Chapter 5

BERKELEY MARINA'S TOXIC WASTES: GENERATION AND MITIGATION

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Introduction

There are 25 major marinas and yacht harbors in San Francisco Bay (Figure 1). Marinas provide a valuable recreation and livelihood for many fortunate people. They provide berths for commercial and recreational fishing, power, sail, and houseboats. Marinas provide a social benefit by generating income for local governments and providing enjoyment for boat owners and lovers.

These benefits are not obtained without costs, however. Generation of toxic wastes is inherent in the operation of marinas. Heavy metals such as copper and zinc, solvents and waste oil are part of the maintenance and repair procedures associated with the boats. Release of petroleum products (diesel, gas, additives and lubricants) and the generation of sewage result from the vessels' operation. Creosote is a biocide used on the pilings to prevent biodeterioration.

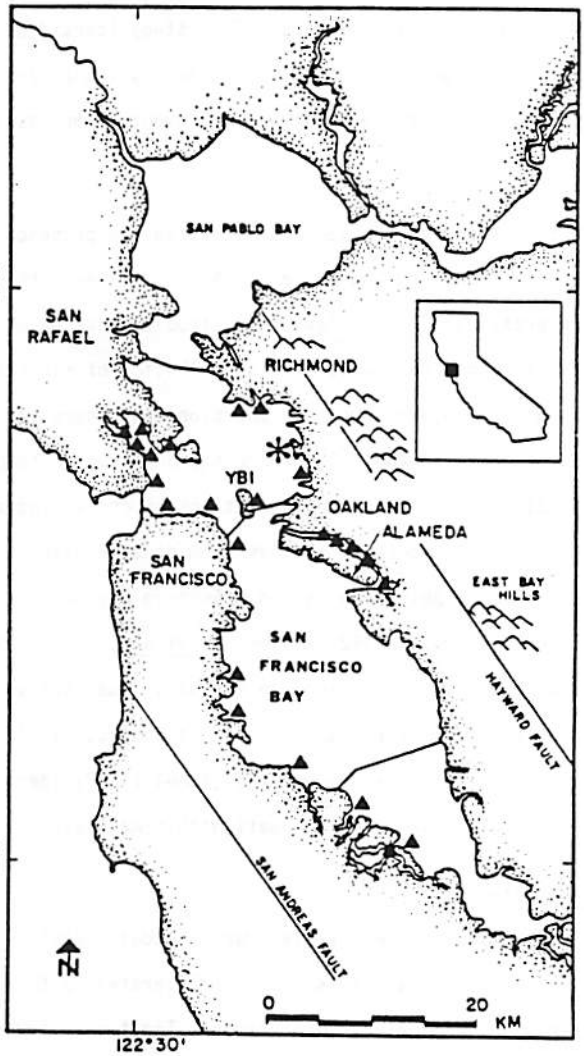

Figure 1. Major Marinas and Yacht Harbors Located in San Francisco Bay.

Source: County and City Telephone Directories. Base Map after Sloan, 1981.

* = Berkeley Marina

The breakwaters constructed to protect the boats from rough water also create barriers to the dilution of the water within the marina. This reduced dilution can lead to the build-up of highly toxic concentrations of the wastes (So, 1978). The quality and quantity of these wastes create a potentially formidable threat to the surrounding ecosystem and the public welfare.

Proper consideration of this threat and efficient design of systems to handle several point sources of wastes can significantly reduce this potential hazard. Other wastes cannot be controlled currently due to either a lack of technological improvements or economic alternatives. The environmental degradation associated with the uncontrolled release of certain wastes from marinas is of varying magnitudes and time-scales. This study identifies and quantifies the toxic wastes generated in a marina of medium to large size (975 berths), analyzes their penetration into the local aquatic ecosystem, and assesses the ensuing environmental impacts and threat to public welfare.

Past Work

Extensive research has been conducted on the presence and dispersion of heavy metals in San Francisco Bay. Bradford and Luoma (1979), Girvin and others (1975), SWRCB (1974) and Thompson and others (in press) are just a few of the studies that have reported heavy metal contamination of the bay water, sediment and fauna. The contribution of marinas to this contamination is not as thoroughly known as that from other sources. Thompson and others (in press) included marinas in the various heavy metal sources in their San Francisco Bay study. Young and others (1979) and Culliname and Whelan (1982) found elevated concentrations of copper and zinc in the sediments and soft tissues of mussels and algae found in marinas from other regions.

Oil and grease pollution in San Francisco Bay has also been the topic of much research (e.g., Stenstrom and Silverman, 1982; Risebrough et al., 1978). No quantitative data are available on the oil and grease concentrations in marinas. Qualitative assessments indicate that chronic, low-level presence of petroleum products is characteristic of marinas (Young et al., 1979). A study by the Associated Bay Area Governments (ABAG) (1977) identifies the problems associated with the release of untreated sewage from boats within marinas.

Methods and Materials

The study site is the Berkeley Marina located east of the Golden Gate Bridge in San Francisco Bay (Figure 1). This marina is owned and operated by the City of Berkeley and the various services are contracted out to private businesses. The types of wastes generated at the marina were determined by interviewing the people responsible for managing them.

Four water, 5 sediment and 5 algal samples were collected at sites 1-9, 11, 12 (Figure 2) on February 20, 1984 for analysis of heavy metal content. Water samples were collected in glass containers from a depth of 0.5m. Sample preparation followed the Standard Methods (APHA, 1975).

Sediment samples were collected at sites in the marina directly beneath the boats and at control sites of comparable depth. Skin-diving techniques were employed to drive 125 ml glass containers into the sediment. The samples were prepared according to the methods described by Thompson and others (in press).

Algae grow at a distinct level in the intertidal zone, both within the marina and at the control sites. Samples were drawn from the rocks in this zone and placed in polyethylene vials. Treatment of the samples followed the procedures described by Luoma and others (1982). Concentrated hydrogen peroxide was also used to obtain complete digestion.

All the treated samples were analyzed for heavy metal concentrations using a Perkin-Elmer 360 Atomic Absorption Spectrophotometer. Much appreciation must be extended to T. Morrison, Science Research Associate, College of Chemistry, for his assistance with preparing and operating the apparatus.

Hydrocarbon presence was determined qualitatively while sampling. Population samples were taken on April 1, 1984, from sites 4, 6, 10 and 11 in the marina and control sites (Figure 2a, b). A 500 cm^2 quadrant was randomly placed in the intertidal zone occupied by barnacles and mussels. Organisms within the quadrant were counted without overturning the rocks. Growth on the underside of certain rocks was counted when possible. Barnacles were counted alive when the casing was occupied

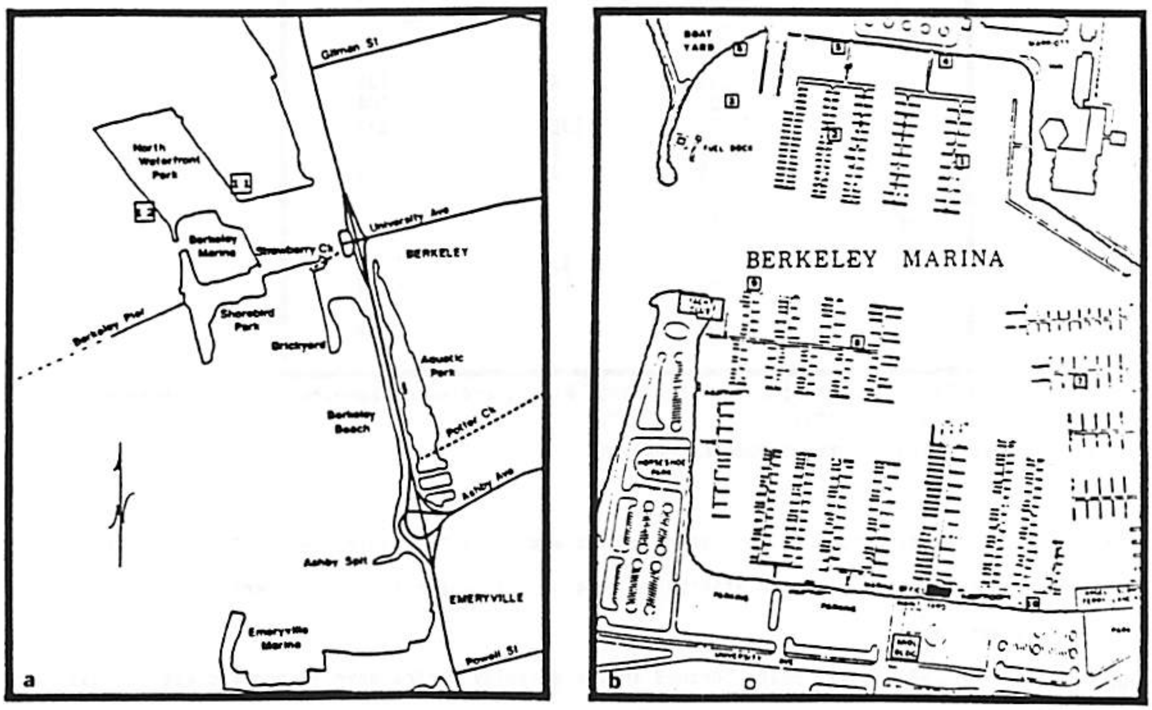

Figure 2a. Locality Map with Sample Sites 11 and 12 Indicated.
b. Sample Sites from Within the Berkeley Marina.

and dead when more than half the casing remained and it was hollow. The dispersion pattern of the barnacle populations was observed qualitatively from studying the entire marina shoreline and several areas outside the marina boundaries.

Results

The results of the heavy metal analysis are presented in Table 1. The metal concentrations in the sediment and algae are consistently higher in the marina samples than in the control samples. The highest measured quantities of both Cu and Zn were from the samples taken directly below the boat yard's run-off. The high estimate of Cu and Zn in algal sample 6 could be due to an insufficient rinsing and may not be an accurate measure of the actual concentrations in the tissues.

Sample Number	Amount of Sample	Cu (ppm)	Zn (ppm)
sediment	(g)		
1	3.20	131	293
2	2.25	132	374
3	4.32	187	433
11	1.81	60	172
12	1.82	83	265
algal	(g)		
4	0.52	46	138
5	0.29	74	104
6	0.81	1320	233
11	0.76	15	35
12	0.15	32	56
water	(ml)		
7	100	1.4	0.18
8	100	1.3	0.19
9	100	1.3	0.18
11	100	1.8	0.22

Table 1. Copper and Zinc Concentrations in Sediment, Algal, and Water Samples from the Berkeley Marina and Control Sites.

Source: Atomic Absorption Spectrophotometer Analysis.

The Cu and Zn concentrations in the water samples are not excessively high. The higher concentration in the control sample could be attributed to a slight suspension of sediment that was stirred up from the wave action.

Approximately 90% of the 975 boats berthed in the Berkeley Marina have either a diesel or gas engine (Worden, pers. comm., 1984). Presence of fuel and oil from these motors was observed by the author on every trip to the marina. One example of an acute release of diesel was around the dock of sample site 7, where a 100 m^2 area of water was covered with a thick layer of diesel. Nice colors, but highly detrimental to the organisms present.

The creosote used on the pilings naturally decays and sloughs off into the water around them (McCleese and Metcalfe, 1979). This decay process results in a chronic, low-level discharge of creosote into the marina water.

The paint, primer, and stains on the boats are stripped down in the boat yard. Lacquer thinner (2 gal/day) is the solvent primarily used for these tasks, with acetone and turpentine being periodically employed. A containment system has been designed to retain these solvents. The wastes are returned to the 55-gallon drums that they were purchased in and shipped to a hazardous waste disposal site (McLeish, pers. comm., 1984).

The boat yard also generates solid wastes containing heavy metals from scraping the paint and primer off the boat hulls. This waste is captured by drains in the ground and transported to the municipal waste water treatment plant. Containment of this toxic waste is not complete, resulting in some penetration to the surrounding environment.

The sewage produced on the boats and from the marina facilities is also treated at the municipal waste water treatment plant (Worden, pers. comm., 1984). The wastes are pumped out of the vessels' holding tanks and transported for treatment.

The diesel and gasoline tanks used by the fuel dock are stored underground and above the waterline. They are monitored for leaks by comparing the inflow and outflow records. No leaks have been observed to date. Waste oil generated by the boat engines is collected at the fuel dock in 55-gallon drums. The drums are then turned over to Artesian Oil Recovery, a firm that recycles it (Chambers, pers. comm., 1984). This collection center does not recover 100% of the waste oil, however. Five 3-to-5-gallon containers filled with oil were placed by the trash dumpster next to the marina office, two of them without lids covering them.

The results from the population sampling are given in Table 2. There are distinctly different densities between the barnacle and mussel populations in the marina and those outside it. No mussels were found on the rocks within the marina. The density of barnacles in all the marina samples was less than the measured density at the control site. The dispersion of barnacles within the marina tends to be uniform, compared to a more clumped dispersion of the control populations. Robust growth of both organisms was observed on the rocks of the exposed side of the marina breakwater.

Discussion

The presence and function of the Berkeley Marina results in an unavoidable generation of toxic wastes. Several effective waste containment systems have been incorporated into the operation of the marina. Disposal of the sewage and most of the waste oil from the boats and the solvents used in the boat yard are among this group of properly handled wastes. The systems are designed to minimize the escape of these potentially hazardous substances. The concern for controlling the release of these particular wastes is well-founded. Their uncontrolled presence in the surrounding environment would impose considerable physiological stresses and ecological disturbances.

Sample Number	No. of Quadrats	Total Alive	Total Dead	Ave. Alive	Ave. Dead
barnacles					
4	15	999	417	67	28
6	16	181	206	11	13
10	10	247	380	25	38
total	41	1427	1003	35	25
11	18	2078	644	115	38
mussels					
4	8	0		0	
10	7	0		0	
total	15	0		0	
11	15	602		40	

Table 2. Sample Populations of Barnacles and Mussels within the Berkeley Marina and from a Control Site.

The hazard posed by releasing untreated sewage into the marina water is addressed by a law which requires boat owners to use the marina's pump facilities to empty their septic tanks. If leaks in the pump pipes were to develop, undesirable organisms would be introduced to the ecosystem. These organisms consist of disease-carrying pathogens and organisms that increase the biological oxygen demand (BOD) (Topping, 1976). An increase in the BOD deprives the resident organisms of the oxygen necessary for their growth and survival.

The collection/recycling system operated through the fuel dock serves to reduce the risks associated with the generation of waste oil. However, the system is not completely effective. Waste oil left by the dumpster indicates that the fuel dock's collection service is not adequately promoted. The waste oil from the marine engines is highly insoluble in water. Release of this waste into the terrestrial and aquatic environments will impair the photosynthetic capacity of the vegetation and the food procurement of the benthic fauna (Cowell, 1976).

The catch system employed by the boat yard to contain solvent wastes appears to be adequate for preventing them from directly reaching the surrounding environment. However, the potential for accidental release or improper handling of these solvents does exist and must be avoided. These substances have been observed to induce behavioral and neural abnormalities in marine organisms (Bakke and Skjoldal, 1979).

The success of these waste-handling systems can be attributed to the foresight, concern, and regulation of the marina designers and personnel. The toxic wastes that pose the most significant threat to ecosystem interactions and public health are those whose release is unregulated. The heavy metals and hydrocarbons that are continuously emitted into the marina compose this group of wastes.

Copper and Zinc are the two most abundant metals found in marinas. Elemental copper is the active ingredient (40 to 51%), combined with other "inert" compounds, of the antifouling paints used on the boat hulls. The inert ingredients may or may not be harmless to the ecosystem; they just are not the active biocidal agent. Antifouling paints are used on the boat hulls to improve the efficiency of the vessel's movement through the water. Copper is one of the three most toxic metals to marine organisms (Bryan, 1976). This property is probably why the copper was chosen as the active agent in the paint. Zinc will enter the marina from the corrosion of the sacrificial zinc anodes used to prevent corrosion of the metal components on the boats' engines.

Physical stresses imposed on organisms by copper and zinc are well documented. Inhibited growth, productivity, and reproductive success are the primary results of toxic exposure to copper and zinc (Bryan, 1976; Hopkin and Kain, 1978, McKenny and Neff, 1979). Physical impairments result from copper concentrations greater than 0.001 ppm and zinc concentrations greater than 0.18 ppm. The toxicity levels vary according to the organisms and life-cycle. These physiological impacts occur at concentrations that are present in all the samples of this study. Heavy metal concentrations observed in previous studies have also exceeded the threshold concentrations that induce physiological stresses (Bradford and Luoma, 1979; Girvin et al., 1975; SWRCB, 1974; Thompson et al., in press). This prevalence of heavy metal contamination in San Francisco Bay indicates that the contribution of marinas relative to other sources is not very significant.

The physiological stresses imposed by chronic low-level exposure to petroleum products and creosote are of interest for this study. The current technology of marine engines is such that a release of their fuels and lubricants cannot be avoided. Previous research has observed reduced productivity and reproductive success of marine organisms from sublethal exposure to petroleum-based products (Marinov, 1972; Lee, 1978). Impaired growth and reproduction of marine fauna have been attributed to creosote exposure (McCleese and Metcalfe, 1979; Zitko, 1975).

The primary ecological concern in relation to toxic wastes is their impact on the reproductive capacity of nearby biota. These effects will change the community structure of the ecosystem by altering the distribution and population stability of certain organisms. Reduced reproductivity of an organism which plays a key role in trophic interactions will initiate changes in the population stability of the organism's prey and predators. The virtual absence of mussels and reduced density of barnacles within the marina suggests this vulnerability.

The major threat to public health and social welfare is related to the persistence of the pollutants and/or their bioaccumulation through the food chain. Persistence is governed by a compound's natural or transformed stability. Transformations are achieved through physical or biological processes. Copper and zinc are naturally stable elements. Hydrocarbons are normally not very stable compounds, but they can be incorporated into the tissues of marine organizms where they do become stable, thus posing a threat of bioaccumulation (Blumer and Thomas, 1965).

Creosote is not very stable in seawater (Borthwick and Patrick, 1982). Zitko (1975) has refuted the transfer of creosote through the food chain. Thus, one marina's contribution of this toxic substance will not pose a significant threat to public welfare. However, a high density of marinas could result in concentrations of creosote so high that ecological disturbances would occur.

The main factor contributing to the bioaccumulation of pollutants through the food chain is their solubility in fat versus water. Water-soluble compounds are easily depurated by organisms, while fat-soluble ones tend to remain in tissues and accumulate (Laughlin, pers. comm., 1984). The tendency for bioaccumulation in aquatic ecosystems is less than in terrestrial ones because there is a pattern for the concentration of a compound to equilibrate between the organism's tissues and the surrounding medium. This concentration is roughly equal for all trophic levels (Ehrlich et al., 1977). The fluid medium around the organism allows for a more active regulation to occur. However, copper is a metal with one of the highest binding coefficients for combining with organic radicals. Thus, bioaccumulation of this particular metal is possible (Bryan, 1976). The binding potential for some petroleum-based hydrocarbons has already been noted.

Conclusions and Recommendations

The Berkeley Marina has influenced the local ecosystem. Reduced population densities can possibly be related to the toxic substances released in the marina. The abundant populations of the affected organisms just outside the marina suggest that this impact has been localized and does not pose a threat to the rest of the bay ecosystem. In order to retain the integrity of the bay ecosystem, the reservoir of organisms outside of the marina's influence must be maintained.

The potential hazards to the human population have been mitigated by preventing the release of the more toxic wastes generated in the marina. Another measure that reduces the threat to public health is the imposition of a city ordinance that prohibits swimming and fishing within the marina. This ordinance prevents direct exposure of people to the contaminated marina waters and thereby significantly reduces the risks of maintaining a polluted body of water so close to dense human populations.

An expansion of marinas or a large increase in the number of them could impose long-term problems that may not be easy to cope with. Proper planning based on enlightened knowledge of both the short-term and long-term impacts associated with marinas will alleviate these potential problems.

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