The Environmental Impacts of Marinas and Their Boats

A Literature Review with Management Considerations

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NOAA/Sea Grant

University of Rhode Island
Marine Memorandum 45

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4/78-1M

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1978

$1.00

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Acknowledgments

The authors wish to identify Warren Johns of the Raytheon Company as key to the preparation of this report for providing funding, technical suggestions, and editorial assistance. Daniel O'Neill also helped with technical assistance and critical reviews. Special appreciation goes to the University of Rhode Island Marine Advisory Service, a Sea Grant Program of NOAA, for financial and clerical aid.

Foreword

This literature review is revised and updated from Chapter II of the Rhode Island "Areawide Water Quality Management Plan, Preliminary Evaluation MARINAS TASK" by the Raytheon Company, Portsmouth, R.I., for the Rhode Island Statewide Planning Program, Providence, R.I. 02907, January 1978.

Some management recommendations are specific to Northeastern boating states. Current marina management practices and structures may vary from region to region. Much of the literature cited pertains to saltwater environments, and this reflects the bias of the report for Rhode Island planning use and that much of the research to date has been done only on salt water. Readers should keep the above limitations in mind when developing management plans for other areas.

The purpose of this review is to summarize all aspects of marina and boat-related environmental effects. Discussion will focus on studies of each component's effects, the management options needed to reduce negative effects and expand positive ones, and future research needs.

Introduction

Any alteration or change in the physiographic features of the shoreline may be assumed to have an environmental impact. Marinas are shoreside facilities for servicing recreational boats. They alter the shoreline and thus are capable of having complex impacts, both positive and negative, on a small portion of shoreline. In this report, "marina" refers to the facility also called boatyard, yacht club, community dock, town dock, etc., serving recreational craft. Defining and measuring the impact of any marina requires that each component be viewed first individually and then as part of the whole system.

In addition to environmental effects, marinas have additional importance for society. Although privately managed, they are major public access points to recreational waters. They have economic value to local communities through employment and tax revenues and they concentrate boating activities, storage, and access, thus freeing shore frontage for other uses.

In addition to providing space for mooring boats, the marina facilities often include other services:

- Launching ramps
- Fuel docks
- Hull and engine repair shops
- Sales rooms for boats, engines and accessories
- Open or enclosed dry-land boat storage
- Boat haul-out facilities (crane, travel lift, railroad)
- Restrooms, showers and locker rooms
- Restaurants
- Groceries
- Bulk ice
- Bait and tackle
- Propane gas
- Laundry facilities
- Swimming pools
- Gift shops
- Motels
- Picnic areas
- Children's playgrounds
- Parking lots

Much of the literature available today adequately describes the components of a marina's impact on the environment, but it provides little hard scientific data to support any conclusions as to the severity of that impact. The reports "Marina del Ray: A Study of Environmental Variables in a Semi-enclosed Coastal Water" (5) and "Ecology of Small Boat Marinas" (36) are two notable exceptions. After searching for such quantitative studies, we find that the qualitative discussions far outnumber the quantitative reports. In fact, there are few scientific reports available that explore the effects of any alteration specifically due to the construction and use of marinas.

Chapter I: The Marina Facility

MARINA SITE LOCATION

Effects

The location, preparation and design of marina facilities (which should include planning for vehicular traffic, access to navigable and recreational waters, fresh water supply, and utilities) are the first factors to be considered when assessing the impact of a marina. The primary negative impacts are habitat loss, pollution by stormwater runoff, and aesthetic (visual) pollution. A marina's impact can also have positive features, since it provides for the concentration of shoreline development (as opposed to many scattered private docks) and may increase the diversity of shoreline habitat, e.g., providing substrate for fouling communities.

Habitat Loss: To provide protection for its facilities and safe moorings for boats, most marinas are located on calm, sheltered shorelines. At one time, salt marshes were preferred sites for marinas because they exist on sheltered shorelines and were regarded as wastelands (44). People have now recognized that salt marshes are important marine ecosystems providing valuable wildlife habitat and nursery grounds for many species. They export plant material into adjacent waters, where it becomes an important link in the estuarine food chain (35). If a salt marsh is removed or covered over to make room for marina facilities, this important marine habitat is lost. Loss of marsh vegetation production can be estimated, but adequately estimating the loss of other components is nearly impossible. Once altered, natural habitat cannot be returned to its original condition. The marina does, however, provide an artificial habitat with its own unique environment.

Runoff: The construction of land-based marina facilities may necessitate the removal of natural vegetative cover and its replacement with impermeable surfaces such as buildings and pavement, which reduce available area for stormwater percolation and cause surface runoff. This runoff can carry a variety of pollutants, including sediment, pesticides, oil and other road dirt, heavy metals, and nutrients, which are all capable of degrading water quality. The environmental effects of storm drainage on the water quality of Marina del Ray (southern California) were studied by Chen, Bowerman and Petridis (10). Their results indicated that heavy metals, such as mercury, cadmium and lead, precipitated and/or settled out of storm water within a short distance from its point of discharge. The presence of a pond intercepting one storm drain seemed to reduce the influx of heavy metals into marina waters. Though Marina del Ray is one of the largest manmade marinas in the world and its stormwater discharge includes mostly urban runoff, the storm drain discharge appeared to have little direct effect on the water quality of the marina (10).

Aesthetics: The coastal zone may be regarded as a valuable aesthetic resource (77). The presence of a marina may change the shoreline's aesthetic value by introducing sights, sounds, and smells foreign to the natural environment. Poorly maintained marinas may further degrade aesthetic values (44). Both aesthetic consideration and man's alterations to the aesthetic environment are difficult to measure; no studies were found which made this attempt. However, it may be assumed that a marina situated on a pristine shoreline will have a negative effect, while one placed on a developed or urban waterfront may actually improve the appearance and environmental quality of the waterfront.

Management Considerations

When building a new marina or expanding an old one, the optimal choice would be a protected area of shoreline that does not include salt marsh. This option is often not available. Gianno and Wang (18) have prepared guidelines for marina development in a marsh environment and offer an example of a composite design to maintain biological productivity. Their guidelines include: 1. Using dredge spoil from the marsh to establish new productive marshes elsewhere; 2. Providing adequate flushing to promote water circulation, which cycles nutrients and prevents eutrophication; 3. Providing contact areas within the marina so fouling communities, an organic food source, can prosper and multiply; and 4. Controlling water quality so that estuarine species can thrive in the marina.

Fouling communities may actually complement neighboring salt marsh systems by serving as an important food supplement for juvenile and adult finfish, particularly at seasons when marsh nutrient export is lowest (36). Nixon, Oviatt, and Northby (36) have suggested that although fouling communities in marinas contribute to biological production, they may not adequately replace other valuable components of salt marsh ecosystems. Although mammal and waterfowl populations were not studied, Nixon, Oviatt, and Northby (36) felt it was unlikely that either of these groups would rest in, or make extensive use of, marinas. Some wildlife species, such as mallard ducks, which have adapted to man's presence, may be able to utilize marina areas (36). In order to maintain fish and wildlife habitat, as much marsh area as possible should be retained at the marina site.

Retaining marshland along the water margin of a marina will also provide a natural buffer to stormwater runoff and prevent the release of untreated runoff directly into marina and coastal waters (38). The report "Coastal Facility Guidelines" (38) suggests the following: that drainage systems be designed to regulate the release of water back into the environment; that outfall sites be chosen so that effluents return into well-flushed waters such as the mouth of a marina or adjacent open coastal water; and that the volume of water entering storm drains be reduced by minimizing the amount of land area waterproofed with asphalt and concrete. Acceptable alternatives to pavement are crushed stones or shells. If a marina is designed with as much porous land surface and vegetative cover as possible, stormwater runoff and its impact may be significantly reduced.

A pleasingly landscaped and well-kept marina is also an important consideration for the maintenance of the beauty of the area. Ill-kept and sloppy marinas may discourage business and create safety hazards, making poor economic sense for the marina operator (44). One owner of a well-landscaped marina on Cape Cod is convinced that his investment in flowers, grass and shrubs is returned several times over in good will and sales income. Therefore, both the marina operator and local planner should be concerned with pride, planning and maintenance of marinas. A good reference which considers landscaping is Marinas: A Working Guide to Their Development and Design by Donald Adie (1).

DREDGING

Effects

A wealth of literature has been published regarding the effects of dredging and dredge material disposal, but most of these studies are concerned with the dredging of rivers and large boat harbors, rather than small, recreationally oriented marinas. For this reason, the specific effects of marina-related dredging are difficult to define and often misrepresented. The waters of many marinas are not deep enough to accommodate all recreational craft, and sites are often dredged during their initial construction. However, the most common dredging practices in marinas are "spot" and maintenance dredging to remove sediments from small problem areas in boat channels or near docks.

Both the act of dredging and disposal of sediments may adversely affect the marine environment. The severity of this effect is not always the same and is dependent upon the dredging method used and the characteristics of the bottom sediment and its inhabitants. Dredging may alter the marina and the adjacent waters by increasing turbidity, reducing oxygen content, causing the buildup of sediments and burial of benthic (bottom-dwelling) organisms, disrupting and removing bottom habitat, creating "stagnant deepwater areas," and altering water circulation (11, 18).

Turbidity: Slotta (49) reports that most investigators conclude that the temporary increase in the turbidity of local waters because of dredging activities does not represent a significant impact on the environment. This conclusion is probably made in part because increases in turbidity generally occur in a localized area which can be avoided by pelagic species, and periodic, high levels of turbidity are natural in estuarine systems (49).

Temporary Reduction of Oxygen Content: Brown and Clark (7) found that during the dredging of a tidal waterway the oxygen content was reduced to levels of from 16% to 33% below normal. They proposed that this reduction was due to the oxidation of resuspended sediments and a decrease in the amount of light available for oxygen-producing photosynthesis by local flora.

Burial of Organisms: Some burrowing organisms may withstand burial of up to 21 cm of sediment, but those benthic species which are sessile (permanently attached to a substrate) may be easily killed by such burial (47).

Disruption and Removal of Bottom Sediments and Change in Benthic Community Characteristics: Reish (41) studied the bottom communities of a boat harbor in southern California for three years after its construction, which included initial dredging of adjacent upland areas. He found that within one year, the soft, gray, clay bottom had been colonized by communities similar to those existing in other portions of the bay.

As a result of his preliminary studies, Slotta (49) notes the possibility that, in an estuary subject to repeated dredging, bottom communities may become modified into a relatively resistant community. A study by Stickney and Perlmutter (52) of dredging in the Atlantic Intracoastal Waterway in Georgia supports Slotta's hypothesis. In a muddy bottom area, the benthic community was completely removed by hydraulic dredging. However, little change in the sediment composition occurred and, within two months, the dredged area supported a benthic community similar to the original.

Creation of Stagnant Water Conditions: Possible water stagnation in marinas with dead end canals has been mentioned (11) but no specific location was cited. It is presumed that such descriptions applied only to areas with extensive Venetian canal development, commonly seen in the southeastern United States.

General Water Quality: Windom (62) studied the effect of dredging in a salt marsh estuarine environment of the southeastern Atlantic Coastal Waterway. He analyzed dissolved oxygen, chemical and biochemical oxygen demand, pH, suspended sediment concentration, mercury, iron, and phosphate in the water from the surrounding area before, during, and after dredging. The results of these analyses indicated that there was no significant change in water quality attributable to the dredging.

Dredge Material Disposal: The effects of dredge material on the environment is relative to the nature of the sediments (whether or not they contain toxic substances) and the selection of the dump site. When open-water sites are selected, the benthic habitat may be drastically altered and large volumes of sediment may be resuspended in the water column (47). Disposal in wetlands can destroy these valuable habitats, and disposal on upland areas may cause pollution of groundwater and topographic and vegetative alterations, to the detriment of native wildlife (40).

Windom (62), in a report previously mentioned, has examined the diffusion of heavy metals into water from polluted and unpolluted dredge spoils. His study reveals that reduced iron (which is soluble) was oxidized to iron hydroxide (insoluble) in suspended sediments during dredging. The presence of hydroxide encouraged the precipitation of heavy metals out of solution and allowed them to concentrate in sediments deposited on a salt marsh. As conditions favoring a reduction reaction again increased, the trapped metals became soluble and were released into overlying waters. On the basis of this and other phases of his study, Windom drew the following conclusions:

1. In natural and relatively unpolluted areas dredging has no significant effect on water quality whether diked or undiked (dredge material) confinement techniques are used.

2. In polluted marine areas, the water quality impairment caused by dredging does not necessarily bear any simple relation to the composition of the sediments to be dredged.

3. The length of time which water mixed with other dredge material is allowed to stay in the spoil area will greatly influence the quality of the effluent from the spoil bank.

4. The dredging of polluted sediments does not necessarily impair water quality in estuarine environments.

Positive Effects of Dredging: Dredging does not always have adverse effects. It may help to improve circulation in choked inlets, increase the availability of food to fish and shellfish, and help to flush and dilute polluted waters (49). Dredge materials are sometimes suitable as sand and gravel for construction (49) or for use in creating artificial habitat. Dredge materials have successfully been used to build salt marshes (64) and to create islands suitable for colonization by important bird species (61).

Management Considerations

Marina designers may reduce or eliminate the need for and cost of dredging by good planning. For example, slips for boats of deep draft should be built in the naturally deeper waters of the marina, and piers and docks should be extended as far as possible into deep water to minimize the need for dredging around them. If maintenance dredging is expected, the plans must include a choice of sites for the drying and disposal of dredge materials. These materials may be spread on the surface of parking lots or storage areas, or even used to build salt marsh, on or adjacent to the marina shoreline (63). When dredging must be employed, it should be planned to prevent dead-end Venetian channels and restricted inlets. Flushing should be encouraged by increasing the width and depth of the marina channels or canal out into navigable waters (54).

Bottom community and sediment characteristics should be taken into account and the dredging timed so as not to conflict with critical periods in the life cycle of important animal species (11). Proper timing can also help to reduce the impact of oxygen reduction by dredging in colder months, when oxygen concentrations are not critical (7). In the New England area, it would seem that dredging should be done in the cold non-boating months. In Rhode Island, however, special consideration must be given to the reproductive cycle of the winter flounder, which spawns in February and March and is extremely important to both the commercial and recreational fisheries.

Most reports on the effects of dredging (49, 51, 62) stress the need for more research before accurate predictions can be made regarding the effects of dredging at a specific site. In his review "Environmental Aspects of Dredging in Estauries"

(62), Windom states, "The impact of dredging on coastal and estuarine environments is site-specific. This means that the results of studies in one area may be quite different from those in another. It is clear...that conclusions drawn from studies of the effects of dredging on a given coastal or estuarine area cannot be applied to predict the effects in another without a degree of uncertainty."

BULKHEADS

Effects

Bulkheads are vertical, walled structures built parallel to the shoreline to protect it from erosion or to provide boat docking convenience (11). Bulkheads are usually made of stone, concrete, sheet metal, or wood. The most severe effects of bulkheads occur when they are constructed within or along the shores of wetlands and used to hold fill deposited on the wetland (11). As well as preventing free water circulation to any wetland behind it, a bulkhead can also prevent the natural seepage of groundwater into local waters (11). The vertical face of a bulkhead protects the upland by taking the brunt of wave energy, but in so doing it creates reflection waves which disturb sediments (13) and encourage scouring at the base of the bulkhead. Reflected waves may also result in increased marina maintenance costs and discomfort for pleasure boaters.

Heiser and Finn (20) found that bulkheads which protrude too far out into the water may increase predation on migrating salmon fry because shallow water, which is required for protection from large predators, is absent. Vertical structures which replace shallow water habitat may have similar effects on other animals adapted to shallow water.

Management Considerations

Bulkheads are expensive to build (9) and for that reason should be kept to a minimum. If erosion on the marina waterfront is a problem, a sloping riprap wall with underlying filter cloth is the preferable form of shore protection. Riprap walls can be less expensive, provide more surface area for the growth of fouling communities, and create habitat for fish fry (20). Problems of scouring and wave reflection are less severe because riprap wall surfaces are irregular and sloping. Since the structure is not solid, it also allows seepage of ground water into the marina. Sloping riprap walls do require more space than vertical bulkheads, and space limitations or specific marina services (e.g., travel lift wells) may preclude their use.

If bulkheads or riprap walls are deemed necessary, they should be located behind all marshland and as far upland as possible with access over wetland on piers. Features such as "weepholes" in bulkheads will allow water to pass through (11).

Where deep waters may subject young fish (or other animals which require shallow waters) to increased predation, Heiser and Finn (20) suggest that bulkheads be placed at a water level where they will be wetted more than one foot deep approximately 10% (or less) of the time during the critical migration period.

BREAKWATERS

Effects

Breakwaters are linear structures which extend out into the water and provide sheltered conditions for craft and marina facilities by dissipating wave energy (1). They may be composed of a wide variety of materials (stone, concrete, metal, wood, tires, fiberglass) and constructed to either sit on the bottom (fixed position) or float on the surface (movable). Since breakwaters provide calm water, they may also increase the amount of shoreline available for salt marsh building. The fouling communities which grow on breakwaters can add to the biological productivity of the area and attract fish. Chen, Bowerman and Petridis (10), however, found that a breakwater constructed around the entrance of Marina del Ray accumulated organic debris. The breakdown of this material resulted in the depletion of dissolved oxygen in the bottom water, which harmed the benthic fauna (10). Certainly, breakwaters can be traps for larger floating debris (bottles, boards, bags), which becomes an aesthetic problem as well (44).

Heiser and Finn (20) report that breakwaters can act as barriers for migrating juvenile salmon. Their study also indicated that young salmon do not readily use the culverts installed in breakwaters to aid fish passage.

Breakwaters can also interrupt longshore currents and the movement of sediments. Many authors (11, 13, 20, 38, 42) mention that solid (surface to bottom) breakwaters, which restrict the opening for water circulation within a marina, will alter sedimentation patterns and the natural flushing which can help remove pollutants from marina waters. The impact of such a disturbance is difficult to measure and probably unique to each marina; thus no reports have been published which have attempted to quantify this effect.

Management Considerations

A floating breakwater can be a cheaper and more environmentally sound alternative to the common, solid breakwater, although it does not provide the same degree of protection. These may be constructed from a variety of materials; for example, one successful breakwater is built with floating tires (45). The floating breakwater is preferred for shore protection because it allows free passage of fish, does not alter current and sediment patterns, and therefore does not have the adverse effects of a solid breakwater.

When solid breakwaters are used, their location must be planned with consideration of natural current and sediment flow, wave patterns, and overall flushing characteristics of the marina basin. Modeling studies (6, 42, 50) are useful in this regard and may be used to plan for adequate flushing of new marinas, or to remedy problems at existing ones. From this modeling work, Richey (42) suggests that breakwaters include as many openings as possible to maximize wave protection while allowing adequate water flow and fish passage. Sloping riprap type breakwaters are preferable to vertical structures because irregular surfaces provide protective habitat for small fish passing around the structure and are more effective in dissipating wave energy.

PIERS, DOCKS, AND WHARVES

Effects

Piers, docks, and wharves can have detrimental effects on both salt and freshwater marshes by blocking light and water flow. As happens with bulkheads and breakwaters, water flow within the marina basin may be altered, especially if piers are supported by closed (solid) bases.

Wood, a major component of many piers, pilings and docks, is usually treated with a preservative (such as creosote, copper napthenate, or various copper and zinc salts (9)) which discourages the establishment of fouling organisms. To be effective, these preservatives must be of a poisonous nature and of low water solubility, which results in a slow leaching rate (9). Most studies have concentrated on the effectiveness of preservatives (9, 44), but not on the environmental effects. A report published by a wood products company (60) discusses the toxicity of creosote to non-target organisms. Although these laboratory tests found that creosote was moderately toxic, by EPA standards, to selected fish species (bluegills at 990 ppb and rainbow trout at 880 ppb), toxic effects under normal field conditions were not explored.

Management Considerations

The effects of docks, piers and wharves can be minimized if they are constructed high enough above marshes to allow light to reach the surface. These structures should also extend out far enough to reach adequate water depths so that dredging will not be required for boat access. Floating docks and pile/timber piers will have the least effect on water circulation, thus should be used in preference to solid structures.

Because these structures provide additional substrate for the growth of fouling communities, marina operators should avoid painting the underwater surfaces with anti-fouling paints (36). Further studies on the environmental effects of wood preservatives are necessary, but, until results are available, their use should not be banned. Meanwhile, prudent use of long-lasting materials such as pressure-treated piles and lumber should be encouraged. For example, when creosote preservatives are used, the highly refined material (grade one) is preferred. Numerically higher creosote grades (2, 3, etc.) have a higher tar content and leach faster (21). A newer and increasingly popular colorless preservative (CCA salt) leaches more slowly and is estimated to be effective for approximately 50 years (21). Metal, fiberglass, or concrete can be used for docks, piles and piers, but historical use patterns, lower cost, ease of handling and availability have made wood the preferred material for marina use in the Northeastern region.

Docks are most commonly kept afloat with plastic foam logs (or billets). Metal barrels, fiberglass tanks and reinforced concrete (foam or air filled) chambers are less commonly used. Many local marina owners in the Northeast seem to prefer the use of the more expensive petroleum-resistant polystyrene foam (Dow Chemical; orange colored) over the expanded bead foam (Cellulite; white color), because the orange foam lasts longer, doesn't absorb water, resists burrowing by marine animals, and doesn't break apart easily. Since the white foam breaks up more easily with resulting white beads floating off and accumulating along the shore, it is recommended that the orange foam be used where it is to be exposed under docks. To date, there has been no research on the environmental effects of various flotation materials.

MARINA USE

Effects and Management Considerations

There are many activities associated with regular marina operations that may damage the local environment. Nearly all marinas have restroom facilities, and a small number have facilities for pumping out the holding tanks of boats. If municipal sewer systems are not available, the marina must have its own septic system. Overloaded or poorly located septic systems may allow sewage effluents to leach into marina waters, causing an increase in the nutrient supply and in biological oxygen demand. Local shellfish beds may be affected by the possible introduction of pathogens. These problems can be avoided if septic systems are designed with adequate capacity and located in proper soils sufficiently far away to prevent the leaching of contaminants into local waters.

Fuel docks may also be a source of pollution through small but numerous oil spills of gas and diesel fuel. These oil spills can be minimized by equipping fuel pumps with back-pressure, automatic-shutoff nozzles, which prevent fuel overflow. Constant maintenance of pumps, hoses and other fueling equipment by careful fuel attendants (38) will also help reduce spills. Similarly, sloppy maintenance practices may also contribute to the pollution of marina waters. For example, when docks and other shoreline structures are painted, care should be taken to keep paint from dripping into the water. Spray painting particularly is to be avoided where it may be toxic.

Marinas are the center of boat-related activities; thus they are also centers of the noise and disturbance associated with these activities. Boat engines contribute to noise, but this disturbance is limited to brief periods when boats leave or enter the marina. Manufacturers, however, should continue to develop methods for reducing the noise levels of boat engines (44). Another noise typically associated with marinas is the incessant clang of sailboat rigging, which Adie (1) suggests can be remedied with a piece of string. Noise levels from outboard motors have been reported to reach a maximum of 80 decibels at 50 feet (66). This is not a high level, but the annoyance of different types of noise is highly variable from listener to listener (65). Unnecessary disturbances, such as loud televisions and radios, late-night parties and over-used P.A. systems, are usually the most annoying (44). Since sound travels easily across the water, marina operators should show consideration for neighbors as well as customers by posting and enforcing rules against unnecessary noise.

The "Marina and Pleasure Boating Facilities Study for Narragansett Bay" (55) points out the exemplary operating policies of the Nantucket Boat Basin, Massachusetts. This policy is backed by strong enforcement and includes control of littering. Littering can be further discouraged by providing strategically placed and frequently emptied trash receptacles, convenient for boater use.

Since recreational boating in Rhode Island is seasonal, the greatest environmental impact (aside from new construction) is likely to occur during the boating season. During winter months, the primary maintenance required at marinas is prevention of ice damage to piers and docks. Many northern marinas prevent the formation of ice by piping compressed air along the bottom and allowing it to bubble up around the docks (9). Some marina owners have found that these bubbling systems reduce the turbidity of local waters and keep the fouling communities on pilings active, but the actual biological effects of these systems have not been studied.

Chapter II: Boats

BOAT USE

Effects

In the early 1900's motorboat use was blamed for major declines in waterfowl populations in Narragansett Bay, Rhode Island. "That this has been brought about within the last five or six years, and through the sole agency of the steam, naptha, and electric launch, there can be no question." Increased bird populations, however, during the 20s, 30s and 40s seemed to discount the validity of their conclusions (43).

By making secluded wildlife habitat accessible, boating can be detrimental to wildlife populations. Studies have been conducted in England (3) and the U.S. (19) to explore the impact of boating on colonies of nesting waterfowl. Several species of duck no longer utilize a London-area reservoir because of increasing boat activity (3), and Harris and Matteson (19) report that nesting success in gull and tern colonies is probably reduced by boaters passing by or visiting otherwise secluded colonies on Lake Superior.

In New Zealand, Sutherland and Ogle (53) examined the effects of jet boats on salmon (*Oncorhynchus tshawytscha)* eggs. The propulsion system and movements of jet boats create water pressure fluctuations which disturb salmon spawning areas in shallow stream beds. From laboratory and field experiments (53), it was estimated that salmon egg mortality can reach 20 to 40 percent from these disturbances.

Lagler et al. (30) were interested in the impact of motorboating on angling success. Their study was conducted on a 36-acre freshwater pond with no previous history of motor use. For study purposes, the pond was subjected to the use of motorized boats on alternate days. Both statistical evidence and fishermen surveys showed that there was no difference in angling success between motor and non-motorized days (30). However, long-term effects (over several years) have not been studied.

Management Considerations

Impact on reproductive success can be nearly eliminated if boating is restricted from nesting and spawning areas during critical seasons (3, 19). The visible presence of humans is a critical factor in wildlife breeding success; thus regulations regarding minimum distances from wildlife nesting areas should be set to reduce distrubance by passing boats (19). The minimum distance required to prevent the disturbance of nesting bird colonies must be determined on a site-specific basis, e.g., colonies which are inaccessible because of rocky cliffs or shielded by vegetation can be safely approached at closer distances than those that are more exposed. For protective management of herring gull colonies situated on bluffs above Lake Superior, Harris and Matteson (19) suggested that people be restricted from approaching within 100 yards during the breeding season. The number and species of nesting birds are also important factors to be considered when determining distance restrictions to boat passage (3). Batten (3) further suggests that vegetation be planted in strategic places to provide screening for popular waterfowl areas.

BOAT MOTORS

Effects

Most studies regarding the interaction of boat motors and the environment focus on chemical pollutants. Little information has been published regarding the effects of boat wakes on shoreline erosion, the turbulence created by propellers, or the physical disruption of benthic fauna and flora. Two notable exceptions are a study by Lagler et al. on outboard motors in relation to fish behavior and production (30), and Zieman's report of the physical damage to turtle grass (*Thalassia testuidinum*) in southern Florida (71). Lagler conducted field studies on freshwater ponds with muddy bottoms and found that although a considerable amount of bottom material was moved by outboard motors in shallow water, the turbidity was not measurably increased (30). Beds of aquatic plants helped to minimize the turbulence created, but plants did not develop in frequently used boat paths where motors were within 12 inches of the bottom (30). It was also found that the number of bottom organisms was substantially reduced in these shallow paths. Zieman found that regular boat use had the effect of destroying turtle grass beds in shallow water (71). In addition, there was, proportionately, less fine sediment, reduced pH, and a reduced oxidation-reduction potential in bottom sediments below these boat tracks (71).

Management Considerations

Physical disruption of bottom life and sediments usually occurs in shallow waters. Most boaters would prefer to avoid the problems of maneuvering in shallow waters, and properly marked channels would minimize physical damage to bottom communities by boat traffic.

OUTBOARD MOTOR EXHAUST

Effects

Motorized recreational boats are generally propelled by outboard motors, inboard/outboard (I/O) or inboard engines. Both inboard/outboard and inboard motors are four-cycle engines which burn either gasoline or diesel fuel. Little information is available on the composition or effects of their exhaust, but information on the emissions from four-cycle engines of land vehicles is well documented and might be applied to inboard motors (4). This discussion centers on outboard motors, since most research on the environmental effects of boat motors has been directed toward them.

In "A Review of Outboard Motor Effects on the Aquatic Environment" (23), Jackivicz and Kuzminski provide a detailed description of the operation of a two-cycle outboard motor as it relates to pollutant emissions. By design, two-cycle engines are less efficient than four-cycle engines. In four-cycle engines, burned fuel is released from the cylinder before new fuel enters on the next piston stroke; in two-cycle engines, fuel intake and exhaust are accomplished in the same stroke. As a result of these combined steps, unburned fuel can be released with exhaust gases, decreasing fuel efficiency and adding pollutants to the water. Another important difference between the designs of two-and four-cycle motors is the manner of lubrication of their internal parts. Lubricating oil is admitted directly into the crankcase of four-cycle engines. But in two-cycle engines, oil must be mixed with fuel to reach and lubricate internal engine parts. Old (pre-1972) outboard motors are equipped with valves in the crankcase to discharge oil directly into the water. By 1972, "scavenger" devices were developed to recycle this crankcase drainage back into the fuel system, significantly reducing the output of oil.

English et al. conducted comprehensive laboratory and field studies on the effects of outboard motor exhaust (14, 15), but their results were based on the operation of motors which were not equipped with crankcase drainage recycling devices. Two comprehensive studies identifying the components and effects of outboard motor exhaust have been reported since the early studies by English et al. (14, 15). Kuzminski directed a series of studies for the Division of Water Pollution Control, Massachusetts Water Resources Commission (Contract No. 15-51451), on the effects of outboard motor exhaust on water quality and associated biota of small lakes (26, 27, 28, 29).

The Boating Industry Association and Environmental Protection Agency (Grant No. R-801799) jointly sponsored another study by three research groups, published under the title "Analysis of Pollution from Marine Engines and Effects on the Environment (57).

After analyzing emissions from outboard motors with and without drainage recycling devices and of varied horse-powers, the EPA researchers identified the following components and concentrations in outboard motor exhaust:

1. Carbon monoxide emissions were high compared to those generally observed from four-cycle automotive engines. The percent of carbon monoxide in emissions ranged from 4.5% at 1000 rpm, to 6.5% at 5000 rpm.

2. Carbon dioxide in emissions ranged from 5.4% at 1000 rpm, to 7.5% at 4000 rpm.

3. Hydrocarbon concentration (expressed in parts per thousand of n-hexane [C_6H_{14}]) in emissions ranged from 7.75 ppt at 1000 rpm to a low of 4.5 ppt at 4000 rpm. The hydrocarbons in exhaust gases were found to be composed of 20-30% olefins, 20-30% aromatics, and approximately 50% paraffins. Hydrocarbon emissions were found to be approximately ten times higher than those of a typical four-cycle gasoline engine.

4. Kuzminski (29) reports that lead emission is most dependent on the speed of operation and prior operational history of the motor. The amount discharged in exhaust varied from 1.84-12% of the lead in the fuel (29).

Once exhausts are released into the water, some hydrocarbons become suspended in the water at propeller depth, while others concentrate at the surface, where they may evaporate (27). Almost all of the lead discharged eventually reaches bottom sediments (29).

Sensitivity to petroleum pollutants, such as outboard motor exhaust, may be highly dependent on the characteristics of affected organisms as well as the physical properties of the pollutant. Clark et al. (12) found that mussels (*Mytilus edulis*) were more sensitive to diluted outboard motor effluent than oysters (*Ostrea lurida*), which can close their shells for long periods of time. The lighter, more refined petroleum products (e.g., diesel oil) are taken up more quickly by these shellfish than are the heavy, more viscous refined products (12). However, URI researchers (31) have discovered that in one boating harbor (Wickford, RI), concentrations of aromatic hydrocarbons (probably from petroleum fuels) actually decreased during the boating season. It was suggested by researchers that these hydrocarbons might be removed from the water by evaporation, or possibly degraded biologically or photo-chemically during the summer.

The concentrations of exhaust found in waters after normal outboard motor use did not inhibit the growth of two species of freshwater algae *(Selenastrum capricornutum* and *Anabaena flasaquae)* studied by Kuzminski and Fredette (26). The EPA/Boating Industry study (57) also found that there was no significant difference between diatom communities, zooplankton communities or organic production in control ponds compared with those subjected to outboard motor use. Both the EPA/Boating Industry report (57) and a report of another general study on Lake X in Florida (22) concluded that outboard motor emissions under normal field conditions do not significantly affect aquatic systems or seriously degrade water quality.

Results of field and laboratory studies conflict regarding the quantity of fuel that can be used per volume of water before becoming noticeable in water or fish. After field tests, the Boating Industry Association-EPA study (57) reported that up to 110.5 gallons of fuel could be used per million gallons of water before any alteration in the taste of fish was demonstrated. In laboratory studies by Kuzminski et al. (28), one gallon of outboard motor fuel was exhausted into 400 gallons of tap water in a stainless steel tank and subsamples at various dilutions were presented to test panels. The odor threshold concentration was found to occur at less than one-third (1/3) gallon of fuel per million gallons of water.

Management Considerations

Little can be done to reduce the impact of boat motor emissions other than reducing boating pressure. Results of boat motor exhaust studies suggest that threshold guidelines cannot be generalized, and any management of motorboat use must consider each waterway individually by reviewing the use and characteristics of each system. Obviously, more research is required on the effects of boat motor exhaust. However, research and development by marine engine manufacturers aimed at reducing the pollutants in emissions, enabling the use of unleaded fuel, and increasing fuel efficiency will be of value in minimizing environmental effects.

BOAT SEWAGE

Effects

Although boat sewage can be a repulsive visual pollutant and contribute to the biological oxygen demand of marina waters (38), the primary concern is its potential for carrying disease-causing pathogens. Problems may occur if boat sewage is released in the vicinity of shellfish beds or into enclosed waterways with limited flushing.

At present, total and fecal coliform counts are used as indicators of sewage pollution in waterways. During one summer boating season, Fufari and Verber (17) analyzed water, shellfish and sediment samples from a saltwater cove in Rhode Island (Potter Cove) and reported that the primary source of coliforms was boat waste, although other sources were present, i.e., cows, seagulls. Cassin et al. (8) also reported that on Labor Day weekend, coliforms increased in the water column and shellfish in direct relations to a small boat population of an estuarine area on the New York coast. In a comparison study, Barbaro et al. (2) sampled marina and non-marina waters during the summer boating season on a Mississippi reservoir. Marina waters contained significantly higher fecal coliform and fecal streptococci counts than non-marina waters (2). Results of a study reported by Seabloom (48) may be contradictory to those conclusions. Coliform counts were taken in two small boat harbors of Washington State. During the boating season, counts increased 11 percent in a small freshwater inlet, but decreased 38 percent in a salt water embayment on Puget Sound. Boat waste studies can be confusing and inconclusive because coliform counts and other measurable effects of boat wastes are influenced by boat densities, the number of people per boat, tides, the day of the week the samples were taken, and other factors (16). In addition, it is difficult to determine if coliforms are from human or animal waste.

Mack and D'Itri (34) studied a freshwater marina area and found that fecal coliforms increased in the dock slips most frequently used by yachts. They also concluded that the number of coliforms was related to the number of yachts in the marina, but no gross pollution was occurring at the marina. In a subsequent study, Mack (33) discovered that the source of a large number of coliforms was actually from local streams feeding into the boating water. Other researchers have found that water quality in some areas is too variable to measure the effect of pollution due to concentrated boat use (58), or that the background levels of coliforms resulting from land-based sewage input were so high that no boating-related impact could be detected (36).

Since coliform counts in surface waters are not always a dependable measure of water pollution by boats (33), Kassebaum (24) explored the possibility of using measurements of coliform concentration in oysters to indicate the impact of boat wastes. Unfortunately, it was found that variation in coliform bacteria concentrations in the oysters was not directly related to boat use in the marina.

Pessoney et al. (39) counted Salmonella and Shigella pathogens rather than total and fecal coliform along the Mississippi coast. While sporadic positive tests were found for the pathogens, they concluded that the water quality in the marinas and harbors tested did not differ greatly from that of the adjacent Mississippi Sound (39).

There is no epidemiological evidence that boat wastes cause disease, but there is the possibility that raw sewage from boats may contain organisms which, when concentrated by shellfish, might transmit disease (16). For this reason, some state health departments restrict the harvesting of shellfish in areas proximate to marinas, even without proof of water contamination (59).

On the federal level, the EPA and Coast Guard have promulgated regulations requiring that vessels with permanently installed heads be equipped, by 1980, with marine sanitation devices (MSD). On inland waters, all boats must be equipped with holding tanks (Type III, devices designed to prevent discharge of any sewage), but those boats on marine and "navigable waters" may utilize devices which release treated sewage (MSD Type I & II) if the effluent meets certain water quality specifications. If these regulations can be adequately enforced, raw sewage from boat wastes will no longer pose a health hazard, but related problems may exist. One of the recommended marine sanitation devices is the holding tank, but it can be too large and cumbersome for some recreational craft and is dependent on the presence of shorebased pumpout facilities (38). Boat wastes from numerous holding tanks can then accumulate at marine pumpout stations, generally to be transferred to municipal sewage systems. Disinfectants used in holding tanks, such as formalin, could become a problem by reducing the normal efficiency of sewage treatment plants (38). An alternative to holding tanks are macerator-disinfectors, which release physically and chemically treated sewage. Proper maintenance of these devices is difficult to enforce and the chemicals used to disinfect the sewage may be more harmful than the raw sewage. No published scientific studies have been found regarding the effects of chemical additives from marine sanitation devices. Preliminary studies (25), however, indicate that these additives could cause significant environmental effects and merit extensive research.

Management Considerations

If Coast Guard regulations on marine sanitation devices are to be effective, the public must be made aware of the importance of using and maintaining these devices. Since the number of available pumpout facilities for holding tanks is presently very limited, marina operators should be encouraged to provide more of these facilities. It is clear that not all boats contain permanently installed heads, and those that do may use Type I and II MSDs, which do not require pumpout. Therefore, only selected marinas, in harbors with large numbers of boats containing heads, need to have pumpout facilities available. Marina experience on waterways with enforced holding tank use indicates that existing fuel docks provide the most convenient location for pumpout services.

Regulations concerning marine sanitation devices will be difficult to enforce; thus other management tools are still necessary. In marina waters where higher levels of pathogens could contaminate shellfish, boat toilet use can be reduced if marinas provide shoreside restrooms. These restrooms should be convenient to the docks, provide hot showers and wash basins, and be well maintained. Reasonable guidelines for the required number of toilets need to be established. These guidelines should be based on the capacity of the marina and its use characteristics.

Boat wastes are considered a problem primarily on enclosed inland waters and semi-enclosed coastal waters, where flushing is minimal. In problem areas, boating can be monitored and regulated. Size, depth, tidal flushing and the characteristics of boat use must all be considered to determine the sewage capacity of a waterway. As an example, Fufari (16) has calculated how many boats may be allowed in shellfish areas (assuming a background count of zero coliforms) to maintain standards of 70 coliforms per 100 milliliter of water. Kassebaum (24) also calculated the allowable number of boats to maintain coliform standards, but emphasizes that if such calculations are to be accurate, they must be derived for each water basin on an individual basis.

Once boats are underway and outside of the marina, any sewage discharged overboard is readily diluted, and has a negligible impact. When all boats meet MSD standards in 1980, the potential for contamination of shellfish will be sharply reduced or eliminated. Thus, current restrictions on the harvesting of shellfish from waters adjacent to marinas need to be reevaluated in light of increasing use of MSDs. Shellfishing should be allowed during nonboating seasons and the shellfish quality should be routinely monitored in marina waters to provide the basis of closure when necessary.

No studies were found on the environmental effects of "gray" water, i.e., galley and shower waste water. Since some concern has been raised about the wisdom of allowing overboard discharge of "gray" water, it is briefly discussed here. This discharge of water, soap, and grime probably has considerably less impact than boat sewage and creates little or no threat of shellfish contamination. However, boat owners concerned about their environment can make use of non-polluting soaps for on-board washing. Until scientific research proves otherwise, discharge of "gray" water does not need regulation.

BOAT MAINTENANCE

Effects and Management Considerations

Regular and seasonal maintenance of boats involves washing, draining bilge water, sanding and painting. All these activities may have minor, but potentially adverse, effects on the marine environment. For example, the amount of detergent introduced into the water when washing boats may be small, but it can cause increased nutrient levels in marina waters and eventually cause a decrease in the dissolved oxygen concentration. Whenever possible, boat owners and marina operators should limit the use of detergents, or use non-polluting detergents.

Individual boat owners can also reduce the amount of petroleum pollutants introduced into the marina when emptying bilge water. In fact, EPA and Coast Guard regulations prohibit the discharge of any oil or oily waste that causes a visible film or sheen on the surface of the water (32). This form of oil pollution can be controlled by the use of oil filtration devices on boat bilge pumps, or devices such as commercial oil-absorbent pads placed in the bilge to soak up fuel and oil before bilge water is discharged. Though pollution by visible oil may be controlled, some petroleum compounds may be dissolved in bilge water and transferred unnoticed to aquatic ecosystems (32).

Other toxic materials may also be transferred to the aquatic environment from the anti-fouling paints which are used on boat hulls, floats and buoys within the marina. After sampling both harbor and coastal mussels, Young (67, 69) found significantly higher PCB (polychlorinated biphenyls) levels in mussels located near centers for the scraping and repainting of boats. Major brands of anti-fouling paint currently used do not contain significant amounts of PCBs, but samples of old anti-fouling paint have shown concentrations as high as 10 percent of the dry weight of the paint (69).

Copper is the most common heavy metal used in anti-fouling paints and is found at high levels in sea-water, sediments, and fouling communities in marinas (36). Young (67, 70) found copper concentrations were significantly higher in mussels taken from boat harbors. It has not been estimated at what rate copper is released into the marine environment from antifouling paints, but Young (68) feels that an "important fraction" must be released before repainting. Although copper concentrations have been found to be significantly higher in the marine environment (36, 68), little is known about its transfer through local food chains or long-range impact. Thus, more research is needed on the fate of copper in marina environments, and manufacturers need to develop and market less toxic alternatives to copper-based anti-fouling paints (38). In the meantime, marina operators can reduce copper levels by not painting non-boat surfaces and by collecting and removing paint particles from boat scraping and painting areas (38). Until reasonable alternatives to existing anti-fouling paint are available, prudent use could continue.

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