Exotic Oyster Survey, Removal and Research in San Francisco Bay

Annual Progress Report (January 28, 2008)

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Background

In June 2004 Andy Chang, a graduate student at U.C. Davis, discovered the empty, paired valves of a large oyster—considerably larger than the largest native oysters—attached to a rock near the eastern end of the Dumbarton Bridge. In late July, 2006, Rena Obernolte, while conducting a survey for native oysters, found five large live oysters in the same area. Obernolte notified us, and our initial search of the immediate area yielded another 15 large oysters. These were later identified genetically as the Pacific Oyster *Crassostrea gigas*, which is native to Japan and not native to the west coast of North America.

Following our initial survey we began contacting staff at relevant agencies to inform them of the discovery and to determine what, if anything, should be done about it. Oysters produce enormous numbers of tiny drifting larvae, and normally it would appear to be a hopeless task to try and eradicate an introduced oyster population. However, exotic oysters had been reared in the Bay in large numbers in the past and had rarely reproduced here; so if the conditions in the Bay were not particularly hospitable to reproduction by these exotic oysters, and if the current population was relatively small and limited in distribution, it seemed that it might be possible to remove a substantial portion of the population and reduce the likelihood that the oyster would become permanently established. We were encouraged by agency staff to do what we could. With much contributed assistance--CDFG, USFWS/Don Edwards and CalTrans helped us get the necessary permits quickly; USFWS/Don Edwards and USGS provided airboats, a boat and crews; and students, researchers and others provided help in the field--we mobilized an effort to survey and collect oysters during the last good low tides of the season, in the first half of August 2006. The San Francisco Bay Joint Venture (SFBJV) provided a small amount of rapid funding to defray some of the costs.

In September 2006 we convened a meeting of interested agencies and organizations to discuss what we found and decide what further should be done (Table 1). At that point we had collected over 250 large exotic oysters on the southeastern shore of the Bay from the Hetch Hetchy Pipeline to about a kilometer south of the San Leandro Marina, a distance of about 22 kilometers, along with a couple of outliers at Foster City and Richmond. Most were found in the 16 kilometers from just south of the Route 84/Dumbarton Bridge to Hayward Landing. All of these were collected in the intertidal zone near the shore (that is, not out on bridge supports or other structures near the center of the Bay), within an estimated tide range of around 0-6' above MLLW. This

suggested that they were not present subtidally. They also were not present in great densities, and although their range covered most of the eastern shore of the South Bay, there are no ports, marinas or natural hard substrate in this area, and thus relatively little suitable substrate for oysters. Thus, it seemed feasible to find and remove a large portion of the remaining oysters.

Table 1. Participants in the September 11, 2006 planning meeting

Participant	Affiliation
Rachel Barnett	California Department of Water Resources
Marcia Brockbank	San Francisco Estuary Project; also there on behalf of the San Francisco Bay Regional Water Quality Control Board
Andrew Cohen	San Francisco Estuary Institute
Natalie Cosentino-Manning	National Oceanographic and Atmospheric Administration
Abe Doherty	California State Coastal Conservancy
Jennifer Feinberg	San Francisco Bay Conservation and Development Commission
Julie Horenstein	California Department of Fish and Game
Mike Koslosky	Hayward Area Parks and Recreation District
Susan Ma	US Army Corps of Engineers
Lia McLaughlin	US Fish and Wildlife Service
Tom Moore	California Department of Fish and Game
Caitlin Sweeney	San Francisco Bay Conservation and Development Commission
Mark Taylor	East Bay Regional Park District
Claire Thorp	National Fish and Wildlife Foundation

The consensus of the meeting was that SFEI should try to survey and remove the oysters and investigate certain key questions. No other agency or organization was available to take it on. No agency had funding they could provide at that point, but the California State Coastal Conservancy (SCC) said they might be able to provide some, and NOAA, the San Francisco Estuary Project (SFEP) and the National Fish and Wildlife Foundation (NFWF) had grant competitions coming up that they felt this project would be a strong candidate for.

As described below we obtained some funding and conducted work on this problem in 2007. In January 2008 we hosted a meeting of the Advisory Panel for the project (Table 2). The Panel meeting reviewed the work to date, confirmed that the oysters posed a substantial and immediate threat to the Bay, and approved an expanded effort to survey and remove the oysters and to research certain questions about sources, vectors and factors that facilitated settlement. The meeting resulted in a statement of conclusions (Attachment 1) that also urged CDFG to help obtain funding for these efforts from the Wildlife Conservation Board and to remove or assist the removal of oysters at an illegally planted site in the North Bay.

The following report summarizes the work and findings to date, the Panel's input, and the current plans for 2008.

Table 2. Advisory Panel members

Member	Affiliation	Participant in the Jan. 14, 2008 meeting
Joy Albertson	US Fish and Wildlife Service	
Pete Alexander	East Bay Regional Park District	X
William Brostoff	US Army Corps of Engineers	
Adrian Deponte	Hayward Area Parks and Recreation District	
Abe Doherty	California State Coastal Conservancy*	X
Naomi Feger	SF Bay Regional Water Quality Control Board	X
John Finger	Hog Island Oyster Company	
Tom Hall	EOA Consultants (representing the South Bay POTW segment of the Regional Monitoring Program)	X
Beth Huning	San Francisco Bay Joint Venture	
Judy Kelly	San Francisco Estuary Project	
John Krause	California Department of Fish and Game	
Peter Lacivita	US Army Corps of Engineers	X
Marilyn Latta	Save the Bay	
Susan Ma	US Army Corps of Engineers	
Karen McDowell	San Francisco Estuary Project	X
Tom Moore	California Department of Fish and Game	
Frances Parchaso	US Geological Survey	X
Korie Schaeffer	National Oceanographic and Atmospheric Administration	X
Delmarie Snodgrass	San Leandro Marina	
Caitlin Sweeney	SF Bay Conservation and Development Commission	
Mark Taylor	East Bay Regional Park District	X
Claire Thorp	National Fish and Wildlife Foundation	
Tanya Veldhuizen	California Department of Water Resources	
Kim Ward	State Water Resources Control Board	

* Now with the California Ocean Protection Council

Available Funding

We received funding from four sources: SFBJV, SCC, NFWF and the Regional Monitoring Program for Trace Substances (RMP) that is conducted by SFEI (Table 3). There are also large in-kind contributions of services from numerous agencies and organizations, including a substantial amount (about $32,000 worth) of unfunded work by SFEI. Fundraising was more difficult and took longer than we had anticipated, and significant funding only became available this summer. By that point it was late to start planning and organizing volunteer work for the summer low tides, and we got less done this summer than we had hoped (and, as a result, more funding remaining at this point than we had anticipated).

Table 3. Funding awarded

Source	Amount	Purpose	Date Funds Available – End Date	Balance Remaining 1/1/08
SFBJV	$2,000	For partial support of survey/removal through 8/12/06	August 2006	$0
SCC	$25,000	For partial support of survey/removal, and some management costs (permit acquisition)	7/9/07* – 3/31/2008	$0
RMP	$30,000	For partial support of survey (including location of shellfish beds) and research (sample collection, genetic analysis, source analysis and age analysis)	5/11/07 – 12/31/2008	$13,530
NFWF	$46,895	For partial support of survey/removal, associated research (vector and impacts), and outreach/information dissemination (press, website, journal)	12/12/2007 – 9/30/2008	$46,895

* SCC made $2,600 available for management and permit acquisition starting 5/8/07, with the remaining funds for survey/removal ($22,400) released on 7/9/07 when all permits were in place.

The contracts and work plans for the different funding sources emphasize different aspects of the work. For example, the RMP was more interested in funding the research components and SCC was more interested in funding the actual removal of the oysters. Some of the agreements also had specific tasks that were not part of the other contracts. These, and the work completed and planned, are discussed below under the general headings of Permits, Survey & Removal, Research and Outreach/Education.

The funds remaining on January 1, 2008 appear sufficient to complete the work commitments in the contracts for the above grants. However, they are not sufficient to complete all the immediate work now considered to be a priority for 2008. Completing the high priority tasks not currently funded (see Table 7 and discussion below) is estimated to require an additional $60,000. About $15,000 of this is research that is contingent upon near-term results; that is, depending on the results obtained in the next few months, it may or may not be a priority to pursue about $15,000 of research currently considered a high priority. Completing the mid-priority tasks would require an additional $18,000, and the low priority tasks would require a further $16,000.

The reality is that we are unlikely to obtain funding quickly enough to complete all of these tasks in 2008, given that the availability of good working low tides peaks in the late spring, and there are few good low tides after the summer. On the other, if this effort is to be pursued seriously we can expect to conduct work at something about this level (ca. $150,000/year) for several years, although the tasks will require adjustment from year to year. In addition, the Panel discussed the need for an expanded scope of genetic research, which is not included in these figures.

The Panel discussed possible sources of funding. One possible source is the Wildlife Conservation Board, which recently granted $207,775 to the Bay Institute as part of a $350,000 two-year budget for work on eradicating an exotic snail from the Loch Lomond Marina area. The grant was made on a recommendation from CDFG. Since the Panel

meeting, we have been working with Abe Doherty on obtaining further funding from SCC.

Permits

We obtained the following permits for this work.

1. *CDFG Letter of Authorization*. We obtained our initial permit on August 4, 2006 authorizing the removal of exotic oysters from south San Francisco Bay on August 8-12, 2006. We obtained a new letter in June 2007 authorizing the removal of *C. gigas* throughout San Francisco Bay through December 31, 2007. The letter requires that "every effort shall be made to limit incidental collection of native oysters...removal of large aggregations of oysters smaller than 70 mm should be preceded by genetic testing if species-specific morphology is questionable." A report on the removal effort including the identity, count and length of shellfish taken is due by January 30, 2008.

2. *CDFG Scientific Collecting Permit*. Andrew Cohen has held a California Scientific Collecting Permit that includes the collection of marine invertebrates since 1992, which he renewed this year to run through 9/6/2009. The holding of a valid collection permit is a requirement of the CDFG Letter of Authorization.

3. *USFWS/Don Edwards National Wildlife Refuge Special Use Permit*. This is needed for work conducted within the Refuge. We obtained our initial permit in August 2006 for work conducted that month. We obtained a new permit in June 2007 for work through October 31, 2007.

4. *CalTrans Encroachment Permit*. This is needed for work conducted in the rights-of-way for the Dumbarton and San Mateo Bridges. We obtained our initial permit in August 2006 for work conducted that month. We obtained an amendment in October 2006 that extended the term to December 31, 2007 (and which also included permission for an SJSU student to hang oyster settling substrates from the closed fishing pier at the west end of the Dumbarton Bridge for a research project related to native oyster restoration).

In addition, we obtained the permission of individual land owners and managers for any work on or passage over the lands they own or manage.

For 2008 we will need a new Letter of Authorization from CDFG, a new USFWS Special Use Permit, and an extension on our CalTrans Encroachment Permit. Based on the strong recommendation from the Advisory Panel for an expanded effort, we plan to ask for 3-year permits/authorization from CDFG and USFWS, who we expect will be able to provide annual oversight through the Advisory Panel, and a 5-year permit from CalTrans.

Survey & Removal

The Initial Work Plan

In 2006-2007 we had proposed to survey for *C. gigas* on all suitable substrate along the shore within the primary areas (defined as the general areas within which *C. gigas* had been found, see Table 4); with surveys of selected sites in secondary areas (the rest of the Bay within *C. gigas*' potential range). Any oysters over 70 mm (2.75") in length, the typical maximum size of the native oyster *Ostrea conchaphila*, would be removed by hand. In addition a small number of smaller oysters might be removed for genetic identification. Any oysters not retained for research would be disposed of. In addition the San Mateo Bridge and power line supports were to be surveyed during minus low tides by boats or airboats provided, piloted, and partially or entirely crewed by USFWS, USGS, the California Department of Water Resources (DWR), or the City and County of San Francisco (CCSF), which had offered these services. If these surveys found that *C. gigas* extended to the lowest intertidal surfaces, indicating that it might also be occurring subtidally, the data would be reviewed with the Advisory Panel and the survey and removal plans adjusted accordingly.[1] It was expected that in subsequent years follow-up monitoring surveys would be conducted to check the effectiveness of the removal. The extent of surveys in the secondary areas and the follow-up surveys were to be determined in consultation with the Advisory Panel.

Table 4. Primary and Secondary Areas for survey and removal work

Primary Project Areas	1. Along the southeastern shore of the Bay from Dumbarton Point in the Don Edwards National Wildlife Refuge in Newark to the San Leandro Marina. 2. The Foster City shore, near the west end of the San Mateo Bridge. 3. The Richmond shore, near Hoffman Marsh. 4. The San Mateo Bridge supports and the supports for the adjacent electrical towers.
Secondary Project Areas	Remaining areas of hard substrate between the southern end of the bay and the western part of Suisun Bay, and in tributaries up to the limit of water with at least 10 ppt salinity.

Work Completed and Priorities for 2008

Summary of Work Completed

As noted above, it took more work and a longer time to obtain funding than we had expected, and as a result we completed less field work than we had hoped in 2007. We surveyed most of Primary Area 1 (southeastern shore from Dumbarton Point to San Leandro Marina) at least once, where most of the population is concentrated, and conducted a second survey over the most densely-settled reaches; did additional

[1] The adjustment might range anywhere from expanding the search subtidally, which could include the use of divers and substantially increase the cost, to aborting the effort as being too difficult.

surveys covering a part of Primary Area 2 (Foster City), where two oysters were collected in summer 2006; and did no additional surveying in Primary Area 3 (Richmond Shore), where one oyster was collected in summer 2006. We did not survey Primary Area 4, the San Mateo Bridge supports and neighboring structures, both because of limited time and because of limitations on the availability of airboats, as discussed below. We did conduct a second survey of the supports and neighboring structures on the eastern section of the Dumbarton Bridge, where USFWS was able to provide airboats. Several small, discrete stretches have been surveyed within the Secondary Area, including a brief survey at and near the site of an illegal oyster planting near San Rafael.

South San Francisco Bay

Figure 1 shows the areas that were surveyed at least once and the total number of live *C. gigas* that have been collected at these sites. In the South Bay, 451 live *C. gigas* were collected along the shore between Dumbarton Point and the San Leandro Marina, with another 7 collected from the supports for the eastern section of the Dumbarton Highway Bridge. Sections of the Primary Area on this shore that were not surveyed include some stretches of riprap between Roberts Landing and San Lorenzo Creek, and between Sulphur Creek and just south of Johnson Landing. Two points within this latter reach were surveyed: Hayward Landing (where a total of 73 oysters have been collected) and Johnson Landing (no oysters collected). These reaches are a high priority for 2008.

There are several intervening stretches of marsh along this shore. We believe there is little appropriate substrate along most of these marshes, and they are a low priority for surveying. However, aerial photographs indicate that there are significant stretches of remnant levee and presumably riprap along the bayward edge of Ideal Marsh (Fig. 2). This is a high priority, but because of the sensitivity of the marsh, we need to consult with USFWS on an appropriate time and method for surveying this site. There is also some hard substrate associated with the bridges and pipeline crossings, etc. of the sloughs and channels south of Dumbarton Point. Surveying these is a mid-level priority.

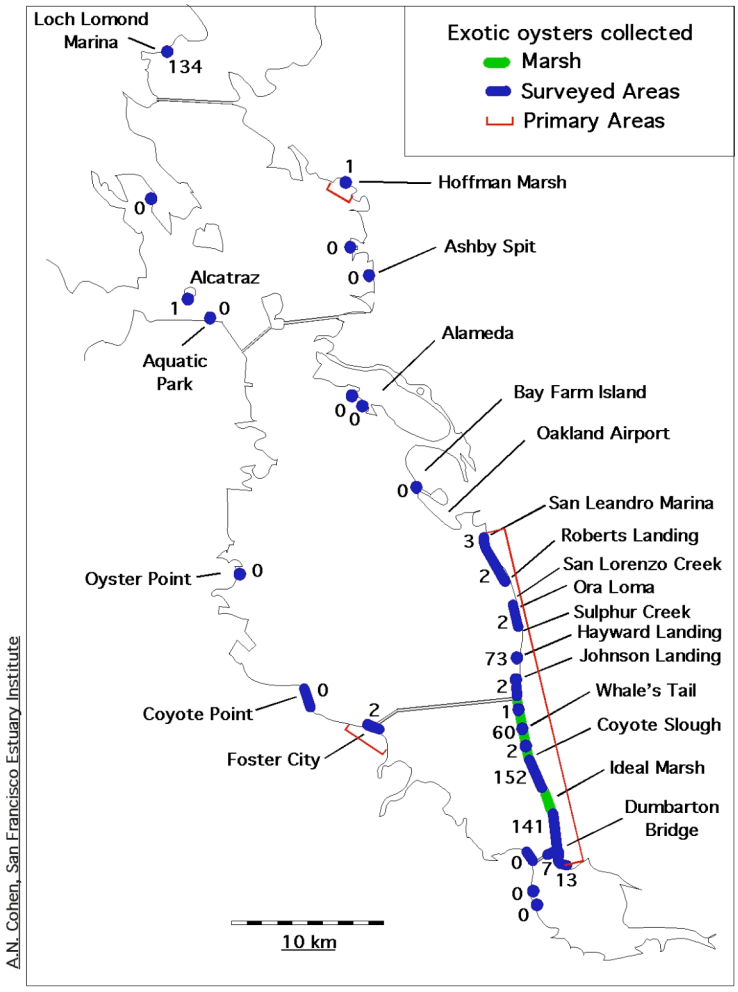
Sites where we found a substantial number of oysters in 2006 or 2007 are also a high priority for resurveying (Table 5). We propose to continue surveying sites until we collect less than about 10 live *C. gigas* per kilometer of hard substrate in a survey.

Table 5. Previously surveyed sites targeted for resurvey in 2008

Site	Approx. length of shore with hard substrate	Live *C. gigas* collected 2006	2007
Hayward Landing	0.3 km	43*	30
Eden Landing, middle section of riprap	0.3 km	ns	60
Coyote Slough to Ideal Marsh	0.6 km	78*	74
Ideal Marsh to Dumbarton Highway Bridge	2 km	115	26
Dumbarton Highway Bridge to Dumbarton Point	1.3 km	13	ns

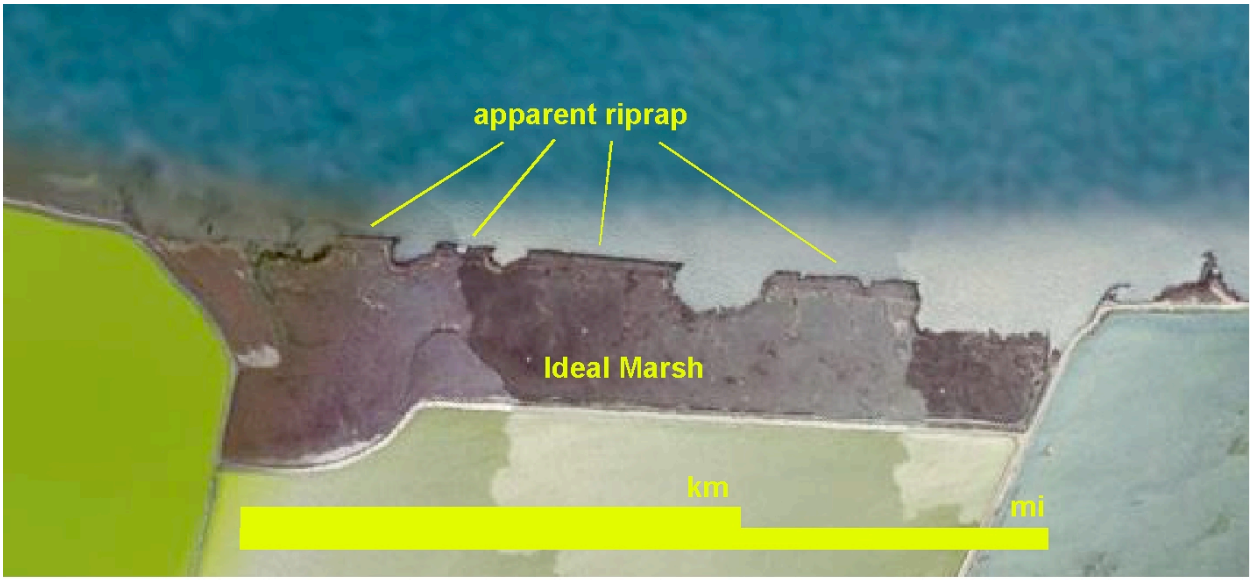
ns = Not surveyed * Surveyed part of the site.

Figure 1. Sites surveyed and oysters collected



Note: One exotic oyster was collected at Vallejo, which is not shown on this map.

Figure 2. Ideal Marsh (on the east shore of San Francisco Bay, north of the Dumbarton Bridge)



At the northern end of the Primary Area on the southeastern shore of the Bay, we surveyed probably 2/3 of the riprapped shore in and around the San Leandro Marina by foot and also surveyed the boat basin by small boat. We found 2 live *C. gigas* and 1 recently dead *C. gigas*[2] on two riprap islands (that is, rock piles) just west (bayward) of the marina. Paul Salop of AMS also found a single live *C. gigas* while conducting water quality sampling at the marina early in 2007. Completing the survey of the marina and continuing it northward around Oyster Point and the Oakland Airport is a mid-level priority for 2008. It is unclear whether security concerns will make it difficult to get permission to survey around the airport's shoreline.

In 2007 we surveyed a portion of the Foster City shore around the west end of the San Mateo Bridge that we had designated as a Primary Area, where 2 live *C. gigas* were collected by USGS in 2006. We found 1 recently dead valve attached to a small rock on shore and another recently dead valve attached to one of the concrete pilings of the fishing pier, close to shore. Surveying the rest of this reach would be a high priority for 2008, as well as some of the other hard substrate along the western shore of the Bay between the San Mateo and Dumbarton Bridges.

Both the Dumbarton and San Mateo Bridges and other structures in their vicinity (fishing piers, railroad bridge, Hetch Hetchy pipeline, transmission towers) provide hard substrate that extends well out into and/or across the Bay. We surveyed the substrate near the eastern, intertidal section of the Dumbarton Bridge in 2006 with USFWS airboats, and the structures near the channel section of the bridge with a USGS boat. In 2007 we had planned to survey the substrate near intertidal eastern and western sections and the channel section of the San Mateo Bridge, since the oysters had been found both at its western end and north and south of its eastern end. In contrast, oysters had only been found at the eastern end of the Dumbarton Bridge: the shore and airboat surveys found 4 live oysters on the bridge supports and a few recently dead oysters on the fishing pier supports but all of these were very close to the shore. None were found further out or in the channel section, and none were found in a survey of the shore near the western end of the bridge and the bridge and pier supports near the western shore that could be reached on foot. We therefore considered the western intertidal section of the Dumbarton Bridge to be a lower priority at that time.

Further consideration of the situation during 2007 made it clear that due to launching difficulties and other issues the USFWS airboats would only be able to help survey the substrates around the eastern section of the Dumbarton Bridge. So we surveyed that section again and found 3 live oysters and one recently dead oysters on the bridge supports that had been missed in 2006. Two of the live oysters were on the 5th support

[2] We interpreted fresh large oyster shells that we found as recently dead and part of the same invasions. Nearly all of these were found attached to hard substrate, as paired valves, or both. In a few locations we also found a substantial number of worn, rounded and usually discolored shells, all of which were single, unattached valves, which we interpret as shells of *Crassostrea virginica* left either from commercial oyster operations or experimental plantings in the Bay from several decades ago.

from shore, which is adjacent to the base of the fishing pier and close to shore. The other live oyster and the recently dead oyster, however, were out near the channel, on the support that is two back from the support on the eastern edge of the channel. The lowest of these was at an estimated tide level of 1.5 feet above MLLW.

Because we've now found oysters out near the channel, surveying the western intertidal section of the Dumbarton Bridge and resurveying the channel section should be a high priority along with the intertidal and channel sections of the San Mateo Bridge. The intertidal sections will be a challenge, and we can think of four possible options for surveying them:

(1) The East Bay Regional Park District (EBRPD) has purchased an airboat and is constructing a launch ramp at the Hayward shoreline. The trailer EBRPD purchased will also allow launching from some sites without a launch ramp. At the Panel meeting, Mark Taylor and Pete Alexander of EBRPD said that they would be willing to use their airboat as a training effort to survey at least the eastern intertidal section of the San Mateo Bridge, which is one of the bridge sections that is a priority for 2008.

(2) We could hire an airboat and driver or other appropriate vehicle from a commercial operator. We discussed this with Clean Lakes, Inc. of Martinez, who said they could provide an airboat and driver for $1500/day or their marsh mog, a tracked vehicle that has been used in the Bay for *Spartina* spraying, for $1800/day. Clean Lakes said they can use the marsh mog on the mudflats, but EBRPD believes that it is only effective in marshes. If feasible to use it, we believe it would have some substantial advantages (better control of speed and stopping) and some possible disadvantages (slower).

(3) We may be able to survey the bridge supports by kayaks, starting from the channel at low tide and following the rising tide in to shore. There are logistic and safety issues to be worked out, but this could be an effective approach.

(4) We could try to survey these sections on foot. We did manage to survey on foot the supports for the fishing pier at the west end of the San Mateo Bridge out to about 0.3 km from shore on a moderate low tide, and could have gone further on a good low tide, and also surveyed the bridge supports and fishing pier supports at the west end of the Dumbarton Bridge out a fair way from shore. But the distances to be surveyed are considerably larger than this, and it is difficult and potentially somewhat dangerous to go out that far on foot. A substantial part of the distances shown in Table 6 are exposed mudflats or very shallow water at the lowest tides, and thus cannot be surveyed by a normal boat at these tides. In addition, some of the structures, especially the large highway bridge supports, have areas of scour around them that retain pools of water at low tide or are partially filled with extremely soft mud, making approach on foot even more challenging.

Table 6. Estimated distance from shore to the end of the structure or channel

Structure	San Mateo East	San Mateo West	Dumbarton East	Dumbarton West
Highway Bridge	6.0	1.3	0.9	0.8
Fishing Pier	–	1.2	0.6	0.7
Pipeline	–	–	–	0.8
Railroad Bridge	–	–	0.3	0.8

The channel sections of both highway bridges and the nearby structures can be surveyed by boat at low tide, and several agencies (USGS, DWR, CCSF) have offered to provide boats and crews for this purpose. USGS surveyed the channel section of the Dumbarton Bridge and nearby structures in 2006, and found no *C. gigas*. We feel this section should be resurveyed, however, because (1) in places the structures were fouled with sponges, tunicates, etc. and were difficult to examine thoroughly, (2) the bridge supports next to the channel are clad in a wooden cribwork which makes them very difficult to examine thoroughly, and (3) we have now found 2 exotic oysters (1 live, 1 recently dead) on a bridge support near the channel. In the past we sampled the fouling on the bridge supports' wooden cribwork by free diving from boats, and we probably need to use divers if we are going to examine these effectively. Both the San Mateo and Dumbarton channel sections are a high priority for 2008.

In addition, there are in a few places wrecks or possibly other small sites of substantial hard substrate that are out on the mudflats a considerable distance from shore. We have not yet tried to locate or examine these, but we consider them a mid-level priority. The access issues are similar to those for the intertidal portions of the bridge structures.

North San Francisco Bay

In 2006 an illegal plant of *C. gigas* was discovered in the intertidal zone below a residence located across a slough from the Loch Lomond Marina in San Rafael. Tom Moore at CDFG discovered that the resident had purchased *C. gigas* seed oysters from the Coast Oyster Company in 1999. The resident, at least initially, claimed that the oysters were his, but denied any responsibility for the planting. No enforcement action was brought (T. Moore, pers. comm. 2007). Fifty-six large oysters collected from the site by CDFG are in a freezer awaiting examination by the CDFG shellfish pathologist (J. Moore, pers. comm. 2007). In late 2007 we visited the site and collected 78 large oysters that appear to be *C. gigas*. While there, we were warned by a neighbor that the resident is a gun-carrying paranoid who had surveillance cameras trained on the beach and has threatened to shoot anyone stealing his oysters. We did not stay at the site long and did not walk the whole site, but there appeared to be a very large number of large oysters there. Most of these were unattached, but a significant number were attached to Franciscan bedrock that outcrops at this site or to boulders or cobbles eroded from the bedrock (including a few clusters attached to rocks). Of the 78 we collected, 66 were unattached and 12 had been attached singly or in clusters to the rocks. We also incidentally collected 16 small oysters (6-24 mm long) that had settled on the large settled oysters. It's unclear from their morphology whether these small oysters are the native *O. conchaphila* or the exotic *C. gigas*.

We surveyed the riprapped outer shore of the marina across the slough from the residence, and did not find any large oysters.

Given the evidence of substantial settlement, we believe this site should be a high priority for removing large oysters and genetically identifying a sample of the smaller ones that are present. Given the circumstances, this could be done entirely by CDFG; but we would be willing to help if there were an appropriate law enforcement presence to ensure the safety of workers (and would like to be present to assess the degree of settlement and possibly collect additional samples for testing). If this site were cleaned up, we would also make it a high priority to survey nearby stretches of hard substrate.

In 2005-2006, we collected three other large oysters at three scattered sites in the North Bay: Richmond, Alcatraz Island and Vallejo. If the Loch Lomond site is cleaned up, we would make further surveying around these sites a mid-level priority, along with other selected hard substrate sites around the North Bay.

A summary of the priorities for survey and removal work in 2008 for the entire Bay is provided in Table 7.

Shellfish Beds

The work plan for the RMP portion of the funding includes noting the location of any significant beds of edible shellfish that are encountered, which were primarily expected to be epifaunal hard substrate species (*O. conchaphila*, *Mytilus* spp. and *Geukensia demissa*). We provided volunteer surveyors with a photo guide to these species, and ask them to note any beds that they saw (Attachment 2). We defined a shellfish bed as an aggregation of sufficient size and density that it could support repeated recreational harvesting. We observed a few modest beds of *G. demissa*; a bed of *Mytilus* sp.; some populations of live or dead *O. conchaphila* which are probably not large enough to meet our definition of shellfish bed, but which we included because they are among the largest populations of *O. conchaphila* that we have seen in the Bay; and a couple of sites where the number of *Mya arenaria* or *Venerupis philippinarum* shells suggested that a bed of these infaunal clams was nearby. These are mapped and described in Attachment 3.

Table 7. 2008 exotic oyster survey and removal priorities

Priority	Site	Comment
SOUTH BAY		
High	Riprap sections from Roberts Landing to San Lorenzo Creek	Not yet surveyed.
High	Riprap sections from Sulphur Creek to just south of Johnson Landing, including Hayward Landing	Either not yet surveyed, or significant numbers of exotic oysters found in the last survey.
High	Eden Landing, middle section of riprap	Significant numbers of exotic oysters found in the last survey.
High	Coyote Slough to Ideal Marsh	Significant numbers of exotic oysters found in the last survey.
High	Bayward edge of Ideal Marsh	Need USFWS approval of survey plan.
High	Ideal Marsh to Dumbarton Highway Bridge	Significant numbers of exotic oysters found in the last survey.
High	Dumbarton Highway Bridge to Dumbarton Point	Significant numbers of exotic oysters found in the last survey.
High	Foster City shore	
High	Selected hard substrate on the Bay's west shore between the San Mateo and Dumbarton Bridges	
High	San Mateo Bridge and nearby structures	
High	Western intertidal section and channel section of Dumbarton Bridge and nearby structures	
Mid	San Leandro Marina to Oyster Point	
Mid	Bridges, pipeline crossings, etc. in sloughs and channels south of Dumbarton Point	
Mid	Oakland Airport perimeter	
Mid	Wrecks, etc. exposed at low tides in the SE Bay	
Low	Marsh at the mouth of San Lorenzo Creek	
Low	Cogswell Marsh	
Low	Marsh just south of San Mateo Bridge toll plaza	
Low	Whale's Tail Marsh	
Low	Marsh just north of Coyote Slough	
Low	Marshes at and south of Dumbarton Point	
NORTH BAY		
High	Planted site near Loch Lomond Marina	Could potentially assist CDFG.
High	Hard substrate near Loch Lomond Marina	Contingent on cleanup of planted site.
Mid	Hard substrate near exotic oyster collection sites in Richmond, Vallejo and on Alcatraz Island	Contingent on cleanup of planted site..
Mid	Other selected hard substrate in the North Bay	Contingent on cleanup of planted site.

Research

Population Identity, Status, Condition & Age

We initially sent Dr. Patrick Gaffney of the University of Delaware samples of mantle tissue for genetic analysis from eight large oysters (108-160 mm long)[3] and seven small

[3] To a layperson, the normally longest dimension on an oyster, from the hinge to the opposite margin of the shell, is its length; the dimension across the shell is its width; and the dimension

oysters (12-44 mm long) that had been collected near the east end of the Dumbarton Bridge in 2006. The mitochondrial DNA (16S) sequences for the small oysters matched GenBank sequences for the native oyster *Ostrea conchaphila*, while all the large oysters came out to *C. giga*s. Since the large oysters showed some sequence variation and had a non-typical morphology (see below), Dr. Gaffney also sequenced some nuclear loci to see if the oysters were an interspecific hybrid, which they were not.

Through Dr. Ted Grosholz at UC Davis, we sent a sample of 59 live oysters to Dr. James Moore, the CDFG shellfish pathologist. He found that 57 of the oysters were female; most of these were very ripe, a few were spawned out. Only a few showed evidence of parasites or lesions.

The various biologists and taxonomists who looked at the large South Bay oysters or photos of them in 2006 pretty much all said something like "I don't know what they are, but they don't look like *C. gigas*." These oysters are extremely variable in shape, and often broader and flatter than *C. gigas* is typically supposed to be. In the draft oyster key for the recent manual of central California marine invertebrates (Coan and Valentich-Scott 2007, at pp. 820-825), these did not key out to *C. gigas*.[4] Possible explanations include the following:

a) They could be derived from a small group of cultivated *C. gigas* that happened to be more variable in morphology than usual.
b) They could be derived from wild *C. gigas* transported from Asia by shipping. *C. gigas* has been cultivated for 300 years, and our image of *C. gigas* is based largely on cultivated oysters.
c) An environmental factor may be the cause of the altered morphology, such as a parasite/disease, toxicity, or something more benign like a particular combination of the food, salinity and temperature regime found in the South Bay.[5]

In contrast, the oysters collected at the site near the Loch Lomond Marina fit the typical description of *C. gigas*. The most striking difference between the South Bay and Loch Lomond populations is illustrated in Figure 3. As can be seen, the Loch Lomond oysters are relatively narrow (largeer length:width ratio), and fit the description in the draft key of

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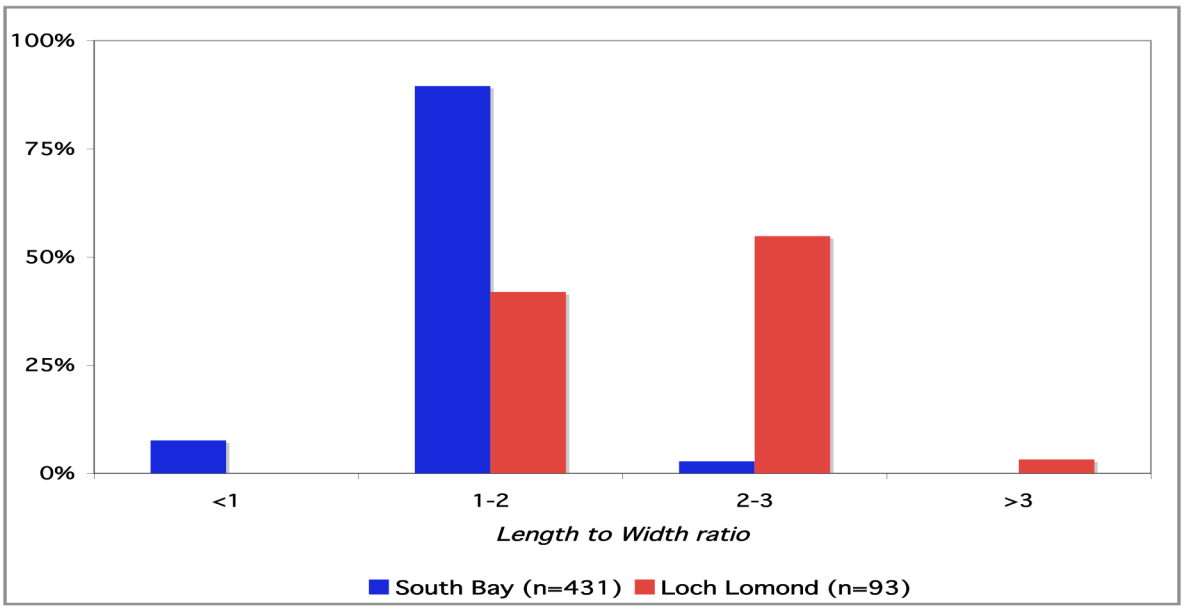
from the top of the top shell to the bottom of the bottom shell is its thickness or depth. To an anatomist or taxonomist, however, the hinge to opposite margin of an oyster is its height, across the shell is its length, and top to bottom shell is its width. With apologies to any taxonomist readers, we use the terms length and width in their lay meaning throughout this report.

[4] After we communicated this problem to the authors, they changed the key, eliminating the reference to length:width ratios discussed below.

[5] Based on observations made in 2006, we and and other researchers suspected that there were morphological differences between *Ostrea conchaphila* collected in the South Bay that year and *O. conchaphila* in the North Bay. These were not the same differences as those observed between the South Bay *C. gigas* and typical *C. gigas*, but might nonetheless lend support to the hypothesis that environmental factors were altering oyster morphology in the South Bay. However, no one has done a careful, mensurative analysis of a large series of *O. conchaphila* from the North and South Bay to confirm or reject the possibility of morphological differences.

"frequently twice as long as wide," while the South Bay oysters are substantially broader and do not fit that description. If there is a genetic basis to the different shapes of these two groups of *C. gigas* oysters, that would imply that they came from different sources and possibly by different vectors. It would also imply that the cause of recent settlement is environmental rather than genetic (see the discussion under *Potential for Establishment*, below).

Figure 3. Length:Width Ratio of South Bay and Loch Lomond *C. gigas*, by ratio classes



Knowing the ages of individual *C. gigas* from the Bay could tell us whether one or more settlement cohorts is present, whether settlement occurred at different sites at different times, and whether there are distinct settlement periods at a site. It would also allow us to estimate the growth rates of individual oysters, and give us a minimum date for the initial settlement in the Bay, which would help to narrow the set of potential source populations and vectors. Unfortunately, distinguishing annual shell rings or ridges on oysters is difficult, and estimates of the ages of adult oysters based on their size are at best somewhat rough and of limited value in a novel habitat where growth rates and size correlations are unknown. However, carbon and oxygen isotope ratios in water vary seasonally, and bivalve shells retain records of these changes that can be analyzed to determine the age of the shell, a technique known as sclerochronology. We collected a large set of *C. gigas* shells from various locations in the Bay, including representatives of both the largest and smallest *C. gigas* that we found, and sent a number of these to Dr. David Goodwin at Denison University in Ohio. Working with the Stable Isotope Laboratory at the University of Arizona, Tucson, Dr. Goodwin has developed stable isotope profiles for the shells of seven live-collected and two recently dead *C. gigas* from the South Bay. These show that there was a significant settlement of these oysters in 2002, and, tentatively, there appears to be evidence of an earlier settlement, probably in or before 1999.

The *C. gigas* attached to rocks at the planted site near the Loch Lomond Marina included some clusters in which a basal oyster was attached to a rock and other oysters were attached to it. These suggest that multiple cohorts had settled. The smallest apparent *C. gigas* that we collected at this site was on one of these clusters and measured 68 x 44 x 22 mm. The largest attached oyster collected at this site was 190 x 106 x 46 mm. Since all of these were collected in a small area at about the same tide level, and thus were subjected to the same environmental conditions, the wide size range also suggests more than one cohort. The attached live and recently dead oysters also had a substantial number of young (1st-year) oysters on them, ranging from 6 to 24 mm long. We don't know whether these are *C. gigas* or *O. conchaphila*; we saved tissue from them for genetic analysis.

Population Source & Vector

C. gigas is the common oyster of West Coast oyster farms, and though there are no oyster farms in San Francisco Bay, it could have arrived in the South Bay by a variety of mechanisms: as larvae drifting in from other bays where it is grown, or drifting south from the illegal planting near Loch Lomond Marina; as larvae in the ballast tanks of a vessel or as adults attached to the hull of a vessel; as an illegal planting in the South Bay; or as larvae spawned from oysters placed in the Bay for bioaccumulation studies. Though *C. gigas* were planted experimentally in the South Bay as recently as 1981 (Tom Moore, pers. comm. 2006), that seems somewhat too long ago to be the source of a population discovered only in the last few years.

Between 1991 and 2002, sets of live *C. gigas* were deployed in San Francisco Bay for various bioaccumulation studies. In 1991 and 1992, CDFG and the San Francisco Bay Regional Water Quality Control Board deployed *C. gigas* for 90-day periods at various sites in the Bay, including South Bay sites, as part of the Bay Protection and Toxics Cleanup Program pilot studies. In 1991-94, the Contra Costa County Sanitation District deployed *C. gigas* near the District's outfall in Suisun Bay for 30- and 90-day periods as part of the Local Effects Monitoring Program. In 1993-2002, *C. gigas* were deployed by the RMP as part of the Status and Trends Monitoring component of the RMP and for a variety or related special studies. In these studies, about 14,000 *C. gigas*, purchased from California and Washington oyster farms, were deployed for 90-100 day periods at 9 locations in the Bay, including South Bay sites. Oysters usable for genetic studies were archived by the RMP only from three cruises (April 1999, Sept. 1999 and Sept. 2000).

As described above, an illegal plant of *C. gigas* was discovered near the Loch Lomond Marina in San Rafael in 2006. These apparently derived, at least in part, from *C. gigas* seed oysters purchased from the Coast Oyster Company in 1999 (T. Moore, pers. comm. 2007).

We are investigating the source of the *C. gigas* settled in the Bay by genetically comparing the South Bay oysters to potential source populations. The genetic work is

being done by Patrick Gaffney. (His identification of the large South Bay oysters as *C. gigas* is described above.) This comparison will compare multiple (probably about 10) nuclear loci from a sample of 24 oysters from each population. We have collected tissue sample sets from the following *C. gigas* populations which we are about to send to Dr. Gaffney:

- South Bay oysters (Dumbarton Point to San Leandro Marina)
- Unattached oysters from the illegally planted site near Loch Lomond Marina
- Oysters from Taylor Shellfish Hatchery in Dabob Bay, WA; obtained from the Hog Island Oyster Company.
- Oysters from Coast Seafoods Hatchery at Quilcene Bay, WA, obtained from the Tomales Bay Oyster Company.
- Oysters from Whiskey Creek Oyster Farms Hatchery at Tillamook Bay, WA and initially reared by Kuiper Mariculture in Humboldt Bay; obtained from the Hog Island Oyster Company.
- Archived (frozen) oysters from the RMP bioaccumulation studies, 1999 wet season cruise (deployed Jan.-Apr. 1999)
- Archived (frozen) oysters from the RMP bioaccumulation studies, 1999 dry season cruise (deployed June-Sept. 1999)
- Archived (frozen) oysters from the RMP bioaccumulation studies, 2000 dry season cruise (deployed June-Sept. 2000)

In addition we plan to send Dr. Gaffney a mixed set of 24 tissue samples that will probably consist of the following:

- Attached *Crassostrea* oysters from the illegally planted site near Loch Lomond Marina (12)
- *Crassostrea* oyster collected at Vallejo on 11/14/2005 (1)
- *Crassostrea* oyster collected at Alcatraz on 11/16/2005 (1)
- *Crassostrea* oyster collected at Richmond on 8/13/2006 (1)
- *Crassostrea* oysters collected by USGS at Foster City on 8/9/2006 (2)
- Oysters collected alive in San Francisco Bay in 1971, 1977 and 1986 whose tissues are preserved in alcohol in the California Academy of Science Invertebrate Zoology Collection, and identified in the collection records as a species of *Crassostrea* (3)
- Small oysters (6-24 mm long) that had settled on the attached *Crassostrea* from the illegally planted site near Loch Lomond Marina (4)

Dr. Gaffney has sequences for these multiple loci from a small number of oysters from Hokkaido, Kyushu, Korea, Portugal (the closely related *Crassostrea angulata*), and from some inbred hatchery lines, which we will also use for comparisons. Apparently, the *C. gigas* raised in all of the oyster farms in California come from one of the three hatcheries listed above. It is unclear how distinct the genetic stock is between these hatcheries or between years at the same hatchery. Depending on the results of this

analysis, we may obtain and analyze additional samples to assess the between-year differences. We expect the results from Dr. Gaffney's analysis later this year.

Potential Impacts

There are two components to the question of potential impacts. First, what is the potential for *C. gigas* to become permanently established in the Bay? And second, how might it affect the Bay if it does become established?

Potential for Establishment

C. gigas has been commercially grown in large numbers at sites in central and northern California since the late 1920s, as well as at other sites from Baja California to British Columbia over comparably long periods. It was commercially grown in San Francisco Bay from 1932-38, and there were occasional experimental plantings in the Bay until 1981. In these commercial operations, oysters are grown to adult size and frequently spawn copiously (D. Alden, J. Finger, pers. comm. 2007). *C. gigas* has settled in large numbers and established reproducing populations at a few locations in Washington State and British Columbia, and a few settlements, possibly representing reproducing populations, have been observed in southern California and possibly Baja California. However, in all this time, there has been virtually no settlement of *C. gigas* in northern or central California. Carlton (1979), for example, reviewing all available records up to 1979, reported only eight observations of settled *C. gigas*, involving one to "several" oysters each time (Table 8). The owners of two Tomales Bay oyster farms recall seeing only "three" and "less than five" settled oysters in their many years working in that bay (D. Alden, J. Finger, pers. comm. 2007). The California Academy of Sciences database contains only one record of a *C. gigas* collected live in San Francisco Bay.

Table 8. Planting and settlement of the Pacific Oyster *Crassostrea gigas* in northern and central California

	Plantings of *C. gigas*	**Records of Settled Oysters**
Humboldt Bay, CA	1953-present	• 1 in 1962 • 1 in 1969 • 6 in 1974
Bodega Bay, CA	1932-38	
Tomales Bay, CA	1928-present	• 1 in 1978? • "some" in the 1970s • "several" in 1974 • 3-5 in recent decades
Drakes Estero, CA	1932-present	• "several" in 1949
Bolinas Lagoon, CA	1955-?	
San Francisco Bay, CA	1932-39; to 1981	• 1 in 1977 • ≈500 collected in 2006-07
Elkhorn Slough, CA	1929-36, 1946, 1950s?	
Morro Bay, CA	1932-present	• 1 in 1942

Sources: Bonnott 1938; Barrett 1963; Berg 1969; Carlton 1979; CAS IZ #3307; T. Moore, J. Finger, D. Alden, pers. comm. 2007

With this background, the recent collection of nearly 500 settled *C. gigas* in San Francisco Bay at two apparently distinct sites, possibly from two different source populations, and apparently involving settlement in more than one year, is striking, and suggests that something now differs from the circumstances of previous decades. On the one hand, it's possible that the settled oysters are genetically distinct from and better adapted to central California conditions than the *C. gigas* that have been grown in central California for decades. On the other hand, perhaps conditions have changed in San Francisco Bay, making it more conducive to *C. gigas* recruitment. One possible factor is an observed change in the timing of phytoplankton blooms and an increase in phytoplankton densities in San Francisco Bay in the last decade (Cloern et al. 2006). The sudden establishment and spread of *C. gigas* after decades of farming has also been documented in Europe and South Africa (Diederich *et al.* 2005; Robinson *et al.* 2005). In any event, despite the several decades that *C. gigas* have been cultured in central California without becoming established, it no longer seems safe to assume that they can't become established here.

Potential Impacts if Established

Although *C. gigas* is valued for food, in some regions where it has become established it has spread invasively, settled in dense aggregations that exclude or smother native species, altered habitats and food webs, and harmed populations of native organisms including other oyster species. For example, in New South Wales in Australia, *C. gigas* displaces and smothers the native Sydney rock oyster which is a prized seafood species and the main focus of oyster production in the region. In 1985 *C. gigas* was listed as a noxious pest species, and was banned both in Victoria and most of New South Wales. In New Zealand, *C. gigas* had similar impacts, growing faster than the native New Zealand rock oysters, preventing them from reaching market size, and eventually overgrowing them. In the past two decades, *C. gigas* has also spread invasively in the Dutch and German Wadden Sea, where it was thought it could not establish, and is overgrowing and eliminating beds of the native blue mussel. Other reported impacts include the fouling of power plant cooling systems in the Netherlands; making shore access difficult; and cutting hands and feet.

In San Francisco Bay, *C. gigas* grows faster than the native oyster and up to four times its size. Evidence suggests it could out-compete the native oyster for food or space, overgrow them, or impair their growth with metabolites or feces (Bayne 2002; Chew 2003). It could similarly affect other epibenthic species, and by consuming and reducing phytoplankton populations, alter food webs and impact both benthic and pelagic species (Nehring 2003; Smaal *et al.* 2005; Ruesink *et al.* 2006; Diederich 2006). USGS noted that the exotic clam *Corbula amurensis* had reduced primary productivity in the North Bay, possibly contributing to the decline of fish species, and that in the South Bay "primary producer biomass is likely to be critical for the life cycle of many species. If the oyster were capable of changing the balance between light and grazing that seems to

control the phytoplankton growth rate in the South Bay, it could mean a reduction in pelagic species in the system" (Dr. Janet Thompson, USGS, pers. comm. 2006).

Many agencies and organizations are currently involved in efforts to restore native oysters and eelgrass beds in San Francisco Bay, to restore intertidal habitats and communities in salt ponds in the southern part of the bay, and to develop subtidal habitat and resource goals for the bay. The establishment and spread of *C. gigas* could threaten species that are critical to these restoration efforts and to achieving subtidal goals, harming them through competition for space or by depleting phytoplankton with impacts propagating up the food chain.

Outreach/Education

The NFWF funding includes an education and outreach component, which is to be achieved through the recruiting of volunteers, through collaborating with local organizations, by journal and news articles, and, if other funding is available for it, by creating a page about *C. gigas* and its invasion and removal on SFEI's Exotics Guide website (www.exoticsguide.org). The CDFG Letter of Authorization also requires educating field workers about the identification and biology of *C. gigas* and *O. conchaphila*.

As discussed above, workers were given information and a photo guide (Attachment 2) to help them distinguish and identify the native and exotic oysters and other common hard-substrate bivalves. They were also provided information on what we know about the *C. gigas* invasion in San Francisco Bay and the reasons for the control effort. Press coverage to date includes articles in the *San Francisco Chronicle*, *Contra Costa Times* and *San Jose Mercury News* and in an article distributed by the Associated Press; and interviewed on KGO Radio News, KTVU TV and on NPR's *All Things Considered*. Information on the *C. gigas* invasion was presented at a native oyster restoration workshop in 2006, and presentations on the shell isotope work were made at the First International Sclerochronology Conference and a meeting of the American Geophysical Union in 2007. A journal article on the shell isotope work is in preparation (Goodwin, DH, Cohen, AN and PD Roopnarine. Sclerochronological investigation of a modern biological invasion event.). I expect that we will also publish a journal article on the genetic and vector analysis, and the removal effort.

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Personal Communications

Drew Alden, Owner, Tomales Bay Oyster Company

John Finger, Owner, Hog Island Oyster Company

James Moore, Shellfish Pathologist, California Department of Fish and Game

Tom Moore, California Department of Fish and Game

Attachment 1. Advisory Panel Conclusions

Advisory Panel on the Survey and Removal of Exotic Oysters from San Francisco Bay

Summary of Conclusions

January 14, 2008

Advisory Panel members in attendance:

Pete Alexander, East Bay Regional Park District
Abe Doherty, California State Coastal Conservancy
Naomi Feger, San Francisco Bay Regional Water Quality Control Board
Tom Hall, EOA Consultants, representing the South Bay POTW segment of the Regional Monitoring Program
Peter Lacivita, US Army Corps of Engineers
Karen McDowell, San Francisco Estuary Project
Francis Parchaso, US Geological Survey
Korie Schaeffer, National Oceanic and Atmospheric Administration (by phone)
Mark Taylor, East Bay Regional Park District

Others:

John Guerreo, US Army Corps of Engineers
Andrew Cohen, San Francisco Estuary Institute
Anna Weinstein, San Francisco Estuary Institute

The Advisory Panel met on January 14, 2008 at the San Francisco Estuary Institute, and heard a report on the project from Andrew Cohen. Among the items discussed were the recent discovery of significant settlement of the non-native oyster *Crassostrea gigas* at widespread sites in the Bay, and multiple though still tentative lines of evidence that there are multiple cohorts of settled *C. gigas* in the Bay, possibly derived from separate sources. These raise the likelihood that the settled *C. gigas*, if left alone, would become established in the Bay. If the oyster were to become abundant, the impacts would include substantial alteration of intertidal and subtidal habitats; competition with native oysters and impairment of native oyster restoration efforts; probable impairment of other intertidal or subtidal restoration goals; and possible impacts on other benthic or pelagic species through reductions in phytoplankton densities.

The Advisory Panel concluded that:

- The *C. gigas* that have settled in San Francisco Bay pose a real and immediate threat of establishment, with potential large-scale impacts to the Bay. Preventing the establishment of this species is essential to restoring habitats and wildlife in the Bay.

- The survey-and-removal effort should be implemented on a larger scale and on a multi-year basis. The survey and removal goal should be: to survey all susceptible parts of the Bay and remove any *C. gigas* found; to annually resurvey and remove oysters at sites until *C. gigas* are found at densities below 10 oysters per kilometer of shoreline; and then to conduct follow-up surveys at annual or other appropriate intervals until there is sufficient cumulative negative evidence to conclude that *C. gigas* is most likely gone from the Bay.

- The research effort is also critical, to investigate source populations, vectors, and the genetic and environmental factors that have facilitated settlement. In particular, a substantially larger genetic research component may be needed to address these questions.

- Additional funding sources will be needed to support this effort. Among other potential sources, funding should be sought from the Ocean Protection Council and from the Wildlife Conservation Board (including Prop 50 funding or other sources), which is providing funds for eradicating an exotic snail from the Bay. The Panel urges CDFG to assist and support this project in obtaining funds from the Wildlife Conservation Board.

- Removal of the large number of illegally planted oysters near the Loch Lomond Marina is urgent and essential. For safety reasons, the participation of CDFG law enforcement staff is critical. We urge CDFG to move forward with this as quickly as possible.

Attachment 2. Photo guide to shellfish provided to volunteer surveyors

Pacific Oyster (*Crassostrea gigas*): Large (>2.75" long), stout, often looks like a barnacle-covered rock.

Olympia Oyster (*Ostrea conchaphila*): Small (<2.75" long), often thin. Our native oyster.

Ribbed Horsemussel (*Geukensia demissa*): Up to 3-4" long, gray-black, shell with radial ridges, attached to rocks by strong fibers or buried vertically in the mud with the end of the shell poking out.

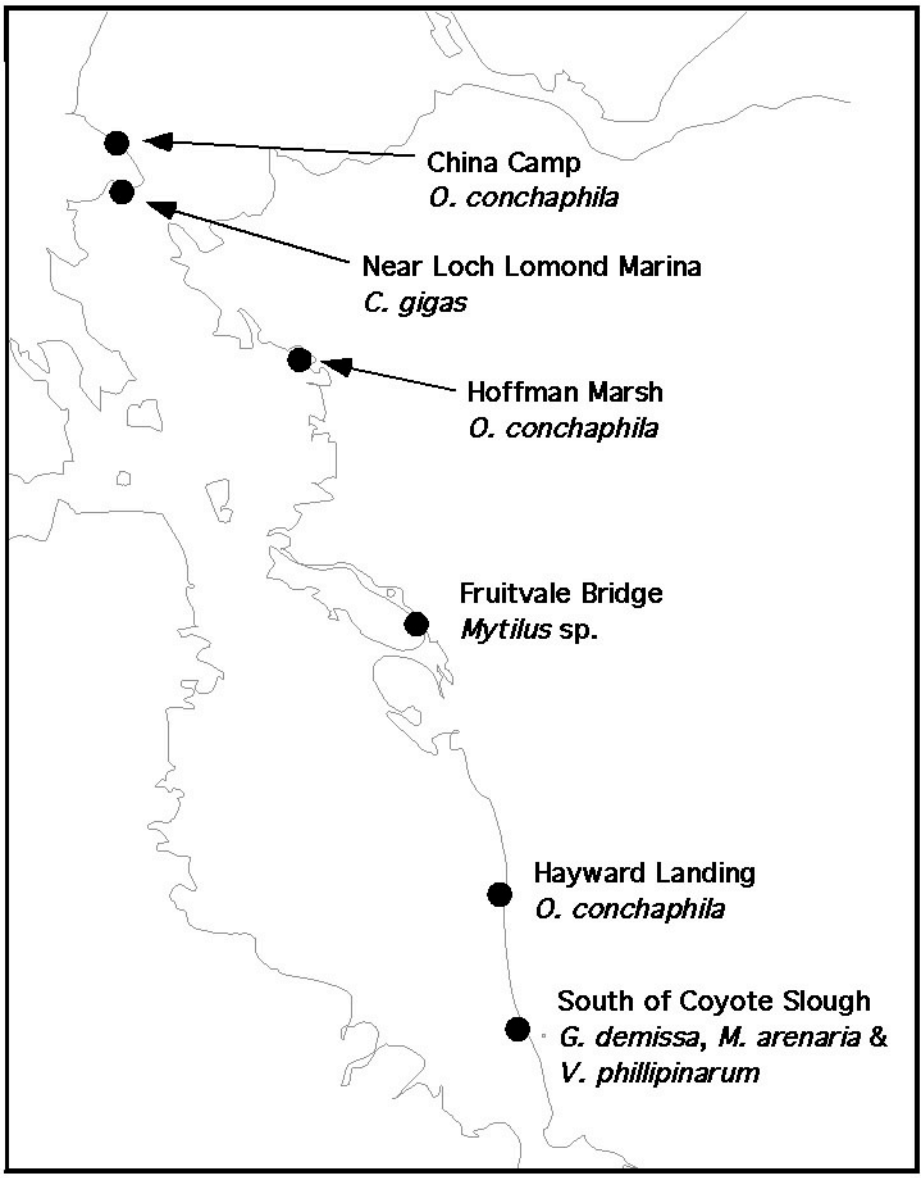
Bay Mussel (*Mytilus* spp.): Up to 3-4" long, blue-black, shell smooth, attached to rocks by strong fibers.

A bed of Bay Mussels.

Attachment 3. Shellfish beds observed

The map and table below summarize the shellfish beds that we observed in San Francisco Bay during the survey and removal of the exotic oyster *Crassostrea gigas* in 2006-07 and other recent work in the Bay. We defined a shellfish bed as an aggregation of sufficient size and density that it could support repeated recreational harvesting. Since we were examining hard substrates, our direct observations of beds was limited to hard substrate species of edible shellfish: *Crassostrea gigas*, *Ostrea conchaphila*, *Mytilus* spp. and *Geukensia demissa*.

Shellfish beds observed



Species	Date of Observation	Location	Description
Crassostrea gigas	12/19/07	Adjacent to Loch Lomond Marina, San Rafael	A large number (at least many hundreds, possibly thousands) of *C. gigas* in a bedrock and cobbly intertidal area across a slough to the east of the Loch Lomond Marina. About 75% of the sample colected were unattached, apparently illegally-planted oysters pruchased from a west coast supplier of seed oysters. The sizes and clustering of the attached oysters suggested that more than one cohort was present. The sampled oysters were heavily infested with the mud blister worm (*Polydora* sp.), which would make them unmarketable.
Ostrea conchaphila	11/15/05	China Camp, San Rafael	A substantial population of live *O. conchaphila* was observed on low intertidal rocks near Rat Island. In 2006, after an unusually wet spring, only dead oysters were reported at this site.
Ostrea conchaphila	8/13/06	Hoffman Marsh, Richmond	A population of live *O. conchaphila* was observed on intertidal rocks at the northern outlet of Hoffman Marsh. It's probably not a large enough population to meet our definition of shellfish bed. This population was also observed in previous years.
Mytilus sp.	4/5/07	Fruitvale Bridge, Oakland	A dense intertidal bed of the Bay Mussel *Mytilus* sp. was observed both on the pilings supporting the fishing pier next to the Oakland end of the Fruitvale Bridge and covering the rocks, sediment and debris underneath the fishing pier. The bed was also observed in 1996 and 2004.
Ostrea conchaphila	8/9/06	Hayward Landing, Hayward	A large number of empty, paired, attached valves of *O. conchaphila* was observed on intertidal rocks. The paired valves indicate recent death, probably during the unusually wet spring of 2006. It probably wasn't a large enough population to meet our definition of shellfish bed.
Geukensia demissa, *Mya arenaria* & *Venerupis philippinarum*	8/13/07	South of Coyote Slough, Union City	The Atlantic Ribbed Horsemussel *G. demissa* was abundant on and among intertidal rocks and boulders that occur in piles or "islands" surrounded by soft sediment between Coyote Slough (also known as New Alameda Slough and the Alameda Flood Control Channel) and Ideal Marsh. These are the apparent remnants of former breakwaters or jetties. Also among these rocks were large numbers of the Japanese Littleneck Clam (*V. philippinarum*, also known as the Manila Clam), and the Atlantic Softshell Clam *M. arenaria*, indicating that there were nearby beds of these infaunal clams.