

## **Survey and Source Determination of the Exotic Oyster *Crassostrea gigas* in San Francisco Bay**

**Estimated Cost:**       **\$30,000**

**Proposed by:**           Andrew Cohen, SFEI

### **BACKGROUND**

Last summer, a population of a large exotic oyster was discovered in southern San Francisco Bay and identified as *Crassostrea gigas* (*C. gigas*). The oysters were found along the Bay's southeastern shore from south of the Dumbarton Bridge to just south of the San Leandro Marina, with a few outlying oysters at other sites. Initial examination found nearly all of them to be in good condition, ripe and ready to spawn.

Although *C. gigas* has been grown commercially in central California since 1928, with many millions of oysters reared through maturity and apparently releasing spawn into the environment, there are records over that period of only a few dozen oysters settling as a result (Carlton 1979). However, we have now collected over 260 *C. gigas* (estimated to be a fraction of the population in the Bay), indicating a rate of settlement that is orders of magnitude greater than observed in the region over the previous 78 years, and in a bay where the oyster has not been grown commercially in recent years. The reason for the enhanced settlement is not known. The oysters might be a genetically distinct strain from previously cultured *C. gigas*; or environmental conditions may have changed in a way that makes it easier for the oysters to settle (for example, higher phytoplankton concentrations have been reported in the South Bay in recent years—Cloern *et al.* 2006). In recent years there have also been reports or records of a few populations of settled *C. gigas* in other parts of California (southern California and Humboldt Bay), where settlement was previously unknown or extremely rare, so it's possible that the recent settlement in San Francisco Bay is part of a broader phenomenon.

In San Francisco Bay, *C. gigas* grows faster than the native oyster and up to four times its size. Evidence suggests it would 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; Ruesink *et al.* 2006; Diederich 2006). Noting that an exotic clam had reduced primary productivity in northern San Francisco Bay, USGS scientists have expressed concern that if the exotic oyster changed "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" (Dr. Janet Thompson, USGS, pers. comm.).

## POSSIBLE MEANS OF INTRODUCTION

*Crassostrea gigas* could have arrived in San Francisco Bay by various mechanisms: as larvae drifting in from other bays where it is grown, or larvae drifting south from a recent, illegal planting of oysters on the Marin shore; in the ballast tanks or on the hull of a vessel; as an illegal planting in the South Bay; or as spawn from oysters temporarily placed in the Bay for bioaccumulation studies. The last alternative potentially involves the RMP. At least three programs used *C. gigas* for bioaccumulation monitoring in the Bay between 1991 and 2002: the Regional Board's Bay Protection and Toxic Clean-up Program in 1991-92; the Central Contra Costa Sanitary District, as part of the Local Effects Monitoring Program, in the North Bay in 1991-94; and the RMP at 9 sites in the Bay in 1993-2002. The RMP placed a total of approximately 14,000 mature *C. gigas* (71-149 mm in height) in the Bay, hung in mesh bags in groups of 150, for 90-100 day periods in the wet (Jan.-Apr.) and dry (June -Sept.) seasons. The dry season coincides with *C. gigas*' reported spawning period in California, and some of the RMP studies discuss changes in the oysters' condition that suggest that they may have spawned during deployment (e.g. Hardin *et al.* 2005). About 2,500 *C. gigas* were deployed in the South Bay at the Coyote Creek or Dumbarton Bridge stations.

Although the RMP's placement of *C. gigas* in the South Bay in the late 1990s to 2002 makes it a leading candidate, it is not yet known which source is in fact responsible for introducing the oysters to San Francisco Bay. Genetic analyses and the determination of the age of the oysters through stable isotope analysis may reduce this uncertainty. Archived (frozen) samples of the oysters used in the RMP studies are available for most years (Paul Salop, AMS, pers. comm.), and so it may be possible through genetic analysis to determine definitively if the RMP oysters were or were not the source of the *C. gigas* population currently found in South San Francisco Bay.

## APPROACH

When *C. gigas* was discovered in San Francisco Bay in the summer of 2006, SFEI's Biological Invasions Program spearheaded an initial effort to survey and remove the oysters from the Bay, organizing volunteers and boats and crews provided by USFWS/Don Edwards National Wildlife Refuge and USGS. Based on that survey and a subsequent meeting of participants, land owners, resource managers and regulatory agencies organized to discuss the problem (see Appendix 1), a plan was developed to (1) survey and remove as much of the remaining population of *C. gigas* from the Bay as possible, and (2) conduct research needed to determine the timing and source of the introduction. This work plan is summarized in the six tasks below. The request to the RMP is for \$30,000 funding to assist with the survey and research components (Tasks 2, 4 and 5), in conjunction with funding from other sources and substantial in-kind assistance from several local, state and federal agencies and volunteers. Other funding, primarily for Tasks 1, 2, 3 and 6, includes \$2,000 provided by the San Francisco Bay Joint Venture for work in 2006, \$25,000 awarded by the State Coastal Conservancy for work in 2007-08, and \$46,895 awarded by the National Fish and Wildlife Foundation for work in 2007-08. Since 2006, SFEI has provided over \$32,000 worth of in-kind services to organize and manage this effort.

**Task 1: Advisory Panel (Not RMP funded)**

SFEI will set up an Advisory Panel including collaborating organizations, funders, affected land owners and land managers and relevant regulatory and resource agencies. Most of the agencies and organizations that attended the Sept. 11, 2006 planning meeting (Appendix 1) indicated an interest in participating on the Panel. The Panel will review the work conducted and the data from the survey and research components and recommend modifications in the work plan as needed. It is anticipated that the Panel members will meet in person about once a year until the Panel determines the eradication is complete or the project is otherwise terminated, and at other times will communicate with each other and the SFEI project manager by email as needed.

**Task 2: Survey (Partially RMP funded)**

Surveys for *C. gigas* will be conducted in conjunction with removal of the oysters. Comprehensive surveys will be conducted in primary areas (where *C. gigas* has been found); with surveys of selected sites in secondary areas (the rest of the Bay within *C. gigas*' potential range). All suitable substrate along the shore will be surveyed in primary areas, with *C. gigas* removed by hand. Agency staff and volunteers organized by SFEI will assist with this work. The San Mateo Bridge and powerline supports will be surveyed during minus low tides by boats or airboats provided, piloted and crewed by USFWS, USGS, DWR or CCSF. Other in-kind assistance provided or offered includes shore crews from USGS, East Bay Regional Park District and Hayward Area Parks and Recreation District; assistance with permit acquisition from CDFG; assistance with volunteer recruitment from Hayward Area Recreation District and Save the Bay (a nonprofit environmental organization); and the loan of field equipment from Save the Bay. Per request of the RMP Technical Review Committee, surveys will also note the location of any significant beds of edible shellfish that are encountered (which will likely consist of the hard substrate species *Ostrea conchaphila*, *Mytilus* spp. and *Geukensia demissa*). Follow-up monitoring surveys will be conducted to check the effectiveness of the removal. The extent of secondary area and follow-up surveys will be determined in consultation with the Panel

<b>Primary Project Areas</b>	<ol style="list-style-type: none"><li>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.</li><li>2. The Foster City shore, near the west end of the San Mateo Bridge.</li><li>3. The Richmond shore, near Hoffman Marsh.</li><li>4. The San Mateo Bridge supports and the supports for the adjacent electrical towers.</li></ol>
<b>Secondary Project Areas</b>	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.

**Task 3: Removal (Not RMP funded)**

All *C. gigas* will be removed by hand. All necessary permits and letters of authorization for the initial survey in summer 2006 were provided by CDFG, USFWS/Don Edwards NWR and CalTrans, or provided verbally by other land owners/managers (park districts and CDFG). Further permits will be renewed or obtained as needed. If surveys find that *C. gigas* extends to the lowest intertidal surfaces, indicating that it may occur subtidally, we will review the data

with the Advisory Panel and adjust plans accordingly. Oysters not retained for research will be disposed of.

**Task 4: Age analysis of SF Bay shells (Primarily RMP funded)**

Oyster shells are so variable in morphology that distinguishing annual shell rings or ridges is problematical, and estimates of age based on size are 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 analysed to determine the age of the shell. Several *C. gigas* shells will be collected from each distinct location in the Bay, including both larger and smaller shells. These will be aged by stable isotope analysis by David Goodwin (Denison University, Ohio) to determine whether settlement occurred at different sites at different times, whether there are distinct settlement periods at a site, and the earliest settlement that can be determined at each site. The earliest settlement dates will help narrow the set of potential source populations, while the other questions will provide information on the geographic and temporal pattern of settlement.

**Task 5: Sample collection, genetic comparisons and analysis of potential source populations (Primarily RMP funded)**

We will collect tissue from oysters from the *C. gigas* population in San Francisco Bay and from various potential source populations, including *C. gigas* from oyster farms and settled populations in California, from an illegal planting in San Francisco Bay, and from samples archived from bioaccumulation studies in the Bay. Our target sample is 24 oysters per population and we expect to sample about 20 populations. Patrick Gaffney (Director of the Marine Biology and Biochemistry Program at the University of Delaware) will extract, amplify and sequence sites of nuclear DNA known to have high variability, and compare the sequences statistically to assess the relative similarity of potential source populations and the San Francisco Bay population. We will research the history of possible vectors, and use this information in combination with the genetic analysis and shell age analysis to determine the likely source population.

**Task 6: Report and outreach (Not RMP funded)**

We will provide annual progress reports on the work completed, the results and the future work plan to the funding organizations and the Advisory Panel prior to the annual Panel meeting; if revisions to the description of work and results or to the work plan are recommended by the Panel, a revised report and work plan will be provided to these parties shortly the annual meeting. This information will also be posted on an SFEI website. At the completion of the project, a final report describing all work and results will be provided to all funding organizations and the Advisory Panel, and all data sets developed will also be made available to these parties. As appropriate, information on the *C. gigas* invasion and the project will be provided at workshops or conferences, and incorporated in manuscripts for science or resource management journals. Some initial information was presented at a native oyster restoration workshop in 2006.

**BUDGET** (\$ amounts provided for RMP-funded elements)

		<b>RMP</b>	<b>non-RMP</b>
<b>Task 1. Advisory Panel</b>			
Labor	Organization & support		other funding
	Panel participation		in-kind
<b>Task 1 subtotal</b>		<b>0</b>	<b>–</b>
<b>Task 2. Survey</b>			
Labor	Planning & management of survey	15,500	other funding
	Boats & crews		in-kind
	Shore crews		other funding & in-kind
	Data entry	1,000	
Other Direct Costs	Supplies		other funding
	Travel		other funding
<b>Task 2 subtotal</b>		<b>16,500</b>	<b>–</b>
<b>Task 3. Removal</b>			
Labor	Planning & management of removal		other funding
	Boats & crews		in-kind
	Shore crews		other funding & in-kind
Other Direct Costs	Supplies		other funding
	Travel		other funding
<b>Task 3 subtotal</b>		<b>0</b>	<b>–</b>
<b>Task 4. Age analysis</b>			
Labor	Sample selection & handling	200	
	Data analysis (Cohen)	500	
Subcontract	Lab costs	1,000	
	Data Analysis (Goodwin)		in-kind
<b>Task 4 subtotal</b>		<b>1,700</b>	<b>–</b>
<b>Task 5. Sample collection, genetic comparisons and source analysis</b>			
Labor	Sample collection	2,500	
	Data collection & analysis (Cohen)	3,500	
Subcontract	Lab costs	4,800	
	Data Analysis (Gaffney)		in-kind
Other Direct Costs	Travel	1,000	
<b>Task 5 subtotal</b>		<b>11,800</b>	<b>–</b>
<b>Task 6. Report and outreach</b>			
Labor	Report preparation		other funding
<b>Task 6 subtotal</b>		<b>0</b>	<b>–</b>
<b>Total</b>			
<b>Tasks 1-6 total</b>		<b>30,000</b>	<b>–</b>

## DELIVERABLES AND TIME LINE

Task or Deliverable	Due Date
<b>Task 1</b>	
Advisory Panel organized	May 31, 2007
1st Advisory Panel meeting	by Oct 31, 2007
Subsequent Advisory Panel meetings	annually until project termination
<b>Task 2</b>	
1st year's survey	March 31, 2008
<b>Task 3</b>	
1st year's removal	March 31, 2008
<b>Task 4</b>	
Age analysis completed	Oct. 31, 2007
<b>Task 5</b>	
Sample collection	July 31, 2007
Genetic & source analysis completed	Oct. 31, 2007
<b>Task 6</b>	
1st draft annual report & future workplan	Oct. 31, 2007
1st final annual report & future workplan	Nov 30, 2007
subsequent reports & workplans	annually until project termination

## REFERENCES

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## APPENDIX 1

### Participants in Sept. 11, 2006 planning meeting to determine response to *Crassostea gigas* invasion

<b>Participant</b>	<b>Affiliation</b>	<b>Email</b>	<b>Phone</b>
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