Tiburon Audubon Center Native Oyster (*Ostrea conchaphila*) Restoration Project Monitoring Report for 2004-2005

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Abstract

An experimental community-based native oyster, *Ostrea conchaphila*, restoration project in Richardson Bay California (northern San Francisco Bay) successfully demonstrated that reefs made of clean oyster shells would be colonized by oyster larvae produced by existing wild native oyster spawners. Native oysters were previously widespread and abundant intertidally and subtidally in San Francisco Bay. Presently they are sparse and restricted in distribution subsequent to impacts of over harvesting, pollution, sedimentation, and non-native predators. A previous study demonstrated that larvae are widespread in the plankton of San Francisco Bay so the hypothesis that shell substrate for settlement was limiting was tested by a pilot-scale placement of shell reef modules in northern Richardson Bay in May-June 2004. Monitoring consisted of monthly inspection of PVC settling plates, fish sampling, and water quality (temperature, salinity, secchi depth) measurements. Ongoing observations of bird species richness and abundance were summarized to include in the baseline characterization of the intertidal and shallow subtidal ecosystem. Bags of oyster shells from four of the 12 reef modules were inspected in September 2004. Native oyster recruits were found at all four sites with up to 13 oysters on 50 shells sampled at one near shore intertidal site. This site was sampled again in February 2005 when 23 native oysters were found on a sample of 100 shells. The mean size of native oysters increased at this site from 19 mm in September to 31 mm in February proving recruitment, growth, and survival of native oysters on the shell substrate.

An unusual thornback fish (*Platyrhinoidis triseriata*) was collected during the monitoring. This is only the second known record of this fish from within San Francisco Bay.

Introduction

Scientific monitoring is an essential component of community based environmental restoration projects because it documents the ecological benefits of the restoration, it permits refinements to the techniques used, and it enhances the learning experience for the volunteers. This report describes the monitoring that has taken place for the IFR/NOAA-funded 2004 Tiburon Audubon Center native oyster (*Ostrea conchaphila*) restoration project in Richardson Bay, California (Figure 1). The purpose of the restoration is to enhance the intertidal and subtidal habitat of Richardson Bay, a sub-bay within San Francisco Bay, to benefit native fishes (including NOAA trust species such as anadromous salmonids), to enrich the benthic biodiversity with a complex living matrix of shells and oysters, and to filter particulates and non-native planktonic larvae from the water of the bay.

The restoration project is taking place within an Audubon Society-designated bird sanctuary. Several resident and migratory bird species reported to eat native oysters will directly benefit from a resurgence in oyster numbers and numerous shorebirds and waterfowl will indirectly benefit from an enhanced and diverse native intertidal and subtidal ecosystem. Harbor seals and California sea lions also use this region of the bay.

Native oysters were once abundant in San Francisco Bay providing ecosystem benefits as well as food for human consumption. While still widespread, the oyster populations are now sparse and ephemeral. One working hypothesis is that their abundance is limited by a lack of suitable substrate, such as oyster shell. The Tiburon Audubon Society oyster project is a pilot-scale test of the substrate-limitation hypothesis that includes monitoring of small constructed oyster shell reefs and the subtidal organisms associated with them.

Methods

There are three parts to the monitoring: (1) measuring settlement of oysters from the plankton to experimental oyster shell reefs and their subsequent survival and growth, (2) sampling of fish and water quality parameters near the experimental oyster reefs, and (3) counts of birds within the greater Richardson Bay Bird Sanctuary where the oyster reefs are located. Experimental settling plates were tested as a quantitative means to monitor the recruitment, growth, and survival of oysters. PVC plastic plates were attached to the oyster reefs and to the buoys marking their locations. The one attached to the reef itself stayed near the bottom of the water column while the one attached to the buoy floated near the water surface, moving up and down with tidal action. One of the 1 square foot settling plates is visible in Figure 2. The large buoy shown in Figure 2 was used to install the palettes in an upright position on the bottom and then replaced with a smaller marker buoy.

The experimental design consists of 12 palettes of bags of oyster shells, six bags per palette (Figure 2), placed in northern Richardson Bay (Figure 1). The palettes were placed in four groups of three palettes. Two groups are in shallow water near shore approximately 1 ft MLLW (mean lower low water) and two groups are in deeper water farther from shore in approximately 3 ft MLLW. The palettes are marked with buoys (Figure 3). The experimental reefs were constructed on wooden palettes to facilitate eventual removal, a condition of the permit from the Bay Conservation and Development Commission, which considers placing oyster shell on the bottom as "fill".

Each month one of the three surface settling plates at each of the four sites was collected by volunteers in a boat and then brought to the Tiburon Audubon Society nearby for inspection, counting and measurement of oysters (if any), and photographic documentation by the volunteers and Tiburon Audubon Center staff assisted by the project scientist, field biologists, and graduate students.

Fish monitoring also took place monthly and consisted of sampling for sharks, rays, and other demersal species using long-lines baited with squid and for smaller fishes and crabs using traps baited with canned cat food. A bottom long-line 10 m long with 10 hooks was placed near each set of three palettes and allowed to fish for approximately 3 hours. Previous sampling in this area found that longer soak time resulted in gear saturation (every hook had a fish) so catch per hook/hour could not be estimated accurately. Catch per unit effort (CPUE) is a valid index of fish stock size and the standard way to monitor fish populations (Murphy and Willis 1996). After the long-lines were retrieved the leaders and hooks were replaced with fish traps, both minnow and standard mesh traps, and the lines of traps were deployed overnight. Five fish traps and five minnow traps were deployed overnight on each of the four long-lines.

Fish were identified (Eschmeyer and Herald 1983; Miller and Lea 1972), measured, and then released alive. A few small fish were preserved as voucher specimens and to educate the volunteers. Data on fish and water quality were recorded on standard waterproof data sheets in the field and then entered into computer spreadsheets for analysis.

Water quality measurements of near surface water temperature, salinity, and secchi depth (water transparency) were made monthly at the same times and locations as the fish long-line sampling. The personnel needs for fish sampling and water quality measurement were for three people for two days each month plus approximately one person-day per month for preparation, clean-up, and record keeping. The field biologists performing the fish and water quality monitoring were experienced in collecting these kinds of data in San Francisco Bay and other coastal environments (e.g., McGowan et al. 2000, McGowan et al. 2001). Dr. McGowan, the scientific advisor for the Tiburon Audubon Center oyster restoration project is an expert on the ecology and sampling techniques for San Francisco Bay fishes (e.g., McGowan 2000a, McGowan 2000b, McGowan 2000c).

Bird data on species and abundance were collected annually by the Audubon Center volunteer boat patrol during the winter months when the sanctuary is closed to boating. Trained volunteers using guidebooks such as Robbins et al. (1966) patrol the boundaries of the Richardson Bay Bird Sanctuary and record observations of weather, bird species and abundances, and occurrences of any unauthorized boating within the sanctuary. Data from winter 2002-2003 were summarized for this report to serve as a baseline for future years.

Results

The 12 reefs (palettes with pyramids of oyster shells) were placed in four groups in Richardson Bay on May 30 and June 1, 2004 after the project received its permit from the Bay Conservation and Development Commission (BCDC). The groups of palettes were placed offshore from the Lyford House in shallow (near) and deep (far) locations and offshore from Blackie's Pasture in shallow (near) and deep (far) locations. This activity conducted by volunteers from the Tiburon Audubon Center and the project scientific staff received much media coverage in local and regional newspapers, on radio, and in a forthcoming television feature.

Settling plates were inspected at monthly intervals beginning in June. The plates were inspected by volunteers at the Tiburon Audubon Center (Figure 4) for oysters and other organisms. Rapid colonization of the settling plates by filamentous algae occurred with some differences noted between sites. After one month of exposure the Lyford House near (shallow) plate had much more algae attached than the corresponding one at Blackie's Pasture (Figure 5 and Figure 6). After three months the Lyford House plate shows increased coverage by algae and sediment as well as increased settlement and growth of barnacles (Figures 6 and 7). Other organisms such as amphipods, isopods, and small clams do not show in these photographs.

No oysters settled on the plates from the end of May to the end of September. The results do show the initial rapid colonization by algae and invertebrates and some differences among sites along shore (Lyford vs. Blackie's), between depths (offshore deep tended to have better recruitment on the plates than nearshore shallow), and the progressive settlement and growth of some algae and invertebrates with time. In February 2005 settling plates were examined from one palette near shore at the Lyford House location. No oysters had settled on either the deep plate or the shallow one attached near the floating buoy. The "deep" plate attached to the reef had very little coverage by fouling organisms relative to the "shallow" plate attached to the buoy. This difference in fouling had been observed on occasion at the other reef modules, too.

On September 25, 2004 one bag of shells was retrieved from one reef palette of shells at each of the four sets of three reefs. Retrieval of the bags of shells was very labor intensive because it had to be done at high water for the boats to be used, it required two boats, and retrieval of a bag of shells that had been tightly lashed to the oyster shell reef palettes was awkward, to put it mildly. The shells were brought to the boat dock for inspection by Tiburon Audubon Center volunteers. Despite the physical effort required, we were pleased to find that native oysters had recruited to the oyster shells from all four locations. The native oysters were attached to inside surfaces of the Pacific oyster shell substrate (Figure 8) and were not visible with casual inspection of the bags of shells.

We needed to return the shells to the reefs during the same high tide so once we established that oysters had recruited to all four sites we decided to subsample the bags of shells to estimate the recruitment rate (Table 1). The largest diameter of each native oyster was measured by vernier calipers to 1 mm.

Table 1. Native oyster recruitment at Tiburon Audubon Center, September 25, 2004 and February 3, 2005.			
Site	Native Oysters	Shells Examined	Size Range (mm)
Blackies Near 9/25/04	12	100	11-38
Blackies Far 9/25/04	2	227	25-38
Lyford Near 9/25/04	13	50	13-31 mean 18.8
Lyford Far 9/25/04	2	100	25-26
Lyford Near 2/3/05	23	100	12-43 mean 30.8

In September 2004 the near shore (intertidal) samples had higher relative abundances than the far (subtidal) samples. In February 2005 a near (intertidal) sample from the same site where oysters were abundant in September had approximately the same relative abundance but the average size was much larger reflecting the growth that had occurred since settlement. The size frequency distribution of native oysters at Lyford Near in September was unimodal with a peak at the smallest size class (10-19 mm). The size frequency distribution at the same location in February was also unimodal but the peak shifted to the 30-39 mm size class. This indicates survival and growth of the 10-19 mm cohort first observed the previous September. A few (13%) of the native oysters measured in February were in the 10-19 mm size class. These must have recruited after September confirming multiple spawning events during the previous summer and autumn. The February sample came from a different near shore reef than the September sample so recruitment is confirmed to have occurred at four of the 12 reefs (every one sampled) and is likely to have occurred at all of them.

Six species of fish have been collected so far during monitoring. In order of relative abundance they are bat ray (*Myliobatis californica*), leopard shark (*Triakis semifasciata*), shiner surf perch (*Cymatogaster aggregata*), diamond turbot (*Hypsopsetta guttulata*), thornback (*Platyrhinoidis triseriata*), and bay pipefish (*Syngnathus leptorhynchus*). The highest percentage of fish was collected in June followed by August, July, and September (Table 2).

Table 2. Fish Catch (%) by Month and Gear during Monitoring near Oyster Reefs in 2004					
Gear	June	July	August	September	Total
Longline	35.1	13.5	16.2	13.5	78.4
Fish Trap	2.7	5.4	13.5	0.0	21.6
Total	37.8	18.9	29.7	13.5	100.0

Longlines caught fish at both intertidal (when submerged) and subtidal sites. Fish traps only caught fish at the subtidal locations, not the intertidal ones. The species caught in the traps (shiner surf perch, bay pipefish, diamond turbot) differed from the ones caught by longline (bat ray (Figure 9); leopard shark (Figure 10); thornback). The bat rays ranged in size (wing span) from 55 cm (1 ft 10 in) to 155 cm (5 ft 1 in). The largest leopard shark was 124.5 cm (4 ft 1 in) in total length. The sex ratio of bat rays was 9 males to 6 females. The sex ratio of leopard sharks was 2 males to 6 females. Small schooling fish were observed near the oyster shell reefs. They have not been collected but are likely to have been northern anchovies (*Engraulis mordax*), or jacksmelt (*Atherinopsis californiensis*), or topsmelt (*Atherinops affinis*). A small cluster of eggs similar to Pacific herring (*Clupea pallasii*) eggs was found on the shell reef at Lyford Near during February 2005.

The thornback caught was notable as the first ever caught in Richardson Bay and only the second from San Francisco Bay based on data from the California Academy of Sciences and the California Department of Fish and Game. It was a male 52 cm (20.5 in) long. Figure 11 shows an underwater photograph of this species.

Surface water temperatures were warm at the experimental sites June-September ranging from 16.6 to 21.1 ^{O} C (62-70 F). Surface salinity ranged from 31.4 to 32.8. Secchi depth ranged from 27.5 cm (11 in) to 160 cm (63 in). In February 2005 the water temperature at Lyford House near was 15.9 ^{O} C (61 F) and salinity was 29, both lower than during the previous summer and autumn. Water stratification (colder water near the bottom) was noted during snorkeling dives on the oyster reefs in September 2004.

The experimental shell reefs were placed on bare mud distant from any known eelgrass so no monitoring of water quality was done in eelgrass beds.

The data from boat patrols during October 2002 through October 2003 (no patrols April-September) were recently entered into a computer and analyzed for this report. On 21 days of patrolling averaging approximately 3 hours per patrol the volunteers noted 27 violations of the Sanctuary boundaries, 20 of which were kayakers. Four motor boats were spotted, two sailboats, and one rower in a shell. Sixteen of the kayakers were present on just two of the 21 days so most days the Sanctuary was just that, a place for birds to rest without human disturbance.

More than 4100 birds were seen representing at least 32 species. The five most abundant birds seen were scaup (*Aythiya marila*), double-crested cormorant (*Phalacrocorax auritus*) , bufflehead (*Bucephola albeola*), surf scoter (*Melanitta perspicillata*), and western grebe (*Aechmophorus occidentalis*). Brown pelicans (*Pelecanus occidentalis*), which are on both the California and Federal Endangered species lists, were seen on more than 1/3 of the patrols. Harbor seals *Phoca vitulina* (58) and California sea lions *Zalophus californianus* (4), which are protected by the Marine Mammal Protection Act, were seen on 1/3 of the patrols. These data are a pre-project baseline against which to measure changes in bird and marine mammal species composition and abundance as oyster restoration proceeds.

Discussion

Colonization of the settling plates was fairly rapid with filamentous algae and barnacles attaching within one month of placement of the settling plates. A variety of amphipods and isopods also found a home on the new habitat. The plastic plates do not appear to be a good substrate for monitoring oyster settlement under the conditions existing in northern Richardson Bay. Native oysters did not settle on the plastic plates June 2004 through February 2005 but they did settle on the shells placed on palettes at the two intertidal and the two subtidal sites. Based on the size frequency distributions of native oysters found in September 2004 and February 2005, there were multiple episodes of spawning and recruitment in summer and autumn 2004. Based on the large size of some native oysters observed in September, they must have settled onto the shells almost as soon as they were placed in the water June 1. This indicates that spawning had commenced at least as early as April or May. Water salinity and temperature were within the reported ranges for oyster spawning throughout the monitoring period so fairly continuous or repeated spawning would not be limited by these factors.

Fishes collected nearby were what had been expected on mud bottoms in this region: flatfish (diamond turbot) and rays and sharks. Leopard sharks are known to use this part of Richardson Bay for pupping and the high proportion of females to males was consistent with this activity. The hooks used on the long lines were large so no newly born sharks were caught. A beach seine or small hooks on the long lines would be better to sample these size classes. The shiner surf perch and bay pipefish are species associated with eel grass, which occurs in Richardson Bay but not close to where the oyster reefs were placed for this project. The thornback was interesting to collect because its main distribution is farther south than San Francisco Bay. There was a surprising lack of catch of small gobies and sculpins in the small minnow traps. These are the species and sizes of fish most likely to benefit from new habitat created by oyster reefs so maybe it is just a matter of time before their populations respond. Other sampling methods such as drop nets and enclosure traps are more efficient for capturing mud-dwelling gobies (McGowan et al. 2001) and special samplers (gobietats) have been devised for capturing reef dwelling gobies, too. These and other non-destructive methods should be considered in future monitoring.

Anecdotal observations of increased bird activity near the buoys marking the oyster shell reefs have been received at the Audubon Center. Forster's terns (*Sterna forsteri*) were observed feeding on small fishes near the reefs and resting on the buoys marking each reef. Gulls (*Larus* species) were observed pecking at something on the reefs when they were exposed at low tide.

The water quality data show that, for native oysters, the salinity is near the upper end of the optimum range and the surface temperature is suitable for spawning (references in Baker 1995 and Harris 2004). A layer of cold water approximately 12 cm deep was observed at the deep reef sites in August indicating a tidal prism or some stratification. The subtidal reefs would have been more influenced than the intertidal reefs by this colder, saltier water layer. This may have affected relative recruitment rates, which were lower at the deep sites than at the shallow ones. The intertidal reefs would be more influenced by occasional exposure above the water surface and by extremes of water temperature caused by air temperature, which typically varies more than the water temperature.

The water transparency (secchi depth) was from about 0.28 m to 1.6 m (approximately 1-5 ft). This is in line with other San Francisco Bay observations in shallow water. The high secchi depth reading coincided with a high tide in late September when water would be expected to be clear. Sedimentation is a potential deterrent to oyster settlement in Richardson Bay and much of shallow sub-tidal San Francisco Bay because the bottom is covered with fine sediment that becomes suspended by wind mixing. Sediment accumulated on some of the near-surface settling plates where it was colonized in August by small clams. Where native oysters occur around San Francisco Bay they are more abundant on coarse, rocky substrate than on soft muddy shores (Harris 2004). The specific name of the native oyster, *conchaphila*, means shell-loving so this makes sense as the preferred substrate for restoration projects.

No potential predators such as green crabs and oyster drills have yet been detected on the settling plates or the bags of shells. Native oysters are inversely related to abundance of non-native oyster drills around San Francisco Bay (Harris 2004).

No problems have been encountered in the restoration so far with the exception that some of the reefs tipped over on their sides when placed in the water. This was due to the unexpected buoyancy of some of the wooden palettes and a shifting of the bags of oysters in some cases. The tipped over reefs were not upside down or completely buried in the sediment so oyster shells were still available for larvae to settle. Native oysters are known to settle on wood, on rope, and even on old battery cases so, after some attempts to right them, the reefs were left as they were. Future experiments using shell reefs on wooden palettes should make sure they are ballasted properly to sit upright.

The next steps for the project will be to expand the amount of habitat restored by placing more shells in shallow water and continued monitoring to document ecosystem improvements. Two kinds of expanded shell placement are being considered: (1) oyster reef palettes in different micro-oceanographic situations (near eelgrass beds and within high larval retention lagoons, and (2) a more natural sand-bar (shell bar) placement of shells to induce the start of a permanent native oyster bed. Decisions about expansion of the program will be made subsequent to discussions with NOAA and the BCDC.

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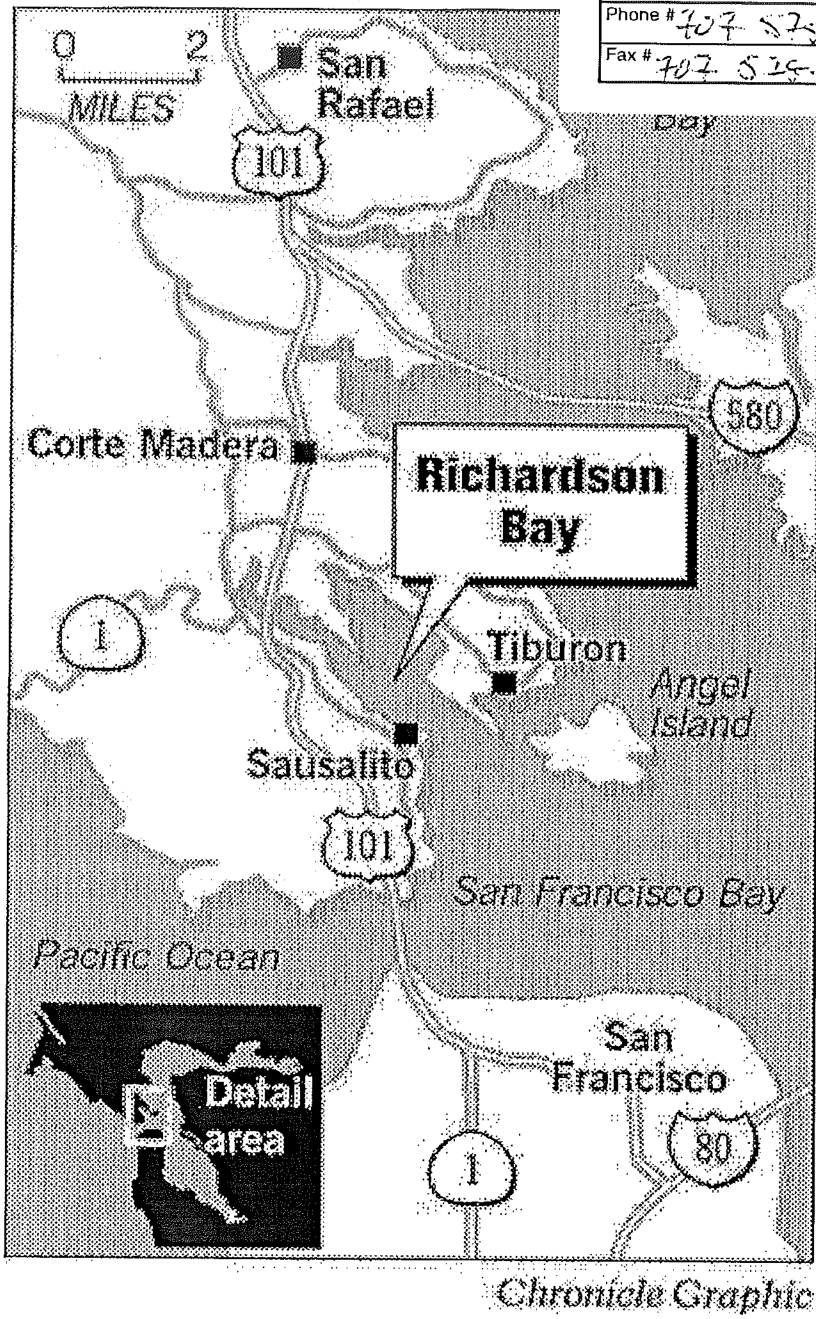


Figure 1. Locator map for the Tiburon Audubon Center native oyster restoration project. (from SF Chronicle North Bay edition).

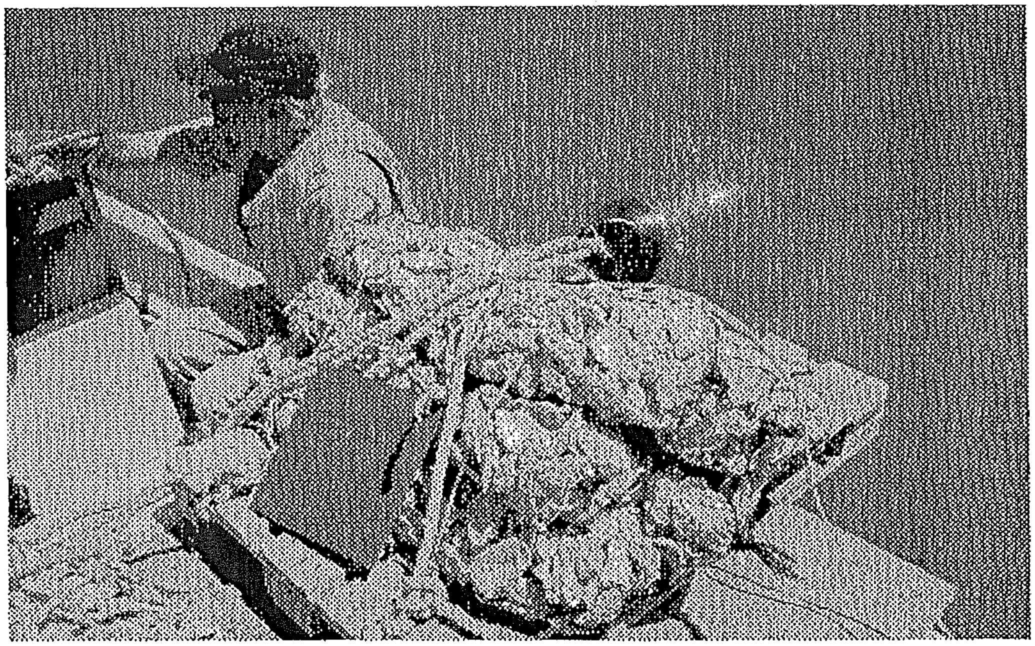


Figure 2. Palette of shells ready to deploy. Note settling plate.

Figure 3. Buoys marking the locations of oyster reefs at one of the four sites.

Figure 4. Volunteers from Tiburon Audubon Center examining an experimental settlement plate from the oyster reefs.

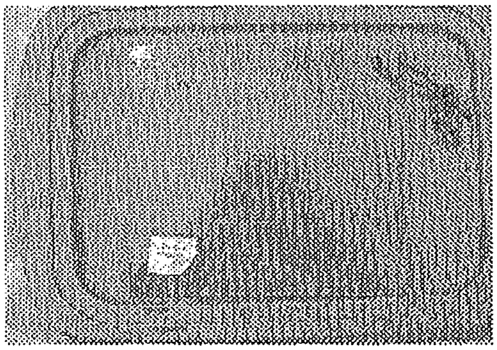
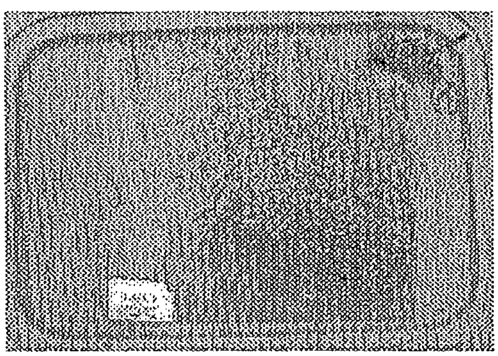


Figure 5. Settling plate from Blackie's Pasture shallow (near) after 1 month.



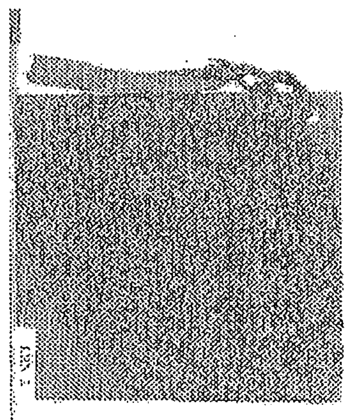


Figure 6. Settling plate from Lyford House shallow (near) after 1 month (left).

Figure 7. Settling plate from Lyford House shallow (near) after 3 months (right).

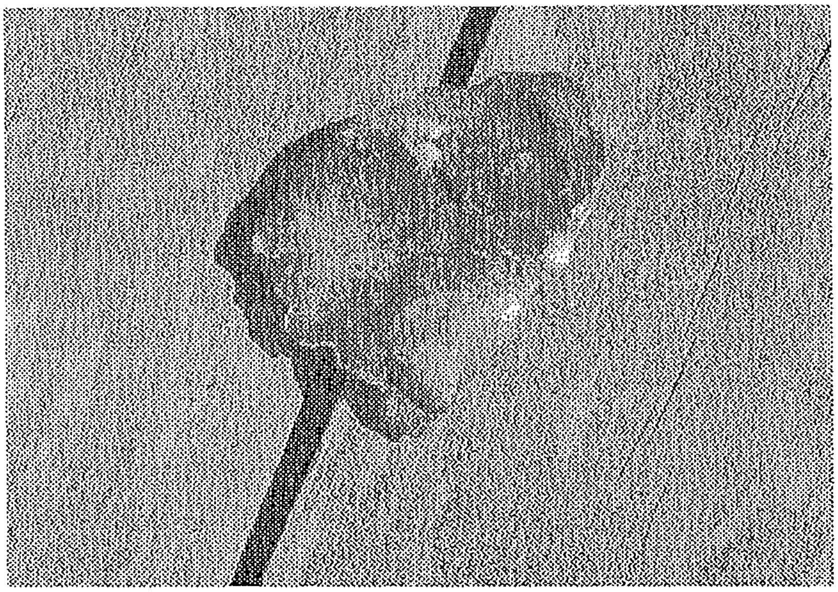


Figure 8. Successful recruitment of native oysters to the Tiburon Audubon Center oyster reefs was discovered by volunteers on September 25, 2004 (below). One new native oyster can be seen above at the lower right of the Pacific oyster used for settlement substrate.

Figure 9. California bat ray caught by longline being boated for measurement.

Figure 10. Leopard shark caught by longline being boated for measurement.

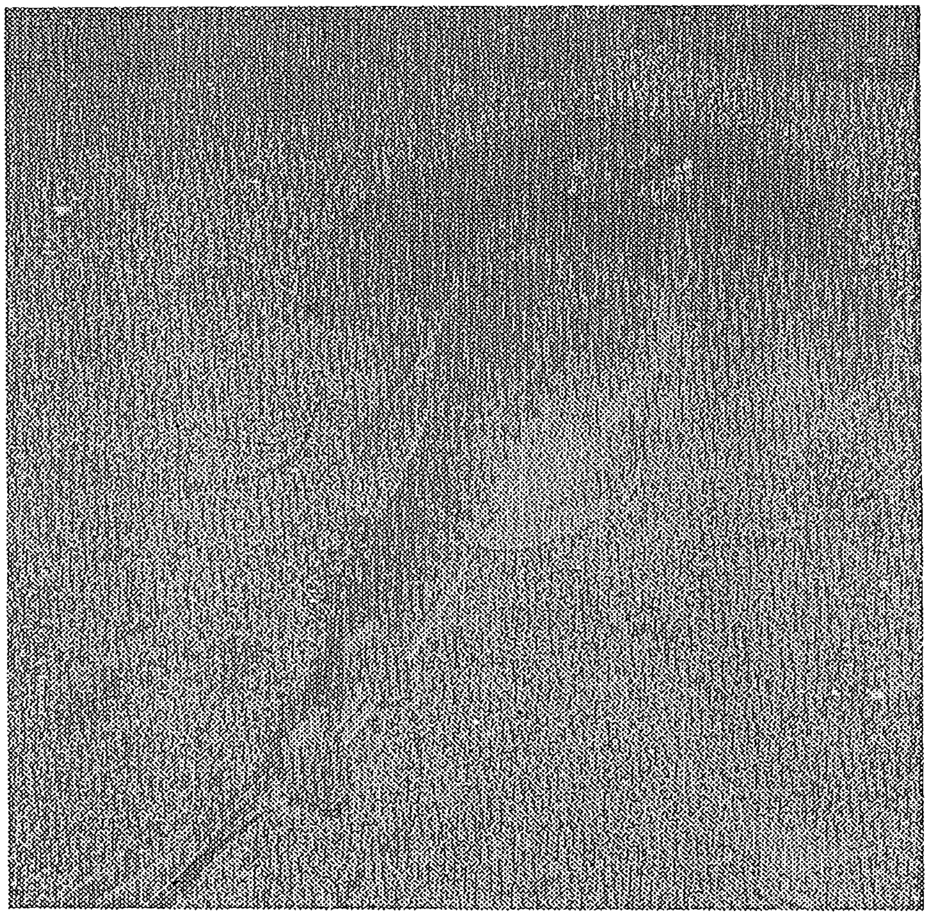


Figure 11. Photograph of a thornback ray, *Platyrhinoidis triseriata*. This species, very unusual for San Francisco Bay was captured during monitoring of the native oyster restoration project reefs in Richardson Bay.