, canopy-dwelling, or benthic invertebrates. These results suggest clear niche partitioning. Competition, predation, food resources, and limits of physiological tolerance likely all play a role in maintaining this uneven distribution of invertebrates.

Each tidal marsh sub-habitat differs in the frequency and duration of tidal inundation, and consequently varies in sediment moisture, oxygen, and salinity; sediment particle size and organic content; and vegetation (Levin and Talley 2000). Levin and Talley (2000) suggest these interrelated factors influence invertebrate distribution in tidal marshes on different spatial and temporal scales. Parameters such as marsh age, salinity, and elevation act over large time-scales to determine which species are present in a marsh; factors such as plant biomass and oxygen concentration affect invertebrates over shorter time-scales and smaller spatial scales, determining where in the marsh certain species will be found. The results from this study are consistent with previous studies showing that the community composition of invertebrates differs by elevation and vegetation zone (reviewed in Levin and Talley 2000).

The channels, being most frequently inundated, support invertebrates that prefer moist environments. Our study found that benthic epifauna were more abundant in the channel than in the higher-elevation sub-habitats. Similarly, studies of southern California

tidal marshes have found benthic infauna to be most abundant at lower elevations (Levin and Talley 2000). Risk of desiccation increases at higher elevation for these invertebrates (Kneib 1984).

The channels also supported the greatest number of insects at China Camp, particularly homopterans and dipterans. Davis and Gray (1966) found that many marsh insects respond to tidal flooding and drying with behavioral rather than physiological adaptations. Even species able to withstand long periods of submersion in laboratory experiments preferred to escape the rising tide by flying, swimming, or running along the water surface whenever possible. The ability of flying and hopping insects, such as homopterans and dipterans, to quickly escape rising tide waters and predators may explain their abundance in the channels, despite being taxa of terrestrial origin. Heterocerid beetles, found in the channels at China Camp, are one of the few families of Coleoptera with marine representatives (Doyen 1976). Wyatt and others (1986) suggest the shape of their burrows, which takes advantage of the surface tension effects of small air-filled openings, allows these beetles to protect their larvae from flooding in intertidal habitats.

Oligochaetes and polychaetes were most abundant in small channels; heterocerid beetles, Dolichopodid flies, and planthoppers were more frequently found in large channels. These invertebrates may be responding to physical differences among channel orders, or biotic differences in food resources, predation, or competition. The narrow width and overhanging vegetation of small channels may reduce drying, limit temperature increases, provide protection from terrestrial predators, or affect food availability by changing the composition of microalgae. Whitcraft and Levin (2007) found more insects and fewer amphipods and oligochaetes in unshaded than shaded plots in a southern California marsh, which they hypothesized was related to the presence of more cyanobacteria in unshaded plots and more diatoms in shaded plots. A similar mechanism could produce the trend seen at China Camp, if the smaller channels at China Camp were more shaded, which does seem to be the case, based on personal observations by the authors.

While the inner banks of the small channels at China Camp were unvegetated, scattered stands of Pacific cordgrass, *Spartina foliosa*, grew inside the banks of large channels. Planthoppers specialize on *Spartina* sap (Denno and others 1987), so it is not surprising that they showed a strong association with *Spartina*. *Corophium alienense* and *Macoma petalum* showed a significant negative association with *Spartina*. *Corophium* abundance was also negatively correlated with plant root density. Brusati and Grosholz (2006) found differences in the invertebrate community between the low-elevation *Spartina* marsh and the nearby mudflat at China Camp and other San Francisco Bay marshes, with greater infaunal density in the mudflat overall, although invertebrate density was higher in the *Spartina* zone at China Camp in one year of their study. Previous studies in California marshes have attributed decreases in abundance of some taxa near marsh vegetation to either a reduced availability of suspended particulates resulting from reduced flow speeds near vegetation (Levin and others 2006) or rhizomes interfering with burrowing (Brusati and Grosholz 2006). Flow of suspended particles would be important to both species that appeared to avoid *Spartina*, because *C. alienense* is a suspension feeder, and *M. petalum* is both a suspension feeder and a surface deposit-feeder.

In contrast to the channels, the marsh plain receives relatively fewer inundation events. Ground-crawling invertebrates such as the amphipod *Traskorchestia traskiana*, *Bembidion* beetles, and lycosid spiders were most abundant on the marsh plain. *T. traskiana* is one of the few salt marsh species able to feed on *Sarcocornia detritus* (Page 1997), which could explain its high population density and domination of invertebrate biomass on the marsh plain. *T. traskiana* was found in greater abundance in the marsh plain near smaller channels, suggesting that this species may prefer the more frequent wetting of this habitat, either to remain moist or to find richer bacterial and algal feeding deposits.

The natural levee, with the least frequent inundation of the three sub-habitats, had the greatest plant diversity of all the sub-habitats, and featured the only woody plant in the marsh: gumplant (*Grindelia stricta*). *Myosotella* snails were most abundant on

natural levees and were absent from the channels. These snails breathe through their lungs like their upland relatives (Cohen 2005); their low mobility likely puts them at risk of drowning in rising tidal waters, and may increase their risk of predation in open areas. The natural levee, with its relatively high elevation and abundant vegetative cover, may provide these snails with refuge from both tides and predators. However, these snails show a preference for the natural levee and marsh plain near low-order channels where inundation is more frequent than near high-order channels, suggesting they prefer a moist environment, despite their avoidance of channels. Araneid spiders were most abundant on the natural levee along large channels. The woody structure of the channel-side gumplant provides these spiders with support for their webs near channels where flying insects are most abundant.

Rocky Intertidal

A relatively diverse community of epifaunal invertebrates lives on low intertidal rocks near Rat Rock (Table 5), including a variety of attached filter-feeders (sponges, hydroids, anemones, oysters and mussels, barnacles, bryozoans, and sea squirts) and a few mobile worms and crustaceans. A handful of clam species were also found in the sediment at this site. While exotic species dominate this community, some natives are common. The dominant barnacles are the white acorn barnacle *Balanus glandula*, and a small, brown barnacle in the genus *Chthamalus*, both of which are native. The small native shore-crab *Hemigrapsus oregonensis* and the native isopod *Gnorimosphaeroma oregonense* are both common on or underneath rocks, and *Hemigrapsus* can also be abundant in the marsh channels. Native Olympia oysters, *Ostrea lurida*, were abundant on these rocks in the fall of 2005, but low salinities during the subsequent unusually wet winter and spring apparently eliminated the population.

Invertebrates as Food Resources

Salt marsh invertebrate communities are typically species poor but may be biomass rich (Kreeger and Newell 2000). Only a few species comprised the bulk

of macroinvertebrate biomass in the tidal marsh study (Figures 2A, 2B, 3A, 3B), although some other species not captured (e.g., *G. demissa* and *S. quoiana*) probably also accounted for significant invertebrate biomass in the marsh.

The strong association of certain invertebrate groups to specific sub-habitats suggests that predators with different feeding specializations may forage primarily in one part of the marsh or another. The distribution of invertebrates among the sub-habitats in our study suggests that the channels offer greater food resources for predators seeking aerial or benthic infaunal prey, while the marsh plain and natural levees offer the greatest resources for predators of surface-dwelling invertebrates. Studies of salt marsh Song Sparrow behavior and trophic ecology suggest that sparrows assimilate the majority of their carbon and nitrogen from invertebrates found on the marsh plain and natural levee (Grenier 2004). However, the dietary composition of most terrestrial marsh predators relative to the marsh sub-habitats has been little studied.

Marsh-feeding fish, on the other hand, have received slightly more attention. While high-marsh invertebrates were found to be an important source of food for fish such as longjaw mudsucker and killifish (*Fundulus parvipinnis*) in a southern California tidal marsh (West and Zedler 2000), stable isotope data suggest that longjaw mudsucker at China Camp were not assimilating invertebrates from the marsh plain as a significant proportion of their diet (Grenier 2004). Visintainer and others (2006) found that copepods, amphipods, mysids, and isopods made up a large portion of the diet of the most common fish species feeding in the China Camp marsh. They further found that stomach fullness and prey taxa richness in these fish varied with channel order in a species-specific way. This pattern supports the hypothesis from our tidal marsh study that unequal distribution of invertebrates by channel order may affect predator foraging patterns. Dean and others (2005) suggest that China Camp is a sink for mysid shrimp, with large mature mysids being heavily preyed upon by marsh fish and birds. Further study is needed to better understand how invertebrate distributions influence both predation patterns and trophic transfer between the China

Camp tidal marsh and adjacent upland and marine habitats.

Future Research

The results presented here contribute to understanding invertebrate diversity and distribution in the intertidal habitats of San Francisco Bay. However these short-term studies do not shed light on seasonal and inter-annual variation in invertebrate community structure. Future field studies on the diversity, distribution, and ecology of the intertidal invertebrate community of San Francisco Bay in various seasons and over longer time scales would improve our understanding of this fauna and its significance in the food web.

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Black Phoebe at China Camp during King Tide Photo by Marilyn Bagshaw



Raptor perching near the marsh. Photo by Tom Muehleisen



Snowy egrets, a type of Ardeid, hunting in the marsh at high tide at China Camp.

Predation along the road and with sea level rise

Excerpts from: Thorne KM, Spragens KA, Buffington KJ, Rosencranz JA, Takekawa J. Flooding regimes increase avian predation on wildlife prey in tidal marsh ecosystems. *Ecol Evol.* 2019;9(3):1083–1094. Published 2019 Jan 13. doi:10.1002/ece3.4792

Also look at the Figures 5 and 6 online. Sarah can request these figures if you want them for class use.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6374721/>

Excerpt of Introduction:

Habitat availability for terrestrial tidal marsh wildlife depends on the spatial and temporal dynamics of tidal inundation, which are controlled by marsh elevation, location within the tidal prism, complexity of internal channel networks, proximity to hard edges at levees, and marsh vegetation (Overton, Casazza, Takekawa, Strong, & Holyoak, [2014](#)). These characteristics influence the plant community and habitat structure (Pennings & Callaway, [1992](#); Silvestri, Defina, & Marani, [2005](#)), thereby shaping the availability of habitat resources to wildlife and exposure of many to predators. During high tides, terrestrial marsh wildlife may temporarily move to higher ground (e.g., levees or uplands) or take cover in taller vegetation, behaviors that likely increase their exposure to predators (Evens & Page, [1986](#)), although the specifics are not well understood (Bias & Morrison, [1999](#)). Coincidentally, increases in tidal flooding have been shown to facilitate foraging opportunities for snowy egrets (*Egretta thula*) and great egrets (*Casmerodius albus*), which feed mostly on fish and invertebrates in shallow water, often in tidal marshes (Erwin, [1985](#)).

Dense human populations around estuaries have caused drastic changes to ecosystem functions and have fragmented or altered wildlife habitats, often resulting in small habitat patches (Barbier et al., [2011](#); Cardinale et al., [2012](#)). Avian species communities and predator–prey interactions may be modified based upon adjacent land cover type, which can influence predator density and type, and decrease the stability of population dynamics (Kareiva, [1987](#); Rosenzweig &

MacArthur, [1963](#)). The synergistic effects of changes in land cover and flooding regimes on tidal marsh community interactions require further study to improve vulnerability estimates for species of concern. Our aim was to assess how inundation regime influences avian predator (raptors, ardeids, and scavengers) behavior.

The premise of our study was to use the natural seasonal variation in lunar tidal cycles to measure whether predator foraging behavior changed with water levels in tidal marshes. We assumed that elevated water levels represent an analog for future high water conditions with climate change. Normally, high water levels are often associated with low pressure storms and are difficult to predict, necessitating our use of the natural tidal cycle for this study. We hypothesized that avian predators would increase their presence and activity during high tides, when increased water levels across the tidal habitats increase vulnerability and availability of prey (Figure [\(Figure 1, 1\)](#), e.g., mice, voles, rails, aquatic species). In this paper, we present evidence that tidal inundation patterns and time of day or year affect the presence, abundance, and behavior of the avian predators within tidal marshes. We enumerate “predation pressure” defined as the combined probability of predator presence related to water level.

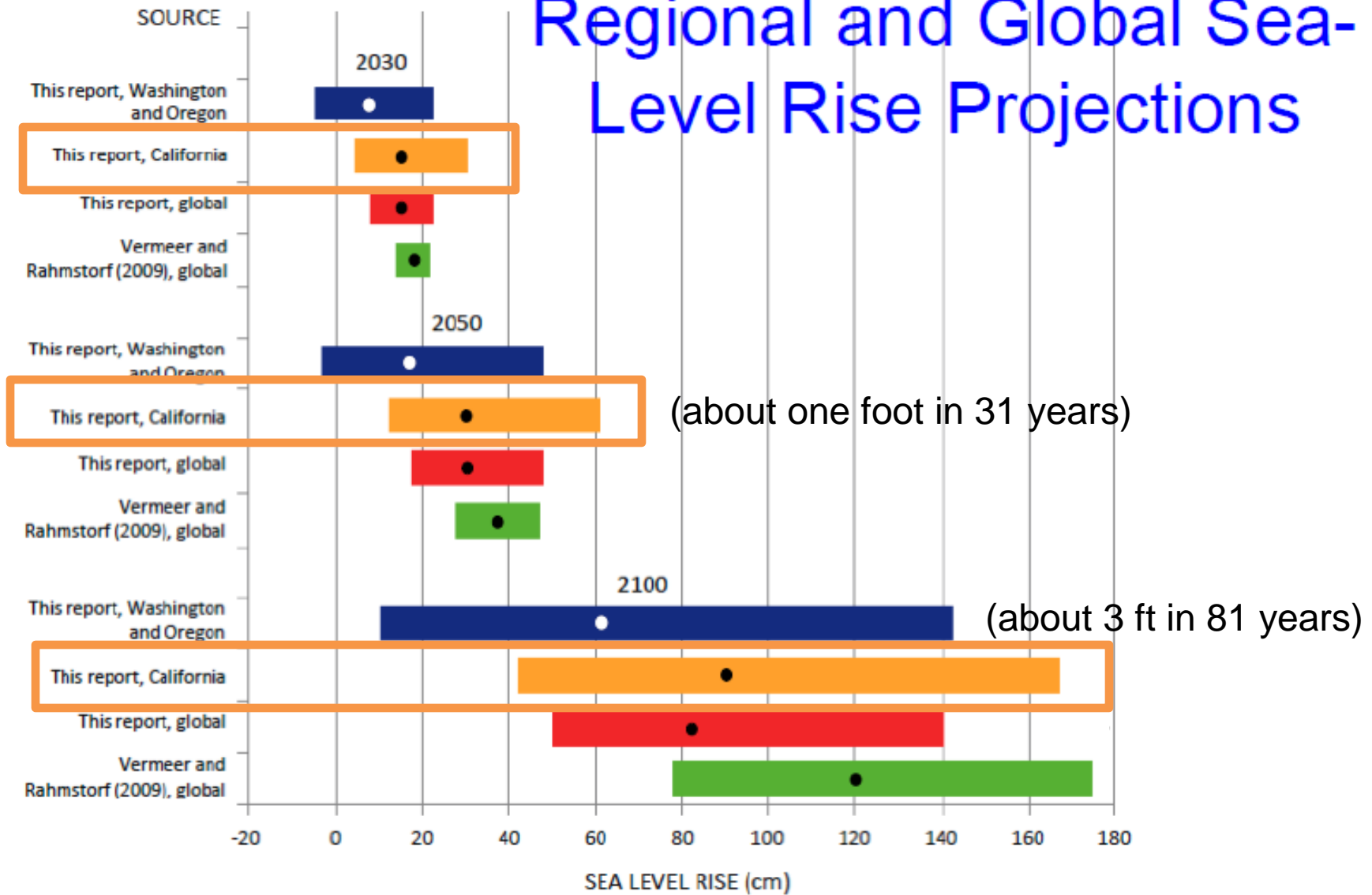
Excerpt from Discussion:

Each marsh site hosted a unique community of native avian predators, likely influenced by the nuances of site characteristics and position within the surrounding landscape. Consequently, the observed predator–prey interactions differed between sites, illustrating the complexity of studying community composition and interactions. For example, at Tolay Slough, the re-occurring presence of red-tailed hawks, a nontraditional marsh predator (Johnston, [1956](#); Page & Whitacre, [1975](#)), was likely a result of the adjacent agricultural fields and nearby power line poles that can serve as roosts (Knight & Kawashima, [1993](#)). The large number of scavengers such as gulls observed at Arrowhead marsh are attributable to nearby urban development (e.g., parking lots, dumps, housing; Vermeer, Power, & Smith, [1988](#)), scavengers have been shown to opportunistically forage on the eggs and nestlings of protected species (e.g., Ridgeways rail; USFWS, [2013](#)); however, none were observed foraging in the marsh during our study. The overall high diversity of raptors observed at China Camp may be related to the adjacent oak woodland habitats (Takekawa et al., [2011](#)).

Human development and restoration actions may enhance the habitat availability and foraging access of predator species. For example, features such as levees have led to colonization of plant species favorable for roosting (e.g., coyote brush, eucalyptus groves), and within close proximity to abundant prey resources in flooded marshes (Tsao, Takekawa, Woo, Yee, & Evens, [2009](#)). Additionally, artificial structures (e.g., powerlines, old abandoned structures, fence lines) create roosting habitats for several of the species observed in this study. A study of white-tailed kites showed that individuals achieved the highest foraging efficiency using the hover and strike method of hunting as compared to roosting; however, they were observed roosting on powerlines, polyvinyl chloride (PVC)-markers, old wooden channel marker signs, and old fence posts, which were used as perches preceding a strike attempt within the marsh (Tarboton, [1978](#)). Thus, adjacent land cover and human modifications influence the predator–prey response to increased flooding levels.

Sea Level Rise

Regional and Global Sea-Level Rise Projections

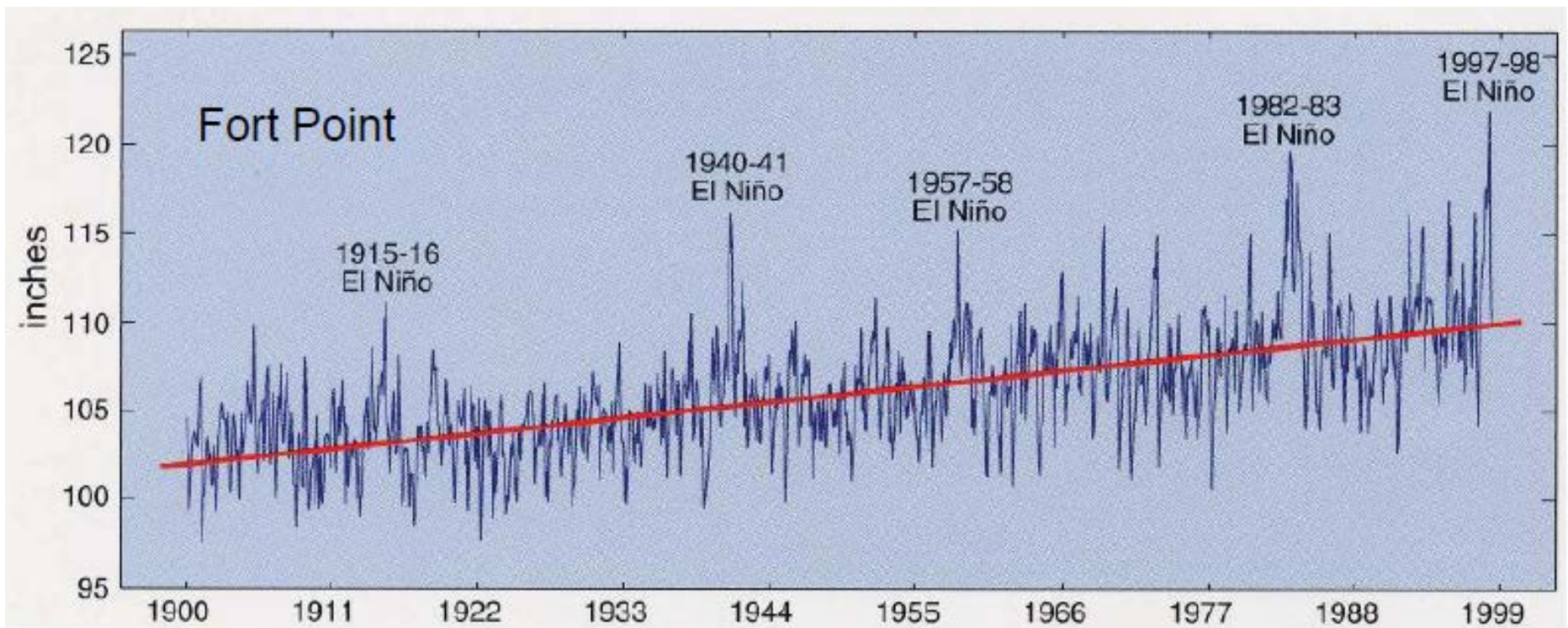


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Advisers to the Nation on Science, Engineering, and Medicine

Chart copied from National Academy of Sciences presentation about Sea Level Rise Report; no change to content http://www.nap.edu/catalog.php?record_id=13389

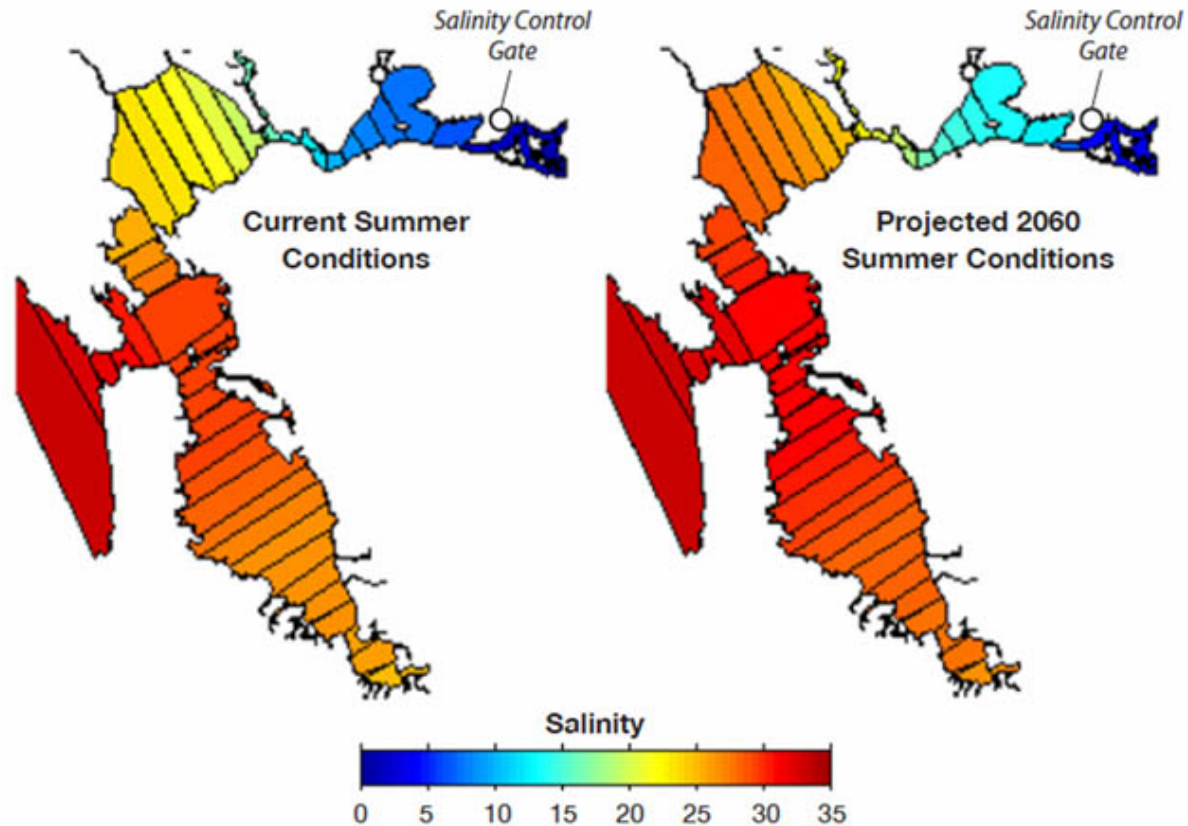
Sea level records from tide gate at Golden Gate shows about 2mm/yr rise



Graph copied directly from National Academy of Sciences presentation about Sea Level Rise Report: http://www.nap.edu/catalog.php?record_id=13389

Sea level rise = water level increase + salinity shift

Salinity Change in the Bay and Suisun Marsh

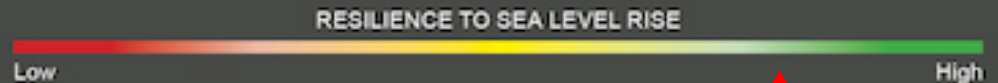


Source: Knowles

Wet-Year summer salinity field shifts upstream
10-15km due to reduced spring/summer
snowmelt runoff

How will tidal marshes fare in the face of sea level rise? A look at 16 marshes in the National Estuarine Research Reserve System indicates they face challenges.

	US State	Marsh Name and National Estuarine Research Reserve	CATEGORIES OF MARSH RESILIENCE TO SEA LEVEL RISE					Overall Resilience
			Marsh Elevation	Elevation Change	Sediment Supply	Tidal Range	Sea Level Rise	
EAST COAST	NH	Great Bay Discovery Center, Great Bay	Green	Green	Yellow	Green	Green	Green
	MA	Sage Lot Pond, Waquoit Bay	Yellow	Red	Red	Red	Orange	Orange
	RI	Nag West, Narragansett Bay	Yellow	Red	Red	Red	Orange	Orange
	NY	Outer Tivoli North, Hudson River	Yellow	Green	Green	Yellow	Red	Green
	DE	St. Jones Reserve, Delaware	Green	Green	Green	Yellow	Red	Green
	MD	Jug Bay, Chesapeake Bay	Green	Orange	Green	Orange	Red	Yellow
	VA	Goodwin Island Reserve, Chesapeake Bay	Green	Green	Yellow	Orange	Red	Green
	NC	Masonboro Island, North Carolina	Yellow	Red	Orange	Orange	Yellow	Yellow
	SC	Crabhaul Creek, North Inlet-Winyah Bay	Yellow	Orange	Orange	Yellow	Yellow	Yellow
	SC	Big Bay Creek, ACE Basin	Yellow	Red	Yellow	Green	Yellow	Yellow
	MS	Grand Bay, Grand Bay	Yellow	Green	Red	Red	Yellow	Yellow
WEST COAST	WA	Sullivan Minor, Padilla Bay	Orange	White	Orange	Green	Green	Green
	OR	Hidden Creek, South Slough	Green	Red	Red	Green	Green	Green
	CA	China Camp State Park, San Francisco Bay	Green	Yellow	Yellow	Yellow	Green	Green
	CA	Upper Slough Marshes, Elkhorn Slough	Yellow	Red	Yellow	Yellow	Green	Yellow
	CA	Oneonta Slough, Tijuana River	Yellow	Green	Orange	Orange	Yellow	Green



NERRA

**National Estuarine
Research Reserve
ASSOCIATION**

Research Citation: Raposa et al 2016
Summary at: www.nerra.org/marsh



Figure 5. Habitat distributions at China Camp under different model scenarios.

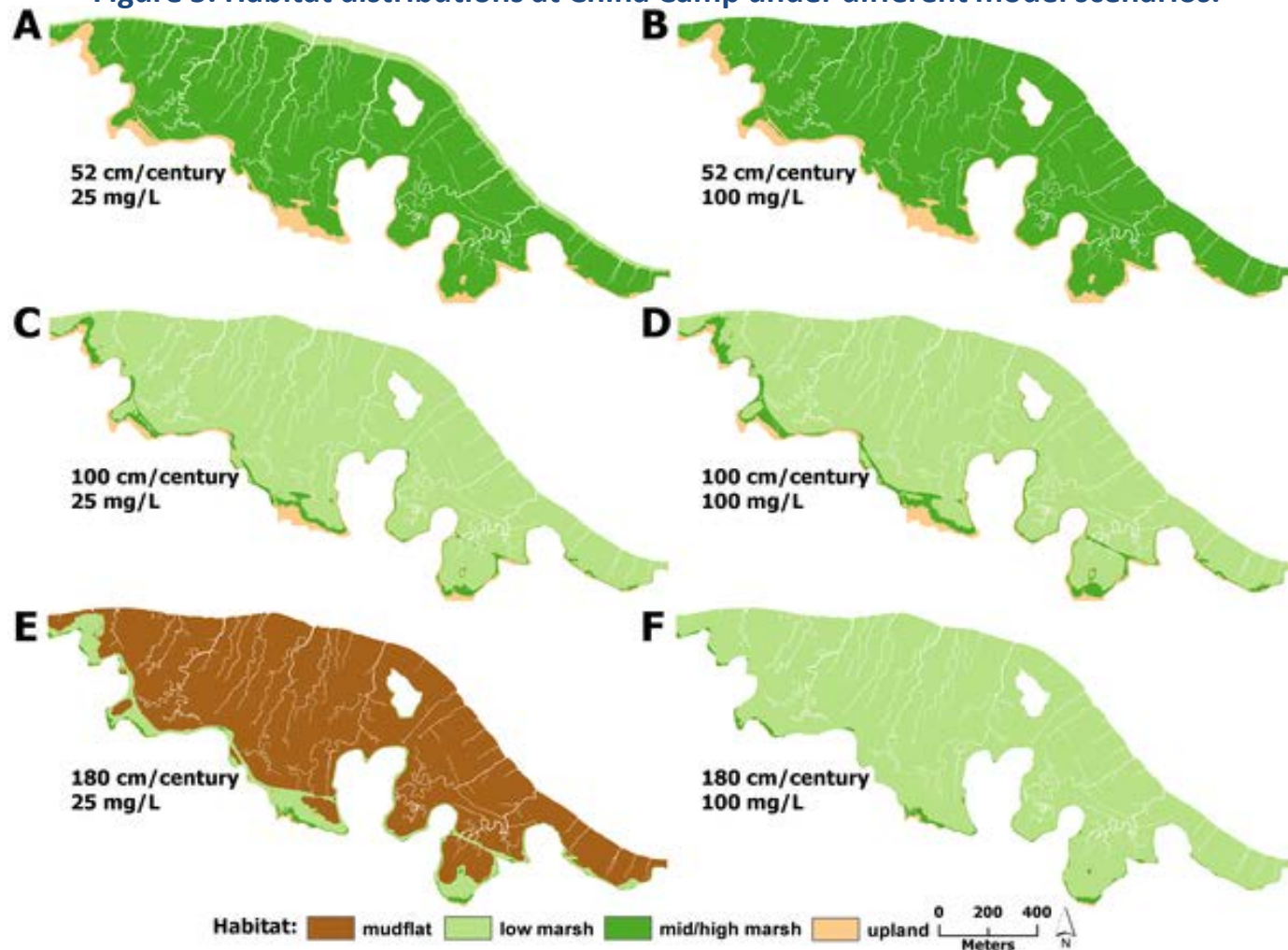


Figure 5: Distribution of modeled marsh habitat types in 2110 at China Camp with 52/century, 100 cm/century, and 180 cm/century sea-level rise at A,C,E) low and B,D,F) high suspended sediment concentrations, respectively.

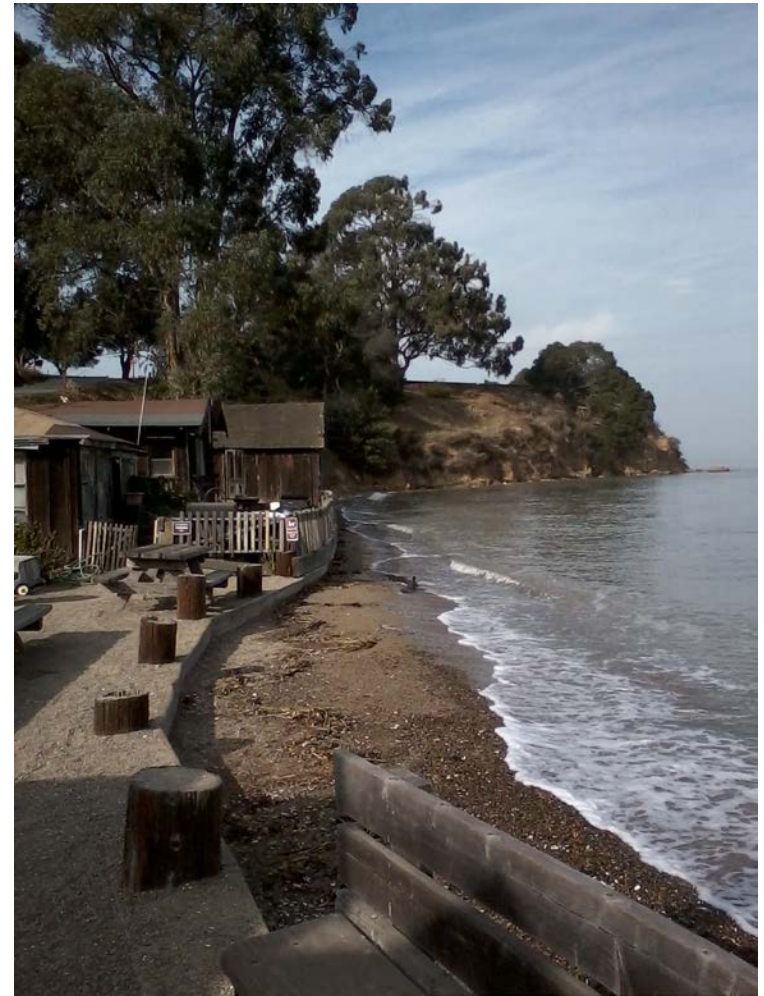
Cultural Connections



Then and Now – China Camp Beach

Historic photo courtesy of CA State Parks

Modern photo by Wil Matthews



Then and Now – China Camp Beach

Historic photo courtesy of CA State Parks

Modern photo by Ed Lai



Then and Now – Boats
Historic photo courtesy of CA State Parks



Back Ranch Meadows during Low tide, Spring



Back Ranch Meadows during King Tide, Winter



Illustration by Michael Harney from *The Ohlone Way* by Malcolm Margolin

Also check out this article:


<https://baynature.org/article/revisionist-natural-history/>

Bay Nature magazine ◦ July-September 2018

Calling for a Revisionist Natural History

by *Priya Shukla*

June 26, 2018

SHARE THIS:   

As the daughter of Indian immigrants in the Bay Area, where multiculturalism was and continues to be ordinary, I always felt at home in my community. I spent weekends with my father chasing quails in Coyote Hills or exploring tide pools in Half Moon Bay, mostly oblivious to the people around us. But just as I began my career in environmental science, my father unexpectedly passed away. I turned to our traditional common ground,

Bringing Wetlands to Market Part 1 Introduction Available at coast.noaa.gov/estuaries Blue, Green, and Bountiful: Wetlands and carbon

Estuary Principle

Principle 5: Humans, even those living far from the coast, rely on goods and services supplied by estuaries.

Research Question

What ecological and other services do coastal wetlands provide?

Introduction

Two of the most important environmental issues of our time are how to slow the rate of climate change and how to protect and sustain the health of coastal ecosystems. Research indicates that coastal wetlands and seagrass beds are especially effective as carbon sinks, or places that take in carbon dioxide from the air and store it for long periods of time. In addition, coastal wetlands provide valuable services that benefit the ecosystem, the many people who live in the coastal zone, and even those who live far from coastal areas. In spite of their importance, many coastal wetlands are being impaired and lost due to the impacts of development and human activity. The Bringing Wetlands to Market project is studying the role of salt marshes in sequestering or storing greenhouse gases to help coastal managers quantify the economic value and benefits of protecting and restoring coastal wetlands. In this activity, students will examine the role of coastal wetlands in the carbon cycle and the ecosystem services they provide, and they will locate and identify wetlands in their own area.

Teacher Background

People everywhere are drawn to the coast for its beauty, productivity, and connections to the wider world. The coast provides abundant food, supports trade and transportation, nurtures our spirit and our need for outdoor recreation, and satisfies us with sweeping views of ocean, bay, estuary, and shore.

Wetlands and nearshore seagrass communities make up a large component of coastal ecosystems. Coastal wetlands provide important ecosystem services that are vital to the health and well being of our nation. They are vital to the health of commercially and recreationally important fisheries, providing food and essential habitat for fish and shellfish. Wetlands serve as nesting and foraging habitat for birds and other wildlife. As “living filters,” wetlands improve water quality by removing pollutants, nutrients, and sediments. Coastal waters generate a large proportion of the oxygen we breathe. Coastal wetlands also provide value to people by serving as buffers, protecting coastal areas from flooding, storm damage, and sea level rise, slowing the erosion of upland areas, protecting built infrastructure, and supporting tourism, hunting, and fishing. Seagrass communities absorb wave energy, stabilize sediments, and provide habitat for juvenile fish and shellfish.



Recent research indicates that coastal wetlands and seagrass communities may capture and store carbon, including carbon dioxide, at rates three to five times greater than forest systems do. They also have the capacity to store carbon over long time periods in their wet, poorly oxygenated soils. That means that they could be extremely valuable as carbon offset areas, which are quantified into shares and traded on global carbon markets.



Coastal wetlands may store carbon at rates three to five times greater than forest systems do

However, wetlands and seagrass beds are under pressure from development, oversupply of nutrients, and climate change, and these can reduce or wipe out a wetland's ability to store carbon. Salt marshes, seagrass beds, and mangrove communities could be of tremendous value to the economy of their coastal communities, but only if they are healthy and functioning well ecologically.

Climate Extension

Because of the connection between atmospheric carbon dioxide and climate change, climate change is an important part of the Bringing Wetlands to Market research project. In this activity, climate change concepts are included in exercises on the carbon cycle and carbon sequestration in wetlands.

Table of Contents

Teacher guide

Exercise 1 Carbon walk

Exercise 2 Carbon storage charts

Exercise 3 Wetland services and finding a local wetland

Teacher guide

Blue, Green, and Bountiful: Wetlands and carbon

Research Question

What ecological and other services do coastal wetlands provide?

Content Objectives

Students will be able to describe the major reservoirs of carbon in the carbon cycle

Students will be able to explain why wetlands and coastal ecosystems are especially useful for carbon sequestration

Students will be able to describe the ecological services provided by wetlands

Students will locate at least one wetland in their local area

Exercises

Summary of exercises: Students will make observations and review the carbon cycle, and learn about the capacity of wetlands to store carbon. They will learn about the important ecosystem services provided by coastal wetlands and seagrass systems. Students will use maps and online resources to locate and identify local wetlands.

Exercise 1: Students will investigate the carbon cycle and describe where carbon occurs

Exercise 2: Students will interpret data and charts to learn about carbon storage in wetlands.

Exercise 3: Students will learn about wetland ecosystem services and students will locate a wetland in their local area

If you only have time for one exercise We recommend "Wetlands and carbon storage"

Next Generation Science Frameworks

Life Science 2 Ecosystems: Interactions, Energy, and Dynamics

LS2.A: Interdependent Relationships In Ecosystems

LS2.B: Cycles Of Matter And Energy Transfer In Ecosystems

LS2.C: Ecosystem Dynamics, Functioning, And Resilience

LS4.D: Biodiversity And Humans

Earth Systems Science 2 Earth's Systems

ESS2.C: The Roles Of Water In Earth's Surface Processes

Earth Systems Science 3 Earth and Human Activity

ESS3.C: Human Impacts On Earth Systems

Assessment Questions

Assessment questions are included as part of student exercises.

Vocabulary

Carbon : An abundant, nonmetallic element that forms the backbone of organic molecules which are the building blocks for all life

Carbon cycle: The exchange of carbon between its main reservoirs—the atmosphere, terrestrial biosphere, ocean, rocks, and sediments. Each of these global reservoirs may be subdivided into smaller pools, ranging in size from individual communities or ecosystems to the total of all living organisms.

Carbon dioxide (CO₂): A colorless, odorless non-combustible gas that is present in the atmosphere. It is formed by the combustion of carbon and carbon compounds (such as fossil fuels and biomass), by respiration of animals and plants, by the gradual oxidation of organic matter in the soil, and by chemical processes that occur with certain geological components.

Carbon sequestration: The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon.

Carbon sink: A carbon reservoir that takes in and stores (sequesters) more carbon than it releases. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are both large carbon sinks.

Carbon source: A reservoir or component of the carbon cycle that releases more carbon than it absorbs. For example, emissions through the burning of fossil fuels are a source of carbon.

Climate change The long-term fluctuations in temperature, precipitation, wind, and other aspects of the Earth's climate. Scientists use the term both in reference to natural and anthropogenic (human - caused) change.

CO₂ equivalent: Wetland ecosystems store carbon, which if disturbed is returned to the atmosphere in the form of carbon dioxide (CO₂). The authors use CO₂ equivalent as units of measure here because of the emphasis on carbon in the climate system

Decomposition: The breakdown of matter by bacteria and fungi. It changes the chemical composition and physical appearance of the materials. It is the process by which carbon is released from decaying biological matter.

Ecosystem services – the beneficial outcomes for the natural environment or for people that result from ecosystem functions. Some examples of ecosystem services are support of the food chain, harvesting of animals or plants, clean water, or scenic views. In order for an ecosystem to provide services to humans, some interaction with humans is required.

Eelgrass: a marine plant with long ribbonlike leaves that grows in estuaries, brackish inlets, and coastal waters.

Flux: (from the root word *flow*) The rate of exchange of a substance between reservoirs or pools; for example, the rate of exchange of carbon moving from the atmosphere to the soil.

Greenhouse gases (GHG): Gases, such as water vapor, carbon dioxide, ozone, nitrous oxide, and methane, which allow solar radiation to pass through to the Earth, but block outgoing longwave radiation. Their action is compared to that of glass in a greenhouse.

Hectare: a measure of area equal to about 2.5 acres

Mangrove: any of several types of trees up to medium height that grow in saline coastal habitats in the tropics and subtropics.

Organic Matter/Organic Material: Anything living or derived from living things, including the dead remains; containing the long chains of carbon atoms characteristic of living things.

Photosynthesis: The process by which plants use the energy from sunlight to convert carbon dioxide into organic material, allowing them to grow.

Reservoirs: In the context of the carbon cycle, the interconnected areas within the Earth System which store and exchange carbon; includes the atmosphere, the oceans, the terrestrial biosphere, and fossil fuels.

Respiration: The process by which living organisms convert organic material into energy needed for living, by taking up molecular oxygen and releasing of carbon dioxide to the atmosphere.

Sink: In the context of the carbon cycle, any process by which carbon dioxide is removed from the atmosphere.

Soil carbon: A major component of the terrestrial part of the carbon cycle. The amount of carbon in the soil is related to the historical plant cover and productivity, which in turn is dependent in part upon climate variables.

Tonnes or metric tonnes: one metric tonne = 1,000 kilograms or about 1.1 US tons