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Behavior of Tiger Muskellunge in Newman Lake, Washington Determined by Ultrasonic Biotelemetry

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Abstract

Ultrasonic transmitters were surgically implanted into 30 adult tiger muskellunge *Esox masquinongy* x *E. lucius* to evaluate long-term (bi-weekly tracking intervals conducted over 29 months) and short-term (hourly locations recorded over 48 hour periods) movement behavior in Newman Lake, Washington. Long-term behavior was analyzed in terms of use-area and distance traveled by season period (winter-spring vs. summer-fall), and was compared to similar tiger muskellunge telemetry data previously collected from Mayfield Reservoir in western Washington. Short-term behavior was analyzed, seasonally, in terms of travel rates and areas of the lake utilized by individual fish. Movement and areas used by tiger muskellunge tracked bi-weekly were greater during winter-spring than in summer-fall. However, mean distance traveled between observations in Newman Lake was approximately twice the distance observed in Mayfield Reservoir. During the 48-h tracking periods, a wide range of individual tiger muskellunge behavior was observed, ranging from fish that occupied short sections of shoreline or particular bays, to fish that traveled many kilometers in short periods of time. Managers of escocid fisheries typically consider northern pike, muskellunge, and tiger muskellunge lie-and-wait littoral predators that have defined home ranges and exhibit limited movement. However, the results of this study suggest otherwise. The varying travel rates and use-areas observed at Newman Lake provide evidence that tiger muskellunge behavior may be lake-specific, or that tiger muskellunge employ different behavioral strategies not only between, but within populations. Further study, on tiger muskellunge waters with varying morphologies and fish assemblages would bolster efforts to determine whether this species should be managed on a lake-by-lake basis. The results of this study also suggest that the Washington Department of Fish and Wildlife's standard warmwater sampling protocols may not be highly effective for sampling tiger muskellunge populations, and that tiger muskellunge-specific sampling protocols need to be developed.

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Introduction

Tiger muskellunge *Esox masquinongy* x *E. lucius* have been stocked in many lakes and impoundments throughout the United States to utilize overabundant non-game fish populations as forage and to provide a unique recreational fishing opportunity for trophy size fish (Wingate 1986). Since 1988, the Washington Department of Fish and Wildlife (WDFW) have stocked tiger muskellunge into 11 lakes across the state. These waters exhibit varying morphology and fish community structure ranging from lowland lakes dominated primarily by spiny-ray fisheries (e.g., Newman Lake) to slightly higher elevation lakes containing mostly soft-rayed fish such as rainbow trout *Oncorhynchus mykiss* and northern pikeminnow *Ptychocheilus oregonensis* (e.g., Curlew Lake). At present, WDFW acquires tiger muskellunge annually as eyed-eggs from external sources and rears them in agency-owned hatcheries until age 1, at which time they are stocked into seven lakes across the state. To ensure the best use of this valuable, but limited resource, WDFW is monitoring tiger muskellunge populations for diet, behavior, and fish community response information.

To effectively manage any fish species, it is essential to understand their behavior as well as other dynamics such as population size, survival, diet, exploitation, and interactions with co-inhabitants of the water in which they live. Fisheries biologists often use various tools to examine these dynamics, such as mark-recapture techniques to determine population size, creel surveys to monitor exploitation, and various types of fish surveys to document the composition of species inhabiting a particular water body. Biotelemetry has been widely used in fishery science to examine fish population dynamics such as behavior and mortality, and to answer more specific management-related questions. Waters et al. (2005) used ultrasonic telemetry to estimate annual instantaneous fishing and natural mortality rates of largemouth bass and found that the age and size distribution of that population could likely be altered through harvest restrictions. Thompson et al. (2007) used telemetry data to determine seasonal instantaneous fishing and natural mortality of striped bass *Morone saxatilis* in a North Carolina lake and suggested that a moderate increase in the minimum size limit would allow increased harvest of larger, older fish. In another study, Bettoli and Osborne (1998) used a reusable ultrasonic tag and float assembly (Osborne and Bettoli 1995) to determine hooking mortality of striped bass in a Tennessee Reservoir. They concluded that year-round minimum size limits would not improve the size structure of the population due to high levels of hooking mortality. Telemetry has also been used to determine movement of fish displaced from their original capture site. Pearson (2002) found that only a small percentage of largemouth bass displaced into an adjoining lake returned to the original capture site and recommended that measures should adopted to reduce inter-lake displacement of tournament-caught fish. Conversely, Richardson-Heft et al. (2000) suggested that long-term stockpiling of tournament-caught largemouth bass released at weigh-in stations did not occur. Many telemetry studies have also been conducted that evaluated the effects of water control structures (e.g., dams) on behavior of fish. Paragamian (1989) found that dams on an Iowa river reduced walleye habitat upstream, but created favorable habitat downstream of the structure. Hubley (1963) tracked channel catfish on the upper Missouri River and suggested that dams did not present obstacles for the movement of telemetered channel catfish in that system. Likewise, telemetry has been used to study esocids, for both broad behavior and life history studies of northern pike and muskellunge (Diana et al. 1977; Dombeck

1979; Chapman and Mackay 1984; Younk et al. 1996), to studies investigating questions more specific to fishery management (Strand 1986; Hanson and Margenau 1992; Brenden et al. 2006). Strand (1986) used telemetry to identify spawning areas of muskellunge in Minnesota. Hanson and Margenau (1992) used radio telemetry to determine that age-0 muskellunge stocked into a Wisconsin lake survived at rates exceeding 90%. Brenden et al. (2006) used radiotelemetry to determine the effect of discharge on muskellunge habitat use on a Virginia river. In that study, the authors theorized that increased discharge (e.g., hydropeaking) reduced winter survival of muskellunge due to energy limitations. In Washington, Tipping (2001) studied the movements and habitat of tiger muskellunge and hypothesized on its relation to potential interactions with salmonids.

Managers of escocid fisheries typically consider pike, muskellunge, and tiger muskellunge lie-and-wait littoral predators that have defined home ranges and exhibit limited movement, however, observations reported by many researchers suggest otherwise. Some researchers concur with this description and suggest that pike are sedentary predators that do not move extensively (Malinin 1969; Lehtonen et al. 1983; Müller 1986), whereas others have reached conflicting conclusions and suggest that pike do not have restricted home ranges (Chapman and Mackay 1984; Diana et al. 1977; Cook and Bergersen 1988). Most researchers, however, have reported varying combinations of behavior. In separate studies, Dombeck (1979) and Strand (1986) reported that muskellunge occupied defined home ranges, but that those fish utilized pelagic, as well as littoral habitat, and moved long distances throughout the studies. Similarly, Miller and Menzel (1986) found that throughout the months following spawning, muskellunge in an Iowa lake exhibited high levels of movement and utilized a variety of habitat types, including open-water habitat, but occupied defined home ranges during summer. Jepsen et al. (2001) studied pike in a natural lake and a reservoir and observed that the reservoir pike occupied restricted home ranges, whereas those inhabiting the lake moved more extensively. Vehanen et al. (2006) observed restricted home range in only a portion of radio-tagged pike studied in a Finnish river system. Like Vehanen et al. (2006), Kobler et al. (2008) observed a high degree of individual variation in habitat choice and movement of pike in a natural lake in Germany. In another study, Crossman (1977) reported that muskellunge had ill-defined home ranges. Some researchers (Diana 1980; Mann 1980; Jepsen et al. 2001; Masters et al. 2005) suggest that escocids employ different behavioral strategies not only between, but within populations. Others propose that differences observed in movement and behavior may be related to such things as prey availability, shoreline structure (Kobler et al. 2008), fish size (Chapman and Mackay 1984), or differences in data collection methodologies (Diana et al. 1977; Ovidio and Philippart 2005; Vehanen et al. 2006). With the wide variation in escocid behavior reported, it is important for fisheries managers in Washington State to know how these fish behave in waters managed for tiger muskellunge.

Although the parent species have been studied, we are aware of only one telemetry study (Tipping 2001) that investigated the behavior of adult tiger muskellunge. In that study, Tipping (2001) utilized ultrasonic biotelemetry to evaluate seasonal movement of tiger muskellunge in Mayfield Reservoir (Lewis County) in Washington State, and to evaluate possible interactions with other fish species (particularly salmonids) in the reservoir. Tipping found that most tiger muskellunge in his study exhibited some seasonal site fidelity, similar to the homing behavior Younk et al. (1996) reported for muskellunge in the upper Mississippi River. Tipping also found that tiger muskellunge exhibited greater movement, utilized larger areas, and occupied deeper (5-10 m), pelagic areas in winter-spring, whereas in summer-fall, fish tended to move less, utilize smaller areas of the lake, and occupy shallow (< 2.5 m), vegetated areas. Tipping concluded that potential predation by tiger muskellunge on salmonids was relatively low. In summer and fall, tiger muskellunge and salmonid species (which tend to occupy pelagic areas of the reservoir), were spatially segregated thus reducing the opportunity for predation. During winter and spring, when their habitats overlapped, tiger muskellunge metabolism was low which also reduced the overall predation potential. At the time of Tipping's study, Mayfield Reservoir was the only water in Washington that had been stocked with tiger muskellunge. Since then, tiger muskellunge have been stocked into ten other waters and WDFW fishery biologists have determined, through standardized surveys (Bonar et al. 2000), that the performance (i.e., growth rates and condition) of those fish has varied, depending upon the water in which they were stocked. This is supported by the fact that Tipping's (2001) results concurred with the findings of some researchers (Crossman 1977; Margenau 1994; Roach 1998) and contrasted with others (Diana et al. 1977; Dombeck 1979; Cook and Bergersen 1988). Although Tipping's study provided valuable baseline seasonal tiger muskellunge behavioral information, we could find no studies that described short-term movement behavior of adult tiger muskellunge. Short-term movement behavioral data, such as hourly tracking intervals, are valuable in that they can be used to model bioenergetics, which estimate nutritional demands and consumption rates for tiger muskellunge. This knowledge will bolster predictions as to which waters will best support tiger muskellunge and how they might perform in the waters stocked. This information will assist WDFW in prioritizing lakes to maximize the use of the limited tiger muskellunge supply.

Monitoring seasonal and/or diel movement can also provide valuable insight into whether existing sampling protocols provide data that accurately reflect relative abundance of tiger muskellunge, or whether tiger muskellunge-specific sampling protocols should be developed. The Washington Department of Fish and Wildlife employs lake sampling protocols (Bonar et al. 2000) which provide a snapshot of the fish communities in a given water. To make effective management decisions, such as angling regulations and stocking densities, fisheries managers must trust that these protocols accurately reflect fish community dynamics, such as relative abundance; an element paramount to any action which affects the balance of predator and prey populations. The 2000 Newman Lake warmwater fisheries survey (Osborne et al. 2004) may be one example of the potential shortcomings of WDFW lake sampling protocols. During this week-long survey, only 11 tiger muskellunge were captured, which raised questions of whether tiger muskellunge density was abnormally low or whether they possibly inhabited open water areas of the lake not sampled using the standard protocols. Fisheries managers in other areas of the country have stressed the need for species-specific sampling protocols. Margenau et al. (2008) reviewed historical northern pike research and management practices in Wisconsin and concluded that a standardized northern pike sampling protocol was a management priority. Pierce (1997) reported that, when used alone, various sampling techniques such as spring near-shore trapnetting, severely underestimated the size of northern pike populations in six Minnesota lakes. Pierce (1997) also suggested that northern pike sampling protocols should include various gear-types or techniques, due to the varying catchability and independent biases of each.

To further the understanding of tiger muskellunge behavior in Washington waters, this study was initiated to:

1. Evaluate the utility of using biotelemetry as a tool to describe fish movement behavior.
2. Evaluate the movement behavior of tiger muskellunge using ultrasonic biotelemetry and its effect on sampling efficiency.
3. Evaluate tiger muskellunge movement behavior using bi-weekly tracking data in Newman Lake and compare it to movement behavior previously described in Mayfield Reservoir.
4. Evaluate short-term (48-hour) movement behavior of tiger muskellunge in terms of travel rates and use-areas in Newman Lake.
5. Evaluate the limitations of various tiger muskellunge tracking protocols.

Study Area

Newman Lake

Newman Lake is a mesotrophic lake (Newman Lake Flood Control Zone District 2005) located 27 kilometers (km) east-northeast of Spokane, Washington, in Spokane County. The lake covers 486 hectares (ha), has a mean depth of 5.8 meters (m), and is 9.1 m at its deepest point. Summer surface water temperatures commonly exceed 25°C. The lake typically freezes over between November and March. Newman Lake has one main, perennial inlet, Thompson Creek, as well as other smaller seasonal streams that flow into the north end of the lake. Water exits the lake from the south via a water control structure and flows approximately 3 miles into a natural depression.

An extensive study in 1974 (Funk et al. 1976) showed that Newman Lake was rich in dissolved nutrients and exhibited poor water quality conditions, including near anoxic conditions at its greatest depth by late summer. In 1985-6, as part of Phase I of the Clean Lakes Restoration Project (United States Environmental Protection Agency), Newman Lake was surveyed again (Thomas et al. 1994) and was found to have conditions similar to those that existed in 1974, as well as problems with turbidity and poor transparency. By 1995, as part of Phase II of the Clean Lakes Restoration Project, several measures had been implemented to control the aforementioned problems including stream bank fencing, septic system management, ordinance development, and public education to increase awareness of the poor conditions. In 1992, a hypolimnetic aerator was installed to increase the dissolved oxygen concentration (Doke et al. 1995). In addition, an alum injection system was installed in 1997 (Moore et al. 1998) to reduce the amount of phosphorous in the water and control algal growth.

Spatterdock *Nuphar polysepala* is the most abundant, and most visible, native aquatic macrophyte in the lake (covering large sections of the extreme north, south, and west shoreline). Other native vegetation includes American waterweed *Elodea canadensis*, coontail *Ceratophyllum demersum*, water-shield *Brasenia schreberi*, big-leaf pondweed *Potamogeton amplifolius*, and fern-leaf pondweed *P. robbinsii*. Non-native, invasive aquatic macrophytes found in Newman Lake include Eurasion watermilfoil *Myriophyllum spicatum* and fragrant water lily *Nymphaea odorata*.

Newman Lake's fish community is composed primarily of spiny-ray populations and is probably best known for its tiger muskellunge and largemouth bass *Micropterus salmoides* fisheries. Tiger muskellunge were first introduced into Newman Lake in 1992, with an initial stocking of 679 fish. Since then, Newman Lake has been stocked with an average of 740 tiger muskellunge annually (Table 1). That stocking rate is the Washington target of one fish per two acres of surface area. Other warmwater game fish in the lake include smallmouth bass *M. dolomieu*, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, pumpkinseed *L. gibbosus*, yellow perch *Perca flavescens*, brown bullhead *Ameiurus nebulosus*, and yellow bullhead *Ameiurus natalis*. Non-game fish species in the lake include common carp *Cyprinus carpio* and tench *Tinca tinca*.

Table 1. Numbers of tiger muskellunge stocked into Newman Lake, Spokane County, from first stocking through 2011.

Year	Number Stocked
1992	679
1994	2366
1995	955
1997	999
1998	500
1999	400
2000	400
2002	500
2004	350
2005	700
2006	700
2007	400
2009	700
2010	700
2011	700

Methods

Transmitter Implantation

Ultrasonic transmitters were surgically implanted into 15 adult tiger muskellunge in April 2004 and 15 in May 2005. Total lengths of implanted fish ranged from 619 to 1,137 mm in 2004, and from 567 to 1,097 mm in 2005 (Table 2). One transmitter recovered from the shoreline substrate and one recovered from a fish tagged in 2004 were re-implanted into fish in April 2005. The temperature sensing transmitters (CTT-83-3) were 16 mm in diameter, 64 mm in length, and weighed 10 g in water (Sonotronics, Tucson, Arizona). The expected minimum battery life for all transmitters was 36 months. All fish were captured by boat electrofishing and capture locations were recorded using a Garmin (Map 235 Sounder) GPS unit. Prior to the implantation surgery, fish were individually anesthetized in a solution of tricaine methanesulfonate (MS-222). Surgical implantation procedures were similar to those used by Hart and Summerfelt (1975). For age determination, all fish were either scanned for coded-wire tags (since 2002, all tiger muskellunge stocked by WDFW have been tagged with coded-wire-tag wire, in differential, sub-dermal body locations to identify year-class), or scale samples were collected. Following transmitter insertion, each incision was closed using a CP-1 cutting needle and 2-0 PDS-II monofilament suture (Ethicon). All fish were allowed to recover in an aerated live-well prior to being released at their location of capture.

Table 2. Total length, weight, and age of tiger muskellunge, and date they were tagged in Newman Lake, Spokane County, Washington.

Fish Number	Length (cm)	Weight (kg)	Age	Date Tagged
69	113.7	12.4	7	Apr 19, 2004
70	72.3	2.5	5	Apr 19, 2004
71	64.6	2.0	3	Apr 19, 2004
72	105.4	10.2	7	Apr 19, 2004
73	72.4	2.4	3	Apr 19, 2004
74	61.9	1.5	3	Apr 19, 2004
75	69.4	2.4	3	Apr 19, 2004
76	82.6	3.6	5	Apr 19, 2004
77	93.3	5.4	6	Apr 19, 2004
78	83.1	4.4	5	Apr 19, 2004
79	65.3	1.8	3	Apr 19, 2004
80	82.7	3.2	5	Apr 20, 2004
81	92.0	4.9	6	Apr 19, 2004
82	84.6	3.8	5	Apr 19, 2004
83	69.8	2.2	3	Apr 20, 2004
69N	87.7	4.5	4	May 31, 2005
70N	89.2	5.5	4	May 31, 2005
71N	91.1	5.9	4	May 31, 2005
72N	59.0	1.3	2	May 31, 2005
73N	89.8	5.6	4	Jun 1, 2005
74N	82.0	3.7	4	May 31, 2005
75N	88.4	5.0	4	May 31, 2005
76N	78.4	2.8	3	May 31, 2005
77N	85.8	5.0	4	May 31, 2005
78N	76.2	3.3	2	Jun 1, 2005
79N	91.4	5.6	4	Jun 1, 2005
80N	109.7	9.4	7	May 31, 2005
81N	56.7	1.1	2	Jun 1, 2005
82N	93.7	5.0	6	May 31, 2005
83N	85.3	5.1	4	May 31, 2005

Because the U.S. Food and Drug Administration requires a 21-day withdrawal period for any food fish subjected to MS-222 (United States Food and Drug Administration 2008), temporary regulation changes were implemented on Newman Lake restricting anglers from harvesting any tiger muskellunge between April 19-May 23, 2004, and between May 31-July 29, 2005 (periods of fish collection and implantation surgeries). To assist anglers in identifying transmitter-implanted tiger muskellunge in the field, each study fish was marked with a fluorescent orange elastimer mark between the rays of the anal fin. To allow fish to acclimate to the transmitters, all tracking was delayed at least 2 weeks following implantation.

Bi-weekly Tracking

Tracking equipment consisted of a USR-96 narrow band scanning receiver and a DH-4 directional hydrophone. During 2004 and 2005, the entire lake was systematically searched by boat twice each month. A fish was assumed to be directly under the boat when the strength of the signal was equal in all directions and a reverberation in the receiver was detected (Tipping 2001). From direct comparison between this reverberation and physically observed fish, the accuracy of fish location using this equipment was estimated within 5 meters. Data recorded at each fish location included longitude, latitude, total depth, presence of vegetation and/or structure, and the pulse interval from the transmitter (which indirectly related to water temperature of the transmitter).

Water chemistry profiles were taken at two locations on the lake during each tracking event to determine dissolved oxygen (mg/l) and temperature (°C) at one- meter increments. Depths occupied by study fish were derived by comparing temperature relayed by each transmitter to the temperatures observed from the water chemistry profile. Tracking was discontinued during periods of ice cover (late November-mid March).

Hourly tracking

Unique behavior observed during portions of the two-week tracking prompted intensive hourly tracking to investigate short-term behavior. Intensive tracking entailed randomly selecting two tagged fish and locating them every hour for 24-hour (h) periods. Location times between the first and second fish during each tracking event were intended to be offset by 0.5 hours, but varied based on our ability to relocate individual fish. Data recorded during short-term tracking were similar to data collected during bi-weekly tracking. Intensive tracking in 2006 occurred on May 21-24 (4 fish), July 23-25 (3 fish), and August 21-22 (2 fish). One specific tiger muskellunge was tracked hourly for 24 hours, and then, because of its unexpected behavior, continuously for a 72-h period. Because of highly variable movement rates observed throughout the 72-h period, we decided that 48-h tracking events, rather than 24-h, would increase the chances of observing typical behavior for a given fish. As a result, hourly tracking for 48-h periods were conducted in 2007 as follows: May 7-9 (2 fish), May 30-June 1 (2 fish), August 6-8 (3 fish), August 13-15 (2 fish), September 16-18 (2 fish), and September 23-25 (2 fish).

Data Analysis

Sampling Efficiency

Locations of tiger muskellunge recorded during hourly tracking were compared to areas of Newman Lake that would typically be sampled using WDFW standardized lake sampling protocols (i.e., electrofishing, gill netting, and fyke netting no farther than 150 feet from shore) (Bonar et al. 2000). Only locations recorded during typical sampling hours (2000-0800 hours) were used in these comparisons.

Bi-weekly tracking data

Fish observations were divided into two groups (winter-spring and summer-fall) similar to those defined by Tipping (2001). Winter-spring locations were defined as those observed between November and June. Summer-fall locations were defined as those locations observed between July and October.

Winter-spring and summer-fall use-areas for individual fish were estimated by the minimum convex polygon method (Winter 1977) using ArcView 9.2 (ESRI 2006). Seasonal use-areas were derived from all locations of individual fish and often included locations from multiple years. Only fish that had at least three locations in both winter-spring and summer-fall groups were used. Statistical comparisons were not performed on seasonal use-area using bi-weekly locations.

Distance traveled was defined as the linear distance (m) between successive two-week locations and was measured using ArcView 9.2. Bi-weekly distance values were log-transformed to normalize the data. Although sample sizes were low, we used a Student's t-test to test for differences in distance traveled between seasonal groups for each individual fish tracked and for all fish combined. Only fish that had at least three locations in both winter-spring and summer-fall groups were used in these analyses.

Hourly tracking data

Travel rates were calculated by dividing the distance a fish traveled (m) by the lapsed time between the successive hourly locations. Due to unbalanced seasonal sampling, only hourly tracking data from 2007 were used in travel rate analyses. Hourly tracking values from 2007 were log-transformed to normalize the data. Differences in travel rates between seasons (spring, summer, and fall) were investigated using a mixed model ANOVA. Only fish tracked for a minimum of 48 h were used to evaluate 48-h travel rates.

Forty-eight hour use-areas (km^2) were estimated by the minimum convex polygon method using ArcView 9.2. Due to low sample size, 48-h use-area data collected in 2006 and 2007 were analyzed using only descriptive statistics.

Water depths where implanted tiger muskellunge were located were also evaluated using ArcView 9.2. Percentages of fish locations falling within five specific depth contours (0-2 m, 2-4 m, 4-6 m, 6-8 m, and 8-10 m) were derived by overlaying location data onto a bathymetric map of the lake.

Additionally, tracking locations from fish tracked hourly for 48-h periods in 2007 were divided into two groups; locations observed in daylight ("Day") and those observed in darkness ("Night"). Day and night delineations were based on sunrise/sunset tables for the lake vicinity. A mixed model ANOVA was used to test for differences in travel rates between day and night groups.

All tests were performed using either Minitab statistical software (Minitab, Inc. 2006) or SAS (Statistical Analysis Software 2009). Tests were considered statistically significant at $\alpha = 0.05$.

Results

From May 19, 2004 to September 19, 2006, 366 bi-weekly locations were recorded for 28 of the 32 transmitter-implanted tiger muskellunge. One fish was located 29 times, but the mean per fish was 13. By the end of the bi-weekly tracking portion of this study, the transmitter fleet had been reduced from 32 to 15 individuals. One tiger muskellunge was confirmed harvested and eight others had either died or expulsed their transmitters. The harvested fish was in good condition and the incision was completely healed. The fate of the other eight fish is unknown.

Sampling Efficiency

In 2006 and 2007, we recorded 431 separate tiger muskellunge locations between 2000 hours and 0800 hours (Figure 1). Of the 155 locations recorded in spring, 92 (59%) were observed in open water >150 ft. from shore. During summer, 181 locations were recorded, of which 136 (75%) were >150 ft. from shore. Sixty-five of 95 (68%) locations recorded in the fall were outside of the 150 ft. shoreline contour.

Comparisons of bi-weekly tracking data

Tiger muskellunge in Newman Lake utilized more lake area during winter-spring (November-June) than in summer-fall (July-October). Lake area used by tiger muskellunge in winter-spring ranged from 0.10 to 2.55 km^2 and averaged 0.95 km^2 (Table 3). Tiger muskellunge utilized areas in summer-fall ranging from 0.06 to 1.31 km^2 and averaged 0.55 km^2. Ninety-one percent (20 of 22) of individual winter-spring use-areas overlapped with summer-fall use-areas, whereas 9% (2 of 22) were exclusive.

Tiger muskellunge movement between 2-week locations averaged 892 m in winter-spring and averaged 671 m in summer-fall (Table 4). Approximately 90% of all bi-weekly movements in both winter-spring and summer-fall were greater than 100 m. Although most (68%) winter-spring bi-weekly movements were greater than summer-fall movements, only one was significantly different (fish 69, $t = 2.47$, df = 8, $P = 0.04$). Fish that moved farther in winter-spring (n = 10), moved an average of 2.8 (range 1.1-5.2) times farther in winter-spring than in summer-fall. Fish that moved farther in summer-fall (n = 7), moved an average of 1.9 (range 1.1-2.8) times farther in summer-fall than in winter-spring.

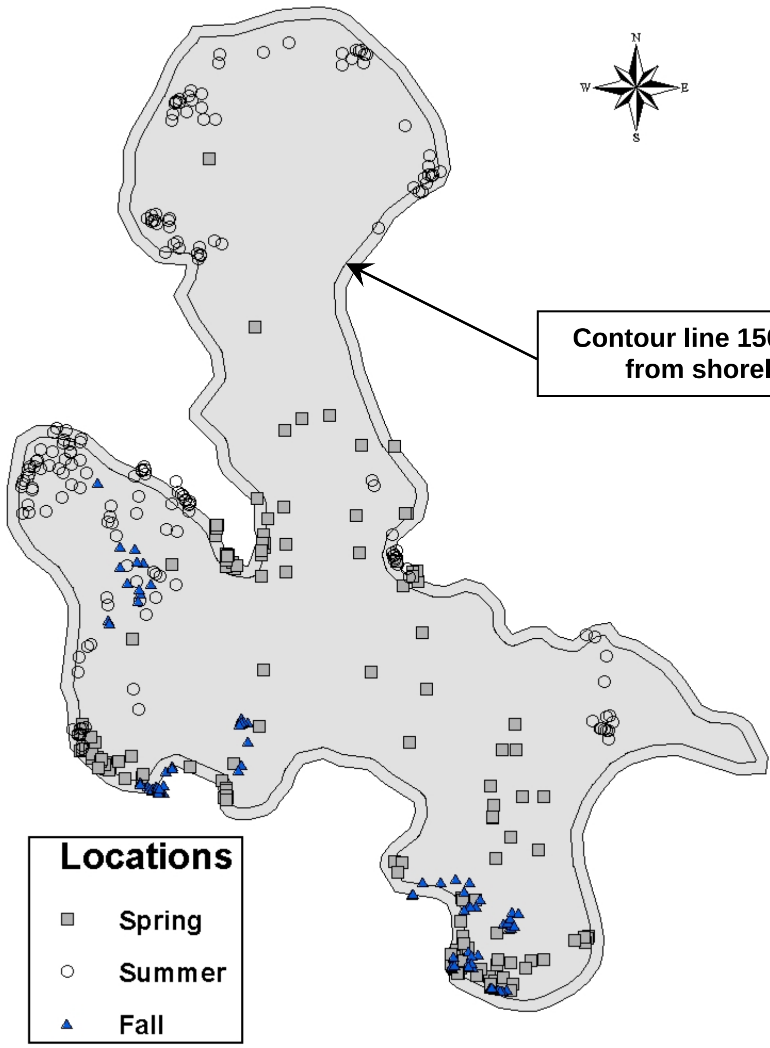

Figure 1. Map of Newman Lake, Spokane County, Washington depicting the contour line 150 ft. out from shore. The 150 ft. contour line represents the outer-most limit of the lake sampled using standard warmwater sampling protocols (Bonar et al. 2000).

Table 3. Estimated area (km^2) used by tiger muskellunge during winter - spring (November-June) and summer-fall (July-October) as determined by bi-weekly tracking in Newman Lake, Spokane County, Washington.

Fish Number	Winter-spring (km^2)	Summer-fall (km^2)
69old	1.79	0.62
72old	1.61	0.11
73old	0.86	0.06
74old	2.55	0.38
75old	1.09	0.54
78old	2.38	1.26
79old	1.35	1.31
80old	0.82	0.70
81old	0.72	0.94
81old-2	1.05	0.09
69new	0.93	0.84
70new	0.57	0.78
71new	0.10	0.22
72new	1.26	0.43
73new	0.22	0.23
75new	0.17	0.26
76new	0.12	0.54
77new	0.40	0.55
78new	0.56	1.19
80new	0.26	0.07
82new	1.74	0.54
83new	0.41	0.41
Mean	0.95	0.55

Table 4. Mean (SD) distance traveled (m) between successive two-week observations (N) during July-October, and November-June, and *P*-value for the comparison between distance traveled in the different time periods for tiger muskellunge in Newman Lake, Spokane County, Washington. Differences were significant at $P < 0.05$.

	Nov-Jun			Jul-Oct			
Fish number	N	Distance Traveled	Percent < 100 m	N	Distance Traveled	Percent < 100 m	*P* -value
69	4	1389.1 (827.1)	0.0	6	495.1 (743.2)	33.3	0.04
72	4	1689.7 (1495.0)	0.0	4	448.7 (363.9)	0.0	0.12
73	3	234.6 (66.2)	0.0	3	118.6 (148.5)	33.3	0.28
74	3	172.3 (72.8)	33.3	3	345.7 (288.0)	33.3	0.81
75	4	565.4 (413.3)	25.0	6	819.5 (329.6)	0.0	0.27
78	3	1560.4 (884.9)	0.0	6	688.6 (370.2)	0.0	0.11
79	4	426.4 (244.8)	25.0	4	1185.2 (660.5)	0.0	0.08
80	4	1736.8 (1069.6)	0.0	5	717.7 (599.9)	0.0	0.38
81	4	1407.0 (709.4)	0.0	6	648.7 (456.5)	0.0	0.11
69N	3	1151.4 (1051.9)	33.3	5	1288.8 (1072.7)	0.0	0.63
70N	6	380.2 (264.5)	16.6	3	868.6 (153.6)	0.0	0.10
75N	4	238.7 (179.7)	25.0	5	551.9 (570.2)	20.0	0.66
77N	5	1410.4 (406.7)	0.0	3	753.3 (417.8)	0.0	0.06
78N	5	827.7 (411.7)	0.0	3	1015.8 (896.8)	0.0	0.75
80N	5	516.9 (591.0)	20.0	3	100.0 (61.4)	66.7	0.19
82N	5	1027.2 (1057.2)	0.0	3	241.1 (156.4)	33.3	0.20
83N	4	527.4 (323.3)	0.0	3	497.6 (246.8)	0.0	0.95
Overall	70	892.4 (809.9)	10.0	71	670.6 (578.2)	9.9	0.06

Comparisons of hourly tracking data

From May 7 to September 25, 2007, 559 hourly locations were recorded from 13 tiger muskellunge. Travel rates exhibited by tiger muskellunge during the 48-h tracking periods averaged 108.4 m/h (range 2.0-616.8) in spring, 102.7 m/h (range 2.8-3650.1) in summer, and 49.4 m/h (range 1.2-456.3) in fall (Table 5). Mean travel rates were significantly different between seasons ($P < 0.001$). Pairwise comparisons of predicted means of seasons showed that tiger muskellunge were significantly more active in spring ($P < 0.001$) and summer ($P < 0.001$) than in fall (Figure 2). Although mean travel rates were greater in spring than in summer, they were not significantly different (P=0.11).

Table 5. Descriptive statistics of travel rates (m/h) for tiger muskellunge tracked hourly for a minimum of 48 hours in Newman Lake, Spokane County, Washington during 2007.

Season	Fish No.	No. hours tracked	No. locations	Min. rate	Max. rate	Mean rate
Spring	75N	48	40	6.0	616.8	125.8
	78N	48	28	5.9	451.4	175.8
	72N	48	47	2.0	356.9	76.5
	80N	48	42	4.5	574.4	82.6
				Overall Spring Mean		108.4
Summer	70N	48	47	3.3	473.2	86.3
	77N	48	34	9.6	317.9	83.5
	83N	48	36	3.7	250.8	63.5
	71N	48	47	2.8	357.7	73.8
	78N	48	48	2.8	3650.1	209.7
				Overall Summer Mean		102.7
Fall	72N	48	47	3.3	456.3	75.6
	75N	48	48	1.2	187.9	22.1
	72N	48	47	2.6	349.3	55.6
	80N	48	48	5.6	301.7	44.7
				Overall Fall Mean		49.4

Areas used by tiger muskellunge during the 48-h tracking periods averaged 0.65 km^2 in spring and ranged from 0.10-1.89 km^2. In summer, 48-h use-area averaged 0.36 km^2 and ranged from 0.06-1.45 km^2. During fall, tiger muskellunge 48-h use-area averaged 0.11 km^2 and ranged from 0.01-0.24 km^2 (Table 6).

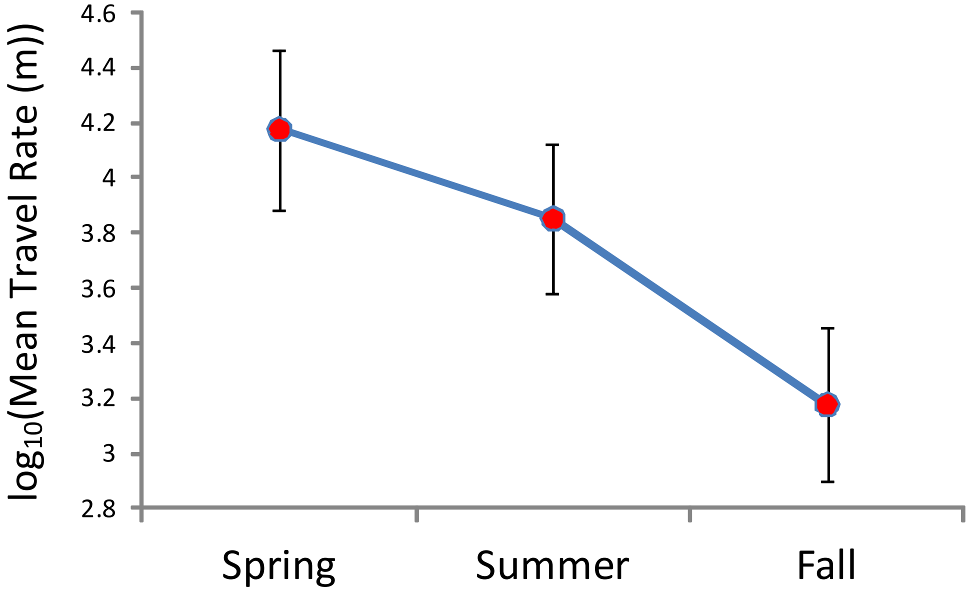

Figure 2. Mean travel rate, by season, with 95% confidence intervals, of tiger muskellunge tracked for 48 hours in Newman Lake, Spokane County, Washington during 2007.

Table 6. Areas (km^2) used by tiger muskellunge tracked for 48 hour periods in Newman Lake, Spokane County, Washington during 2006 and 2007. The location number marked with the asterisk was the 48 continuous hour period randomly selected from the 72 total continuous hours tracked.

Season	Fish No.	No. locations	48 hour use-area
Spring	78N	48*	1.89
	75N	40	0.32
	78N	28	0.79
	72N	47	0.10
	80N	42	0.16
		Overall Spring Mean	0.65
Summer	78N	47	0.44
	81 old	36	0.06
	78N	47	0.20
	70N	47	0.36
	77N	34	0.11
	83N	36	0.09
	71N	47	0.19
	78N	48	1.45
		Overall Summer Mean	0.36
Fall	72N	47	0.24
	75N	48	0.01
	72N	47	0.14
	80N	48	0.05
		Overall Fall Mean	0.11

During spring, tiger muskellunge most often occupied water less than 2 m in depth (Figure 3). The percentage of tiger muskellunge locations observed in depths of 6-8 m (19%) and greater than 8 m (15%) were similar, but less than half of what was observed in the shallowest depth contour (43%). Although most (32%) tiger muskellunge were observed in water 2-4 m deep during summer, similar percentages were also observed in the 0-2 m (27%) and 4-6 m (22%) depth contours. In the fall, tiger muskellunge were most often located in areas of the lake that were either shallow (0-2 m; 30%) or relatively deep (6-8 m; 34%).

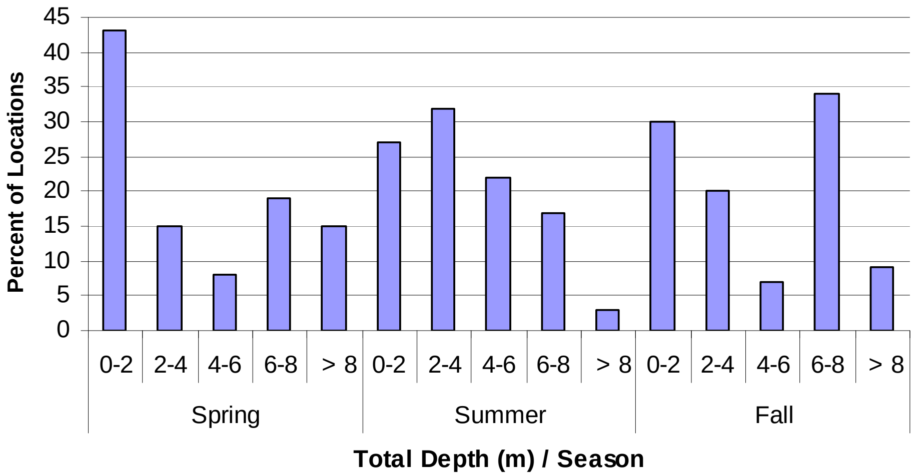

Figure 3. Percent of seasonal tiger muskellunge locations observed within specific depth contours of Newman Lake, Spokane County, Washington during 2006 and 2007. Data represent only those locations recorded during hourly tracking.

Results from the mixed model ANOVA show a significant difference in travel rates between season (i.e., spring, summer, fall; $P < 0.001$) and diel period (i.e., day, night; $P = 0.0047$), as well as the interaction between these two factors ($P = 0.0081$). During spring, tiger muskellunge were significantly more active ($P = 0.0002$) during the day than at night (Figure 4). Mean day-time and night-time travel rates were not significantly different during summer ($P = 0.627$) or fall ($P = 0.156$). Athough the two greatest day-time travel rates occurred during summer (3,650 and 1,809 m/h), a higher proportion of movements >200 m/h were observed during spring (29%) than in summer (16%).

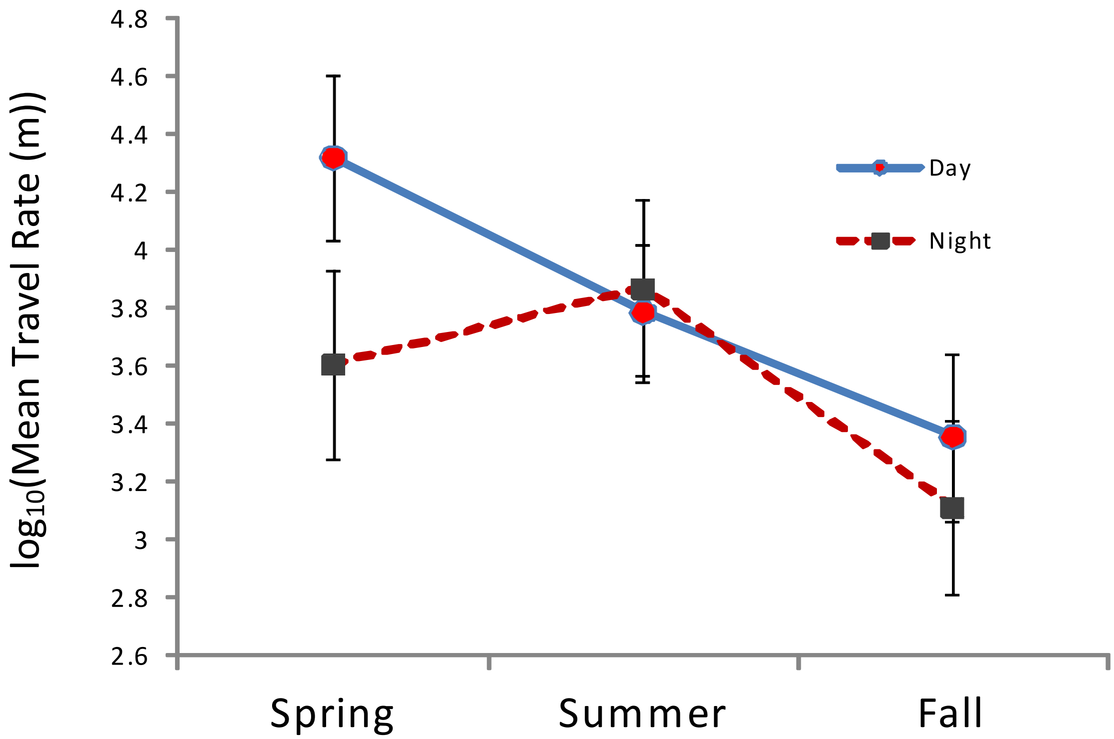

Figure 4. Mean day-time and night-time travel rates, by season, with 95% confidence intervals, of tiger muskellunge tracked for 48 hours in Newman Lake, Spokane County, Washington in 2007.

Discussion

Historically, WDFW's use of underwater biotelemetry to examine the behavior of warmwater game fish has been limited. Tipping's (2001) work on Mayfield Reservoir during the early 1990's was not only WDFW's most recent attempt at using this technique on warmwater fish, but was the only behavioral study on tiger muskellunge movement that we could find in the literature. As with most species dynamics, certain types of behavior, like movement, are likely to be lake-specific. To further the understanding of how tiger muskellunge function in lowland lakes, we initiated this biotelemetry study in Newman Lake to gain insight into tiger muskellunge movement patterns in a fish community markedly different than those typically stocked.

We found biotelemetry to be a useful tool to determine habitat use and monitor movements of tiger muskellunge in both the short and long term. Applying this technique allowed us to identify some unique and previously un-described movement patterns of tiger muskellunge. Some tiger muskellunge moved long distances and traversed large areas of the lake in short periods of time, while others remained more sedentary.

Efforts to determine the specific depth occupied by tiger muskellunge using temperature-sensing transmitters were unsuccessful although we could determine the depth of the water at the location in which the fish was located. Depth determination using these transmitters worked optimally in mid to late summer when stratification in Newman Lake was best defined. However, in spring to early summer, and in fall, lake stratification was not well defined and as a result, determination of specific depths occupied by tiger muskellunge was difficult. Future studies attempting to define occupied depths should use depth-sensing transmitters, rather than those that rely on cross-referencing depth with temperature.

The results of this study suggest that WDFW standard warmwater sampling protocols may not be highly effective for sampling tiger muskellunge populations. From locations recorded between 2000 hours and 0800 hours, we found that a relatively high proportion of tiger muskellunge occupied open water areas beyond what is sampled using WDFW standard lake sampling protocols (Bonar et al. 2000). Although WDFW standard sampling protocols are effective at sampling many warmwater species such as largemouth bass and sunfish, relative abundance of tiger muskellunge observed in these surveys, such as the 2000 Newman Lake survey (Osborne et al. 2004), may be underestimated. Considering this, the formulation of specific protocols for monitoring tiger muskellunge populations may be warranted. For some warmwater fish species, WDFW has adopted species-specific sampling protocols to monitor specific populations. In 2001, WDFW began using fall walleye index netting (FWIN) sampling protocols to monitor the walleye populations in the state (Morgan 2002). In 2010, WDFW also began using spring pike index netting (SPIN) sampling protocols to sample northern pike. These standardized protocols are useful in comparing those specific populations between waters and years. Similar species-specific protocols are needed to effectively sample tiger muskellunge populations. Considering that, further study may provide additional insight into tiger muskellunge behavior in other waters and bolster efforts to develop better protocols for monitoring tiger muskellunge populations.

Use-areas of Newman Lake tiger muskellunge varied greatly. Although larger during winter-spring, use-areas often overlapped with summer-fall use-areas. This result concurs with Tipping, as well as Miller and Menzel (1986) who observed similar behavior. Miller and Menzel (1986) reported that muskellunge in an Iowa lake became sedentary in late summer. However, these results contrast with those of Dombeck (1979) who reported that muskellunge in two Wisconsin lakes exhibited the smallest home ranges during winter. Ill-defined home ranges have also been reported for muskellunge (Crossman 1977) and northern pike (Dianna et al. 1977).

Seasonal movement patterns were similar between tiger muskellunge in Newman Lake and Mayfield Reservoir (Tipping 2001), where tiger muskellunge generally moved more during winter-spring than in summer-fall. However, mean distance traveled between observations in Newman Lake during winter-spring (892 m) and summer-fall (671 m) was about twice that observed in Mayfield for those same seasons (winter-spring 503 m; summer-fall 268 m). Tipping reported that 57% of summer-fall bi-weekly movements, and 30% of winter-spring movements in Mayfield Reservoir were >100 m. In Newman Lake, approximately 90% of both summer-fall and winter-spring movements were >100 m.

To our knowledge, short-term movement patterns of adult tiger muskellunge have never before been studied. During the 48-h tracking periods at Newman Lake, we observed a wide range of individual tiger muskellunge behavior, ranging from fish that occupied short sections of shoreline or particular bays, to fish that traveled many kilometers over short periods of time. Although some of the fish we tracked exhibited little or no movement, many others moved long distances and at high speeds; two previously undescribed traits of this “lie-and-wait” predator (Scholz and McLellan 2009; Wydoski and Whitney 2003). One particular tiger muskellunge, tracked hourly, moved a total of 15.8 km in 72 hours. On a separate occasion, this same fish traveled over 910 m in only 15 minutes (a travel rate of 3,650 m/h). Travel rates such as these have never been reported for tiger muskellunge, and only occasionally for either of the parent species (Dombeck 1979; Strand 1986; Cook and Bergersen 1988; Burkholder and Bernard 1994).

Coincident with the high travel rates, some tiger muskellunge utilized large areas of Newman Lake during the 48-h tracking period. In one instance, a tiger muskellunge traversed over 42% of the lake in 72 hours. Tipping reported that some tiger muskellunge movements encompassed over half of Mayfield Reservoir. However, his data were points collected bi-weekly over an 8-month period (winter-spring), and short-term movements were not investigated. Considering this, Tipping’s (2001) travel rates and use-area size may be underestimated.

Tipping (2001) reported that tiger muskellunge in Mayfield Reservoir were typically found in vegetated areas <2.5 m deep during summer and fall, and inhabited deeper, open water during spring. We found that, although tiger muskellunge utilized water <2 m to some extent, 73% of all summer locations, and 70% of all fall locations were in water >2 m. During spring, we found that more fish (43%) occupied the 0-2 m depth strata than any other.

Predation on salmonids by tiger muskellunge is certainly a concern in Washington, although most waters stocked with tiger muskellunge also contain trout. Considering this, Tipping (2001) suggests that predation potential may be reduced where tiger muskellunge are spatially segregated from salmonids during summer and fall, and undergo reduced metabolism during winter and spring when their habitats overlap. This may be true in Mayfield Reservoir; however, our results suggest that spatial movement patterns may be lake-specific. Fisheries managers should consider these differences when deciding which lakes to stock with tiger muskellunge, how many to stock, and the potential impacts they may have on salmonids if both species inhabit the same water.

Biotelemetry has been realized as a useful tool to examine behavior of warmwater fish species; however, there are limitations to its utility depending upon the tracking protocols used. Tiger muskellunge at Mayfield Reservoir were tracked at one and two week intervals, as were the fish during the early part of this study. However, several authors have suggested that variation in tracking frequency may influence results (Todd and Rabeni 1989; Clapp et al. 1990; Jones and Rogers 1998; Horton et al. 2004). This was realized in our study, as we found that much information can be lost when tracking over wide time intervals. For example, we tracked one particular fish during spring and recorded its locations every two weeks. Concurrently, we tracked the same fish for three consecutive days and recorded its locations each hour. Using the minimum convex polygon method (Winter 1977) to determine 72-h use-area, we observed that this fish occupied a large proportion of the lake during those three days (Figure 5). In contrast, a polygon encompassing all bi-weekly locations would suggest that this fish utilized a relatively small proportion of the lake during the same season; when in fact, the actual lake area used by this fish was much larger. Furthermore, none of the bi-weekly locations were encompassed in the area used during the 72-h tracking period which accentuates this point.

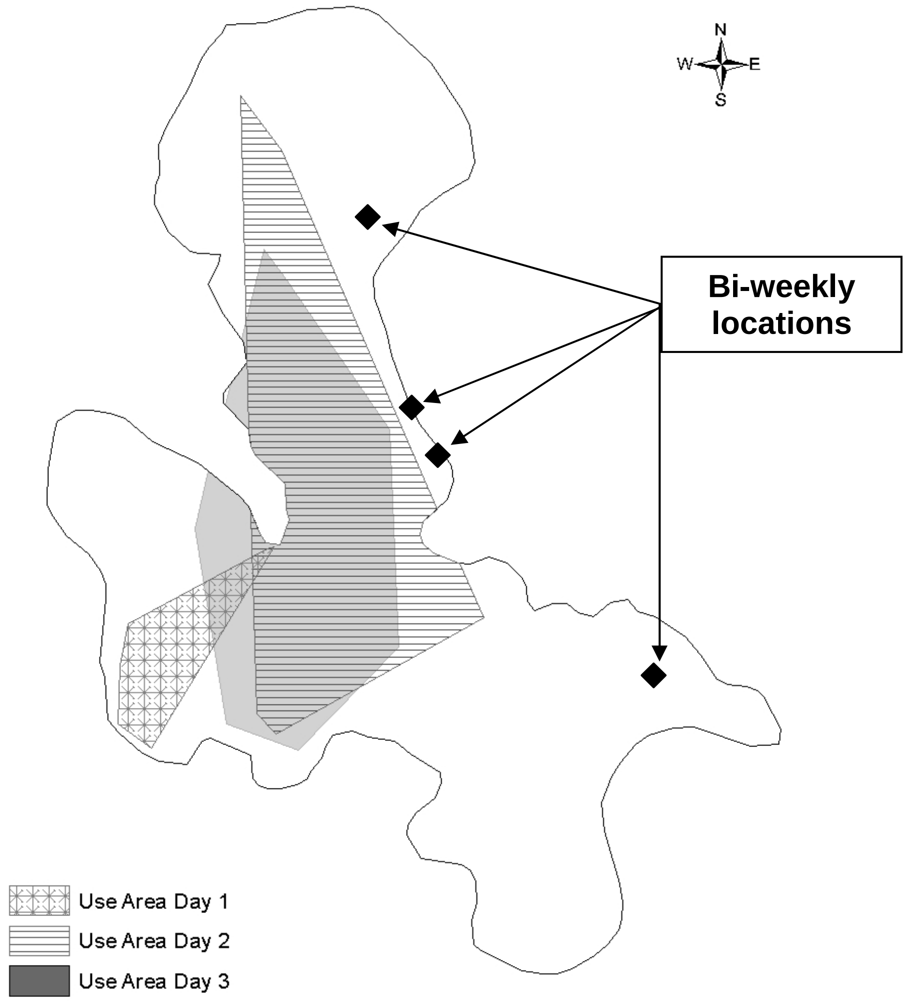

Figure 5. Areas of Newman Lake used by a single tiger muskellunge in spring, over 72 hours in relation to locations observed during bi-weekly tracking.

The tiger muskellunge movement and behavior observed at Newman Lake was both unique and unexpected. However, the reason for this is unknown. One possible explanation may be the limited abundance of preferred prey in Newman Lake. Esocids, including tiger muskellunge, prefer soft-rayed, fusiform prey up to ⅓ of their body length (Weithman and Anderson 1977; Gillen et al. 1981; Engstrom-Heg et al. 1986; Nilsson and Bronmark 2000; Baker and Bolding, in prep.). Previous warmwater survey data (Osborne et al. 2004; Osborne and Divens, in prep.) indicate that Newman Lake contains few prey species that meet those criteria, and tiger muskellunge, as a consequence, may be driven to search for food throughout large areas of the lake. At present, nutritional demands and consumption rates of tiger muskellunge are unknown. However, the tracking data collected in this study will bolster efforts to model tiger muskellunge bioenergetics. Knowledge of bioenergetics may ultimately help fisheries managers decide whether waters with limited preferred prey, such as Newman Lake, are suited for tiger muskellunge, or whether those fish initially destined for those waters would be better utilized elsewhere.

To determine whether tiger muskellunge behavior truly differs between lakes, further study is needed. Although some facets of our results (e.g., bi-weekly tracking) suggest that tiger muskellunge behavior is lake-specific, other parts of our study, such as short-term movement behavior, have never before been studied and should be considered baseline. We believe that future studies should be conducted on other waters, which vary in morphology and fish assemblages. In Washington, Curlew Lake (Ferry County) is a likely candidate. Curlew Lake is a relatively deep, mixed species water that was first stocked with tiger muskellunge in 1998 to utilize the abundant northern pikeminnow population and to produce a potential trophy fishery. In addition to northern pikeminnow, Curlew Lake contains populations of rainbow trout, largemouth and smallmouth bass, chiselmouth *Acrocheilus umatilla*, peamouth *Mylocheilus caurinus*, bridgelip sucker *Catostomu columbianus*, and largescale sucker *C. macrocheilus*, most of which fit the soft-rayed, fusiform shape criteria for tiger muskellunge preferred prey. Conducting a short-term behavior study at Curlew Lake would provide insight into whether tiger muskellunge behavior is truly lake specific. Knowledge of tiger muskellunge movement behavior, coupled with information obtained from diet studies and standard warmwater surveys, will not only help our agency manage this species to its potential, but may also provide useful information to the angling public who target, or would like to fish for tiger muskellunge.

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