The Effects of Motorized Watercraft on Aquatic Ecosystems

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Introduction

What do we mean by "motorized watercraft?"

Motorized watercraft include powerboats, fishing boats, pontoon boats, and "jet skis" or personal watercraft (PWC). They are propelled by some sort of motor: outboard, inboard, inboard/outboard, or jet propulsion. Most of these propulsion systems make use of a propeller. In the discussion of impacts presented here, all craft will be lumped together as "boats," unless otherwise stated (for example, see special section on PWCs). "Boat activity" refers to the ways in which these watercraft are used: fishing, cruising, water-skiing, racing. No distinction will be made between the types of activities unless otherwise stated.

Why are motorized watercraft important to aquatic ecosystems?

There are a number of reasons why boats and boat activity are an important issue. Numbers of registered boats in Wisconsin have increased by 87% since the late 1960's (567,000 in 1997-98 compared to 303,000 in 1968-69). Size of boats has also increased: over 40% of the registered boats were between 16 and 39 feet long in 1997-98 compared to just 18% in 1968-69. Along with the bigger boats have come bigger engines. The Duluth News-Tribune reports that horsepower has doubled on new boats registered in MN between 1981 and 1999. There has also been an explosion in recent years in new types of watercraft, especially personal watercraft. PWCs in WI increased from 6500 in 1991 to 28,900 in 1998, representing 5.1% of all registered watercraft. These smaller, more powerful craft have unique issues, due to their maneuverability and accessibility to shallow and remote areas. Finally, increased development of lakes and rivers leads to increased boat activity, especially in areas that have traditionally not been used for recreation.

How might boats affect aquatic ecosystems?

Boats may interact with the aquatic environment by a variety of mechanisms, including emissions and exhaust, propeller contact, turbulence from the propulsion system, waves produced by movement, noise, and movement itself. In turn, each of these impacting mechanisms may have multiple effects on the aquatic ecosystem. Sediment resuspension, water pollution, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion are the major areas of concern and will be addressed in the following pages. Impacts of boats that primarily affect human use of lakes, such as crowding, safety, air quality, and noise will not be addressed specifically.

As we discuss the impacts and effects of boats on the aquatic environment, we need to recognize that:

1) boating is a highly valued recreational activity in Wisconsin ($200 million spent on boating trips per year, $250 million on equipment);
2) most people use boats for fishing (58%);
3) public access is important and actively encouraged by the State of Wisconsin;
4) many of the issues associated with boating are complex, with sociological as well as ecological consequences; and
5) boating activities must be evaluated in the context of the characteristics of each waterbody and other factors that may be more important for the overall health of the aquatic ecosystem.

How is this document organized?

I have organized the material in this document in terms of the aspect of the aquatic ecosystem that may be affected by boat activity. The sections include:

A. Water Clarity (Turbidity, nutrients, and algae)
B. Water Quality (Metals, hydrocarbons, and other pollutants)
C. Shoreline Erosion
D. Aquatic Macrophytes (Plant communities)
E. Fish
F. Aquatic Wildlife
G. Personal Watercraft ("Jet skis")

Each section includes an introduction, a summary of three to five studies relevant to the issue, some conclusions, and a list of additional references for further reading. The introduction attempts to define the issue, explain why it is important to aquatic ecosystems and identify factors that affect it, and summarize some of the particular concerns related to boat activity. The conclusion summarizes the current state of knowledge, identifies uncertainties, and suggests management strategies that may be useful to deal with the issue. At the end of the document, I have included a summary section that incorporates information gleaned from all of the individual sections. A complete list of all studies mentioned in the text is given in the last section, entitled “For Further Reading."

A. Water Clarity (Turbidity, nutrients, and algae)

Introduction:

What do we mean by "water clarity?"

Water clarity is a measure of the amount of particles in the water, or the extent to which light can travel through the water. There are many ways to express water clarity, including Secchi disk depth, turbidity, color, suspended solids, or light extinction. Chlorophyll *a*, a pigment found in all plants, is often used to determine the amount of algal growth in the water and is related to water clarity as well.

Why is water clarity important in aquatic ecosystems?

Water clarity is important for a number of reasons. It affects the ability of fish to find food, the depth to which aquatic plants can grow, dissolved oxygen content, and water temperature. Water clarity is often used as a measure of trophic status, or an indicator of ecosystem health. Water clarity is important aesthetically and can affect property values and recreational use of a waterbody.

What factors affect water clarity?

Algal growth, runoff, shoreline erosion, wind mixing of the lake or river bottom, and tannic and humic acids from wetlands can all affect the clarity of the water. Water clarity often fluctuates seasonally and can be affected by storms, wind, normal cycles in food webs, and rough fish (e.g. carp, suckers, and bullheads).

How might boats affect water clarity?

Propellers may disturb the lake or river bottom directly, or indirectly through the wash or turbulence they produce, especially in shallow water. This may affect water clarity by increasing the amount of sediment particles in the water or may cause nutrients that are stored in the sediments, such as phosphorus, to become available for algal growth. Waves created by watercraft may contribute to shoreline erosion, which can cloud the water.

Studies:

Yousef and others (1980) is the most often cited publication on motor boat impacts. Turbidity, phosphorus, and chlorophyll *a* (chl *a*) were measured on control and intentionally mixed sites on three shallow Florida lakes (all less than 6 m or 18 ft deep), both before and after a set level of motor boat activity. On the two shallowest lakes, significant increases were seen in these parameters on the mixed sites, but not at the control sites. Average increases in phosphorus ranged from 28 to 55%. Maximum increases in turbidity and phosphorus occurred within the first two hours of boating activity. Turbidity declined at a slower rate after boating ceased, taking more than 24 hours to return to initial levels.

Hilton and Phillips (1982) developed an empirical model to predict the amount of turbidity generated by boats passing a stretch of river based upon field measurements of turbidity and timing of boat passes. The model assumes that each boat pass generates the same amount of turbidity and that it decays exponentially with time, such that the amount of turbidity at a given time is dependent upon the timing of the last boat pass. Using the model with maximum expected boat activity, the authors determined that turbidity returned to background levels 5.5 hours after cessation of boat movement, indicating long term build-up of turbidity was unlikely. The model also predicted that on an annual basis, 8 to 44% of the turbidity in the river could be attributed to motorboat activity, depending upon the amount of algal growth that occurred at the test sites.

Johnson (1994) investigated the role of recreational boat traffic in shoreline erosion and turbidity generation in the Mississippi River. Turbidity was monitored at several depths and distances from shore during weekends of heavy boating activity. Turbidity increased the most near the bottom of the river, but did not vary with distance from shore. Peak turbidity corresponded with peak boating activity, but only in sites with high boating activity.

U. S. Army Corps of Engineers (1994) investigated the relationship between boat traffic and sediment resuspension on the Fox River Chain O' Lakes in northeastern Illinois. Samples were collected in channels connecting the lakes so that boats could be counted with some accuracy. There was a direct correlation between the number of boat passes and the amount of suspended solids in the water column. However, the amount of resuspension varied with water depth and sediment type. In silt substrate, the highest amounts were seen in water depths of 3 ft, about half as much at 6 ft, and none at 8 ft. In marl substrate, effects were seen at 3 ft, but not 6 or 8 ft. The authors also determined that sediment resuspension by boats at 3 ft was equivalent to the amount of disturbance generated by a 20 mph wind, but that the frequency of boat passes was much higher than the frequency of winds of that magnitude.

Asplund (1996) investigated the effects of motor boats on sediment resuspension and concurrent effects on nutrient regeneration and algal stimulation in several Wisconsin lakes. Weekend and weekday water quality was measured on 10 lakes during three summer holiday weekends and an additional weekend in August. Motor boat use increased on holiday weekends compared to weekdays (200-350% increase). Water clarity usually decreased, associated with increases in turbidity, particularly in near-shore sites. Chl *a* showed no consistent trends. Phosphorus (TP) often increased in the mid-lake sites, while ammonia generally decreased in both areas. Shallower lakes tended to experience greater changes in turbidity and TP than deeper lakes. Water clarity and boat activity were measured on an additional 20 lakes during every summer weekend. Motor boat use increased consistently on weekends for most of the lakes in the study. Water clarity did not show a consistent increasing or decreasing trend for any individual lake on weekends. However, weekend Secchi disk readings were 10% lower than weekday readings on average for the entire data set. Clear water lakes tended to show slightly larger drops in clarity than turbid lakes, and had more weekends with decreased clarity. The magnitude of change in water clarity was small compared to seasonal changes and differences among lakes.

Conclusions:

What do we know?
Boats have been shown to affect water clarity and can be a source of nutrients and algal growth in aquatic ecosystems. Shallow lakes, shallow parts of lakes and rivers, and channels connecting lakes are the most susceptible to impacts. Depth of impact varies depending upon many factors including boat size, engine size, speed, and substrate type. Few impacts have been noted at depths greater than 10 feet.

What don't we know?
Less certain is the overall impact boats have on water clarity compared to other factors such as shoreline development, watershed runoff, storm events, and natural food web cycles. The cumulative impacts of boats on water clarity are also uncertain, as is the link between increased sediment resuspension and algal growth. Translating effects observed under experimental conditions to what happens under actual conditions can be difficult.

What can we do about it?
No-wake zones in shallow areas of lakes and rivers could help to reduce impacts on water clarity, both by reducing the overall amount of boat activity in these areas and by limiting impacts from high-speed boats. In certain cases it may be beneficial to restrict boat activity altogether, such as in extremely shallow waters where boats can disturb the bottom even at no-wake speeds.

Also see:

Garrad, P. N. and R. D. Hey. 1988. River management to reduce turbidity in navigable Broadland rivers. J. Environ. Manage. 27:273-288.

Gucinski, H. 1982. Sediment suspension and resuspension from small-craft induced turbulence. U.S. EPA Chesapeake Bay Program, Annapolis MD. 61 pp. (EPA 600/3-82-084)

Moss, B. 1977. Conservation problems in the Norfolk Broads and rivers of East Anglia, England - phytoplankton, boats, and the causes of turbidity. Biol. Conserv. 12:95-114.

B. Water Quality (Metals, hydrocarbons, and other pollutants)

Introduction:

What do we mean by "water quality?"
By water quality, we are referring to the chemical nature of a water body, particularly as affected by anthropogenic (human) sources. Metals (lead, cadmium, mercury), nutrients (phosphorus, nitrates), and hydrocarbons (methane, gasoline, oil-based products) can all be added directly to the water column through a number of sources, including boat motors. These added chemicals can affect other parameters, such as pH and dissolved oxygen.

Why is water quality important in aquatic ecosystems?
As discussed earlier, nutrients can affect the algal growth in lakes and rivers and have an effect on water clarity. Dissolved oxygen and pH levels influence the type and abundance of fish. In high enough amounts, metals and hydrocarbons can be toxic to fish, wildlife, and microscopic animals. In addition, these substances may have human health effects if a lake or reservoir is also used as a drinking water supply.

What factors affect water quality?
Runoff from watersheds, both urban and agricultural, is a major source of nutrients, pesticides, metals, and hydrocarbons in aquatic ecosystems. Point sources of pollution (from industrial or municipal wastes) are also common, especially in river systems. Even remote lakes can be affected by atmospheric deposition of metals and acid-producing chemicals.

How might boats affect water quality?
Boat engines are designed to deliver a large amount of power in a relatively small package. As a result, a certain amount of the fuel that enters into a motor is discharged unburned, and ends up in the water. Two-stroke engines, which make up a vast majority of the motors in use on all types of watercraft, have been particularly inefficient. Estimates vary as to how much fuel may pass into the water column (25-30% is a reasonable average) and depends upon factors such as engine speed, tuning, oil mix, and horsepower. Other concerns include lowered oxygen levels due to carbon monoxide inputs, and spills or leaks associated with the transfer and storage of gasoline near waterbodies.

Studies:

Schenk and others (1975) used small (0.5 to 4 acres), shallow (4 to 12 feet deep) ponds to investigate impacts of motors on water quality. They ran motors continuously for three years at a rate of 1 gallon of fuel per day per 1 million gallons of water (equivalent to 3 times the maximum likely boat activity on a heavily used lake). No changes were observed in standard water quality parameters (pH, nutrients), except due to scour of sediments, which caused elevations in alkalinity and hardness. Increased lead and hydrocarbon concentrations were detected in the water column and sediments of the test lakes. However, no acute toxicity was observed on any species. Phytoplankton growth, diversity, and species composition were unchanged. Zooplankton and bottom dwelling organisms were not affected. No changes in the fish community composition or mortality rates were exhibited.

Hallock and Falter (1987) measured nitrogen, carbon, and phosphorus levels in small enclosures after operating outboard engines in them for a period of time. Combining this information with estimates of the annual fuel consumption by motor boat users on a heavily used lake, they calculated the proportion of nutrient loading contributed by outboard motors. In this study, motorboat exhaust contributed about 1% of the total nitrogen loading to the lake, while the amount of phosphorus was negligible. On lakes which receive heavy use year-round (in the southern U.S.), motorboats could contribute up to 5% of the nitrogen loading. However, nutrient loading from other sources is much more significant.

Mastran and others (1994) determined the spatial distribution of polyaromatic hydrocarbons (PAH) in a reservoir used for both drinking water and recreation. Engine sizes are limited to a maximum of 10 horsepower in this reservoir.   PAHs are a group of organic compounds found in petroleum products that can be released into the environment through combustion processes. Some of these PAHs are known to be carcinogenic, and thus of concern in a drinking water reservoir. The researchers found detectable levels of PAHs (up to 4 parts per billion) in the water column during times of peak boating activity (June), but not during October, when boat activity was minimal. PAHs were found in the sediments during both times, and tended to be higher in the vicinity of three marinas on the reservoir. Other sources of PAHs in the sediments could be from urban runoff and atmospheric deposition.

Reuter and others (1998) investigated the role of motorized watercraft on methyl *tert*-butyl ether (MTBE) levels in a California lake. MTBE is a fuel oxygenate required by many states to be added to gasoline to reduce carbon monoxide emissions in urban areas. MTBE is also a possible human carcinogen and imparts a noticeable taste and odor to drinking water in very low concentrations. The authors found that MTBE was detectable (0.1 µg/L) throughout the lake and throughout the year, but that it rose to 12 µg/L during mid-July in the upper waters of the lake, corresponding to peak boat use and the strongest stratification. This level exceeds drinking water standards under consideration in California. The authors determined that the exhaust from 2-stroke outboard motors was the primary source of MTBE, explaining 86% of the variability in MTBE levels. However, levels declined through the fall due to volatilization at the water surface and did not appear to persist from one year to the next.

Conclusions:

What do we know?

There have been numerous studies on the effects of outboard motor exhaust and related pollution from fuel leakage. (See **Wagner (1991**) for a good review of these studies.) In general, these studies have shown minimal toxic effects on aquatic organisms because 1) the amount of pollution is small compared to the volume of a lake; and 2) most hydrocarbons are volatile and quickly disperse. However, polyaromatic hydrocarbons and fuel additives have been detected in some cases, and could be a concern for drinking water supplies.   Build-up of certain compounds in sediments has been documented, especially near marinas or other high concentrations of boats, and may be detrimental to bottom dwelling organisms.

What don't we know?

Most studies have focused on short-term or acute effects of outboard motor fuel and exhaust. Less clear are the long-term or chronic effects on organisms or human health of repeated exposure to low levels of pollutants.

What can we do about it?

Cleaner technology, such as four-stroke engines, and more efficient two-stroke models should help to reduce the inputs of fuel and exhaust into water bodies over time. Education of boaters and stricter controls of places that store and sell fuel near the water would help to reduce sediment contamination from fuel transfer and storage. Keeping engines well-tuned and using manufacturers' recommended mix of oil and gasoline would help engines run more efficiently and reduce the amount of unburned fuel that is discharged.

Also see:

Hilmer, T. and G. C. Bate. 1983. Observations on the effect of outboard motor fuel oil on phytoplankton cultures. Environmental Pollution 32:307-316.

Jackivicz, T. P. and L. N. Kuzminski. 1973. A review of outboard motor effects on the aquatic environment. J. Water Pollut. Control Fed. 45:1759-1770.

Wachs, B, H. Wagner, and P. van Donkelaar. 1992. Two-stroke engine lubricant emissions in a body of water subjected to intensive outboard motor operation. The Science of the Total Environment 116:59-81.

C. Shoreline Erosion

Introduction:

What do we mean by" shoreline erosion?"
Shoreline erosion is a term that refers to the process by which soil particles located along riverbanks or lakeshores become detached and transported by water currents or wave energy.

Why is shoreline erosion important in aquatic ecosystems?
Shoreline erosion may affect water clarity in near shore areas, shading submerged aquatic plants as well as providing nutrients for algal growth. It can interfere with fish use of shallow water habitat, as well as wildlife use of the land-water edge. Excessive shoreline erosion can negatively affect property values and can be expensive for riparian dwellers to prevent and control.

What factors affect shoreline erosion?
Shoreline erosion is affected by two main factors: 1) the intensity or energy of the erosive agent, i.e. water movement; and 2) the characteristics of the bank material itself. Water currents, waves, and water levels are the primary agents that cause shoreline erosion, although overland runoff can also erode shorelines. The erosivity characteristics of shoreline soils can also affect erosion rates – less cohesive materials such as sand erode more quickly than clay. The amount of vegetative cover, slope, and human disturbance also affect shoreline erosion rates at a given site. A certain amount of natural erosion may occur with storm or flood events, but usually erosion is minimal on natural shorelines. Shoreline development can affect erosion rates significantly by removal of vegetative cover or compaction of bank material.

How might boats affect shoreline erosion?
Boats produce a wake, which may in turn create waves that propagate outward until dissipated at the shoreline. Wave height and other wave characteristics vary with speed, type of watercraft, size of engine, hull displacement, and distance from shore. Propeller turbulence from boats operating in near shore areas may also erode shorelines by destabilizing the bottom.

Studies:

Bhowmik and others (1992) developed an equation to predict the maximum wave height of a recreational watercraft based upon the speed, draft, and length of the boat and the distance from a measuring point. Generally, the deeper the draft and longer the craft, the bigger the waves that were produced, while increased speed and distance diminished the size of the waves. During the controlled boat runs that were used to develop the model, wave heights averaged between 1 and 25 cm, with 10 to 20 waves produced per event. Maximum wave heights observed were up to 60 cm. During uncontrolled boating observations on the Mississippi and Illinois rivers, wave activity was observed to be continuous during peak boating times, with wave heights up to 52 cm.

Nanson and others (1994) monitored bank erosion and wave characteristics produced by three ferry boats in a set of staged boat passes to determine if speed limits on boat traffic could reduce river-bank erosion rates. Most of the measurements of the boat waves were positively correlated to rates of bank recession. Maximum wave height within a wave train was the simplest measure and was associated with a threshold in erosive energy at wave heights between 30 and 35 cm (12-14 in.). Above this threshold almost all bank sediments were observed to erode. Further monitoring revealed that reducing wave heights to < 30 cm, through speed limits on boats and reducing the frequency of boat passages, caused a decline in riverbank erosion. This threshold may vary from river to river depending upon the particle size and cohesiveness of the bank material.

Johnson (1994) placed iron stakes along transects in 1989 to monitor shoreline erosion along several stretches of the Mississippi River. Over a 3.5 year period, shoreline recession of up to 14 feet was observed in a channel subjected to intense boating activity (Main Channel) compared to less than 3 feet in a channel with similar river currents and light boating activity (Wisconsin Channel). [Author's update: Transects resurveyed in 1997 indicated 28 ft. of recession in the Main Channel compared to 4 ft. in the Wisconsin Channel. On average, the riverbank is eroding at a rate of 3 feet per year.]

Johnson and others (In preparation) investigated shoreline erosion due to recreational activity along several sites in the Lower St. Croix National Scenic Riverway. Over 4 successive boating seasons (1995-1998), 9 sites had net erosion, 2 sites had net deposition and 3 sites had no net change. When sorted by impact category, those sites with no boat waves and no foot-traffic trampling had sediment deposition or no net change in profile. Little net change was noted at sites with boat waves only. Shoreline erosion was documented at all sites with trampling only, as well as at all sites experiencing both waves and trampling. The surveys suggest that foot-traffic trampling and boat waves are major contributing influences to shoreline erosion in the study area. In the summer of 1998, additional investigations of off-peak and peak boating days included the measurement of maximum wave heights, number and type of boats, and shoreline sediment mobilization (erosion and resuspension). The study results confirmed that wave heights below 0.4 feet did not mobilize sediments, as determined in controlled run studies. However, the more boat waves 0.4 feet and higher in a 30 minute monitoring period, the greater the amount of sediment mobilized. Likewise, the larger the maximum wave height in a 30-minute monitoring period, the greater the amount of sediment mobilized. Of all the boat types recorded, runabouts and cruisers had the highest correlation to the measured maximum wave heights, amount of sediment mobilized, and number of waves greater than the sediment mobilization threshold (0.4 feet). Wind-generated waves above the threshold were not recorded during the study period.

Conclusions:

What do we know?

Waves or wake produced by boats is the primary factor by which boats can influence shoreline erosion. Wave heights depend upon speed, size and draft of boat, but can reach heights of 40-50 cm (15-20 in.) equivalent to storm-induced waves. However, wave heights dissipate rapidly as they move away from the boat, while wind waves increase with larger distances. Therefore, river systems, channels connecting lakes, and small lakes are likely to be most influenced by boat-induced waves, as boats may operate relatively close to shore and wind-induced waves are reduced. Shoreline erosion has been documented in river systems and has been attributed to frequency and proximity of boat traffic. Loosely consolidated, steep, unvegetated banks are more susceptible to shoreline erosion.

What don't we know?

It is unclear what effect boat waves have on shoreline erosion or bank recession in lake or still water environments. All studies to date have been on river systems. Also unknown is the cumulative impacts that boat waves can have on shorelines, especially in combination with wind-induced waves. While equations exist to predict how much of a wake a given boat can produce, very little information is available to suggest how much boat traffic a given shoreline can sustain. Also, individual boat waves may dissipate quickly, but boat traffic often mixes waves from several boats and can create much bigger waves that persist for longer periods of time.

What can we do about it?
No-wake zones are designed to minimize boat wake, so the obvious solution would be to use no-wake zones to limit shoreline erosion, particularly in channels or small sheltered lakes (i.e. areas where effective wind fetch is less than 1000 feet). Currently in WI, boats are restricted from operating at speeds greater than no-wake within 100 feet from fixed structures such as boat docks and swimming platforms. Many lake communities have established no-wake ordinances at 100 feet from shore or more. Seawalls and riprap have been used extensively in lakes and rivers to prevent shoreline erosion; however, these engineering approaches have little wildlife value and are expensive. Maintaining and restoring natural shorelines would help reduce the impacts of all types of waves on shoreline erosion.

Also see:

Bhowmik, N. G. 1976. Development of criteria for shore protection against wind-generated waves for lakes and ponds in Illinois. University of Illinois Water Resources Center Research Report No. 107, Urbana, IL. 44 pp.

Kimber, A., and J. W. Barko. 1994. A literature review of the effects of waves on aquatic plants. Natl. Biol. Surv., Environ. Manage. Tech. Center, Onalaska, WI. LTRMP 94-S002. 25 pp.

D. Aquatic Macrophytes (Plant communities)

Introduction:

What do we mean by "aquatic macrophytes?"
Aquatic macrophytes are large rooted plants that inhabit the littoral (shallow water) zone of most lakes and rivers. They are usually divided into three categories: submerged, emergent, and floating-leafed species. Common species include coontail, milfoil, elodea, pondweeds (submerged species), bulrushes, reeds, sedges, wild rice, and cattails (emergent), and water lilies, spatterdock, and lotus (floating).

Why are aquatic macrophytes important in aquatic ecosystems?
Aquatic plants perform many important ecosystem functions, including habitat for fish, wildlife, and invertebrates; stabilization of lake-bottom sediments and shorelines; cycling of nutrients; and food for many organisms. In some lakes, submerged plants grow in abundance, yet they also may compete with algae for nutrients and help maintain better water clarity. Emergent and floating-leafed species may be valued for their aesthetic qualities and help provide a more “natural” buffer between a developed shoreline and the open water.

What factors affect aquatic macrophytes?
There is considerable variability in plant communities, both within the same lake or river and among similar bodies of water. Macrophyte growth is limited by a number of factors, including light availability, nutrients, wave stress, bottom type, water level fluctuations, and water temperature. The shallow water extent of submerged plant growth is usually limited by bottom conditions and wave stress, while the deep water limit is usually dependent upon light availability. Eutrophication, boat traffic, controlled or raised water levels, shoreline development, invasive species, and rough fish can all have in impact upon aquatic plants, either through changes in abundance or species composition.

How might boats affect aquatic macrophytes?
Boats may impact macrophytes either directly, through contact with the propeller and boat hull, or indirectly through turbidity and wave damage. Propellers can chop off plant shoots and uproot whole plants if operated in shallow water. Increased turbidity from boat activity may limit the light available for plants and limit where plants can grow. Increased waves may limit growth of emergent species. Finally, boats may transport non-native species, such as Eurasian water milfoil, from one body of water to another.

Studies:

Zieman (1976) compared sea grass communities and sediment characteristics in undisturbed and motor boat disturbed areas off the Florida coast. Undisturbed sea grass beds had finer sediments than disturbed areas. In disturbed areas, channels receiving continuous boat traffic had coarser sediments than channels cut into the sea grass by a single boat pass. Sediments had lower pH and redox potential in the channels, indicating that removing aquatic vegetation altered sediment chemistry. As a result, channels cut by motor boats were found to persist for 2-3 years. Recolonization of disturbed areas was slow because of slow rhizome growth. Motor boat impacts are likely to be more pronounced in shallow high use areas with plant species that tend to be slow growing.

Murphy and Eaton (1983) looked at the relationship between boat traffic, turbidity, and macrophytes from several hundred sites in an English canal system. Abundance and biomass of macrophytes were negatively correlated to boat traffic, particularly at high levels (over 2000 boat passes per year). The impact on submerged vegetation was greater than on emergent plants. Total suspended solids were strongly correlated to boat traffic and negatively correlated to submerged macrophyte abundance, suggesting that boat traffic was indirectly suppressing macrophyte growth by generating turbidity. Direct physical damage by boats likely caused the decline in emergent macrophytes.

Vermaat and de Bruyne (1993) investigated factors that limited the distribution of submerged plants along three stretches of a lowland river in the Netherlands. Low light caused by high turbidity and periphyton growth, limited plants to water less than 1m deep. However, plant growth was much higher in the section that received the least amount of boat traffic, even though light conditions were similar to the other sites. In an experiment, plants collected from all three sites grew better in sheltered conditions than plants exposed to waves. The authors speculated that waves from boat traffic limited the shoreward extent of plant growth.

Mumma and others (1996) found a direct correlation between recreational use and drifting plants along stretches of the Rainbow River in Florida. Recreational use included canoeing, inner tubing, and motor boating, but no distinction was made among uses and their effect on the plants. Plants appeared to be damaged either by cutting or uprooting. However, the amount of plant biomass removed by the recreators per hour during peak use times represented a minute percentage of the total plant biomass in the upstream reaches of the river. Also, the researchers found that water depth and substrate type, not the level of use, influenced overall plant biomass among different sites.

Asplund and Cook (1997) studied the effects of motor boats on submerged aquatic macrophytes in Lake Ripley, Jefferson County, WI. Four enclosures, two of solid plastic and two of mesh fencing, were placed in about 1 m of water adjacent to high boat traffic areas. These enclosures were intended to exclude motor boat access and, in the solid-walled enclosures, to block the turbidity generated by boat-induced sediment resuspension. At the end of the study, plant biomass, height and percent cover were measured inside the enclosures and in control plots. Excluding motor boats from the experimental plots significantly increased macrophyte biomass, coverage, and shoot height compared to impacted areas. Results indicated that motor boats affected plant growth through scouring of the sediment and direct cutting; however, turbidity generated by boats did not appear to limit macrophyte growth in this experiment.

Conclusions:

What do we know?

Several researchers have documented a negative relationship between boat traffic and submerged aquatic plant biomass in a variety of situations. The primary mechanism appears to be direct cutting of plants, as many have noted floating plants in the water following heavy boat use. Other researchers have determined that scouring of the sediment, uprooting of plants, and increased wave activity may also be factors. Where frequent boat use has created channels or tracks, it was noted that these scoured areas persist for several years.

What don't we know?
While boats can uproot plants and reduce growth, it is still unclear what the long-term effects of boat traffic are on the macrophyte community, especially in lakes. Most studies that noted decreased plant growth in high boat traffic areas were in rivers where boat traffic is more confined and waves may be more of a factor. Also unknown is the effect on macrophyte species composition and the subsequent effect on other components of the aquatic ecosystem, such as the fish community and water quality. As one study noted, the amount of plant material chopped up by boats was a very small proportion of the whole plant community. It is unclear if such a small amount of plant material lost has larger-scale or longer-term impacts.

What can we do about it?
No-wake zones and restricted motor areas effectively reduce the impact of boats on aquatic plants (see **Asplund and Cook 1999**). Limiting boat traffic in areas with sensitive species or where a large proportion of the plant material is floating or emergent may be a good way to guide boat activity to more appropriate parts of a waterbody. While no-wake zones do not prevent all impacts, they do serve to reduce the overall amount of boat activity in a given area. Basing no-wake zones on water depth or the maximum depth of plant growth may be more useful than those based upon fixed distances from shore.

Also see:

Johnstone, I. M., B. T. Coffey, and C. Howard-Williams. 1985. The role of recreational boat traffic in interlake dispersal of macrophytes: A New Zealand case study. J. Environ. Manage. 20:263-279.

Schloesser, D. A., and B. A. Manny. 1989. Potential effects of shipping on submersed macrophytes in the St. Clair and Detroit Rivers of the Great Lakes. Mich. Academician 21:110-118.

E. Fish

Introduction:

What do we mean by "fish?"
In this discussion of boat impacts on fish or fish communities, we will consider impacts on a variety of levels: 1) individual fish, 2) fish populations, and 3) the community of all fish in a body of water. Aspects such as mortality and behavior affect individual fish, breeding success or recruitment affects fish population dynamics, and species composition and overall abundance of fish affect the fish community.

Why are fish important in aquatic ecosystems?
Fish form an important part of the food web in aquatic ecosystem, and can be either top predators, intermediate herbivores, or plankton eaters. A variety of birds and other animals depend upon fish as their primary food source. The presence or absence of individual species, as well as overall fish numbers can be an indicator of ecosystem health and can affect water clarity and water quality. Fisheries form an important resource for food and recreation for humans as well. In fact, angling is the most popular recreational activity on most Wisconsin waters.

What factors affect fish?
Climate, food availability and quality, suitability of shelter, and the presence of predators (including humans) affect individual fish, as well as fish populations. Water quality, turbidity, and the presence of pollutants can also affect fish reproductive success, which affects fish populations. Species composition is usually determined by a number of factors including water quality, water temperature, and pH. Angling also has a large impact on fish populations and community structure and is usually closely regulated to try to maintain a balanced fishery. In sum, any human activity that affects water quality and habitat has the potential to affect fish populations and overall community structure.

How might boats affect fish?

Direct contact of boats or propellers may be a source of mortality for certain fish species, such as carp. Pollution from exhaust or spills may be toxic to some fish species. Boat movement can affect individual fish directly by disturbing normal activities such as nesting, spawning, or feeding. Increased turbidity from boats may interfere with sight-based feeding or success of eggs or fish spawning. On a population level, boats may affect fish through habitat alteration caused by waves or propeller damage.

Studies:

Lagler and others (1950) addressed several important topics using control and experimental ponds: bluegill and largemouth bass production, location of nests, guarding behavior, mortality of eggs and fry, and habitat alteration. Some differences among motor and non-motor ponds were seen in fish production, but these differences were small and may have been due to other factors. The motor boat followed a defined path around the perimeter of the pond and thus inhibited macrophyte growth, scoured the sediments, and reduced the number of bottom dwelling organisms in its path. Otherwise, the motorboat ponds exhibited no changes in turbidity, water chemistry or phytoplankton production. Motorboat use did cause male sunfish to abandon their nests temporarily, but it did not affect the location of nests. Motorboat use did not significantly affect mortality of eggs or fry. Angling success was monitored on a non-motor lake on which a motor boat was operated every other day during several 3-week periods. No differences in angling success (either catch or strike frequency) were observed on motor vs. non-motor days.

Mueller (1980) used an underwater camera to record guarding behavior by sunfish in response to passes by a canoe, slow motorboat (2 mph), and fast motorboat (11 mph) at varying distances from nests. Boat passage caused fish to leave nests to take cover, leaving eggs vulnerable to predation. In control areas, fish left the nests just as often but for shorter periods of time, primarily to ward off intruders. Absence times were longer if boat passes were close or cover was far away. Fish abandoned nests more frequently in response to slower moving boats, most likely because of increased time for detection.

Kempinger and others (1998) studied the frequent occurrence of fish kills on a stretch of the Fox River in Oshkosh, WI, between Lake Butte des Morts and Lake Winnebago since the 1950's. Throughout the ice-free season in 1988, they monitored cages with fathead minnows and freshwater drum placed at various sites along the river. They discovered that an outboard-motor testing facility located along the river was primarily responsible for the fish kills, due to elevated levels of carbon monoxide in the water. Fish kills were most apparent during warm temperatures and low flow or reversed flow conditions due to incoming seiches from Lake Winnebago. As a result of the study, the testing facility now limits its testing to no more than 1500 horsepower at one time, and ceases operation during low flow and higher temperatures.

Conclusions:

What do we know?

Very few studies have documented direct impacts of boat activity upon individual fish behavior or mortality. The few studies cited here demonstrate that boat activity can disturb fish from their nests, but that overall breeding success is likely not affected. Toxic effects on fish have generally not been observed, except in extreme situations (such as near boat testing facilities). Of much greater concern and effort, however, is the effect of boats on fish habitat (water quality, clarity, and aquatic plants) which subsequently may impact fish populations. These studies have been summarized elsewhere.

What don't we know?

While the effects of boats on fish habitat has been studied extensively, as well as the effects of habitat degradation on fish populations, the link between boat activity and fish populations has not been well defined. How much boat activity can a lake or river handle before fish populations are affected? How much habitat is needed for successful fish recruitment? Is fishing success affected by boat activity? Would restricting boat activity enhance fish populations? These are questions that have not been addressed or answered to date.

What can we do about it?
Keeping boats out of known fish spawning areas may help to improve overall fish success, however, it would be detrimental to anglers. Most boat activity usually occurs after peak fish spawning times, but extending protection of critical areas through early June may help to protect certain species. A more useful approach would be to protect shallow waters and plant beds from boat activity through the use of no-wake zones. No-wake zones in prime fishing areas may also help to reduce user conflicts by creating a separation between anglers and high-speed boaters.

Also see:

Savino, J. F., M. A. Blouin, B. M. Davis, P. L. Hudson, T. N. Todd, and G. W. Fleischer. 1994. Effects of pulsed turbidity on lake herring eggs and larvae. J. Great Lakes Res. 20(2):366-376.

F. Aquatic Wildlife

Introduction:

What do we mean by "aquatic wildlife?"
Aquatic wildlife refers to animals that spend part or all of their life in aquatic environments, or depend upon them for food or reproduction. Examples include waterfowl, shorebirds, herons, eagles, loons, turtles, frogs, and in saltwater systems include manatees, seals, and dolphins. Fish will be addressed in a separate section.

Why are aquatic wildlife important in aquatic ecosystems?
Aside from the aesthetic value of being able to see eagles, loons, deer, and other animals near water, certain species form an essential part of the food chain, especially those that feed on detritus or carrion or those that feed on the top predator fish. The presence of loons and osprey can be an important indicator of ecosystem health.

What factors affect aquatic wildlife?
Wildlife use of aquatic ecosystems depends upon a number of factors. Good water quality and the availability of suitable habitat are important for most species. Other species require a certain amount of wild or natural area in order to find enough food or to be protected from predators. The quantity and quality of food is also essential. For example, loons need an abundant fish population in order to sustain their growth. Species that migrate may need a high quality food source in order to build up enough energy to reach their wintering grounds. Finally, some species are very sensitive to human presence and may not be able to survive on waters that are too “busy” or populated.

How might boats affect aquatic wildlife?
Boats may have direct impacts on wildlife through contact with propellers or disturbance of nests along the shoreline by excessive wave action. Disturbance by the fast movement of watercraft or even the presence of humans near feeding ground or breeding areas may prevent certain species, especially birds from being successful. Noise or harassment may cause some wildlife to vacate nests, leaving eggs or young vulnerable to predators. Indirect effects may include destruction of habitat or food source in littoral areas, or impaired water quality.

Studies:

Kahl (1991) describes detailed observations of the response of canvasbacks to fishing and hunting boats at feeding areas. Disturbances caused the flock to flush and reduced the amount of time the birds spent at feeding areas, possibly increasing energy costs and delaying migration. High frequency of disturbance caused the birds to establish refuge areas in the middle of the lake where they remained for up to 60 min. per disturbance. Boating disturbance accounted for ~50% of daylight hours spent away from feeding areas. Canvasbacks were less likely to flush and flushed at closer distances in response to slower moving boats.

Rodgers and Smith (1995, 1998) directly measured the flushing response of 16 waterbird species exposed to 5 different human activities, including walking, ATV, motorboat, canoe, and automobile. The earlier study focused on nesting birds, while the latter focused on foraging and loafing birds. The authors found considerable variation in flushing distances among different species in response to the same activity (mean distances ranging from 5 to 35 m). In general, birds which were more habituated to human presence (gulls, terns) exhibited the least flushing distance. Walking and canoeing tended to flush birds at greater distances than motorized activity, perhaps due to the slower speeds and more time for birds to become aware of the disturbance. Nesting birds tended to allow closer approaches before flushing, likely because of the greater cost of leaving a nest versus a feeding area. In both studies, the authors recommend buffer zones of 100 m to protect most bird species, or mixed colonies of either nesting or foraging birds. This figure includes a 40 m "buffer" to account for alarm behaviors that do not result in an actual flush.

Madsen (1998) studied the disturbance effects of a variety of recreational activities on coot, widgeon, and mute swan flocks in 2 Danish wetlands. Moving hunting boats caused the most disturbance in terms of flushing frequency (2 times per day on average) and disruption time (up to 75 minutes), compared to stationary boats, fishing, windsurfing, and sailing. However, windsurfing had the highest flushing distance of any activity (450-700 m). Widgeon and mute swan were disturbed much more easily than coots. Repeated disturbances during a day reduced foraging time by 13-33%. In terms of overall effects of recreational activity, birds were disturbed 16% of the daylight hours during the months of September and October.

Stalmaster and Kaiser (1998) observed the effects of recreational activity on wintering bald eagles in a wildlife area in northwest Washington. They observed fewer eagles and less feeding activity during times of highest recreational use (weekends, early morning hours). Foot traffic disturbed individual eagles to a greater extent than motor boats (greater flushing responses and distances), but boat activity disturbed a greater proportion of the eagle population. Eagles resumed feeding relatively quickly after initial disturbances of the day, but were slow to resume after about 20 disturbances. Boat activity was more disturbing on narrow than on wide river channels. The authors estimate that feeding by eagles was reduced by 35% in the wildlife area because of recreational use and suggest limiting boat traffic within 400 m of eagles, especially during early morning hours.

Conclusions:

What do we know?

Boat activity certainly causes many wildlife species to be disturbed from a variety of activities. For some species, this may represent just a temporary disturbance, with little long-term effect. For other species, or in cases where unique habitats are disturbed by high frequency or intensity of boat use, boat activity can have effects on the entire population. Migratory birds may require more protection as their energy needs can easily be disrupted by excessive disturbance. Manatees have been observed with scars and lesions from contact with boat propellers, but few other species likely receive this direct sort of impact.

What don't we know?

Very little research has been done on small animals that use shorelines, such as turtles, frogs, shorebirds, and mammals. Long term effects on wildlife use of an aquatic ecosystem is also difficult to assess, as motor boat activity often goes along with increased development and impaired water quality. Many species may simply move elsewhere if a particular body of water becomes too busy.

What can we do about it?

Buffer zones have been suggested for a variety of bird species, ranging from 100 to 180 m. Protecting littoral zone habitat or known breeding areas with no-wake zones would help to provide this buffer, though it would not eliminate boat activity. Preventing access to undisturbed shorelines or areas may be warranted if it can be shown that these areas provide a unique resource to wildlife populations. Loon nesting sites, heron rookeries, “turtle beaches,” and eagle wintering sites, would all be possible candidates for such a restriction. In some cases, all human activity, not just motor boat use, may need to be restricted in order to protect wildlife populations.

Also see:

Bratton, S. P. 1990. Boat disturbance of ciconiiformes in Georgia estuaries. Colon. Waterbirds; 13(2):124-128.

Mikola, J., M. Miettinen, E. Lehikoinen, and K. Lentilä. 1994. The effects of disturbance caused by boating on survival and behaviour of velvet scoter *Melanitta fusca* ducklings. Biol. Conserv. 67: 119-124.

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G. Personal Watercraft (“Jet skis”)

Introduction:

What do we mean by "personal watercraft?"
Personal watercraft (PWCs), commonly referred to as “jet skis”, include a variety of watercraft that are designed for use by one or two individuals (though newer models are being developed for 3 people). Riders either sit or stand, depending upon the design. Propulsion systems are generally quite different from traditional outboard motors, making use of a water pump rather than propellers to move the craft through the water. Steering is accomplished by ejecting the water at high force through a movable nozzle. PWCs are designed to be powerful and maneuverable and can operate in waters less than 12 inches deep.

Why are PWCs important in aquatic ecosystems?
Since the introduction of the first Jet Ski in 1973, PWC use has skyrocketed throughout the country, especially since the late 1980’s. It is estimated that 200,000 PWCs are sold annually in the U.S., representing 30% of all new sales of watercraft. They still represent a small proportion of overall watercraft in use (about 1 million compared to 12 million outboards), but on certain lakes and rivers, they can achieve relatively high numbers. Along with the increase in numbers has come increasing conflicts with other users, as they tend to be more noticeable and create noise and perceptions of reduced safety and increased crowding.

How might PWCs affect aquatic ecosystems?
PWCs can have many of the same effects as described in other sections. However, because of their unique propulsion systems and use characteristics, this special section has been included to summarize studies that have addressed the impacts of PWCs specifically. For example, PWCs are often criticized for the noise that they produce, due to their frequent stops and starts and operation at full throttle. Most PWCs employ two-stroke technology for their engines, thus making them a concern for their air and water emissions of hydrocarbons and other pollutants. Because PWCs can be operated in shallow water, at high speeds, and in remote areas not usually frequented by boats, disturbance to wildlife may be more of a concern than other types of watercraft. Finally, while PWCs do not generally have propellers, the turbulence produced by the jet propulsion may still disturb plant growth and sediments, especially during acceleration or turns when the thrust may be oriented downward.

Studies:

Noise
Wagner (1994) described a study of PWC noise vs. outboard motor noise on a heavily used lake. The study showed that the actual noise level (in terms of decibels) is not much higher than most other types of

watercraft. The loudness decreased with distance from the watercraft, such that the sound level was within background levels at distances of 300 feet or more. However, the PWCs tended to have more variable sound levels and a higher pitch than most other types of watercraft. These frequent changes in pitch tend to make the noise more noticeable to human ears, and were usually the cause of complaints. Responding to these concerns, PWC manufacturers have introduced quieter technology in recent years.

Disturbance to wildlife
Burger (1998) compared the effects of motorboats and personal watercraft on flight behavior over a colony of common terns on an island in Barnegat Bay, New Jersey. The presence of any watercraft caused birds to fly over the colony. However, personal watercraft caused more birds to flush than did motorboats, particularly early in the nesting season (150-200 birds for PWCs compared to 20-30 for boats). Racing and fast-moving watercraft elicited a higher response than slow moving boats, as did boats that operated outside of the established channel. More birds flew in the air the closer the approach by a boat or PWC. The proximity of watercraft and either the fast movement or noise of those operating at high speeds were the most disturbing attributes, and tended to be those associated with PWCs. These disturbances may cause a drop in breeding success for some colonies of terns.

Emissions
The **California Air Resources Board (1998)** has argued that emissions from PWCs on a per machine basis are actually higher than that for a typical outboard motor, due to their larger horsepower, higher speed of operation, and sustained high speeds. Estimates of 2-3 gallons of unburned fuel per hour are typical. However, it has been estimated that all outboard motors discharge 25-30% of their fuel unburned, not just PWCs. The actual amount discharged is a function of speed, tuning, size of engine and other factors.

Physical impacts
The **Personal Watercraft Industry Association (1997),** found that PWCs had no effects on water clarity and seagrass disturbance in a shallow estuary at depths of 21-36 inches when operated on plane (20-30 mph). Some resuspension of fine sediments was documented during tests with frequent stops, starts, and turns in a confined area, however. This study only considered effects of single Jet Ski runs, and did not address cumulative impacts of sustained Jet Ski use in shallow water.

Conclusions:

What we do we know?
Available research into the impacts of PWCs on lakes and other water bodies is relatively limited. In general, the issues that are raised in regard to PWC use apply to all motorized watercraft. There is some evidence that noise and emissions are perhaps a bigger concern than for other types of watercraft, largely due to the way in which the machines are operated (high speed, frequent stops, starts, and turns). One study also showed that PWCs present a larger threat nesting waterbirds. PWCs may be more disturbing due to their ability to access areas typically avoided or restricted to other types of watercraft.

What don't we know?
Very few studies have been done which have documented physical impacts of PWCs on aquatic vegetation or sediment resuspension. No studies have compared the effects of PWCs to those of outboard motors. While PWCs may not have as much impact as a propeller-driven craft at a given depth, their operation in shallower water may have more overall effect. This area of concern remains to be addressed.

What can we do about it?
Manufacturers have voluntarily been introducing quieter, cleaner burning machines in response to citizen complaints and EPA rules requiring 75% reductions in air emissions from all marine engines by 2025. Wisconsin currently has a no-wake rule for PWCs within 200 feet of shore, which effectively minimizes the effect of PWCs on shallow water habitat. This no-wake restriction also reduces the noise level experienced by people on shore. Enforcement of this no-wake rule would go a long way toward minimizing the effects of PWCs. Restricting PWC use in natural areas or critical bird breeding areas may be justified in some cases; however restricting all motorized watercraft may be necessary to truly protect

species of concern. Some states and the National Park Service have considered or enacted bans on PWCs within their jurisdiction, largely based upon disturbance to wildlife and the noise issue.

Also see:

San Juan Planning Department. 1998. Personal Watercraft Use in the San Juan Islands. A Report Prepared for the Board of County Commissioners, San Juan County, Washington.

<u>Summary Section</u>

Potential mechanisms by which boats impact aquatic ecosystems and the effects that they can have on the aquatic environment. Shaded areas indicate where a "Mechanism" has an "Effect."

Mechanism: *Effect:*	**Emissions and exhaust**	**Propeller or hull contact**	**Turbulence**	**Waves and wake**	**Noise**	**Movement**
Water Clarity (turbidity, nutrients, algae)						
Water Quality (metals, hydrocarbons, other pollutants)						
Shoreline Erosion						
Macrophytes (plant communities)						
Fish						
Wildlife (Birds, mammals, frogs, turtles)						
Human enjoyment (air quality, peace and quiet, safety, crowding)						

What do we know?

While the effects of boats on aquatic systems are complex and depend on a number of factors, a few general observations can be made. First, the physical effects of propeller, waves, and turbulence appear to be more of an issue than engine fuel discharge. Water clarity, aquatic plant disturbance, and shoreline erosion all are serious issues that can be exacerbated by boat traffic. Second, most of the impacts of boats are felt most directly in shallow waters (less than 10 feet deep) and along the shoreline of lakes and rivers not exposed to high winds (less than 1000 feet of open water). Third, these effects can have repercussions for other features of the aquatic ecosystem, including the fish community, wildlife use, and nutrient status. These observations all emphasize that the most important area of a lake or river to protect is the shallow-water, near-shore habitat known as the littoral zone. Boats that operate in deep waters with large surface areas are not likely to be impacting the aquatic ecosystem.

What don't we know?

Given these observations, there are still a number of unknowns regarding motor boat impacts. Most of the studies that are summarized here have focused on the short term or acute impacts of boat activity, pollution, disturbance, sediment resuspension, etc. It is not very clear what role boats can play in the long term changes of a water body, i.e. changes in macrophyte community, overall water quality, or fish and wildlife use. Many other factors influence these same features and many have changed along with boat activity. For example, increased shoreline development often causes increased boat activity, yet it is difficult to separate out which factor is more important for plant community changes. As another example, it has been demonstrated that boats and PWCs can disturb breeding bird activity, but it is difficult to determine what effect this may have on overall bird populations, due to the increasing amount of all human activities in historic breeding areas of many bird species.

What can we do about it?

While specifics of boat use management will be covered extensively in other chapters, we will make a few comments here regarding ways in which environmental impacts of boats can be reduced.

No-wake zones

Given that most impacts of boats are exhibited in shallow-water near-shore areas, protecting these areas with no-wake zones would be the most effective way of reducing impacts. No-wake zones have a dual benefit by both slowing boats down and directing traffic elsewhere. Currently in Wisconsin, boats are required to operate at no-wake speeds within 100 feet of piers, docks, and moored boats, while PWCs are required to operate at no-wake speeds within 200 feet of the shoreline. Lakes less than 50 acres in size are entirely no-wake. While established primarily for safety and navigation reasons, these restrictions appear to be adequate for protecting against shoreline erosion, at least in developed lakes. In many cases, however, these restrictions do not adequately protect shallow-water sediments or beds of aquatic macrophytes. Some communities have extended no-wake restrictions to 200 or even 300 feet through local ordinances. These extended no-wake areas have the potential to protect a much more significant proportion of the littoral zone and may help to reduce shoreline erosion.

A much more useful way of establishing a no-wake area would be to determine the depth at which plants grow in a given waterbody, and then establish a no-wake zone based upon water depth and vegetation parameters. At minimum, a no-wake zone based upon a 6-foot depth would reduce disturbance to sediments. A deeper depth threshold could be justified if the tops of plants come within 5 feet of the surface, or if the sediments were particularly fine. These guidelines could then be coupled with the minimum 100-foot no-wake zone to protect shorelines.

Restricted areas

In some cases, protection of aquatic resources may require restricting all boat activity, not just speed. Boats can still disturb plants, sediments, and wildlife at no-wake speeds. These types of restrictions need to be based upon unique features of a resource and are often used to provide a certain type of experience on remote or "wild" lakes. For example, to adequately protect waterbird breeding areas, a "buffer zone" of at least 100 m (300 feet) has been suggested, in which all human activity would be banned. Similar areas could be established for emergent or floating-leafed plant beds, which may be impacted by boats operating at any speed. Research on Long Lake in the Kettle Moraine State Forest – Northern Unit showed that no-motor zones did a better job of preventing disturbance of submerged plants than simple no-wake zones (Asplund and Cook 1999). Some lakes currently have electric-motor only or no-boat restrictions, which may help to protect particularly unique or sensitive natural areas. These types of restrictions need to balance protection of the resource with the right of public access.

Enforcement and Education

Many of the environmental problems associated with boat activity could be resolved with better enforcement of existing ordinances or regulations and promoting awareness among boaters. Slow-no-wake rules are often ignored or misunderstood by boaters, such that impacts to sediments, aquatic plants, and shorelines occur even in no-wake zones. Another important avenue is informing recreators about the value of plants, littoral zones, and natural shorelines and how their activities may affect the aquatic ecosystem. If people understand that their activities may be hurting the ecosystem, they may be willing to confine their activities to more appropriate places.

Technology

Recent technology spurred by Federal air quality standards has the potential to reduce water pollution impacts from outboard motors as well. All 2-stroke engine manufacturers, including traditional outboard motors and PWCs, must reduce air emissions by 75% by the year 2025. Most manufacturers have already introduced cleaner burning 2-stroke engines and PWCs. Four-stroke engines, which use fuel more efficiently, produce cleaner exhaust, and run more quietly than traditional 2-stroke engines, are becoming much more common. However, technology may have the opposite effect on physical impacts, as engine sizes continue to increase and PWC manufacturers continue to emphasize speed and power. The consequences of operating bigger and faster machines in our inland waterways must continually be addressed in the future.

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