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A Literature Review of Wake Boat Effects on Aquatic Habitat

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A Literature Review Of Wake Boat Effects On Aquatic Habitat

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EXECUTIVE SUMMARY

The operation of wake boats in a manner that creates large waves can erode shorelines and resuspend sediments and is an emerging threat to natural resources in inland lakes. Wake boats can produce waves with 1.7–17 times the energy of other comparable-sized powerboats and their propellers generated enough turbulence to resuspend bottom sediments in water up to 33 feet deep. The large waves generated by wake boats take between 400–1,023 feet to dissipate to heights and wave energies observed 100–200 feet away from typical boats operating at cruising speed. Further, the use of ballast tanks in wake boats results in a dramatic increase in risk for transporting Dreissenid mussels and other aquatic invasive species and pathogens among water bodies. The cumulative negative effects of wake boats on natural resources has the potential to lead to loss of habitat, resulting in the decline of aquatic ecosystems and angling opportunity. These concerns can be mitigated by operating farther from shore to allow waves to dissipate before reaching shore, operating in deeper water to prevent bottom scour and resuspension of sediments, and disinfecting ballast tanks.

Michigan's current boating laws and regulations are intended to both promote public safety and avoid property damage but were created prior to the commercialization and popularization of wake boats in the early 2000s. As a result of the large waves and increased scour caused by these vessels, the existing 100-foot operating buffers around docks and shorelines on inland lakes are not sufficient to protect aquatic resources. The Michigan Department of Natural Resources, Fisheries Division (Division) recognizes the recreational value and popularity of wake boats, and recommends the following voluntary best operating practices in support of the continued use of wake boats while minimizing the effects on natural resources:

1. Boats operating in wake-surfing mode or wake-boarding mode, during which boat speed, wave shapers, and/or ballast are used to increase wave height, are recommended to operate at least 500 feet from docks or the shoreline, regardless of water depth.
2. Boats operating in wake-surfing or wake-boarding modes are recommended to operate in water at least 15 feet deep.
3. Ballast tanks should be completely drained prior to transporting the watercraft over land.

It is recommended that awareness and voluntary adoption of these best operating practices be encouraged through outreach actions and materials to educate wake boat operators.

INTRODUCTION

Wake boats are powerboats specially designed to increase wave height for watersports. The hull is shaped to achieve significantly increased wakes, and many have a hydrofoil device that lowers the stern when the boat is under power. Most wake boats also have built-in ballast tanks that can be filled with lake water to increase the weight in the stern of the boat and create larger waves. While wake-boarding, a rider is towed with a rope, usually at a speed of 20–23 mph. They use the wake of the boat to perform jumps and tricks. wake-surfing involves a person trailing behind a boat on a short surfboard and surfing on the boat's wake without being attached to the boat by a rope. wake-surfing generally occurs at speeds of 9–11 mph. Many wake boats can operate in modes to support wake-surfing or wake-barding and have the ability to significantly increase wave height through ballast and wave shapers at the required speed for the respective activity. Through direct observations by Division employees and feedback from the public, it has become clear that waves generated by wake boats create concerns about risks to aquatic natural resources.

The State of Michigan, with the Department of Natural Resources as the trustee, has an obligation to preserve and protect natural resources as required by Article 4, Section 52 of the Michigan Constitution. The Division's mission is to protect and enhance Michigan's aquatic life and habitats for the benefit of current and future generations. Its strategic plan (MDNR 2023) serves as a guide to natural resource managers tasked to maintain healthy aquatic ecosystems and provide diverse freshwater fishing and recreational opportunities that enhance quality of life in Michigan. The first goal listed in this plan is to "ensure healthy aquatic ecosystems and sustainable fisheries". In addition, the Division has identified specific habitat conservation priorities for the nearshore zones of lakes through its Wildlife Action Plan (MDNR 2015). In the context of these priorities to conserve nearshore aquatic habitats, the goals of this document are to review the current state of knowledge regarding the effects of wake boat activity on natural resources and provide the Division's position on the operation of wake boats to protect aquatic resources held in public trust.

The Michigan Department of Natural Resources is obligated to preserve and protect natural resources. In support of that duty, Fisheries Division routinely produces scientific research and literature reviews through Fisheries Reports that address potential effects on aquatic natural resources. This Fisheries Report includes a review of the existing scientific literature regarding wake boats and provides best operating practice recommendations for wake boat operation to minimize effects on aquatic natural resources. It does not address public safety or social considerations related to wake boat operation, nor does it provide Departmental recommendations for regulation or legislation.

ENVIRONMENTAL EFFECTS OF WAKE BOATING

The environmental effects of powerboating have been well documented. Waves from powerboats can increase shoreline erosion, decrease water clarity and plant abundance (Asplund and Cook 1997), and increase phosphorus in the water column (Yousef et al. 1980). Recently, there has been an increase in the popularity of wake boats (Gouday and Girod 2015; National Marine Manufacturers Association 2021) which use ballast, wave shapers, and other hull designs to produce waves that are substantially larger and more powerful than those generated by the typical powerboat. Aftermarket wave-shaping fins are sometimes used to increase wake size even on typical motorboats; Marr et al. (2022) found that these devices increased wave height, energy, and power to create waves similar to wake boats.

MacFarlane (2018) found that wave energy from ballasted wake-surfing craft was 5–17 times higher than a benchmark speedboat and Marr et al. (2022) found that waves produced by wake boats were 2–3 times higher, had 3–9 times more energy, and were 6–12 times more powerful than a typical motorboat. Mercier-Blais and Prairie (2014) compared wave energies produced by a wake boat operated in wake-surfing (10 mph, one ballast tank filled), wake-boarding (20 mph, both ballast tanks filled), and cruising (30 mph, empty ballast tanks) modes and discovered wave energies were significantly different between operating modes at a distance of 328 feet. The waves created in wake-surfing mode were on average 1.7 times higher than those created in cruising mode. Similarly, Water Environmental Consultants (2021) showed that waves produced by a wake boat in wake-surfing and wake-boarding mode had 581% and 68% more energy, respectively, than waves produced by the same vessel operated in cruising mode at a distance of 100 feet. Both Gouday and Girod (2015) and Ruprecht et al. (2015) found that wake boats operating in wake-surfing mode produced the largest waves compared to other modes, with maximum wave energy approximately four times that of waves generated in wake-boarding mode.

The energy created by such large waves requires a substantial distance to dissipate; Mercier-Blais and Prairie (2014) used statistical models to determine that the distance required for wake boat-generated waves to dissipate completely is approximately 984 feet. This is further supported by Water Environmental Consultants (2021), who determined that waves from a wake boat in wake-boarding and wake-surfing mode would need distances of 225 feet and 950 feet, respectively, to dissipate to the wave heights observed 100 feet from the same boat in cruising mode. Additionally, Marr et al. (2022) found that wake boat waves required substantial distances to attenuate to reference conditions of a typical motorboat operating in planing mode at a distance of 200 feet for wave height (>500 feet), energy (>575 feet), and power (>600 feet, the maximum distance at which waves were measured in the study). In contrast to the studies above, Fay et. al (2022) claims that operating distances of 200 feet are sufficient to reduce wave energy and minimize erosion and resuspension. However, these conclusions are inconsistent with other studies and are built upon substantive analytical and methodological concerns. For example, Fay et al. admit that their methods for modeling waves are not appropriate beyond distances of 100 feet. Therefore, our assessment of threats to Michigan's natural resources relies more heavily on results from studies that conducted direct measurements and/or used appropriate models and methods. From those studies, we found that wake boat waves require at least 400–1,023 feet to dissipate to energies of a typical motorboat at 100–200 feet from the sailing line or have minimal resource impacts.

SHORELINE EROSION

Shoreline erosion can lead to degradation of fish habitat and water quality due to physical disruption of rooted plants and resuspension of sediment and nutrients and is a concern for lakefront property owners because it results in a loss of property and can damage infrastructure. Sedimentation can degrade habitat and threaten fishes (Muncy 1979; Dombeck et al. 1984, Ventling-Schwank and Livingstone 1994), and the shoreline armoring that typically is installed by property owners experiencing erosion degrades fish habitat as well (Jennings et al. 1999, Wehrly et al. 2012). The main factors that influence shoreline erosion are wave energy, aquatic plants, the slope of the nearshore and bank areas, and characteristics of the bank material. As larger waves strike a shoreline, they are able to dislodge and move more and larger particles (NRCS 1996, NRCS 1997, Priestas et al. 2015). Recreational boating activity can exacerbate erosion by increasing the wave energy that reaches the shoreline (Johnson 1994; Nanson et al. 1994; Bauer et al. 2002), and it follows logically that the increased wave energies produced by wake boats intensify this effect (Table 1). A recent study on 1,700-acre Whitestone Lake in Ontario (Houser et al. 2021) showed that 61–72% of total wave energy originated from powerboats. Water Environmental Consultants (2021) compared wave energy from wake boats to the monthly maximum wave energy from wind for two locations in Lake Rabun, Georgia; when wake boats passed 100 feet from shore, the wave energy produced in wake-boarding and wake-surfing modes was 553% and 2,546% higher, respectively, than the monthly maximum energy from wind-driven waves. Wake-boat-induced wave energy was 192% higher for wake-boarding mode and 679% higher for wake-surfing mode, compared to wind-driven wave energy, when the wake boats passed 500 feet from shore. It would take between 225 feet (wake-boarding mode) and 950 feet (wake-surfing mode) for waves to decrease to the 0.8-foot wave height typically observed 100 feet from a cruising wake boat. Even though these distances would allow the waves to decrease to similar heights, the waves from wake-boarding and wake-surfing modes had longer wave periods, and therefore more energy, than the cruising mode wake. Wake boats create larger wakes than traditional watercraft, therefore the greater energy of waves created by wake boats operating in wake-boarding or wake-surfing mode are likely to exacerbate boat wave induced erosion.

Many construction projects that address shoreline erosion occur below the ordinary high-water mark and are regulated by the Michigan Department of Environment, Great Lakes and Energy under Part 301 (Inland Lakes and Streams) of the Natural Resources and Environmental Protection Act (NREPA 1994a). As part of the Part 301 permit review process, the Division is consulted to ensure that projects do not adversely affect fisheries resources. In the past several years, applicants frequently have listed erosion from wake boats as part of their rationale for shoreline armoring. This reactive response of hardening shorelines, as opposed to proactively reducing the erosive forces at the shoreline caused by wake boats, will only lead to greater environmental degradation from armored shorelines due to wave reflection off these structures.

SEDIMENT RESUSPENSION

Sediment resuspension increases nutrients and decreases water clarity in lakes, subsequently reducing the ability of fish to find food, the depth to which aquatic plants can grow, and the dissolved oxygen content within the water column (Gardner 1981; Canfield et al. 1985; Chambers and Kaiff 1985; Barrett et al. 1992; Irvine et al. 1997; Stuart-Smith et al. 2004; Trebitz et al. 2007). Numerous studies indicate that decreases in water quality (e.g., Jacobson et al. 2008; Phelps et al. 2019) can stress or kill fishes. In addition, as sediments are resuspended and nutrients become available in the water column, excessive algae growth can occur. Boat wakes resuspend sediments, especially fine substrates such as silt or sand, in shallow waters (USACE 1994) and this resuspension increases with wave energy. Existing studies have shown that resuspended sediments caused by powerboats increase turbidity and phosphorus concentrations in rivers, lakes, and shallow experimental ponds (Yousef et al. 1980; Johnson 1994; USACE 1994; Asplund 1996, 1997; Anthony and Downing 2003).

Wake boats have greater potential to exacerbate sediment resuspension through increased wave energy and propeller turbulence (Table 1). Mercier-Blais and Prairie (2014) determined sediment resuspension was significantly higher than background conditions up to 492 feet from wake boats operating in wake-surfing mode and 656 feet from wake boats operating in wake-boarding mode and was highest when wake boats were operated in wake-surfing mode at a speed of 10 mph. Mercier-Blais and Prairie’s extrapolations indicate that distances of 675 and 938 feet from the line of travel are required for wake boat waves to produce sediment resuspension equivalent to normal levels on ~1,136-acre Lake Lovering and ~439,847-acre Lake Memphremagog, respectively. Previous studies of typical powerboats indicated that propellers from outboard engines create turbulence that can reach as deep as 10 feet (Gucinski 1982; Keller 2017). Field testing by Raymond and Galvez-Cloutier (2015) found that wake boat propellers generated water velocities with the capacity to resuspend unconsolidated sand, silt, and smaller organic materials at a depth of 15 feet while the boat was in wake-boarding or wake-surfing modes. Models developed by Ray (2020) calculated that modern wake boats can cause sediment resuspension in water down to 33 feet deep.

Table 1. Summary of wake boat effects measured or modeled at various distances from the boat's line of travel, and whether those distances were considered in determining the range of distances at which wake boat waves dissipate to energies of a typical motorboat at 100–200 feet from the sailing line or have minimal resources impacts.

Source	Distance (ft)	Data type	Considered	Notes
Water Environment Consultants (2021)	100	Field data	No	Wave energy from wake-boarding (553%) and wake-surfing (2,546%) greater than monthly maximum wind-driven wave energy.
Water Environment Consultants (2021)	100	Field data	No	Wave energy from wake-boarding (68%) and wake-surfing (581%) greater than cruising vessel wave energy.
Ray (2020)	135	Field data	No	Wake boat wave 9 inches high.
Fay et al. (2022)	200	Mathematical model	No	Claims minimal impacts at this distance.
Water Environment Consultants (2021)	225	Mathematical model	No	Wave height attenuation from wake-boarding to wake boat cruising at 100ft. Note that wave power may still be greater and that wake boat weight and hull design increase cruising wakes, thus this is an underestimate relative to typical boats.
Water Environment Consultants (2021)	300	Field data	No	Wake-boarding wave energy at 300ft similar to wake boat cruising energy at 100ft. Note that wake boat weight and hull design increase cruising wakes, thus this is an underestimate relative to typical boats.
Goudey and Girod (2015)	300	Field data	No	Measured large waves during wake-boarding (9.87in) and wake-surfing (12.92in) in deep water.
Ray (2020)	300	Field data	No	Wake boat wave 7.75 inches high.
Mercier-Blais and Prairie (2014)	328	Field data	No	Energy of wake waves decreased significantly, but not assessed relative to typical motorboat.
Macfarlane et al. (2018)	400	Field data	Yes	Maximum wave height and energy similar to reference motorboats.
Mercier-Blais and Prairie (2014)	492	Field data	Yes	Sediment resuspension observed from wake-surfing.
Water Environment Consultants (2021)	500	Field data	Yes	Wave energy from wake boating (192%) and wake-surfing (679%) greater than monthly maximum wind-driven wave energy.
Marr et al. (2022)	>575	Field data	Yes	Total wave energy similar to reference motorboat at 200ft.
Marr et al. (2022)	>600	Field data	Yes	Total wave power similar to reference motorboat at 200ft.
Mercier-Blais and Prairie (2014)	656	Field data	Yes	Sediment resuspension observed from wake-boarding.
Mercier-Blais and Prairie (2014)	675–938	Mathematical model	Yes	Estimated distances at which a wake boat waves result in equivalent sediment resuspension to normal conditions on two lakes.
Mercier-Blais and Prairie (2014)	879–1023	Mathematical model	Yes	Estimated distances at which a wake boat waves result in equivalent turbulent kinetic energy to normal conditions on two lakes.
Water Environment Consultants (2021)	950	Mathematical model	Yes	Wake-surfing wave height attenuation to typical boat at 100ft.Note that wave power is likely greater and that wake boat weight and hull design increase cruising wakes, thus is an underestimate relative to typical boats.
Mercier-Blais and Prairie (2014)	984	Mathematical model	No	Modeled complete dissipation of wake boat waves.
Ray (2020)	1000	Field data	No	Wake boat wave 4 inches high.

AQUATIC *PLANTS*

Reductions in native aquatic plants will affect fish populations. Aquatic vegetation provides rearing areas for juvenile fishes (Bryan and Scarnecchia 1992), allows for increased fish growth and total fish biomass (Radomski and Goeman 2001; Nohner et al. 2018), and reduces wave energy in the nearshore zone. While there are no studies that directly address the effects of wake boats on aquatic plants, previous research on powerboats provides a basis for inference. For example, Asplund and Cook (1997) documented 20% reductions in aquatic plant coverage due to the physical disturbance caused by recreational boating in Wisconsin, which has similar 100-foot regulations to Michigan. They also found that excluding powerboats from experimental plots dramatically increased aquatic plant biomass, coverage, and shoot height compared to areas with boats. Results indicated that powerboats affected plant growth through scouring of the sediments and direct cutting as opposed to increased turbidity, and it was unclear if the amount of plant material lost would have larger-scale or long-term impacts on the ecosystem (Asplund 2000). Murphy and Eaton (1983) documented an inverse relationship between recreational boating traffic and both submersed and emergent aquatic plant abundance in canals in British Columbia. Since wake boats produce greater wave energy, propeller turbulence, and sediment resuspension compared to the powerboats observed in these studies, it follows that wake boats could significantly disrupt native aquatic vegetation in inland lakes.

AQUATIC INVASIVE *SPECIES*

Aquatic invasive species (AIS) are non-native organisms that cause significant negative effects when introduced to inland lakes and other aquatic ecosystems. The State of Michigan's AIS Management Plan (MDEQ 2013) prioritizes the need for preventing accidental AIS introductions, which may be greatly increased by wake boats due to the presence of large ballast tanks that can be filled from or emptied directly into the water body they are operating on. For example, research has shown that ballast tanks from wake boats operated on a lake with the invasive Zebra Mussel *Dreissena polymorpha* typically carried 247 Zebra Mussel veligers per sample (Doll 2018), which was much greater than stern drive motor compartments (13 veligers per sample), outboard motor lower units (1 veliger per sample), live wells, or bilges. Although wake boat ballast tanks are typically emptied before trailering, they are rarely ever completely dry which increases the survival time for invasive species potentially trapped inside. Doll (2018) found that 5% of zebra mussel veligers remained alive in ballast tanks after 48 hours. Transportation of other invasive species and fish pathogens is also possible. Furthermore, the greater propeller turbulence and increased scouring caused by wake boats may result in fragmentation and proliferation of aquatic invasive plants already found in the waterbody (Keller 2017).

COMPOUNDING *FACTORS*

The effects of wake boats are not the only changes occurring on Michigan's lakes. Shoreline armoring such as seawalls and riprap are being installed throughout the state, and this shoreline armoring reflects wave energy back into the lake as well as laterally toward neighboring properties. Shoreline armoring degrades up to 54% of lake shorelines in some highly populated areas (Wehrly et al. 2012), which are also the areas that receive greater boating traffic. Shoreline armoring increases wave energy in lakes and is often present on lakes with wake boats, thus it exacerbates the effects of wake boats on aquatic resources. These effects are further compounded by the reductions in aquatic vegetation (Radomski and Goeman 2001) and large woody habitat that historically occurred throughout Michigan's inland lakes (Wehrly et al. 2012). Aquatic plants and large woody habitat reduce wave energy in the nearshore zone, so their removal creates circumstances for increased wave erosion and reflection.

CURRENT BOATING LAW

Existing boating law in Michigan states, “A person shall not operate a vessel on the waters of this state at a speed greater than slow–no wake or the minimum speed necessary for the vessel to maintain forward movement when within 100 feet of the shoreline where the water depth is less than 3 feet, as determined by vertical measurement, except in navigable channels not otherwise posted (NREPA 1994b).” Furthermore, reckless operation that disregards the safety or rights of others or endangers the property of others is illegal; causing damage with a vessel’s wake is a specific example of recklessness identified in the most recent Handbook of Michigan Boating Laws and Responsibilities (MDNR 2021). These laws are intended to both promote public safety and avoid property damage but were created prior to the commercialization and popularization of wake boats in Michigan in the early 2000s. As a result of the effects of wake boats outlined above, the Division concludes that the current 100-foot buffer is not sufficient to protect public trust aquatic resources.

POTENTIAL SOLUTIONS

The negative effects of a wake boat decline as the boat travels farther away from the shoreline. Increasing the minimum distance that boats are allowed to operate at greater-than-no-wake speed near docks and shoreline would allow more time for wave energy to dissipate and increase protection of nearshore areas. For example, operating distances from certain structures, boats, and/or people has increased to 200 feet in South Carolina (South Carolina Public Act 124 of 2022) and Tennessee (Public Chapter No. 872, SB 2107). Similar legislation has been proposed in other states. However, if increased wake-boat buffer distance requirements are considered for smaller lakes, there may be less space for wake boats to operate above no-wake speed. This situation can be compounded if the lake has large shoals or shallow water areas less than 3 feet deep that would further restrict boat use. Therefore, a minimum lake size could be considered for wake boats. For example, Indiana law restricts operation of a boat at a speed greater than 10 mph on a lake less than 300 surface acres in size (Harwood 2017), Tennessee law does not permit wake-surfing or wake-boarding on lakes less than 50 acres or on lakes or areas with widths less than 400 feet, Oregon law (Chapter 119 of 2022, SB 1589) prohibits wake-surfing and restricts boats’ operating weights on certain parts of the Willamette River, and the Cook County Commissioners banned wake boating on 728-acre Caribou Lake in Minnesota. The Vermont Department of Environment Conservation is currently considering a draft rule that would limit wake boats to lakes with at least 50 contiguous surface acres that are 500 feet from the shore and 20 feet deep, and wake boating would only be allowed to occur in parts of those lakes that meet these distance and depth requirements. Most relevant studies (Mercier-Blais and Prairie 2014; Ray 2020; Water Environment Consultants 2021; Marr et al. 2022) show that an operating distance of at least 500 feet is necessary to reduce concerns to shoreline disturbance, with some providing evidence for operating distances near 1,000 feet (Mercier-Blais and Prairie 2014; Ray 2020; Water Environment Consultants 2021) and others providing evidence for distances of at least 400 feet (Macfarlane et al. 2018). Our assessment of the available studies at this time is that at least a 500-foot buffer is necessary to protect aquatic natural resources.

Shallow water increases the likelihood that turbulence from wake boat propellers can scour the bottom, disrupt aquatic plants, and resuspend sediment; accordingly, a minimum water depth for wake boat operation would provide additional protection of aquatic resources (Keller 2017). Based on the field data for wake boats (Raymond and Galvez 2015), the Division recommends that wake boats operating in wake-surfing or wake-boarding mode do so in water that is at least 15 feet deep.

Ecozones, which protect significant ecological areas within lakes where the use of watercraft may be limited or prohibited for fish, wildlife, botanical resource management or the protection of users, could also be implemented to mitigate wake boat damage. The State of Indiana began using “ecozones” to protect aquatic habitat in 2000 (Harwood 2017; Asplund 2000), but current law in Michigan does not have a mechanism for an ecozone approach.

Education and awareness campaigns are an important component of a comprehensive approach to protecting inland lakes from damage caused by wake boats. Providing operational recommendations into educational materials on responsible wake boat operation in boating safety classes, and providing informational flyers with these recommendations to new wake boat owners may improve awareness and implementation of best operation practices. Similar education campaigns have been implemented elsewhere; for example, the State of Oregon requires boaters to complete an educational program to wake board and wake surf on certain sections of the Willamette River.

CONCLUSION

Wake boats provide a means of outdoor recreation, but the waves and propeller turbulence they generate can cause increased damage to aquatic environments through a number of mechanisms. The cumulative effects of these damages are expected to lead to loss of habitat and resulting declines in aquatic ecosystems and angling opportunities. The recommendations below are intended to provide best operating practices under which the recreational opportunities that wake boats provide can be enjoyed in a manner that minimizes harm to the natural resources and property of Michigan citizens:

1. Boats operating in wake-surfing mode or wake-boarding mode, during which boat speed, wave shapers, and/or ballast are used to increase wave height, are recommended to operate at least 500 feet from docks or the shoreline, regardless of water depth.
2. Boats operating in wake-surfing or wake-boarding modes are recommended to operate in water at least 15 feet deep.
3. Ballast tanks should always be drained prior to transporting the watercraft over land.

It is recommended that awareness and voluntary adoption of these best operating practices be encouraged through outreach actions and materials to educate wake boat operators.

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