sculpins, rockfish, perch and herring. Hard substrates are an important feeding habitat for harbor seals, including from the Golden Gate east to Treasure Island, northwest to Tiburon Peninsula, and southward to Yerba Buena Island (Goals Project 2000, Green *et al.* 2006). Also, many harbor seal haul-out sites are located in close proximity to subtidal hard substrate including Point Bonita, Castro Rocks, Yerba Buena Island, and Angel Island (Goals Project 2000). Sea lions also feed in deep, marine waters of San Francisco Bay; however, they feed mostly on seasonally abundant herring associated with hard structures and eel grass beds in the Central Bay, and on spawning salmonids that are migrating up the Bay across multiple habitats to freshwater tributaries. Pacific herring is a major prey item for many marine mammal species that are drawn to the Bay, including harbor porpoise and Steller sea lions.

SHELLFISH BEDS

(by Andrew Cohen, Natalie Cosentino-Manning and Korie Schaeffer)

General Description

Past studies in San Francisco Bay have used the term "shellfish bed" to refer to locations where commonly harvested mollusks or crustaceans were found in sufficient concentrations to warrant their harvest. Earlier studies (e.g., Bonnot 1932 and 1935, Skinner 1962, Barrett 1963) primarily referred to locations of commercial interest, including planted or cultured beds of exotic bivalves. The species involved included the native Olympia oyster (*Ostrea conchaphila*), the exotic Virginia oyster (*Crassostrea virginica*) and Pacific oyster (*C. gigas*), the exotic soft-shell clam (*Mya arenaria*) and Japanese littleneck or Manila clam (*Venerupis philippinarum*), and the native bay shrimp (*Crangon* spp.), all of which were commercially harvested for food. More recent studies (e.g., Wooster 1968, USEPA 1972, Dahlstrom 1977, Jones & Stokes 1977, Sutton 1978, 1981) have focused on concentrations that are or could be sport-harvested, primarily beds of the clams, *V. philippinarum* and *M. arenaria*. Sutton (1978) also delineated beds of the rough piddock (*Zirfaea pilsbryi*), a native clam that bores into soft rock or clays, as a potential species for sport harvest, and suggested that there may be significant subtidal beds of the native bentnose clam (*Macoma nasuta*), which was commonly harvested by Native Americans. Some studies refer in passing to beds of the exotic freshwater Asiatic clam (*Corbicula fluminea*; harvested for food or bait), native California mussel (*Mytilus californianus*), bay mussel (consisting of the native *M. trossulus*, the exotic *M. galloprovincialis*, and their hybrids), exotic ribbed horsemussel (*Geukensia demissa*), native ghost shrimp (*Neotrypaea californica*), and the blue mud shrimp (*Upogebia pugettensis*). Jones & Stokes (1977) and Sutton (1978) implied that the ribbed horsemussel might be a sport-harvested species in the San Francisco Bay. The ghost shrimp and blue mud shrimp are used for fish bait, though it's not clear that there are or ever were beds of blue mud shrimp in San Francisco Bay.

In this report, "shellfish bed" is defined structurally rather than in terms of human usage. As a working definition, we propose that in order to constitute a bed, living specimens of the nominal bivalve must cover at least 50 percent of the surface over at least several square meters and, in concentration, must provide a distinct, three-dimensional substrate. We discuss five types of shellfish beds that occur or may occur in San Francisco Bay: beds of California mussels and bay mussels, which occur on hard surfaces to which they attach by byssal threads; beds of the ribbed horsemussel, which typically occur either partially buried in the sediment in salt marshes, or on hard surfaces similar to California and bay mussels; beds of the green bagmussel, which in dense concentrations occur in a mat of interwoven byssal threads on the sediment surface, and beds of the Olympia oyster, which cement to hard substrates including other oysters, and which in the past built up in extensive congregations on bottom sediments in the Bay.

Little to no information is available on biotic assemblages associated with specific types of shellfish beds. Where specific information is available, it is discussed below. Some information on species use of shellfish beds in general exists based on observations within San Francisco

Bay and elsewhere. For example, three marine mammal species, the harbor seal (*Phoca vitulina*), the California sea lion (*Zalophus californianus*) and the California sea otter (*Enhydra lutris*) are thought to be commonly associated with shellfish beds based on location of prey items (S. Allen, National Park Service, pers. comm.). Harbor seals have been observed foraging at two oyster restoration sites, Bair Island and the Marin Rod and Gun Club. Sea otters, if feeding within the Bay, would be attracted to shellfish beds for food, as they do within other estuaries such as Elkhorn Slough in Monterey Bay.

California Mussel (Mytilus californianus) Beds

Mytilus californianus is a native, primarily outer coastal species that ranges from Baja California to the Aleutian Islands. It forms large beds on rocks and pilings exposed to the surf. It feeds mainly on suspended organic detritus and plankton, especially dinoflagellates (one species of which, *Gonyaulax catenella*, produces a neurotoxin that accumulates in *M. californianus* and may render the species unsafe to eat during the summer months). *M. californianu* attains a maximum length of 25 cm, but usually grows no bigger than 13 cm in intertidal populations in California (Haderlie and Abbott 1980).

In San Francisco Bay, *M. californianus* is found only in the western part of the Central Bay, with records inside the Bay as far as the east side of the Tiburon Peninsula, Angel Island, Alcatraz Island and northwestern Yerba Buena Island (A.N. Cohen unpublished data). Here it is primarily found on rocks and seawalls, and occasionally on floating docks or buoys. No studies have been made of the distribution or species composition of its beds in the Bay. There are, however, many studies of *M. californianus* beds on the outer coast, where it typically forms beds down to around MLLW and up to the surge zone in exposed sites. It is usually associated with the gooseneck barnacle (*Pollicipes polymerus*), either intermixed or in alternating beds. Other organisms typically found on or among them on the outer coast include sea cucumbers, *Cucumaria* spp., the pile worm, *Nereis vexillosa*, the isopods, *Cirolana harfordi*, *Idotea wosnesenskii* and *Idotea stenops*, the barnacles, *Semibalanus cariosus*, *Balanus glandula* and *Tetraclita rubescens*, and feeding on the mussels, the sea star, *Pisaster ochraceus* (Kozloff 1973). Some of these may be associated with *M. californianus* near the mouth of San Francisco Bay.

Bay Mussel (Mytilus trossulus/galloprovincialis) Beds

In California, the bay mussel, identified in older literature as *Mytilus edulis*, is in fact a mix of two species, the native *Mytilus trossulus* and the Mediterranean mussel (*Mytilus galloprovincialis*), which are difficult to differentiate without molecular analysis. *M. trossulus* is the dominant mussel from northern California to Alaska, and *M. galloprovincialis* is dominant in southern California, where it was introduced sometime prior to 1947 (Cohen and Carlton 1995). San Francisco Bay and nearby bays in central California are in the boundary zone between the two populations, where both of the species and their hybrids occur in substantial numbers (McDonald and Koehn 1988, Sarver and Foltz 1993, Geller *et al.* 1993, 1994). It is not known whether the location of this boundary in central California is determined by the two species' environmental requirements, and thus is relatively stable, or is an invasion front, and thus likely to shift further north as *M. galloprovincialis* continues to expand its range[2]. In the latter case, we would expect the bay mussels in San Francisco Bay to become increasingly dominated by *M. galloprovincialis*.

The larvae of bay mussels can settle on the outer coast, and adults are occasionally found there. In wave-exposed situations, however, they are out-competed by *M. californianus*, which attach more strongly and grow larger (Haderlie and Abbott 1980). In San Francisco Bay, bay mussels are found mainly from the northern South Bay to southern San Pablo Bay, with a few records ranging as far as the Dumbarton Bridge, Port Sonoma, and Martinez (Hopkins 1986, Cohen and Chapman 2005, A.N. Cohen unpublished data). Roughly the same distribution was reported by Packard (1918) in dredge samples from the 1911 to 1912 Albatross survey, suggesting that the arrival

[2] Global warming could shift an environmental boundary northward also, though probably not quickly as an invasion front.

of *M. galloprovincialis* has not markedly affected the range in the San Francisco Bay.

In the Bay, bay mussels are commonly observed to form beds on seawalls, dock sides and pilings, and possibly also on bedrock or riprap, though there are no studies of the distribution of these beds. Similarly, although there are published studies of the bay mussel bed community in other Pacific Coast bays, there are none in San Francisco Bay, and studies from these other bays may not apply to the distinct, invasion dominated biota of San Francisco Bay. In general, however, we expect a wide variety of organisms in bay mussel beds in the Bay, on and among the shells and among their byssal threads, (e.g., sponges, hydroids, snails (limpets and *Urosalpinx cinerea*), barnacles, tanaids, sphaeromatid and cirolanid isopods, gammarid and caprellid amphipods, bryozoans and tunicates) with the communities varying with salinity, tidal exposure, and other variables. One mussel bed observed over the past decade, on pilings and rocks near the Fruitvale Bridge in Oakland, has consistently yielded numerous large specimens of the yellow sponge, *Halichondria bowerbanki*, large colonies of the hydroid, *Obelia cf. longissima*, large numbers of the barnacles, *Balanus glandula* and *Amphibalanus improvisus* along with a few *Amphibalanus amphitrite*, the tanaid, *Sinelobus* sp., the isopod, *Cirolana cf. harfordi*, the amphipod, *Ampithoe valida* and the tunicates, *Molgula manhattensis* and *Styela clava* (Cohen *et al.* 2005, A.N. Cohen unpublished data).

Ribbed Horsemussel (Geukensia demissa) Beds

The ribbed horsemussel (*Geukensia demissa*) in a non-indigenous, invasive species that was first collected in South San Francisco Bay in 1894 (Stearns 1899). It is now one of the most abundant bivalves in San Francisco Bay (Cohen and Carlton 1995). It commonly forms beds in salt marshes and along the edge of steep salt marsh channels from the South Bay to San Pablo Bay, where it frequently lies embedded with its posterior margin protruding above the mud (Cohen and Carlton 1995, A. Cohen, San Francisco Estuary Institute, pers. comm.). The ribbed horsemussel is also found on rocks and along seawalls in Lake Merritt, a shallow, brackish lagoon on San Francisco Bay. It may also occur in beds on soft bottom and natural and artificial hard bottom subtidal areas from the South Bay to San Pablo Bay, but no surveys have been completed to identify or document such beds. There is no documented information on taxonomic groups associated with ribbed horsemussel beds, but native barnacles, *Balanus glandula*, have been observed attached to individual mussels within the beds (A. Cohen, San Francisco Estuary Institute, pers. comm.).

Green Bagmussel (Musculista senhousia) Beds

The green bagmussel (*Musculista senhousia*) is native to Japan and China and was introduced to central California with Japanese oysters (*Crassostrea gigas*) for harvest (Kincaid 1949). It was first collected in San Francisco Bay in 1946 (Carlton 1979). Green bagmussels tend to occur in very high densities along the eastern shore of Central San Francisco Bay (A. Cohen, San Francisco Estuary Institute, pers. comm.). It occurs in the bottom of Lake Merritt in dense byssal mats that can be pulled from the bottom in sheets and in the Oakland estuary mixed with bay mussels and *Diadumene* sp. anemones (A. Cohen, San Francisco Estuary Institute, pers. comm.). It is frequently the most common benthic organism from South Bay to San Pablo Bay, where it has been collected at densities of up to 1,000 to 2,000 clams/m^2 and is occasionally collected in Suisun Bay but not necessarily at densities high enough to form beds (Nichols and Thompson 1985, Hopkins 1986, Markmann 1986).

Olympia Oyster (Ostrea conchaphila) Beds

Shellfish bed habitat includes areas of living Olympia oysters (*Ostrea conchaphila*, formerly *O. lurida*), and remnant beds composed of dead shell material. Olympia oysters can survive in a broad range of habitats but are most abundant in estuaries, small rivers, and streams. Along the Pacific coast, Olympia oyster beds are formed in the subtidal zone and are bordered by mud flats at high tidal elevations and by eelgrass beds at low tidal elevations. They are found at depths of 0 to 71 meters (Hertlein 1959). Oysters may attach to the underside of

rocks higher in the intertidal zone, where the bottom is gravel or rock (Kozloff 1973).

Native oyster bed habitat is undoubtedly the most poorly understood of any San Francisco Bay subtidal habitat types. While anecdotal information indicates that historically Olympia oysters were a large component of the Bay ecosystem, to date no live subtidal Olympia oyster beds have been documented in San Francisco Bay. Intertidal populations, however, have been found throughout the Bay (Figure 11) and are currently receiving much attention by researchers and restoration practitoners. Elsewhere along the Pacific coast, Olympia oyster shell serves as a substrate for epifauna such as mussels, *Mytilus galloprovincialis* and *M. trossulus*, barnacles, and boring sponges (Baker 1995). Information on invertebrate taxa associated with oyster beds in the Bay is limited to on-going monitoring at three restoration sites (Richardson Bay, Bair Island, and Marin Rod and Gun Club), which use Pacific oyster shell as substrate for Olympia oyster recruitment (MACTEC 2006; Table 7).

The Richardson Bay oyster restoration site included a fish-monitoring component. Long-line and minnow trap techniques were used on a monthly basis for a period of 8 months. The most abundant species included the bat ray (*Myliobatis californica*), leopard shark (*Triakis semifasciata*), shiner surf perch (*Cymatogaster aggregata*), diamond turbot (*Hypsopsetta guttulata*), thornback (*Pltyrhinoidis trisderiata*), and bay pipefish (*Syngnathus leptorhynchus*) (McGowan 2005).

Diving benthivore birds such as the eared grebe (*Podiceps nigricollis*), the ruddy duck (*Oxyura jamaicensis*), and the common goldeneye (*Bucephala clangula*) have been observed foraging in shellfish beds (Table 5). Eared grebes may be observed throughout the year in San Francisco Bay (Goals Project 2000). Eared grebes make shallow dives for prey items such as small crustaceans, fishes, and mollusks (Fix and Bezener 2000). An estimated 85 percent of the Northern American ruddy duck population primarily uses the San Francisco Bay as over-wintering habitat (Goals Project 2000). The greatest ruddy duck abundance has been observed in the South Bay (Goals Project 2000), which is a historic area for native oysters (Figure 11). Ruddy ducks feed on submerged aquatic vegetation and small crustaceans (Fix and Bezener 2000). Similar to other diving benthivores, the common goldeneye is most abundant during the winter months, with San Francisco Bay representing a major over-wintering area. Goldeneyes feed on a variety of prey including crustaceans, mollusks, small fishes, and plant material (Fix and Bezener 2000).

Table 7. Sessile invertebrates associated with native oyster restoration sites at Marin Rod and Gun Club and Redwood City sites in San Francisco Bay from MACTEC (2006).

		Native Oyster Restoration		
	Species	RC Pallets	MRGC Necklace	MRGC Pallets
Sponges	*Halichondria bowerbanki*	X	X	X
	Haliclona sp.	X		
	Clathria prolifera	X		
Hydroids	*Tubelaria sp.*	X	X	X
	Obelia sp.	X	X	X
Anenomes	*Diadumene sp.*	X	X	X
	Haliplanella lineata	X	X	
Flatworms	*Platyhelminthes sp.*	X	X	
Scale Worms	*Halosydna brevisetosa*		X	
	Harmothoe "imbricata"	X		
	Lepidontus squamatus			
Family Syllidae	*Typosyllis nipponica*	X		X
Family Neridae	*Neanthes succinea*	X	X	X
	Nereis vexillosa		X	
	Nereis latescens		X	
Family Eunicidae	*Marphysa sp.*	X		
Family Terebellidae		X		
Barnacle	*Balanus sp.*	X	X	
Isopods	*Synidotea laevidorsalis*	X	X	X
	Paranthura elegans	X		
	Sphaeromatid type	X	X	X
Amphipods	Unknown gammaridian sp.	X	X	X
	Ampelesca sp.	?	X	
	Corophium sp.	X	X	X
Caprellid shrimp	*Metacaprella kennerlyi*		X	
	Caprella sp.			
Caridea shrimp	*Palamon macrodactylus*	X		X
	Hemigrapsus nudus	X		
	Hemigrapsus oregonensis	X	X	X
	Rhithropanopeus harrisii	X		
Pycnogonida		X		
Gastropods	*Urosalpinx cinera*	X		
	Crepidula plana	X		
	Crepidula convexa	X		
	Philine sp.	X		
Opisthobranchs	*Sakuraeolis enosimensis*	X	X	
	Dirona picta		X	
	Elysia hedgpethi		X	
	Haminoea sp.	X		

RC Pallets — Oyster shell pallets at Redwood City site.
MRGC Necklace — Oyster shell necklace at Marin Rod and Gun Club
MRGC Pallets — Oyster shell pallets at Marin Rod and Gun Club site.

Table 7. Sessile invertebrates associated with native oyster restoration sites at Marin Rod and Gun Club and Redwood City sites in San Francisco Bay from MACTEC (2006).

		Native Oyster Restoration		
	Species	RC Pallets	MRGC Necklace	MRGC Pallets
Bivalves	*Venerupis philipparum*	X		X
	Musculista senhousia	X	X	X
	Ostrea conchaphila	X	X	X
	Mytilus edulis (mussel)		X	
Bryozoans	*Schizoporella sp.*	X	X	X
	Bugula sp.	X	X	X
	Watersipora subtorquata	X		
	Conopeum sp.			X
	Other unknown species	X	X	X
Tunicates	*Molgula manhattensis*	X	X	X
	Styela clava	X	X	X
	Ciona sp.	X		
	Botrylloides sp.	X		

RC Pallets — Oyster shell pallets at Redwood City site.
MRGC Necklace — Oyster shell necklace at Marin Rod and Gun Club
MRGC Pallets — Oyster shell pallets at Marin Rod and Gun Club site.

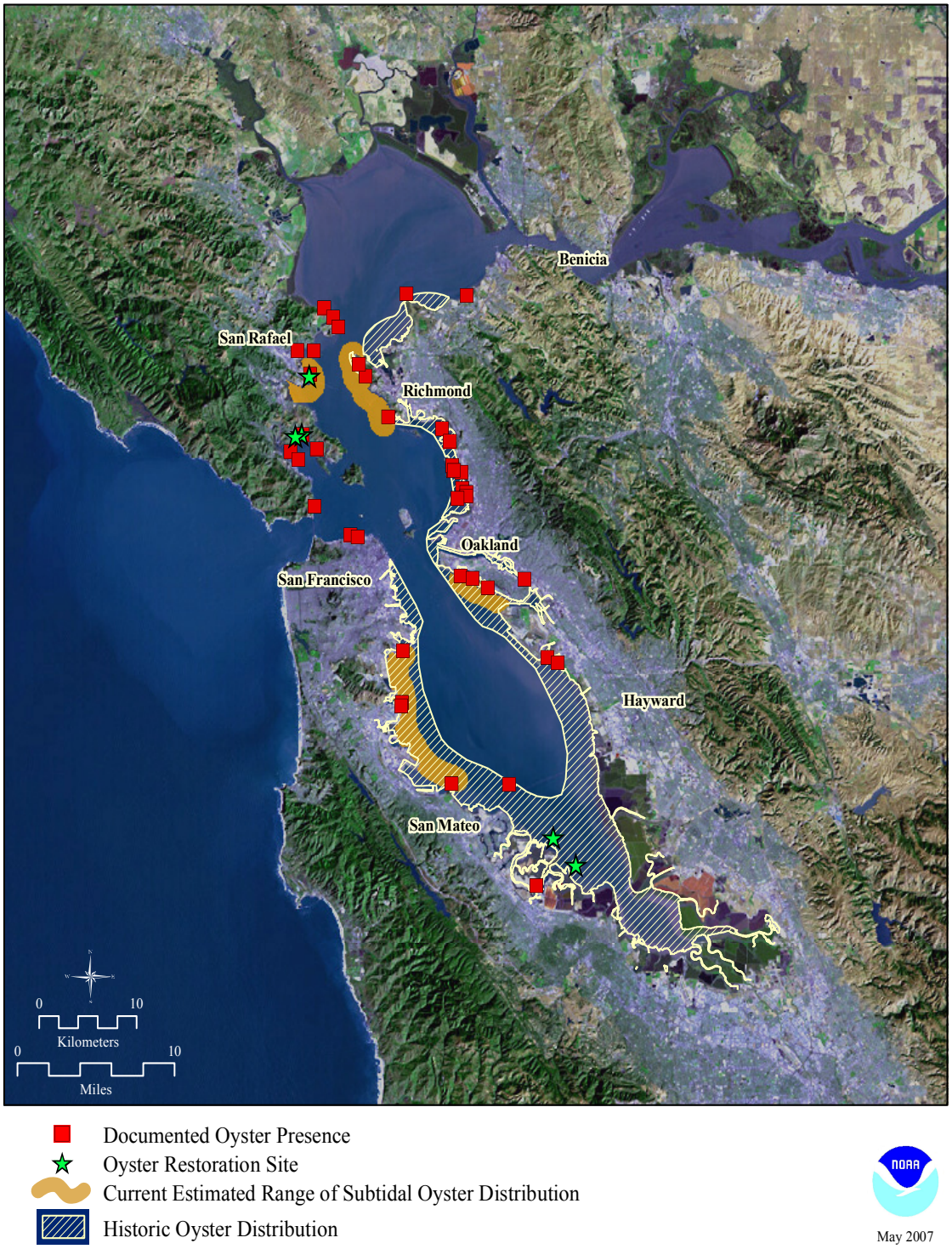

Figure 11. Historic native oyster distribution from Barrett (1963), sites of known oyster occurrence at present from Harris (2004), and native oyster restoration sites in San Francisco Bay. Historic oyster distribution is for the period prior to 1915 and is an approximation.

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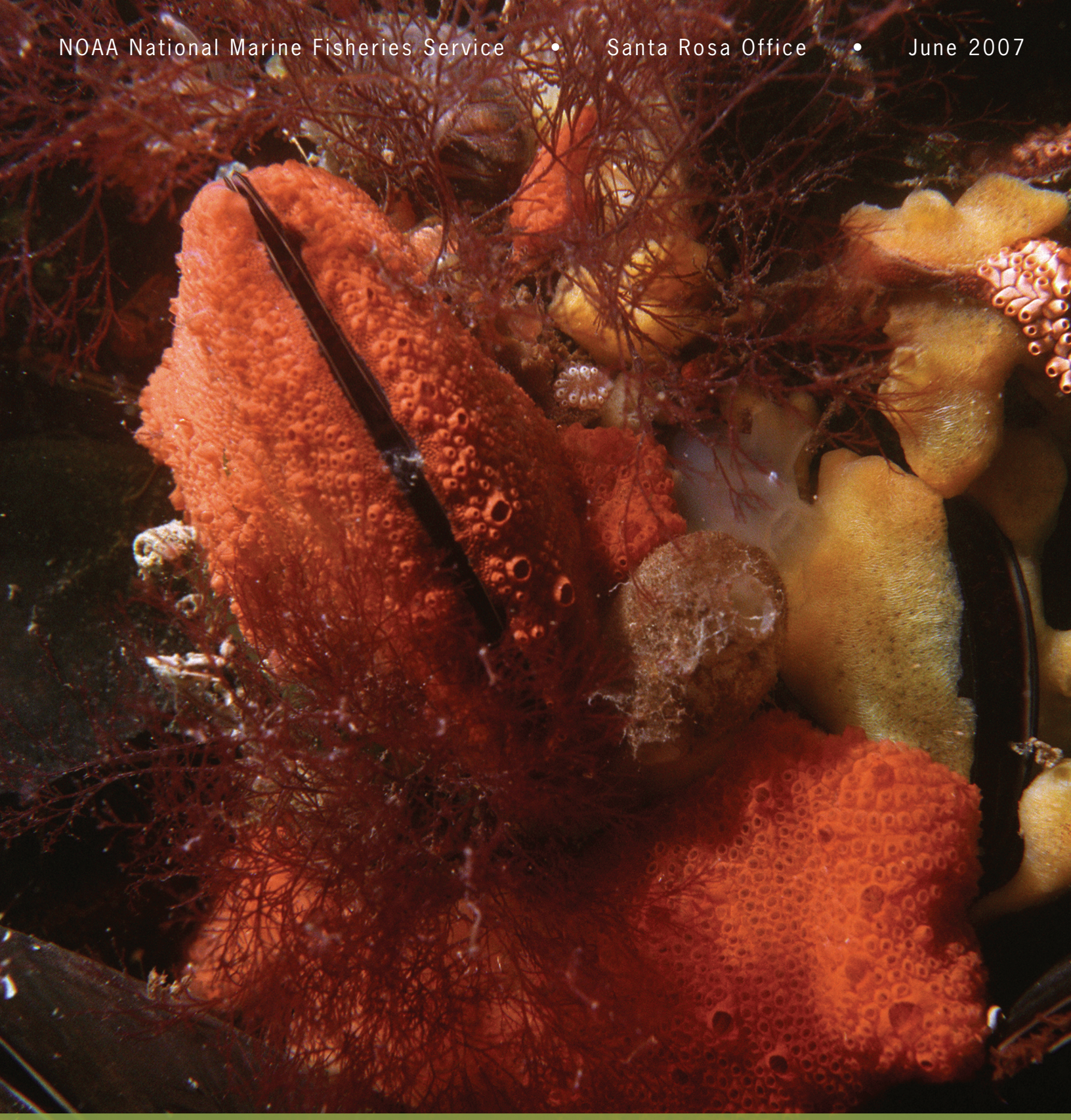

Report on the Subtidal Habitats and Associated Biological Taxa in San Francisco Bay

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