Seasonal Movements of Muskellunge in North Bend Lake, West Virginia

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Abstract: North Fork Hughes River, West Virginia, is a native muskellunge (*Esox masquinongy*) stream and is impounded by North Bend Lake, a 12.4-km long, 123-ha impoundment that serves as an important brood source for the West Virginia Division of Natural Resources. Muskellunge movement was monitored from 26 March 2010 through 2 January 2014 to monitor seasonal movements and to verify muskellunge migration through the outlet structure of the dam. Twenty-four fish were collected using pulsed DC boat-mounted electrofishing equipment and surgically implanted with acoustic transmitters. Six submersible data loggers were stationed throughout the lake. Data logger data were downloaded monthly throughout the study, resulting in 1,256,046 detections of implanted fish. Seasonal movement of marked fish was consistent during the four years of the study. Most fish moved throughout the entire length of the lake, and seven implanted fish left the lake through the outlet structure of the dam. Fish occupied the upper half of North Bend Lake in spring, and spent the summer and winter in the lower half of the lake. Fish occupied the lower lake in early and late fall, but exhibited a collective movement to the upper lake in October. Based on their upstream movements in early spring, muskellunge appeared to use the upper areas of the lake for spawning purposes. Knowledge of seasonal movements of muskellunge in North Bend Lake, particularly in spring, will enhance future broodstock collection efforts. Dam escapement by muskellunge may have a significant effect on fisheries in small impoundments, and should be considered in muskellunge management plans in similar systems.

Key words: acoustic telemetry, data loggers, dam escapement

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Muskellunge (*Esox masquinongy*) are a popular and economically valuable sportfish endemic to the upper Mississippi River drainage eastward to the St. Lawrence River (Etnier and Starnes 1993). Artificial propagation and stocking of muskellunge support fisheries once sustained solely by natural reproduction as well as create new fisheries to expand angling opportunities (Dombeck et al. 1984, Kerr 2011, Miller et al. 2012). Forty-six percent of muskellunge fisheries in North America are a result of introductions by stocking (Kerr 2011). The West Virginia Division of Natural Resources (WVDNR) has propagated muskellunge since 1958, and 42% of its muskellunge fisheries are sustained by stocking (Kerr 2011). From 1969 to 2013, 50% of muskellunge registered with the West Virginia Husky Musky Club, a statewide muskellunge angling club, were caught from stocked waters. States that stock fingerling muskellunge often have source lakes from which they collect broodstock to supply eggs and milt for rearing operations in state hatcheries (Jennings et al. 2009, Jennings et al. 2010, Kerr 2011). North Bend Lake has served as one of the WVDNR's source populations for broodstock since 2006 and is stocked with fingerlings annually at a rate of 1.3 fish ha^{-1}. Although broodstock muskellunge have been collected annually from North Bend Lake during spawning season since 2006, there has been little research on the seasonal movement of adult muskellunge in that water body. Muskellunge generally spawn in April in West Virginia, when water temperatures reach 10 C (Miles 1978). A better understanding of seasonal movement, particularly during spring spawning season, in North Bend Lake would help biologists to identify spawning areas and more efficiently collect broodstock.

Spawning site fidelity or "homing" has been documented in muskellunge (Crossman 1990, Younk et al. 1996, Weeks and Hansen 2009, Jennings et al. 2011). Spawning habitat generally consists of shallow (<1 m) littoral or backwater areas over variable substrates (muck, silt, sand, vegetation, detritus, woody debris) (Dombeck 1979, Dombeck et al. 1984, Younk et al. 1996, Zorn et al. 1998). Dombeck et al. (1984) attributed reproductive failure of formerly self-sustaining muskellunge populations in midwestern lakes to habitat loss or alteration by development and erosion. Zorn et al. (1998) emphasized the importance of spawning habitat in the reproductive success of muskellunge in self-sustaining systems. Increasing shoreline development threatening naturally reproducing muskellunge systems will make the identification and protection of these critical habitats important in the future (Zorn et al. 1998, Margenau 1999, Rust et al. 2002). Habitat destruction, pollution, and overexploitation are the most critical concerns for muskellunge management across North America (Kerr 2011). Findings regarding muskellunge spawning behavior will be valuable to future management of systems that support natural reproduction and provide broodstock sources for artificial propagation and stocking efforts, particularly in a state such as West Virginia where extraction industries are prevalent.

Another challenge faced by managers to maintain quality muskellunge fisheries is the escapement of fish through dams (Margenau and Snow 1984, Storck and Newman 1992, Wahl 1999, Wolter et al. 2013). Wolter et al. (2013) found that 25% of a muskellunge population escaped from Lake Sam Dale, Illinois within one year. Dam escapement by muskellunge from North Bend Lake was thought to occur but had not been confirmed. Muskellunge occur at low densities throughout their native range (Graff 1986, Simonson and Hewett 1999, Kapuscinski et al. 2013). Emigration by muskellunge from a trophy fishery in a small impoundment such as North Bend Lake may have a strong effect on the population. Thus the main objectives of this study were to monitor seasonal movement of muskellunge in North Bend Lake and to determine the prevalence of dam escapement by muskellunge.

Methods

Study Area

Located in Ritchie County, West Virginia, North Bend Lake is a 12.4-km long, 123-ha impoundment of the North Fork of the Hughes River, a native muskellunge stream that is a tributary to the Little Kanawha River in the Ohio River watershed (Figure 1). Impounded in 2003, the lake is operated for flood control, water supply, and recreation. The lake level is not regulated (normal pool elevation of 217 m above sea level) and has a surface release through a riser connected to the dam near the left descending bank. A USGS water-stage recorder (station number 03155405) maintained by the West Virginia Conservation Agency is located on the dam. The lake is relatively narrow (mean width = 74 m) with two small coves, and is characterized by standing (flooded) timber throughout. It is managed as a trophy muskellunge fishery with catches of several

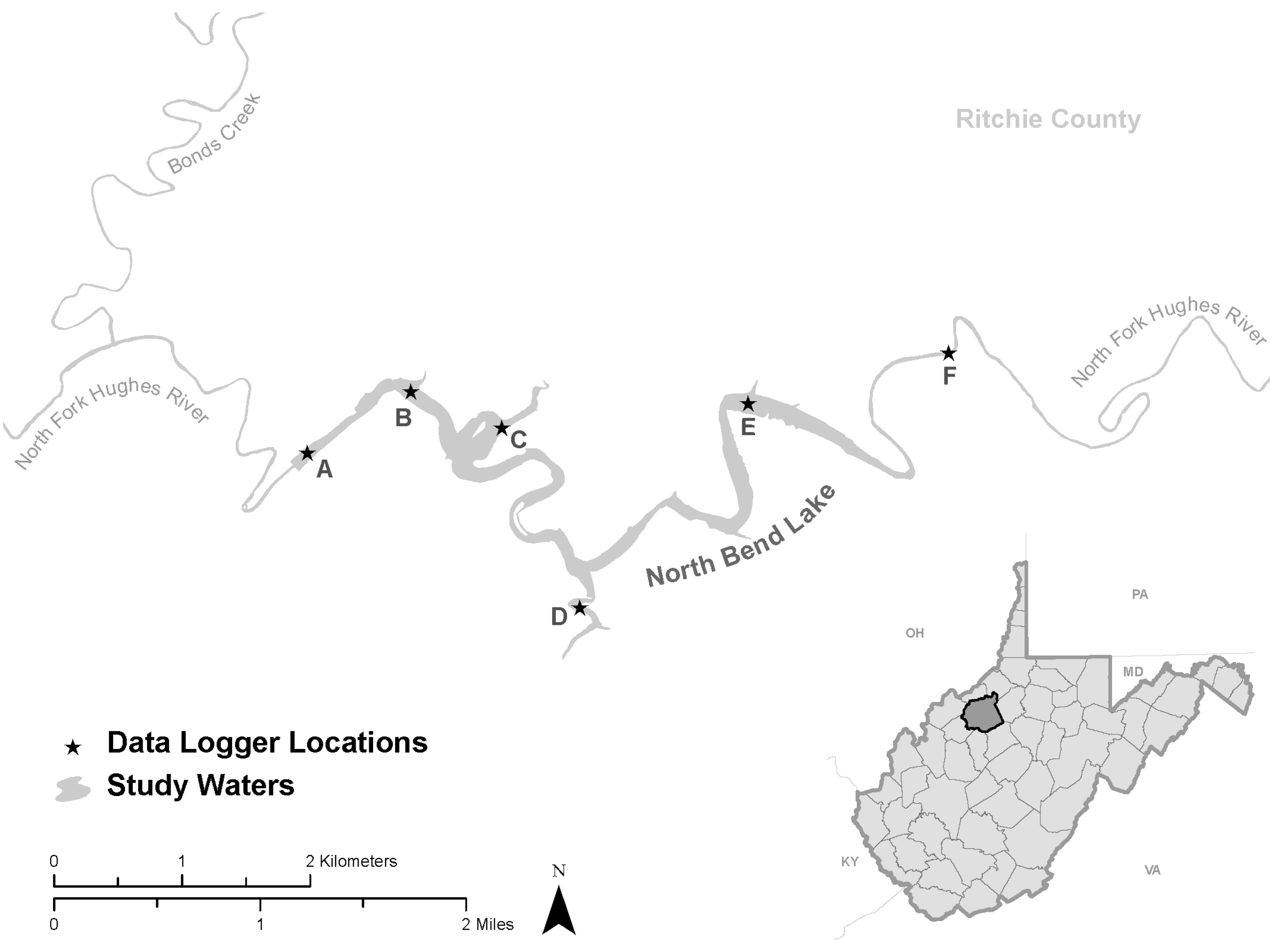

Figure 1. North Bend Lake, a small impoundment of the North Fork of the Hughes River located in Ritchie County, West Virginia. Data logger deployment locations are indicated by stars. The lower lake as referred to in the paper includes data loggers A, B, and C; the upper lake includes data loggers D, E, and F. The dam is located at 39.219626N, 81.098858W.

fish larger than 16 kg in recent years. The minimum-length limit for muskellunge in North Bend Lake is 102 cm total length (TL), and the daily bag limit is two fish.

Fish Tagging

Muskellunge were collected using pulsed DC boat-mounted electrofishing equipment (Smith Root 5.0 GPP) from all sections of the lake to obtain a representative sample of the population. Fish were measured for TL (cm) and were surgically implanted with acoustic transmitters (Sonotronics model CT-05-48-I; 70–81 kHz: 79 × 15.6 mm; 12 g in water; 48-month estimated battery life) following methods of Lucas and Baras (2000) and Wagner et al. (2000). Tags were less than 2% of the weight of the smallest tagged fish following Winter (1996). A total of 24 fish, 12 males and 12 females (mean TL of 91 cm, range 68–109 cm) were tagged during this study (Table 1). Twelve were tagged in March 2010, six in March 2011, four in March 2012, and two in May 2012. All tagged fish were sexually mature. Muskellunge were anesthetized in a solution of water and 100-mg L^{-1} of tricaine methanesulfonate (MS-222) prior to surgery. For future identification in case of acoustic tag loss or failure, each fish was implanted with a Passive Integrated Transponder (PIT) tag (Biomark HPT12; 12.5 mm; 134.2 kHz) in the left dorsal musculature and an external bird tag (National Band #1005, size 3) affixed to the dorsal fin. External bird tags were used so that anglers could easily report catching tagged fish. After each fish was tagged, it was allowed to recover in a livewell of fresh lake water and was released at the capture site.

Table 1. Summary of information for muskellunge implanted with acoustic transmitters and tracked in North Bend Lake, West Virginia, 26 March 2010 through 2 January 2014. Fate was determined at the end of the four-year study. The total number of detections was 1,256,046.

Fish	Date implanted	Sex	Length (cm)	Detections	Months tracked	Loggers	Fate
1	3/10/10	F	102	5345	3	5	Unknown
2	3/12/10	M	89	134,826	28	6	Transmitter failure
3	3/12/10	F	88	6431	5	5	Unknown
4	3/12/10	M	95	36,025	16	6	Dam escapement
5	3/12/10	M	68	31,017	19	6	Dam escapement
6	3/12/10	F	84	57,229	37	6	Unknown
7	3/12/10	M	90	69,958	45	6	Transmitter failure
8	3/12/10	M	91	63,415	24	6	Transmitter failure
9	3/12/10	F	85	5523	4	4	Unknown
10	3/17/10	M	90	11,068	13	6	Unknown
11	3/17/10	F	73	30,768	21	6	Dam escapement
12	3/18/10	F	109	98,846	17	6	Transmitter failure
13	3/8/11	M	101	10,791	5	5	Dam escapement
14	3/8/11	F	93	34,335	34	6	Alive
15	3/8/11	M	87	72,625	22	6	Dam escapement
16	3/8/11	F	85	116,813	34	6	Alive
17	3/8/11	F	71	47,933	34	6	Alive
18	3/8/11	M	94	82,108	16	6	Transmitter failure
19	3/14/12	M	98	92,705	22	6	Alive
20	3/14/12	F	86	69,663	22	6	Alive
21	3/14/12	F	108	95,943	22	6	Alive
22	5/17/12	F	107	28,608	5	6	Mortality
23	5/17/12	M	86	21,750	7	6	Dam escapement
24	3/14/12	M	100	32,321	9	6	Dam escapement

Fish Movement

Six submersible data loggers (Sonotronics model SUR-2) were stationed at strategic locations throughout North Bend Lake (Figure 1). Data loggers recorded the date and time that marked fish were detected within data logger range. In a pilot study, we used ground truthing to establish the detection range of each submersible data logger. The study determined that data loggers deployed at greater depths had a greater range for detecting tagged fish, and the lake was narrow enough that each data logger had full lateral coverage of the lake at its deployment location (unpublished data). Furthermore, data logger A, deployed 0.2 kilometers upstream of the dam (KUD), had a detection range of over 400 m, and therefore was able to detect fish at the outlet structure, along the dam, and at both corners of the dam on either shoreline. The six data loggers did not provide full areal coverage of the lake, but because they provided full lateral coverage (shoreline to shoreline) at their deployment locations, movement by tagged muskellunge into various areas of North Bend Lake could be evaluated.

Data logger data were downloaded monthly March 2010–January 2014. Microsoft Access was used to analyze seasonal movement (i.e., spring: March, April, May; summer: June, July, August; fall: September, October, November; and winter: December, January, February). Fish were also tracked by boat in April, June, and July 2013 in North Bend Lake and in October and November 2013 in the tailwaters of North Bend dam using a portable digital receiver (Sonotronics USR-08), an omnidirectional hydrophone (Sonotronics TH-2), and a directional hydrophone (Sonotronics DH-4).

Results

Between 26 March 2010 and 2 January 2014, individual fish logged 5,345–134,826 detections (mean of 52,335 detections per fish) (Table 1). Fish were located by data loggers for 3–45 mo (mean of 19 mo): 7 fish were tracked for <1 yr; 11 for 1–2 yrs; 4 for 2–3 yrs; and 2 for 3–4 yrs. Data loggers recorded 1,256,046 detections from tagged fish (range: 37,542–387,347 detections per data logger; mean: 209,341) (Table 2). Two data loggers in the lower part of the lake (B and C) had the greatest number of detections of tagged fish and each stored 31% of all detections. However, most fish moved throughout the lake, with 20 of the 24 implanted fish recorded at all six data loggers.

Seasonal movement of marked fish was consistent during the four years of the study. Fish occupied the upper half of North Bend Lake in spring, and spent the summer and winter in the lower half of the lake (Figure 2). Based on their upstream movements in early spring, muskellunge appeared to use the upper areas of the lake for spawning purposes. Throughout the study, 77%–96% of all locations received during April were from the two data loggers located in the upper lake (E and F). There was no difference between males and females in the timing of movement past the uppermost receivers in spring. Fish occupied the lower lake in early and late fall. Movements during mid fall were also consistent throughout the study. During October, 80% of all locations received were from data loggers located in the upper part of the lake (D, E, and F).

During the study we experienced complications on 10 different occasions with all six data loggers that interrupted data transcription, including data logger malfunction, dead batteries, and theft. Problems were resolved in all cases within an average of 36 days (range: 2 to 68 days).

At the end of the study six (25%) implanted fish remained alive and active in North Bend Lake (Table 1). Seven fish (29%) had migrated out of the lake through the outlet structure of the dam; five fish (21%) had unknown fates; five (21%) transmitters failed; and one fish (4%) died.

Of the seven fish that migrated out of the lake through the outlet structure of the dam, four were actively tracked in the tailwaters in fall 2013, and one fish was harvested by an angler 56 km downstream of the lake in November 2011. Two additional fish that appear to have escaped through the outlet structure of the dam were last detected by the data logger that was closest to the dam (data logger A), a pattern followed by the other five fish found in the tailwaters. The lake elevation at the time each escaped fish was last detected was at least 0.31 m above normal pool (Figure 3). The lake level was falling at the time of escapement for five fish, and rising for the other two fish. Six of the seven emigrant fish were males. Four muskellunge migrated out of the lake during winter, two in summer, and one during fall; no fish migrated through the outlet structure of the dam in spring. Fish left the lake at all times of day and night. Five transmitters failed during the study. One fish was last detected

Table 2. Detections recorded by submersible data loggers located at North Bend Lake, West Virginia, 26 March 2010 through 2 January 2014. The total number of records was 1,256,046. Data logger locations are indicated as a number of kilometers upstream of the dam (KUD).

Logger	KUD	*n* records	Date deployed	Last record	*n* tagged fish detected
A	0.2	82,200	03/18/10	08/13/13	21
B	1.1	386,366	05/06/10	01/02/14	24
C	2.3	387,347	05/06/10	01/02/14	24
D	4.0	91,659	03/09/10	12/31/13	24
E	6.6	270,932	03/09/10	12/09/13	24
F	9.5	37,542	03/09/10	11/26/13	22

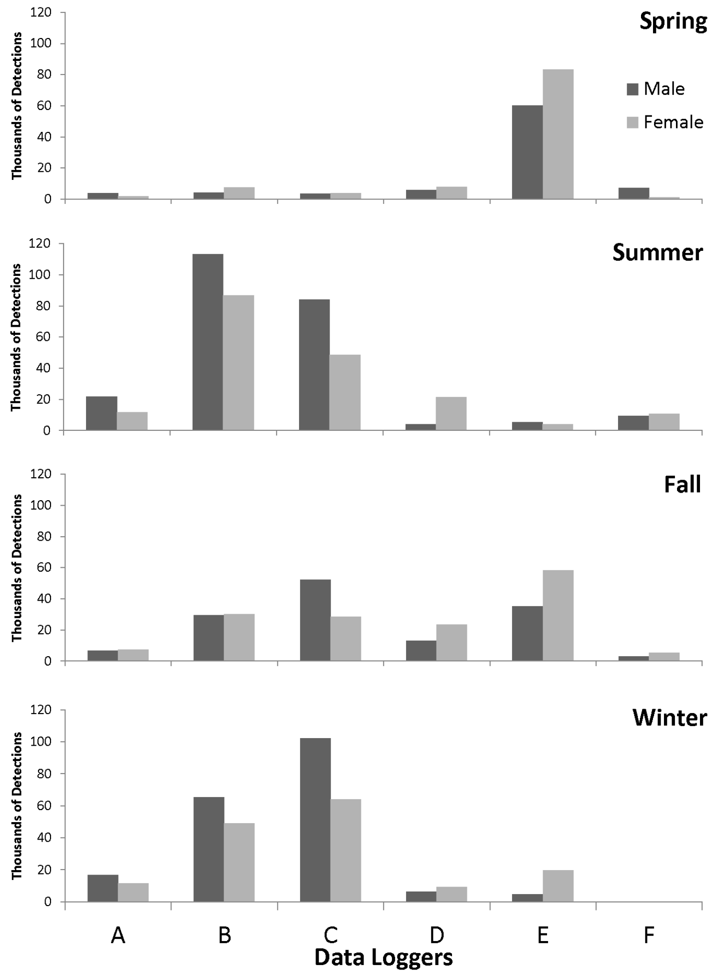

Figure 2. Detections of male and female muskellunge by season and data logger location. Data loggers located in the lower lake are A, B, and C, and in the upper lake are D, E, and F. Spring is considered March, April, and May; summer is June, July, and August; fall is September, October, and November; winter is December, January, and February.

on 28 August 2011 and was found dead on 29 April 2013 at which point the transmitter was recovered. Three fish were collected with electrofishing gear in the lake more than eight months after their last detection. The last fish was missing for a 11-mo period. Avoidance by these fish of the data loggers or active tracking events are unlikely,

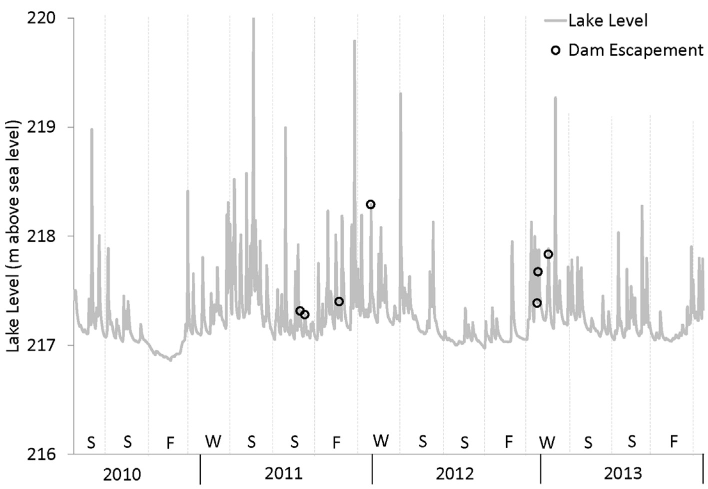

Figure 3. Lake level (m above sea level) and dam escapement by muskellunge from North Bend Lake by year and season. Lake level is indicated by the continuous line, and occasions of dam escapement are indicated by hollow black circles. Spring (S) is considered March, April, and May; summer (S) is June, July, and August; fall (F) is September, October, and November; winter (W) is December, January, and February. Muskellunge emigrated from the lake in all seasons and at all times of day. Dam escapement mostly occurred when lake levels were falling. USGS gauge station 03155405 was used to generate mean daily lake levels.

given the small size and narrow widths of the lake and the detection range of the receivers.

Five fish were characterized with unknown fates. Escapement of these fish through the outlet structure of the dam was unlikely since the last location detected for each fish with an unknown fate was not from the data logger closest to the dam. Transmitter failure or harvest by angler are the most probable explanations for all fish with unknown fates. Two of the five fish with unknown fates were of harvestable size at the time of their last detection.

Discussion

Muskellunge spawning areas appear to be concentrated in the upper half of North Bend Lake based on upstream movements of muskellunge during spring. In West Virginia, muskellunge generally spawn in April when water temperatures reach 10 C (Miles 1978). In North Bend Lake most fish detections in April were in the upper part of the lake, a finding consistent with observations made during brood stock collection in previous years. Upstream movements by muskellunge prior to spawning have been observed in other systems in North America (Minor and Crossman 1978, Dombeck 1979, Younk et al. 1996). However, contrary to the present study, Miles (1978) did not observe a pre-spawning upstream movement by muskellunge in Middle Island Creek and its tributaries in West Virginia and attributed the lack of movement to suitable habitat present in resident pools. This annual pattern of upstream movement to the same area of the lake prior to spring spawning may indicate spawning site fidelity by muskellunge in North Bend Lake consistent with other studies that have documented reproductive homing in this species (Crossman 1990, Younk et al. 1996, Weeks and Hansen 2009, Jennings et al. 2011). Strand (1986) and Younk et al. (1996) found that muskellunge males generally arrived at spawning areas before females and stayed longer while females visited multiple spawning areas and did not remain in any one location for very long. Minor and Crossman (1978) also found that males generally occupied a single spawning site whereas females spawned in more than one area. In the present study, there was no difference in the timing of movement past the data loggers located in the upper lake between male and female muskellunge, but specific spawning sites were not identified.

The fact that North Bend Lake muskellunge are from stream stock (adapted to stream conditions) and not lake fish could also explain this upstream movement pattern. A pre-spawn upstream movement has been documented in other stream stock piscivores in impounded systems (i.e., walleye [*Sander vitreus*] in the Cedar River system, Iowa [Paragamian 1989], and in the New River upstream of Claytor Lake, Virginia [Palmer et al. 2005]; sauger [*S. canadensis*] in the Tennessee River system [Pegg et al. 1997]). Spoelestra et al. (2008) noted that the mobility of stream fish is an advantage in a system with changing environmental conditions (oxygen, flow, turbidity) that allows them to use preferred habitat as needed or available.

Reasons for collective upstream movement during fall are beyond the scope of this study, but may be due to higher oxygen levels or greater availability of prey in the upper lake. Dombeck (1979) found that muskellunge respond to changes in oxygen levels and move from areas of low dissolved oxygen to areas of higher dissolved oxygen. Dombeck (1979) speculated that increased movement in fall may also be related to increased feeding activity during gonadal maturation. Bozek et al. (1999) found that the greatest proportion of muskellunge containing food items occurred in fall. Similarly, Sammons and Glover (2013) observed a collective movement in fall by striped bass (*Morone saxatilis*) to shallower, warmer, and more oxygenated water in an Alabama reservoir that may have been in response to forage distribution. Paragamian (1989) observed peak movement by walleye in spring and fall, similar to the present muskellunge study. Other studies have documented a collective movement by muskellunge in fall toward wintering areas (Dombeck 1979, Younk et al. 1996). Muskellunge in North Bend Lake moved into the lower lake for winter, possibly seeking deeper water. Similarly, Younk et al. (1996) found that muskellunge winter and summer ranges often overlap, which is typical of many freshwater fish species (Paragamian 1989, Tipping 2001, Weller and Winter 2001).

Although detection ranges varied for data loggers based on depth (130 m detection range at 2 m deployment depth to more than 275 m detection range at 6 m deployment depth [unpublished data]), North Bend Lake was narrow enough that each data logger scanned the entire width of the lake at the depth deployed. Lake width in the upper area averaged less than 35 m. Melnychuk (2012) identified absorption or disruption of a transmitter soundwave by environmental factors including wind, soft substrate (i.e. silt), suspended matter, turbulent flow, waves, rain, discharge, boat traffic, dams, aquatic vegetation, and bottom topography to be primary sources of acoustic strength depletion in an aquatic system. Shroyer and Logsdon (2009) found that acoustic detection distances can differ substantially among and even within water bodies due to thermal stratification, boat traffic, suspended sediment, variable bottom contours, water turbulence, and large woody debris. In addition to these environmental factors that vary among study systems, fish behavior, acoustic transmitter variability, and data logger deployment methods can affect detection range (Clements et al. 2005, Heupel et al. 2006, Simpfendorfer et al. 2008, Shroyer and Logsdon 2009, Melnychuk 2012). Detection ranges reported in recent freshwater acoustic telemetry studies were greater than those in the present study (Wingate and Secor 2007, Simpfendorfer et al. 2008, Shroyer and Logsdon 2009). The abundance of standing timber and the soft substrate that characterize North Bend Lake are environmental variables that may have significantly reduced detection range in the present study. To account for such site-, organism-, and technology-specific variations in detection, ground-truthing should be incorporated into all future acoustic telemetry studies.

Dam escapement has been identified as a management concern by biologists working with a variety of fish species (Axon and Whitehurst 1985, Storck and Newman 1992, Paller et al. 2006, Spoelstra et al. 2008, Weber et al. 2013). Up to 29% of implanted muskellunge in the present study migrated through the outlet structure of the dam and out of North Bend Lake over the 4-yr period, 86% of which were males. Dam escapement occurred at all times of day and in all seasons except spring, when muskellunge were mostly found in the upper part of the lake. Wolter et al. (2013) found 25% of muskellunge escaped through the outlet structure of the dam from an Illinois reservoir in a single year. Weber et al. (2013) reported an annual dam escapement rate of at least 13.6% by walleye in an Iowa reservoir, and found that mean daily discharge was the most important factor influencing escapement. Contrary to the present study, Wolter et al. (2013) found no difference in escapement between male and female muskellunge and that dam escapement by muskellunge occurred mostly during daylight hours in late spring. Dombeck (1979) found that water level fluctuations had no obvious effects on muskellunge movements. The USGS gauge station in North Bend Lake did not measure discharge, but rising or falling lake-level fluctuations did not appear to influence muskellunge dam escapement; however, all cases of dam escapement occurred when lake levels were at least 0.31 m above normal levels. One of the fish that escaped from North Bend Lake was harvested 56 km downstream exhibiting the potential for long-range movement by muskellunge. Likewise, Spoelestra et al. (2008) observed downstream movement by saugeye (Sander vitreus × S. candadensis) of over 45 km after dam escapement from an Ohio impoundment.

These findings have important implications for muskellunge fisheries in impoundments, sustained either by natural reproduction or stocking. Post-stocking mortality rates are commonly high in muskellunge (Margenau 1992, Hanson and Margenau 1992, Szendry and Wahl 1996, Farrell and Werner 1999, Warren 2013), and muskellunge typically occur at low densities (Graff 1986, Simonson and Hewett 1999, Kapuscinski et al. 2013). Therefore, in muskellunge fisheries sustained by stocking, where population reductions due to dam escapement occur, greater stocking rates or dam modifications may be required to maintain a viable fishery. Additionally, dam escapement by stocked piscivores has been found to have deleterious effects on downstream fish populations (Tyus and Saunders 2000). Managers should be aware of dam escapement and consider the potential for downstream effects when establishing or maintaining a piscivore fishery in an impoundment.

Management Implications

Documentation of seasonal movements of muskellunge in North Bend Lake provided valuable information for broodstock collection and propagation efforts in the future. In a state so economically dependent upon resource extraction, protection of upstream spawning areas will be important to sustaining viable muskellunge fisheries and broodstock source populations in the future. Dam escapement by muskellunge has not been well studied, but results from this study indicate that it could have a significant effect on the fishery. Thus, emigration from impounded systems should be considered in muskellunge management plans.

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