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HABITAT PREFERENCES AND MOVEMENT PATTERNS OF THE LAKE STURGEON (*ACIPENSER FULVESCENS*) IN BLACK LAKE, MICHIGAN[1]

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
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Committee members

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I thank my parents, Mariette and Richard Hay for their encouragement and support which has always been present throughout all my endeavors.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Lake sturgeon (Acipenser fulvescens) were tracked daily using biotelemetry in Black Lake, Michigan, during the summers of 1985 and 1986 and for 2 weeks in October 1986 and January 1987. Sturgeon exhibited depth preferences of 10.3 ± 2.14 m (mean ± SD) in summer and 7.1 ± 0.76 m in winter. Muck was the preferred substrate, correlating with the preferred depth and preferred foods (crayfish and mayfly larvae). Lake sturgeon neither schooled nor aggregated, and diel activity rhythms were absent. The fish exhibited a wide range of daily movements from 18 to 6,877 m day^{-1}. They did not have a home range. The amount of linear movement was positively correlated with water temperature ($r = 0.9425$). Body length (L) and average daily linear movement (S) were best described by $L = 7731.8 - 101.05S + 0.38S^2$. No differences were noted in amount of linear movement based on sex of the fish.

INTRODUCTION

The study of sturgeons in North America (family Acipenseridae) has significantly increased in the last decade (McCleave et al. 1977; Haynes et al. 1978; Dadswell 1979; Haynes and Gray 1981; Buckley and Kynard 1985; Thuemler 1985; Wooley and Crateau 1985; Threader and Brousseau 1986) as many species are on the United states federal endangered species list (Anon 1983a). This research has led to the development of management plans to maintain these species and protect their habitat (Haynes et al. 1978; Dadswell 1979; Thuemler 1985; Wooley and Crateau 1985; Threader and Brousseau 1986).

Lake sturgeon (*Acipenser fulvescens*), which reside in the Mississippi, Great Lakes--St. Lawrence, and Hudson Bay drainage basins (Harkness and Dymond 1961) are currently classified as rare by the United States Department of the Interior (Anon 1983a) and threatened by the American Fisheries Society (Deacon et al. 1979). In the State of Michigan, the Department of Natural Resources considers lake sturgeon to be threatened (Anon 1983b). Protection is provided to those populations which cannot sustain any fishing pressure and a controlled harvest is permitted on the others. However, as lake sturgeon have not been studied as comprehensively as other species, management of this important fish is hampered by lack of data.

An important component of management practices is knowledge of microhabitat use by a species and their movements within that habitat. Data on sturgeon microhabitat choice are equivocal. The most complete description (Harkness and Dymond 1961), indicates that lake sturgeon are a shallow-water fish most commonly caught over mud substrates, at depths less than 4.6 m. However, they also cite other instances where lake sturgeon were captured at greater depths and over various substrates, suggesting that the availability of food may influence habitat selection.

Information on lake sturgeon movements is vague and conflicting. Harkness and Dymond (1961) list differing accounts of amount and extent of movements, but report that fish in lacustrine environments generally have restricted movements. Priegel and Wirth (1971), based on evidence from mark-recapture experiments in Lake Winnebago, stated that sturgeon travel widely but have a home basin. Bassett (1982), using radio telemetry, concluded that sturgeon in Indian Lake move little, usually less than 1 mile during the whole summer.

Seasonal and diel patterns of movement have not been studied for lake sturgeon. White sturgeon (*Acipenser transmontanus*) alter their movement patterns with respect to water temperature (Haynes et al. 1978), and Gulf of Mexico sturgeon (*Acipenser oxyrhynchus desotoi*) show seasonal migration patterns which appear to be temperature related

(Wooley and Crateau 1985). White sturgeon exhibit diel activity patterns, altering the depths they occupy at different times of the day (Haynes and Gray 1981). This same trend has been noted in juvenile Russian sturgeon (Acipenser gueldenstaedti) (Levin 1981). However, shortnose sturgeon (Acipenser brevirostrum) do not exhibit distinct diel differences in behavior (McCleave et al. 1977). As the habitat of the white and Russian sturgeon is more similar to that of lake sturgeon (Haynes and Gray 1981; Levin 1981), it was hypothesized that lake sturgeon behavior would show similar diel locomotor behavior patterns.

It has been suggested that sturgeon may school (Williams 1951; Priegel and Wirth 1971). Dadswell (1979) suggested that schooling and pair bonding may occur for shortnose sturgeon, as fish captured in the same locality on the same day at the start of the study, were recaptured together after 1 year or longer.

In view of these uncertainties, and the importance of additional data for improved management practices, this study sought to determine habitat preferences and daily and seasonal movement patterns of lake sturgeon. On the basis of previous observations, noted above, it was hypothesized that: (1) lake sturgeon prefer depths of 3-6 m; (2) lake sturgeon choose their microhabitat with respect to food distribution; (3) lake sturgeon exhibit diel activity patterns; (4) lake sturgeon have individual home ranges within a lake; and (5) lake sturgeon have different seasonal movement patterns, being less active in winter. In addition, correlates with linear movement were sought on the basis of body length, sex, and order of capture of the fish.

STUDY SITE

Black Lake is a 4,101-ha brown-water lake located in the northeast section of the Lower Peninsula of Michigan, Presque Isle and Cheboygan counties, (45° 29' 55" W, 84° 19' 22" E) (Figure 1). The major inflows are the upper Black and Rainy river systems, with four additional streams making minor contributions. The lower Black River is the only outflow. The lake has a large shallow sandy perimeter which first gradually (1:0.0033) and then sharply (1:0.0615) slopes to a large flat muck basin in the southern portion (Figure 2). Maximum depth is 16.7 m.

Black Lake sturgeon, originally part of the Great Lakes population, have been isolated from Lake Huron since 1903 by a dam constructed at Alverno, 8 km downstream from the lake. Upstream migration on the Black River terminates at Kleber Dam, 11 km from the river's mouth. The Rainy River has never been known to contain lake sturgeon (M. Shouder, Michigan Department of Natural Resources, personal communication), and the four other streams are too shallow for adult sturgeon to enter (<0.1 m).

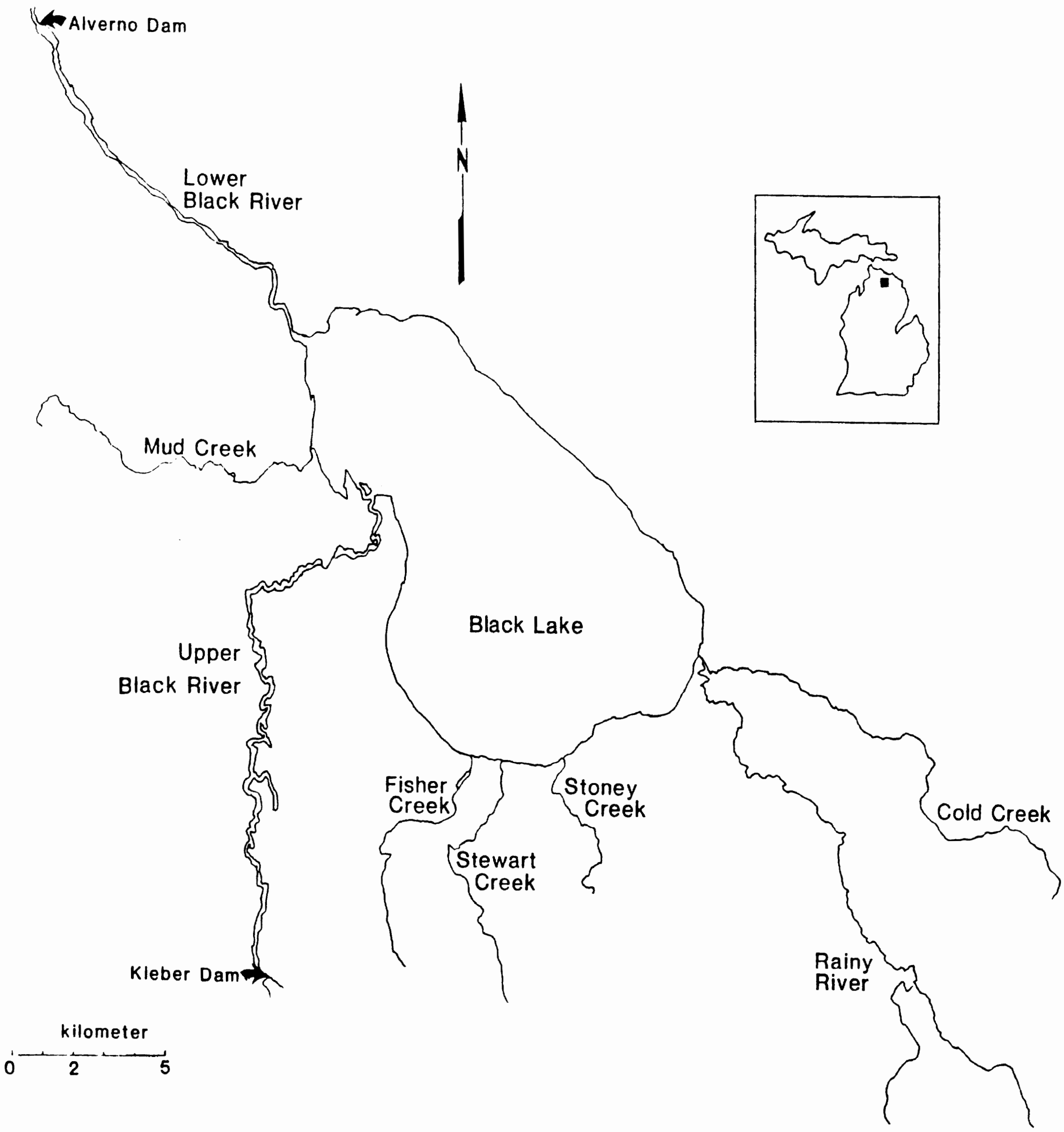


Figure 1. Map of Black Lake in Cheboygan and Presque Isle counties, Michigan (inset).

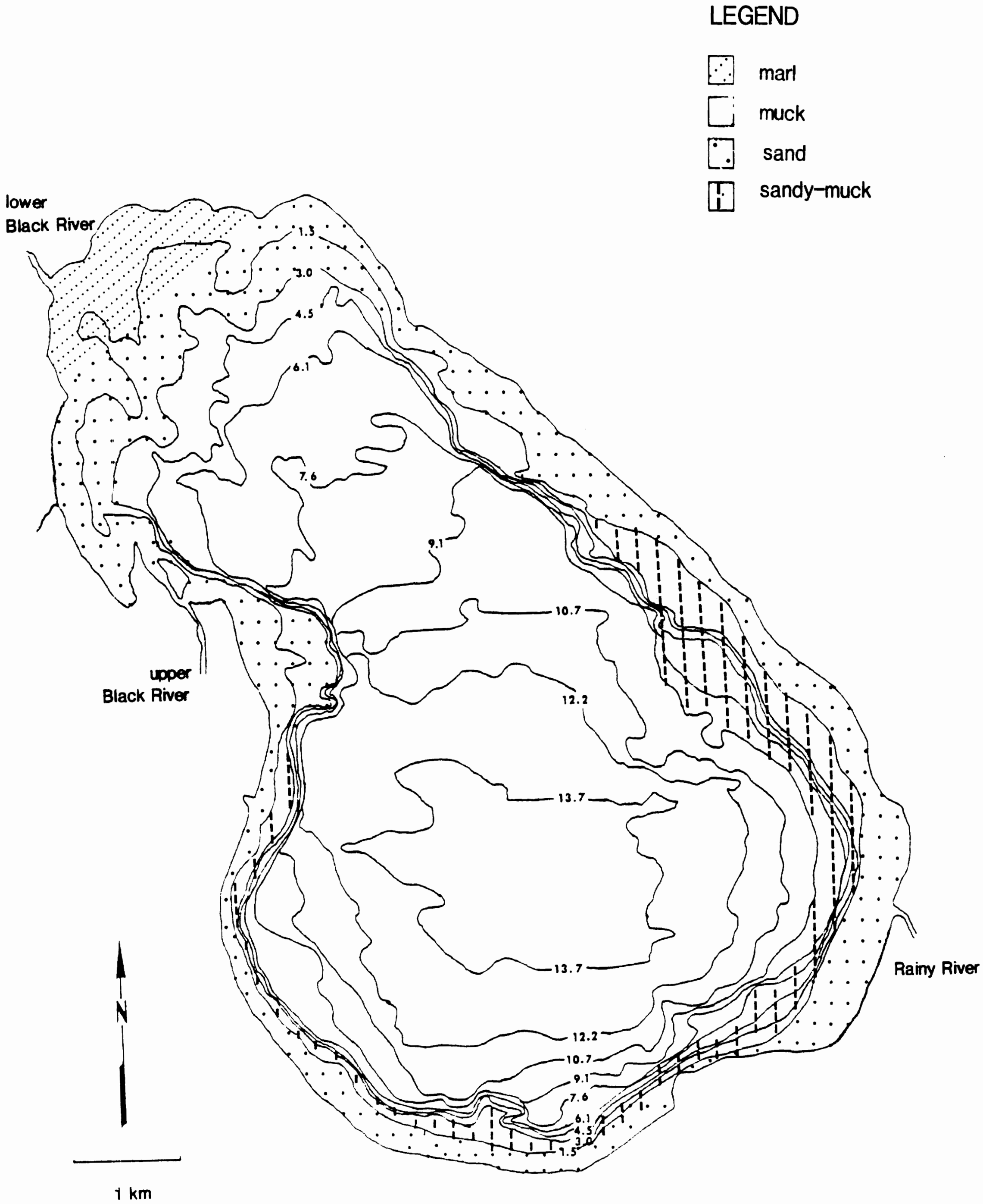


Figure 2. Depth contours (m) and substrate types in Black Lake, Michigan.

METHODS

Twelve sturgeon were captured during spring spawning in 1985 and 1986. In May of 1985, three fish were captured using long-handled dip nets at a spawning site near Kleber Dam. A fourth sturgeon was taken in the lake by gill net. In May of 1986, eight sturgeon were captured in the lake off the mouth of the upper Black River using gill nets, two sturgeon being caught one day each week for four consecutive weeks. For three of these weeks, the two fish were caught simultaneously and were assumed to have been swimming together.

Upon capture, sturgeon were taken immediately to shore and placed on a stretcher. Each fish was measured for total length (cm) and weight was estimated by sight (kg). The head of the fish was enclosed in a wet burlap sack which helped keep it docile throughout the surgical procedure. An incision 4-6 cm in length was made 15- to 20-cm anterior and left of the vent. Sex was determined visually, then a transmitter was inserted and attached to the body wall, using the posterior suture closing the incision. This procedure prevented the fish from extruding free-floating transmitters through the intestine (Summerfelt and Mosier 1984; Chrisholm and Hubert 1985; Marty and Summerfelt 1986). In 1985 radio (AVM fish modules) transmitters were used and in 1986 ultrasonic (Sonotronics UCTT-85) transmitters. The incision was closed by four to six sutures and then painted with malachite green, as were any visible sores. Each fish was injected with tetracycline (50 mg/kg) as a prophylactic measure. The entire surgical procedure lasted approximately 10 minutes.

All fish collected were released into the river, at the site of capture for those from the river and at the mouth for those from the lake, and held facing into the current until they actively struggled to swim off, usually after 1 to 6 minutes. Released fish swam to the middle of the river, oriented with their heads upstream, and remained in this position from 15 minutes to 6 hours.

In 1985 the positions of all sturgeon were sought daily from implantation until mid-July. In 1986 the positions of sturgeon were sought daily from the day of implantation until the end of August, for 2 weeks in October and for 2 weeks in January. To avoid possible abnormal behavior due to capture and surgery, sitings for the first week after implantation were not included in the results. Sturgeon were tracked with a radio antennae in 1985 and a directional hydrophone in 1986. A fish was considered located when the transmitted signal could be received at any point in a 360° circle when the gain of the receiver was reduced to the lowest level (Winter 1983). Upon location the position was determined by triangulation on shore landmarks (accuracy ±5 m).

Each time a sturgeon was located during the summer months, a benthic sample was taken using an Ekman grab and the substrate type noted. Depth of the water column was recorded for all sitings. I assumed the fish were near the bottom, as sturgeon are a bottom-dwelling species (Harkness and Dymond 1961). Once each day a temperature-oxygen profile was determined with a Yellow Springs Instrument (YSI) dissolved oxygen meter.

Benthic samples were preserved immediately with 4% formalin. Later the same day each sample was washed in a 500-micron sieve and all remaining material sorted. Molluscs were left to air dry and other organisms were placed in a vial with 70% ethanol. Benthos were identified to genus or species wherever possible, and the number of each was recorded. The number of organisms per square meter was calculated for each substrate type and for water depth intervals of 3 m.

Substrate preferences of sturgeon were determined by calculating the percent occurrence over each bottom type. Four different substrate types were visually identified in Black Lake--muck, sand, sandy-muck, and marl (Figure 2). Muck was defined as soft material largely of organic origin without sand intermingled, but composed of silt and clay with considerable amounts of organic material. Sand was material of crystalline rock origin less than 0.3 cm in diameter but still large enough to be palatable as grit. Sandy-muck was an approximately equal combination of the above two types. Marl was a calcareous material composed principally of carbonates (Dodge et al. 1981).

One-way analysis of variance (ANOVA) or Kruskal-Wallace (KW) tests were used to detect differences in the depth distributions among individual sturgeon and between the months located. Duncan's multiple range test was used to differentiate between preferred and avoided depths.

Mean monthly temperature and oxygen profiles were calculated for the water at 0-, 5-, 8-, and 10-m depths.

Gut contents were analyzed for 13 sturgeon speared by fishermen during the February 1986 season. The gut was divided into stomach, pyloric apparatus, and 10-cm sections of the fore and hindgut. All organisms, except oligochaetes, were identified to family and genus where possible and the number recorded. Oligochaetes were identified to class. Percent occurrence, wet biomass (g), and electivity indices were calculated for each major group using average abundance data from all bottom types combined (Ivlev 1961).

For 3 weeks in July 1986 and 2 weeks in January 1987, sturgeon were monitored to determine diel activity patterns. Fish were observed for 4 to 12 consecutive hours on successive days until a 24-hour cycle had been completed. Sturgeon locations were obtained every hour and hourly linear displacement movements were computed. Checks were made at least four times per hour to determine if a fish was actively moving and its direction.

Sturgeon locations were plotted on maps of Black Lake which had been prepared from a combination of aerial photographs, topographic maps, and lake inventory maps. Average daily linear movement was calculated as the straight-line distance traveled on consecutive days divided by the number of consecutive days. Home range was estimated by the minimum area method (Winter 1977). A two-way analysis of variance was used to determine if data for individual sturgeon could be combined for daily linear movement. Correlations between daily linear movement and (1) body length and (2) sex were determined.

The possibility that sturgeon schooled or formed aggregations was determined by comparing the straight-line distance between the two fish which had been captured for implantation at the same time (three pairs). The monthly average distance separating each pair and the overall monthly average were determined.

Results for all statistical tests were considered significant at $P \leq 0.05$ and data were verified for normality using the Lilliefores test (Conover 1980). All numerical data are shown with ± one standard deviation.

RESULTS

In 1985 radio transmitters proved to be ineffective for tracking lake sturgeon, as locations could not be determined consistently when the fish were deeper than 5 m. Therefore the depth, activity, and movement data are for the eight lake sturgeon tracked using ultrasonic transmitters in 1986-1987. Four fish were female and four were male. The fish ranged from 112 to 179 cm in length.

Lake sturgeon displayed no differences among individuals with respect to depth distribution (KW, $P = 0.7582$). However, significant depth preferences within the lake were shown (ANOVA, $P = 0.0006$) (Figure 3). Seven and 10 m were more common over all other depths, and areas of 1-, 2-, 3-, and 15-m depths were less common (Duncan's Multiple Range test, $P \leq 0.05$). No differences were detected among preferred depths based on the month in which the sturgeon were located ($P = 0.5560$), except that mean winter depth of 7.1 ± 0.76 m was significantly less than the 10.3 ± 2.14-m mean summer depth.

Muck was the most available bottom type in Black Lake, and it was utilized 74.8% of the time. It was present at depths from 3 - 17.8 m, but the fish were located most frequently (86%) along the sloped regions. The flat area in the deepest part of the lake was used infrequently (Figure 4). Sturgeon were located over sand 15.4% of the

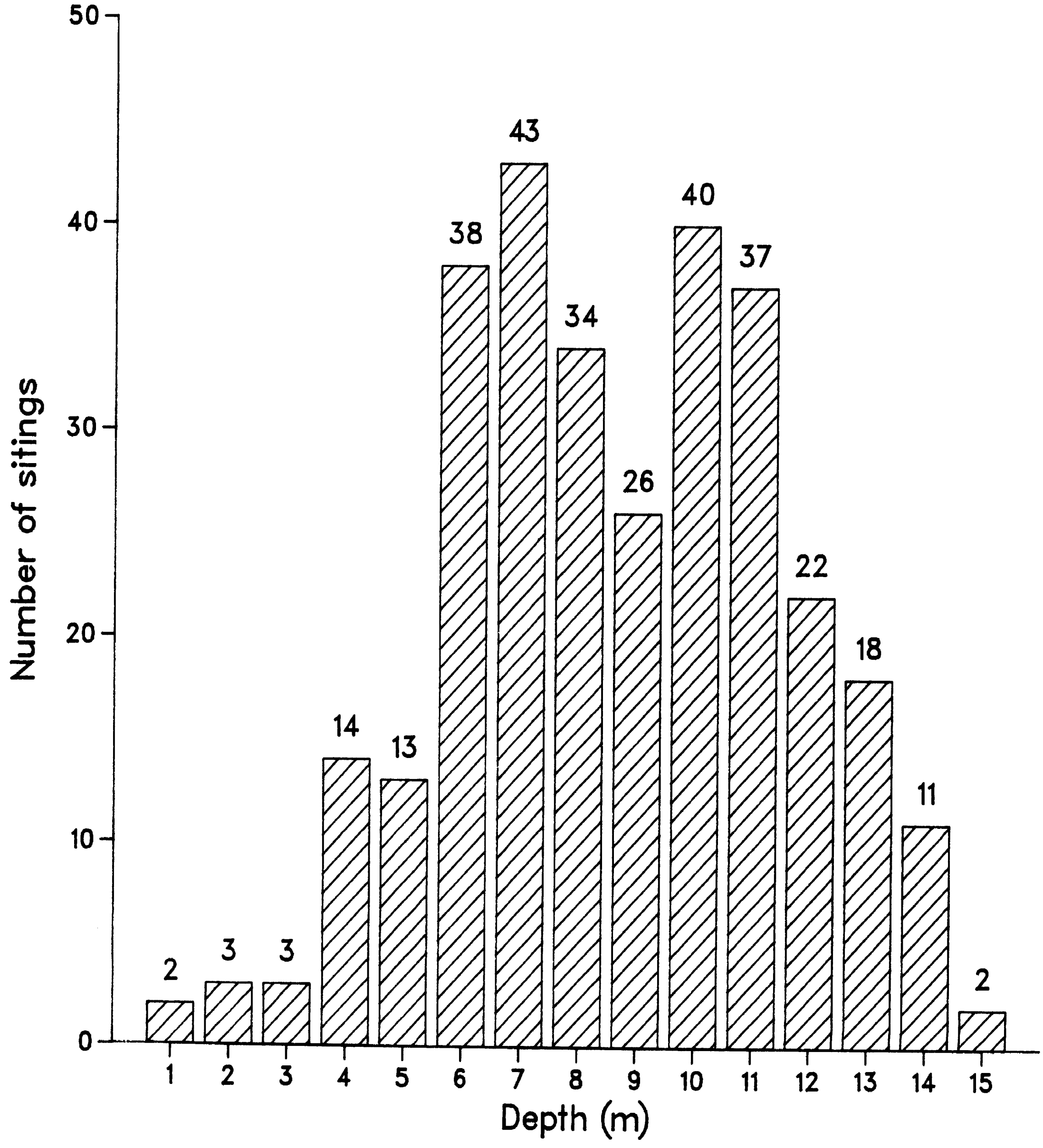


Figure 3. Number of lake sturgeon sitings at various depths.

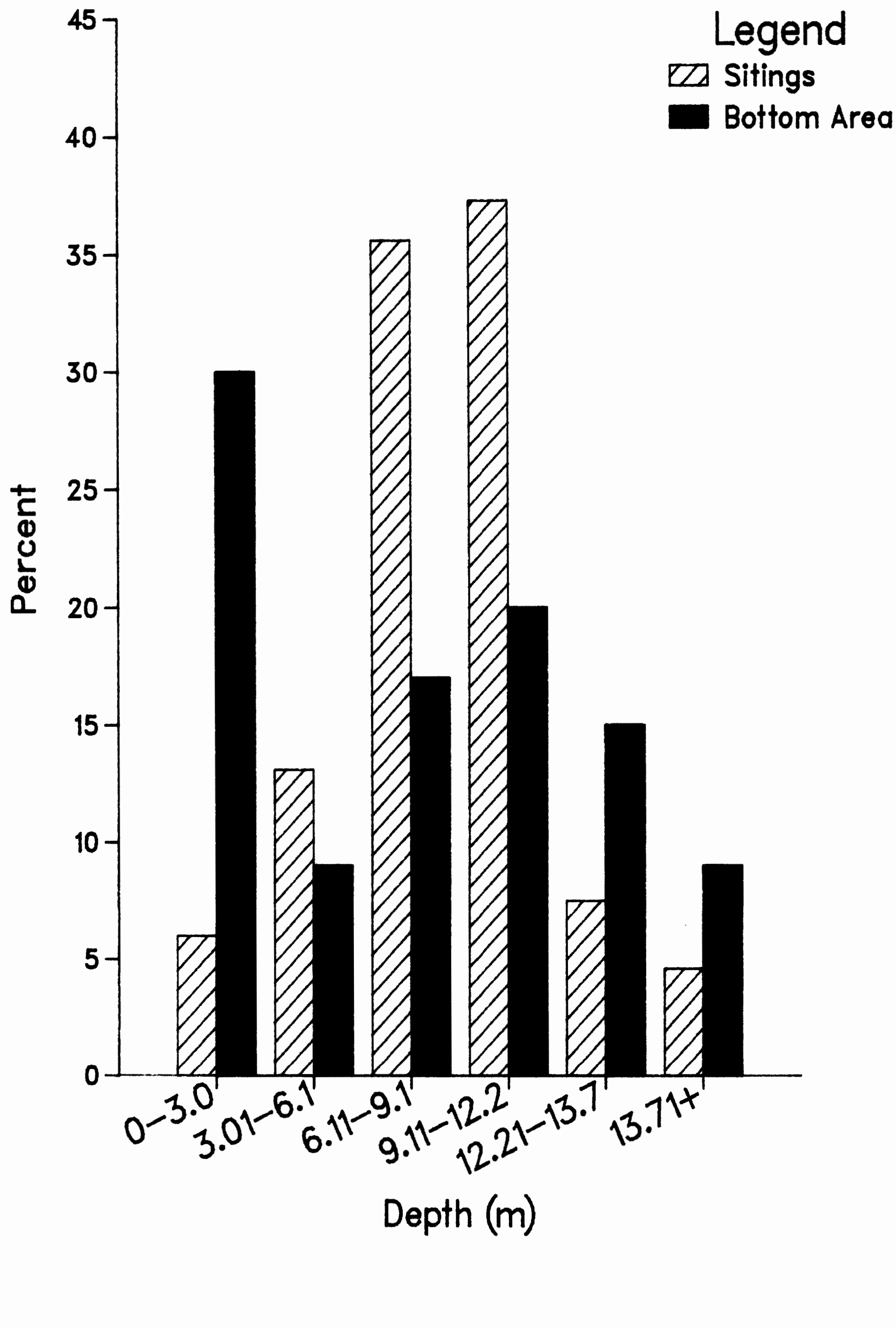


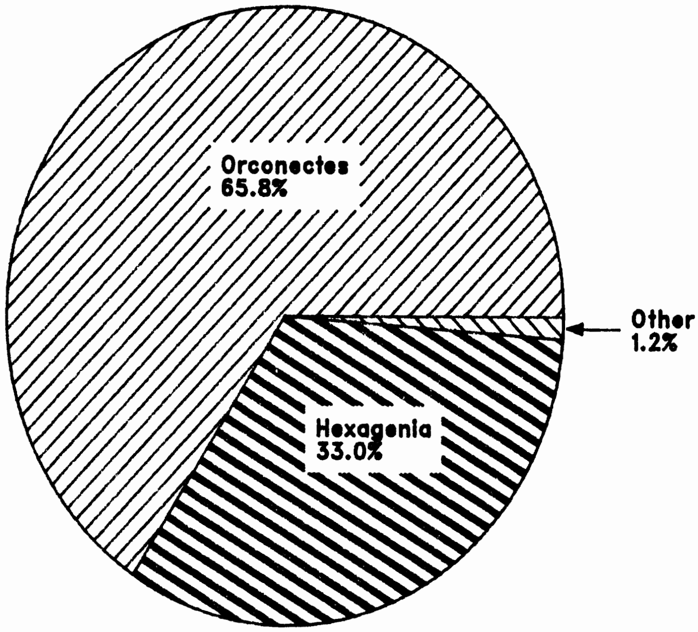
Figure 4. Percent of lake bottom for various depth categories and occurrence of lake sturgeon sitings at each depth.

time and this substrate ranged from 1.3 - 6.3 m in depth. Sandy-muck, which occurred at depths of 1.3 - 11.0 m was used only 9.8% of the time, but was also not readily available except on the steep contours along the southern portion of the lake. Marl was located only in the northern portion of the lake (depths 1 - 2.5 m) and tagged lake sturgeon were never located over this substrate. However, two visual sitings of non-tagged sturgeon were made in the deepest portion of this area during the course of the study.

Temperature profiles (May - January) indicate that a thermocline did not form in Black Lake. Water temperatures differed by 1.3 ± 2.1°C between the surface and bottom. The oxygen levels (percent oxygen saturation = 95.35% ± 8.97, n = 42) were similar between the surface and the bottom of the lake.

Gut contents of speared sturgeon (132 to 193 cm in length) contained representatives of six taxonomic groups (Figure 5B). In the foregut (mean length = 46.83 ± 11.46 cm), 71.4% of the food was in the 20-cm anterior to the stomach. In the hindgut (mean length = 73.83 ± 11.88 cm) 80% of the food was in the 50-cm posterior to the stomach. Except for one fish, all sturgeon had food present in their stomachs. Only leeches were found in the vicinity of the pyloric apparatus. All food was encapsulated in mucous. In winter, crayfish comprised the largest biomass component of the gut contents followed by mayfly larvae, which were the most numerous food item (Figure 5A). Leeches and

A



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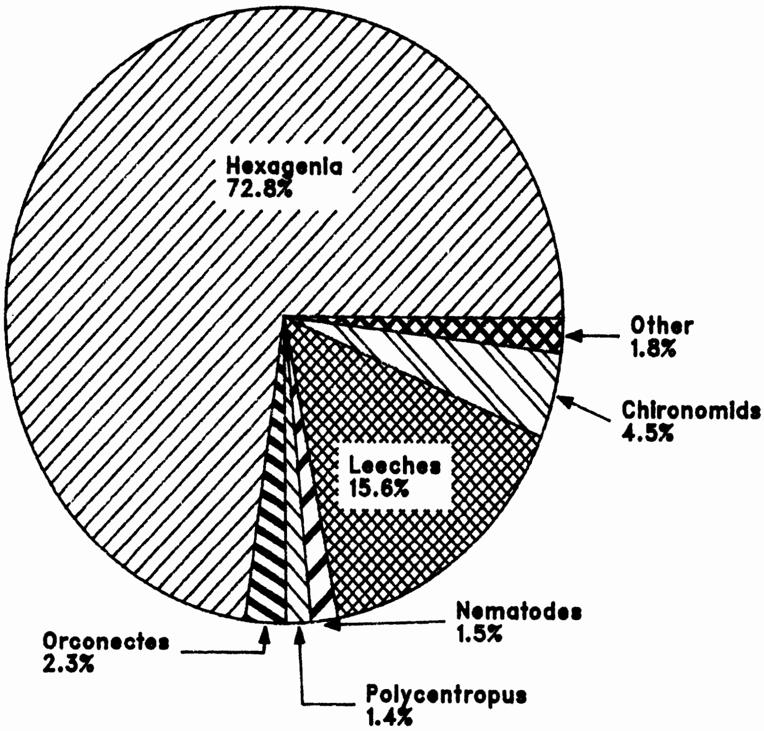

Figure 5. A. Biomass of food items from the guts of lake sturgeon speared in February 1986.

B. Percent occurrence of food items from the guts of lake sturgeon speared in February 1986.

chironomids were the next most numerous items, but contributed little to the biomass.

Benthos samples yielded 33 different organisms (Appendix 1). Five taxonomic groups composed the bulk of the samples. Hexagenia sp., chironomids, and molluscs were well represented on three substrates (Figure 6) and in depths over 3 m (Figure 7). Chaoborus punctipennis were in the deeper muck and sand-muck substrates and Pontoporeia hoyi in the shallower sandy-muck and muck substrates. Crayfish were not found in any of the samples.

Seven groups of organisms were found both in the gut contents of lake sturgeon and in the environment. All seven groups were found in high densities in muck, which was the preferred substrate of sturgeon. Electivity indices (Figure 8) showed that mayfly larvae, caddisfly larvae, and Amnicola, a mollusc, were positively selected.

No diel periodicity of activity was found. Lake sturgeon appeared to spend the majority of their time at the bottom of the water column, as indicated by the intensity of the ultrasonic signal. Occasionally sturgeon were seen rolling on the surface of the water or jumping out, but no pattern was evident for this behavior.

In summer, adult lake sturgeon moved continuously over 24 hours (Figure 9) and exhibited two behavioral patterns. The first was "milling" where the fish continuously moved over a small area. Activity ceased for periods of 2-3 minutes at irregular intervals. During milling lake

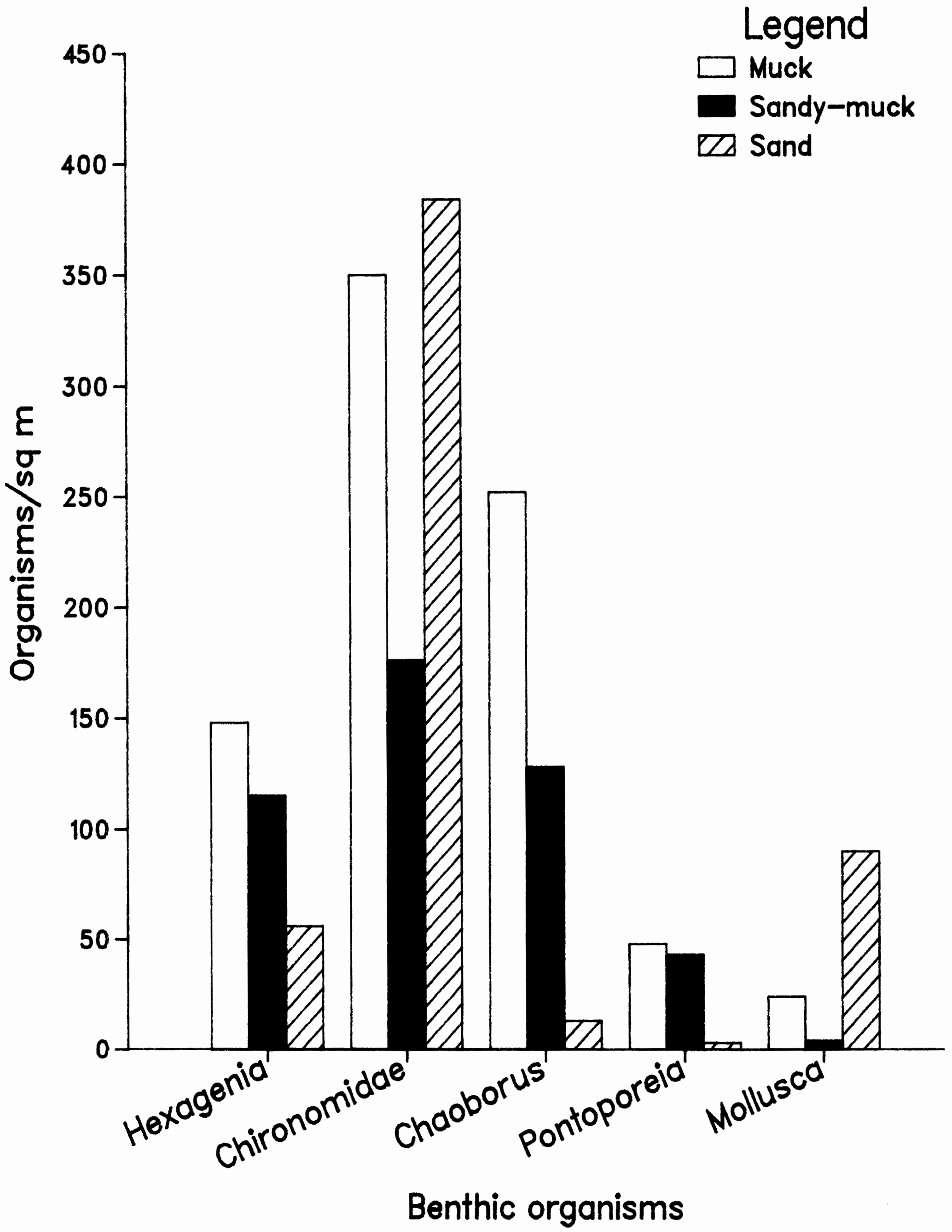

Figure 6. Mean number of most common benthic organisms per square meter in different bottom substrates.

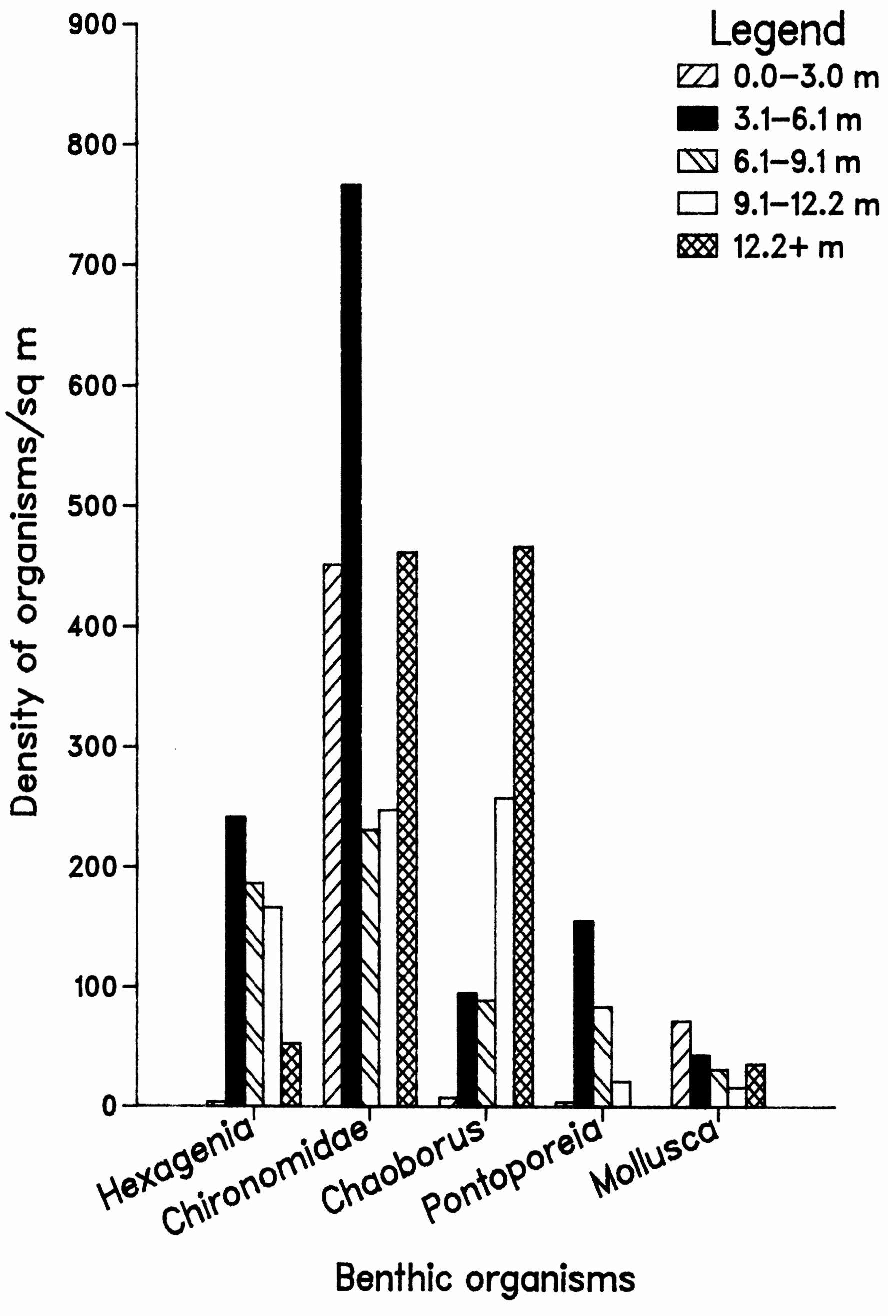

Figure 7. Density of most common benthic organisms per square meter at various depth categories.

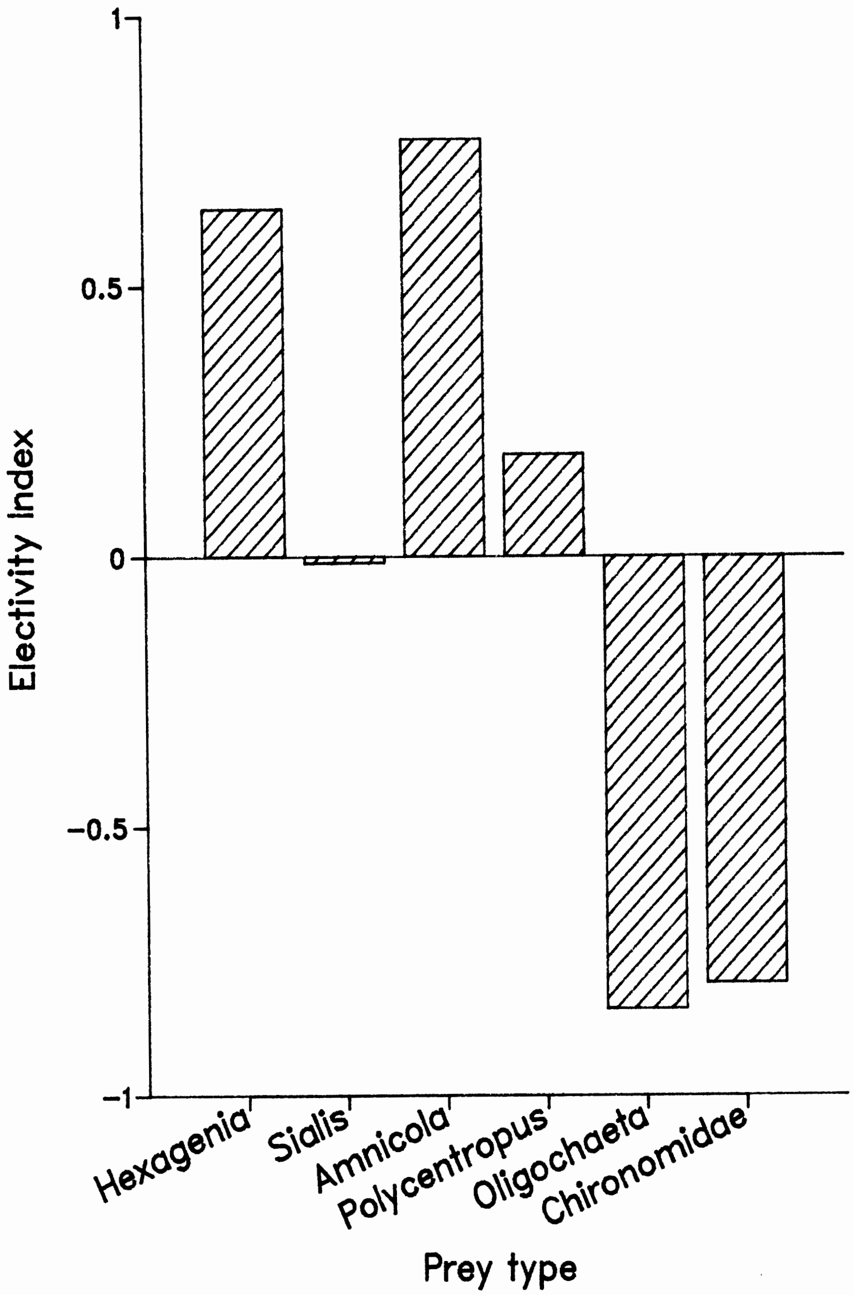

Figure 8. Electivity indices for prey types found in lake sturgeon guts.

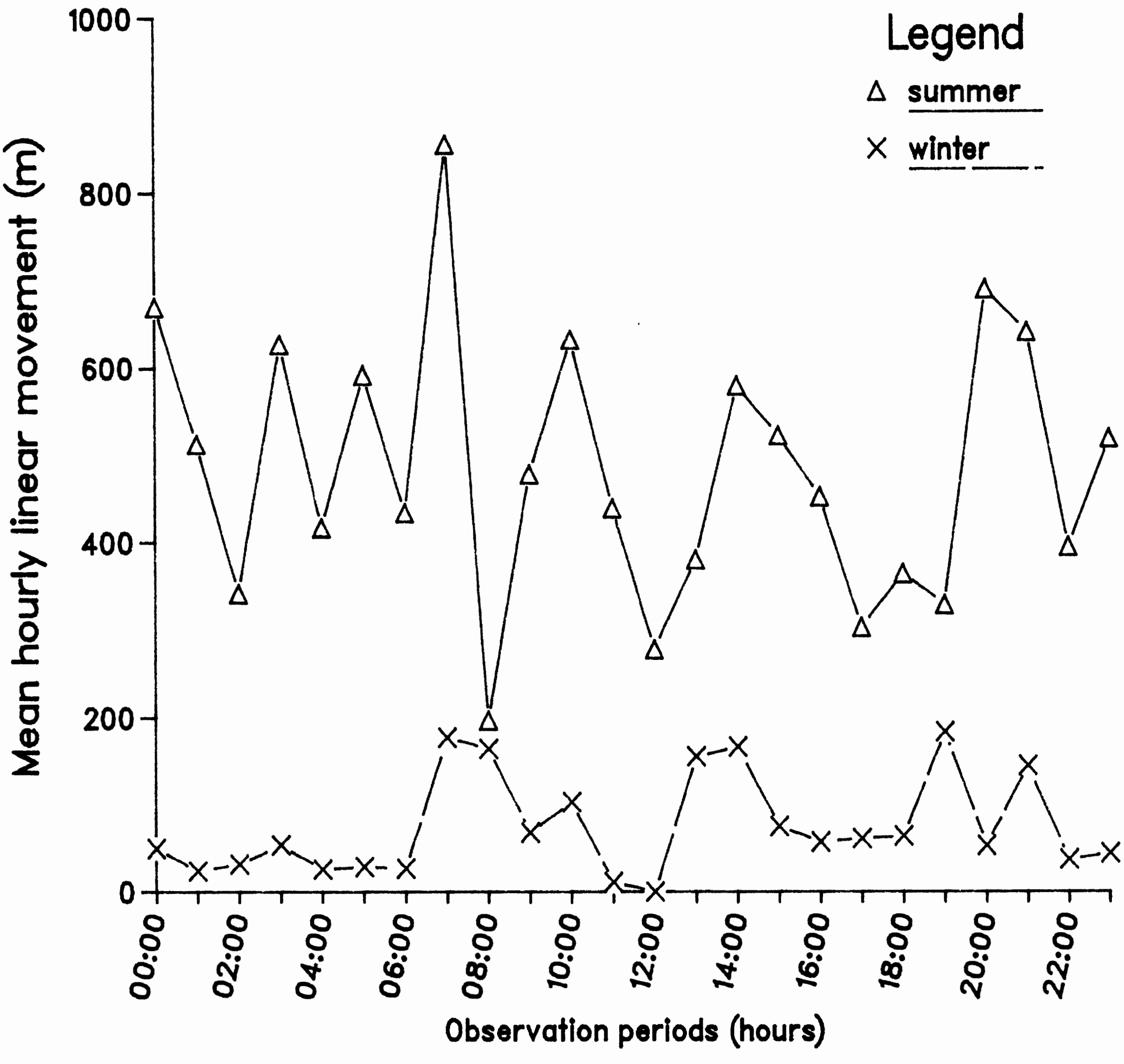

Figure 9. Mean hourly linear movement for seven lake sturgeon tracked 24 hours during July 1986 and January 1987 in Black Lake.

sturgeon were presumed to be searching for food and stopping briefly to feed. The second behavior was moving directionally across the lake bottom at speeds from 53 m/ hour to 1,018 m/hour (mean 491 ± 236 m/hour, n = 63).

In the winter, a different activity pattern was evident. The fish milled for 2-3 hours in the same circular pattern as in the summer, but then rested for periods of approximately 3 hours. Directional movement was not always evident. Sturgeon displayed limited movement, the extent of which varied with individuals. Distances traveled were from 0 to 183 m/hour (mean = 72.2 ± 71.8 m/hour, n = 49).

Lake sturgeon daily linear movement ranged from 18 to 6,877 m. A restricted home range was not evident for any of the individuals. All fish avoided areas less than 3 m deep, but traveled extensively throughout the rest of the lake. Some individuals avoided small areas of the deeper inshore water at the south end of the lake, but no consistent pattern was present among the individual fish.

The mean daily linear movement, grouped by month, was similar among sturgeon ($P > 0.05$). Except during January, one fish always moved a significantly greater distance than the others, but this was a different individual fish each month. Since no other significant differences were apparent among individual fish, the mean of the average daily linear movement per individual was used to compare movement during different months.

Sturgeon daily linear movements were less in October and January compared to the summer ($P \leq 0.05$) (Figure 10). Movement during January was also significantly less than that noted in October. These fall and winter reductions in mobility were strongly correlated with the seasonal decrease in water temperature (Figure 11).

Movement of mature fish was also correlated with body length, the relationship being best described by a second degree polynomial (Figure 12). This polynomial represented seven of the eight fish believed to be mature adults due to size and gonadal state (Harkness and Dymond 1961; Priegel and Wirth 1971; Foltz and Meyers 1985; Threader and Brousseau 1985). No correlation was found between the sex of the sturgeon and linear movement, either including ($r = 0.4259$) or excluding the immature fish ($r = 0.5699$).

Since sturgeon have been hypothesized to school from analysis of spring netting data and the winter fishery catches (M. Shouder, Michigan Department of Natural Resources, personal communication), the average distance separating two fish which were caught simultaneously was compared. On three occasions in 1986, two mature fish were caught at the same time. The closest any two fish of the same pair reoccurred was 325 m. The average distance separating pairs was substantially higher (Figure 13). The only evidence of schooling or aggregating was visually noted during the spawning runs.

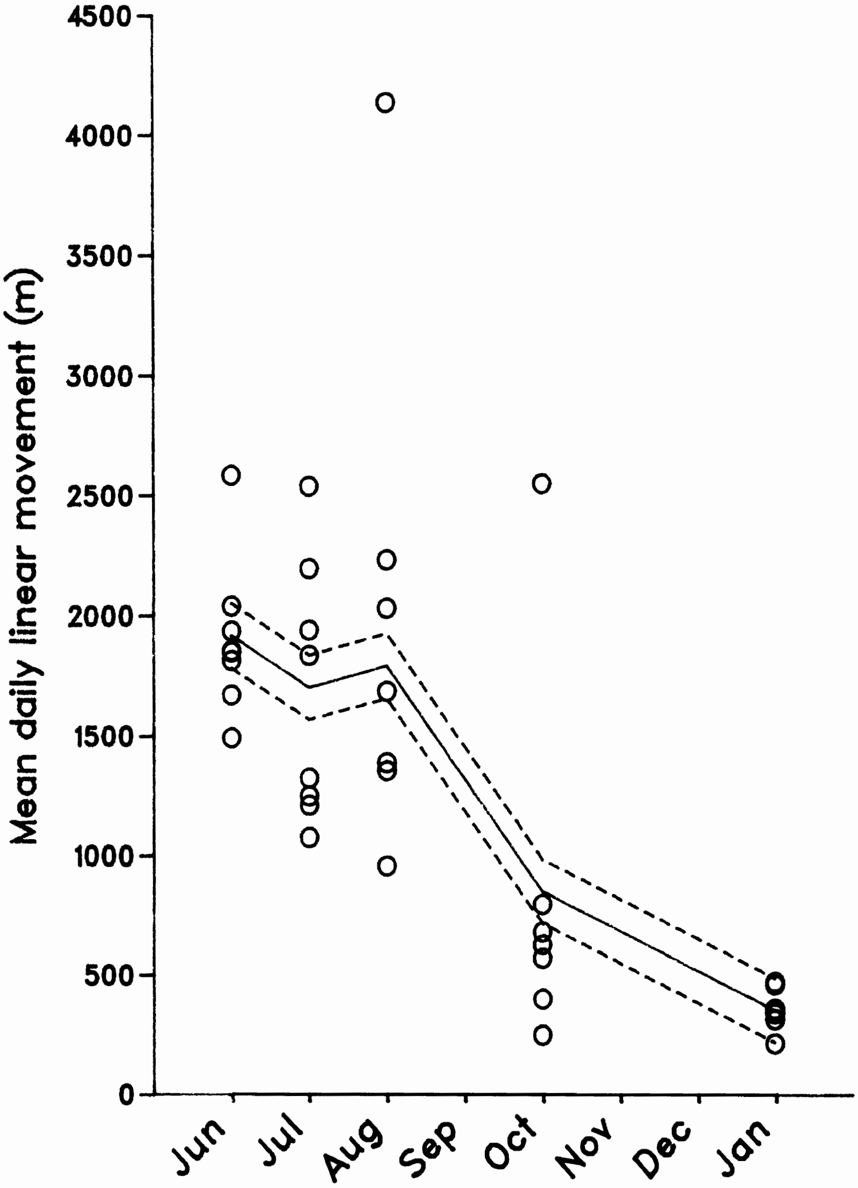

Figure 10. Monthly mean of daily linear movement for individual lake sturgeon (symbols) as well as overall mean daily linear movement (solid line) and 95% confidence limits (dotted lines).

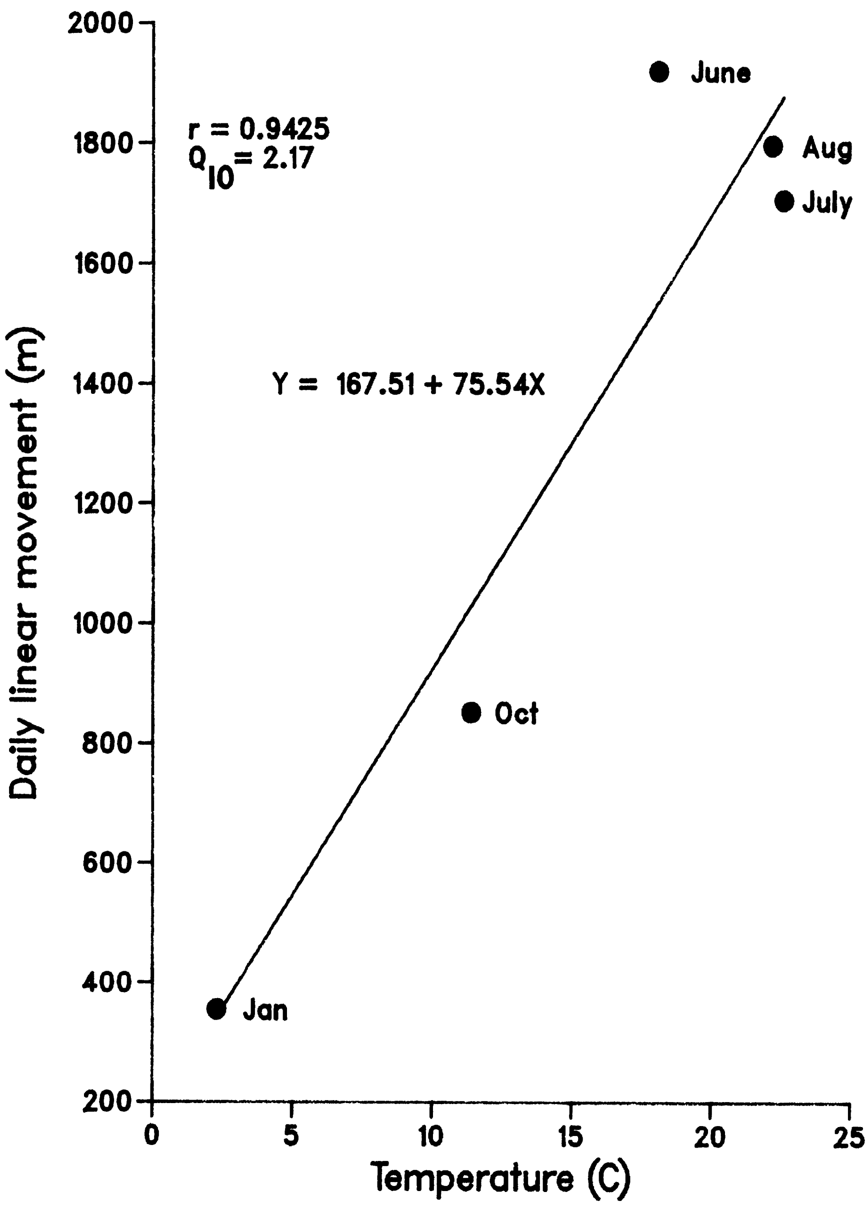

Figure 11. Relationship between monthly average of daily linear movement by lake sturgeon and monthly average water temperature in Black Lake.

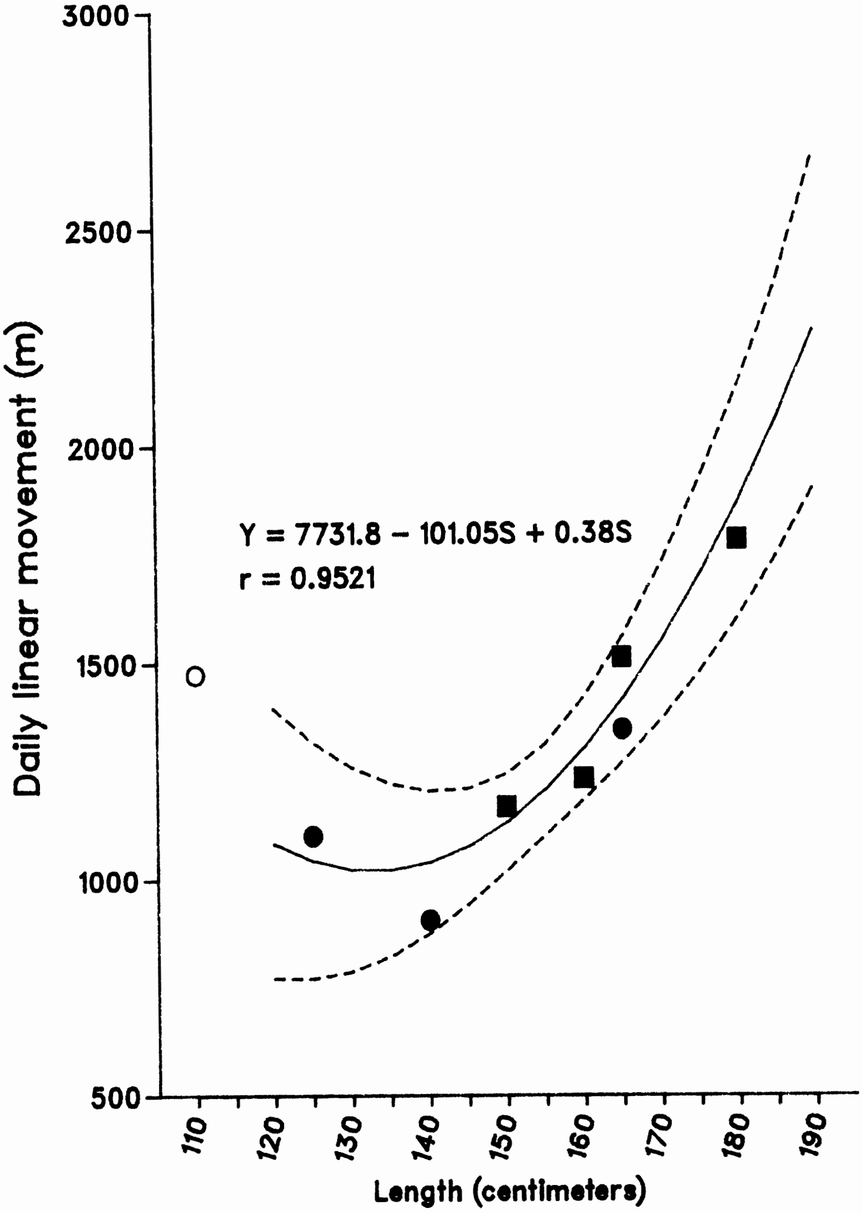

Figure 12. Polynomial relationship between lake sturgeon body length and mean daily linear movement (solid line) ±95% confidence limits (dotted lines). Values for males (solid circles), females (solid squares), and immature male (open circle) included.

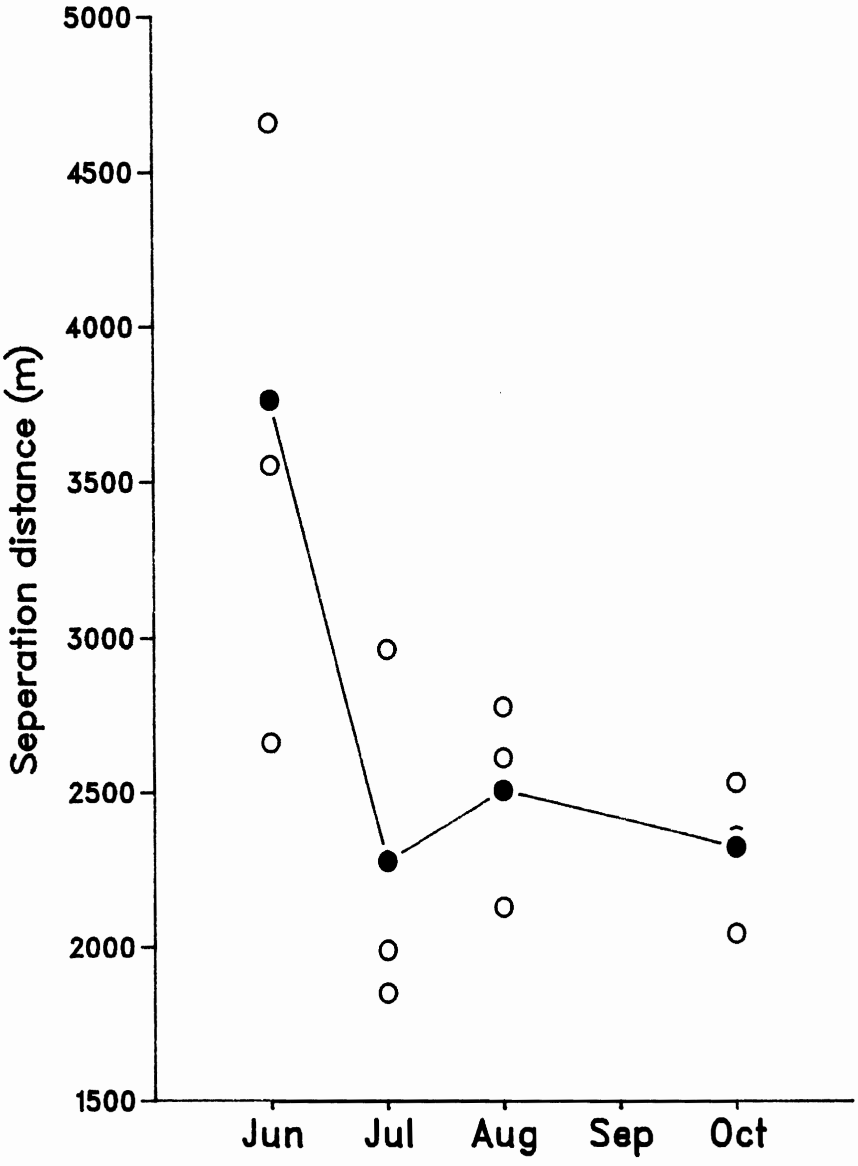

Figure 13. Average distance separating three pairs of lake sturgeon (open symbols) and mean separation distance (solid symbols), by month.

DISCUSSION

Any animal must select habitats that provide for food and reproductive opportunities. This study is concerned with the former needs, whereby fish acquire resources for growth and other activities. In this study, sturgeon selected portions of the lake correlated with hydrographic factors, bottom type, and food consumed. A single causal factor for habitat selection could not be differentiated, nevertheless, food distribution was probably most important.

Both depth and substrate choices correlated with location of the densest biomass of the preferred food items. Harkness (1923) and Harkness and Dymond (1961) report a similar pattern for Lake Nipigon sturgeon. The preferred depths were shallower than those determined for Black Lake sturgeon, but the preferred food items were located in this shallow water and were scarce below 9 m (Adamstone and Harkness 1923). Hence, although water depth differed, substrate and food preferences were similar for the two populations.

Gut contents of Black Lake sturgeon (Figure 5A) were similar to the findings of other studies (Harkness 1924; Schneberger and Woodbury 1944; Probst and Cooper 1954; Harkness and Dymond 1961; Magnin and Harper 1970; Magnin 1977; J. Kempinger, Wisconsin Department of Natural Resources, personal communication), although the numbers of chironomids and oligochaetes in the gut were lower. The winter diet of the Black Lake sturgeon was very similar to that found for Lake Nipigon sturgeon in July and August (Harkness 1923), suggesting no seasonal diet change. Harkness (1923) found that mayflies made up the majority of the sturgeon gut biomass. In the Black Lake sturgeon, mayflies made up the second largest portion of the gut biomass, only crayfish being greater. Thus, food items selected by sturgeon from different populations were similar, with some variation due to differences in forage populations available in different lakes.

The importance of food in habitat selection, and the occurrence of preferred food at different depths in various lakes, may explain the confusing and patchy depth reports for sturgeon in the literature. Williams (1951) stated that fish were found in deep water in summer and in deeper holes in winter. Harkness and Dymond (1961) reported that lake sturgeon in Lake Nipigon were not usually found deeper than 9 m, and a high proportion occurred in water less than 4.6 m deep. However, they also reported that sturgeon in Lake Winnipeg were caught at 1.5 m of water in June and at 14 m in August, while in Lake Huron sturgeon have been caught in the spring at the 18-m depth and in the summer at the 1.5-m depth. Black Lake sturgeon did show definite preferences by season and were usually found between 6 and 13 m. In addition, the location of lake sturgeon along the sloped areas of the lake was consistent with observations in Indian

Lake (Bassett 1982) and Lake Winnebago (J. Kempinger, Wisconsin Department of Natural Resources, personal communication).

Fish such as sturgeon actively forage rather than ambush food. Therefore, locomotion is a crucial part of food acquisition. A variety of foraging patterns have been described for fish including territoriality, home range, and schooling. Because of their size and energy needs, sturgeon are not territorial but have been postulated to have home ranges (Priegel and Wirth 1971; Bassett 1982). The only conclusive evidence has been the work by Kempinger (Wisconsin Department of Natural Resources, personal communication) who tracked a fish in Lake Winnebago. This individual remained within a 5.6-km radius for 111 days during the summer. While this may constitute a summer home range, the individual was only located 28 times during this period and it may have traveled outside this area on the days not tracked. If 5.6 km does constitute a restricted home range, the Black Lake sturgeon may not exhibit one due to the small size of the lake.

The importance of locomotion to food acquisition is implied by the seasonal and size correlations with daily movement. It is known that metabolic requirements and growth potential increase with temperature (Webb 1978; Brett and Groves 1979). Accordingly, daily movement and presumably foraging were greatest at higher temperature, and decreased with lower temperature. Similar relationships have been found for other species, such as white sturgeon (Haynes et al. 1978). In addition, large fish required a larger absolute ration and tended to travel larger distances. This also is consistent with observations for other species (Webb 1978; Brett and Groves 1979).

Various methods have been used to study sturgeon and some of the disagreements among studies may relate to methodology, in particular the frequency of observations. Sturgeon exhibited a wide range of movements in Black Lake, similar to those observed by Priegel and Wirth (1971) for Lake Winnebago sturgeon. Bassett (1982) noted that movement by Indian Lake sturgeon was restricted, but this conclusion was based on fish located only four times over 12 days. Such a short sporadic tracking period probably did not allow true patterns to be discerned. Future studies on sturgeon movements need to make regular observations of the fish. As sturgeon in this study traveled more than 6 km per 24-hour period, observations taken at lengthy time intervals could lead to errors.

Methods for determining gut contents and benthic abundance also have biases. Generally determining the prey of a species can easily be accomplished by the analysis of the contents of the gut (Hyslop 1980). However, with endangered species it is often difficult to obtain a sufficient number of samples for good statistical analysis. Unfortunately, stomach pumps which may sample stomach contents without sacrificing the fish, cannot be used on lake sturgeon due to their convoluted foregut. Sampling benthic abundance is a problem as well. Standard sampling methods using Ekman or Ponar grabs often miss prey species, as such a small portion of the substrate available to fish, is taken (D. White, The University of Michigan, personal communication). Unless very large sample sizes are obtained, lapses in the data occur. The instance of not sampling any crayfish in this study's benthic samples is a case in point.

Two assumptions were made in this study. First, based on past observations (Harkness and Dymond 1961; Priegel and Wirth 1971), it was presumed that sturgeon were on the bottom of the lake each time they were located. Despite the fact that they are a bottom-dwelling species, fish occasionally roll on the lake surface. Thus, some locations may have been made where fish were not in contact (or selecting) bottom substrates. Second, it is doubtful that straight-line linear movements are the way which lake sturgeon travel. However, this is still a valid method of calculating movement distances; at worst this method implies the minimum interval a fish travels and at best the exact amount moved. Since lake sturgeon travel so extensively, management of the species should seek to protect entire lake systems as crucial habitat and to provide viable spawning sites. Dredge-and-fill operations and water-level manipulations, the latter especially during spawning season, need to be strictly controlled. In addition, juvenile habitat preferences need to be defined and the metabolic rates of the species determined.

In Michigan, plans have been proposed to restock lake sturgeon into areas which previously had populations. Before fish are placed back into traditional waters, it is critical to insure that the proper habitat parameters still exist. These include (1) sufficient bottom substrate with enough of the preferred food items of mayfly larvae, chironomid larvae, and crayfish (Harkness and Dymond 1961; Priegel and Wirth 1971; this study); (2) availability of protected spawning sites either in accessible rivers or along the lake shore (Baker 1980; Anderson 1984); (3) lakes of sufficient size to allow movement and solitary behavior of the species (Lake Nipigon 484,837 ha, Harkness and Dymond 1961); Lake Winnebago 55,770 ha, Priegel and Wirth 1971; Black Lake 4,101 ha, this study).

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APPENDICES

Appendix 1. Benthic organisms collected from Black Lake, Michigan during the summers of 1985 and 1986.

Benthic organisms			Number
Annelida			
Oligochaeta			83
Nematoda			*
Mollusca			
Unidentified			12
Pelycepoda	Unioninae	*Lampsilis radiata*	6
		Liqumia recta	1
		Anodonta grandis	1
	Sphaeriinae	*Sphaerium* sp.	40
		Musculium transversum	4
		Stagnicola catascopium	1
		Unidentified	5
	Pisidiinae	*Pisidium* sp.	4
Gastropoda	Lymnaeidae	*Stagnicola reflexa*	1
	Planorbidae	*Gyraulus circumstriatus*	1
	Valvatidae	*Valvata tricarinata f tricarinata*	4
		Valvata lewisi	2
	Viviparidae	*Campeloma decisum*	1
Arthropoda			
Amphipoda	Haustoridae	*Pontoporeia hoyi*	110
	Hyalellidae	*Hyalella azteca*	178
Isopoda	Asellidae	*Asellus* sp.	47
Insecta			
Ephemeroptera	Ephemeridae	*Hexagenia* sp.	375
	Caenidae	*Caenis* sp.	1
Megaloptera	Sialidae	*Sialis* sp.	9
Trichoptera	Leptoceridae	*Oecetis* sp.	6
	Polycentropodidae	*Polycentropus* sp.	1
Diptera	Chironomidae	Chironomid larvae	897
		Chironomid pupa	25
	Chaoboridae	*Chaoborus punctipennis* larvae	496
		Chaoborus punctipennis pupa	55
Chordata			
Osteichthyes	Percidae	*Etheostoma nigrum*	2

* Actual number not counted.