Big Shag Lake
(Marquette County, T45N/R26W/Sec. 25 & 26)
(West Branch Escanaba River, Last Surveyed 2019)

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Environment

Location

Big Shag Lake is a 188-acre natural lake located in Forsythe Township in southcentral Marquette County (T45N/R26W/Sec. 25, and 26) in Michigan's Upper Peninsula (Figure 1). The city of Marquette is located approximately 28 miles north and is the largest city in the Upper Peninsula. Gwinn is an unincorporated community located just 3.8 miles northeast of Big Shag Lake and is a popular destination for citizens interested in fishing, hunting and many other recreational outdoor activities.

Geology and geography

The geological bedrock formations encompassing Big Shag Lake are unique given the position within a moraine separated by two rock types. The rock types are igneous and sedimentary, formed during the Precambrian and Paleozoic periods, respectively. The northwest region of the Big Shag Lake landscape is dominated by Archean Granite, Gneissic, Michigamme, and Bijiki Iron formations and are typical of Precambrian igneous bedrock types (MDNR 2001). The southeast region is dominated by Munising and Trempealeau formations and are more typical of Paleozoic sedimentary bedrock types (MDNR 2001). Geological formations within this region attracted the mining industry more than a century ago and provided mining opportunities for those inhabiting the Gwinn and nearby New Swanzy communities.

Surrounding surficial geology of Big Shag Lake consists mostly (77.3%) of medium textured materials with Karlin Sandy Loam, Carbondale & Tawas, and Greenwood & Dawson soils (USDA 2017). The adjacent land cover is dominated by forest (77.4%), wetlands (8.9%), and urban development (6.9%). The immediate shoreline of Big Shag Lake is rocky with steep drop-offs comprised of pebble, cobble, and boulder sized rocks. A series of rocky points exist around the lake projecting seaward below the ordinary high-water mark. Given the steep slope of the landscape and narrow southwest to northeast axis of the lake, substrate materials that support the points are vulnerable to wake-induced shoreline erosion.

Watershed description

Big Shag Lake, Mitchell Bay, Little Shag Lake, Miller Lake, and Hay Wire Lake are all adjacent to one another and represent a complex of waterbodies located within the upper reaches of the Escanaba River watershed. Although Big Shag Lake is disconnected without inlets or outlets, surrounding wetland areas drain to Miller Creek which flows southwesterly to Chandlers Brook. Chandlers Brook serves as a tributary to the West Branch of the Escanaba River. The West Branch of the Escanaba River flows easterly for approximately 6.7 miles where it meets the confluence of the Main Branch of the Escanaba River. The Main Branch of the Escanaba River flows southeasterly through Delta County where it empties in to Little Bay de Noc, a Green Bay estuary area located along Lake Michigan's northern shore.

Chemical and physical characteristics
On 14 August 2019, a limnological survey was conducted in Big Shag Lake, at the deepest point in the lake, to measure dissolved oxygen (mg/L), water transparency (Secchi depth) as well as temperature (°F), pH, and conductivity (mS/cm). pH ranged from 7.9 at the water surface to 6.1 near the bottom of the lake. Conductivity ranged from 91.8 mS/cm at the water surface to 219.0 mS/cm near the bottom of the lake.

Dissolved oxygen or "DO" is a critical component to aquatic habitat in aquatic ecosystems. In lakes, DO may be derived from the atmosphere as well as from aquatic plants as a byproduct of photosynthesis. Levels of DO can limit the distribution and growth of fish in lakes as well as the size composition and biomass of zooplankton. Concentrations of DO begin to limit cool- and warmwater fish populations below 3.0 mg/L and are often lethal below 0.5 mg/L (Wehrly et al. 2015). As DO becomes limited, two regions of a lake that are characterized by low levels of DO can occur. The hypoxic region, which is characterized by having low levels (e.g., less than 4.0 mg/L) of DO and the anoxic region which contains no DO. On 31 March 2019, DO in Big Shag Lake ranged from 12.9 mg/L at 3 feet deep to 0.29 mg/L at 29 feet deep (Figure 2). During the winter, Big Shag Lake becomes hypoxic between 6 and 9 feet of water and is anoxic (no oxygen) below 19 feet of water. These data suggest that approximately 20 percent of the surface acreage of Big Shag Lake contains depths with sufficient oxygen to support aquatic life during the winter months. On 14 August 2019, DO in Big Shag Lake ranged from 8.5 mg/L at the surface to 0.0 mg/L at 29 feet deep (Figure 2). In the summer, Big Shag Lake becomes hypoxic between 12 and 15 feet of water and is anoxic below 16 feet of water. These data suggest that approximately 48 percent of the surface acreage of Big Shag Lake contains depths with sufficient oxygen to support aquatic life during the summer months.

Water transparency, measured using a Secchi disk, provides an index of phytoplankton production and overall lake productivity. For example, lakes with greater transparency are often classified as Oligotrophic, meaning there are low levels of lake productivity (e.g., lower standing crop biomass). On 14 August 2019, water transparency was reported to be 14.0 feet deep, which more transparent (less productive) than similar sized waterbodies in the region (11.5 feet) and across the state of Michigan (11.5 feet) (Wehrly et al. 2015). These data suggest that Big Shag Lake is less productive and may have less fish biomass per acre compared to similar sized waterbodies in Michigan.

Thermal stratification occurs in deeper lakes during the summer months and is characterized by three water layers. The uppermost layer (epilimnion) is typically warmer and has adequate levels of sunlight to support photosynthesis. The middle layer (metalimnion) is the region where a more significant change in water temperature occurs. The point at which temperature change or drop is the greatest in this middle layer is called the `thermocline'. The bottom layer (hypolimnion) lies directly below the thermocline and typically contains less dissolved oxygen compared to other layers. On 31 March 2019, Big Shag Lake water temperature ranged from 36.9 °F near the surface to 42.3 °F at 29 feet deep (Figure 2). On 14 August 2019 Big Shag Lake water temperature ranged from 72.6 °F near the water surface to 49.0 °F at 29 feet deep (Figure 2). Summer temperature data suggests that Big Shag Lake thermally stratifies, and that the thermocline is located at 16 feet depth.

Big Shag Lake is positioned on a southwest to northeast axis and contains a series of rocky points. The total fetch length from the southwest to the northeast shore is approximately 1.0 mile long and has an

estimated average depth of approximately 19 feet. The average width of Big Shag Lake is approximately 985 feet and ranges from 748 to 2,646 feet. Based upon lake fetch length and average depth, the northeast shore of Big Shag Lake has the potential to receive 12-inch waves (moderate energy) during a 35 mile per hour windstorm (WI DNR 2021). Given the wind protected nature of the northern and southern shores, those areas would only experience 5-inch waves (low energy) in a 35 mile per hour windstorm (WI DNR 2021).

Shoreline erosion caused by natural wind events is unlikely and hard armoring in this waterbody is not justifiable in most instances. However, the use of recreational vessels that enhance nearshore wave energy have the potential to unnaturally damage nearshore aquatic resources. According to Mercier-Blais and Prairie (2014), wake boat wave energy can dissipate having no significant effect on the shoreline provided the watercraft is operating more than 984 feet (or 300 meters) from shore. Considering both sides of the watercraft, this would suggest that operating a wake boat on a water body with an average width less than 1,968 feet wide (984 feet * 2) would likely result in significant impact to shoreline aquatic resources. Therefore, operation of a wake boat vessel on a waterbody similar to Big Shag Lake is an example of `unreasonable use'. Finally, based upon the natural moderate to low energy potential in Big Shag Lake, hard armoring materials (e.g., steel, limestone, vinyl, rip rap) should not be used to modify the shoreline.

Development, public ownership, and access

On 14 August 2019, the Big Shag Lake littoral zone and lakeshore were visually surveyed to quantify physical habitat parameters including residential development (dwellings per mile), boat dock density (docks per mile), large woody debris (submerged logs per mile) and the average percent shoreline armored (Table 1). Results of this physical habitat survey show that residential development in Big Shag Lake is high compared to similar sized waterbodies in the region and across the state of Michigan. The Big Shag Lake shoreline is sparsely populated with large woody debris with a density of 100 logs per shoreline mile. A large majority of the Big Shag Lake shoreline is held in private ownership, however there is a Michigan Department of Natural Resources (MI DNR) public boat launch located (GPS 46.270418 -87.499507) on the northeast end of the lake (Figure 1).

History

During the early 20th Century, John Nicholas Lowe was a fisheries biologist who taught at the Northern State Teachers College (now Northern Michigan University). J. N. Lowe had assembled fish collections from several waterbodies in Michigan's Upper Peninsula to document fish communities in lakes where information had not previously existed. Big Shag Lake was surveyed by J. N. Lowe on 14 September 1924 and on 5 June 1926. A total of seven species were captured including Yellow Perch, Common White Sucker, Blacknose Shiner, Northern Redbelly Dace, Mimic Shiner, Iowa Darter, and Golden Shiner. At this time, J. N. Lowe noted that Big Shag Lake was a "shallow lake, good for bass".

During the 1930s and 1940s, fisheries management essentially began in Big Shag Lake. The lake was first mapped by the Michigan Department of Conservation (hereinafter referred to as "MI DNR") in 1936 and 1937. From 1933 to 1943 Bluegill, Largemouth Bass, Walleye, Smallmouth Bass, and Yellow Perch were all stocked in Big Shag Lake (Table 2). Stocking Bluegill, bass, and Yellow Perch and other warmwater species was common during this period in Michigan. However, by the early 1940s stocking of warmwater species had already been largely reduced given their unique ability to reproduce naturally beyond state hatchery capabilities (Cooper 1948). By 1946, the Michigan Fish

Commission had a policy to curtail stocking of warmwater species given the "incontestable evidence that the average planting of these-warmwater species has involved an insignificant number of fish as compared to the number already present" (Cooper 1948, pp 8). By 1937, there were approximately 18 camps that existed on Big Shag Lake. In the next two decades, additional residential development would occur along the shore of Big Shag Lake prompting increased angling pressure and more in-depth fisheries management efforts.

During the 1950s and 1960s, agency staff sought to learn more about the Big Shag Lake fish community by conducting fisheries surveys. At the same time, petitions were signed by anglers and requests were issued to the MI DNR to stock trout in Big Shag Lake. Due to the lack of deep habitat in Big Shag Lake, no immediate action was taken with respect to trout stocking. During the late 1950s, the MI DNR used the following criteria to justify stocking trout: 1) a lake intended to be stocked with trout needed to have an area or layer of water suitable for trout which was being used little or not at all by other desirable species, and 2) the lake had to have suitable conditions for trout that currently was not providing a satisfactory fishery because no suitable species were present, or the populations were stunted. In the former, trout were planted to make up for unused strata without any other action. In the latter instance, the undesirable populations were removed using fish toxicants and trout stocking followed. Increased interest in stocking Big Shag Lake with various species was likely a result of increased shoreline development that occurred along the lake. By 1957, the number of cottages on the lake increased nearly 6-fold with a total of 106 cottages along the shoreline (compared to 18 just two decades prior).

In July of 1957, a fish community survey was conducted by the MI DNR Institute of Fisheries Research and included measurements of water transparency, temperature, and dissolved oxygen. Secchi disk depth, used to measure water transparency, was reported to be 9.0 feet. Water temperature in Big Shag Lake ranged from 71.7°F at the surface to 66.0°F at 23 feet deep. The temperature profile collected suggested that Big Shag Lake did not thermally stratify and therefore would only produce, at best, a `marginal' fishery for trout. Dissolved oxygen was measured at the water surface (9.7 mg/L) and at 22 feet deep (5.4 mg/L). The dissolved oxygen profile suggested that sufficient oxygen existed to support aquatic organisms from the surface to 22 feet deep. The netting survey captured Bluegill, Pumpkinseed, Yellow Perch, Walleye, and Common White Sucker. Yellow Perch and Common White Sucker dominated the catch by number.

The general fishing reputation in the late 1950s was that Big Shag Lake was good for Yellow Perch and fair for Smallmouth Bass. Agency staff noted that spawning habitat available at that time was good for Yellow Perch, Smallmouth Bass, and other sunfishes, and fair for Walleye. As the MI DNR gained additional information about Big Shag Lake, no fish stocking occurred in Big Shag Lake during the 1950s or 1960s. Favorable fishing reports accompanied additional requests for stocking during the late 1950s and early 1960s. For example, in 1960, a letter was sent to the MI DNR from an area resort owner requesting that Big Shag Lake be stocked. The resort owner was concerned that the 1957 survey may have reduced the fish population, and fishing was `not what it used to be'.
In April of 1963, a winter/spring fish kill was reported in Mitchell Bay of Big Shag Lake. Agency staff noted specimens of Largemouth Bass, Walleye, Bluegill, Yellow Perch, minnows, and adult frogs dead on the lake bottom with many seagulls feeding. The fish kill was noted to have occurred as the channel between Mitchell Bay and Big Shag Lake became blocked by ice. The decomposition of

aquatic vegetation, which is abundant in Mitchell Bay, further depleted oxygen and resulted in the fish kill. Additionally, agency staff noted that the 1962 to 1963 winter had been `unusually severe' (cold).

In the Summer of 1968, a stocking petition was again submitted to the MI DNR in request for stocking Walleye. Managers at the time had documented an abundant population of stunted Yellow Perch and were hesitant to stock younger Walleye due to the lack of resources that already were hindering growth of Yellow Perch. Also, at that time there was not access to larger (e.g., fall fingerling) Walleye for stocking, so no fish were stocked until the early 1970s.

In the 1970s, fisheries management of Big Shag Lake was diverse and focused on surveys, habitat improvement, species introductions, maintenance stocking, and manual removals. During the early 1970s, managers were concerned that the level of development that had occurred around Big Shag Lake had negatively impacted shoreline habitat. Common practices among lake riparians included "beach cleanup" as logs, sticks, rocks, etc., were removed from the lake shoreline for easier access and aesthetics. As a result, in 1973 the MI DNR conducted a physical habitat assessment of the Big Shag Lake shoreline to quantify available fish habitat and develop a habitat rehabilitation strategy. Agency staff noted that fish habitat was more common in areas adjacent to undeveloped areas of the lake. The installation of brush shelters was recommended to be placed along the 2- to 5-foot depth contour to improve habitat for bass and panfish. These structures were installed in Big Shag Lake soon after the habitat evaluation. Rocky habitat was found in the south arm of the lake and was noted to be sufficient to support natural reproduction of Walleye. Marginal spawning habitat was noted to exist for Northern Pike in areas where high water had flooded vegetation (Note: at this time Northern Pike had not been previously captured in Big Shag Lake). Additional notes from this 1973 habitat survey stated that Tiger Muskellunge would be an `attractive addition' to the Big Shag Lake fishery for anglers seeking trophy fishing opportunities. Tiger Muskellunge were also expected to prey upon an overabundant, undersized Yellow Perch population, resulting in an improved size structure for that species.

To accompany the recent habitat assessment, MI DNR also conducted a fish community survey of Big Shag Lake in August of 1973. A total of six species were captured including Bluegill, Common White Sucker, Pumpkinseed, Smallmouth Bass, Yellow Perch, and Walleye. Yellow Perch were noted to be abundant and undersize. Only a few Walleye were represented in the catch and those captured were noted to be old. The older Walleye captured suggested that natural reproduction had not occurred recently (all fish greater than 20 inches). Walleye gonads, liver, and kidneys were noted to be diseased which may have explained the lack of natural reproduction. Fishing reports at the time of this survey indicated that Smallmouth Bass fishing was `fair to good'.

In June of 1973 managers of Big Shag Lake responded to an additional public request from a house representative for stocking Walleye. Prior to this, the last time Walleye were stocked was in 1942 (420,000 spring fry). Managers noted that natural reproduction had taken place and maintained the Walleye population in Big Shag Lake for some time. However, more recent declines in the Walleye fishery had occurred due to competition and predation, as well as the gradual loss of shoreline habitat that resulted from `beach cleanup' and development by cottage owners. In 1974 and 1975, 800,000 spring fry and 3,160 fall fingerling Walleye were stocked in Big Shag Lake, respectively.

Following stocking in 1974 and 1975, the MI DNR conducted a netting survey in May of 1978 to evaluate survival and growth of stocked Walleye as well as to provide additional information on the

Big Shag Lake fish community. Fishing reports for Big Shag Lake collected just prior to the 1978 survey found that fishing for sunfish was reported as `good', fishing was `fair for Smallmouth Bass', Walleye fishing was noted as `poor', and Yellow Perch were all `too small'.

The spring 1978 netting survey captured a total of nine species including Bluegill, Hybrid Sunfish, Common White Sucker, Northern Pike, Pumpkinseed, Smallmouth Bass, Longnose Sucker, Yellow Perch and Walleye. Only three Walleye were captured, and all were greater than 25 inches suggesting limited to no survival of Walleye stocked in 1974 and 1975. Suckers were noted to be large and abundant, and panfish were common in the south end of the lake and included fish of attractable size. Yellow Perch were noted as being `extremely abundant' and undersized. Lastly, one Northern Pike was captured representing the first record of this species being captured in Big Shag Lake. In August of 1978 managers surveyed Big Shag Lake to gather limnological information including water transparency, temperature, and dissolved oxygen. Secchi disk depth was reported to be 10.5 feet. Water temperature in Big Shag Lake ranged from 72.0°F at the surface to 68.0°F at 22 feet deep. Similar to the oxygen profile gathered in 1957, Big Shag Lake did not show signs of thermal stratification. Dissolved oxygen ranged from 8.6 mg/L at the surface and 7.9 mg/L at 22 feet deep. The dissolved oxygen profile suggested that sufficient oxygen existed to support aquatic organisms from the surface to 22 feet deep.

In late May of 1978, a public meeting would be held with MI DNR biologists and interested riparians. The purpose of the meeting was to share results from the Walleye evaluation survey. Additionally, managers were interested in obtaining public comments so the future of Big Shag Lake fisheries management could be developed. The meeting was held 31 May, and approximately 33 people attended and included residents from both Little Shag Lake and Big Shag Lake. Managers at this public meeting discussed the results of stocking 800,000 Walleye spring-fry in 1974 and 3,160 fall fingerlings in 1975. Based on a survey conducted in the spring of 1978, stocking was unsuccessful given that only 3 Walleye were captured. Failure of stocking spring fry and fall fingerling Walleye prompted managers to develop a plan to utilize Mitchell Bay for rearing. A 5-step plan was developed: 1) place a barrier between Big Shag Lake and Mitchell Bay in the fall, 2) remove all desirable fish from Mitchell Bay and release them in Big Shag Lake, 3) chemically treat Mitchell Bay to remove all suckers and any remaining predators, 4) stock and routinely feed Walleye until the following spring, and 5) remove the barrier the following June to allow Walleye to swim freely into Big Shag Lake.

There are no records to indicate Mitchell Bay was ever used for rearing Walleye. However, another 25,000 spring fingerling Walleye were stocked in Big Shag Lake in 1979. In addition to stocking Walleye, MI DNR introduced Tiger Muskellunge in 1978 by stocking 550 fall fingerlings. By the late 1970s and early 1980s, there were reports of large numbers of big Yellow Perch being caught in Big Shag Lake in addition to a few large, older Walleye. Surveys conducted during this timeframe showed an aging Walleye population with limited to no return on investment from stocking 800,000 spring fry, 25,000 spring fingerlings, and 16,160 fall fingerlings.

In early 1979 MI DNR drafted and shared the "Big Shag Lake Management Plan" with Big Shag Lake residents and anglers. As part of the management recommendations, a manual removal survey was conducted by MI DNR in May of 1979 to reduce the biomass of Common White Sucker and Yellow Perch. During this period, managers hypothesized that an overabundant population of Yellow Perch and Common White Sucker were negatively impacting reproduction and stocking efforts for gamefish

(namely, Walleye). Therefore, a total of 38 pounds per acre of Common White Sucker and 11 pounds per acre of Yellow Perch were removed from Big Shag Lake. Managers also recommended the treatment of the Big Shag Lake shoreline using Antimycin (a fish toxicant) to reduce the nearshore abundance of undersized Yellow Perch. However, there is no record that a treatment ever occurred.

During the 1980s fall fingerling Tiger Muskellunge were stocked every other year. Despite the failed stocking attempts in the 1970s, Walleye were stocked every other year as well with the hope that manual removal of Common White Sucker and Yellow Perch in 1979 would improve Walleye survival. In 1980, anglers reported that Yellow Perch fishing was `superb' during the winter of 1979 to 1980. Male Yellow Perch averaged approximately 8.0 inches and females ranged from 9.0 to 10.5 inches. That winter, ice shanties populated the southern end of the lake, near Mitchell Bay, as well as the northern end of the lake near the public access site.

Big Shag Lake was surveyed by MI DNR in June of 1981 to evaluate stocking of Walleye and the recent introduction of Tiger Muskellunge as well as evaluate the impacts of a recent manual removal assessment. Both small mesh fyke nets and experimental gill nets were used and a total of nine species were captured including Bluegill, Pumpkinseed, Bluntnose Minnow, Smallmouth Bass, Largemouth Bass, Common White Sucker, Yellow Perch, Tiger Muskellunge, and Walleye. All species captured were growing below state average, except for Walleye, which were growing approximately an inch above state average. A total of nine Walleye were captured including 3, age-two fish and 6, age-three fish. Common White Sucker were noted to be reduced in number and managers noted a `tremendous number' of juvenile Yellow Perch. A Common Loon was also observed on Big Shag Lake during the 1981 survey.

In September of 1982, Big Shag Lake was surveyed again by MI DNR to evaluate the Yellow Perch population following the manual removal that had occurred in 1979. Gear used during this survey included trap nets, gill nets, and a large seine. A total of 8 species were captured including Tiger Muskellunge, Walleye, Smallmouth Bass, Pumpkinseed, Bluegill, Bluntnose Minnow, Yellow Perch and Common White Sucker. The gear type used, and the timing of surveys made the evaluations of the manual removal difficult. That said, managers noted a reduced number of Yellow Perch captured and a larger average size. In 1983, a letter was sent by an angler who sought to compliment MI DNR on the good work being done with Muskellunge in Marquette County. The angler noted that they fished Big Shag Lake in June of 1983 and `really enjoyed the Muskie action".

In June of 1984, Big Shag Lake was surveyed by MI DNR to evaluate Walleye stocking that had occurred biennially since the late 1970s. A series of monofilament gill nets and experimental gill nets were set to capture and quantify the survival of stocked Walleye. The use of various mesh-size gill net was meant to improve the capture probability of Walleye. However, despite intense sampling, very few Walleye were captured. At this time Tiger Muskellunge stocking was considered successful as several stocked-year-classes were captured and growth seemed satisfactory. Managers noted that Tiger Muskellunge were being sought by anglers and appeared to be of high sporting value.

In June of 1989, a general survey was conducted on Big Shag Lake to gather information about the fish community as well as evaluate the Walleye and Tiger Muskellunge stocking efforts. Fyke nets and gill nets were used and a total of 7 species were captured including Yellow Perch, Pumpkinseed, Bluegill, Largemouth Bass, Walleye, Common White Sucker, and Tiger Muskellunge. A total of 8 Walleye and

1 Tiger Muskellunge were captured during that survey and managers noted that fishing pressure was making it difficult to manage for predator species in Big Shag Lake.

During the early 1990s, the Big Shag Lake Association had developed a collaborative relationship with MI DNR. An association meeting was held, and fisheries information was shared by MI DNR with residents of Big Shag Lake. The association provided positive feedback with respect to the information shared and volunteered to provide MI DNR with scale samples from Walleye, bass, and Tiger Muskellunge to help management efforts. During the mid-1990s, MI DNR staff began attending annual meetings held by the Big Shag Lake Association. Information gathered during fisheries surveys was provided to the association and often inserted as appendices in their annual newsletters.

In 1992 the Big Shag Lake Association contacted MI DNR to request information gathered from previous surveys. Additionally, the association inquired as to whether Mitchell Bay would be blocked off for fish rearing as proposed during the 1970s, or if this was a `dead issue'. According to an MI DNR response, Mitchell Bay was not blocked off for fish rearing because recent advances in fish rearing capacity made more fish available. For example, Walleye were able to be produced in rearing ponds providing an efficient and economically productive alternative. Also, blocking off Mitchell Bay would be problematic for boaters potentially causing conflict. In response to the 1992 letter, managers also stated that Big Shag Lake might benefit from additional manual removal surveys in the future to help improve the size structure of some panfish. MI DNR requested that the Big Shag Lake Association provide volunteers to assist with the removal effort. The Big Shag Lake Association, through additional correspondence with MI DNR, approved of the intent to conduct a `sucker removal' survey.

In May of 1993, a general survey was conducted on Big Shag Lake in addition to a sucker removal. Only fyke nets were used in this survey and a total of 8 species were captured including Bluegill, Pumpkinseed, Yellow Perch, Smallmouth Bass, Walleye, Largemouth Bass, Common White Sucker, and Tiger Muskellunge. A total of 6.9 pounds per acre of Common White Sucker were removed from Big Shag Lake (compared to 38 pounds per acre removed in 1979). Panfish were noted to be common and of sufficient size to be attractive to anglers. Several year classes of Smallmouth Bass were captured, and many fish were within the 2-to-4-pound range. At this time, managers noted that Big Shag Lake attracted a diverse angler crowd including those seeking Tiger Muskellunge, Walleye, as well as panfish and bass angling opportunities. Managers recommended a continuation in stocking of Walleye and Tiger Muskellunge. Despite the recommendation to continue stocking, Tiger Muskellunge were last stocked in Big Shag Lake in 1990.

By the mid-1990s, the Big Shag Lake Association had reported that Green Sunfish were captured by anglers in Big Shag Lake (confirmed by MI DNR). The association report also stated that Northern Pike had become established in Big Shag Lake, although only one had been captured (in 1978) during previous MI DNR surveys. In 1998, Big Shag Lake was surveyed to evaluate the new statewide 14-inch minimum size limit for bass. Fyke nets were used and a total of 6 species were captured including Bluegill, Largemouth Bass, Northern Pike, Pumpkinseed, Yellow Perch, and Smallmouth Bass. Consistent with local association reports, several Northern Pike were captured in Big Shag Lake suggesting that the species had become established. At that time, agency staff mentioned that this was the first capture of Northern Pike in Big Shag Lake, however this was incorrect. Northern Pike were first captured in 1978 during a spring assessment, and acknowledgement of this capture was stated in

the 1979 management plan drafted by MI DNR staff. Agency staff and area residents are unaware as to how Northern Pike were introduced in Big Shag Lake.

The 1998 netting survey did not catch many bass. As a result, MI DNR conducted an additional electrofishing survey in May of 1998 and a total of 212 Largemouth Bass were captured averaging 10.0 inches. Largemouth Bass size ranged from 4.0 to 18.0 inches and 3 percent of fish captured were equal to or greater than 14.0 inches. Managers noted that Largemouth Bass were growing well below state average. By the late 1990s, area residents and anglers were concerned about the number of Northern Pike in the lake. In 2000, MI DNR noted that someone introduced Northern Pike into Big Shag Lake around 1994. However, as noted earlier, an additional review of local survey records indicated that Northern Pike were first captured in 1978. While Northern Pike had been in Big Shag Lake for several decades, numbers appeared to increase in surveys during the late 1990s and early 2000s. During this same period, Walleye evaluations determined that few if any stocked fish were surviving to a harvestable size.

In April of 2000, a survey was conducted by MI DNR to evaluate Walleye stocked during the late 1990s as well as provide general fish community information. A total of 7 species were captured including Walleye, Bluegill, Largemouth Bass, Northern Pike, Pumpkinseed, Common White Sucker, and Yellow Perch. A total of 14 Walleye were captured suggesting that survival of stocked fish was limited. As a result, Walleye were last stocked in Big Shag Lake in 1999. A total of 61 Northern Pike were captured ranging in size from 9.0 to 35.0 inches. The average size of Northern Pike was 17.4 inches and growth rates were noted as very poor (-4.8 inches below state average). During the early 2000s fisheries management in Big Shag Lake shifted to focus on providing a mixed bag fishery for Northern Pike, Largemouth Bass, Bluegill, Pumpkinseed and Yellow Perch.

In 2002, MI DNR presented fisheries information to the Big Shag Lake Association at an annual meeting. Topics discussed at this meeting included the discontinuation of Walleye stocking, riparian land use, zebra mussel monitoring, minnow habitat improvement, small fish sampling, and the future management of Big Shag Lake. The presentation was noted as being well received. Anglers mentioned that Northern Pike were being captured, but larger fish were not common. Large bass were reported to have been caught regularly and Bluegill were reported to be larger than they were in recent times. Lasty, one person expressed concern about the lack of suckers and Yellow Perch.

During late April and early May of 2007, a survey was conducted on Big Shag Lake to evaluate growth of Northern Pike as well as collect general information about the fish community. During the time that this survey was conducted, anglers reported that bass and panfish angling was `good'. A total of 10 species were captured including Northern Pike, Walleye, Smallmouth Bass, Largemouth Bass, Bluegill, Pumpkinseed, Yellow Perch, Common White Sucker, Bluntnose Minnow, and Golden Shiner. Age analysis indicated that Bluegill and Pumpkinseed were growing at or slightly below state average. Northern Pike were growing at approximately 5.2 inches below state average and the age at which the species reached a harvestable length (24 inches) was 9 years. After the 2007 survey, fisheries management in Big Shag Lake focused on three directives: 1) improve the size of Northern Pike with a no minimum size limit regulation, and 2) improve shoreline habitat within the littoral zone, 3) conduct a Status and Trends assessment within the next 7 to 10 years.

In April of 2009, a winter/spring fish kill was reported in Big Shag Lake. An area landowner noted that approximately 3,000 Bluegill had died and were decaying on the bottom of the lake within Mitchell Bay. The 2008 to 2009 winter was noted as severely cold, and anglers had reported that augers had `bottomed out' in the channel between Mitchell Bay and Big Shag Lake which suggests that the channel was completely frozen through. Similar to the winter/spring kill that occurred several decades prior (1963), fish likely were trapped in Mitchell Bay as the decomposition of plant material depleted oxygen to lethal levels.

In October of 2009, a fish community survey was conducted on Big Shag Lake to gather additional information about Largemouth Bass. Largemouth Bass were underrepresented in the 2007 survey so additional effort was targeted for bass while Northern Pike, Bluegill, and Yellow Perch were also sampled. At that time, Largemouth Bass were growing well below state average and it took approximately 8 years to reach legal size (14.0 inches).

During the 2010s a "no minimum size limit" regulation was put in place for Northern Pike in Big Shag Lake to improve the size structure of this species. The no minimum size limit regulation allowed five fish of any size to be harvested, with only one being greater than 24 inches allowed in the daily possession limit. Additionally, MI DNR Fisheries Division and Parks and Recreation Division worked to replace the boat ramp at Big Shag Lake as well as improve habitat near shore.

In June of 2018, a winter/spring fish kill was reported in Big Shag Lake. Several lake riparians, reported dead fish nearshore in the northeastern region of Big Shag Lake. Pictures shared with MI DNR depicted Yellow Perch and Bluegill washed ashore. Similar to the 1963 and 2009 fish kill events, these were likely a result of oxygen depletion during the winter months. MI DNR staff conducted a qualitative visual assessment and counted approximately 60 dead panfish nearshore. This was likely an underestimate of the total mortality given that the assessment occurred four days after the initial observation of dead fish. Aside from the dead fish observed, many live Bluegill were noted to be on spawning beds. Largemouth Bass were also observed swimming in deeper water adjacent to spawning beds. Mitchell Bay was surveyed as well, and no mortalities were observed there.

In August of 2018, MI DNR met with interested citizens about the Big Shag Lake fishery. A brief overview of Big Shag Lake past fisheries management strategies was shared with those in attendance and MI DNR expressed interest in conducting a more recent survey to guide future management of the fishery. A fish community survey was scheduled for 2019 following Status and Trends protocols (Wehrly et al. 2015). In addition to a fisheries survey, MI DNR staff coordinated with Northern Michigan University (NMU) faculty to assist in monitoring dissolved oxygen and temperature in waterbodies near Marquette, Michigan. Information gathered from temperature and dissolved oxygen profiles was intended to provide additional data relative to the recent increase in winter/spring fish kills that had occurred in several Upper Peninsula waterbodies.

Current Status

Beginning on 10 June 2019, MI DNR conducted a discretionary survey in accordance with Status and Trends survey protocols (Wehrly et al. 2015) to assess the Big Shag Lake fish community. A variety of gear types were used including 2 experimental gill nets, 4 large mesh fyke nets, 2 small mesh fyke nets and 1 seine. Experimental gill nets and small mesh fyke nets were set for two nights while large mesh fyke nets were set for three nights. Four seine hauls were completed in Big Shag Lake nearshore

areas. On 29 July 2019, three 10-minute boat electrofishing transects were sampled to provide additional fish community information. In March and August of 2019, limnological profiles were collected from the northeast basin of Big Shag Lake and included temperature and dissolved oxygen information. Limnological data from March of 2019 were collected by NMU faculty and students, and August limnological data were collected by MI DNR staff. The above surveys in addition to data collected by MI DNR during historical surveys and the Master Angler database are all referenced in the Analysis section.

Gamefish species including Bluegill, Largemouth Bass, Northern Pike, Pumpkinseed, and Yellow Perch were measured to the nearest tenth of an inch. Aging structures (10 per inch group) were collected from each gamefish species for age and growth analysis. Scales were collected from panfish species less than 6.0 inches and bass less than 10.0 inches. Anal fin spines were collected from panfish greater than 6.0 inches, bass greater than 10.0 inches, and all Northern Pike.

A total of 1,843 fish weighing 224.1 pounds and representing 8 species were captured during the 2019 survey (Table 3). Piscivores, such as Largemouth Bass and Northern Pike comprised 8 percent of the catch by number and 69 percent of the catch by biomass. Planktivores-insectivores such as sunfishes, minnows, and darters comprised 92 percent of the catch by number and 31 percent of the catch by biomass. There were no benthivores (i.e., Common White Sucker) captured during the survey. The total standing crop (Schneider 2000) for Big Shag Lake in 2019 was approximately 35 pounds per acre.

Bluegill - A total of 1,244 Bluegill were caught across all gear types. Bluegill averaged 3.0 inches and comprised 67.5 percent of the catch by number and 19.7 percent of the catch by biomass (Table 3). Bluegill size ranged from less than an inch to 8.0 inches with 7 percent of the catch meeting or exceeding the preferred size of 6.0 inches. The age distribution of Bluegill (Age 4 to 10) indicated annual recruitment from 7 year-classes (Table 4). Six- and seven-year-old Bluegill were each growing approximately two inches below state average (Table 4). An insufficient number of samples were collected to make robust conclusions about the growth of remaining age classes, however, among 7 year-classes, Bluegill were generally growing below state average. The length distribution of Bluegill (Table 5) indicated that recruitment of age classes younger than four-years-old does occur annually.

Large mesh fyke net catch per unit effort (CPUE) of preferred size Bluegill was 6.4 fish per net night during the 2019 survey. The average size of Bluegill captured in large mesh fyke nets was 5.3 inches and 41 percent of the catch exceeded the preferred size of 6.0 inches (Table 6). According to the Bluegill size score index (Schneider 1990), fish captured in large mesh fyke nets in 2019 were rated "acceptable" (Table 7). Boomshocking CPUE of preferred size Bluegill was 0.4 fish per minute. The average size of Bluegill captured Boomshocking was 3.5 inches and 9 percent of the catch exceeded the preferred size of 6.0 inches. The Bluegill size score index for fish captured Boomshocking in 2019 was considered "very poor" (Table 7).

Pumpkinseed - A total of 196 Pumpkinseed were caught across all gear types. Pumpkinseed averaged 7.7 inches and comprised 10.7 percent of the catch by biomass. Pumpkinseed size ranged from 2.0 to 8.0 inches with 31 percent of the catch meeting or exceeding the preferred size of 6.0 inches (Table 3). The age distribution of Pumpkinseed indicated annual recruitment from 7 year-classes (ages 3 to 10,

excluding 9). Four- and five-year-old Pumpkinseed were growing above state average, while age 6 Pumpkinseed were growing slightly below state average (Table 4).

Northern Pike - A total of 61 Northern Pike averaging 19.9 inches comprised 3.3 percent of the catch by number and 50.9 percent of the catch by biomass (Table 3). Northern Pike size ranged from 15.0 to 25.0 inches with 5 percent of the catch meeting or exceeding 24.0 inches. The age distribution of Northern Pike indicated annual recruitment from two- to seven-years-old. Age 3-, 4-, and 5-year-old Northern Pike were all growing below (-3.0 inches) state average. The age at which Northern Pike reach legal size is approximately 6 years-old or older.

Largemouth Bass - A total of 36 Largemouth Bass averaging 10.8 inches comprised 2.0 percent of the catch by number and 12.9 percent of the catch by biomass (Table 3). Largemouth Bass size ranged from 3.0 to 16.0 inches with 17 percent of the catch meeting or exceeding the minimum size for harvest (14.0 inches). The age distribution of Largemouth Bass indicated annual recruitment from three- to nine-years-old. Age four- and seven-year-old Largemouth bass were growing below state average (-3.0 inches). Age analysis indicated that Largemouth Bass reach legal size (14.0 inches) at approximately 8-years-old or older. The catch per unit effort of Largemouth Bass was 1.0 fish per minute and 1.2 fish net night for electrofishing and all netting gear combined, respectively.

Yellow Perch - A total of 43 Yellow Perch averaging 7.7 inches comprised 2.3 percent of the catch by number and 5.2 percent of the catch by biomass (Table 3). Yellow Perch size ranged from 2.0 to 11.0 inches with 70 percent of the catch meeting or exceeding the minimum preferred size for harvest (6.0 inches). The age distribution of Yellow Perch indicated annual recruitment from one- to eight-years-old and Yellow Perch were growing at or above the state average. The catch per unit effort of Yellow Perch was 0.26 fish per minute and 2.08 fish per net lift for electrofishing and large mesh fyke nets, respectively.

Forage fish captured during this survey included Bluntnose Minnow, Central Mudminnow, and Iowa Darter. Since 1924, a total of 18 fish species have been captured in Big Shag Lake (Table 8). Bluegill, Pumpkinseed, Common White Sucker, and Yellow Perch occur most often through the survey history (Table 8).

Analysis and Discussion

Big Shag Lake is a medium-sized shallow lake with a heavily developed shoreline that contains fish species typical of inland lakes in northern Michigan. Results from this survey suggest that follow-up assessments should be conducted to provide additional information relative to chemical, physical, and biological components of the Big Shag Lake fishery.

Chemical and biological parameters measured in 2019 surveys suggest biological oxygen demand in Big Shag Lake is high and may be limiting available in-lake habitat. These finding contrast historical measurements (e.g., 1957, 1978) that found sufficient DO throughout the water column. In 1957 and 1978, DO was measured in the center of the lake. In 2019, per Status and Trends protocols, dissolved oxygen was measured at the deepest point in the lake, located in the northeast basin. Differences in sampling location may explain observed differences in available oxygen in Big Shag Lake. Additional dissolved oxygen measurements should be collected both at the historical sampling site, in addition to

the deepest point in the lake. Results from measurement of physical habitat in Big Shag Lake also warrants additional attention.

Physical parameters measured (e.g., development) indicate that the Big Shag Lake shoreline has been impacted by development. The density of large woody debris in Big Shag Lake is less than half the observed density in the region (Table 1). Natural, undeveloped lakes throughout northern Michigan and Wisconsin have large woody debris densities ranging from 470 to 1,545 logs per mile of shoreline (O'Neal and Soulliere 2006). These data suggest that Big Shag Lake is heavily developed and that riparian landowners are likely to be negatively impacting the ecological integrity of Big Shag Lake by removing nearshore habitat. Protection and rehabilitation strategies that maintain or improve the abundance of woody debris nearshore are well developed (WI DNR 2014) and should be adopted in Big Shag Lake.

The number of species (or species richness) in Big Shag Lake is low compared to the northern region of the state (Wehrly et al. 2015). Surprisingly, there were no benthivores (e.g., suckers, bullheads) captured during this survey. Common White Sucker had been captured in all previous surveys conducted in Big Shag Lake since 1924. However, Common White Sucker were absent in the 2019 survey which is concerning given the variety of gear types used. Benthivores, or bottom dwelling species, play a role in defining a healthy inland lake ecosystem (Cook et al. 2005). Benthivores such as suckers serve as forage for a variety of piscivores including bass, Northern Pike, and Yellow Perch at varying life periods (e.g., larval, juvenile, adult). Common White Sucker are highly fecund and deposit eggs each spring that are consumed by Yellow Perch just prior to their own annual spawning cycle. Common White Sucker also serve as a host for glochidia of several Michigan mussel species currently listed as "Special Concern" including the Elktoe and Flutedshell species (INHS 2021, Mulcrone and Rathbun 2018). Lastly, suckers are utilized for food by bird and mammalian predators (Jackman et al. 1999). Given the low levels of dissolved oxygen measured, and the lack of benthivores captured during this survey, additional survey efforts are warranted to confirm the absence of benthivores.

Bluegill and Pumpkinseed- Growth metrics from captures using all gear types show an abundant and undersized population of panfish inhabiting Big Shag Lake. And although the Bluegill size score is rated as `poor to acceptable', there are large trophy sized fish routinely captured in Big Shag Lake. For example, a review of the last decade's Master Angler records indicates that Bluegill larger than 10 inches are captured and submitted nearly every other year. Additionally, three Master Angler sized Pumpkinseed (>9.0 inches) have been reported in the last 5 years. These capture records suggest that Big Shag Lake has the potential to grow large panfish, however angler pressure may limit the number of preferred size fish which is typical for well-developed waterbodies with access.

The recent fish kill that occurred in Big Shag Lake in 2018 was likely the result of natural processes but may also indicate enhanced eutrophication resulting from increased use of lawn fertilizers and spring runoff. Fish kills that occur because of natural processes can sometimes beneficially reduce over-populated, slow growing panfish and actually increase growth rates and improve fishing (MDNR 2021). If this were to occur in Big Shag Lake, anglers might expect an improvement in Bluegill size structure by 2022. Currently, Bluegill are growing approximately 2.0 inches below state average. If future surveys continue to show poor growth in Bluegill, alternative regulations that improve the

abundance of predators (namely, Largemouth Bass) may be considered to help reduce competition and improve body size of Bluegill.

Largemouth Bass and Smallmouth Bass - The electrofishing catch per unit effort for Largemouth Bass (1.0 fish per minute) in Big Shag Lake was low compared to other inland lakes in the region (1.32 fish per minute), but high compared to waterbodies across the state (0.72 fish per minute). Growth analysis suggests all age groups of Largemouth Bass are growing below state average and that it takes more than 8 years to reach 14.0 inches which is slow compared to the State of Michigan average (6 years). Abundance and growth data from Largemouth Bass captured in 2019 are very similar to those captured in 2009, suggesting that management actions may be necessary to improve the size structure of this highly sought-after gamefish. Prior to initiating any regulation changes, Largemouth Bass should be sampled for weight at length data. These data will help confirm that food resources are limited, resulting in stunting of the population. If resources are limited given the number of Largemouth Bass available, regulations that encourage increased harvest may be used to reduce the abundance of fish subsequently improving size structure.
No Smallmouth Bass were captured during the 2019 survey. The absence of Smallmouth Bass during this survey is concerning as these fish were routinely captured during the 1970s and 1980s and provided an attractive, albeit intermittent limited fishery.

Northern Pike - The catch per unit effort for Northern Pike from large mesh fyke (3.4 fish per net night) and gill nets (4.8 fish per net night) was high compared to waterbodies across the state (1.55 and 4.00 fish per net night, respectively). Growth analysis suggests that all groups of Northern Pike are growing below state average and it takes more than 6 years to reach the harvestable size of 24.0 inches which is slow compared to the State of Michigan average (4 to 5 years). While growth of Northern Pike is still below the state average, there are noticeable improvements compared to previous surveys. In 2007 and 2009, Northern Pike were growing more than 5 inches below the state average. Results from the 2019 survey show that Northern Pike are now growing 3 inches below state average, a 40% improvement. This improvement in growth of Northern Pike is likely the result of the current management regulation which permits 5 fish to be harvested of any size, with only one greater than 24.0 inches allowed in the daily possession limit. A continuation of this regulation that promotes harvest of undersized individuals should continue to improve the size structure of this population.

There have been conflicting reports about the time during which Northern Pike were introduced in Big Shag Lake. The exact year when Northern Pike were introduced into Big Shag Lake is unknown. There is also no known record of where these Northern Pike originated from. However, Northern Pike were first captured in survey gear in spring of 1978 based on historical survey records and a management plan drafted in 1979. Anglers reported catching Northern Pike during the early to mid-1990s and surveys conducted by MI DNR began capturing an increasing number of Northern Pike by the late 1990s. Regardless of their origin, Northern Pike are now an established gamefish in the Big Shag Lake fish community and should be managed accordingly.

Yellow Perch - The catch per unit effort for Yellow Perch from electrofishing (0.26 fish per minute) and large mesh fyke nets (2.08 fish per net night) was low compared to waterbodies across the state (2.53 and 4.00, respectively). However, of those captured many (70 percent) are equal to or greater than the preferred size for harvest (7 inches) making this an attractive fishery. The growth of Yellow Perch in Big Shag Lake suggests that fish reach the preferred size of harvest in four years. This is

comparable to the growth of Yellow Perch across the state which reach the preferred size for harvest in 3 to 4 years.

There have been periods in the Big Shag Lake history when Yellow Perch were overabundant and undersized. However, there is currently a reasonable fishery for Yellow Perch that provides good sized fish for those willing to devote the effort to capture them. It is possible that Northern Pike are foraging on young Yellow Perch given the absence of Common White Sucker. This increase in predation could be reducing the abundance of undersized individuals resulting in growth rates that are slightly above state average with a large proportion of fish greater than the preferred size for harvest.

Management Direction

The Big Shag Lake fish community provides an attractive `mixed-bag' fishery for Northern Pike, Largemouth Bass, Yellow Perch and two dominant panfish species (Bluegill and Pumpkinseed). Moving forward there are chemical, physical and biological strategies that may be adopted to further improve management of the Big Shag Lake fishery.

Chemical & Physical

1). Dissolved oxygen and temperature profiles should be collected at the deepest point in the northeast basin, as well as in the center of the lake where measurements were taken historically. These profiles should be collected in March and early August of the same year to verify the extent to which Big Shag Lake is hypoxic and or anoxic during more harsh seasons.

2). Interested riparians should consider volunteering with the Michigan Clean Water Corp (MiCorps; https://micorps.net) involvement to begin annually monitoring long-term water quality of Big Shag Lake. MiCorps is a network of volunteer water quality monitoring programs in Michigan created to collect and share water quality data to use for aquatic resources management and protection. Beneficial data collected by MiCorps volunteers include chlorophyll-a concentration, temperature, dissolved oxygen, secchi depth, and total phosphorus. These data may provide additional insight about low dissolved oxygen levels in the lake.

3). Managers are encouraged to collaborate with Big Shag Lake riparians to share information about the importance of preserving shoreline habitat and avoiding the use of `hard armoring' on lake shorelines.

4). Develop a comprehensive habitat improvement strategy, guided by dissolved oxygen and temperature profile data, that mimics habitat densities in undeveloped lakes.

5). Given the lake size and width, recreational vessels that unreasonably enhance wakes should be prohibited to preserve the integrity of the Big Shag Lake shoreline, especially rocky points. Riparians are encouraged to seek ordinances that prevent recreational activities, documented to negatively impact aquatic public trust resources, from continuing to occur.

Biological

1). Continue the "no minimum size, five-fish limit with no more than one Northern Pike greater than or equal to 24 inches" regulation to improve size structure in Big Shag Lake.

2). Evaluate the Northern Pike population using a species-specific survey to evaluate the effectiveness of the no minimum size regulation. Bycatch of Common White Sucker should be documented to confirm the presence or absence of this species.

3). Conduct a late spring or early fall electrofishing assessment to gather length and weight information from Largemouth Bass. These data will provide confirmation that bass abundance is high, and resources are limiting fish condition. Following confirmation of limited resources, harvest regulations may need to be adjusted to encourage increased harvest and improve growth rates of this population.

4). Additional stocking of Walleye is not recommended. Despite stocking at multiple life periods and removing Yellow Perch and Common White Sucker, a viable Walleye fishery has failed to develop. At present, Big Shag Lake is limited by a lack of habitat (low dissolved oxygen), a lack of forage, and competing gamefish are showing signs of increased competition. Stocking of additional predators would not be prudent.

References

Mercier-Blais, S., and Y. Prairie. 2014. Project Evaluation of the Impact of Waves Created by Wake Boats on the Shores of the Lakes Memphremagog and Lovering. University of Quebec at Montreal Department of Biological Sciences.

Cook, S. J., C. M. Bunt, S. J. Hamilton, C. A. Jennings, M. P. Pearson, M. S. Cooperman, and D. F. Markle. 2005. Threats, conservation strategies, and prognosis for suckers (Catostomidae) in North America: insights from regional case studies of a diverse family of non-game fishes. Biological Conservation 121: 317-331.

Cooper, G. P. 1948. Fish stocking policies in Michigan: Contribution from the Michigan Institute of Fisheries Research. Michigan Department of Conservation, Fisheries Research Report 1167, Ann Arbor.

INHS 2021. Illinois Natural History Survey: Freshwater Mussel Host Database - INHS Mollusk Collection (illinois.edu). Freshwater Mussel Host Database.

Jackman, R. E., W. G. Hunt, J. M. Jenkins, and P. J. Deitrich. 1999. Prey of nesting bald eagles in northern California. Journal of Raptor Research 33: 87-96.

MDNR (Michigan Department of Natural Resources). 2001. Bedrock Geology of Michigan. Land and Minerals Division.

MDNR (Michigan Department of Natural Resources). 2021. DNR - Information about Fish Kills (michigan.gov). Information about Fish Kills.

Mulcrone, R. S. and J. E. Rathbun. 2018. Pocket field guide to the freshwater mussels of Michigan. Michigan Department of Natural Resources, 78 pp.

O'Neal, R. P., and G. J. Soulliere. 2006. Conservation guidelines for Michigan lakes and associated natural resources. Michigan Department of Natural Resources, Fisheries Special Report 38, Ann Arbor.

Schneider, J. C. 2000. Interpreting fish population and community indices. Chapter 21 in Schneider, James C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates, Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

USDA (United States Geological Survey). 2019. Web Soil Survey: Web Soil Survey - Home (usda.gov).

Watters, G. T. 1994. An annotated bibliography of the reproduction and propagation of the unionoidae (primarily of North America). Ohio Biological Survey Miscellaneous Contributions, Number 1.

Wehrly, K. E., D. B. Hayes, and T. C. Wills. 2015 Status and trends of Michigan inland lake resources, 2002-2007. Michigan Department of Natural Resources Fisheries Report 08, Lansing.

WI DNR 2014. Fish Sticks: Improving lake habitat with woody structure (Best Practices Manual). Wisconsin Department of Natural Resources Management Bureau.

WI DNR 2021. Waterway and wetland permits: calculating energy along a shoreline | Wisconsin DNR.

Figure 1. Map of Shag Lake, Marquette County Michigan.

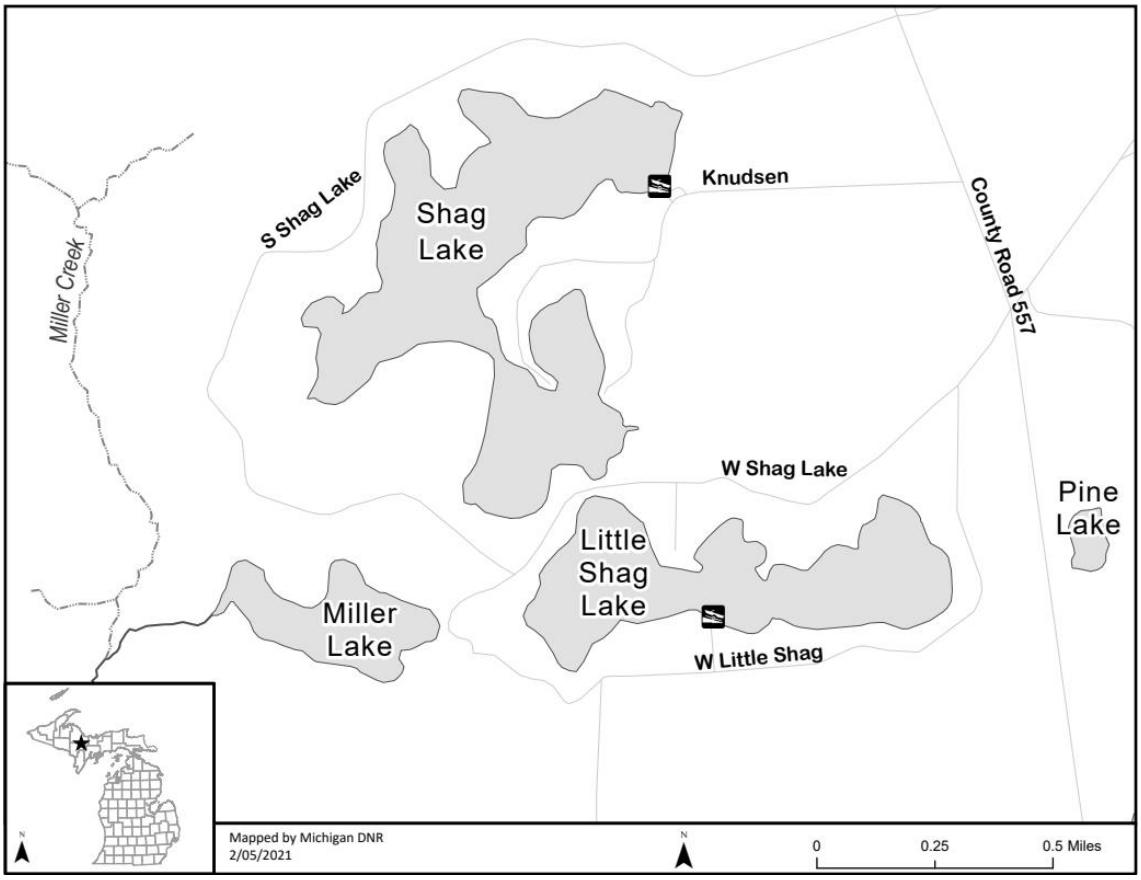

Figure 2. Temperature (°F) and dissolved oxygen (mg/L) of water in Big Shag Lake (Marquette County, Michigan) recorded 31 March 2019 (Left) and 14 August 2019 (Right). Data points depicted as circles represent temperature, while data points depicted as triangles represent dissolved oxygen.

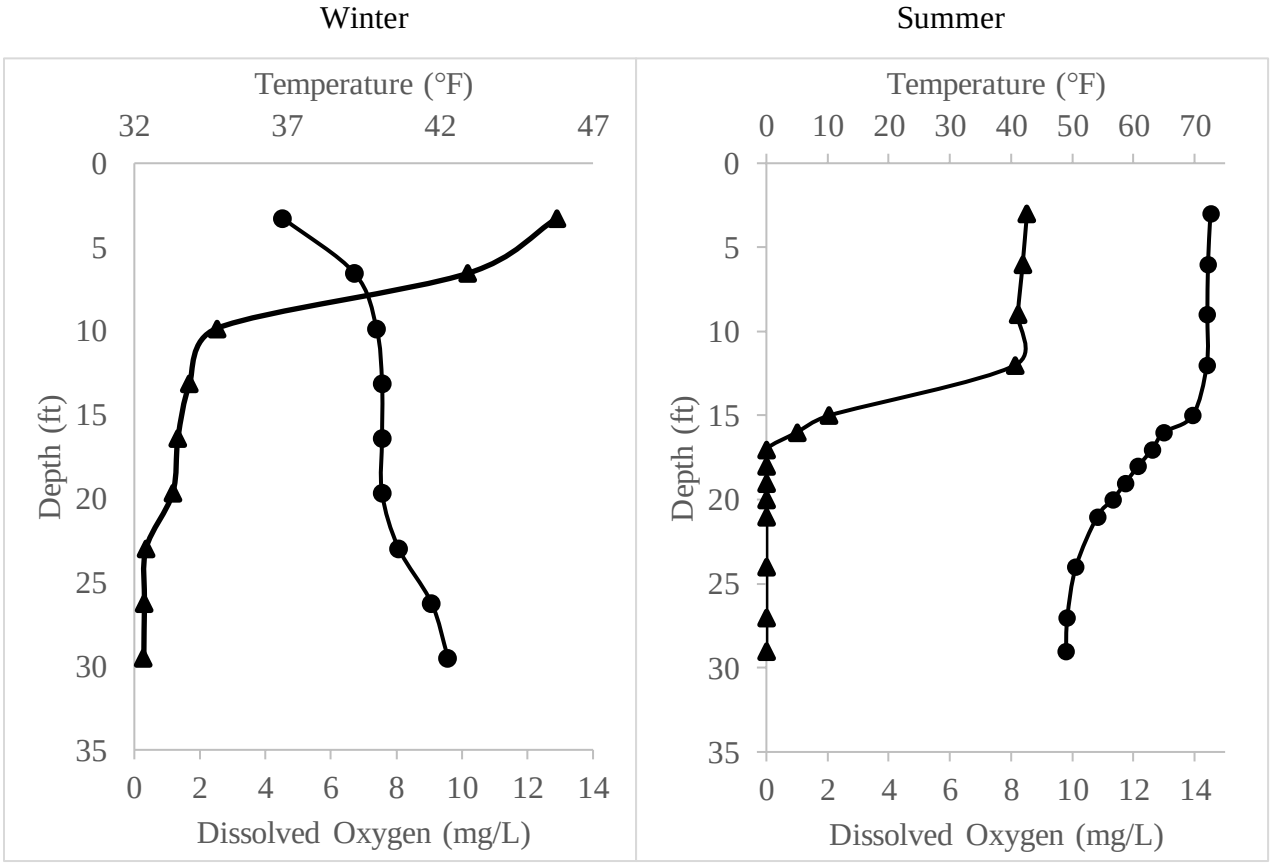

Table 1. Physical indicators including dwelling density (per mile), boat docks (per mile), shoreline armoring (average % armored), and large woody debris (per mile) measured in Big Shag Lake, and the regional average (Northern Lake Michigan Management Unit).

Physical Indicator	Big Shag Lake	Region
Dwelling Density	29.0	15.1
Boat Docks	29.2	11.3
Shoreline Armoring	17.5	16.9
Large Woody Debris	100.0	223.2

Table 2. Historical stocking record for Big Shag Lake (Marquette County) by species, year, number (N) stocked, number (N) per acre, and age/size (in.) at stocking.

Species	Year	N Stocked	N / Acre	Age/size (in.) at Stocking
Bluegill	1933	1500		5 month
Largemouth Bass	1933	200		4 month
Walleye	1933	210000		Swim-up fry
Bluegill	1934	2000	10.64	4 month
Largemouth Bass	1934	200	1.06	4 month
Walleye	1934	60000	319.15	Swim-up fry
Bluegill	1935	4000	21.28	4 month
Bluegill	1936	5000	26.60	5 month
Smallmouth Bass	1936	300	1.60	4 month
Walleye	1936	180000	957.45	Swim-up fry
Bluegill	1937	4800	25.53	4 month
Smallmouth Bass	1937	350	1.86	3 month
Bluegill	1938	10000	53.19	5 month
Largemouth Bass	1938	400	2.13	5 month
Smallmouth Bass	1938	100	0.53	Adults
Walleye	1938	528000	2808.51	Swim-up fry
Bluegill	1939	8000	42.55	4 month
Smallmouth Bass	1939	300	1.60	4 month
Walleye	1939	450000	2393.62	Swim-up fry
Yellow Perch	1939	2900	15.43	7 month
Walleye	1940	420000	2234.04	Swim-up Fry
Bluegill	1940	10200	54.26	4 month
Largemouth Bass	1940	300	1.60	3 month
Smallmouth Bass	1940	300	1.60	3 month
Walleye	1942	420000	2234.04	Swim-up fry
Largemouth Bass	1943	200	1.06	4 month

Smallmouth Bass	1943	200	1.06	4 month
Walleye	1974	800000	4255.32	Swim-up fry
Walleye	1975	3160	16.81	Fall fingerling
Tiger Muskellunge	1978	550	2.93	Fall fingerling
Walleye	1978	13000	69.15	Fall fingerling
Walleye	1979	25,000	132.98	
Tiger Muskellunge	1980	500	2.66	7.24
Tiger Muskellunge	1982	550	2.93	5.94
Walleye	1983	27,950	148.67	
Tiger Muskellunge	1984	460	2.45	6.85
Walleye	1985	20,196	107.43	1.61
Tiger Muskellunge	1986	400	2.13	7.13
Walleye	1987	16,750	89.10	2.36
Tiger Muskellunge	1988	400	2.13	9.49
Walleye	1989	14,550	77.39	2.36
Tiger Muskellunge	1990	400	2.13	9.17
Walleye	1991	17,635	93.80	1.89
Walleye	1993	21,063	112.04	1.61
Walleye	1995	18,700	99.47	2.09
Walleye	1997	20,100	106.91	1.97
Walleye	1997	6,520	34.68	3.19
Walleye	1998	1,112	5.91	5.59
Walleye	1999	19,280	102.55	2.01

Table 3. Species, number (N), percent by number (% by N), weight (WGT, in pounds), percent by weight (% by WGT), total length (TL) range in inches (in.), and average total length (Avg.TL) of fish captured during 2019 fisheries survey conducted in Big Shag Lake, Marquette County. Results include fish capture results from all gear types combined.

Species	N	% by N	WGT (lbs.)	% by WGT	Range TL (in.)	Avg.TL (in.)
Bluegill	1244	67.5	44.1	19.7	0.0 to 8.0	3.0
Bluntnose Minnow	253	13.7	1.5	0.7	1.0 to 3.0	2.3
Central Mudminnow	6	0.3	0.1	0.0	2.0 to 3.0	2.7
Iowa Darter	4	0.2	0.0	0.0	2.0 to 2.0	2.5
Largemouth Bass	36	2.0	28.9	12.9	3.0 to 16.0	10.8
Northern Pike	61	3.3	114.1	50.9	15.0 to 25.0	19.9
Pumpkinseed	196	10.6	23.9	10.7	1.0 to 8.0	4.4
Yellow Perch	43	2.3	11.7	5.2	2.0 to 11.0	7.7

Table 4. Species, Age (years), number (N) aged, range in total length, State of Michigan average (Avg.) size at age, average total length in Big Shag Lake and growth index of selected panfish species collected in Big Shag Lake, Marquette County 2019.

Species	Age	N Aged	TL Range (in.)	State Avg. TL (in.)	Avg. TL (in.)	Growth Index*
Bluegill	4	1	4.50 to 4.50	6.20	4.50	-2.00 inches
	5	4	4.40 to 6.50	6.90	5.40	
	6	14	4.50 to 7.60	7.40	5.49	
	7	14	5.30 to 7.60	8.00	6.12	
	8	5	5.40 to 7.60	8.40	6.06	
	9	1	7.30 to 7.30	8.70	7.30	
	10	1	8.00 to 8.00	-	8.00	
Pumpkinseed	3	2	4.00 to 4.10	5.20	4.05	-0.30
	4	11	4.10 to 6.50	5.80	4.70	
	5	11	5.30 to 7.30	6.30	6.49	
	6	11	5.50 to 8.00	6.80	6.47	
	7	9	5.80 to 8.00	7.20	7.40	
	8	2	8.00 to 8.50		8.25	
	10	1	8.70 to 8.70		8.70	

*Growth index is the average deviation from the state average length at age.

Table 5. Species, inch group, and total abundance of Bluegill and Pumpkinseed captured (all gear types) in Big Shag Lake, Marquette County 2019.

Species	Inch Group	Abundance
Bluegill	0	2
	1	320
	2	567
	3	104
	4	59
	5	101
	6	59

	7	31
	8	1
Pumpkinseed	1	18
	2	55
	3	25
	4	22
	5	16
	6	26
	7	29
	8	5

Table 6. Number (N) of Bluegill (BLG) captured, large mesh fyke net effort (net nights), number of preferred size Bluegill captured, percent preferred size Bluegill, average (Avg.) net total length (TL, inches), and catch per unit effort (CPUE) of preferred size Bluegill in Big Shag Lake, Marquette County 2019.

N BLG	Net Effort	N Preferred Size*	% Preferred Size*	Avg. TL (in.)	CPUE of Preferred Size* BLG
187	12	77	41.2	5.3	6.4

*Preferred size Bluegill is equal to or greater than 6.0 inches.

Table 7. Scores (1 – 7) for five indices of Bluegill population characteristics obtained during lake surveys. Ranks (very poor to superior) correspond to the scores provided. (Reproduced from Schneider 1990).

		Large Mesh Fyke Net				
Rank	Score	Avg.TL[a]	%>6 (in.)[b]	%>7 (in.)[c]	%>8(in.)[d]	Growth Index[e]
Very Poor	1	<5.0	0-9	0-1.9	<0.1	<-1.0
Poor	2	5.0-5.4	10-24	2-4	<0.1	-1.0 to -0.6
Acceptable	3	5.5-5.9	25-49	5-9	<0.1	-0.5 to -0.1
Satisfactory	4	6.0-6.4	50-74	10-29	0.1-0.9	0.0 to 0.4
Good	5	6.5-6.9	75-85	30-49	1-9	0.5 to 0.9
Excellent	6	7.0-7.5	86-95	50-79	10-39	1.0 to 1.4
Superior	7	≥7.6	≥96	≥80	≥40	≥1.5

[a] Average total length of catch in inches.

[bcd] Percent of catch greater than 6.0, 7.0, and 8.0 inches in total length, respectively.

[e] Average deviation (inches) from the state average length at age.

Table 8. Historical capture occurrence by species and survey year in Big Shag Lake (Marquette County).

Species	1924	1926	1957	1973	1978	1981	1982	1989	1993	2000	2007	2019
Blacknose Shiner	X	X										
Bluegill			X	X	X	X	X	X	X	X	X	X
Sunfish Hybrid					X							
Bluntnose Minnow						X	X				X	X
Central Mudminnow												X
Common White Sucker	X	X	X	X	X	X	X	X	X	X	X	
Golden Shiner	X	X									X	
Iowa Darter		X										X
Largemouth Bass						X		X	X	X	X	X
Mimic Shiner		X										
Northern Pike					X					X	X	X
Northern Redbelly Dace		X										
Pumpkinseed			X	X	X	X	X	X	X	X	X	X
Smallmouth Bass				X	X	X	X		X		X	
Longnose Sucker					X							
Tiger Muskellunge						X	X	X	X			
Yellow Perch		X	X	X	X	X	X	X	X	X	X	X
Walleye			X	X	X	X	X	X	X		X	