Planning for Native Oyster Restoration in San Francisco Bay

Final Report to California Coastal Conservancy Agreement # 05-134

Edwin Grosholz[a], Jim Moore[b], Chela Zabin[a], Sarikka Attoe[a] and Rena Obernolte[a]

[a]Department of Environmental Science and Policy
University of California, Davis

[b]California Department of Fish and Game

Funding provided by the
California Ocean Protection Council

Introduction

Historically, native Olympia oysters *Ostreola conchaphila* (=*Ostrea lurida*) (Turgeon et al. 1998) were an abundant and ecologically important part of the fauna in West Coast estuaries and an important fishery (Barnett 1963, Baker 1995). Unfortunately, the popularity of the fishery that began in the 1850s resulted in the complete collapse of native oyster populations along the west coast of the U.S. during the late 19th and early 20th centuries (Barnett 1963, Baker 1995). Not only was the fishery lost, but so were the key ecosystem services provided by native oysters. Studies of oysters in estuaries in the eastern U.S. have shown that native oyster reefs (*Crassostrea virginica*) act as a "foundation species" by creating a refuge from predators and physical stress as well as a food source resulting in increased local diversity of fishes and invertebrates (Zimmerman 1989, Lenihan 1999, Micheli and Peterson 1999, Lenihan et al. 2001). In the largely unstructured, soft-sediment habitats of West Coast estuaries, aggregations of native oysters were likely to have provided similar functions and have been shown to increase invertebrate species richness (Kimbro and Grosholz 2006).

The introduction of exotic Pacific oysters (*Crassostrea gigas*) from Asia in the early 20th century provided a successful replacement for the native oyster fishery. However, Pacific oysters have not replaced the ecosystem services that were historically provided by native oysters in Central California. They do not reproduce and have not established naturalized populations in this region, although evidence indicates *C. gigas* have recently established reproductive populations in San Francisco Bay (Cohen, unpubl. data). The farming of Pacific oysters has meant that no harvest pressure has been placed on native oysters for nearly a century, but paradoxically, these populations have not recovered their historic abundances (Browning 1972, Baker 1995).

There is now increasing interest by coastal resource managers, environmental and community groups to restore native oyster populations in California to improve the health of estuarine ecosystems. In June 2005, the California Ocean Protection Council recognized native oyster restoration as a high priority. As a result, there is a critical need to understand what the status is of oyster populations in San Francisco Bay in order to lay the ground work for subsequent restoration programs. In particular, we need to understand what processes may be limiting the recovery of the native oyster to its formerly high abundances. Invasive space competitors and predators may be contributing to reduced population growth and may also pose a future obstacle to restoration (Grosholz et al. 2000, Grosholz et al. 2001, Kimbro et al. *in review*).

The primary aim of this project is to provide critically needed information for native oyster restoration groups regarding how to prioritize sites for restoration efforts. Information about where and why to expect high recruitment, growth and survival and which predators and competitors are most likely to limit growth and survival will be key to the success of these efforts. Determining what factors most strongly affect recruitment, growth and survival will help guide the location of priority sites for restoration programs, and will inform ongoing and future restoration efforts regarding additional investments that may be needed to control oyster predators and competitors.

Survey of Intertidal Oyster Populations

Distribution of native oysters. From July 2006 to June 2007, we surveyed most of the accessible rocky shoreline of San Francisco Bay for the presence of native oysters. We used a variety of information sources including unpublished reports and anecdotal observations of oyster presence. In addition, we consulted various shoreline maps to determine substrate types and accessibility of potential sites. All sites were generally visited once, by 1-3 researchers, with appropriate substrate searched for at least half an hour. We recorded GPS points and took qualitative notes on each site. In addition, at a subset of sites we recorded density by counting oysters in 5-10 randomly placed 0.25 m^2 quadrats. Below is a map of sites surveyed (Fig. 1).

Figure 1. Map of sites surveyed for presence or absence of native oyster populations. Green markers indicate that live oysters were found; yellow markers indicate that only dead oysters were found (still attached to substrate) and red markers indicate no oysters or oyster shells found.

Table 1. Location, date and results of site surveys to determine the present distribution of intertidal populations of native oysters in San Francisco Bay. Sites are arranged from north to south. Presence or absence of oysters are indicated by "p" or "a" respectively. In some cases, intact oyster shells were present indicating oysters were no longer present but recently dead "a (d)". The type of site was either a single visit to determine presence of oysters ("p/a survey"), and if oysters were present in sufficient numbers, the site was either surveyed for oyster density ("density survey") or established as a site for longer-term study with many repeated visits ("long-term site").

Site	Date	Lat./Long.	P/A	Site Type
Midshipman Point	6/1/2006	N 38 73.77 W 122 26.5741	a	p/a survey
Black Point Boat Launch	6/1/2006	N 38 65.277 W 122 30.2295	a	p/a survey
Black Point North	6/1/2006	N 38 64.030 W 122 30.405	a	p/a survey
Petaluma Point	6/1/2006	N 38 62.037 W 122 29.1730	a	p/a survey
Point Pinole	8/10/2006	N 38 45.366 W 122 21.871	a (d)	long-term site
Mare Island	6/3/2006	N 38 4.313 W 122 15.371	a	p/a survey
Black Point South	6/1/2006	N 38 39.65 W 122 29.3397	a	p/a survey
Davis Point	6/3/2006	N 38 3.098 W 122 15.504	a	p/a survey
Rodeo Marina	12/4/2006	N 38 02.237 W 122 16.417	a	p/a survey
Pinole Bayfront Park	11/17/2006	N 38 00.725 W 122 17.806	a	p/a survey
Buckeye Point	11/18/2006	N 38 00.395 W 122 28.417	a (d)	p/a survey
Weber Point	11/18/2006	N 38 00.293 W 122 28.219	a (d)	p/a survey
China Camp Village	6/13/2007	N 38 00.207 W 122 27 876	a (d)	p/a survey
China Camp Village	11/18/2006	N 38 00.192 W 122 27.872	a (d)	p/a survey
McNear's	8/10/2006	N 37 59.497 W 122 27.0166	p	long-term site
Richmond Rod & Gun	12/4/2006	N 37 58.719 W 122 22.082	a (d)	p/a survey
Loch Lomond Marina	8/10/2006	N 37 58.361 W 122 28.608	p	long-term site
West Marin Island	7/17/2007	N 37 57.923 W 122 28.340	a (d)	p/a survey
East Marin Island	7/17/2007	N 37 57.886 W 122 28.208	a (d)	p/a survey
East Brothers Island	7/17/2007	N 37 57.795 W 122 25.971	p	p/a survey
Pt. San Pablo Harbor	12/3/2006	N 37 57.792 W 122 25.243	a (d)	p/a survey
West Brothers Island	7/17/2007	N 37 57.760 W 122 26.101	p	p/a survey
Point Molate	12/3/2006	N 37 57.671 W 122 25.652	p	p/a survey
Point Orient	7/24/2006	N 37 57.307 W 122 25.310	p	long-term site
Pt San Quentin N	6/13/2007	N 37 56.545 W 122 28.856	p	density survey
Pt San Quentin N	6/28/2007	N 37 56.545 W 122 28.856	p	density survey
San Quentin South	10/2/2006	N 37 56.545 W 122 28.840	a (d)	density survey
San Quentin South	11/3/2006	N 37 56.545 W 122 28.840	a (d)	density survey
San Quentin South	6/13/2007	N 37 56.545 W 122 28.840	p	p/a survey
Richmond Bridge	7/17/2007	N 37 56.055 W 122 25.732	a	p/a survey
Red Rock	7/17/2007	N 37 55.765 W 122 25.807	p	p/a survey
Keller Beach	12/4/2006	N 37 55.271 W 122 23.250	p	density survey
Keller Beach	6/28/2007	N 37 55.271 W 122 23.250	p	density survey
Paradise Cay	11/18/2006	N 37 55.007 W 122 28.567	a	p/a survey
Ferry Point	7/25/2006	N 37 54.574 W 122 23.281	p	long-term site
Sandpiper Spit	11/18/2006	N 37 54.520 W 122 22.614	p	p/a survey
Sandpiper Spit	6/28/2007	N 37 54.520 W 122 22.614	p	p/a survey
Point Isabel	7/25/2006	N 37 53.854 W 122 19.480	a (d)	p/a survey
Fleming Point	7/25/2006	N 37 53.544 W 122 25.243	a	p/a survey
Tiburon-Belvedere	7/27/2006	N 37 52.957 W 122 28.31	p	long-term site

Brickyard Park	11/3/2006	N 37 52.851 W 122 30.255	p	p/a survey
China Cove	3/15/2007	N 37 52.228 W 122 25.650	p	p/a survey
Cesar Chavez Park	6/14/2007	N 37 52.185 W 122 18.812	p	p/a survey
Angel Isl. Harbor	12/2/2006	N 37 52.146 W 122 26.076	p	density survey
Angel Isl. (Ayala Cove)	12/2/2006	N 37 52.009 W 122 26.103	p	long-term site
Angel Isl. Harbor (ledge)	12/2/2006	N 37 52.006 W 122 26.104	p	density survey
Angel Isl. Harbor (right)	12/2/2006	N 37 52.003 W 122 26.231	p	density survey
Bay Model (Sausalito)	3/1/2007	N 37 51.879 W 122 29.685	p	p/a survey
Quarry Point	3/15/2007	N 37 51.796 W 122 25.261	p	p/a survey
Berkeley Marina	7/25/2006	N 37 51.793 W 122 18.730	p	long-term site
Kayak Landing	3/15/2007	N 37 51.761 W 122 26.486	p	p/a survey
Earl F. Dunhy Park	3/1/2007	N 37 51.680 W 122 29.240	p	density survey
Locust St. Sausalito	3/1/2007	N 37 51.674 W 122 29.115	p	density survey
Stuart Point	3/15/2007	N 37 51.568 W 122 26.608	p	p/a survey
Seal sculpture, Sausalito	3/1/2007	N 37 51.047 W 122 28.749	p	density survey
Emery Point	7/25/2006	N 37 50.732 W 122 18.152	p	p/a survey
Emeryville Marina	7/25/2006	N 37 50.229 W 122 18.912	p	p/a survey
Ft. Baker	11/3/2006	N 37 49.913 W 122 28.426	a	p/a survey
Wave Organ, SF	11/5/2006	N 37 48.508 W 122 26.414	p	p/a survey
San Francisco Marina	11/5/2006	N 37 48.473 W 122 26.581	a	p/a survey
Aquatic Park, SF	8/11/2006	N 37 48.398 W 122 25.469	p	long-term site
Encinal Ramp, Alameda	7/28/2006	N 37 46.157 W 122 17.452	p	long-term site
Intertidal Walkway	7/28/2006	N 37 46.050 W 122 16.751	a	p/a survey
Alameda Marina	7/28/2006	N 37 45.965 W 122 17.342	a (d)	p/a survey
Candlestick Park	11/5/2006	N 37 42.531 W 122 22.873	p	density survey
Grant St., Hayward	12/1/2006	N 37 39.894 W 122 09.643	p	p/a survey
Oyster Point	7/26/2006	N 37 39.656 W 122 22.516	p	long-term site
Oyster Point Launch	7/26/2006	N 37 39.656 W 122 22.516	p	long-term site
Rock N of Sierra Pt	10/5/2006	N 37 38.347 W 122 38.865	p	density survey
Sierra Point Yacht Club	10/5/2006	N 37 37.160 W 122 38.130	p	density survey
Hayward Reg. Shoreline	12/1/2006	N 37 37.138 W 122 9.0355	a	p/a survey
Bayfront Park, Millbrae	11/20/2006	N 37 36.243 W 122 22.397	p	density survey
Bayside Park, Burlingame	11/20/2006	N 37 35.532 W 122 21.338	p	density survey
Coyote Point (jetty)	7/26/2006	N 37 35.484 W 122 19.1285	p	long-term site
Anza Lagoon	11/20/2006	N 37 35.468 W 122 20.804	a (d)	p/a survey
Peninsula Beach	11/20/2006	N 37 35.398 W 122 19.482	a	p/a survey
San Mateo Bridge Pier	11/21/2006	N 37 34.411 W 122 15.714	a (d)	p/a survey
Little Coyote Point	11/20/2006	N 37 34.359 W 122 15.982	a (d)	p/a survey
Shipwreck	10/13/2006	N 37 33.171 W 122 9.436	p	p/a survey
Sandpiper Park	11/21/2006	N 37 32.223 W 122 13.978	a	p/a survey
Dumbarton Bridge	10/7/2006	N 37 30.612 W 122 6.6813	a	long-term site
MSI, Redwood City	11/21/2006	N 37 30.320 W 122 12.948	p	p/a survey
Port of Redwood City	11/21/2006	N 37 30.261 W 122 12.818	p	p/a survey
Pete's Harbor	11/21/2006	N 37 30.040 W 122 13.448	a	p/a survey
Docktown	11/21/2006	N 37 29.743 W 122 13.244	p	p/a survey
Bayfront Park	12/1/2006	N 37 29.277 W 122 10.631	a	p/a survey
Alviso Marina	12/1/2006	N 37 25.863 W 122 58.857	a	p/a survey

While a few oyster scars were found at many locations in the Bay, most live oysters were found between the Richmond and San Mateo bridges. It was obvious early on in the survey that many oyster populations, especially in the northern San Francisco Bay and San Pablo Bay had experienced a recent massive die-off within the past several months. Oyster shells with both valves still intact were abundant, while live oysters were few. Our subsequent work indicates that upper valves do not remain intact for more than a few months indicating that these sites had live oysters recently. At these sites, we recorded numbers of live, recently dead (top valve still intact) and scar (bottom valve only) oysters in 5-10 randomly placed 0.25 m^2 quadrats (Table 1). We measured live and recently dead oysters in these quadrats to determine whether there was a difference in mortality by size class.

Table 2. Examples of the densities per 0.25 m^2 quadrats of live oysters, recently dead oysters and oyster scars at a subset of San Francisco Bay sites, Fall 2006-Spring 2007.

Site	**Live**	**Dead (both valves)**	**Scar**
China Camp	0	2.6	4.8
South of Richmond Bridge	0	0	6.4
Point San Quentin South	0	3.2	5.0
Keller Beach	0.4	1.2	0.8
Angel Island Harbor	4.4	0.2	1.6
Brickyard Park, Strawberry	1.2	0.4	0.2
Earl F. Dunhey Park, Sausalito	3.6	0	1.8
Candlestick State Park	2.6	1.4	0.2
Sierra Point Yacht Club	2.4	1.2	2.3
Bayfront Park, Millbrae	1.8	0.2	0
Bayside Park, Burlingame	0.2	0.2	0
Port of Redwood City	0.2	0.2	0

The die-offs observed at many sites, especially in the North Bay, may have been the result of persistent, heavy rainfall during the winter and spring of 2006. Lowered salinities persisted well into the spring beyond the period typical for this region. As Table 3 shows, at the Marin Rod and Gun Club, where salinities were recorded monthly during this period, salinities below 10 ppt were measured well into April and salinities of 15 ppt or lower were measured until June. Therefore, there was an extended period of low salinity for nearly three months (Mar-May), which may have contributed to the die-off of many North Bay populations.

Table 3. Monthly surface water salinity (ppt) at Marin Rod and Gun Club Pier, San Rafael, CA (N 37°56.694, W 122°28'769).

Date	Salinity		Date	Salinity
Jul-05	26.5		Apr-06	5.6
Aug-05	27.7		May-06	12.5
Sep-05	28.3		Jun-06	15
Oct-05	31.3		Jul-06	24
Nov-05	26.8		Aug-06	28
Feb-06	13.4		Sep-06	30
Mar-06	7.3		Oct-06	31

Oyster Population Density. In addition to the presence-absence survey, we carried out a series of long-term population measurements at 13 study sites. Sites were chosen to represent four broad geographical areas in San Francisco Bay: 1) North Bay; 2) Central Bay West; 3) Central Bay East; 4) South Bay (location information in Table 1). Sites were selected after our initial survey and represented areas with the most abundant oyster populations within each of these regions. In the North Bay, we were not able to find sites with many live oysters. Here, and at one site in South Bay, we selected sites with high numbers of recently dead oysters and/or oyster scars, which indicated that the site had at one time been good habitat. The oyster densities at the 13 sites in Fall 2006 are represented graphically below.

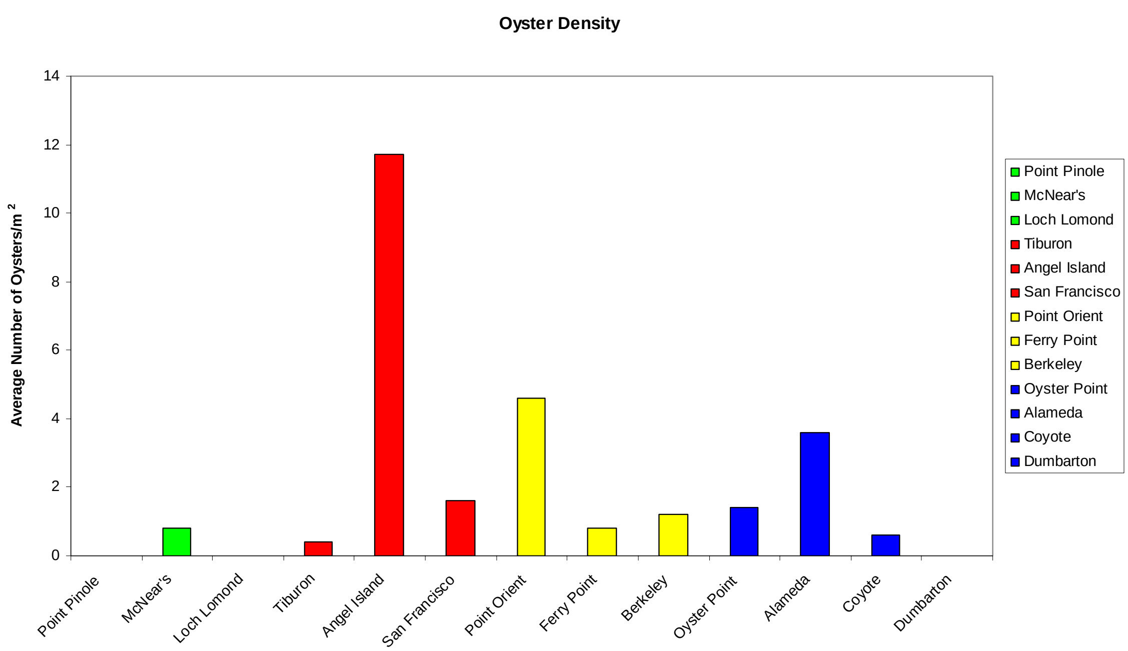
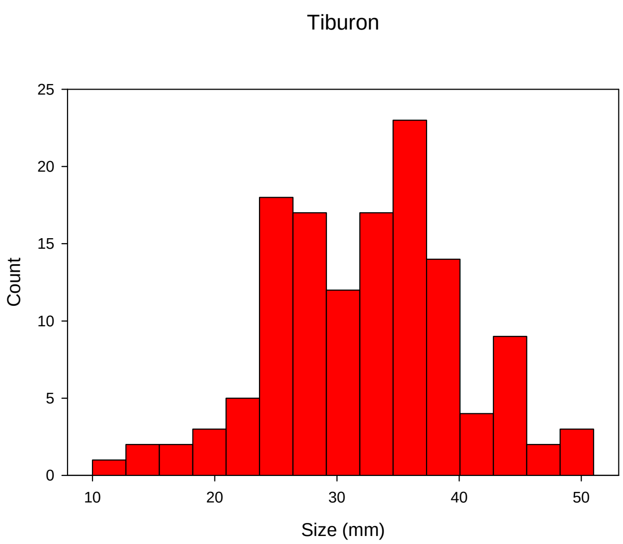
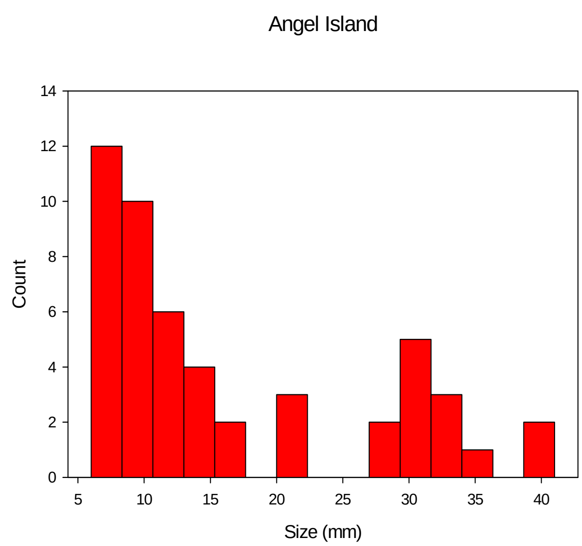


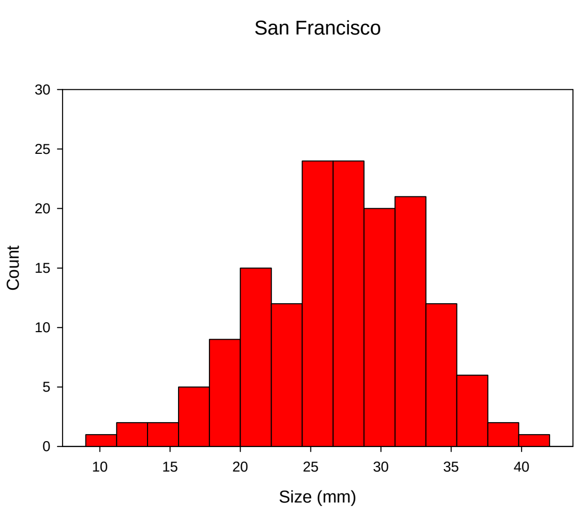
Figure 2. Oyster population density by site within each of the four regions of San Francisco Bay: North Bay (green bars), Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

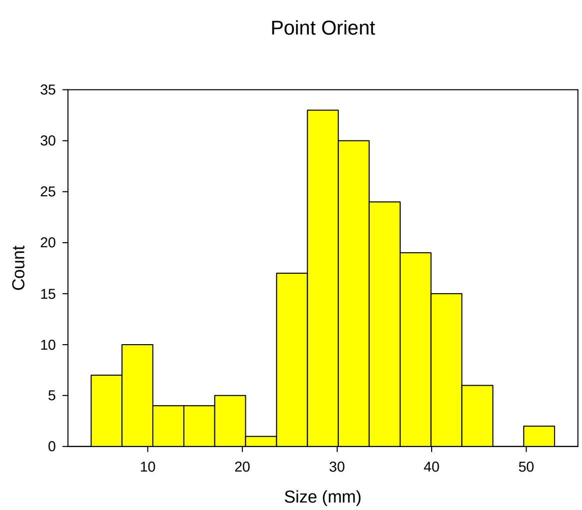
Oyster Population Size Structure. We used two methods to gather data about recruitment at our long-term study sites. For locations where we had sufficient numbers of live oysters (9 of 13 sites), we gathered data on size-class frequency. We did this as part of our growth study (see below), in which 40-80 oysters along a 30 m transect line were tagged in July 2006 and tracked over the course of a year. Sites were revisited bimonthly, and as oysters died, we tagged new individuals to keep a target number (40+) of tagged individuals at each site. The size frequency data were generated using the initial size of each oyster when it was first tagged. Oysters were measured along their longest axes with vernier calipers; we estimated measurement error at ~3 mm. These data are represented in size frequency histograms, below.

Nearly all sites showed a unimodal size distribution, with a single peak centered around the 20 or 30 mm size classes, indicating lack of recent recruitment. Three of these, Berkeley Marina, Oyster Point and Coyote Point, had a mean size class above 35 mm, suggesting that most of the oysters at these sites are older relative to the other locations. Only Angel Island and Point Orient showed a bimodal distribution suggestive of more than one cohort at these sites.









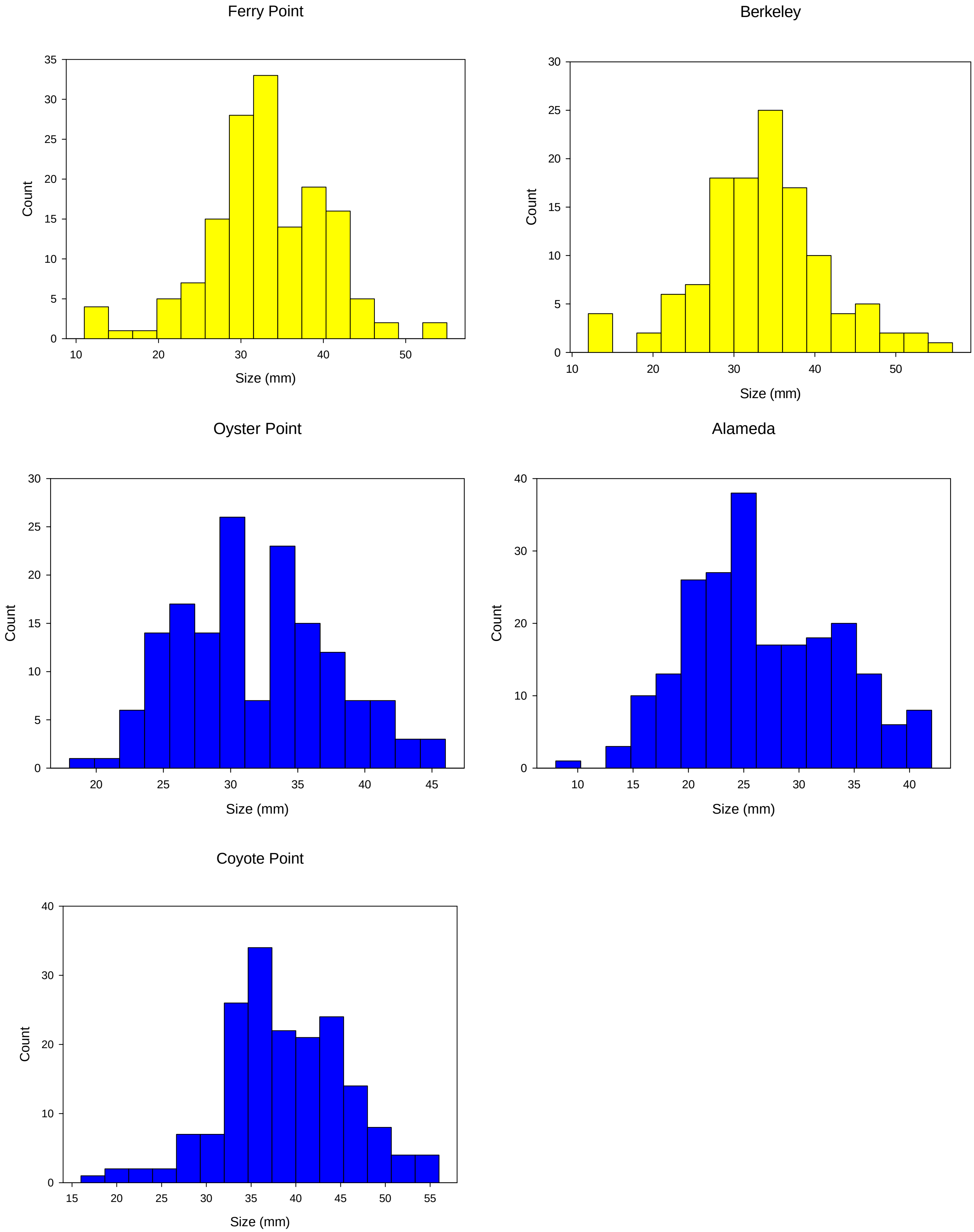
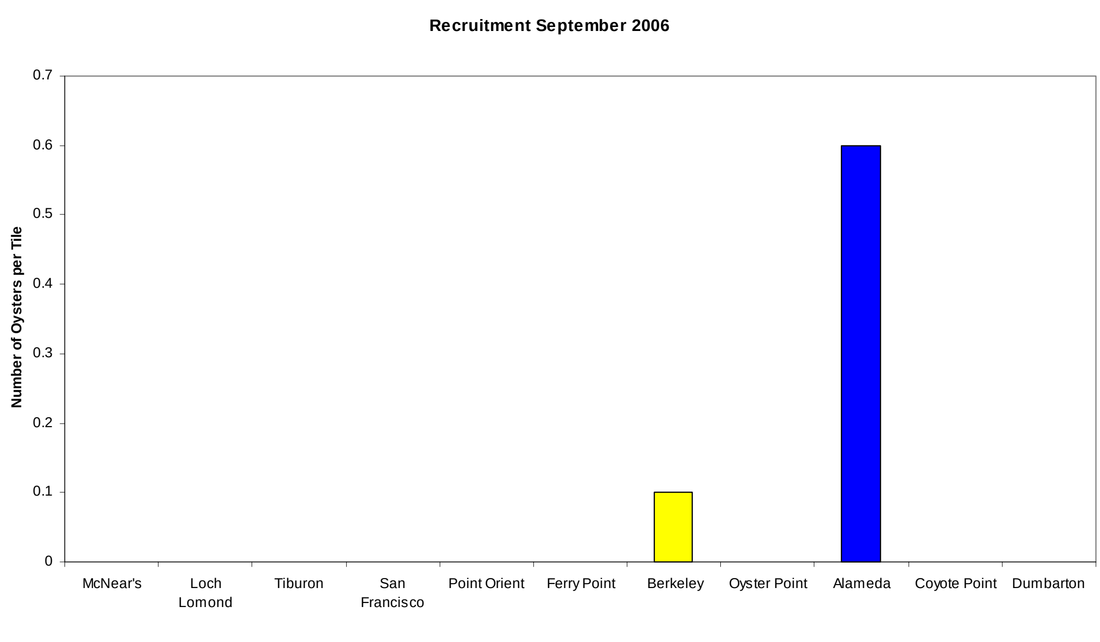


Figure 3. Population size structure of native oysters by site within regions: North Bay (green bars), Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

Native Oyster Recruitment. In addition to examining existing size distribution, we measured recruitment directly by deploying recruitment surfaces in the oyster zone at 12 long-term sites (see Table 1) beginning in August 2006. (Angel Island was added as a study site later; recruitment tiles were not placed there in 2006). At each site, we established a 30 m transect line parallel to the water's edge at approximately the 0 tide mark. We marked the end points of the transect line with rebar poles. We placed 10 PVC plates (10 by 10 cm gray) every 3 meters along the transect line. These were attached to a PVC T that was hammered into the substrate and were oriented downward. These were checked for oyster spat and a fresh set of plates set out monthly through November (the expected end of the oyster settlement season). Plates were put out again in March 2007 at all 13 sites. Plates were attached to cement pavers which in turn were attached to rebar hammered into the substrate. These were oriented vertically, facing north (or in locations where north was shoreward, east) to lessen the possibility of heat stress. During this season, half of the plates were replaced monthly. The rest remained in place for the entirety of the settlement season. All plates were checked for oyster spat bimonthly. We also set up 5 permanent photo quadrats along the same transect on the existing substrate at each site. These were photographed and checked bimonthly for recruits.

Recruitment in 2006 was very low (Fig. 4). Six recruits were found on plates at Alameda and two at Berkeley. There were no recruits at the other sites. We began to see recruits on existing substrate in December 2006 and through February 2007 – much later than projected based on the literature and experience from local oyster recruitment projects. Other oyster researchers in the Bay also noted a late recruitment pulse (Abbott, Mulvey, Norton, Obernolte, Welaratna, personal communication).

At the end of the study in 2007, we recorded a significant increase in oyster recruitment relative to the previous year. Oyster recruits first appeared in our August check of the recruitment surfaces, with the biggest pulse coming into Loch Lomond and a few individuals showing up at Point Pinole, Alameda and Oyster Point. The remainder of the recruitment season ran beyond the length of this project.



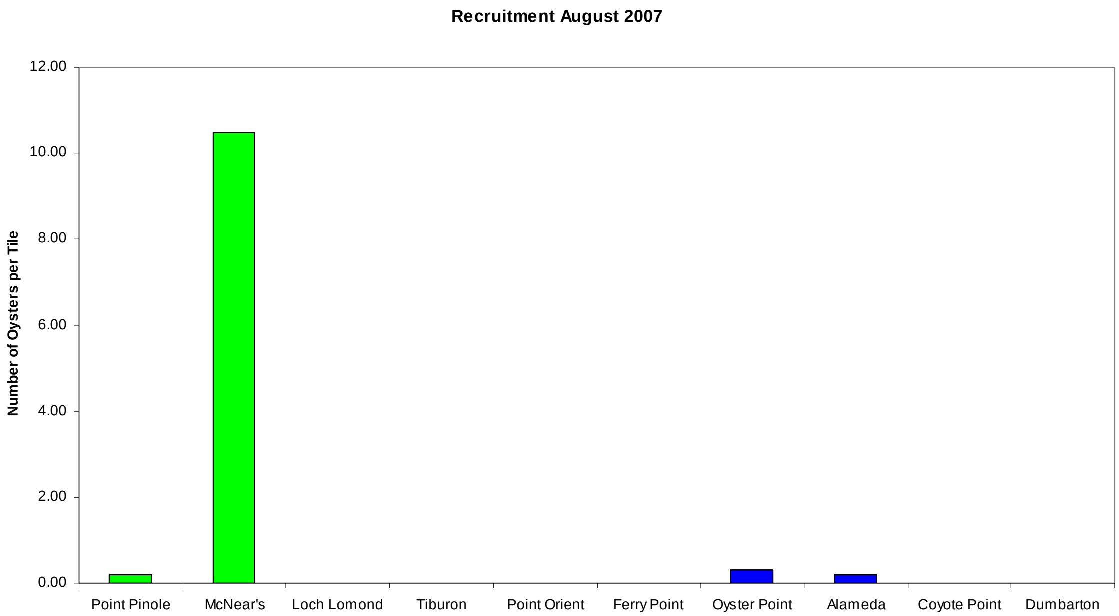


Figure 4. Recruitment of native oysters for 2006 (upper) and 2007 (lower) by site within regions: North Bay (green bars), Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

Native Oyster Growth Rate. To determine the growth rates of oysters at our study sites, we attached numbered plastic tags onto 40-60 oysters near our permanent transect line at each of our long-term study sites (see Table 1). Individual oysters were located and remeasured every 2 months from August 2006 to June 2007. When tagged oysters died or were lost, we tagged additional oysters to keep a target number of ~50 tagged individuals at each site. Oysters were measured with calipers in the field along their longest axes. We calculated growth rates in mm/day by subtracting the first measurement we had for an individual oyster from the last measurement and dividing this by the number of days between the dates on which these measurements were made (Fig. 5).

As small oysters might be expected to grow more quickly than large ones, we regressed growth against size at first measurement. While small oysters did see greater percentage increases than larger ones, overall growth rate (expressed as mm/day) was approximately the same for all oysters of the sizes we encountered. This allowed us to confidently calculate a mean growth rate (below). Measurement error was estimated at 0.03 mm/day. Sources of measurement error include shell chipping, which can result in an oyster being smaller than previously recorded, overgrowth by barnacles and other organisms, and oysters growing over or around objects, as well as human error in measuring or recording.

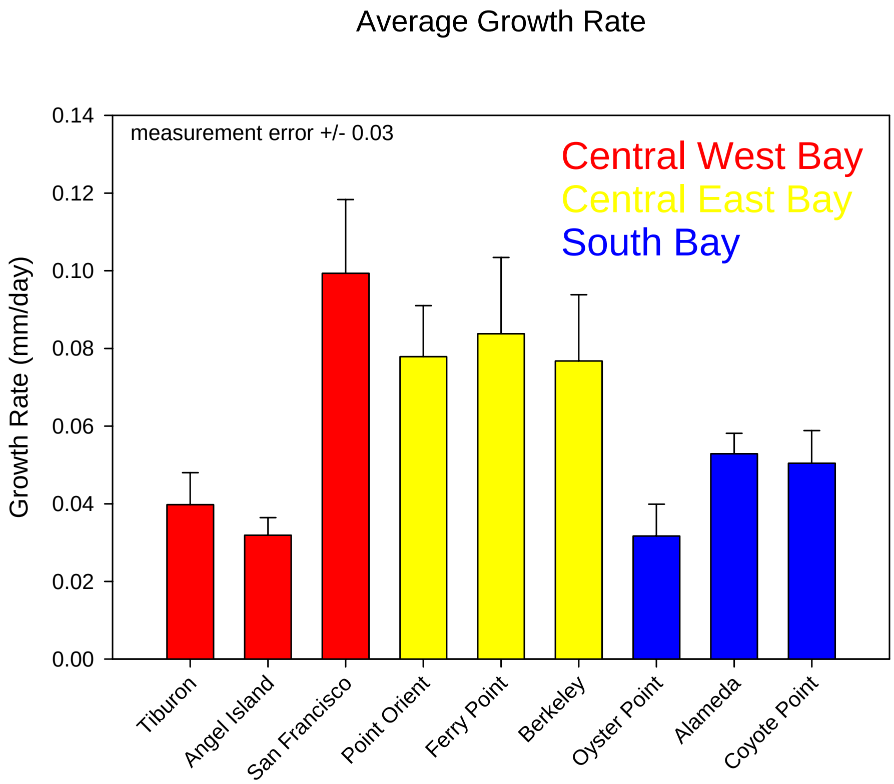


Figure 5. Native oyster growth rates by site within regions: Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

Native Oyster Mortality. When oysters tagged for the growth study (above) died, but remained on the rock with a tagged shell, we were able to measure size at time of death. This allowed to us calculate mortality rates for each site and to determine if there were differences in mortality rates by size class. Mortality rate was calculated as the number of dead individuals vs. the number of total individuals. We calculated mortality rates for each visit to each site, then took the mean of these monthly measures to calculate a yearly rate. The rates for each site are depicted below.

Typically, larger individuals are less vulnerable to attacks by predators such as oyster drills, whereas small oysters may be more vulnerable both to predation and stressors such as desiccation. Strong stressors, such as long-term lowered salinity like that seen in the spring 2006, would be expected to impact all size classes. The mean size for dead vs. live oysters for each site is shown below. The leftmost bar at each site represents the dead oysters.

By far the highest mortality was found at the San Francisco site. Interestingly, this site also has the highest densities of oyster drills (see Fig. 9 below). Overall, mortality was fairly similar across our other sites. We found little difference in the sizes of live oysters vs. dead (intact but empty shells) at most sites as well, although live oysters were somewhat larger than empty shells at Ferry Point and Berkeley Marina.

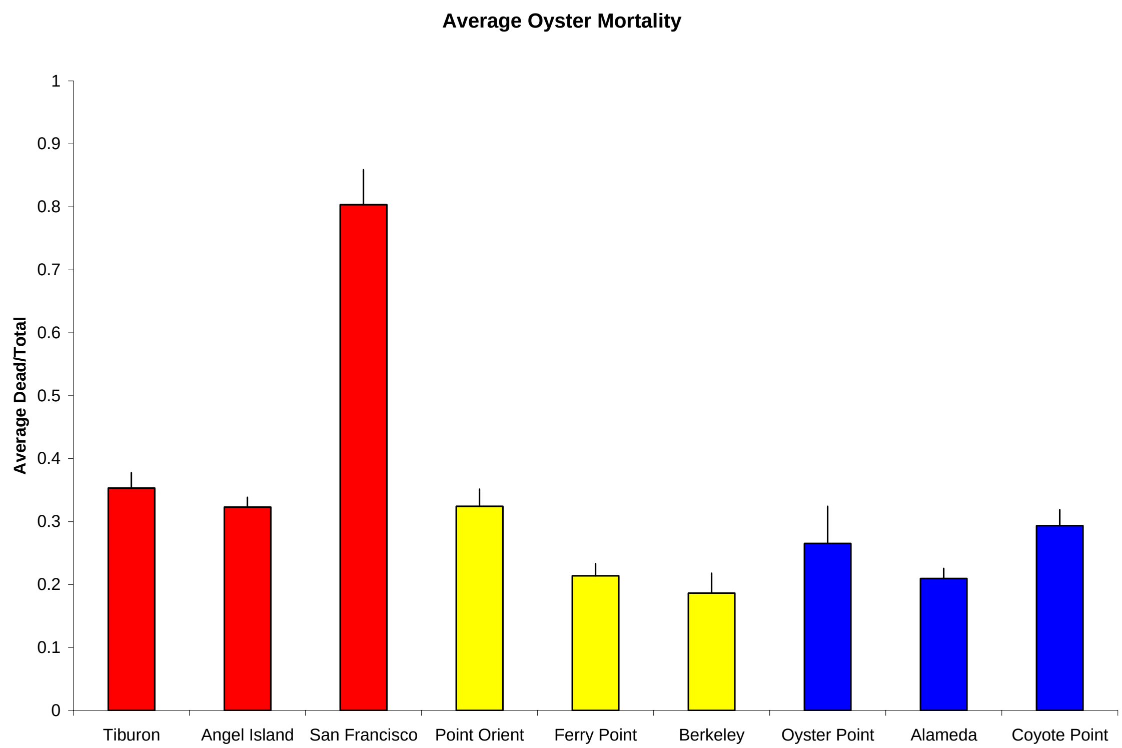


Figure 6. Native oyster mortality by site within regions: Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

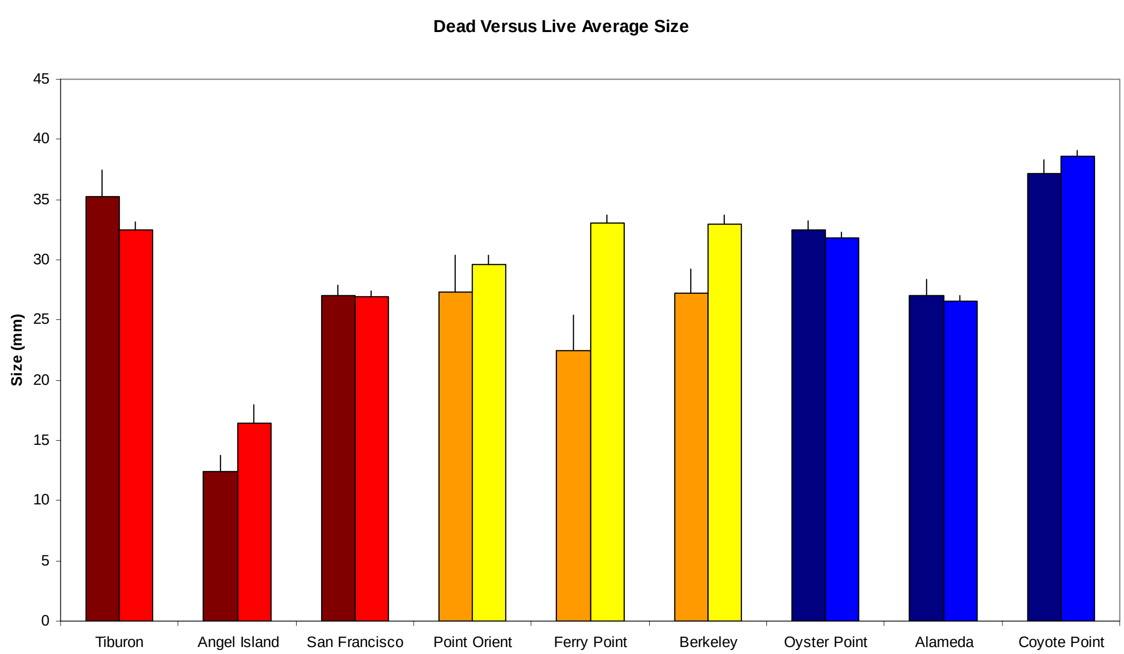


Figure 7. Comparison of mean size of dead (intact but empty shell, left bar) vs. living oysters (right bar) for each site within regions: Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars).

Native Oyster Size Distribution. Many sites did not have much variation in size classes and there were relatively few tagged oysters that died during the course of our study. To examine this question with more data, we pooled oyster sizes for each of the three geographic regions for which we had sufficient numbers. We used a chi-square test to determine whether oysters in any particular size class died more frequently than would be expected based on chance alone, given the proportions in each size class. Below are size-frequency histograms for dead oysters for Central Bay West, Central Bay East and South Bay.

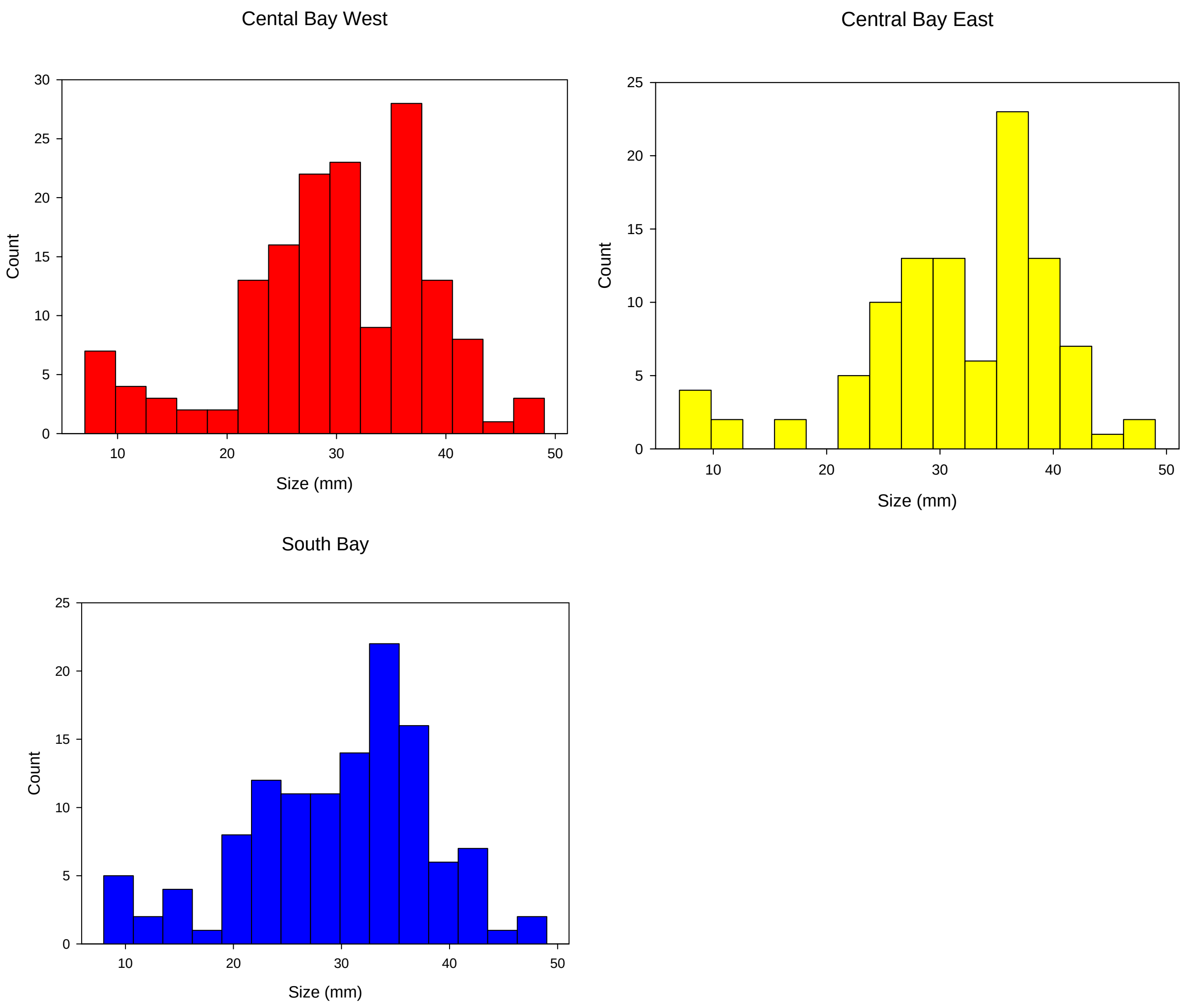


Figure 8. Comparison of mean size of living vs. dead (intact but empty shell) by site within regions: Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars)

When compared to the overall proportions of oysters in each size class, these histograms show that smaller oysters (1-20 mm) died in higher numbers and larger oysters (41 to 60 mm) died in lower numbers than expected. The chi-square test indicated that these differences were statistically significant (X^2=18.9, df = 3, P < 0.0005).

Predatory Drill Abundances. As mentioned above, high mortality among small size classes might be suggestive of increased predation on young oysters. The Atlantic oyster drill *Urosalpinx cinerea* and a native whelk *Acanthina spirata* are two snail species known to prey on native oysters and are considered a limiting factor in some West Coast estuaries (Kimbro et al. *in review*).

We surveyed for oyster drills (whelks) at our long-term (see Table 1) study sites over the course of two minus-tide series in late Sept-early Oct 2006 and late May-early June 2007. At each site, we searched for drills in ten 1 m^2 quadrats randomly placed along our permanent transects. We turned small cobbles within each quadrat to check for the snails on the sides and undersides of rocks. Drills were only found at five locations. The native drill was the only drill found at the San Francisco site (indicated by the *** in the figure below); the Atlantic drill was the only drill found at the remaining sites.

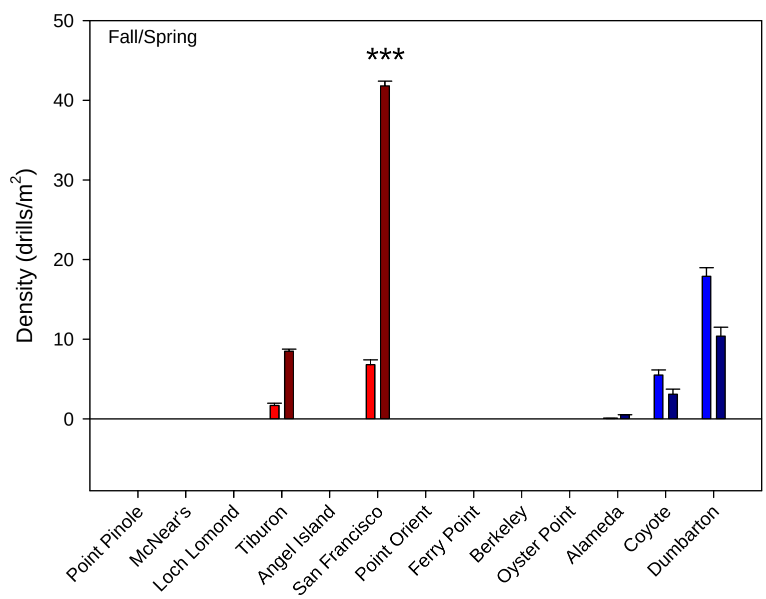


Figure 9. Density of oyster drills by site within regions: North Bay (green bars), Central Bay West (red bars), Central Bay East (yellow bars) and South Bay (blue bars). For each pair of bars per site, the lighter (left) bar indicates the fall survey and the darker (right) bar indicates the spring survey.

Other predators are known to prey on native oysters including birds and fishes (Barnett 1963, Baker 1995). Bat rays (*Myliobatus californica*) and some other sharks and ray are known to be significant oyster predators. Also predatory crabs including both native *Cancer* spp. and introduced European green crabs (*Carcinus maenas*) are known to consume oysters under some circumstances. None of these other predators were present on a regular basis, although data were collected only on oyster drills. However, experiments with crabs and whelks in Tomales Bay strongly indicate that oyster drills are much more important consumers of oysters than crabs (Kimbro et al. *in review*).

Space competitors. To determine whether competition for space might be a limiting factor for native oysters at our study sites, we assessed the abundance of other sessile organisms in the oyster zone using photoquadrats. In September 2006 and January and June 2007 we photographed the organisms inside 10 cm^2 photoquadrats randomly placed along our permanent transects. The images were downloaded and percent cover of each type of organism was determined by projecting 25 points onto the computer screen. Mussels, barnacles and algae were the major organisms in the oyster zone. At most sites and most time periods, greater than 40 % of the hard substrate in oyster zone was bare.

These results suggest that space may not be currently limiting native oyster populations, at least in the Central Bay and some areas of the North Bay. However, in the South Bay and areas of the North Bay, where hard substrate is rare, substrate limitation may be among the factors limiting recruitment and population growth generally.

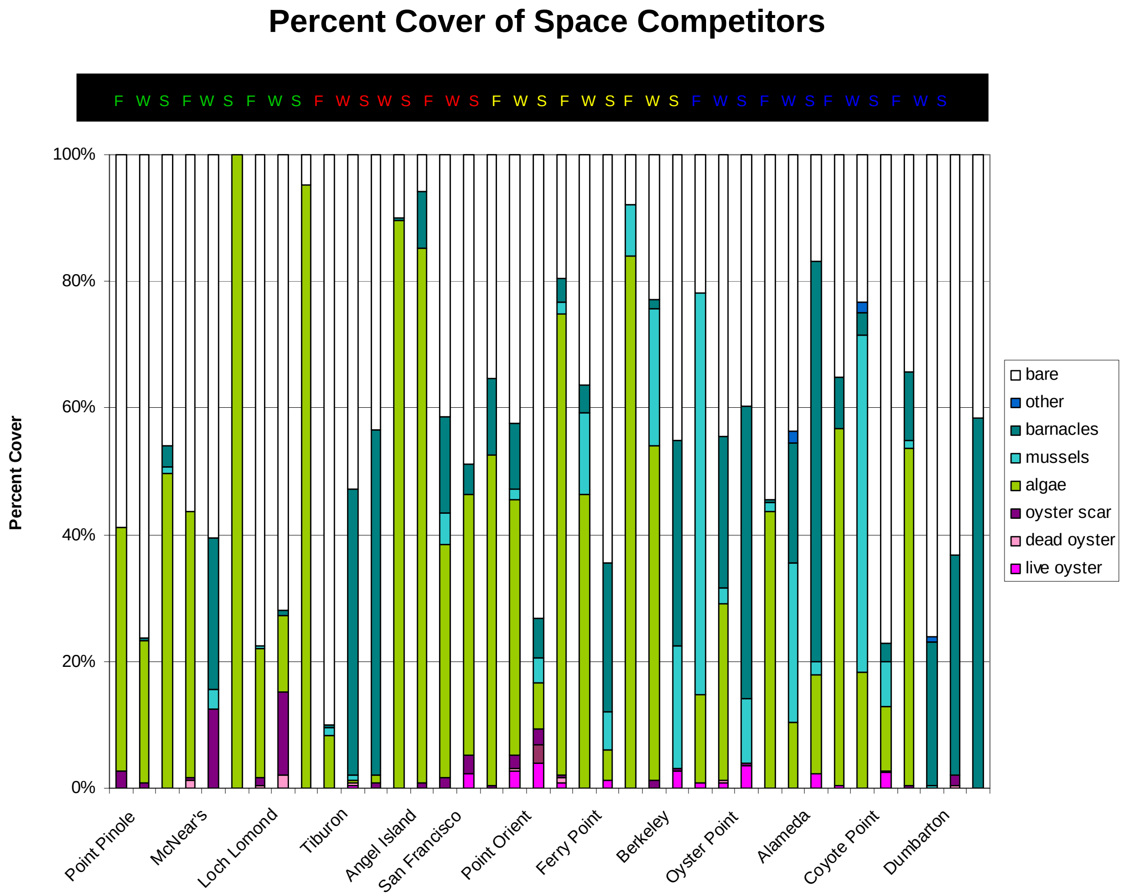


Figure 10. Seasonal variation in cover of space competitors by taxa in photo quadrats. Each group of three bars represent cumulative cover of various taxa for each season (F=fall, W=winter, S=spring) for each site. Regions are indicated by the color of the seasonal labels above the bar: North Bay (green), Central Bay West (red), Central Bay East (yellow) and South

Survey of Subtidal Oyster Populations

Presence of subtidal oyster populations. The presence of oysters in San Francisco Bay may be significantly influenced by remnant subtidal populations. Intertidal areas may be in part maintained by recruitment from subtidal habitats if in fact oysters are present in abundance. Although historical records suggest the presence of significant subtidal populations, there is only casual mention and minimal evidence suggesting the presence significant subtidal populations. Other than the Sailing Lake site, an anomalous site with very restricted flow and consequently very high larval retention, we have not been able to identify another subtidal population. Our methods were limited by equipment and funding and the possibility exists that more intensive and better funded efforts may yield evidence of such populations in the future.

In drawing these conclusions, we relied on several different methods to survey the presence or absence of subtidal populations of native oysters in the same regions of San Francisco Bay (north, central and south) as our intertidal surveys. We conducted these surveys at several locations in each of the three regions of the bay using a variety of methods that depended on the availability of the appropriate instruments and boat support and the applicability of the instruments in habitats typical of each part of the bay.

In collaboration with the Gulf of the Farallones National Marine Sanctuary and Moss Landing Marine Laboratories, we used side-scar sonar to identity subtidal structures within the bay that looked like oyster beds and/or rocky reefs that might provide good oyster habitat. We used the sonar in several locations in the Central Bay (offshore of our San Francisco study site, around Angel Island, offshore of Sausalito) and South Bay (offshore of our Coyote Point and Oyster Point sites) (Table 4). Sidescan sonar is inaccurate and often unworkable in depths and topography of much of the South Bay, particularly in areas less than 3 m deep. This method was used only within the deeper, dredged channel areas. In some cases, the steepness of the channel sides made image resolution impossible. We did locate several structures in the Central Bay that appeared to be solid and topographically complex.

We returned to these locations and investigated the areas imaged with the sonar using an oyster dredge. We made several tows with the dredge around these structures and in several other locations in Central Bay and Richardson Bay. The features imaged by the sonar device turned out to be shell piles. Native oyster shells were present but not abundant, along with the shells of other bivalves, but no living bivalves were found.

We were also able to conduct a limited number of tows using the oyster dredge from aboard the R/V *Brownlee,* a research/education vessel owned by the Marine Sciences Institute. As guests of the MSI, we were only able to make our tow during their scheduled bottom trawl – twice on each of two days we went out with them (Figure 11).

We made additional tows aboard a privately-owned research vessel in various locations in South Bay in collaboration with another research project; and as part of that project, examined data from dozens of other tows made in the same area. We found one live oyster during these tows. It was attached to a bryolith (free-living bryozoan colony) and was in turn being overgrown by the bryozoan. The areas towed for these two projects are depicted on the map below, and locations presented in Table 5.

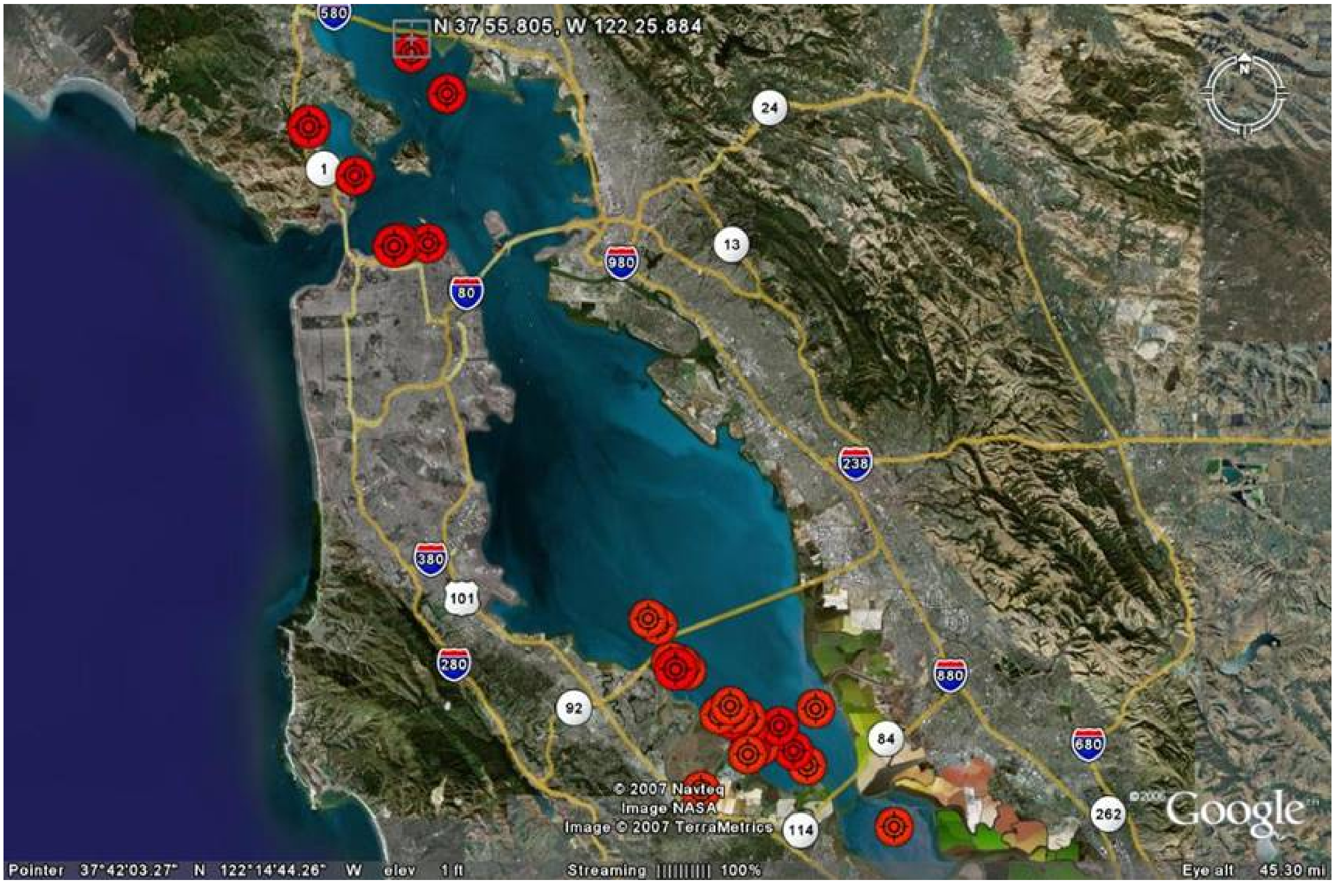


Figure 11. Map of subtidal sampling sites where data were collected using several methods including side scan sonar and benthic tows using an otter trawl or an oyster dredge.

We also explored the feasibility of using a high resolution sonar imaging device DIDSON (Dual frequency IDentification SONar). On loan from Sound Metrices, Inc., we tested the DIDSON device with oyster shells in a swimming pool. We found that images of objects the size of native oysters can only be visualized when the device is firmly anchored or moored to a fixed location. It was clear that deploying this device from a boat or other non-stable platform in field conditions would be unworkable, since the turbulence caused by wind waves in the pool made use of the device difficult.
In addition, we looked for oysters on rocks and maritime structures in and around Oyster Point Marina using an underwater camera mounted on a pole. The pole-cam belongs to NOAA and was being tested for use in a project at the marina. In clear water, such as shallow water (less than 1 m) over rocky rip-rap and on seawalls, we could see oysters. In more turbulent conditions and over muddy bottoms, we couldn't see well enough to

determine whether oysters were present. This technique could be useful for looking at specific structures in relatively shallow water under calm conditions, but not for a widespread visual survey of the bay.

Table 4. Locations of sidescan sonar tows at North and Central Bay sites (top table) on 09/28/07 and Central and South Bay site (bottom table) on 09/29/07.

Tow	Starting Lat./Long.	Ending Lat./Long.
1	N37 48.831 W122 25.989	N37 48.854 W122 26.480
2	N37 48.783 W122 25.332	N37 49.925 W122 26.053
3	N37 49.925 W122 26.053	N37 50.257 W122 26.517
4	N37 50.584 W122 27.162	N37 50.792 W122 27.650
5	N37 51.229 W122 28.127	N37 51.599 W122 27.715
6	N37 52.517 W122 26.439	N37 52.514 W122 25.791
7	N37 54.144 W122 26.481	N37 54.982 W122 26.897

Tow	Starting Lat./Long.	Ending Lat./Long.
1	N37 34.547 W122 14.879	N37 34.339 W122 14.459
2	N37 35.115 W122 14.391	N37 34.655 W122 13.465
3	N37 34.655 W122 13.465	N37 34.751 W122 13.448
4	N37 31.068 W122 07.811	N37 30.311 W122 07.449
5	N37 30.355 W122 07.476	N37 30.872 W122 08.043
6	N37 39.843 W122 21.186	N37 40.722 W122 21.307
7	N37 42.377 W122 15.945	N37 42.307 W122 15.823

Table 5. Locations and dates of subtidal tows using oyster dredge from small boats. The approximate speed (knots) and depth (m) are estimated mean values during at the start and end of each tow.

Date	Latitude	Longitude	Location name	Duration	Speed	Depth (m)
9-Oct-06	37 31.611	122 09.806	S. San Francisco	5 min	1	13
9-Oct-06	37 31.528	122 09.04	S. San Francisco	5 min	1	3
11-Nov-06	37 48.721	122 25.276	Sausalito	7 min	1	20
11-Nov-06	37 51.085	122 28.264	Sausalito	5 min	1	7
11-Nov-06	37 52.784	122 30.350	Strawberry	5 min	1	2
11-Nov-06	37 52.898	122 30.378	Strawberry	5 min	1	7
11-Nov-06	37 48.849	122 25.289	N1 feature	5 min	1	7
11-Nov-06	37 48.855	122 26.289	N1 feature	5 min	1	7
5-Dec-06	37 54.717	122 19.15	Redwood City	5 min	1.3	1
13-Mar-07	37 29.317	122 05.63	S. of Dumbarton	3 min	1	2
13-Mar-07	37 31.883	122 09.86	Greco Island	3 min	1	3
13-Mar-07	37 34.22	122 14.35	S. of San Mateo	5 min	1	5
13-Mar-07	37 34.24	122 14.43	S. of San Mateo	3 min	1	3
20-Mar-07	37 31.55	122 10.80	SW Bay	1 min	1.2	3
20-Mar-07	37 33.15	122 09.02	East Shipwreck	1 min	2	3
3-Mar-07	37 55.639	122 25.481	Off Red Rock	5 min	1	n/a
3-Mar-07	37 54.334	122.24.424	Richmond Harbor	5 min	1	n/a

Survey of Native Oyster Health

Prevalence of parasites and pathogens.

Collections. Oysters were collected at low tide by hand and transported to the California Department of Fish and Game Pathogen Containment Facility at the Bodega Marine Laboratory, from which all effluent is chlorinated (10ppm, 2hrs) and de-chlorinated before release. Collecting a target number of n=60 was attempted although in some locations density was so low that only smaller numbers could be obtained. A sample size of 60 allows for the detection, with 95% confidence, of pathogens/conditions if present in at least 5% of the population (USF&WS and AFS-FHS 2007). The oysters were either processed upon arrival or held overnight on ambient (10-15°C) aerated seawater and processed the following morning.

Processing and Examination. For each population sample the range of shell heights was measured and recorded. Each oyster was shucked and the body and inner valves were examined for the presence of macroscopic lesions or other conditions. For oysters less than ~ 20mm in shell height a single transverse cross-section was excised that included portions of the mantle, digestive gland/gut, kidney, gill, gonad and to a variable extent the heart and posterior adductor muscle. For larger oysters an anterior transverse cross-section was excised that included mantle, digestive gland/gut, gonad and labial palps, and a posterior transverse section including mantle, gonad, heart, posterior adductor muscle and gill. The January 2005 sample from Candlestick Point was processed in a different manner that only allowed detection of systemic conditions such as disseminated neoplasia. Sections were fixed in Davidson's solution for 24 hours, transferred to 70% ethanol and processed for the production of 5µm, hematoxylin- and eosin-stained paraffin tissue sections using standard methods. Sections were examined under a light microscope and the presence of all pathogens, parasites and pathologic conditions were noted. The presence of brooded larvae in the gill was recorded as pre-veliger stages (blastula, trochophore) and veligers (those with a partially or fully developed velum). When present, brooded larvae were also examined for the presence of pathogens and disease.

Results. A map showing the location, date, and number of samples in each collection of native oysters from San Francisco Bay is shown in Figure 12. Full histological sections were examined from a total of 585 oysters (not including 48 from the January 2005 Candlestick Point sample, for which only a single small piece of digestive gland tissue was examined). The results from the survey are summarized in Table 6. An example of the hermaphroditic gonad of ostreid oysters is shown in Figure 13. Brooded larvae were observed in some but not all samples collected from late Spring to late Summer (Table 1, Figures 14-15). The extent to which brooded larvae are retained during histological processing is undefined and may vary between samples. No pathogens or disease were noted among the larvae examined. Small numbers of ciliates were present in a small fraction of a minority of the samples in the gill (nine individuals from a total of five locations) or gut lumen (one individual); these symbionts are ubiquitous in cultured and wild oyster populations worldwide and generally considered of no significance unless there is evidence of invasion of healthy tissue, which was not observed among these samples. Similarly, eleven sections of metazoan organisms or their gametes or larvae were observed in proximity to the gill or within the gut lumen of oysters from various locations but did not appear to be harming them. These organisms should not be considered pathogens or even symbionts in the absence of additional information. Small focal bacterial infections were observed in two oysters. Shell-boring polychaetes (*Polydora* spp. and possibly other genera) were observed in low numbers at most locations and caused minimal damage to the shell, with the exception of the sample from Sailing Lake, for which the densities of *Polydora* sp. were very high on many shells, possibly due to the exclusion of predators within this unique environment. With that exception only two conditions potentially associated with significant disease were noted. The condition known as disseminated neoplasia (also hemocytic neoplasia) was observed in four populations ranging in prevalence from 1.7-27% (Table 1, Figures 16-17). The condition is characterized by the presence of unusually large cells with very large nuclei and prominent nuclei throughout the open circulatory system. Severity of the condition ranged from very low (neoplastic cells comprising less than 1% of circulating cells) to very high (greater than 95% of circulating cells). A ‘microcell’ or very small protozoal parasite was observed in four out of 60 (6.7%) of oysters sampled from Fort Mason Marina and one out of 60 (1.7%) from Bair Island (Table 1, Figures 18-19). The parasite was observed exclusively in the intestinal epithelium and was always associated with a significant host response (hemocyte recruitment). The microcell was typically found in foci of debris within the columnar epithelium of the intestine. The microcells were very small with a central nucleus and appeared to be identical to that described by Friedman et al. (2005) from nearby populations. A haplosporidian parasite described by Friedman et al. (2005) in two of five individuals collected from the St. Francis Yacht Harbor was not observed.

Consequences of disease for native oyster health

Generally, infectious disease did not appear to be having a dramatic impact on these populations, although the high prevalence of disseminated neoplasia in the January 2005 sample from Candlestick Point suggests that this disease may be significant in some locations. These findings are generally in agreement with those of the preliminary study of Friedman et al. (2005), which utilized more limited sample sizes. To conclude, of the potential obstacles for restoring native oysters, parasites and pathogens appear to be relatively unimportant. Diseases appear to have little influence on population growth and are very unlikely to be responsible for the lack of recovery of native oysters since the cessation of harvest pressure. This contrasts sharply with the important role of disease in confounding restoration of *Crassostrea virginica* is the eastern U.S. However, with native Olympia oysters, this does not appear to be a concern for current or future restoration planning.

Table 6. San Francisco Bay native oyster sampling sites. The Jan-05 sample from Candlestick Point consisted of small pieces of tissue only appropriate for detecting the presence of neoplasia.

Site	Collection Date	Shell height, mm	N	Pre-veligers brooded in gill	Veligers brooded in gill	Neoplasia	Intestine Microcell
Point Orient, Richmond	Aug-06	24-35	60	4	4	0	0
Marin Rod and Gun Club	Nov-06	5-22	25	0	0	0	0
Ferry Point, Richmond	Sep-06	22-37	22	1	2	0	0
Sandpiper Spit, Richmond	Nov-06	27-43	23	0	0	0	0
Strawberry	Nov-06	32-55	51	0	0	0	0
Tiburon	Sep-Oct-06	25-44	34	2	0	0	0
Berkeley Marina	Oct-06	28-37	11	0	0	0	0
Emery Point	Jun-07	26-47	30	4	7	0	0
Fort Mason Marina	Jun-06	22-35	60	0	0	0	4
Candlestick Point	Jan-05	9-40	48	n/a	n/a	13	n/a
Candlestick Point	May-07	21-47	60	2	5	1	0
Oyster Point	Aug-06	39-47	54	1	1	8	0
Coyote Point, San Mateo	Oct-06	25-40	35	0	0	1	0
Bair Island Restoration Project	Nov-06	15-47	60	0	0	0	1
Sailing Lake, Mountain View	Jan-Feb-05	17-86	60	0	0	0	0
Total			633				

Figure 12. Locations of collections. The month and year of collection and number collected are also shown.

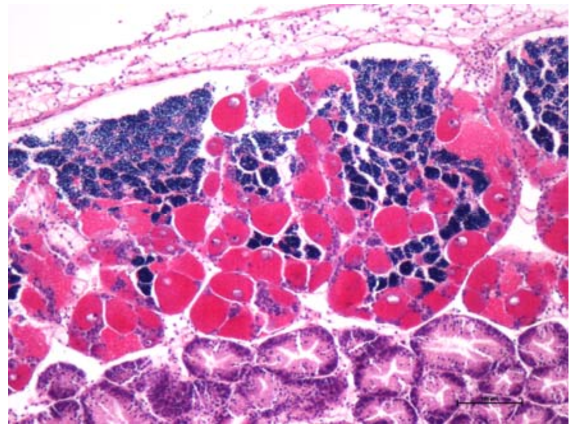


Figure 13. Typical hermaphroditic gonad encompassed by mantle above and digestive gland below. Strawberry, Tiburon, November 2006.

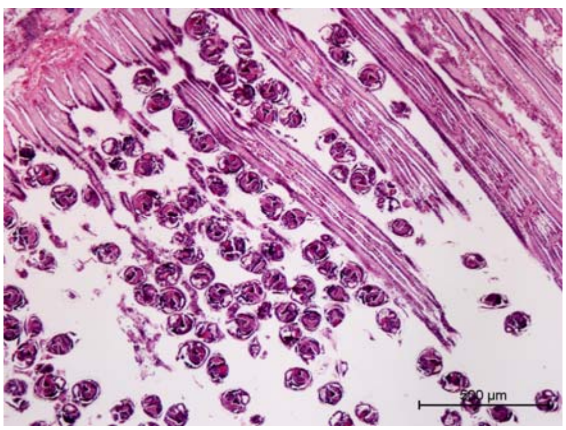


Figure 14. Brooded larvae residing between gill filaments. Point Orient, August 2006.

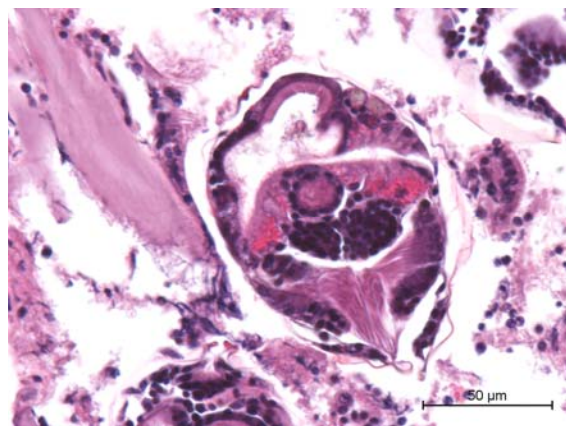


Figure 15. Brooded veliger larvum, Point Orient, August 2006. Arrow points to velum.

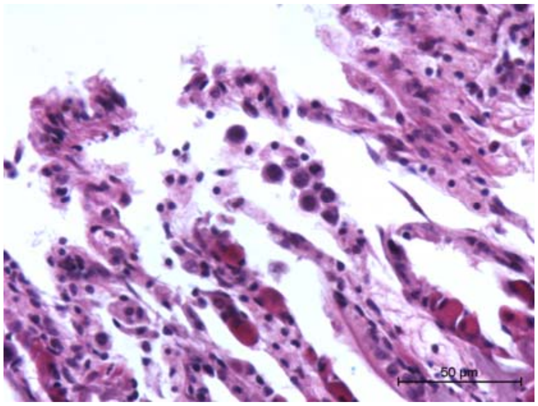


Figure 16. Disseminated neoplasia, Candlestick Point, May 2007. Gill tissue. Long thin arrow points to neoplastic cell, short arrow points to normal hemocyte.

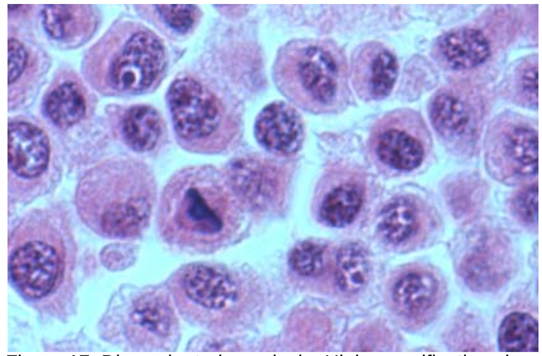


Figure 17. Disseminated neoplasia. High magnification showing mitotic figure (long arrow) and prominent nucleoli (short arrows).

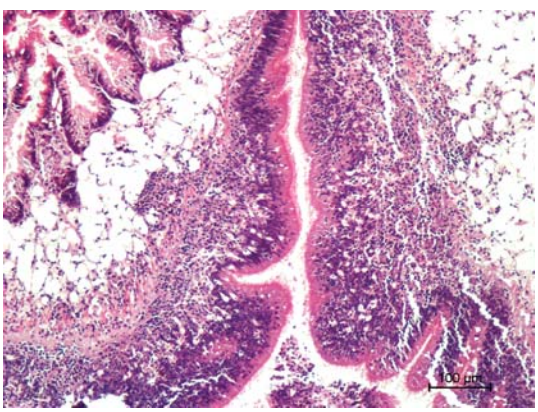


Figure 18. Portion of intestine infected with microcell. Fort Mason Marina, June 2006.

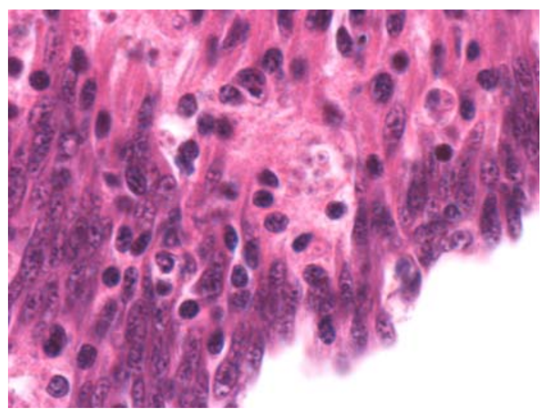


Figure 19. Microcell parasite in intestine (arrow). Bair Island, November 2006

Outcomes of the California Native Oyster Workshop (2007)

Background

The California Native Oyster Workshop was held Tuesday, July 24, 2007 from 8 a.m. to 5 p.m. at the Marin Rod and Gun Club in San Rafael. The workshop was sponsored by UC Davis, the California Coastal Conservancy and the California Ocean Protection Council to document the current status of native oyster populations, including the influences of predators, competitors and pathogens; provide updates on current SF Bay oyster restoration projects; begin a five-year plan for oyster restoration; and develop recommendations for the SF Bay Subtidal Habitat Goals Project.

Table 7. List of attendees for the California Native Oyster Workshop.

Name	Organization/Affiliation
Robert Abbott	MacTec
Sarikka Attoe	UCD
Andrew Beahrs	
Erin Bomkamp	BCDC
Kathy Boyer	SFSU
Bree Candiloro	Save the Bay
India Clarke	UCD
Andy Cohen	SFEI
Natalie Constantino-Manning	NOAA
Kerri Davis	BCDC
Anna Deck	UCD
Abe Doherty	Coastal Conservancy
Nancy Ellis	Randall Museum
Brenda Goeden	BCDC
Toby Garfield	RTC
Ted Grosholz	UCD
Jessica Hamburger	BCDC
Richard Jenkins	Richardson Bay Audubon Center
David Kimbro	UCD
Marilyn Latta	Save the Bay
Melanie Lopes	Save the Bay
Eric Loveland	SFSU
Austin McInerny	Center for Collaborative Policy
Todd Meyer	Marin Rod and Gun Club
Jim Moore	BML-CDFG
Wendy Norden	Richardson Bay Audubon Center
Rena Obernolte	MacTec
Chris Raleigh	CICORE
Beth Schriock	Richardson Bay Audubon Center
Ashley Smith	SFSU

Carla Stedwell	Richardson Bay Audubon Center
Laura Wainer	Save the Bay
Sumudu Welaratna	SJSU
Chela Zabin	UCD
Jon Lew	Tamiscal High School
Gavin Archibald	SFSU
Ben Beckes	NPS
Peter Schwalbenberg	
Gwen Conahan	RTC
Jessica Donald	RTC

Workshop Summary

1. Welcome, Introductions and Workshop Overview

Todd Meyer, president of the Marin Rod and Gun Club, welcomed attendees to the event. Austin McInerny, facilitator from the Center for Collaborative Policy, gave an overview of the agenda. Abe Doherty of the California Coastal Conservancy, a member of the Administrative Core Group of the San Francisco Bay Subtidal Goals Habitat Project, discussed how the workshop will help identify priorities for funding native oyster restoration programs around San Francisco Bay. Natalie Cosentino-Manning of the NOAA Restoration Center said her organization is the federal partner with the Conservancy in providing restoration funding and in working to develop management goals for the bay.

2. Overview of Current Knowledge and Restoration Efforts

The morning session was devoted to presentations by researchers and restorationists on various aspects of native oyster history, ecology, monitoring and restoration. Presentations were 15 minutes long, with five minutes afterwards allocated for questions. PowerPoint files of each presentation are available. A summary of the question/comment and answer sessions for each of the presentations follows.

Andy Cohen, San Francisco Estuary Institute

<u>Oyster History and Oyster Restoration</u>

Q: What is appropriate salinity?

A: 17 parts per thousand up to 29 parts per thousand, depending on the season and timeframe.

Q: What is the date of the lower layer of the shellmounds?

A: Most of the work was in the early 1900s, work since then has been reanalysis. It should be looked into.

Q: Bay dredging – there have been leases for 15 tons per year, do you know what the sources could be?

A: The sources: 1) could be ancient – Pleistocene era; 2) some of the leases could be on shellfish beds, it may be based on cultivated beds, Eastern, Japanese.

Q: Do you think there ever was the amount of oysters in the bay we imagined?

A: There are some massive shell beds in the bay. What period of time they accumulated, we don't know. Some have been dated geologically. That needs to be figured out.

Ted Grosholz, University of California, Davis
<u>Overview of Native Oyster Ecology and Restoration</u>
Q: What kind of data is your conclusion based on of no subtidal populations?
A: I'll save the answer – other presentations will present the data in more detail. Basically, after a lot of looking, we came up empty-handed. Again, this year was a very bad year for oysters.

Jim Moore and Christy Juhasz, Bodega Marine Lab
<u>Health Assessment of *Ostrea conchaphila* in California</u>
Q: Fish diseases – do you think the oyster is a harbor for those diseases, or other species?
A: Probably other species are harboring it.
Q: Is Neoplasia found in gigas?
A: Neoplasia has never been described in gigas. It could be a non-native introduced disease, but if you look at the range of this disease, I think it is naturally occurring.
Q: The Candlestick site is curious, why such high prevalence, it's a particularly stressed site, it's near Hunters Point.
A: You saw it's also high in Drake's Estero. It is equally found in pristine and non-pristine sites. It does not appear to be stress induced.
Q: What are the visual signs?
A: Extremely watery, almost no meat there. They look emaciated.
Q: What other species affected, and how?
A: It occurs in areas with bivalves of high density. The populations are completely separate. There is some controversy that it could be a retrovirus.

Sarikka Attoe, University of California, Davis
<u>San Francisco Bay Native Oysters: How Are They Doing?</u>
Q: As far as competitors, Asian clams eat the same food.
A: (Ted) There are not many Asian clams in SF Bay, there's not a lot of distribution overlap.
Q: For recruitment, what's your level of confidence in the methods you used?
A: Oysters like the PVC tiles, and then we sanded off rocks and haven't found anything. I think there is not enough recruiting.

Chela Zabin, Smithsonian Environmental Research Center
<u>Native Oyster Populations in San Francisco Bay: Lessons for Restoration and Next Steps</u>
Comment/Suggestion: I'd caution you – I've found populations on floating docks to be a poor indicator of subtidal populations, conditions differ. Your map of subtidal sampling – the main areas where there were historic populations – that area was not sampled, it's further north in South Bay.
A: I would suspect we have subtidal populations, would target from Coyote Point to Candlestick Park, then offshore of the Richmond sites.
C: They may or may not be related. I would look where historic sites were.
A: Yes, but I would suspect those would be good places to look.

David Kimbro, University of California Davis
<u>Invasive Species Deplete Tomales Bay's Olympia Oysters by Eliminating Trophic Cascades</u>

Q: What is the non-native crab eating?
A: It's not a specialist like the native crab, it's a generalist – it loves clams, mussels, algae...
Q: Can this be translated to SF Bay?
A: No. Other efforts would be the first step. We've been researching in Tomales Bay since 2002. You compile the data first. In SF Bay, it didn't seem like they were finding any drill holes.
C: In 20 years, we hardly ever found a drill hole in an oyster in SF Bay.

Sumudu Welaratna, San Jose State University
<u>San Francisco Bay Native Oyster Recruitment Study at 2006-07 and the Development of Shared Protocol for Oyster Monitoring Efforts in San Francisco Bay</u>

Q: The recipe you're using - how long does it last before it degrades?
A: We hope one year or longer. We will see.
Q: Did you try different recipes?
A: We tried different recipes, now we're using Portland cement. In one month, it's starting to degrade already.

Robert Abbott, Rena Obernolte, Brian Mulvey, Mac Tec, Inc.
<u>Olympia Oyster Habitat Construction Methods and Results: 2005-2007</u>

Q: Are the reefs imitating some kind of structure that was there originally?
A: There used to be a lot of complexity to the substrate historically, it's very altered.
Q: Your recommendation about Sailing Lake – it's pretty unique.
A: It should be looked at – I've heard anecdotal discussions – at Lake Merritt, on the trash racks, there are oysters. Peacock Gap Lagoon, the duck pond by Redwood City, they might harbor vestigial populations.

Newell Garfield, Dale Robinson, Chris Raleigh, Dwight Peterson, Jim Pettigrew and Regan Long, CICORE and COCMP Program, Romberg Tiburon Center, San Francisco State University
<u>An Integrated Observing System for San Francisco Bay. Developing Products That Integrate Many Data Sources.</u>

Q: About the salinity relation to die-off…
A: It was local discharge, not from the Sierras.
Q: The salinity dropped through April/May, it got to as low as between 0 and 5.
A: That was from the larger reservoirs. But the initial drop was all local.

Marilyn Latta, Save the Bay
<u>Volunteers on the Half Shell! Native Oyster Restoration in San Francisco Bay Using Community Volunteers</u>

Q: Have there been efforts to artificially raise spat?

A: Yes. We don't want to unless we know we can't do it naturally. (Others:) We don't want to do it if it could affect the genetic structure. We could raise some in Bodega Bay, strictly in quarantine, but that would be a route to small-scale work until we have a facility in SF Bay.

3. Public Involvement in Restoration

During this portion of the workshop, facilitator Austin McInerny worked with workshop participants to brainstorm ideas for increasing public awareness of native oyster restoration in the three following areas:

- **Define the Messages We Want to Communicate**
- **Discuss and Identify Best Methods for Communicating Messages**
- **Identify Sources of Program Funding**

Ideas were posted on charts as the brainstorming session progressed. The chart contents are listed below.

Define the Messages We Want to Communicate

- Restoring native oysters will increase biodiversity
- Manage expectations
- Foundation species
- Oak tree/forest synonym
- Giving a home to those who don't have a home
- Observe blank stare & reframe
- The bay's alive – living
- Oysters filter the water – cleaning
- Building a healthier bay
- Restoring native oysters will increase the health of the bay
- Interaction with bay – rolling up our sleeves & doing work with the bay
- Modern-day incarnation of deep interaction that used to be here
- Bay has been here a long time – will be
- Interesting aspect: anthropomorphize, charisma (honeybee)
- Draw connection to characteristic mega-fauna: salmon, herring, sea lion

- Interesting trivia/facts: hermaphrodite, brood young, filter
- Process of restoration: active learning, community building
- Community building: people & oysters
- Response to apathy: things do change – it's about quality of life; learning
- Fishery: give this message outside SF Bay
- Fishery as central message: SF Bay – long-term effort – people can take food from bay. 50 year plan: to eat one
(Some participants expressed concerns about this message)
- Use fishery issue as platform to talk about pollution
- Response to filtering concern: different parts of bay need different strategies. "It's okay in this part of bay"
- To urban kids: make <u>animal</u> exciting
- Transgendered!

<u>Discuss and Identify Best Methods for Communicating Messages</u>

- Catchy phrase – keep it simple
- Media danger: <u>misunderstood</u>
- Commonwealth Club – nontraditional groups
- Classroom educational materials & coupled with volunteer activity
- Jerry McEwan(sp?) & Natalie as resources: <u>media specialists</u>
- Flyer with fishing license, boating license
- Don't assume audience is simple: complex message told clearly works
- Think of different generations of audience
- YouTube
- "Non-native" message – consider ethnic sensitivity

- Target the expert reporters
- Easy ends – talk with museum people to understand their display desires
- Watch card (like Monterey Aquarium seafood)
- Oystermobile – aquarium car to schools
- Mascot: "Ollie the Oyster," "Oscar the Oyster"
- Gastronomic (boat?) tour of edible oyster fisheries
- Gay Pride Parade float

Ideas from first brainstorming session that fit here as well:

- Interesting aspect: anthropomorphize, charisma (honeybee)
- Draw connection to characteristic mega-fauna: salmon, herring, sea lion

Identify Sources of Program Funding

- Private: oyster industry

(Time ran out on this item.)

4. Developing the Future Plan for Oyster Restoration

Four Restoration Questions: Abe Doherty of the California Coastal Conservancy and Natalie Cosentino-Manning of the NOAA Restoration Center gave an introduction to the San Francisco Bay Subtidal Habitat Goals Project. The Project is considering lower intertidal and subtidal areas of the bay, looking at management, restoration and science, and attempting to arrive at goals for those three areas. The project is expected to be finished in late 2008. This afternoon's exercise will help in the goals development process. The Project is developing recommendations both for the entire San Francisco Bay, as well as three discrete subregions: the South Bay, which is defined as anything south of the Bay Bridge; the Central Bay, from Point San Pedro to Point San Pablo, and San Pablo Bay. Participants are asked to provide as much detail as possible at a regional level.

In order to develop habitat goals for native oysters in San Francisco Bay, Doherty and Cosentino-Manning asked workshop attendees to help the Project by answering the following four questions:

1. What are the major or unique features that influence native oyster survival and distribution?
2. What are the specific geographical recommendations for restoration/enhancement of native oysters (locations that may be suitable for restoration and have reasonable ease of access and support of the subtidal owners)?
3. What are the potential restoration benefits from restoring native oysters?
4. What are the possible constraints and concerns regarding native oyster restoration?

McInerny passed out sheets of papers listing the four questions with space to jot down thoughts. He asked participants to brainstorm individually, using the worksheet, for five minutes. Then attendees circulated among four stations, one for each question, writing their ideas on charts posted at each of the stations. Participants were asked to place a checkmark next to ideas of others' that they supported. After this portion of the exercise was complete, participants were each given a limited number of colored dots (5 dots for all questions except the more complex Question 1, which was allocated 6 dots) and asked to vote for their top ideas by placing a dot next to each one. The group then reviewed the results at each station. At this time, some repeated or very similar answers were consolidated, and at the station for Question 4, two new answers were added. The results are shown in the tables below, ranked by number of votes.

Results:

1. What are the major or unique features that influence native oyster survival and distribution?

Answer	Subregion	Checks	Dots
Lack of hard substrate	South of Dumbarton Bridge San Pablo N China Camp –S Mare Island	3	13
Competitors: Too many barnacles/mussels can kill oysters Algal cover Also tunicates & bryozoan competition especially in South Bay		1	9
Threat of low salinity→ die off	San Pablo Bay Central Bay (somewhat)	3	8
Little recruitment		1	8
Altered hydrology/ loss of wetlands to reduce catastrophic freshwater events		0	8
Scour/sedimentation		3	7

Local pops that are large enough to reproduce	Central Bay South Bay	0	4
Oyster drills in higher abundance Other predators	South Bay Tiburon	3	3
Flow and export of larvae within & outside ("Lost") of SF Bay		2	2
Stress (temp, salinity, sediment burial)		2	2
High flow and rocky substrate	Central Bay Coyote Point	0	1
Disease in some locations		0	1
Allee effects: current adult density is too low to create consistent fertilization & recruitment		0	0
No upstream population		0	0
Low flow (no circulation)	South Bay	0	0
Pollution hotspots, general pollution		0	0
Rocky cobble substrate		0	0

2. What are the specific geographical recommendations for restoration/enhancement of native oysters? – Be specific.

Answer	**Subregion**	**Checks**	**Dots**
Angel Island	West Central Bay	3	11
Marin Rod and Gun Club	North Central	2	11
Oyster Point	South Bay	2	9
South Bay Salt Ponds		1	9
Point Orient/Ferry Point	East Central Bay	1	8
Romberg Tiburon – Subtidal lands that Toby mentioned		1	5
CDFG Lands (Eden Landing Hayward, Corte Madera Ecological Reserve)		0	4
Alameda		0	3
Emeryville Crescent/Radio Beach		1	2
Port of Oakland (Radio Beach, MLK Shoreline, Oyster Bay)		0	1
EBRPD Lands (Middle Harbor, Oyster Bay)		0	1
Coyote Point Marina		0	1
Mission Creek – SF		0	0

3. What are the potential restoration benefits from restoring native oysters?

Answer	**Subregion**	**Checks**	**Dots**
Physical structure, including: Foundation species – increase benthic diversity up to 47 small invertebrate species ↓? facilitate fish biomass + diversity		2	15

Increased substrate for spawning – herring, gobies			
Community education			8
Ultimate restoration of Bay food webs. – some evidence of surf scoters consuming oysters but also other invertebrates associated with oyster beds		3	6
Bring Bay to more natural state			6
Shoreline stabilization? "Living shorelines"			6
Enhance (potentially) adjacent eelgrass Other habitats	Central Bay	3	5
Native species presence resists invasion by non-natives/successfully compete with invasives			5
Idea of a potential fisheries supports efforts to reduce pollution			5
Oysters can serve as monitors for water quality through tissue samples			4
Increase light penetration/water quality	San Pablo North Bay South Bay	1	2
Possible future food source (oysters themselves) Plus increased food chain cascades			2

4. What are the possible constraints and concerns regarding native oyster restoration?

Answer	**Subregion**	**Checks**	**Dots**
Funding/sporadic funding ▪ For restoration itself (7) ▪ For long-term monitoring + assessment of projects (5)		0	12
Not enough knowledge of biology			11
Low recruitment (Could be moved to Question #1)	North, Central, South		8
Lack of substrate (Could be moved to Question #1)	North + South Bay		5
Timelines that are hard to align: funding cycles with planning, permitting, restoration, seasonal monitoring, volunteer schedules			5
Need techniques that can be scaled up in size/area			5
Land ownership	North Bay: Richmond shoreline, Chevron properties hindrance due to homeland security	1	4

	issues; Central Bay: Tiburon/Belvedere, private subtidal ownership		
Not entirely sure if it is ever possible to create a dense, self-sustaining pop in SF Bay when none of us have ever seen one there			3
Regulatory process: Fill/structures require permits Substrates & materials should not be harmful to the bay Potential for programmatic permit or standardized guidelines			2
Difficulty in demonstrating/proving exact ecosystem services/functions *subset of biology issue			2
Need group discussion with whether to use cutch (concerns with genetics + disease/parasite transmission) if proceed/is agreement, need local facility to grow culture			1
People will eat them + be exposed to toxins			0
Difficult to agree on a "biodegradable" substrate we can feel good about putting in the Bay in sort of large quantities			0
Angry public			0
Pollution + safety concerns for using volunteers + for welfare of restoration staff			0
Ease of access to sites			0
Competition between priorities/species (added later)			
Media attention (added later) tough			

Discussion of Restoration Question Results:
Question 1: The group discussed whether the results were odd or surprising in any way. One participant noted that until recently, disease would have been considered a major factor, but the research findings discussed in the morning session are showing so far that it is not so important.
Question 2: Participants identified different reasons for their votes – some people valued opportunity to access a site; others prioritize the opportunity for restoration and biology. The question was asked whether there is a preference for doing restoration at sites that look good, or at sites that need help to be restored. Some participants prioritized sites that have mud instead of a hard substrate.
Question 3: One participant said it was interesting that increased light penetration/water quality didn't get as many votes.
Question 4: At the end of the review, one participant added two new items to the list.

Developing the Vision for a Five-Year SF Bay Oyster Restoration Plan: The attendees then discussed the next steps toward developing a five-year restoration plan, and the potential definitions of success for such a plan. Results from brainstorming on these two questions were charted.

Discussion: Among the issues raised in the discussion, one participant said there may need to be a prioritization for species bay-wide, as there could be competition for funding with restoration and management of other species.

It was noted that many of the projects are ending soon, and there is a need for funding for continuing research and experimentation. The big issue is recruiting substrate.

Questions were raised about how quantitative a definition of success would need to be to satisfy funders, given the scientific and management uncertainties. Would a success definition of a self-seeding population be sufficient?

Abe Doherty said it would be important for the group to agree on priorities. To begin with, there are clear priorities about pursuing 1-2 acre sites, there is a need to refine techniques, and in five years, the group wants three sites. That helps articulate the need. Then after that, more quantitative metrics might be easier. Funders would like the acreage of habitat, and the size of the population would be helpful, as well. It's clear there's a need to work on techniques first, but in five years, there should be defined methods and testing at larger scales. The Baylands Goals Project established acreage goals for habitat types, and it was very successful in getting funding. Legislators look at numbers.

Ted Grosholz noted that it's difficult to make predictions without the experience of a successful project. At Bair Island, the populations haven't persisted. It will be possible to project reasonable numbers after there are 1-2 years of success, and the oysters reach a modest size. To see recruitment would be a quantum leap in success. At this point, restoration projects have not been able to make oysters settle, or make them survive.

One participant noted that at the Marin Rod and Gun Club, it looks as if a reproductive population may now be being reached, after the earlier North Bay salinity-related die-off.

One participant felt it would be possible to find an acceptable metric.

One suggestion for a possible approach was to project the numbers of acres, the acres of shoreline with rocky areas that are not colonized by native oysters, but potentially could be.

Five-Year Restoration Plan Charts:

<u>Discussion: Five Year Vision</u>

Next Steps

- 1-2 acre replicates around the Bay
  - Sediment variation
  - Use anglers/scuba

- Various configurations of materials
  - Bags
  - Balls

- Five-year monitoring

- Design for scientific significance

- "Sea-meant" or other
  - Experiment with different biodegradable materials –
  - Want natives to build
  - No plastic, rebar – potential hazards
  - No leaving footprints
  - Remove later?

- Don't scale up until materials issue resolved
- Plastics – no
- Pacific oyster shell – further study, resolve differences

- 3 larger projects in 3 bays

- Try in both healthy/less healthy areas –

- Learn lessons

- Vary:
  - Depths
  - Larger structures

- BCDC wants structures removed – no vote trigger – bay fill
  - Resolve permitting

- No need for hard substrate –
  - Burlap, etc.

- Further study Angel Island, Alameda, Point Orient – larger populations

- Choose larger public demo site

- UC Davis data in poor year – need 2nd or 3rd year of data

Discussion: Five Year Vision
Definition of Success

- No public outcry
- ↑ in oyster pop – 10%?
  - Est.'d existing pop. at 300,000
- Self-sustaining pop
  - Reprod
  - Bimodal histogram
  - Native/restored pop?
- Spillover of natural recruitment to other areas
- Increased reef-associated species
- Increased biodiversity
- No significant increase in non-native species
  - Or: Restoration does not facilitate non-native species
- ↑ perception of success, involvement by community
- Maintain or protect existing pops

No Consensus

- To define success – need research on current status of species – #s
- Concern that ambitious #s could backfire
- Use Bair, Marin RG, method: #/spat expected given size of area
- Others question whether #s possible now

Acknowledgements. We have along list of persons to thank for their cooperation and collaboration with this project. We thank the staff of the Marine Science Institute for their help and assistance and the generous use of their otter trawl for subtidal oyster surveys. We particularly thank Jackson Gentry for his cooperation and collaboration with subtidal surveys and the use of his boat for oyster dredge surveys. We are indebted to both Cordell Bank and Gulf of the Farallones National Marine Sanctuary and particulary Michael Carver for their help and assistance and use of their boat for sidescan sonar surveys. We are very grateful to Dr. Gary Greene and Eric Niven, Moss Landing Marine Lab, for the use of and technical assistance with their sidescan sonar. Our thanks to Sound Metrics Corp., Lake Forest Park, WA, for permitting a free trial use of the DIDSON (high resolution sonar). We thank many folks with knowledge and expertise of local oyster populations for unpublished observations and data including Brian Mulvey, Bud Abbott, Sumudu Welaratna, Marilyn Latta, and many others. In particular, we thank Natalie Cosentino-Manning and the staff of the NOAA Restoration Center for all their help with coastline mapping information and help and assistance with the CA Oyster Restoration workshop. We also thank Austin McInerny and Ariel Armbruster and CCC staff for their help with mediating and recording the proceedings of the workshop.

References

Baker, P. 1995. Review of ecology and fishery of the Olympia oyster, *Ostrea lurida* with annoted bibliography. Journal of Shellfish Research 14: 501-518.

Barnett, E. M. 1963. The California oyster industry. California Fish and Game Bulletin 123. 103pp.

Browning, B. M. 1972. The natural resources of Elkhorn Slough: their present and future use. California Department of Fish and Game Coastal Wetland Series #4. 121 pp.

Elston RA, Moore JD, Brooks K. 1992. Disseminated neoplasia of bivalve molluscs. Reviews of Aquatic Sciences 6:405-466.

Friedman CS, Brown HM, Ewing TW, Griffin FJ, Cherr GN. 2005. Pilot study of the Olympia oyster *Ostrea conchaphila* in the San Francisco Bay estuary: description and distribution of diseases. Diseases of Aquatic Organisms 65:1-8.

Grosholz, E. D., P. G. Olin, B. Williams, and R. Tinsman. 2001 Reducing predation on Manila clams by nonindigenous European green crabs. Journal of Shellfish Research 20: 913-919.

Grosholz, E. D., G. M. Ruiz, C. A. Dean, K. A. Shirley, J. L. Maron, and P. G. Connors. 2000. The impacts of a nonindigenous marine predator in a California bay. Ecology 81: 1206-1224.

Kimbro, D. L. and E. D. Grosholz. 2006. Disturbance influences richness, evenness, but not diversity in a native California oyster community. Ecology 87: 2378-2388.

Kimbro, D. L., Grosholz, E. D., Baukus. A. J., N. J. Nesbitt and N. M. Travis. Evolutionary history and invasive species alter estuarine trophic cascades. Ecology Letters (*in review*).

Lenihan, H. S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69: 251-275.

Lenihan, H. S., C. H. Peterson, J. E. Byers, J H Grabowski, G. W. Thayer, D. R. Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. Ecological Applications 11: 764-782.

Micheli, F., and C. H. Peterson. 1999. Estuarine vegetate habitats as corridors for predator movements. Conservation Biology 13: 869-881.

Turgeon, D. D., J. F. Quinn, Jr., A. E. Bogan, E. V. Coan, F. G. Hochberg, W. G. Lyons, et al. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks, 2nd ed. American Fisheries Society Special Publication 26, 526 pp.

USFWS and AFS-FHS (U.S. Fish and Wildlife Service and American Fisheries Society-Fish Health Section). 2007. Standard procedures for aquatic animal health inspections. *In:* AFS-FHS. FHS blue book: suggested procedures for the detection and identification of certain finfish and shellfish pathogens, 2007 edition. AFS-FHS, Bethesda, Maryland.

Zimmerman R.T., T. Minello, T. Baumer, and M. Castiglione. 1989. Oyster reef as habitat of estuarine macrofauna. NOAA Technical Memorandum NMFS-SEFC 249.