Impacts of Artificial Structures Placed in San Francisco Bay

A Report for the San Francisco Bay Subtidal Goals Project (July 2008)

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Many types of structures have been built or placed in or over the waters of San Francisco Bay, including wharves, piers, pilings, jetties, breakwaters, floating docks, buoys and moorings that service shipping and boating activities; sea walls and riprap that armor shores and protect them from erosion; nine major bay-crossing bridges and at least eleven smaller bridges over marginal arms of the bay that carry auto roads or railroads, and an unknown number of foot bridges; transmission towers and power lines; cooling water intakes for power plants and outfalls for power plants and water treatment plants; and across the floor of the bay, pipes and cables. There has been no general assessment of the effects of these structures on Bay organisms, and so an overview must be pieced together from generally unpublished sources of Bay information and inferences from studies on the impacts of structures that have been conducted elsewhere. Impacts from these structures include eliminating existing bottom habitat, creating hard substrate, shading, changing water circulation, altering adjacent habitat, changing fish behavior, creating resting or nesting sites for birds or pinnipeds, and probably facilitating the establishment of some exotic species.

There is no overall summary of the amount and distribution of artificial structures in the Bay, the portion of the shoreline that has been hardened, etc. There are six public cargo ports, several proprietary cargo terminals (including oil terminals and automobile importing terminals, primarily in Contra Costa and Solano counties) and several current or former military terminals (Mare Island Naval Shipyard, Alameda Naval Air Station and Hunters Point Shipyard, all closed, and Concord Naval Weapons Station, still active) in the Bay, along with over 200 marinas providing slips for over 33,000 boats in the Bay and Delta combined (Marine Exchange 1994; LTMS 1998). The San Francisco Bay Area Seaport Plans (BCDC 1996, 2003) report that there were a total of over 57,000 linear feet of cargo berths in the Bay in 1994, with a projected 62 effective berths in 2020 (Table 1). A recent boating guide (Dinelli and Dinelli 2003), lists 65 marinas and yacht clubs with nearly 19,000 berths distributed around the Bay (Table 2).

Table 1. Berth Length and Number at Cargo Ports in San Francisco Bay (based on BCDC 1996, 2003)

Port	Length of Berths (ft) in 1994	Projected Effective Number of Berths in 2020
Port of Redwood City	1,805	5
Encinal Terminals	1,313	0
Port of Oakland	21,110	21
Hunters Point Naval Shipyard	0	2
Port of San Francisco	25,373	14
Port of Richmond	4,409	12
Selby	0	5
Port of Benicia	3,200	3
Total	57,210	62

Table 2. Berths at Marinas and Yacht Clubs in San Francisco Bay (listed in Dinelli and Dinelli 2003)

	Number of Marinas	Number of Berths
Suisun Bay	6	1,555
San Pablo Bay	9	2,391
Central Bay	28	8,361
South Bay	22	6,560
Total	65	18,867

Eliminating Existing Habitat

Jetties, breakwaters and similar structures eliminate the habitat they are placed on, usually shallow subtidal and intertidal mud or sand bottom. Although no figures are available, the fraction of such habitat that has been eliminated in the Bay by building structures is probably small. The impacts of placing structures on rarer habitats, such as hard substrate, eelgrass beds or shellfish beds, would be more significant.

Increasing Hard Substrate

Natural hard substrate (mainly bedrock outcrops and associated boulders and cobbles) is rare throughout most of the Bay, except for the western part of the Central Bay. All of the structures listed above provide additional hard substrate in the Bay, however these artificial substrates generally do not closely resemble natural hard substrate. Floating substrates (docks, buoys, moorings) and pier pilings provide habitat conditions that differ greatly from natural substrates (Glasby and Connell 1999; Connell 2000; Holloway and Connell 2002), while rock jetties and breakwaters and unshaded concrete structures are probably most similar to natural substrates (e.g. Connell and Glasby 1999). The physical differences vary. Floating structures maintain organisms at a near-constant, mainly shallow water depth, which differs from any fixed natural substrate on which shallow water organisms are affected by the rise and fall of the tides. Floating structures to a greater or lesser degree may also isolate the organisms growing on them from benthic predators and other benthic organisms. Floating substrates also affect the exposure of organisms to surface lenses of fresh water and to floating oil and other contaminants. The texture, rigidity, temperature response and surface chemistry of materials found on artificial structures including wood (chemically treated and untreated), plastic, styrofoam, concrete, rubber and metals can differ greatly from the characteristics of natural structures. The surface orientation and the degree of shading of artificial surfaces can also depart significantly from that of most natural surfaces, with near vertical and horizontal overhanging surfaces being far more common on artificial structures. Published studies have found that natural and artificial hard substrates located near each other tend to be dominated by different suites of species (Connell and Glasby 1999; Glasby 1999b). Some studies have found that artificial substrates are more dominated by exotic species (Lambert 2002; Glasby et al. 2007). Connell and Glasby (1999) concluded that "artificial structures may increase the abundance and diversity of subtidal epibiota in the shallow areas of an estuary, but are not surrogate surfaces for epibiotic assemblages that occur on nearby natural rock."

There are no published studies quantitatively comparing species composition on artificial and natural hard substrates in the Bay. Researchers' qualitative perceptions have differed, on the one hand finding greater dominance by exotic species on artificial substrates, most notably on docks and other floating substrates (personal observations); and on the other hand finding little difference between the biotas of submerged rocks and artificial marina substrates in the Central Bay (Chris Brown, pers. comm.).

Certain fish species are commonly found in association with artificial structures (Clynick 2008), possibly because of food or cover provided by the epibiota on the structure or a preference for shade or the shadow line. In San Francisco Bay, fish commonly found near or in the fouling growth on floating docks and pilings include Bay Pipefish (*Syngnathus leptorhynchus*), Shiner Surfperch (*Cymatogaster aggregata*) (both naturally occurring in eelgrass) and the non-native Chameleon Gobies (*Tridentiger trigonocephalus or T. bifasciatus*) (personal observations).

Altering Adjacent Habitat

Structures built in the water can alter water flows and patterns of sediment erosion and deposition. Depending on the circumstances, sediments can be scoured around the base of structures and/or deposited in the lee of structures (Whitehouse 1998; Sumer 2001; Sumer and Fredsoe 2003). The long jetty at the south end of Mare Island contributed to the substantial accretion of sediment along the western shore of the island during the 20th century (Atwater et al 1979). At the Point Isabel Regional Shoreline in Richmond, sediment built up between a detached breakwater and the shore has developed into a salt marsh (personal observations).

Bay mussels, including both a native (*Mytilus trossulus*) and an exotic species (*M. galloprovincialis*) and/or hybrids between them, are common or abundant on many of the structures in the Bay. Over time, the accumulation of dead shells from these structures can change the adjacent bottom type to shell hash (Pentilla and Doty 1990; Nightingale and Simenstad 2001).

Floating docks that ground on low tides can eliminate eelgrass below them (Nightingale and Simenstad 2001), and probably affect other benthic organisms as well. Chains used to anchor mooring buoys, barges, rafts, booms, etc. can damage bottom vegetation by dragging on the bottom. Buoys moored with rope lines, especially with mid-line floats, cause less damage than buoys attached by chains (Nightingale and Simenstad 2001).

Shading

Studies in the Pacific Northwest and elsewhere have found that shading by overwater structures reduces or eliminates eelgrass and seaweeds beneath them (Pentilla and Doty 1990; Fresh et al. 1995, 2001; Burdick and Short 1999; Nightingale and Simenstad 2001). On hard substrate, shading decreases algal cover and in some studies reduces the abundance of spirorbid worms and grazing snails, and increases the abundance of attached Invertebrates, including sponges, serpulid worms, barnacles, bryozoans and tunicates (Glasby 1999a,b; Blockley 2007), but no consistent effects were observed on soft sediments under structures (Lindegarth 2001). Shading can also impair prey capture by fish, which are primarily visual feeders, and possibly affect their spatial orientation, schooling or predator avoidance behaviors, all of which are partly sight-dependent (Nightingale and Simenstad 2001). In the Hudson River Estuary, Able et al. (1998) compared fish distributions underneath the center of large commercial, piling-supported piers, in piling fields consisting of an array of pilings where the pier or deck had been removed, and in adjacent open water. Relative to the other sites, the pier sites had much lower light levels (<0.12 μE/m^2-s throughout the water column at the pier sites compared to >566 μE/m^2-s at 0.5 m depth and >9 μE/m^2-s on the bottom at the piling field and open water sites); typically lower fish abundance and species richness; greatly reduced abundance of young-of-the year fish; and increased abundance of eels. Another study found that caged fish under piers showed periods of starvation compared to caged fish at pier edges and in open water, and that this was likely due to shading impacts on prey capture (Duffy-Anderson and Able 1999; Nightingale and Simenstad 2001).

The effects of shading by overwater structures can be reduced by reducing the width or raising the height of the structure (that is, by increasing the distance between the water surface and the underside of the structure) or orienting the structure in a north-south direction, and possibly by incorporating gratings or glass blocks in the structure to transmit light, increasing the space between pilings, or using materials that reflect light (e.g. concrete rather than wood pilings) or reflective paint on the underside of docks (Burdick and Short 1999; Nightingale and Simenstad 2001; Fresh et al. 2001; but see Loflin 1993). Covered moorages, boathouses, houseboats, and other vessels moored alongside can enlarge the shade footprint of piers and floating docks and extend their impact (Nightingale and Simenstad 2001). Impacts from shading appear to be less under floating docks that are attached by chains that allow some movement rather than fixed in position by pilings (Pentilla and Doty 1990; Nightingale and Simenstad 2001).

Altering Fish Behavior

Various studies have reported fish behaviors that appear to be responses to encountering artificial structures, including reluctance to pass under docks and piers, pausing and going around docks, schools breaking up on encountering docks (Weitkamp 1982; Nightingale and Simenstad 2001). Juvenile salmonids, for example tend to remain along the line of shadow and avoid areas of deep shadow (Nightingale and Simenstad 2001). Impacts from these responses could include migration delays due to disorientation and increased predation risk due to breaking up of schools or deflection into deeper waters (Nightingale and Simenstad 2001).

Creating Resting and Nesting Sites

High relief natural landscape features such as cliffs and trees are rare in or near the shore of much of San Francisco Bay, and high relief artificial structures may provide sites for bird resting or nesting in areas where they are otherwise absent or rare. Low artificial structures near the water may also provide resting sites for birds or pinnipeds, especially if they are not connected to the mainland. The following is an incomplete description of the use of such structures in San Francisco Bay.

Raptors have been observed on artificial structures in or near San Francisco Bay salt marshes, including White-tailed Kite (*Elanus leucurus*) and American Kestrel (*Falco sparverius*) on low perches (posts), and Peregrine Falcon (*Falco peregrinus*) on transmission towers (personal observations). Since the 1990s, Peregrine Falcon have occasionally attempted to nest on the Oakland Bay Bridge and hunted from the Golden Gate Bridge (Bell 1994; Granholm 2007). Peregrine Falcon nesting on the Coronado Bridge over San Diego Bay periodically took California Least Tern (*Sternula antillarum brownii*) from a nearby colony, and there have been concerns about similar interactions in San Francisco Bay (Bell 1994).

Many birds use jetties and breakwaters as resting sites, including a colony of California Least Terns that uses the detached breakwater off the former Alameda Naval Air Station. California Least Terns have also been observed resting on the abandoned western end of the Berkeley Pier (Granholm 2007). Gulls (*Larus* spp.) frequently rest on pier railings and other structures; pelicans, herons and egrets patronize certain docks; and Turkey Vultures (*Cathartes aura*) sometimes rest on a small abandoned pier near the mouth of Meeker Slough in Richmond (personal observations). Small numbers of Western Gulls (*Larus occidentalis*) nest on the Richmond Bridge and the Oakland Bay Bridge (Granholm 2007; SFSU 2007). Double-crested Cormorants (*Phalacrocorax auritus*) nest on the Richmond Bridge (about 500 nests currently), the Oakland Bay Bridge (about 800 nests currently), the cable-crossing structure near the Oakland Bay Bridge (2 nests observed in 2007) and the transmission towers just south of the western span of the San Mateo Bridge and on Redwood Creek (Stenzel et al. 1995; Strong 2005; Granholm 2007; SFSU 2007; personal observations). In 2007, four Brandt's Cormorant (*Phalacrocorax penicillatus*) nests were seen on the cable-crossing structure near the Oakland Bay Bridge (Granholm 2007). Cormorants frequently rest on buoys in the Bay, and their common presence around piers and docks could raise the rate of predation on fish near those structures (Nightingale and Simenstad 2001). Decades ago, large numbers of Double-crested Cormorants roosted on a two-mile-long transmission line over the Richmond Channel, which was constructed in 1923 and removed some time after the early 1940s. In the early 1940s there were around 2,000-2,500 cormorants roosting on the line each night in the winter, and about 500 each night in the spring when many cormorants had departed for coastal breeding colonies (Bartholomew 1942, 1943).

Harbor Seals (*Phoca vitulina*) often haul out on breakwaters. Since 1989, several hundred California Sea Lions (*Zalophus californianus*) (with a maximum of around 1100 animals) have congregated in the winter on docks at Pier 39, on rare occasion joined by a Harbor Seal or Steller Sea Lion (*Eumetopias jubatus*). California Sea Lions often haul out on buoys and occasionally on other docks in the Bay (MMC 2007; personal observations).

Facilitating Invasions

It has frequently been observed that exotic organisms are more common on various artificial hard substrates than on natural hard substrates (Lambert 2002; Glasby et al. 2007; personal observations), though not all observers have found this when the substrates are exposed to similar physical parameters (Chris Brown, pers. comm.). Glasby et al. (2007) found that exotic species were more abundant and native species less abundant on floating structures and pilings compared to rocky reefs and sandstone seawalls, and that exotic species, especially colonial tunicates, recruited better to floating structures. They argue that artificial structures may thus facilitate the establishment or dispersal of exotic organisms in estuaries. In the Gulf of Maine, several exotic species that are common foulers of artificial structures apparently became established first in bays and estuaries where such structures are common, and subsequently spread to rocky reefs in the open waters of the Gulf (Harris and Mathieson 2000; Harris and Tyrell 2001; Bullard et al. 2007).

In the Bay, there are many exotic species that are dominant foulers of hard substrates. Thus the proliferation of artificial hard substrates in the Bay, especially in parts of the Bay where natural hard substrates are rare (*i.e.* most of the Bay outside of the western Central Bay), provides additional settlement opportunities for these exotic organisms, facilitating their spread and increasing their abundance within the Bay, and probably facilitating their eventual spread to other bays and estuaries along the coast (Chris Brown, pers. comm.). This is true regardless of whether or not artificial hard substrates favor exotic species compared to natural hard substrates.

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