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DISTRIBUTION, ABUNDANCE, AND FEEDING ECOLOGY OF YOUNG-OF-THE-YEAR PADDLEFISH IN UPPER LAKE SAKAKAWEA, NORTH DAKOTA

A Thesis

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by

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AUTHORIZATION TO SUBMIT
THESIS

This thesis of James P. Fredericks, submitted for the degree of Master of Science with a major in Fishery Resources and titled "Distribution, abundance, and feeding ecology of young-of-the-year paddlefish in upper Lake Sakakawea, North Dakota," has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

As part of a comprehensive assessment of the Yellowstone-Sakakawea stock of paddlefish, *Polyodon spathula*, this study was designed to develop quantitative sampling methods to assess year class strength of young-of-the-year (YOY) and yearling paddlefish in Lake Sakakawea, a Missouri River mainstem reservoir. Development of sampling methods necessitated a better understanding of physical, chemical, and biological factors (zooplankton density, water temperature, depth, velocity, and transparency) affecting distribution and abundance of YOY paddlefish, as well as an understanding of food habits, feeding behavior, mode of feeding, and growth. Based on visual counts and trawls, YOY paddlefish were far more abundant in 1993 than in 1992, consistent with evidence suggesting that 1992 was a poor year for reproduction of paddlefish because of low spring discharges in the Yellowstone River. Although visual counts and trawls both effectively sampled YOY paddlefish in 1992 and 1993, counts were more efficient. In 1993, I sampled 43 YOY/hour with counts, but only 5.2 YOY/hour with the trawl.

Young-of-the-year paddlefish appeared abruptly and were at their greatest densities during the periods August 16-19, 1992 and August 23-28, 1993, which were consistent with periods of greatest zooplankton densities. Paddlefish were counted and trawled throughout 34 km of reservoir where the river current decreased from around 1 m/s to 0 m/s, and where transparency (Secchi depth) increased from less than 10 cm to over 40 cm. Highest counts in August and early September were in a 10 km reach where zooplankton densities increased from less than 10 per liter to greater than 200 per liter. Young-of-the-year paddlefish gradually dispersed throughout September and became more uniform in distribution throughout the study

site. Distribution of YOY was related mainly to water temperature, depth, and to zooplankton densities in 1992 and 1993.

The periods of highest counts of YOY and highest zooplankton density corresponded to periods of greatest feeding activity. In 1992 stomach fullness index (SFI) values were highest in during the first week in August (598.6) and declined by over 50% by August 27 (226.6). In 1993 mean SFI and condition factors were highest in mid-August (494.2) and mid-September (557.3) and lowest in early August (190.7) and late-September (156.3). All YOY paddlefish in this study were selectively feeding on the largest zooplankters available, primarily *Leptodora kindtii* (a predaceous cladoceran) and insect larvae. *Leptodora* averaged 85% by number of the stomach contents of 50 YOY paddlefish, but constituted less than 1% by number. Based on mean size of YOY sampled, growth in 1992 and 1993 was initially rapid. Mean body length of YOY captured August 1-6 was 98.6 mm in 1992 and 89.5 mm in 1993. By August 21-28, mean body length was 122 mm in 1992 and 126.6 mm in 1993. Following the rapid growth in early to mid-August, mean body length increased very little through late September. Mean body length from August 21 to September 5, 1992 increased only 2.5 mm, and only 1.6 mm from September 7 to September 26, 1993.

ACKNOWLEDGMENTS

I would like to thank the North Dakota Game and Fish Department for providing funding for this research, with a special thanks to Fred Ryckman, Jeff Hendrickson, and Greg Power for their optimism and willingness to help in any way throughout the project. I thank Dennis Scarnecchia, for the many hours spent, both in the field and at the editing desk, and for his contagious enthusiasm for paddlefish and particularly for this project. I would like to thank committee members Mike Falter and George Belt for devoting time to this project and for taking an interest in my graduate research. Thanks to my wife, Anja, for her statistical counsel and for her support. Finally, I appreciate the help of my field and lab assistants, John Bassinette, Jeff Brost, Paul Jarvis, Andy Whipple, and Brad Jarrett.

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INTRODUCTION

The paddlefish *Polyodon spathula* is a large, planktivorous fish indigenous to the Missouri River, Mississippi River, and adjacent Gulf Coast drainages (Gengerke 1986). In the past century, the distribution and abundance of the paddlefish have been reduced (Carlson and Bonislawsky 1981) as their habitat, which traditionally consisted of large, free-flowing rivers with an abundance of side channels and backwaters, has been greatly altered by river regulation and impoundment. Regulation and impoundment have resulted in loss of shallow, rich backwater areas important to paddlefish, and dams have impeded or blocked spawning migrations and permanently flooded traditional spawning sites (Unkenholz 1986).

In a few cases, however, where spawning sites have been maintained, dams have increased the carrying capacity for paddlefish populations by creating lake-like rearing habitat, with a resulting increase in zooplankton production (Sparrowe 1986; Unkenholz 1986). Paddlefish spawning in the Yellowstone River and in the Missouri River and its major tributaries below Fort Peck Dam have evidently benefited from the construction of Garrison Dam, and the resulting formation of Lake Sakakawea (Figure 1). These paddlefish, referred to as the Yellowstone-Sakakawea stock, represent one of the last self-sustaining, harvestable populations in the country (Scarnecchia et al. 1994a). Tagging studies have indicated that each April through June, adult paddlefish migrate over 160 km upstream from Lake Sakakawea to spawn in the Yellowstone and Missouri Rivers (Rehwinkel 1978). Once hatched, the paddlefish larvae move downstream to rear for 9-15 years in the plankton-rich reservoir before maturing and migrating back up the rivers to spawn.

Assessment of the status of the Yellowstone-Sakakawea stock is based in part on the number and age structure of fish harvested at main fishing sites on the Yellowstone River and below the Yellowstone's confluence with the Missouri River. Inasmuch as males from a cohort of paddlefish first mature and recruit to the fishery at 9-11 years, 6-8 years before the first females mature, the number of young male recruits can be used to forecast year class strength, and to indicate potential recruitment problems before the females, the largest and most desirable fish, become vulnerable to harvest (Scarnecchia et al. 1994a). Although this age-structure method provides managers with an idea of the number of females to expect 6-8 years prior to their maturity, biologists still have no knowledge of potential reproduction and recruitment problems in the 9-11 years prior to sexual maturity of the males. Currently, paddlefish eggs and larvae are collected in the Yellowstone and Missouri Rivers during and immediately following spawning (Gardner 1992). Although sampling eggs and larvae is useful for indicating the occurrence of spawning and hatching, an index of advanced young-of-the-year (YOY) and yearling (age 1) paddlefish would be even more useful for estimating larvae survival and ultimate year-class strength. Ideally, this method would result in reliable, quantitative annual indices of relative abundance of YOY and yearling paddlefish.

Objectives

Successful development of YOY and yearling indices has been hindered by lack of effective quantitative sampling methods, and by a poor understanding of YOY and yearling distribution in Lake Sakakawea. Therefore, the objectives of this research were:

1) to develop techniques and equipment for quantitative assessment of YOY and yearling paddlefish, and

2) to assess the importance of total zooplankton densities, water temperature, water depth, water velocity, and water transparency on distribution and abundance of YOY paddlefish in upper Lake Sakakawea from July through September.

Objectives one and two are considered individually as Chapters One and Two. Objectives three, four, and five, address feeding ecology and growth, which interrelate with distribution and sampling strategy and are critical to successful development of indices of relative abundance and for an understanding of the ecological basis for indices. These related objectives, considered in Chapter Three, are

3) to assess daily and weekly variations in feeding activity, as measured by stomach fullness and condition factor, of YOY paddlefish in upper Lake Sakakawea from July through September,

4) to determine if and when YOY paddlefish in upper Lake Sakakawea shift from a selective mode of feeding to non-selective filter feeding, and

5) to estimate growth using mean body length of YOY paddlefish in upper Lake Sakakawea in 1992 and 1993.

STUDY AREA

Lake Sakakawea, a mainstem impoundment of the Missouri River in the western third of North Dakota, was created by the closure of Garrison Dam in 1953. At approximately 149,000 hectares and 270 km in length, it is one of the largest man-made lakes in the United States (Figure 1). The reservoir supports popular fisheries for walleye *Stizostedion vitreum vitreum*, sauger *S. canadense*, chinook salmon *Oncorhynchus tshawytcha*, smallmouth bass *Micropterus dolomieui*, northern pike *Esox lucius*, and other game fishes. In recent years, recreational use of the upper reaches of Lake Sakakawea has been minimal, in part because low water levels combined with submerged trees and shifting sandbars have created hazardous boating conditions.

In this study, sampling efforts were concentrated in the upper end of the reservoir, from Tobacco Garden and Whitetail Bays (River mile (RM) 1509), to the area 30 km upriver (RM 1527) (Note: River mile (RM), an English unit, was used because it is commonly used for navigation and mapping). Within this 30 km area, Lake Sakakawea ranges from 1-4 km wide. This area was initially selected because YOY paddlefish were sighted there on calm days just below the water surface in 1991 by state and federal fisheries personnel (Jeff Hendrickson, Missouri River Fisheries Biologist, North Dakota Game and Fish Department (NDGF); Personal Communication). Additionally, in years preceding 1991 there had been many unconfirmed sightings of young paddlefish in this area, which is about where the current from the Missouri River dissipates and sediments settle out.

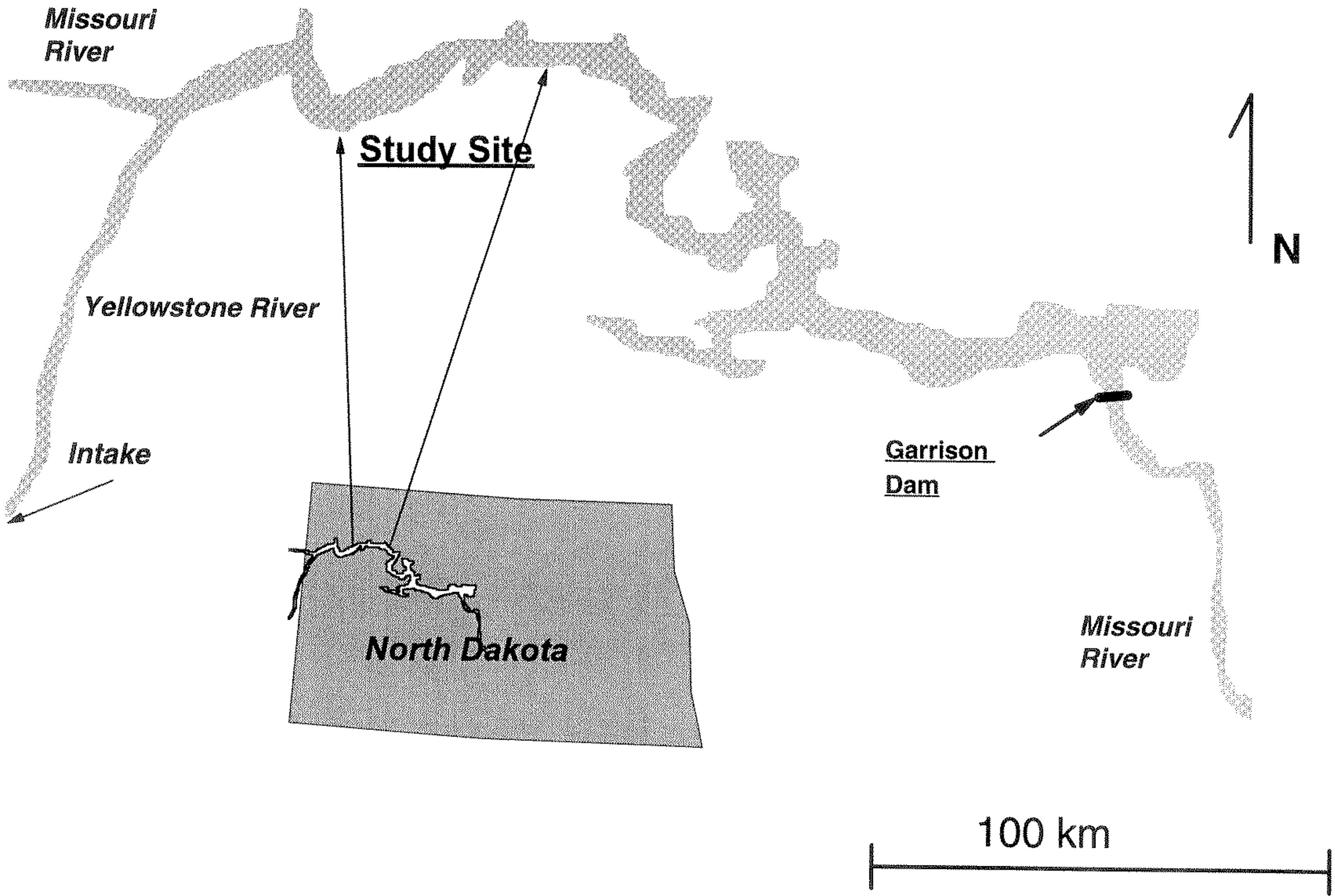


Figure 1. Lake Sakakawea, North Dakota, and location of study site.

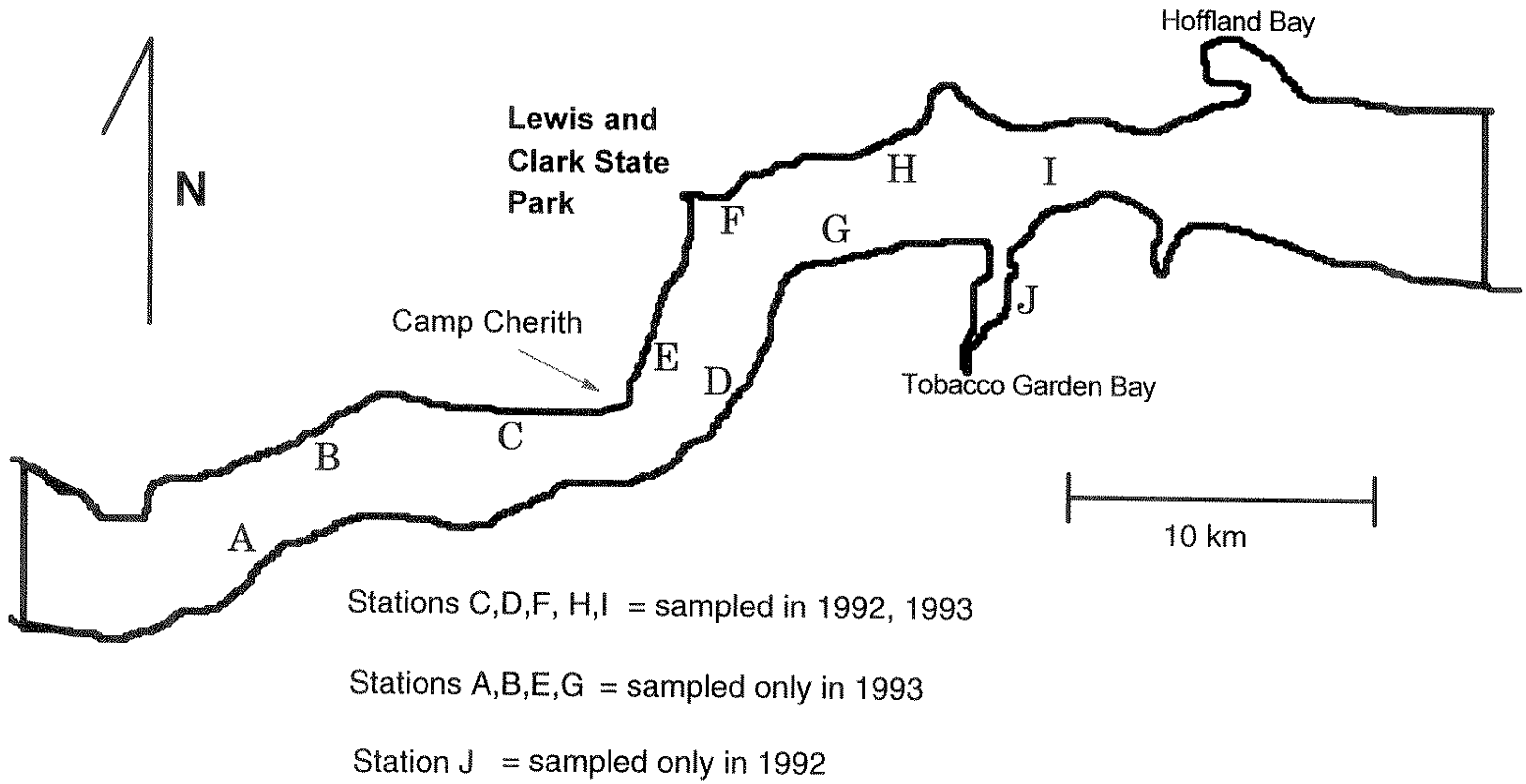


Figure 2. The 34 km study area and specific stations sampled in 1992 and 1993.

CHAPTER 1. DEVELOPMENT OF METHODS FOR QUANTIFYING RELATIVE ABUNDANCE OF YOUNG-OF-THE-YEAR AND YEARLING PADDLEFISH IN LAKE SAKAKAWEA

INTRODUCTION

Little research has been conducted on techniques for sampling young-of-the-year (YOY) and yearling (age 1) paddlefish, and no standard method currently exists for quantitative assessment. Pasch et al. (1980) found 640 hours of gill-net effort in Old Hickory Reservoir in Tennessee, yielded only 7 YOY paddlefish and concluded that the method was ineffective for sampling small paddlefish. Ruelle and Hudson (1977) successfully trawled YOY paddlefish from the bottom (10-12 meter depths) of Lewis and Clark Lake, a Missouri River impoundment. The value of trawling as quantitative sampling method for YOY paddlefish is, however, undetermined.

The size, depth, and steep shoreline of Lake Sakakawea make even qualitative sampling difficult. Prior YOY sampling efforts on Lake Sakakawea with an otter trawl, a beam trawl, and a shrimp trawl, have met with limited success (Jeff Hendrickson, Missouri River Fisheries Biologist, North Dakota Game and Fish Department (NDGF), Personal Communication). The only trawling method that effectively captured YOY paddlefish was an otter trawl towed between two boats. The most effective capture method was not trawling, but consisted of one or two people standing in the bow of a slow moving boat and dip-netting the fleeing paddlefish from the surface. This method was used by Hendrickson et al. (1992) in July, 1991, on a warm, calm day when YOY paddlefish were observed immediately below the water surface.

Because research and development of quantitative sampling and enumeration methods for young paddlefish were considered critical for stock assessment, my first objective was to develop techniques and equipment for quantitative assessment of YOY and yearling paddlefish.

METHODS

On August 1, 1992, I began experimenting with techniques to quantify YOY and yearling paddlefish. Based on previous observations of YOY paddlefish in Lake Sakakawea, physical constraints (high turbidity and submerged debris), and results of studies elsewhere (Pasch et al. 1980; Ruelle and Hudson 1977), the three methods initially attempted were trawling, visual counts, and electrofishing.

Trawling

Initial sampling efforts were concentrated 1-2 km up the reservoir from Whitetail Bay, where we had previously observed the highest density of YOY paddlefish on the water surface. I experimented with various trawl depths and speeds. The trawl, which was 3.5 meters by 7 meters, with 1.25 cm mesh and a 0.15 cm cod-end insert, was towed between two boats at a speed of 7-9 km/hr for exactly five minutes. Three tows were conducted at each of six sampling stations, so that each station was trawled for a total of 15 minutes. During the 1992 field season, I sampled with the trawl using this method for two sampling weeks (August 22-27 and August 29-September 3). Because of equipment failures, I was unable to trawl during the two remaining sampling weeks of 1992 (August 16-20 and September 4-9).

Although trawling met with little success in 1992, I attributed the ineffectiveness mainly to the low numbers of YOY and yearling paddlefish present that year. Because we successfully trawled YOY and yearling paddlefish in 1992 at times when they were abundant based on visual counts, I believed that trawling would be effective given sufficiently high concentrations of YOY and yearlings. In 1993, I continued with the same trawling technique from July 12 to September 25, over a series of nine sampling stations, five of which had been sampled in 1992.

Visual Counts

While experimenting with the trawl during the period from July 24 to August 13, 1992, YOY and yearling paddlefish were consistently and repeatedly seen in particular areas, regardless of time of day and weather. This consistency, and an apparent positive relation between the number of YOY captured in the trawl and the number seen on the surface, suggested the use of visual counts (hereafter referred to as counts) as a quantitative measure of relative abundance. Counts were made along cross-sections and at specific stations, each of which was designed to provide somewhat different information on paddlefish distribution and abundance. The counts at cross-sections (directly across the reservoir) were designed to obtain a snapshot of large-scale distribution and abundance of YOY paddlefish throughout the area thought to be inhabited by them, to detect any large-scale movements of YOY paddlefish aggregations, and to investigate if counts effectively quantified relative abundance of YOY and yearlings. The counts at specific stations were designed to provide more specific information on factors affecting YOY distribution and abundance.

Cross-section counts

Cross-section counts of YOY and yearlings were conducted one day each week in 1992 and one day every two weeks in 1993, at 4.8 km (3 m) intervals from RM 1527 to RM 1506. Young-of-the-year and yearling paddlefish were enumerated by two observers, one person in the front of the boat and the driver in the back of the boat. Each observer was responsible for one side of the boat, and the paddlefish were counted out loud to ensure that each was not counted more than once. Only fish within 10 meters of either side of the boat were counted.

Station Counts

I also established a series of sampling stations from Reservoir Mile (RM) 1527 to RM 1509 (Figure 2). Initially, stations were located where we saw YOY paddlefish in loose aggregations, or where they had been observed in 1991. Additional stations were selected to encompass the range of habitats in the upper reservoir. The uppermost stations were generally characterized by relatively high velocities (0.3-1 m/s), low transparencies (<5 cm), and low zooplankton densities (<5 organisms/l). In contrast, the lowermost stations were generally characterized by negligible water velocities, higher transparencies (>30 cm), and higher zooplankton densities (150 organisms/l).

In 1993, high river flows and regional precipitation resulted in substantially higher pool elevation, greater surface area, and deeper water throughout the study area. The increase in surface area and depth allowed the addition of two sampling stations above our most up-reservoir station of 1992, and an additional station in an area that had been too shallow in 1992. For this reason we routinely sampled nine stations in 1993 as opposed to six stations in 1992. By expanding the study area up the reservoir, I continued to encompass the region of Lake Sakakawea where the current dissipated, while retaining most of the stations sampled in 1992.

Counts at stations were conducted along 1.6-km (1 mile) transects, and lasted ten minutes. We counted YOY and yearling paddlefish over three parallel transects at each station. The distance of the transects was initially measured with an impeller-type flow meter for ten minutes to insure consistent boat speed among the transects. In 1993, I obtained a Long Range Navigation (LORAN) system, which facilitated the creation of a parallel series of transects, with fixed endpoints, that could be duplicated at each station (Appendix 1). The LORAN system also enabled me to monitor boat speed so that we could conduct the counts at a relatively consistent speed of 8-9.5 km per hour.

In 1992, I sampled the stations each week from August 16 to September 9, so that 1-3 days separated sampling periods. In 1993, I sampled the stations every other week, from July 12 to September 25, so that sampling periods were separated by at least 7 days.

Morning and afternoon differences in counts--In order to assess if counts at each station differed between morning and afternoon, counts were conducted at the same station twice in a given sampling week, once in the morning (0730-1200 h) and once in the afternoon (1400-1900 h). The counts were then compared to each other.

Effect of wave height on counts--In order to assess the effects of wave height on counts, I visually estimated the height of waves during the counts, and categorized wave height quasi-quantitatively as "0" (calm = 0.0-0.15 m), "1" (slightly choppy = 0.16-0.42 m), "2" (moderately rough = 0.43-0.73 m), or "3" (very rough = 0.74-1.0 m). During conditions when waves exceeded one meter in height, I did not conduct counts for reasons of safety.

Electrofishing

On August 8 1992, I evaluated our ability to sample YOY and yearling paddlefish with a boat-mounted electrofisher with personnel from NDGF. Both AC and pulse DC current were used. I attempted to sample paddlefish during daylight hours, as well as 2-3 hours after sunset.

Analysis

I compared the success of counts (number counted per transect) and trawl catch (number captured per tow) in 1992 and 1993 based on highest means at a single station, highest means over an entire sampling period, and means of stations sampled both in 1992 and 1993 during the same calendar week.

Effect of wave height on counts was assessed with a one-way analysis of variance (ANOVA) using YOY per 1.6 km transect as the dependent variable and categorized wave height as the independent variable. Morning (0700-1200 h) and afternoon (1400-1900 h) counts were compared as treatments in a split-split plot ANOVA that also used sampling period and station as treatments (Chapter 2).

To compare the methods of visually counting and trawling, I trawled immediately after conducting counts at each station and used regression analysis to relate counts and trawl catch at each station. I used non-parametric regression (Spearman's rank) to avoid dependence on assumptions of normality and homogeneity of variance.

RESULTS

Trawling

Deep water trawling

Initial trawl attempts in 1992 near Whitetail Bay were unsuccessful. The water depth in this area was 4-5 meters, which was too shallow to effectively trawl with otter boards. Six of eight attempted tows ended with the trawl either snagged on woody debris or with the otter boards buried in the sediment. I attempted to trawl nearer to the surface by shortening the lengths of lead ropes and increasing the boat speed, but unless the net was immediately behind the boat in the propeller wash, the otter boards were too heavy for sampling water shallower than 4 meters, which comprised most of the study area during 1992.

Surface Trawling

I removed the otter boards and trawled by pulling the net between two boats. To ensure a wide opening to the trawl, two 4 kg weights were secured to the weighted line of the trawl, a distance of 2.75 meters from the outside edge of the trawl, which resulted in the trawl extending down to depths of 1-2 meters. This method was effective for capturing YOY paddlefish, as it had been in 1991 when used experimentally by NDGF and the U.S. Fish and Wildlife Service (USFWS; Hendrickson 1992).

Young-of-the-year--The entire 1992 trawling effort, which consisted of 42 tows of five minute duration, yielded 15 YOY paddlefish, or 0.35 YOY per trawl and 0.07 YOY per minute. The highest catch during three tows at a single station was 3, or 1 YOY per trawl and 0.2 YOY per minute. Overall, surface trawling was more effective in 1993 than in 1992. During the four sampling periods in 1993, when YOY paddlefish were present, 216 tows of five minute duration yielded 93 YOY paddlefish, or 0.43 YOY per trawl and 0.09 YOY per minute. The highest catch in three tows at a single station was 9, or 3 YOY per trawl and 0.6 per minute. Perhaps the best comparison of trawling success between the 1992 and 1993 is the number of YOY captured per tow during the sampling week each year when YOY were most commonly observed. From August 24 to August 27, 1992, we captured 9 YOY in 36 tows for a mean of 0.25 YOY per trawl, whereas from August 23 to August 27, 1993, we captured 52 YOY in 54 tows for a mean of 0.96 YOY per trawl, almost four times the catch rate of the best week in 1992 (Table 1). Trawled paddlefish ranged in length from a YOY 69 mm body length (BL; front of eye to fork in caudal fin; Ruelle and Hudson 1977) to a small adult 785 mm BL.

Table 1. The number of YOY paddlefish captured per tow in 1992 and 1993. All four comparisons indicate higher densities of YOY in 1993 than in 1992.

Statistic	1992	1993
Highest mean per tow at a station	1	3
Highest weekly mean	0.25	0.96
Mean of comparable stations and weeks	0.16	0.88
Total number trawled	17	93

Yearlings--The trawl was effective in capturing yearling paddlefish, particularly in 1992. A total of four yearling paddlefish was captured in the trawl during 1992, or a ratio of 0.29 yearlings per YOY. Only one yearling was captured in the trawl during 1993, or 0.01 yearlings per YOY. The lower ratio obtained by trawling in 1993 is consistent with results of counts (Figure 3).

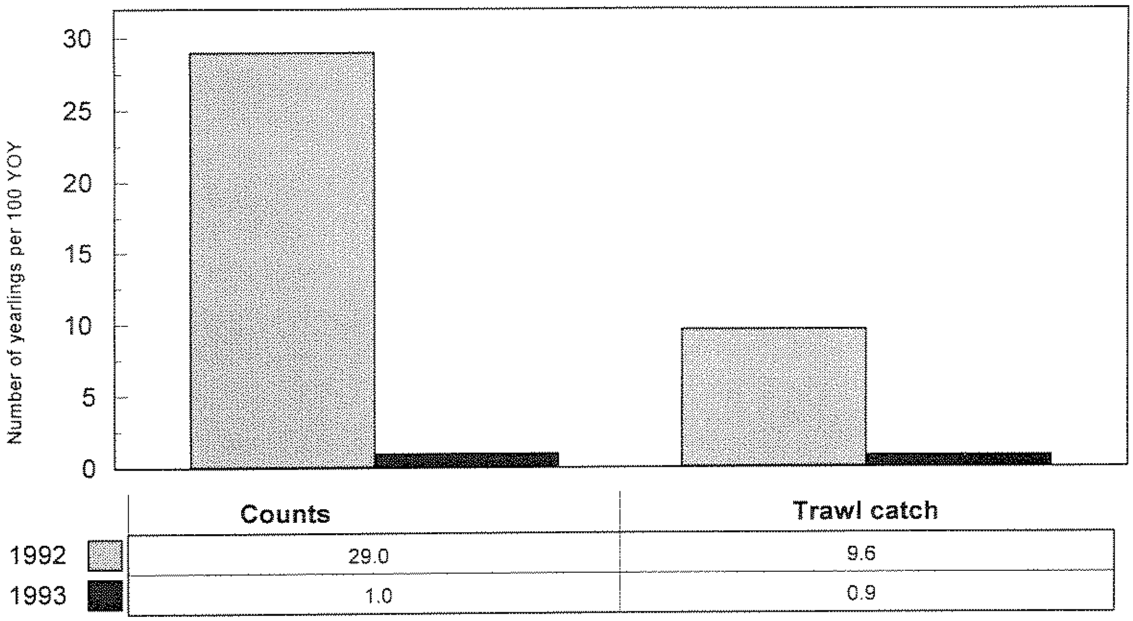


Figure 3. The number of yearling (age 1) paddlefish per 100 YOY based on counts and trawl catches in 1992 and 1993.

Visual Counts

Cross-section counts

The scarcity of YOY in 1992 resulted in no apparent pattern of YOY counted per km over the eight cross-sections. In 1993, the cross-sectional counts indicated that paddlefish were concentrated from RM 1518 to RM 1515 in late August, but gradually became more uniformly distributed over the 34 km study area by late September (Figure 4). The largest increase of YOY occurred between August 14, when only two were counted, and August 30, when 101 YOY were counted.

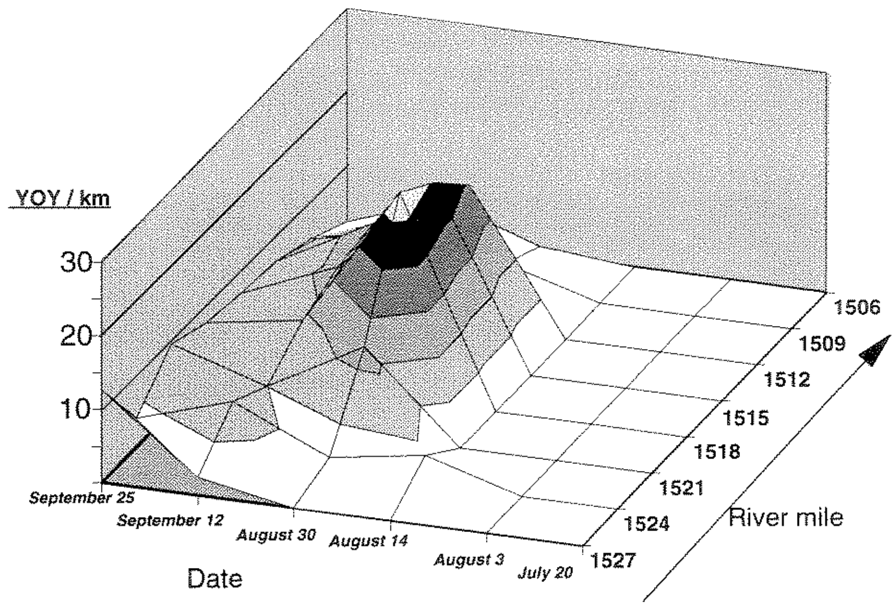


Figure 4. Counts of YOY/km in 1993 by sampling date and location. River mile (RM) 1527 is up-reservoir (near Plum Creek), and RM 1506 is down-reservoir (Hoffland Bay).

Station counts

Young-of-the-year--As with the cross-section counts and trawl catches, the station counts indicated much higher densities of YOY paddlefish in 1993 than in 1992 (Table 2). In 1992, the most YOY counted in three transects at a single station was 31, or 10.3 YOY per transect, and the mean count per transect over all (36) transects during the week of highest densities was 3 YOY. In 1993, in contrast, the most YOY counted in three transects at a single station in 1993 was 110, or 36.7 YOY per transect (more than 3 times the highest 1992 value). The mean count per transect over all 54 transects during the week of highest densities was 14.2 YOY, which was more than four times the highest 1992 value.

Yearlings--In 1992 I counted 24 yearlings and 249 YOY throughout all counts (including cross-sections) for a ratio of 9.6 yearlings per 100 YOY.

In 1993 I counted 15 yearling paddlefish and 1756 YOY paddlefish, for a much lower ratio of 0.85 yearlings per 100 YOY (Figure 3).

Table 2. The number of YOY visually counted per 1.6 km (1 mile) transect in 1992 and 1993. All four comparisons indicate higher densities in 1992 than 1993.

Statistic	1992	1993
Highest mean at a single station	10.3	36.7
Mean during week of highest density	3	14.2
Mean of comparable stations and weeks	1.6	8.2
Total number counted	249	1756

Effect of morning and afternoon on counts--In 1992, the generally low densities and very scattered observations yielded a large number of zero counts, and I found no significant difference in counts of YOY between morning (0700-1200 h) and afternoon (1400-1900 h; ANOVA, $p>0.1$). The tendency, although not statistically significant, was for higher counts in the morning than in the afternoon. Of 18 paired morning and afternoon station counts, 10 were higher in the morning, four were higher in the afternoon, and four did not differ from morning to afternoon. Mean YOY per transect in the morning was 2.2 versus 1.6 in the afternoon (Figure 5). In 1993, however, morning or afternoon did have a significant effect on number of YOY counted (ANOVA, $p<0.05$). Of 31 paired morning and afternoon counts, 20 were higher in the afternoon. Over the period August 23 - September 25, the overall mean counts of YOY per transect were 8.8 in the morning and 10.2 in the afternoon. In 1993, there was also a significant interaction between the morning and afternoon effect and the station effect (ANOVA, $p<0.05$), indicating that the tendency for higher afternoon counts was not consistent over all stations.

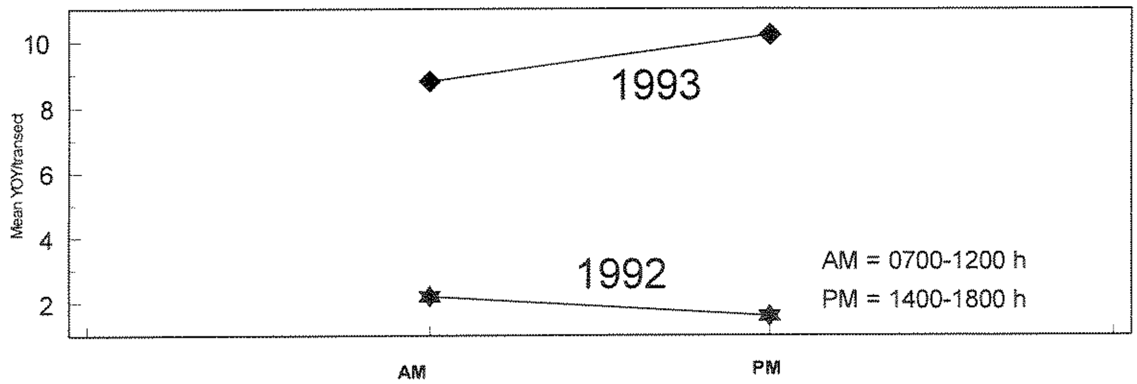


Figure 5. Mean number of YOY per 1.6 km transect counted during the morning and afternoon sampling periods.

Effect of wave height on counts--Statistically, wave height had no overall significant effect on the ability to count YOY paddlefish (ANOVA, p=0.2599). Young-of-the-year paddlefish were observed on the water surface in all weather conditions ranging from hot, calm days with no waves, to cool, stormy days with waves exceeding one meter in height. Although statistical differences among the four categories were not found, higher waves at least appeared to be associated with higher counts of YOY. The mean of counts during times of little or no wave action (6.39 YOY/transect) was lower than counts during times when wave height was classified as other than calm (11.4-11.6 YOY/transect). On average, I counted fewer YOY when water was calm or had a slight ripple than in rougher water, and the highest average of YOY were counted when wave height was classified as slightly choppy (0.16 to 0.42 m waves; Figure 6).

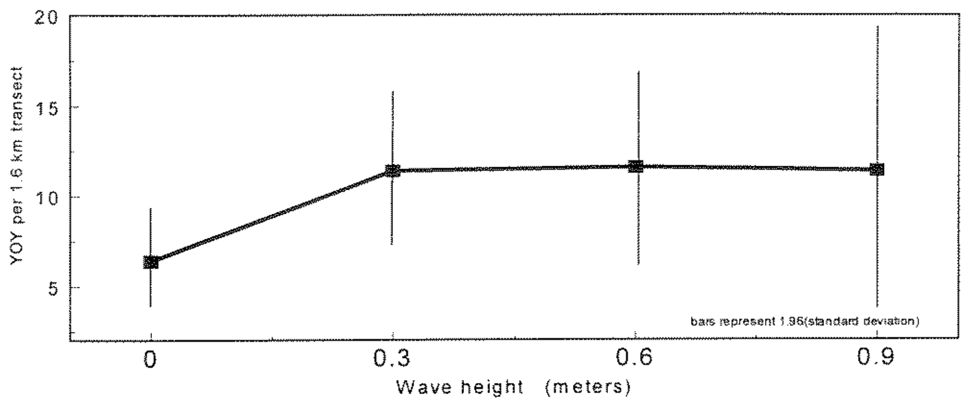


Figure 6. Mean number of YOY paddlefish counted per transect during four different categories of wave height.

Electrofishing

I was unable to see or net a single paddlefish immobilized by the electrofishing gear. Either the paddlefish were sensitive enough to the electric current to avoid the field, or they simply sank when immobilized and were not easily seen by the netters in the turbid water (Secchi depth = 25 cm). Although several YOY and yearling paddlefish were seen at night when the electrical current was turned off, indicating that they spent some time on the surface after dark, no paddlefish were seen when the electrical current was on. I concluded that electrofishing, using the methods we attempted, was not an effective sampling technique for either YOY or yearling paddlefish.

Comparison Between Visual Counts and Trawling

I combined data from 1992 and 1993 and found YOY counts and trawl catch at the same station to be strongly and positively correlated ($r = 0.67$, Spearman's $r_s = 0.72$, $p<0.01$). The positive relationship supported the idea that both methods were reliable indicators of YOY densities

(Figure 7). Based on the number of YOY sampled per unit time, the trawl was less efficient than counts in both 1992 and 1993 (Figure 8). The greater efficiency of counts was not unexpected. I counted within a width of 20 meters, whereas the trawl sampled no more than its width of eight meters.

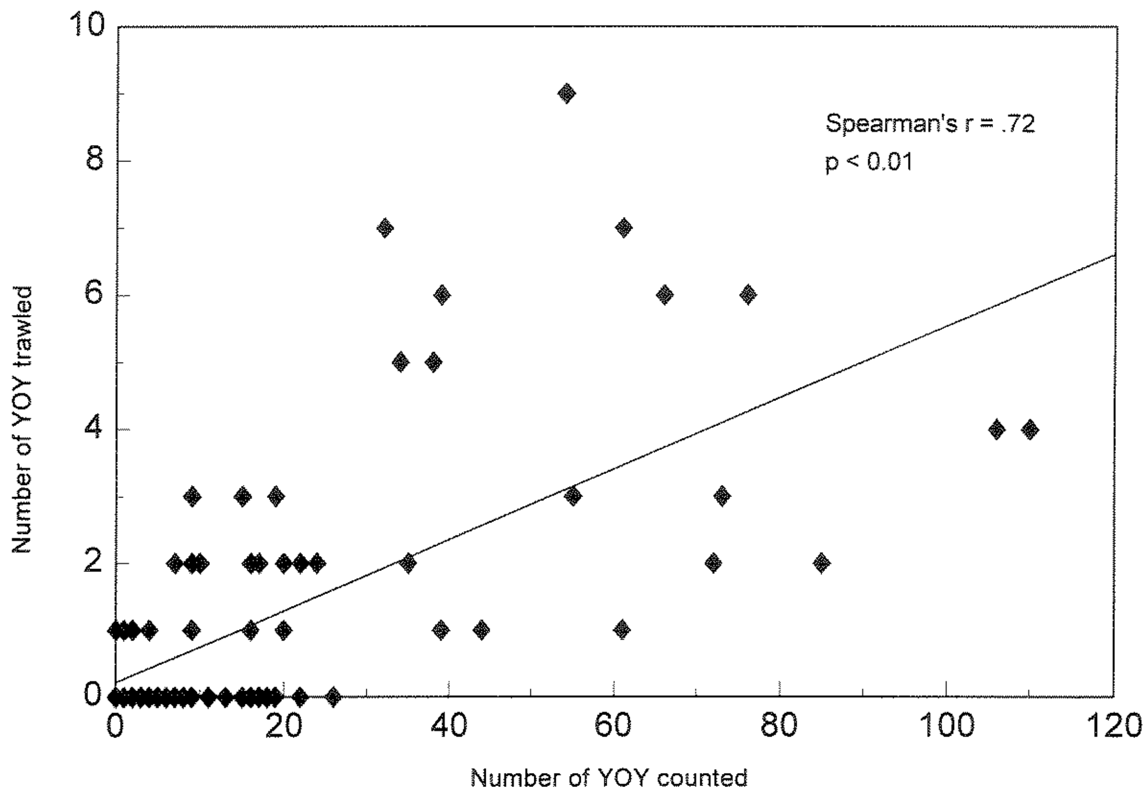
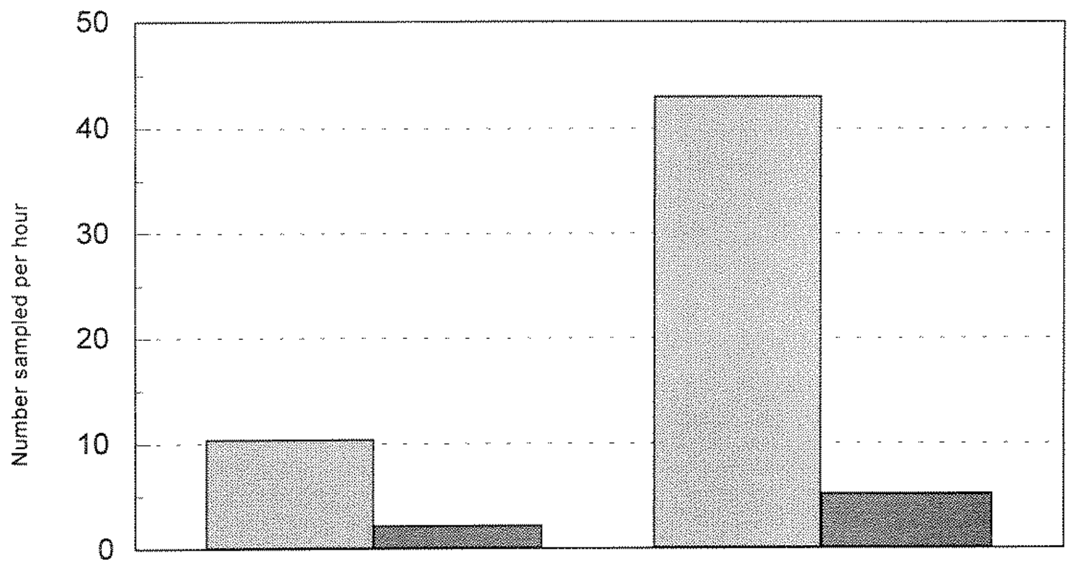


Figure 7. Relation between total YOY trawled at a station (Y) and total number counted at the same station (X).



	1992	1993
Counts	10.4	43.0
Trawl catch	2.2	5.2

Figure 8. Number of YOY counted and trawled per hour of sampling effort in 1992 and 1993.

DISCUSSION

Quantitative Effectiveness of Visual Counts and Trawls

For counts and trawling to be useful in developing indices of paddlefish abundance, they must provide reliable estimates of relative abundance. Although the low numbers of YOY in 1992 made evaluation of the sampling methods for that year difficult and inconclusive, the results from 1992 are valuable in making year-to-year comparisons. Several pieces of evidence support the idea that these methods, especially counts, provide reliable quantitative measures of relative abundance.

The first piece of evidence comes from the 1991-1993 relationship between Yellowstone River discharge, paddlefish harvest in May and June, and subsequent relative abundance of YOY and yearling paddlefish as indicated by my sampling in August and September. Spawning migrations of mature paddlefish are stimulated in part by high river discharges associated with spring runoff (Unkenholz 1986). Abundance and harvest of paddlefish at Intake, Montana are related to high Yellowstone River discharge in May and June (Stewart 1991). During the six week paddlefish season (May 15 to June 30) in 1991, the Yellowstone River discharged in excess of 35,000 cfs for 34 days, whereas in 1992, discharge exceeded 35,000 cfs only 4 days (Appendix 2). Discharge in 1993 was intermediate, with 13 days exceeding 35,000 cfs. Harvest totals for the Yellowstone River were closely associated with discharges of the respective years. In 1991, the harvest at Intake was one of the highest on record, an estimated 4,215 adult paddlefish (Stewart 1992). Conversely, harvest in 1992 was one of the poorest seasons on record, an estimated 740 adult paddlefish (Stewart 1993). The harvest in 1993 was intermediate, an estimated 1635 adult paddlefish (Stewart 1994).

Inasmuch as higher catches and more successful spawning of paddlefish have been linked to higher stream flows in spring, one might expect to see more YOY in Lake Sakakawea in 1991 than in 1992, and an intermediate number in 1993. Trawling success rates of Hendrickson in 1991 (30 YOY/km; Hendrickson 1992), prior to this study, were much higher than in 1992. Although I did not regularly measure the distance of my tows, they were approximately 0.6 km. Using this approximation, my highest trawl catch rate at a single station in 1992 was only 1.6 YOY/km, (less than 5 % of 1991), whereas trawling success in 1993 (11.2 YOY/km) was intermediate. No count data are available for 1991, but as anticipated, counts were much higher in 1993 than in 1992. These similar trends in discharge, harvest, and YOY densities throughout the three year period suggest to me that the low counts and low trawl catches of YOY in 1992 may be the result of unusually low spawning activity, as a result of low Yellowstone River discharges, that in turn resulted in few YOY paddlefish in Lake Sakakawea (Figure 9).

The second piece of evidence supporting the reliability of counts and trawl catches as indicators of relative abundance is the strong positive correlation between the YOY counts and trawl catch at a given station. Such a positive correlation would be expected if counts and trawl catch are both effective measures of relative abundance.

The third piece of evidence supporting the reliability of counts is the general spatial and temporal pattern of YOY abundance observed in 1993, which supports the value of the counts. Both cross-section counts and station counts in 1993 were characterized by the abrupt appearance of YOY during the period August 23-30. Cross-section counts showed a temporal and spatial pattern that peaked in late August from RM 1518 to RM 1512. In later weeks, YOY abundance gradually assumed a more uniform distribution, characterized by lower counts throughout the study area. This pattern is consistent with the idea that YOY paddlefish did not appear until mid-August, but were in high concentrations by late August, and gradually dispersed by late September.

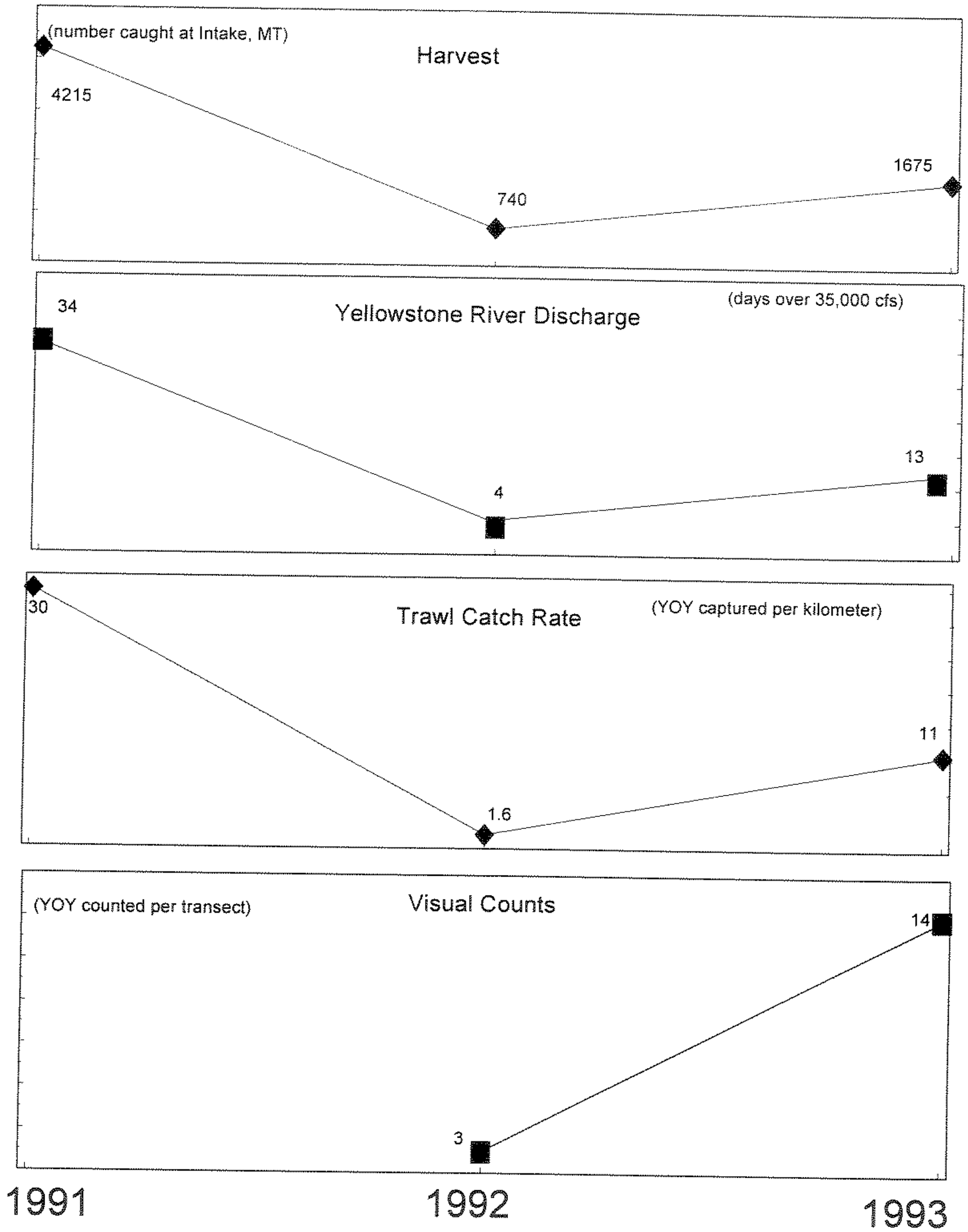


Figure 9. Paddlefish harvest at Intake, Yellowstone River discharge, trawl catch rate, and visual counts from 1991 to 1993.

The fourth piece of evidence supporting both counts and trawls as effective measures of YOY abundance is that the ratios of yearlings to YOY counted are as would be expected if 1991 was a strong reproductive year, 1992 a weak year, and 1993 an intermediate year. If river discharge and harvest rates are representative of respective spawning success and year-class strengths, the abundance of yearlings would be expected to be high in 1992 and low in 1993. This expectation is supported by the visual counts, in which 29 yearlings per 100 YOY were counted in 1992, but only 1 yearling per 100 YOY was counted in 1993, and by trawl catches, in which nearly 10 yearlings were caught per 100 YOY in 1992, but less than 1 yearling per 100 YOY in 1993.

Versatility of Visual Counts

Evidence that YOY and yearling paddlefish can be counted during windy days with waves in excess of one meter is of particular importance because of the variable daily and seasonal weather conditions on Lake Sakakawea. Accounts of sampling YOY paddlefish on Lake Sakakawea in 1991 indicated that calm water with little or no wind activity was favorable, and perhaps necessary, for YOY to be near the water surface (Hendrickson 1992). Evidence from my study, however, suggests to me that calm water is perhaps least favorable, and that a slight chop (0.3 m waves) may be preferable.

One factor that may have contributed to the lower mean number of YOY counted per transect in calm water was the fixed 10 m counting range on each side of the boat. This distance limitation was established initially because I believed 10 m to be the maximum distance from which we could accurately count YOY during the windiest conditions (1 m waves). In calm water, however, we could have counted much beyond the 10 m range.

YOY/hour, but trawled only 5.2 YOY/hour. The trawl averages do not include the time required to prepare and check the trawl before and after each tow, which obviously further decrease its relative efficiency.

Thirdly, although counts require only one boat, trawling requires two boats, which increases cost, as well as the possibility of lost data due to equipment failures. Fourthly, in the volatile summer weather at Lake Sakakawea, high winds and high waves (>1 m) can make trawling difficult and potentially dangerous, whereas visual counts appear to be as reliable during these conditions as during calm weather.

The counts may also suffer some disadvantages. One main disadvantage is the inability to collect length or weight data. If this information is necessary, however, I found that, while standing on a slow-moving boat (5-10 km/hr), I was often able to dipnet YOY paddlefish from the surface as they attempted to flee. Using this method, catch rates ranged from 30 YOY/hour, when YOY were abundant near the surface, to less than one, when YOY were scattered and scarce.

A second potential disadvantage is the effect on counts, if any, of physical conditions, such as wave height. My results were inconclusive regarding effect of wave height, but more investigation should be conducted on its potential effects. A third factor that may influence counts is behavioral change of YOY paddlefish in response to predators. For example, flocks of seagulls, which I observed feeding on YOY paddlefish, may somehow bias counts if YOY actively avoid them by swimming deeper. No research has been conducted on the significance of such predators to YOY in Lake Sakakawea. Fourth, variation among observers may decrease the accuracy of counts. Some people may initially have difficulty seeing and identifying the young paddlefish, and the 10 meter counting range requires consistent ability to judge distances.

Although more research is needed to answer these questions about counts, the method has potential as an inexpensive, easy-to-use and reliable sampling method to annually assess relative year class strength of this stock of paddlefish. Both the station counts and cross-section counts seemed to provide reliable indices of relative year-class strength, and both would be useful on an annual basis. Cross-section counts are perhaps more advantageous than station counts in that they cover a large area in a short period of time, while still depicting temporal and spatial distribution and indicating relative abundance from year to year.

CHAPTER 2: ENVIRONMENTAL FACTORS AFFECTING DISTRIBUTION AND ABUNDANCE OF YOUNG-OF-THE-YEAR PADDLEFISH IN LAKE SAKAKAWEA FROM JULY THROUGH SEPTEMBER.

INTRODUCTION

Successful assessment of relative abundance and year-class strength of young-of-the-year (YOY) paddlefish depends largely on an understanding of spatial and temporal distribution and abundance of the fish during late summer and early fall when the fish are most easily seen. It is also dependent on an understanding of the physical, chemical, and biological factors affecting YOY distribution and abundance. Young-of-the-year paddlefish distribution is not well understood in any system and has been largely unknown in Lake Sakakawea. Factors that may influence distribution and abundance include total zooplankton density, water temperature, water depth, water velocity, and water transparency.

Because Lake Sakakawea is the recipient of the Yellowstone River drainage, the upper half of the reservoir is subject to high turbidity during the late spring and summer months. In recent years, fishermen have reported large numbers of young paddlefish in the turbid waters of upper Lake Sakakawea. In July and August, 1991 North Dakota Game and Fish Department (NDGF) and the U.S. Fish and Wildlife Service (USFWS) identified concentrations of YOY paddlefish in a "limited area" of Lake Sakakawea near River mile (RM) 1521 (Hendrickson 1992). The stomach contents of four captured paddlefish indicated little recent feeding (Greg Power, Fisheries Supervisor, NDGF, personal communication), and zooplankton samples indicated low densities of zooplankton in July. The area was characterized by slow current from inflow of the Missouri River with high turbidity and water depths of one to three meters. Hendrickson reported that over a 30-day period, the concentration of YOY paddlefish moved 2-3 km down the reservoir, away from the shore, and that this movement corresponded to a slight decline in the reservoir level.

My second objective was to assess the importance of total zooplankton densities, water temperature, water depth, water velocity, and water transparency on distribution and abundance of YOY paddlefish in upper Lake Sakakawea from July through September.

METHODS

Assessment of factors affecting distribution and abundance of YOY paddlefish is dependent on reliable methods of quantifying relative abundance. Based on results of this study, I concluded that the visual count method was the most effective method available (Chapter 1), and, therefore, counts were used as the primary method. Distribution and abundance of YOY paddlefish were assessed by counting YOY on two different spatial scales, along cross-sections and at stations.

Cross-Section Sampling

In order to obtain a broad picture of distribution and abundance, to avoid overlooking major concentrations of paddlefish, and to detect any sampling periods was used for cross-section sampling and for laboratory analysis of zooplankton.

Visual counts

At each station, counts were conducted in conjunction with Objective 1 over three 1.6-km transects per station. Transect locations were recorded using the LORAN system so that they could be precisely (within 10-20 m) resampled. I used the counting procedure described in the methods section of Chapter 1 to estimate relative abundance of YOY at each station based on the number of YOY paddlefish counted per transect.

Zooplankton Sampling

At each station, I collected three horizontal surface tows with a 10.16 cm diameter Wisconsin net (80 µm mesh) to estimate zooplankton densities where YOY paddlefish were counted, which was also near the surface. The tows were made approximately 500 meters apart in order to best represent the entire station area. The volume of water in each tow was measured with a flow meter mounted inside the mouth of the net. Tows were 30 to 100 meters in length, and sampled zooplankton from 250-1,000 liters of water. Samples were preserved in a solution of 70% ETOH, 3% glycerine and later stained with 1-2 ml of both Lugols iodine and eosin Y. Quantification of zooplankton density, as a variable that might influence YOY paddlefish distribution and abundance, was limited to total number of organisms (excluding rotifers) per liter of water. Samples were diluted and subsampled so that a counting maze contained a manageable number of organisms (100-200). Classification of organisms was based on a combination of size and taxon, as described in Chapter 3.

Measurement of Physical Characteristics

At each station, I measured the physical parameters of water temperature, water depth, water velocity, and transparency. Measurements were made approximately 500 meters apart, in the same area that the zooplankton was collected. As with zooplankton density, temperature and water velocity were both measured immediately below the surface to reflect the conditions where YOY were counted. Water velocity was measured with both a Marsh-McBirney flow-meter and a neutrally buoyant object floated along the side of the boat. A boat-mounted sonar was used to determine depth, and I measured transparency with a 20 cm Secchi disk (Goldman and Horne 1983), using procedures outlined by Lind (1985, p 28-29).

Analysis

In both 1992 and 1993, I evaluated factors affecting distribution and abundance of YOY paddlefish by station (as measured by counts of YOY/km) using two statistical analyses that each assessed effects of a different set of environmental variables on counts of YOY at a station (Figure 11). The first analysis was a correlation matrix designed to depict the strength of the correlations between the variables of mean YOY per station, total zooplankton density, water temperature, water depth, water velocity, and transparency. Because the three counts at each station were not independent, I used the mean of the three counts at a station in the correlation matrix. A correlation matrix was used rather than a multiple regression procedure because of the high correlation between the independent variables.

The second analysis procedure, a split-split-plot analysis of variance, assessed the effects of week (sampling period) and location (station) on the number of YOY/km (and also included the morning and afternoon effects on counts discussed in Chapter 1). This analysis was to designed to assess whether I counted more YOY paddlefish at specific sampling stations during each sampling period, and to determine if any stations had consistently higher counts throughout August and September, thereby indicating the presence of a specific nursery. For this analysis, the three YOY counts per transect were nested within their station. The first three sampling periods of 1993 (July 12 - August 14) were excluded from the analysis because of the predominance of zeros in the YOY counts. This exclusion did not effect the outcome of the ANOVA, other than that inclusion of these weeks merely increased the significance of the week (period) effect.

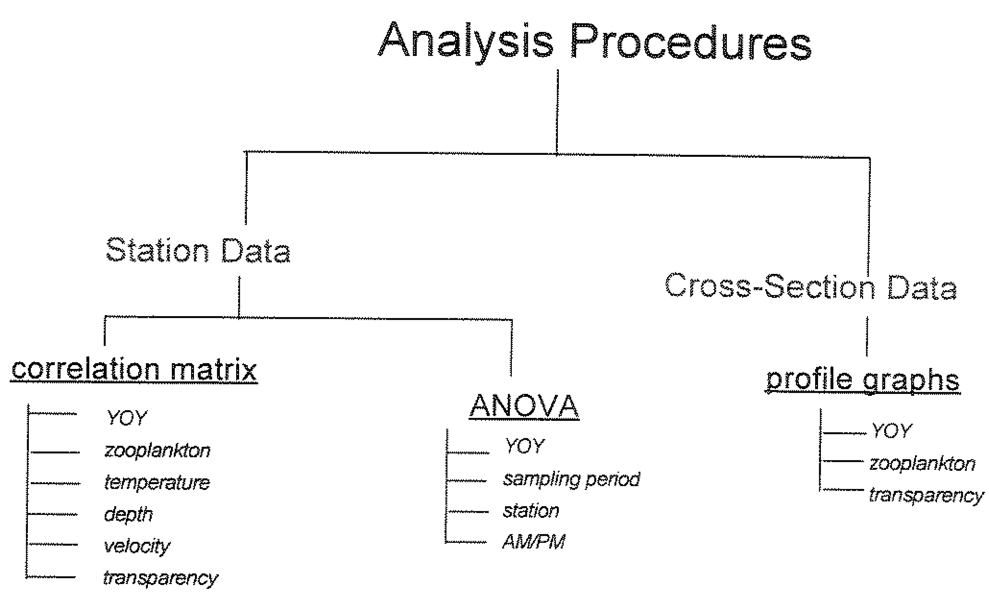


Figure 11. Procedures used for analysis of factors related to the distribution of YOY paddlefish.

RESULTS

Cross-Sections

Low Counts in 1992

Cross-sections in 1992 were characterized by low counts (usually < 2 YOY/km) and scattered sightings of YOY. Highest counts and the broadest distribution, based on the cross-sectional counts, occurred on August 21, when I counted 4.6 YOY/km at RM 1521 and saw YOY at each cross-section from RM 1521 to RM 1506. At no other time during the entire sampling period (August 19 - September 4) did I count more than 1 YOY/km. Because of only sporadic sightings of YOY paddlefish in 1992, no clearly defined spatial or temporal pattern was evident in YOY distribution. Zooplankton and transparency profiles indicated a zone of several kilometers, from RM 1518 to RM 1509, where suspended sediments settled and transparency and zooplankton densities increased (Figure 12). Counts of YOY paddlefish were not associated with any particular combination of transparency and zooplankton density.

Higher Counts in 1993

In contrast to 1992, a clear temporal and spatial pattern of YOY distribution was evident in the 1993 cross-sections. The pattern began with a sudden appearance of YOY in the study area on August 30. Highest counts on this day were in the area from RM 1518 to RM 1512, where counts ranged from 7 YOY/km to 10 YOY/km. This area, which was also where zooplankton densities and transparency increased rapidly, continued to exhibit the highest counts of YOY in the following four weeks.

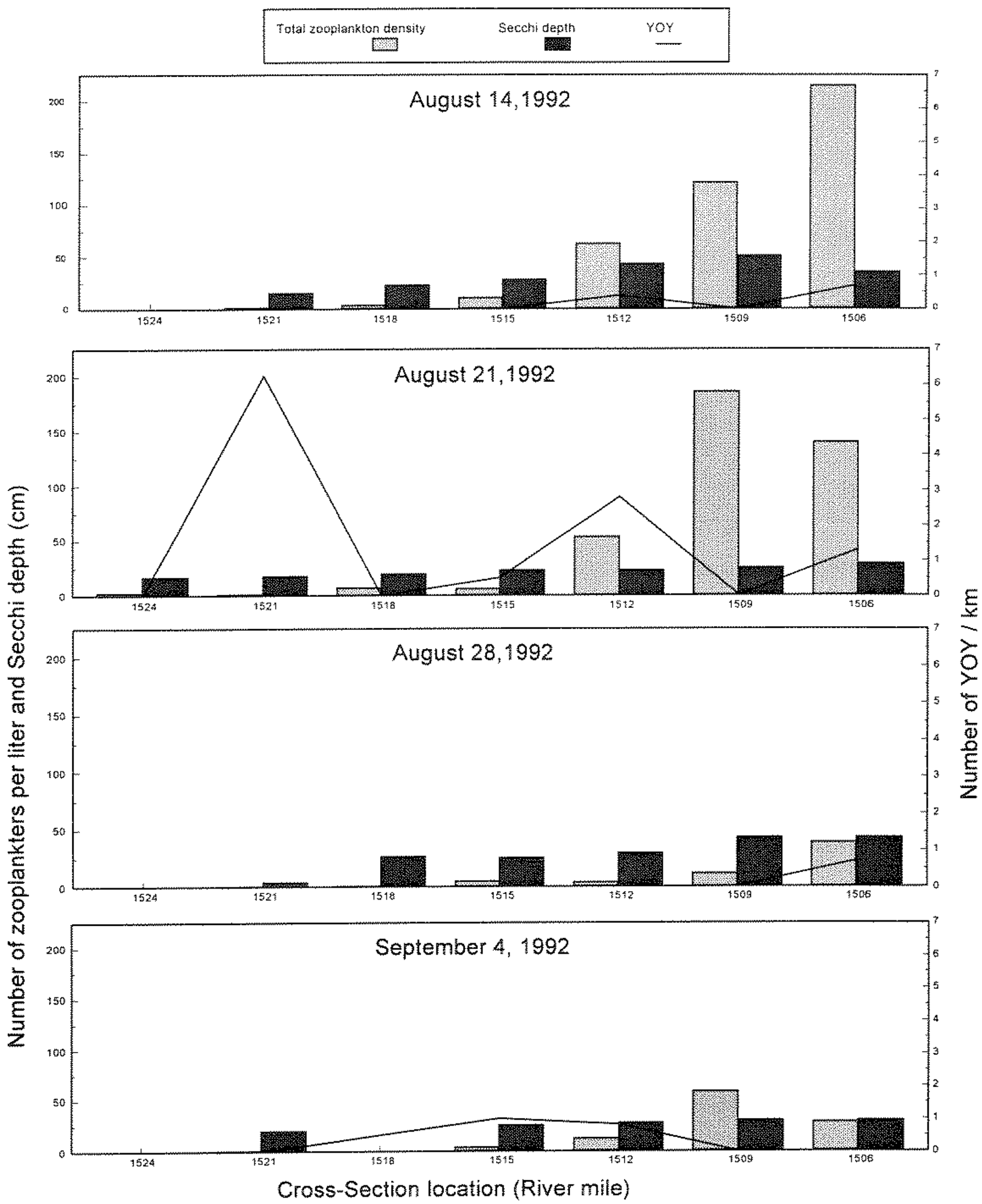


Figure 12. Profiles of YOY paddlefish counts, water transparency (Secchi depth), and total zooplankton density from RM 1521-1506 from August 14 to September 4, 1992.

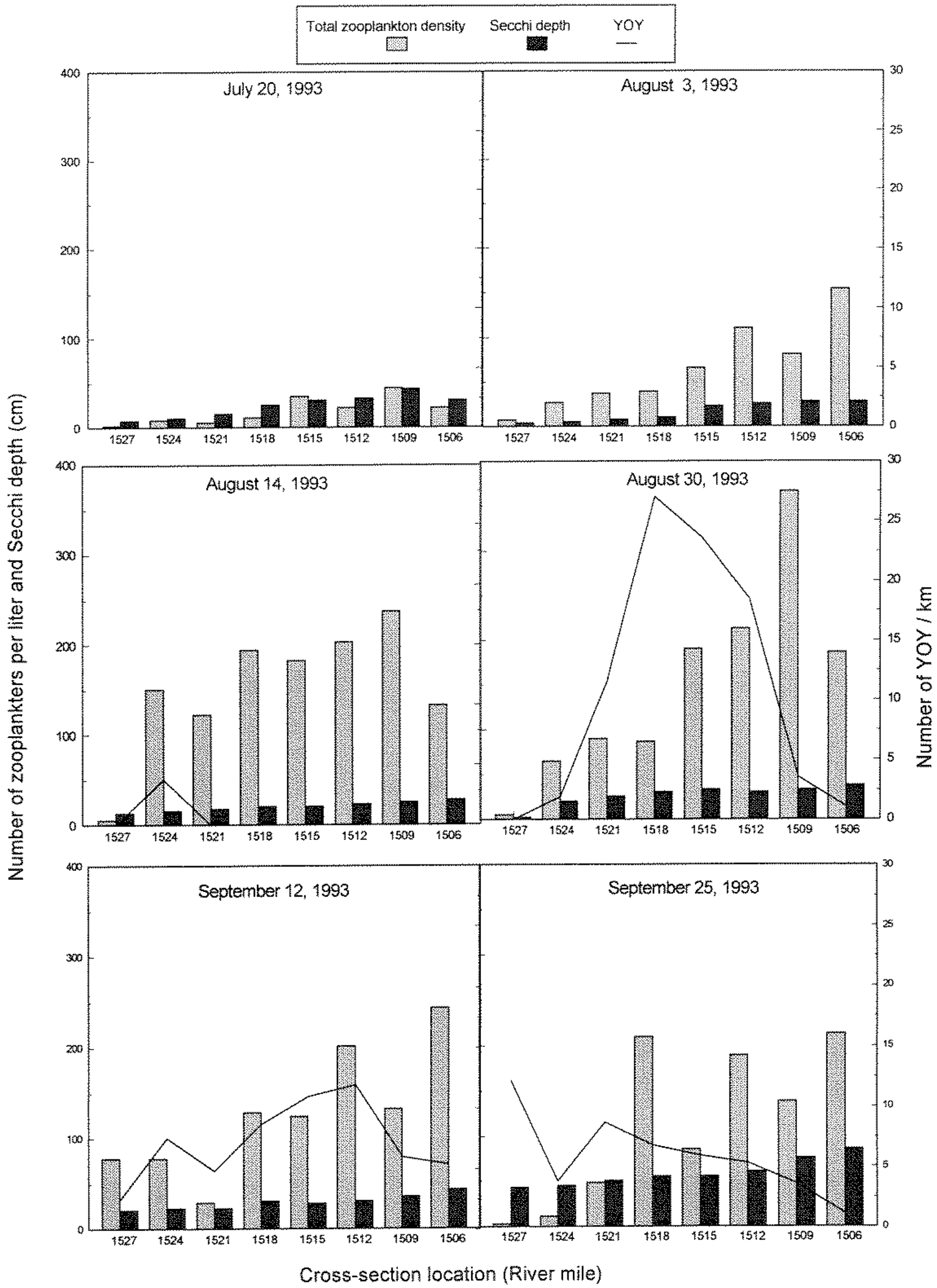


Figure 13. Profiles of YOY paddlefish counts, water transparency (Secchi depth), and total zooplankton density from RM 1527-1506 from July 20 to September 25, 1993.

By September 25, distribution was nearly uniform throughout the entire 34 km study area (Figure 13). In both 1992 and 1993, the period of highest YOY counts coincided directly with, or occurred immediately after, the period of greatest total zooplankton density.

Station Sampling

Range of Environmental Characteristics

The progressive change of Lake Sakakawea from a riverine to a reservoir environment within the study area was associated with a progressive increase in zooplankton density and water transparency, as water velocity decreases. In the uppermost two stations of the study area (RM 1527-1525), total zooplankton densities were often less than five organisms/liter, whereas in the lower stations (RM 1512-1509), zooplankton densities generally exceeded 150 organisms/liter and occasionally exceeded 300 organisms/liter. An increase in zooplankton density was associated with the settling of suspended sediments and with lower velocities. As water velocity decreased from about 1 m/s at the upper station to 0 m/s at the lower stations, transparency increased from less than 10 cm to more than 50 cm.

Water temperatures in the study site ranged from 11 C and 23 C (a 12 C difference) in 1992 over the four week period from August 19 to September 9, whereas in 1993, the temperatures between these dates only varied by 9 C (14-23 C). The greater temperature stability in 1993 than in 1992 may have been related to the difference in reservoir levels between the two years. In August, 1992, Lake Sakakawea was low (555.9 m above msl) and had dropped another 0.3 m by the end of September. At these reservoir levels, water depths at the upper portion of the study area (above RM 1518) in July and August, 1992 were less than one meter and by September were too shallow to operate the boats. Water depths at lower stations were 3-5 m. In contrast, because of high amounts of precipitation and high river discharges in 1993, Lake Sakakawea had reached a much higher level by August, 1993 (559.0 m above msl), and depths were 3-9 m throughout the study area.

Relations between YOY Counts and Environmental Characteristics

Relationships among YOY counts, zooplankton density, water temperature, water depth, water velocity, and transparency were only partially consistent between 1992 and 1993 (Table 3). In 1992, water temperature ($r = 0.43$, $n = 42$) and water depth ($r = 0.55$, $n = 42$) were the two variables most strongly correlated with mean YOY counts/station, whereas in 1993, water temperature ($r = -0.07$) and water depth ($r = 0.19$) were only weakly correlated with YOY counts. Both relationships in 1992 were positive, indicating that greater numbers of YOY were visually counted in deeper areas and in warmer waters. Although zooplankton density was not strongly correlated with YOY counts in 1992, it was the variable most closely related with YOY counts in 1993 ($r = 0.52$, $n = 108$). The positive correlation between transparency and YOY counts, and the negative correlations between water velocity and YOY counts in both 1992 and 1993 (Figure 14,15) indicated that more YOY were counted in more transparent waters where the low velocities enabled suspended sediments to settle out of the water.

Table 3. Correlations between number of YOY paddlefish counted at a station (YOY), total zooplankton density (zooplankton), water temperature (temp.), water velocity, water transparency (Secchi depth), and water depth in 1992 and 1993. Correlations greater than 0.40 are in bold.

VARIABLE	YEAR	YOY	Zooplankton	Temp.	Velocity	Secchi depth	Depth
YOY	1992						
	1993						
ZOOPLANKTON	1992	.15					
	1993	**.52**					
TEMP.	1992	**.43**	.16				
	1993	-.07	.14				
VELOCITY	1992	**-.41**	**-.49**	.01			
	1993	-.23	**-.43**	.03			
SECCHI DEPTH	1992	.39	.33	-.05	**-.78**		
	1993	.21	.23	**-.45**	**-.63**		
DEPTH	1992	**.55**	.27	.13	**-.47**	**.58**	
	1993	.19	.26	-.01	-.36	**.55**	

Effect of Sampling Period and Sampling Station on YOY counts

In both 1992 and 1993, sampling period, sampling station, and the interaction between these two variables all exerted significant effects on counts of YOY paddlefish (Tables 4,5). The effect of period (week) was expected, as higher YOY counts were apparent in mid to late August than before (late July) and after (late September) this period. The significant effect of station on YOY counts indicated that distribution of YOY was not uniform throughout August and September, and higher counts of YOY were associated with particular stations. The interaction between period and station indicated that, from August 16 to September 9, 1992 and from August 23 to September 25, 1993, relative abundance of YOY paddlefish was not constant throughout the study site, and a specific, localized nursery area was either non-existent, or non-stationary. Difference between morning and afternoon (AM/PM) counts, addressed in Chapter 1, were inconsistent between 1992 and 1993.

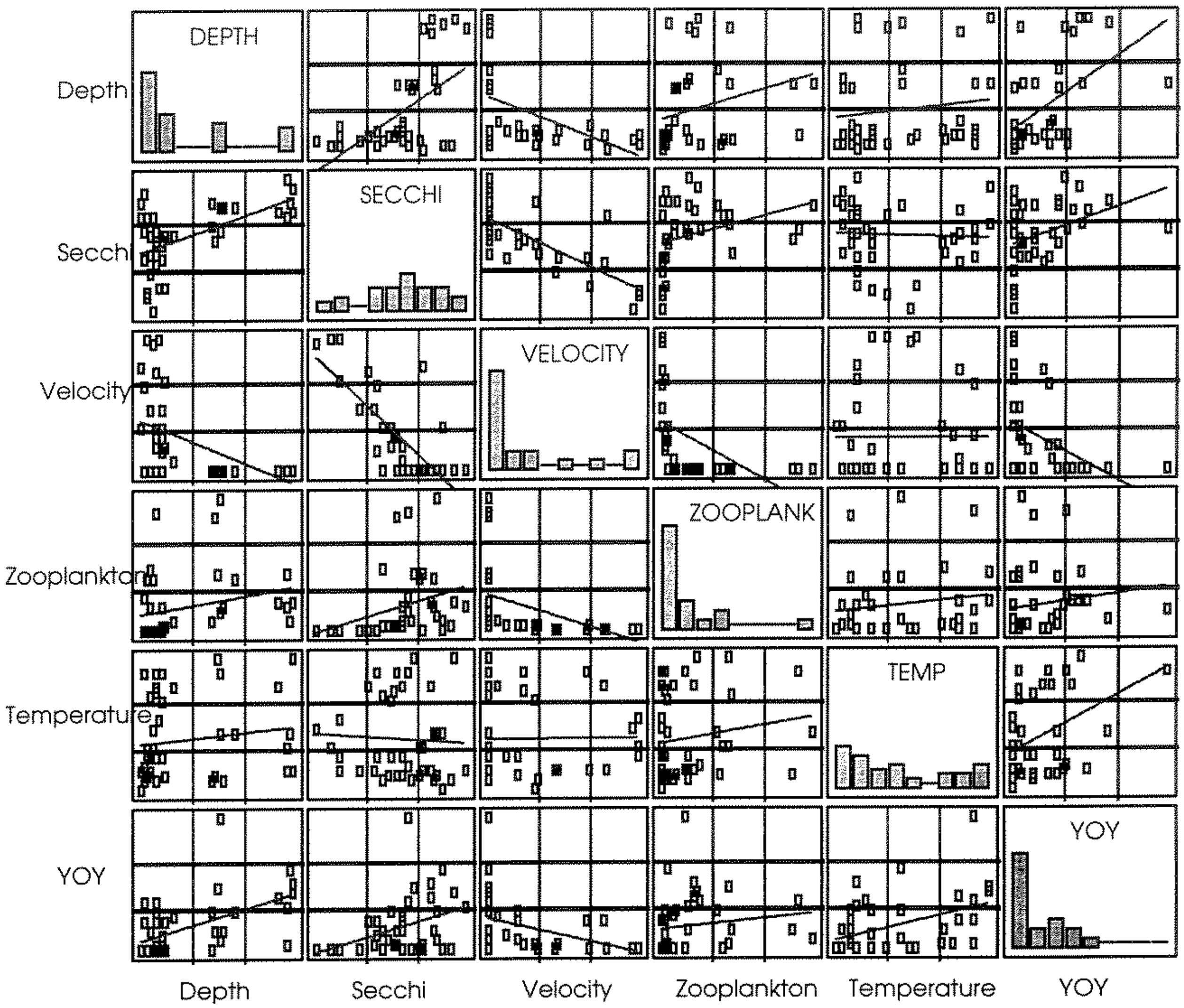


Figure 14. Graphically depicted relationships between number of YOY paddlefish counted at a station (YOY), temperature, total zooplankton density, water velocity, water transparency (Secchi), and depth in 1992. Diagonal bar graphs are frequency histograms.

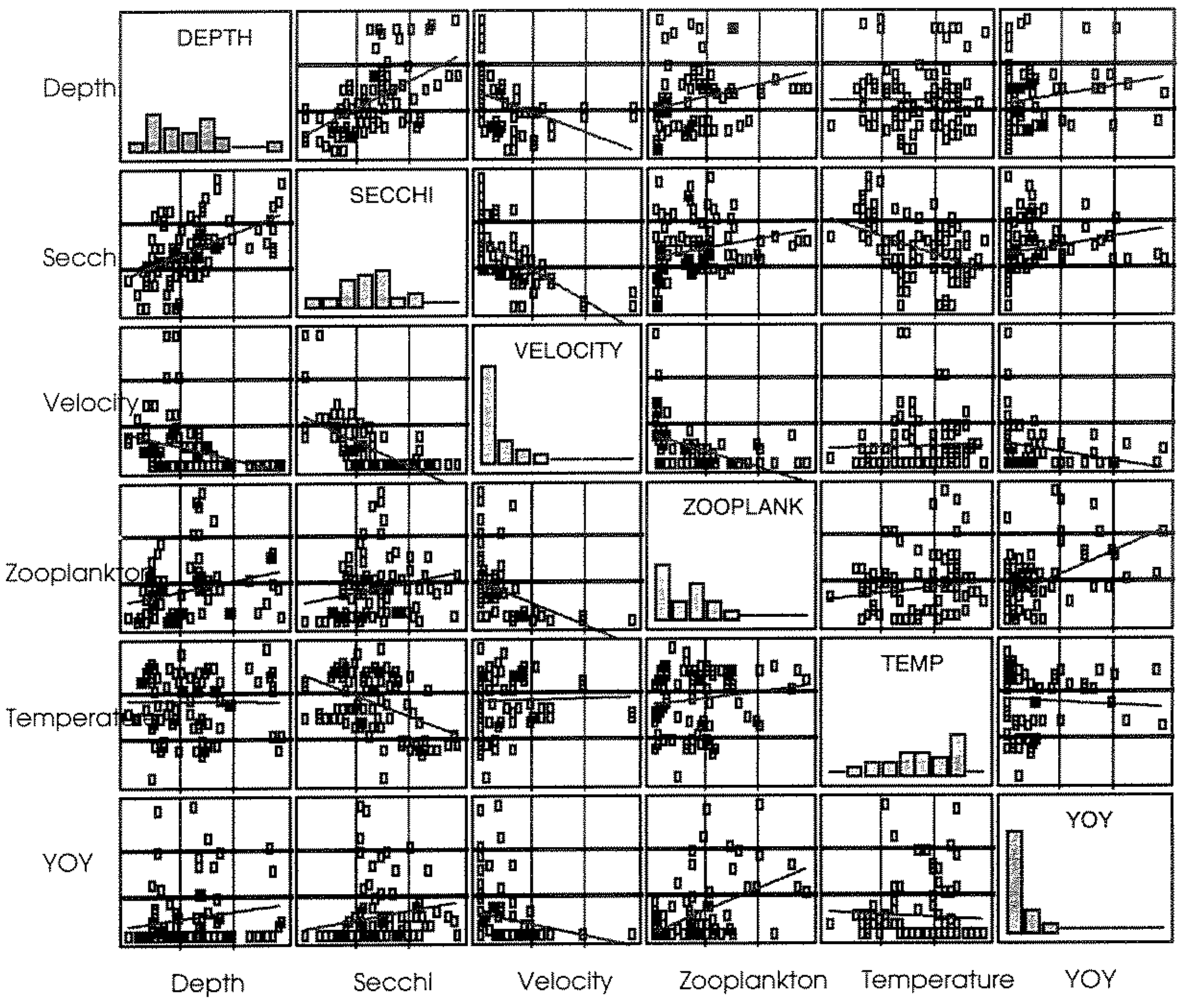


Figure 15. Graphically depicted relationships between number of YOY paddlefish counted at a station (YOY), temperature, total zooplankton density, water velocity, water transparency (Secchi), and depth in 1993. Diagonal bar graphs are frequency histograms.

Table 4. A split-split plot analysis of variance (ANOVA) for 1992, showing effects of sampling station, week (period), morning versus afternoon counts (AM/PM), and the interactions.

Effect	df Effect	MS Treatment	MS Error	F	p value
Period	2	34.48	2.18	15.74	<0.01
Station	5	37.05	2.18	9.17	<0.01
AM/PM	1	5.78	3.32	1.73	>0.1
Station x period	10	12.01	2.18	5.46	<0.01
Period x AM/PM	2	1.59	3.31	0.48	>0.1
Station x AM/PM	5	6.16	3.32	1.85	>0.1
Station x period x AM/PM	10	13.3	3.32	4.00	<0.01

Table 5. A split-split plot analysis of variance (ANOVA) for 1993, showing effects in of sampling station, week (period), morning versus afternoon counts (AM/PM), and the possible interactions.

Effect	df effect	MS Treatment	MS Error	F	p value
Period	2	1388	24.62	56.4	<0.01
Station	8	345.5	38.27	9.0	<0.01
AM/PM	1	76.0	13.85	5.4	<0.05
Station x period	16	300.4	24.62	12.2	<0.01
Period x AM/PM	2	8.6	13.85	0.6	>0.1
Station x AM/PM	8	91.5	13.85	6.6	<0.05
Station x period x AM/PM	16	101.2	13.85	7.3	<0.01

Consistent with the cross-sectional surveys, counts of YOY paddlefish at the stations in both 1992 and 1993 were marked by a sudden increase of YOY in mid to late August. The 1992 counts of YOY paddlefish were higher, and the fish more widely distributed, during the week August 16-19 than at any other time during the period three weeks before (July 23 -August 15) and three weeks afterward (August 20 - September 9; Table 6).

Although the time required to learn the study area and develop methods of quantitative assessment prevented the standardization of counts until August 16, 1992, based on general observations and unstructured counts during the three weeks preceding this date (July 23 - August 15), I believe that YOY were not as abundant and were less widely distributed before August 16 than afterward. In 1993, YOY counts and trawl catches were highest from August 23 to August 28. The mean YOY counts during this period was 14 YOY/transect, whereas from August 9-14, the previous sampling period, the mean was less than 1 YOY/transect (Table 7).

Table 6. Visual counts (VC) and trawl catches (TC) at the six sampling stations in 1992. Counts and trawls were conducted in morning (0700-1200 h; AM) and afternoon (1400-1900 h; PM). Each count number represents the total number counted in three 1.6 km transects, and each trawl catch number represents the total number captured in three trawls of five minutes each. Missing data is denoted by -.

		WEEK							
		Aug 16-19		Aug 23-26		Aug 30-Sep 2		Sep 6-9	
STATION	TIME	VC	TC	VC	TC	VC	TC	VC	TC
1	AM	7	-	0	0	0	0	0	-
	PM	5	-	0	0	0	0	-	-
2	AM	1	-	0	0	1	0	0	-
	PM	1	-	0	1	0	0	-	-
3	AM	8	-	7	0	9	0	-	-
	PM	1	-	3	0	2	0	0	-
4	AM	31	-	0	1	4	0	-	-
	PM	14	-	9	0	2	0	4	-
5	AM	4	-	4	0	11	0	-	-
	PM	11	-	0	1	0	0	1	-
6	AM	12	-	15	3	1	3	-	-
	PM	13	-	9	3	19	0	10	-
Total/period		108	-	47	9	49	3	15	-
Mean/transect		3		1.3		11.		0.42	

Table 7. Visual counts (VC) and trawl catches (TC) at nine sampling stations in 1993. Counts and trawls were conducted in the morning (0700-1200 h; AM) and afternoon (1400-1900 h; PM). Each count represents the total number counted in three 1.6 km transects, and each trawl catch represents the total number captured in three trawls of five minutes each. Stations also sampled in 1992 are marked by *.

Sampling Period

		July 12-16		July 26-31		August 9-14		Aug 23-28		Sep 7-12		Sep 20-25		TOTAL	
STATION	TIME	VC	TC	VC	TC	VC	TC	VC	TC	VC	TC	VC	TC	VC	TC
A	AM	0	0	0	0	0	0	4	0	7	0	17	0	28	0
	PM	0	0	0	0	0	0	9	0	20	2	26	0	55	2
B	AM	0	0	0	0	0	0	13	0	16	1	9	0	38	1
	PM	0	0	0	0	0	0	24	2	22	2	16	0	62	4
C *	AM	0	0	0	0	0	0	9	2	20	1	1	0	30	3
	PM	0	0	0	0	4	1	44	1	26	0	22	0	96	2
D *	AM	0	0	0	0	0	0	61	1	85	2	19	0	165	3
	PM	0	0	0	0	0	0	66	6	39	1	15	0	120	7
E	AM	0	0	0	0	3	0	73	3	4	0	8	0	88	3
	PM	0	0	0	0	2	0	106	4	38	5	4	0	150	9
F *	AM	0	0	0	0	3	0	17	2	6	0	18	0	44	2
	PM	0	0	0	0	1	0	34	5	7	0	8	0	50	5
G	AM	0	0	0	0	2	1	35	2	110	4	5	0	152	7
	PM	0	0	0	0	0	0	39	6	61	7	17	0	117	13
H *	AM	0	0	0	0	0	0	72	2	16	2	1	0	89	4
	PM	0	0	1	0	0	0	32	7	10	2	16	0	59	9
I *	AM	0	0	0	0	0	0	76	6	1	1	9	0	86	7
	PM	0	0	0	0	0	0	55	3	54	9	13	0	122	12
Total/period		0	0	1	0	15	2	769	52	542	39	224	0	1551	93
Mean/transect		0		0.02		0.28		14.24		10.047		4.14			

DISCUSSION

Spatial and Temporal Distribution

Although counts indicated a wide distribution of YOY throughout the 34 km area in late summer and early fall, higher counts were related to zooplankton density, water temperature, water depth, and lower water velocity. The strong positive relationship between YOY counts and zooplankton density in 1993, and the apparent coincidental timing of their peak periods of abundance, suggest that zooplankton density is a critical determinant of temporal and spatial YOY paddlefish distribution. Although *Leptodora* (*Leptodora kindtii*), a predaceous cladoceran, was found to be the primary food item in 1992 and 1993 (Chapter 3), I was unable to relate *Leptodora* density to YOY distribution and abundance because of the scarcity, or absence, of *Leptodora* in most zooplankton samples. Because the dominance of *Leptodora* in the YOY diet, combined with its low frequency in the zooplankton samples, implies a strong electivity for it by YOY paddlefish, it is reasonable that YOY distribution would be strongly influenced by the distribution and abundance of *Leptodora*. Attempting to relate the distribution of *Leptodora*, or even total zooplankton density with paddlefish density may, however, be misleading. Several studies have demonstrated the reduction in cladocerans and other zooplankters as a result of *Leptodora* predation (Branstrator and Lehman 1991; Wright 1965; Lunte and Luecke 1990), indicating that areas of high *Leptodora* density may quickly be depleted of other zooplankton. Salki et al. (1985) documented such interactions using large-scale enclosures. In his study, increased numbers of yellow perch *Perca flavescens* and pearl dace *Semotilus margarita* decreased the number of *Leptodora*, which, in turn resulted in increased numbers of *Bosmina longirostris*. With similar interactions in Lake Sakakawea, YOY paddlefish might then cause a significant reduction in *Leptodora* densities, resulting in increases in other zooplankters.

Although YOY paddlefish were counted throughout the ranges of water temperature (10-23 C), water depth (1-12 m) and water velocity (0-1 m/s), higher counts were associated with higher temperatures, greater depths, and slower velocities. In part because scant field research has been conducted on the physical habitat requirements of YOY paddlefish, Crance (1987) used the "Delphi technique" (a technique based on consensus of expert opinion, best used when a field data is lacking) to develop habitat suitability index (SI) curves for early larvae, advanced larvae and early juveniles (YOY), and adult paddlefish (Figure 16). Habitat variables considered included water temperature, depth, and velocity.

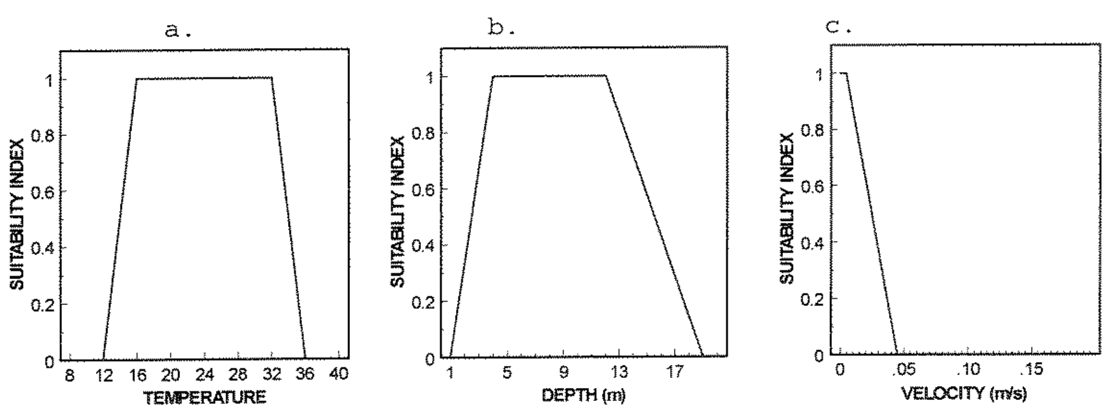


Figure 16. Habitat suitability index curves developed for YOY paddlefish for a) temperature, b) depth, and c) velocity using the Delphi technique (Crance 1987).

In comparing Crance's (1987) curves with my results, the temperature range (11-23 C) during the 1992 YOY counts (August 16-September 9) was partially outside the range defined by the SI curve as the most suitable range (16-32 C) for early juvenile paddlefish, and also partially below the 18-32 C range Graham et al. (1986) reported as being optimal for paddlefish growth in hatchery ponds. Based on these reported ranges, the strong positive correlation between temperature and YOY counts in 1992 is not surprising. The longer duration of the 1993 season (July 12-September 25), and the more gradual drop in temperature may explain the lack of a strong correlation between temperature and YOY counts in 1993. In addition, the Yellowstone-Sakakawea stock of paddlefish is one of the most northerly stocks of paddlefish (Gengerke 1986), so it is expected that such a stock would be subjected to lower water temperatures than stocks further south. The Yellowstone-Sakakawea stock also grows more slowly, matures at an older age, and lives longer than more southerly stocks (Scarnecchia et al. 1994b), consistent with the idea that it rears in colder than optimal waters.

Depth was the variable most strongly (and positively) correlated with YOY abundance in 1992. Based on Crance's (1987) SI depth curve, which suggests 4-13 m as optimal for YOY paddlefish, much of the area in 1992 was too shallow for YOY paddlefish, and the observed positive relation between depth and YOY abundance might then be expected. In contrast to 1992, greater reservoir depths in 1993 resulted in nearly the entire area of Lake Sakakawea from RM 1527 to RM 1506 exceeding Crance's (1987) optimal values. Depth was not strongly correlated with YOY paddlefish abundance in 1993. The large change in depth between 1992 and 1993 made it difficult to interpret if depth is a relevant variable influencing YOY distributions and abundance, or if it was just associated with other habitat features important to YOY.

Although I saw YOY paddlefish on several occasions in areas where velocity exceeded 1 m/s, the higher velocity areas in the upper reaches of the study site, which were characterized by lower zooplankton density and low transparency, were associated with low counts of YOY paddlefish in both 1992 and 1993. This result is consistent with Crance's (1987) SI curve for water velocity, where the optimal velocities for early juvenile paddlefish were < 0.05 m/s (i.e, little or no current), and velocities exceeding 1 m/s were deemed unsuitable.

The presence of YOY paddlefish throughout the 34 km study area in late summer and early fall, combined with the shifting distribution of YOY, based on counts at sampling stations, seems to refute the notion that any small, localized site served as a nursery area. Rather, the cross-sections and stations indicated that the entire study area, and probably beyond it, particularly the area including RM 1518 to RM 1512, was utilized by shifting concentrations of YOY.

The apparent absence of a small, localized nursery area is not surprising considering the expansive area of habitat optimally suited for YOY paddlefish based on depth and velocity (depths > 4 m, velocity = 0 m/s). The increasing abundance of zooplankton densities from the upper reaches to the lower reaches of the study site also suggest that the entire region below RM 1518-1515 was well suited for YOY paddlefish. In addition, although YOY were widely distributed in the areas that would be considered optimal, they were also occasionally seen in the upper stations, where, amid low zooplankton densities, shallow water, high velocities, and extremely low transparency, I would expect to see few or none. Paddlefish may only be in these areas briefly, and their occurrence in suboptimal areas may be evidence of a pattern of YOY movement from more riverine areas to more suitable, less riverine rearing areas from July through September.

Implications of Spatial and Temporal Distribution on Sampling YOY paddlefish

Timing is arguably the most critical factor affecting YOY distribution in the upper Lake Sakakawea. Both 1992 and 1993 were marked by the sudden appearance high YOY counts in the study area in mid to late August. In neither year were counts during this initial week equaled in the following weeks. This pattern of sudden appearance and gradual diminution suggests that accurate assessment of relative abundance from year to year depends on counting (and trawling) during the period that YOY first appear in the reservoir. Based on results from 1992 and 1993, a delay of even one week in counting could result in a significant underestimate of year-class strength. Rather than a period of several weeks when densities remain relatively constant, the initial pulse of YOY is evidently followed by gradual dispersal of YOY throughout the upper portion of the reservoir.

CHAPTER 3. VARIATIONS IN FEEDING ACTIVITY, MODE OF FEEDING, AND MEAN SIZE OF YOUNG-OF-THE-YEAR PADDLEFISH IN UPPER LAKE SAKAKAWEA IN AUGUST AND SEPTEMBER

INTRODUCTION

Little information currently exists on the feeding ecology and necessary feeding conditions for young-of-the-year (YOY) paddlefish in natural habitats. Much of the past research on feeding ecology has involved adult fish (Rosen and Hales 1981; Eddy and Simer 1929), or YOY fish in hatchery environments (Michaletz et al. 1982; Mims 1984; Graham 1986). Information on the daily and weekly periods of feeding activity, size-specific food habits, and growth rates of YOY paddlefish in Lake Sakakawea is important for understanding and assessing their year-class strength and relative abundance and, ultimately, for the successful management of this stock.

Daily and Seasonal Variations in Feeding Activity

Little is known of YOY paddlefish feeding activity in Lake Sakakawea, nor of the importance of zooplankton as food throughout the summer and early fall. Rosen and Hales (1981) reported that feeding activity, as measured by stomach fullness, of adult paddlefish in a free-flowing stretch of the Missouri River peaked in May and November, and was minimal from mid-June to early September, and that feeding peaks coincided with periods of greatest zooplankton densities. Jeff Hendrickson (Fisheries Biologist, North Dakota Game and Fish Department (NDGF), Personal Communication) reported that during the summer of 1991, YOY paddlefish were located in Lake Sakakawea in extremely turbid waters that would support minimal zooplankton production. Stomach contents of four paddlefish captured in the area in 1991 indicated little recent feeding (Greg Power, Fisheries Supervisor, NDGF, Personal Communication). Because of the rapid growth of YOY paddlefish, it seems unlikely that they feed only minimally during summer, yet at that time factors such as predation or low zooplankton availability may result in depressed feeding activity.

Mode of Feeding

YOY paddlefish feed primarily on zooplankton, but also on terrestrial and aquatic insects, and algae (Michaletz et al. 1982; Ruelle and Hudson 1977). Research shows that adult paddlefish are filter feeders that swim with their large mouths open and indiscriminately strain food from the water column with their gill rakers (Rosen and Hales 1981). It is also widely accepted that YOY paddlefish do not initially filter-feed in the first weeks of life, but instead actively select and capture the larger organisms from the plankton (Michaletz et al. 1982; Rosen and Hales 1981; Ruelle and Hudson 1977). It is not clear, however, when the young fish switch from feeding selectively to filter feeding, nor what causes the change of feeding mode. Rosen and Hales (1981) reported that YOY began filter feeding when they achieved total lengths (TL) of 225-250 mm, which suggests to me that size of YOY in Lake Sakakawea may be a key determinant of the change in feeding mode.

Growth of YOY and Yearlings

Several studies have addressed growth of YOY paddlefish and have demonstrated a wide variation in growth between systems (Houser and Bross 1959; Pasch et al. 1980; Ruelle and Hudson 1977). In a highly productive hatchery pond in Missouri, paddlefish reached 720 mm TL in 110 days (Hamilton 1986). In contrast, Robinson (1966) reported that wild paddlefish in Montana only reached 208 mm TL by the end of the first growing season. Year-to-year variations in growth also appear to be significant. Over a four year period, Ruelle and Hudson (1977) found distinct annual variations in size attained by YOY paddlefish in Lewis and Clark Lake, a main stem Missouri River reservoir. The average length by the end of August, 1970, was 265 mm TL (10.4 inches), whereas fish captured in late August in 1972 averaged only 160 mm TL (6.3 inches).

Objectives

Development of accurate methods for assessing year-class strength and relative abundance of the Yellowstone-Sakakawea stock of paddlefish depends on a broad understanding of the ecology of YOY paddlefish in Lake Sakakawea. Our objectives were:

1) to assess daily and weekly variations in feeding activity, as measured by stomach fullness and condition factor, of YOY paddlefish in upper Lake Sakakawea in August and September,

2) to determine if and when YOY paddlefish shift from a selective mode of feeding to non-selective filter feeding, and

3) to estimate growth using mean body length of YOY paddlefish in upper Lake Sakakawea in 1992 and 1993.

METHODS

YOY and yearling paddlefish were collected with a surface trawl and with hand-held dipnets from Lake Sakakawea between River mile (RM) 1527 and 1506, during the periods August 1-September 9, 1992 and August 3-September 25, 1993. Body length (BL; front of eye to fork of caudal fin; Ruelle and Hudson 1977), weight, time, and location of capture was recorded for all YOY and yearling paddlefish caught. To determine whether changes in within-day feeding activity (based on stomach fullness) could be assessed without sacrificing paddlefish, I pumped the stomachs of three YOY paddlefish with squirt bottle and then removed the stomach and checked for significant remaining stomach contents. I found significant proportions of stomach content remaining and concluded that vigorous stomach pumping using this technique could not be used to make stomach fullness comparisons, and that variations in the stomach fullness index could only be made by sacrificing a sample of paddlefish. Although most of the YOY paddlefish collected and measured for length and weight were released, in all, a total of 22 YOY in 1992 and 80 YOY in 1993 were thus preserved for laboratory analysis of feeding activity and food habits.

In 1992, YOY paddlefish were collected over a five-week period from August 5 to September 3. Although I attempted to collect at least five fish per weekly sample, the low numbers of YOY counted and captured in 1992 resulted in samples fewer than five YOY during the first week in August ($n = 3$) and the first week in September ($n = 1$). The 22 paddlefish were all collected at or near the same station, during the same time of day (1100-1300 h) at one week intervals during the five week period so that any variation in feeding activity could be attributed to the effect of the different weeks.

In 1993, I was able to collect larger samples of YOY paddlefish, particularly during the periods August 21-25 and September 9-10. As in 1992, I collected the samples during the same time of day (1100-1300 h) at the same station; however, instead of one week intervals as in 1992, I collected samples at two week intervals. I also collected specimens from the furthest up-reservoir reaches of the study site, enabling me to compare spatial variations in feeding activity. In addition, stomach samples from two yearling paddlefish were collected in 1993.

To evaluate whether feeding activity varied significantly during a one day period, I collected a sample of 10 YOY paddlefish during each of three time periods (0700-0730 h, 1330-1400 h, and 1600-1630 h) at the same station (Station E) on August 28, 1993. I was unable to evaluate within-day variations in feeding activity in 1992 because of the inability to collect sufficient YOY.

The 22 YOY in 1992 and 80 YOY in 1993 that were collected for laboratory analysis of feeding activity and food habits were killed by piercing the brain in order to prevent regurgitation (Sigler and Sigler 1990), and fixed in formalin for at least one week before being transferred to a 70% ETOH--3% glycerine preservative.

Stomach Content Analysis

Stomach content weight was derived using blotted, damp weights. Body weight of the preserved specimen was first measured, then the stomach was removed and weighed. All stomach contents, including frequently encountered parasitic worms, were removed, and stomach content weight was calculated as the weight of the full stomach minus the weight of the empty stomach and parasites.

After removing the stomach contents, I added 80-100 ml of 70% ETOH and thoroughly mixed the solution. I then identified and quantified taxa and size of organisms ingested, based on three subsamples of the total volume of the stomach content solution. Zooplankton from both the stomach samples and water samples collected during the same sampling period (in conjunction with Chapter 2) were identified and classified as *Leptodora (Leptodora kindtii), Daphnia spp., Simocephalus spp., Bosmina longirostris, Ceriodaphnia spp., Moina spp., Scapholeberis spp.,* calanoids, cyclopoids, and species of the Families Chydoridae and Sididae (both small cladocerans), and of the orders Diptera (flies and midges), Ephemeroptera (mayflies), and Plecoptera (stoneflies). I compared frequency of species composition and size of ingested organisms with species composition and size of zooplankters collected with a plankton net where the fish were captured. In the case of *Leptodora*, only relatively indigestible parts of organisms were usually identifiable. I therefore measured and quantified caudal spines (CL) and fit them to a linear regression in order to estimate the size of the original organism ($TL = CL * 5.86 - 0.57$, R-square = 0.80, $p<0.01$, $n = 90$).

Indices of Feeding Activity

The two methods used to assess variations in feeding activity were stomach fullness index (SFI) and condition factor (K). Stomach fullness index (Windell 1971), calculated as

$$SFI = \frac{(\text{stomach content weight} * 10{,}000)}{\text{body weight}}$$

is the ratio of the stomach content weight to fish weight and is a measure of recent feeding activity.

The second method, condition factor, is a measure of robustness or plumpness (Sigler and Sigler 1990) that can potentially indicate changes in feeding intensity (Wootten 1990). Although perhaps less sensitive than the SFI, condition factor is particularly useful because fish need not be sacrificed for collection of the data. Condition factor was calculated in metric units, as

$$K = \frac{\text{weight} * 10^5}{\text{body length}^3}$$

Analysis

Variation in Feeding Activity

Analysis of variance (ANOVA) was used to assess whether feeding activity, as measured by SFI and condition factor, varied from July to September, varied between morning, afternoon, and evening, and varied between upper and lower reaches of the study area. Because field weights prior to August 27, 1992 were unavailable, I was unable to make condition factor comparisons for the 1992 season. Where appropriate, I made pairwise comparisons with Fisher's Protected Least Significant Difference test (LSD).

I used a two tailed t-test on condition factor of all paddlefish captured in 1993 to determine if fish collected in the morning (0700-1200

h) were significantly more robust than those collected in the afternoon (1400-1600 h).

Mode of Feeding

I compared the observed zooplankton composition in the stomach sample with the zooplankton composition in the adjacent water sample to determine whether the individuals were selecting particular species, or categories of zooplankton (chi-square < 0.05), or if they were indiscriminately filtering the water (chi-square > 0.05). Grouping of zooplankters into three categories (large cladocerans and insects, small cladocerans, and copepods; Table 8) was necessary to create sufficiently large expected values for the chi-square test. Most statisticians recommend combining cells to avoid values as low as one (Daniel 1990), and if not combined, expected values would have been less than one percent for the two most common food items in the stomach samples, *Leptodora* and insect larvae. Body lengths of YOY were then related to mode of feeding to determine if the onset of filter feeding was associated with the attainment by the YOY of a particular length. I also used a t-test to determine if YOY paddlefish selected the largest individuals of the most abundant species (*Leptodora*) found in stomach samples.

Growth

Mean body length of all YOY paddlefish captured during each sampling period was used as an index of growth in August and September. To determine if mean body length of YOY decreased up reservoir and increased down reservoir in 1993, locations of capture (station) were used as treatments in a one-way ANOVA with body length of fish captured at each station as observations.

Table 8. Three categories of zooplankters used for statistical comparison of YOY paddlefish stomach content and zooplankton samples from Lake Sakakawea.

Large Cladocerans and Insect Larvae	Small Cladocerans	copepods
Leptodora kindtii	*Bosmina longirostris*	calanoids
Daphnia spp	*Ceriodaphnia spp.*	cyclopoids
Simocephalus spp	*Moina spp.*	
Sididae	*Scapholeberis spp*	
Dipterans	Chydoridae	
Ephemeropterans		
Plecopterans		

RESULTS

Variation in Feeding Activity

Variation in Feeding Activity from August through September

In 1992, stomach fullness (SFI) declined from a mean of 598 to 226 during the four sampling periods from August 3 to August 27, 1992 ($p<0.1$; Table 9), concurrent with a decline in *Leptodora* densities during the same period (Figure 17). Fuller stomachs in 1993 were also associated with the periods of greatest zooplankton density. Highest mean SFI values in 1993 were in the down-reservoir reach during the periods August 21-25 and September 9-10, whereas mean SFI values in the up-reservoir reach, and those collected during the periods August 3-12 and September 22-24 were consistently lower (Table 10).

Table 9. Mean 1992 stomach fullness index (SFI) values of YOY paddlefish captured at one week intervals (significant pairwise comparisons are marked with *).

Sampling Period	Mean SFI	Sample Size
Aug 4-5	*598.6	n = 3
Aug 13	410.3	n = 6
Aug 18	376.6	n = 6
Aug 27	*226.9	n = 6
Sep 3	235.5	n = 1

Table 10. Mean 1993 stomach fullness index (SFI) values for YOY paddlefish captured up-reservoir (above RM 1521) and down-reservoir (below RM 1521).

Sampling Period	Up-reservoir		Down-reservoir	
	n	SFI	n	SFI
Aug 3-12	0		5	190.7
Aug 21-25	5	243.6	19	494.2
Sep 9-10	3	75.8	12	557.3
Sep 22-24	4	111.0	1	156.3

Inasmuch as sample sizes were small during all but two of the sampling periods (four and five), I found no statistically significant results in the comparisons of stomach fullness that included both sampling period and reach as treatments. Comparing up-reservoir and down-reservoir samples separately, however, indicated that stomach fullness did differ according to sampling period in the up-reservoir reach (ANOVA, $p<0.05$), and in the down-reservoir reach (ANOVA, $p<0.05$). Stomachs were significantly fuller during the periods August 21-25 and September 9-10 than during the earlier period of August 3-12 (Fisher's LSD, $p<0.05$; Figure 18).

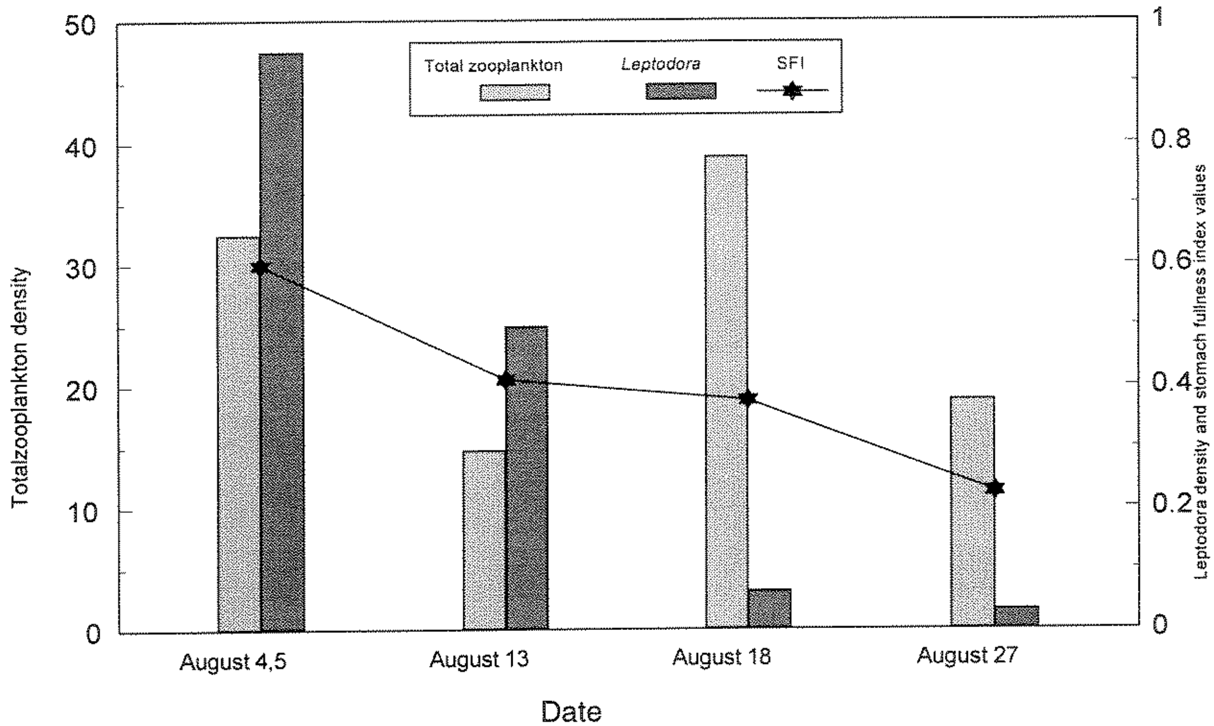


Figure 17. Mean stomach fullness index values, total zooplankton density (organisms/liter) and *Leptodora* density (second Y axis) in 1992.

Variation in Feeding Activity between Morning, Afternoon, and Evening

YOY collected during morning, mid-day, and evening of August 28, 1993, showed significant differences in stomach fullness (ANOVA, $p<0.01$), with the highest mean SFI (783.9) from YOY collected in the morning (0700-0730 h) and lowest mean SFI (238.2) from YOY collected in the evening (2000-2030 h). The mean SFI value at mid-day was intermediate (409.6). These results indicated that, at least on this day, YOY paddlefish fed most actively during the night or early morning.

Condition factor of YOY paddlefish collected in morning (0700-1200 h) was not significantly different from those collected in the afternoon

(1400-1900 h; ANOVA, $p > 0.1$). The mean condition factor was 1.48 (n = 73) during the morning and 1.46 (n = 118) during the afternoon.

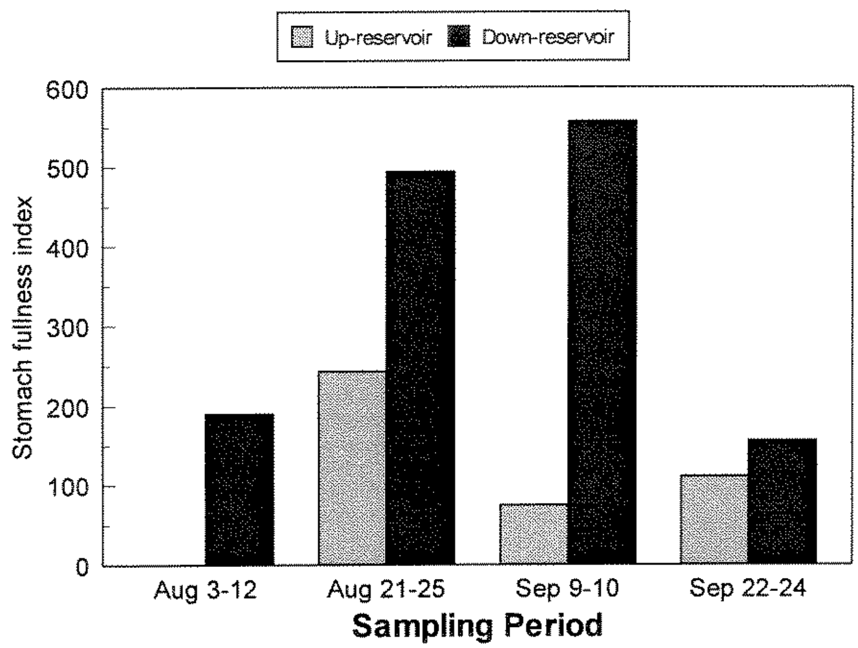


Figure 18. Mean 1993 stomach fullness index (SFI) values for YOY paddlefish captured at both up-reservoir (above RM 1521) and down-reservoir (below RM 1521) reaches.

Mean condition factor values varied significantly from August 3 to September 25, 1993 (ANOVA, $p<0.01$), and, like SFI means, were highest during the middle two sampling periods (August 21-25 and September 9-10) and lowest during the first and last sampling periods (August 3-12 and September 22-24). Condition factor and mean zooplankton densities varied similarly to each other (Figure 19).

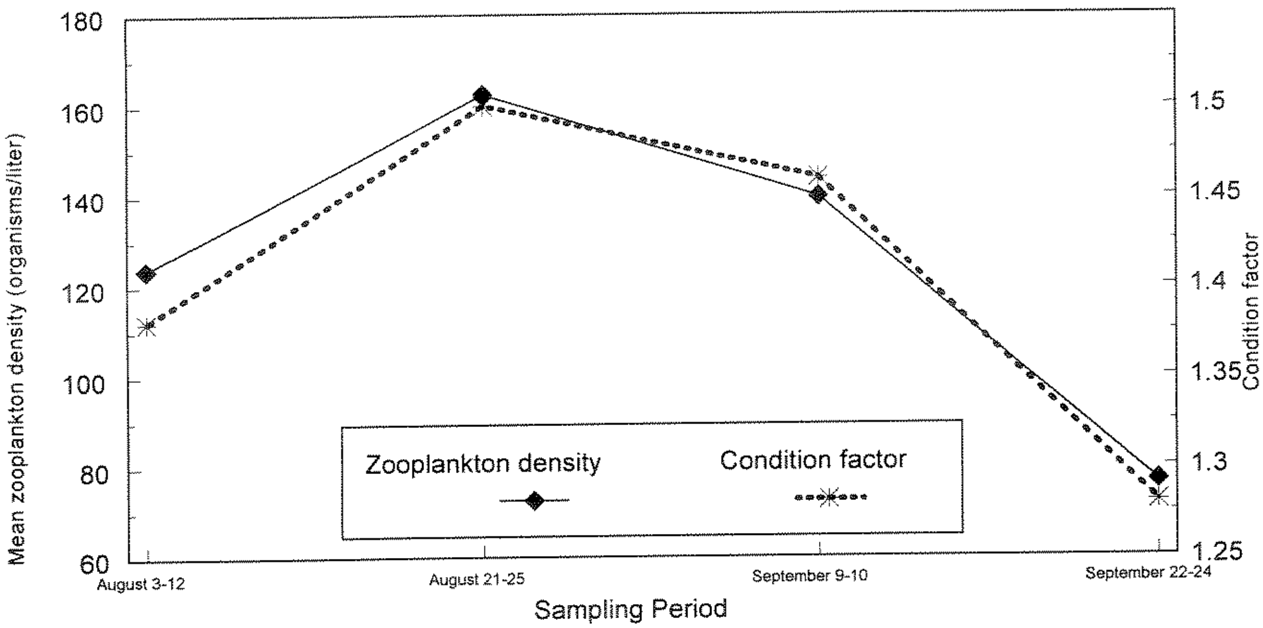


Figure 19. Mean condition factor of all YOY captured, and mean zooplankton density of all stations sampled in August and September, 1993.

Mode of Feeding

All YOY examined contained particular categories of zooplankton in different proportions than expected based on ambient zooplankton composition within the water (chi-square test, $p<0.01$; Figure 20). Although all YOY paddlefish were determined to be selectively feeding, the yearlings, in contrast, did not select particular categories of zooplankters from the water, and instead appeared to feed by filtering all available zooplankton (chi-square test $p>0.1$; Table 11).

Leptodora, a predaceous cladoceran and the largest food item eaten, (Table 12) constituted more than 90% of the stomach contents, by total number, of most YOY sampled in both 1992 and 1993. In addition, YOY paddlefish selected larger than average individual *Leptodora* (t-test, p<0.01). Mean body lengths of *Leptodora* found in the YOY stomachs ranged from 5.0-6.8 mm, whereas the mean body lengths of *Leptodora* for each sampling period found in the plankton tows were only 2.5-3.3 mm.

Mean electivity values (E; Ivlev 1961) of the various groups indicated that *Leptodora* and insect larvae, the largest organisms eaten, were the most highly selected for, with E values approaching one (Figure 21). Further evidence of the importance of *Leptodora* was provided by the close relationship between stomach fullness and the percent of the stomach contents consisting of *Leptodora*. As a rule, YOY paddlefish that had emptier stomachs had lower percentages of *Leptodora* in their stomachs, whereas YOY with full stomachs fed almost exclusively on *Leptodora* (Figure 22).

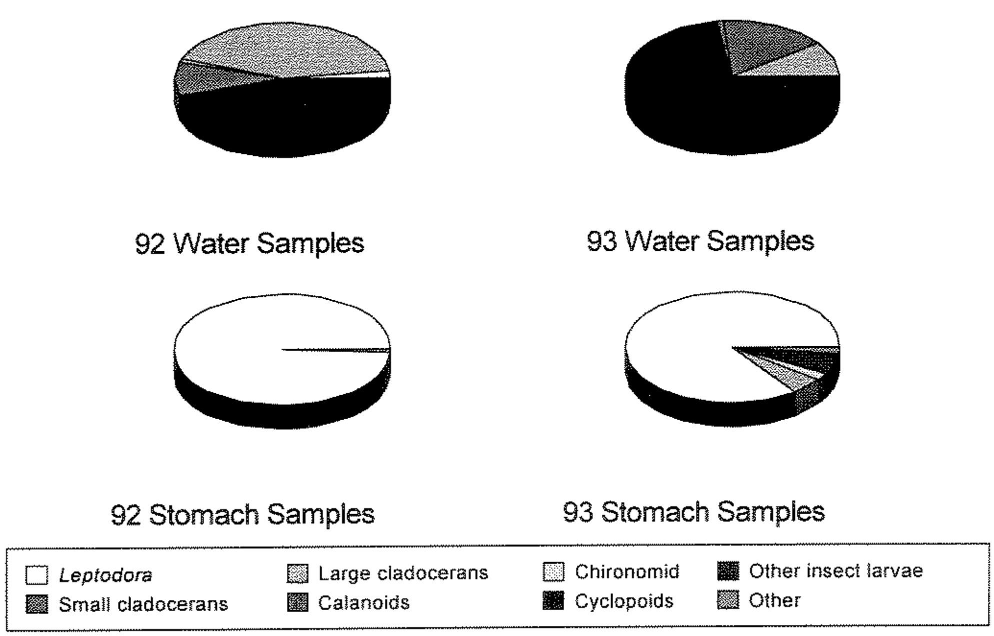


Figure 20. Relative abundance of zooplankton groups from water samples and from YOY paddlefish stomachs.

Table 11. Estimated stomach contents of 49 YOY paddlefish by percent and total number of organisms. All YOY demonstrated selective feeding (chi-square > 12; $p < 0.05$), whereas the two yearlings demonstrated filter feeding (chi-square < 12; $p < 0.05$).

Date	BL	*Leptodora*	Other Large Cladocerans	Chironomids	Other Insect Larvae	Small Cladocerans	Calanoids	Cyclopoids	Estimated Total Number	Chi-square
YOY										
8-25-93	74	0.88	0.12	0	0	0	0	0	1540	709
9-10-93	81	0.88	0.08	0	0	0	0	0	520	641
8-3-93	82	0.94	0.06	0	0	0	0	0	1000	1151
8-8-93	84	0.34	0.07	0.03	0	0	0	0	580	233
8-3-93	85	0.83	0.17	0	0	0	0	0	1560	1151
8-4-93	95	0.88	0.12	0	0	0	0	0	1560	1151
9-9-93	95	0.85	0.15	0	0	0	0	0	2860	700
8-21-93	96	0.99	0.01	0	0	0	0	0	3460	709
8-24-93	97	0.32	0.16	0	0.53	0	0	0	380	709
9-9-93	97	1.00	0	0	0	0	0	0	300	700
8-12-93	104	1.00	0	0	0	0	0	0	40	271
8-25-93	104	0.96	0.04	0	0	0	0	0	3720	709
9-10-93	105	0.44	0	0	0.56	0	0	0	180	700
9-10-93	105	0.98	0.01	0.01	0	0	0	0	6180	700
8-21-93	108	0.98	0.02	0	0	0	0	0	4840	709
9-22-93	110	0.95	0.05	0	0	0	0	0	1760	757
8-25-93	112	0.93	0.06	0.01	0	0	0	0	2820	698
9-10-93	114	0.11	0.44	0	0.33	0	0	0	180	700
8-25-93	118	0.99	0.01	0	0	0	0	0	3340	709
8-24-93	120	0.96	0.03	0.01	0	0	0	0	3020	709
9-22-93	120	0.98	0	0.01	0.01	0	0	0	1010	757
8-21-93	125	1.00	0	0	0	0	0	0	7440	709
8-24-93	125	0.23	0.23	0.29	0.26	0	0	0	700	709
8-25-93	125	0.97	0.03	0	0	0	0	0	3340	709
8-21-93	127	0.99	0.01	0	0	0	0	0	3920	709
8-24-93	127	0.55	0.31	0.02	0.01	0.01	0	0	1820	692
8-25-93	127	1.00	0	0	0	0	0	0	8740	709
8-21-93	128	1.00	0	0	0	0	0	0	4880	709
9-10-93	129	1.00	0	0	0	0	0	0	7290	700
8-25-93	130	0.96	0.03	0	0	0	0	0	5040	703
8-25-93	133	0.98	0.01	0	0.01	0	0	0	3700	700
8-24-93	134	0.65	0.03	0.03	0	0	0	0	620	709
8-21-93	135	0.99	0.01	0	0	0	0	0	3220	709
8-25-93	136	0.99	0.01	0	0	0	0	0	5660	709
8-21-93	138	1.00	0	0	0	0	0	0	6580	709
9-10-93	140	0.50	0	0	0.50	0	0	0	280	700
8-25-93	141	0.99	0.01	0	0	0	0	0	3200	709
8-25-93	141	0.98	0.01	0	0	0	0	0	6400	704
9-22-93	142	0.33	0	0.33	0.33	0	0	0	60	757
8-25-93	143	0.96	0.04	0	0	0	0	0	4280	709
9-10-93	149	1.00	0	0	0	0	0	0	6480	700
9-10-93	151	1.00	0	0	0	0	0	0	10680	700
9-10-93	152	0.97	0.03	0	0	0	0	0	8680	700
9-10-93	155	0.99	0	0	0	0	0	0	7340	700
9-10-93	160	0.78	0.18	0.02	0.01	0	0	0	1660	700
9-10-93	160	1.00	0	0	0	0	0	0	7140	700
9-22-93	160	0.80	0	0	0.20	0	0	0	100	700
9-10-93	163	1.00	0	0	0	0	0	0	15620	700
9-24-93	175	1.00	0	0	0	0	0	0	3880	757
Average	-	**0.85**	**0.05**	**0.02**	**0.06**	**0**	**0**	**0**	**3665**	-
Yearlings	370	0	0.28	0	0	0.03	0	0.68		0.73 *
	344	0.10	0.03	0	0	0.12	0	0.75		4.42 *

Table 12. Means and standard error of different categories of zooplankton collected in 1992 and 1993. Values represent body length in mm (not including caudal spines or filaments).

Taxon	Mean Length	Standard Error	Range	n
Leptodora kindtii				
(stomach samples)	5.67	0.094	3.4-8.8	100
(water samples)	3.0	0.094	1.2-6.6	152
Daphnia spp.	0.75	0.030	0.4-2.3	100
Other large cladocerans	0.73	0.020	0.4-1.4	100
Small cladocerans	0.38	0.012	0.2-0.9	100
Chironomids	1.46	0.095	0.4-5.5	100
Other insect larvae	1.72	0.133	0.5-4.0	31
Calanoids	0.79	0.030	0.4-1.8	100
Cyclopoids	0.59	0.020	0.3-1.3	100

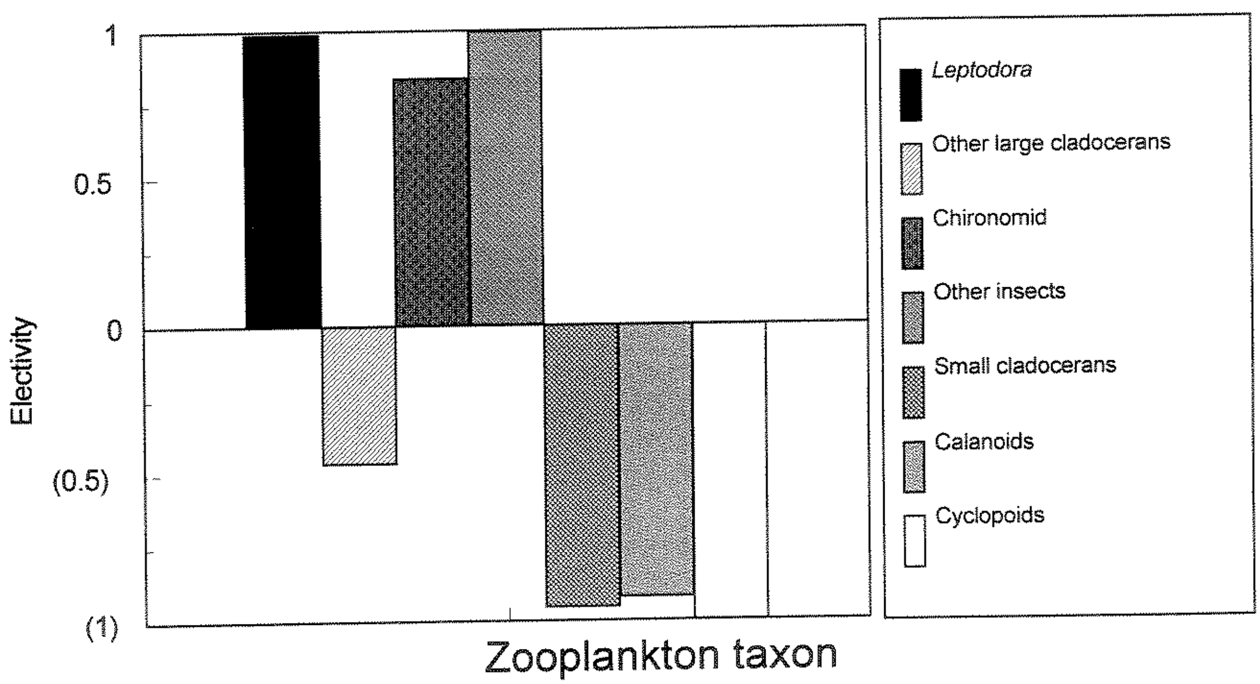


Figure 21. Electivity index values (Ivlev 1961) for various categories of zooplankton found in water samples and in stomachs.

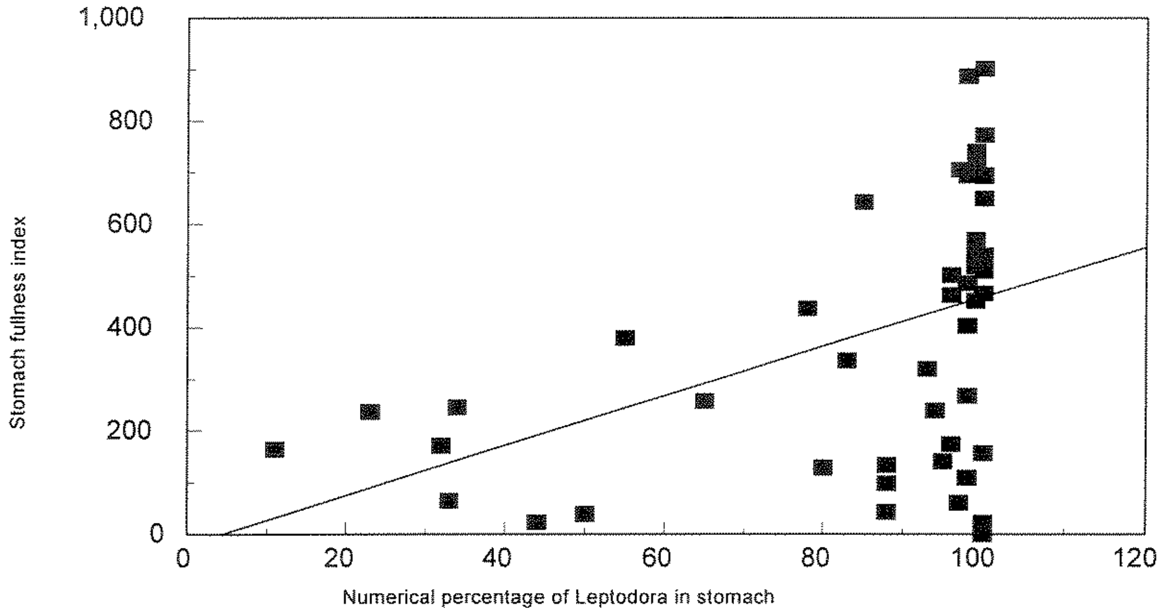


Figure 22. Amount of *Leptodora* in YOY paddlefish diets and the degree of stomach fullness.

Growth

Mean body length of YOY collected in 1992 was 124 mm by the second week of August and did not increase significantly during the following three week period ending September 9 (ANOVA, $p > 0.1$; Appendix 3). The low abundance of YOY in 1992, and hence the difficulty in sampling them, unfortunately prevented me from investigating the growth through September.

Mean body length of 1993 YOY was less than in 1992 in early August, but had become slightly greater than in 1992 by late August. From September 7 to September 26 1993, mean body length increased only slightly. Increases in mean length during the final weeks of both 1992 and 1993 did not exceed 2 mm (Figure 23). Using an analysis of variance, I did not find that YOY captured at down-reservoir stations were significantly larger based on body length than YOY captured at up-reservoir stations (p>0.1), and thus I found no evidence that YOY grew as they moved down the reservoir.

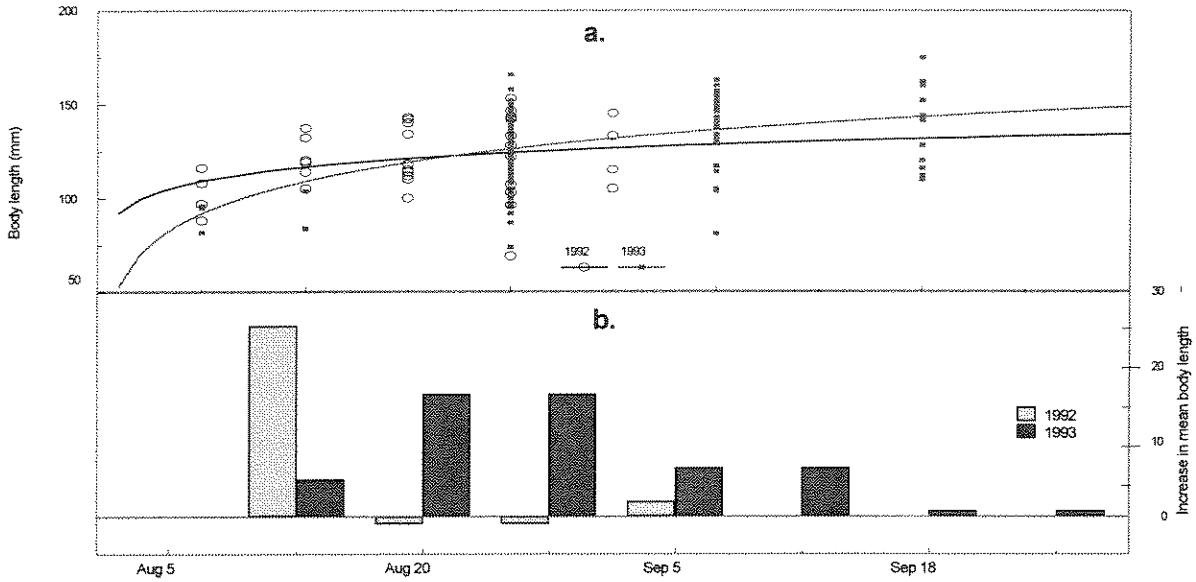


Figure 23. (a) Mean body length of YOY paddlefish in 1992 and 1993 and (b) weekly increase in mean body length in August and September.

DISCUSSION

Variation in Feeding Activity

Based on stomach fullness and condition factor, greater feeding activity of YOY was associated with the periods of highest zooplankton densities, which also corresponded with periods of greatest YOY counts. In addition, feeding activity appeared to increase from the upper reaches of the study site, where zooplankton densities were lower, to the lower reaches, where zooplankton densities were higher. The concurrence of greater YOY paddlefish feeding activity with higher zooplankton densities is consistent with results for adult paddlefish in the Missouri River

(Rosen and Hales 1981). Timing of peak zooplankton densities and feeding activity in Lake Sakakawea, however, evidently differed from the free-flowing reach of the Missouri River, where zooplankton density peaked in March and November (Rosen and Hales 1981). In Rosen and Hales' (1981) opinion, the drop in zooplankton densities during summer was probably the result of "highly unstable conditions and excessive waterborne sand" during high summer discharges. I detected no such drop in zooplankton densities during summer in Lake Sakakawea.

Young paddlefish evidently do not feed by sight, but instead, feed when their rostrum, which possesses sensory capabilities (Nachtrieb 1910), comes in contact with or near to a large zooplankter or insect (Michaletz 1982). With this capability, YOY paddlefish may be equally capable of day or night feeding. Comparisons of stomach fullness by time of day on August 28, 1993 indicated that YOY fed more actively during the early morning or night than at mid-day and evening. These results are consistent with those of Wagner (1908), who reported that stomachs of adult paddlefish from Lake Pepin (upper Mississippi River) were full in the morning and empty by mid-afternoon, which led him to conclude that paddlefish fed during the night or early morning. Ruelle and Hudson (1977) also concluded that young paddlefish fed actively at night, as evidenced by the nocturnally active insect species in their stomachs.

Although my use of stomach fullness to detect periods of feeding activity assumed a moderately rapid evacuation of the digestive system, I believe that evacuation rates in this study were sufficiently rapid to meet this assumption and that my conclusion of more active feeding at night or early morning was justified. Rosen (1976) reported that paddlefish reduced their stomach content by 60% in 12 hours at 18 C. Water temperatures in Lake Sakakawea from 0700-2000 h on August 28 were 17-20 C, suggesting that evacuation rates of YOY in this study would probably be similar to those reported by Rosen (1976). Cooler water would possibly result in higher SFI values by slowing evacuation rates, but mean SFI in early August and late September were significantly lower than in mid August and early September, even with the cooler waters at those times.

Because of the importance of *Leptodora* in the diet of YOY paddlefish in Lake Sakakawea (Table 11), it seems reasonable that YOY might pattern their behavior around diel migrations of *Leptodora,* or in general, around migration of any particularly important zooplankters in their diet. Research on the vertical migrations of *Leptodora*, the primary prey item for YOY paddlefish in the study, is limited. Havel (1985) found that *Leptodora* fed more actively under lighted conditions, and suggested that this species is a visual predator. If feeding occurs under lighted conditions, *Leptodora* in Lake Sakakawea would likely be near the surface during the day because of the low water transparency. Daylight vertical migrations are only partially supported by the research of Vijverberg (1991), who studied vertical migrations of *Leptodora* and found diel vertical migrations (DVM) occurred both at night and during the day. Extent of DVM was increased by fish predation, and larger *Leptodora* exhibited more pronounced DVM under conditions of higher probability of being preyed upon. Vijverberg concluded that vertical migrations of *Leptodora* are dynamic and are based largely on predator avoidance. Although other zooplankters are generally reported to migrate toward the bottom, and hence become vulnerable to predation during the day (Goldman and Horne 1983), Zettler and Carter

(1986) found that many zooplankters exhibited suppressed downward vertical migrations during daytime in turbid waters, so that they were higher in the water column during midday in turbid water than in clear water. More research is needed on the relation between *Leptodora* distribution (vertical and horizontal) in Lake Sakakawea and its relation to habitat conditions and to YOY distribution and abundance.

Sampling methods such as the visual counts or surface trawling that rely on feeding-associated behavior may be more effective during some periods than others if pronounced daily or seasonal variations exist in feeding activity of YOY. Yellow perch, for example, are nearly inactive at night (Scott and Crossman 1973), and passive sampling for them at night is often ineffective. I found no consistent tendency, however, for higher counts of YOY in either morning or afternoon (Chapter 1), which suggests that daily variation in feeding activity is not preventing quantitatively adequate counts or trawl catches. Based on observations, at least some of the YOY paddlefish in Lake Sakakawea are evidently near the surface during day and night regardless of feeding activity.

Mode of Feeding

In this study, all YOY paddlefish collected were using a selective, rather than a filtering, mode of feeding, regardless of their size. This selective feeding manifested itself in a strong electivity for specific prey organisms. *Leptodora,* which constituted less than 1% of the total zooplankton by number, constituted 85% of the stomach contents by number. Cyclopoids, in contrast, were the most common organisms in the zooplankton by numbers, but constituted less than 1% of the organisms in the stomach samples. Cyclopoids are not only smaller than *Leptodora,* but are also more evasive (Zaret 1980), and these differences may contribute to their near absence from YOY stomachs. Nevertheless, in Missouri, Michaletz et al. (1982) found cyclopoids in stomachs of both selective and filter feeding YOY (some less than 70 mm TL), indicating that even very small YOY are capable of capturing copepods.

The large size of *Leptodora*, relative to the other zooplankters, suggests that the YOY paddlefish are intentionally selecting the largest available prey, either because of their profitability as food, ease of capture, or both. In addition, the YOY were also selectively eating the largest individual *Leptodora.* Similar size selective predation by YOY paddlefish was also reported by Ruelle and Hudson (1977) from Lewis and Clark Lake. They found that about 75% of the stomach content by numbers was large cladocerans, mainly *Daphnia spp.*, even though *Daphnia spp.* constituted only about 13% of the plankton community. As in Lake Sakakawea, YOY paddlefish selected the largest *Daphnia spp.*, which were mainly gravid females. Cyclopoids and calanoids, the most abundant zooplankters in the water, were nearly absent in stomach samples. The apparent preference of YOY paddlefish for cladocerans over copepods is consistent with other planktivorous fishes (Zarret 1980), and would be expected according to Brooks and Dodson (1965) who suggest that "natural selection will tend to favor the predator that most consistently chooses the largest food morsel available". Obviously, the benefit of selecting large individual zooplankters (based on minimizing energy expended and maximize reward) is related to predator size, prey density, and efficiency of filter feeding mechanisms.

Analysis of the two yearling paddlefish (344 and 370 mm BL) indicated that they were not feeding selectively, but had begun filter feeding. Cyclopoids and calanoids were well represented in these stomach samples. The exact time that YOY paddlefish in Lake Sakakawea switch to filter feeding is thus not known. Other studies, however have indicated that the transition occurs coincident with gill raker development. Rosen and Hales (1981) reported that gill rakers of an 85 mm BL paddlefish had a maximum length of 0.4 mm, a size ineffective for filter feeding. They suggested that filter feeding was not possible for fish less than 225-250 mm TL. Although results of this study indicated that all YOY fed selectively, regardless of size, mean length in late September had reached 252 mm TL, sufficiently large for effective filter feeding according to Rosen and Hales (1981). Perhaps size at which filter feeding commences differs substantially depending on locality and available food. Or perhaps I may have selectively sampled YOY in our counts and trawls by taking all of the samples from near the surface. If paddlefish near the surface are selectively feeding, while larger YOY beneath them are filter feeding, only selectively feeding paddlefish would be captured.

In addition, evidence that all individuals in our study were selectively feeding does not prove that they were unable to filter feed. In contrast to the conclusion of Rosen and Hales (1981) that small paddlefish (less than 225 mm TL) would not be able to filter feed, Michaletz et al. (1982) reported that (based on YOY stomach contents and direct feeding observations) YOY paddlefish were almost exclusively filter feeding by 120 mm TL, before their gill rakers were fully developed. Young-of-the-year paddlefish could be induced to switch from selective feeding to filter feeding when the zooplankton community changed from large cladocerans to smaller rotifers and nauplius larvae. In contrast, selective feeding may be possible for yearlings. Ruelle and Hudson (1977) reported that stomach contents of a 367 mm BL paddlefish indicated it was feeding selectively.

Mean Body Lengths from Early August through September

Growth, based solely on mean body lengths, was rapid in early August, but slowed in September, consistent with lower zooplankton densities, lower stomach fullness values, and lower condition factors. In Lake Sakakawea, YOY paddlefish continue to grow at least periodically between late September of their first year and July of their second year, as evidenced by the substantially larger size of yearlings than of YOY. Yearling paddlefish captured in late July and early August 1992, ranged from 260 to 350 mm BL (460-635 mm TL), whereas YOY captured September 20-26, 1993 ranged from 110 to 175 mm BL (202-352 mm TL). This difference represents growth of more than 100 mm BL (200 mm TL) throughout the fall, winter and spring. Research in other studies indicates that YOY continue to grow, sometimes rapidly, throughout the winter. In Fort Gibson Reservoir, Oklahoma, Houser (1965) estimated that mean length of YOY paddlefish which was 495 mm TL ($n = 9$) in August, had increased to 724 mm TL ($n = 6$) by December, and to more than 900 mm TL ($n = 2$) by the next June. Pasch et al. (1980) reported that YOY grew 65 mm and 90 mm TL during period September to May in two different years in Old Hickory Reservoir, Tennessee. Russell (1986) reported that paddlefish growth is more rapid in reservoirs than in rivers and attributed the faster growth rates in reservoirs to greater zooplankton availability.

One factor that may exaggerate the apparent growth of paddlefish over their first winter is possible underestimation of average YOY paddlefish size in August and September of their first year. The observed size of YOY assumes that those YOY that I was able to sample with dipnets and trawls were representative of the size of YOY throughout the reservoir. If the YOY do not exhibit swimming behavior near the water surface consistently, and regardless of size, a size bias in my sampling would have resulted. The apparent plateau in size attained in August and September (Figure 23) may then be a function of change in behavior, rather than cessation of growth.

SUGGESTIONS FOR FUTURE RESEARCH

Results of this study suggest that visual counts along transects or cross-sections will be an accurate and efficient method of assessing relative abundance of YOY and yearling paddlefish on an annual basis. Additional research addressing the factors affecting the occurrence of YOY and yearlings near the surface, and therefore their susceptibility to being counted, may increase the accuracy and reliability of the counts. The following topics are of particular relevance to the counts:

1) *Determination of the whereabouts of the YOY prior to their achievement of 80-100 mm BL and their appearance in August.* In 1993, I sampled very few YOY under 100 mm BL, and was unable to trawl or count YOY in either the up-reservoir or down-reservoir stations prior to August. Intensive bottom trawling in the riverine areas above my study site might help to identify the habitat associated with the smaller YOY.

2) *Identify factors affecting countability of YOY and yearling paddlefish.* Avian predators and boat traffic in upper Lake Sakakawea are two notable factors that may cause YOY to avoid the surface. The potential bias of counts by these and other factors would not be easily assessed, but a successful quantification of any biases would improve the accuracy of the counts.

3) *Identify the causes associated with the near-surface swimming behavior of YOY paddlefish.* My research suggests that YOY are not near the surface exclusively to feed and indicates that other factors, such as predator avoidance, or water temperature, may be more important. The occurrence of yearling paddlefish, and, occasionally, of large adult

paddlefish near the surface suggest that the motive is not entirely related to size. A better understanding of how feeding mode and the size of paddlefish relate to the near-surface swimming behavior will improve the understanding of the basis of YOY and yearling counts in Lake Sakakawea and facilitate the application of the visual count method to other systems.

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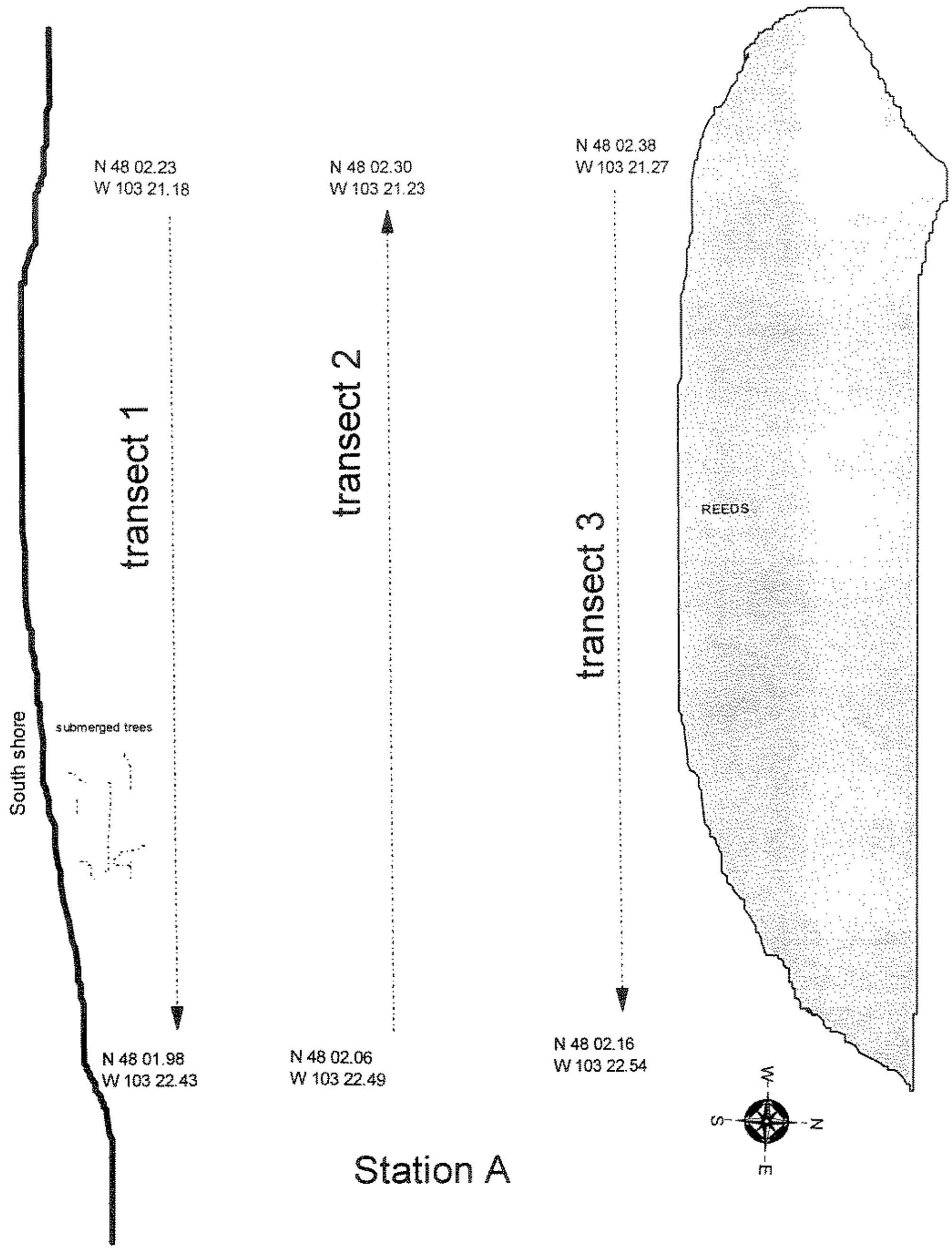
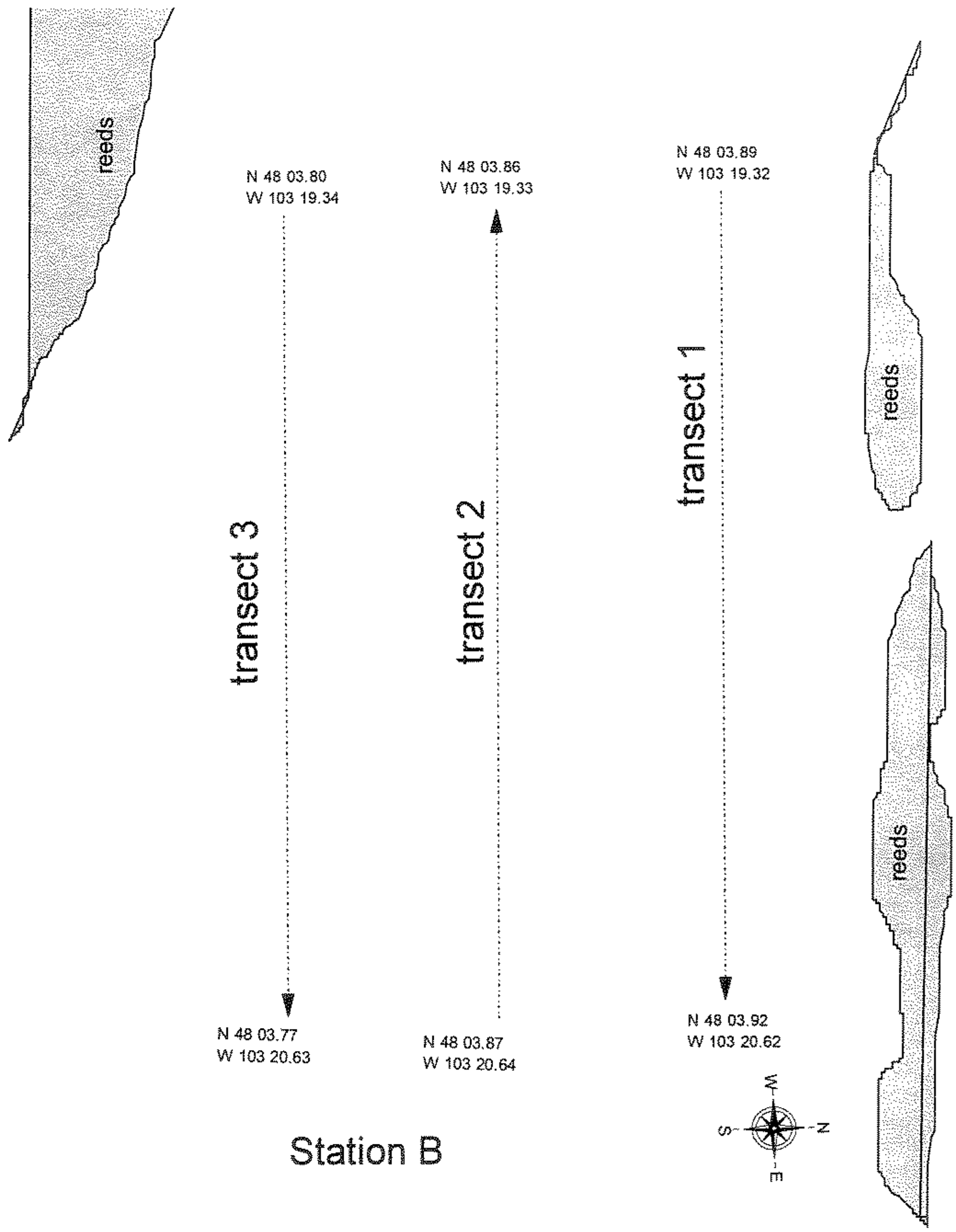
APPENDIX 1

LOCATION OF TRANSECTS AT EACH STATION



Appendix 1-A. Latitude and longitude of transects at Station A.



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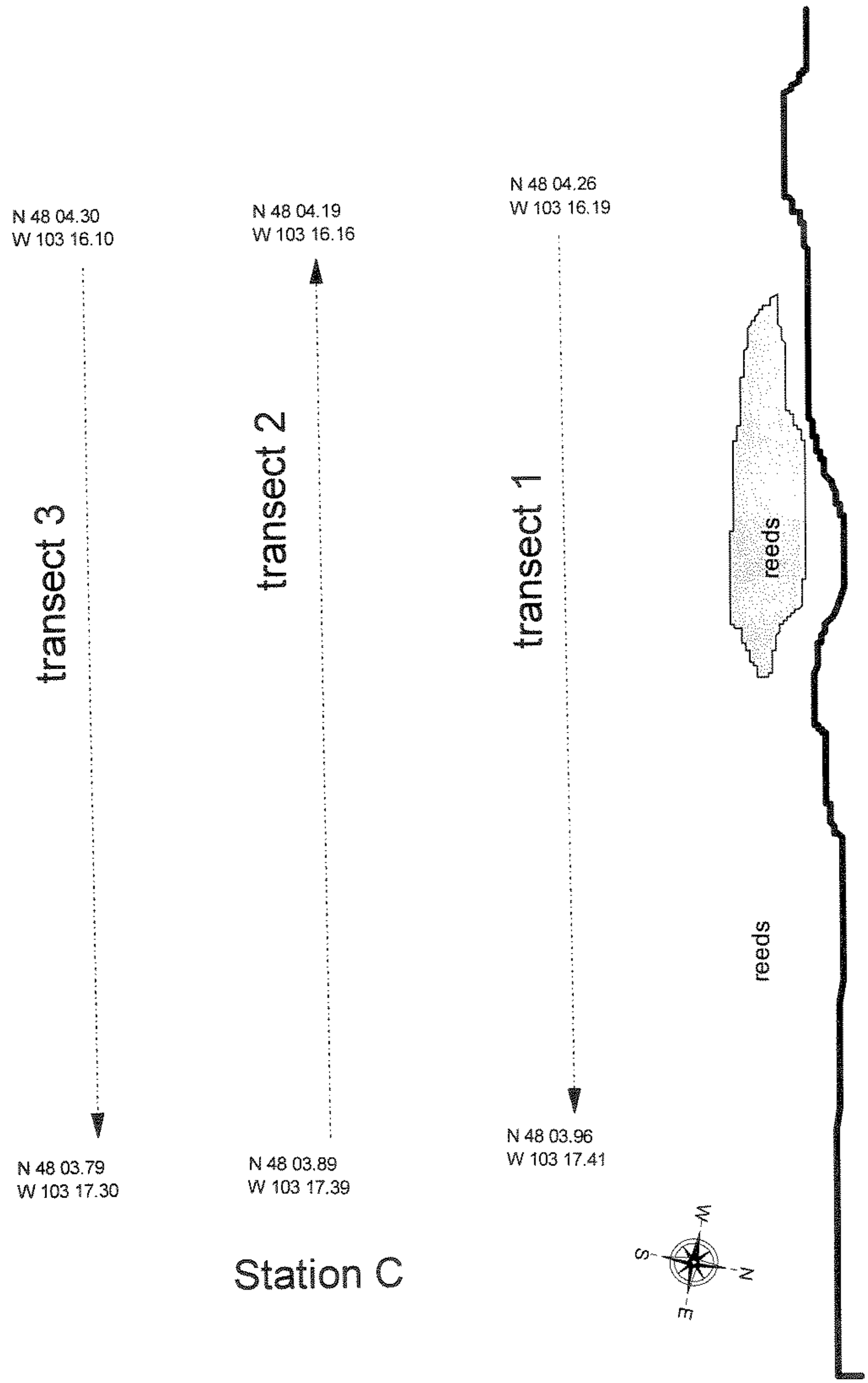

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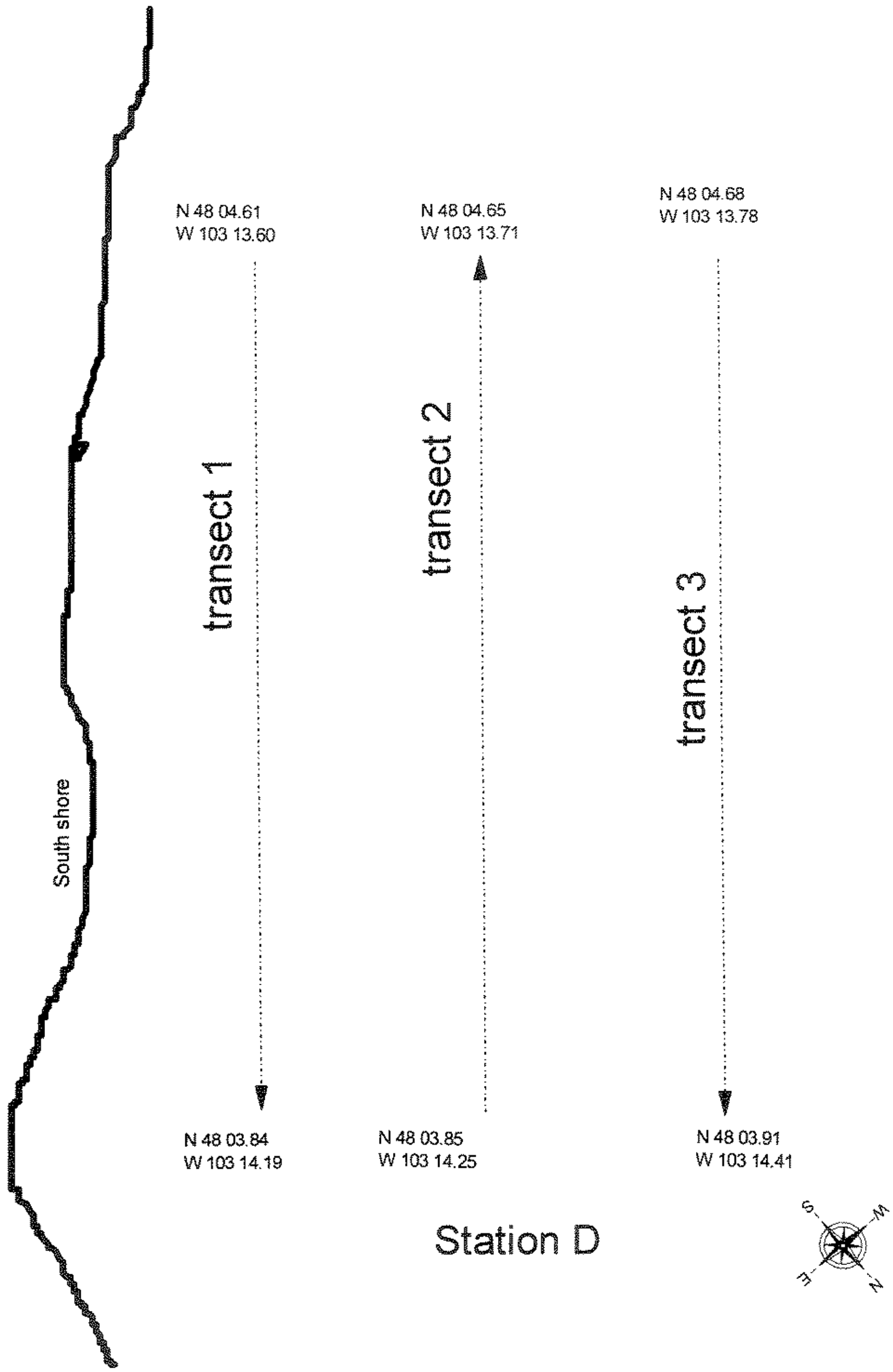
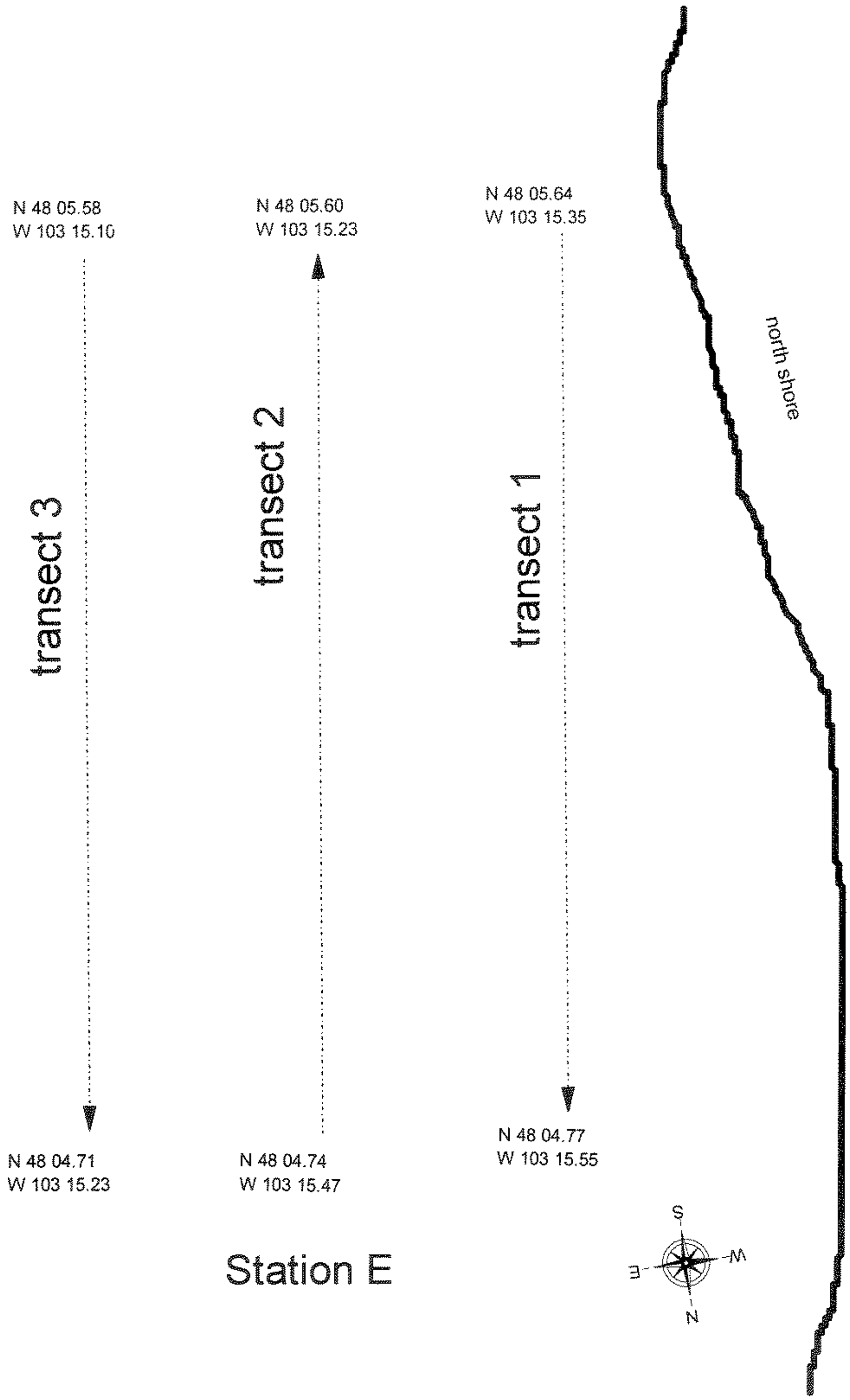
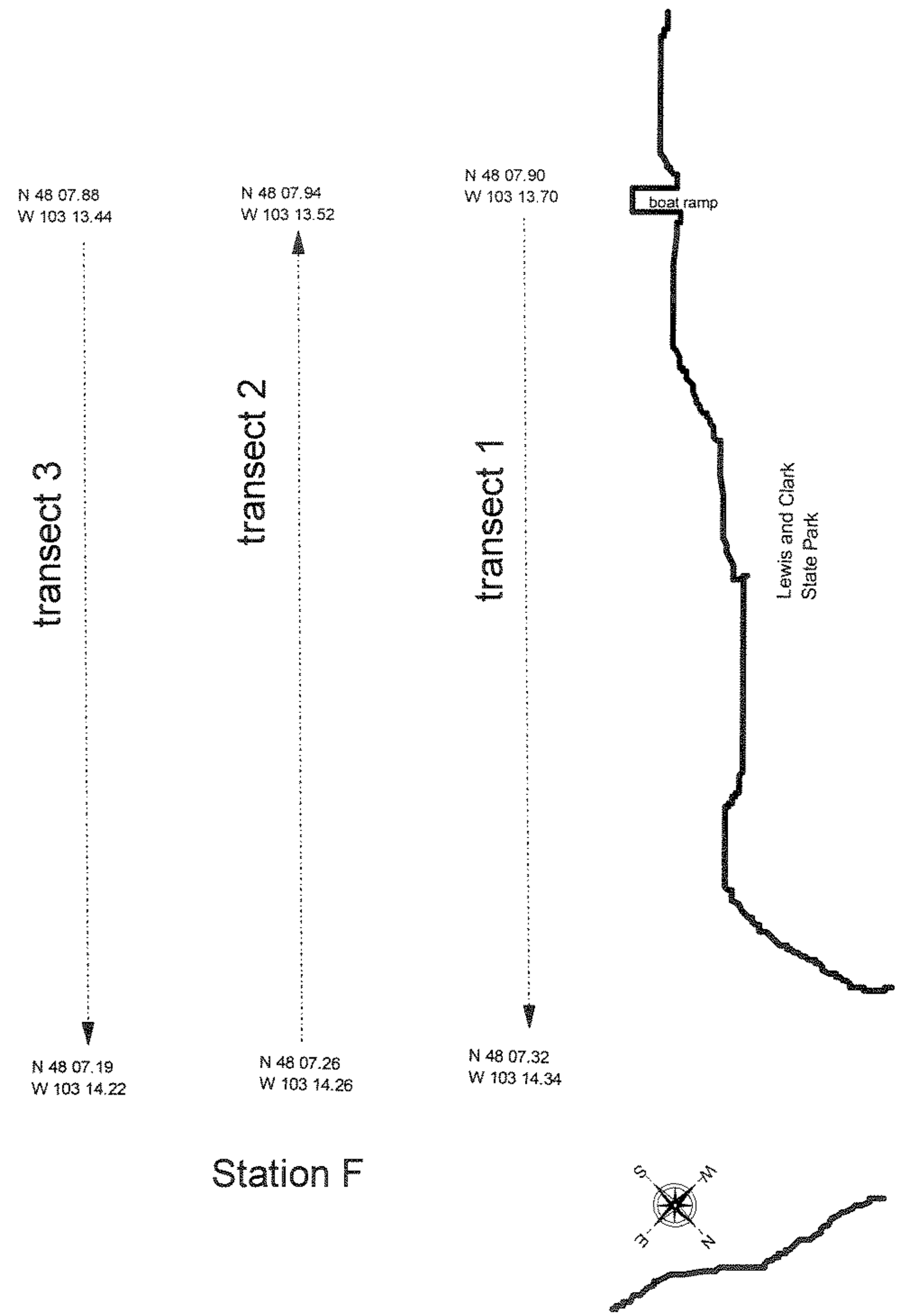


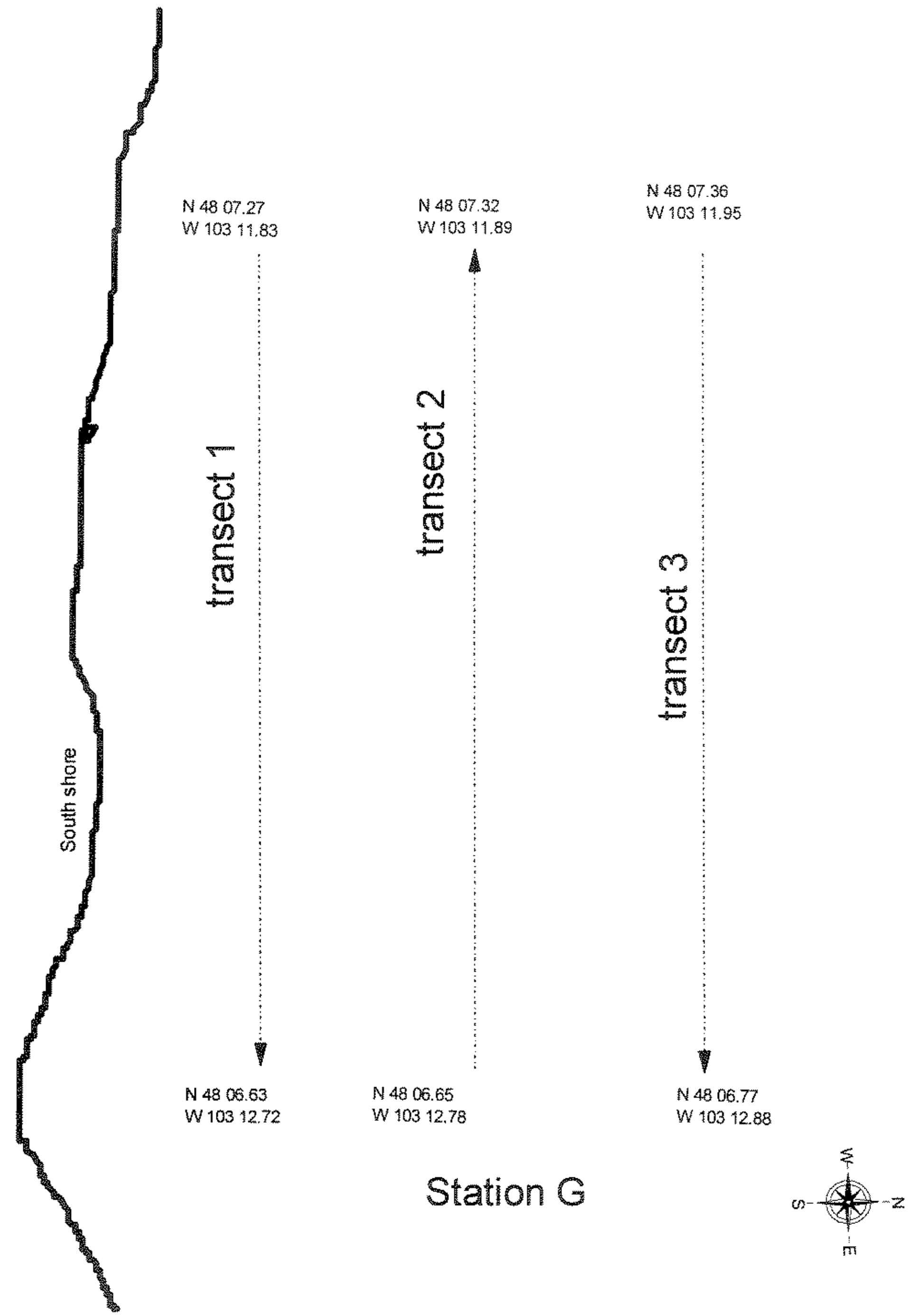
Appendix 1-d. Latitude and longitude of transects at Station D.



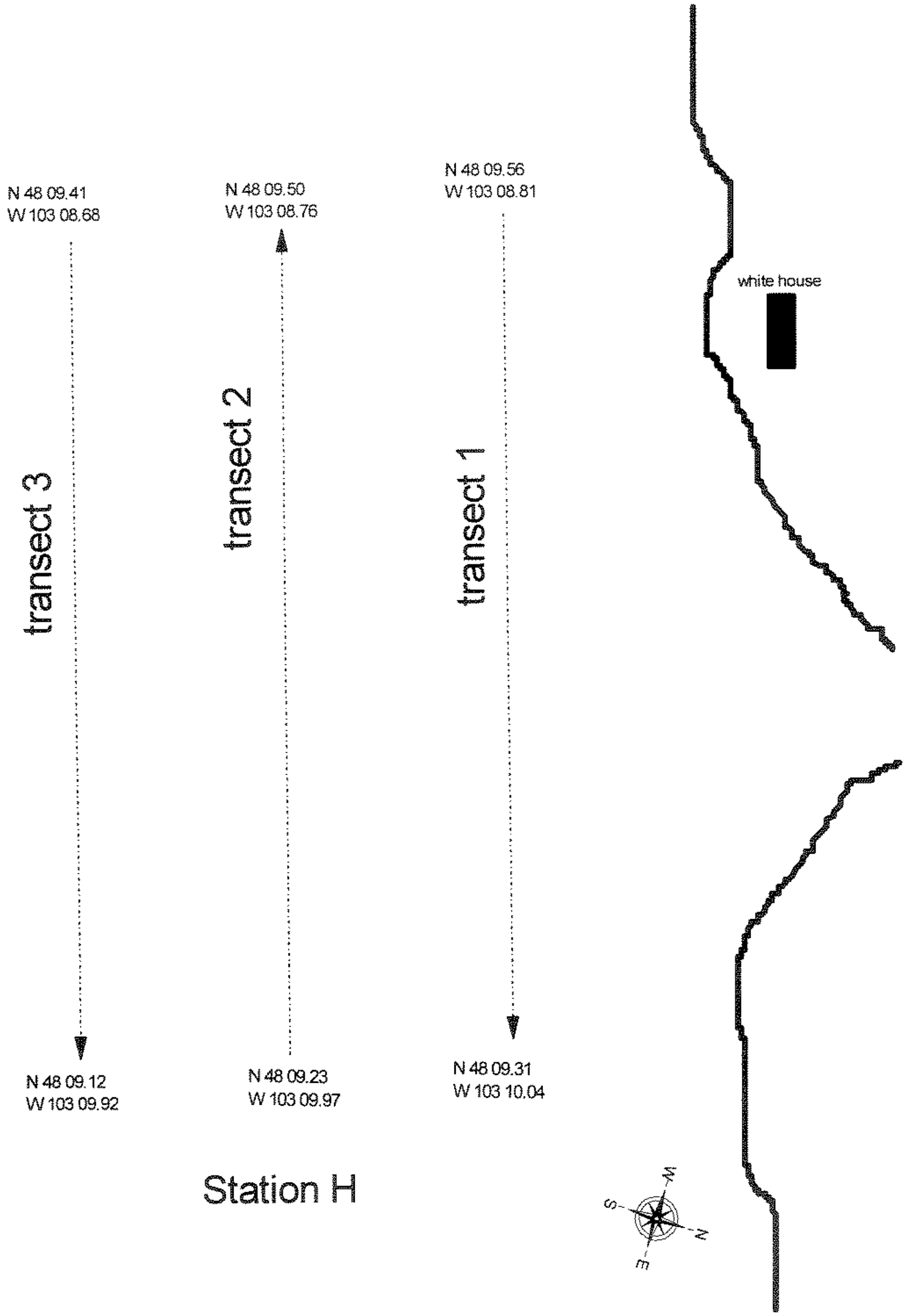
Appendix 1-e. Latitude and longitude of transects at Station E.



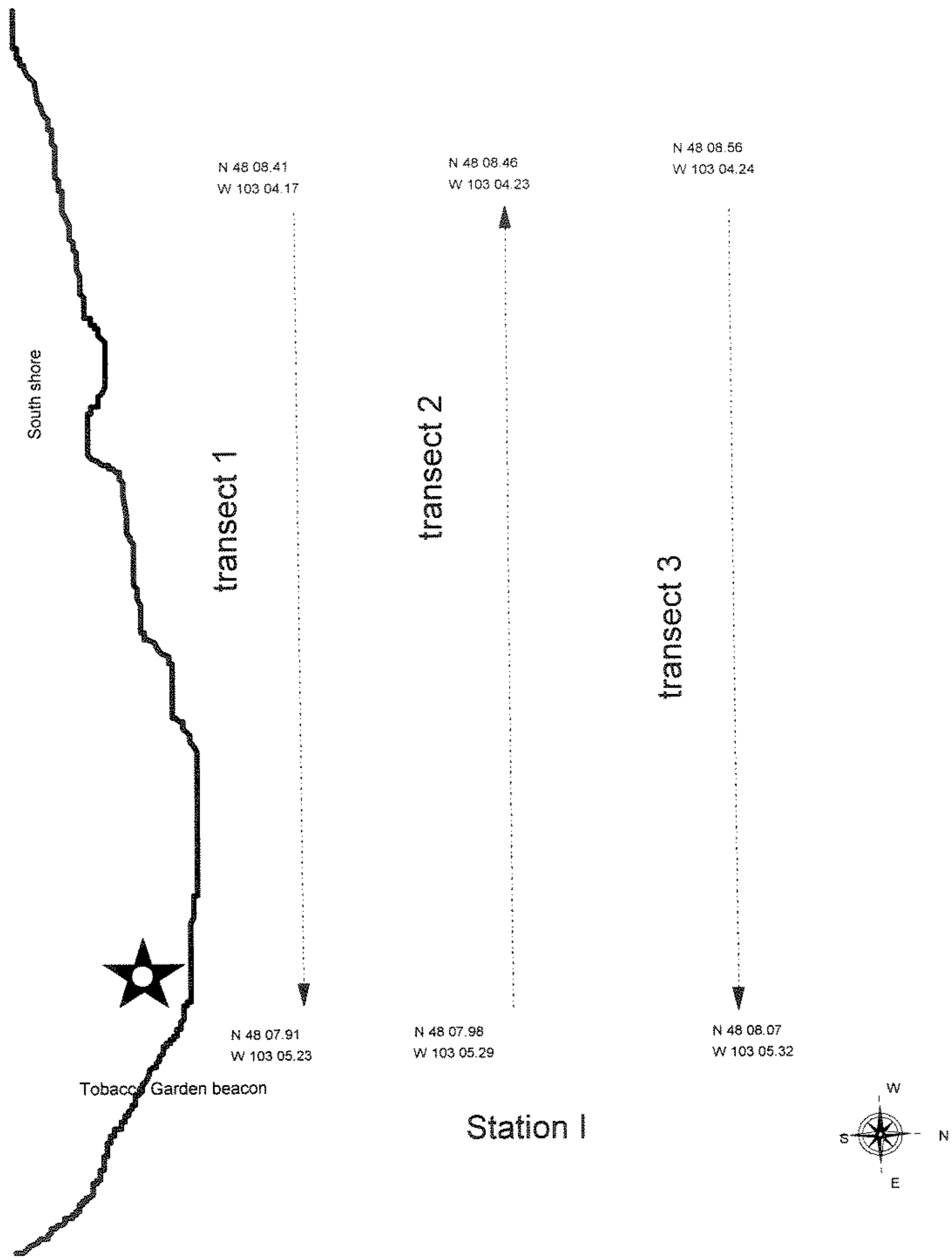
Appendix 1-f. Latitude and longitude of transects at Station F.



Appendix 1-g. Latitude and longitude of transects at Station G.



Appendix 1-h. Latitude and longitude of transects at Station H.



Appendix 1-i. Latitude and longitude of transects at Station I.

Appendix 2. Discharge of the Yellowstone River (cfs) at Sidney, Montana during 1991, 1993 and 1993.

Date	1991	1992	1993
5/15	15300	14800	13900
5/16	16900	12800	18300
5/17	16200	11400	23400
5/18	17500	10500	27500
5/19	19700	12300	33400
5/21	25200	12900	31400
5/23	37400	16900	33000
5/24	39300	19700	36000
5/25	42400	20000	40200
5/26	45600	18000	40000
5/27	47200	17700	33900
5/28	48000	18300	28400
5/29	50000	18900	26900
5/30	47800	19100	30000
5/31	39400	22000	33600
6/1	34300	19900	34700
6/2	32500	18100	34500
6/3	30900	16900	33700
6/4	29500	15800	33600
6/5	31600	14700	33200
6/6	37400	14600	31600
6/7	44400	15000	29200
6/8	49000	14700	33500
6/9	54600	14900	39300
6/10	60200	14200	37500
6/11	61800	12900	37600
6/12	62200	12000	39400
6/13	58900	11600	35600
6/14	56600	12500	34800
6/15	58000	14400	37600
6/16	61300	15300	36500
6/17	61300	16700	32000
6/18	53100	21300	31200
6/19	45700	32700	34100
6/20	46100	39300	35300
6/21	48600	38700	33800
6/22	51800	36000	33000
6/23	46000	35000	33300
6/24	52500	33800	34900
6/25	55900	30800	36200
6/26	58900	28700	36000
6/27	56600	27500	31600
6/28	49500	26100	27500
6/29	44300	24500	25800
6/30	43800	24400	26300

Appendix 3. Mean body length of YOY paddlefish captured in August and September of 1992 and 1993.

Sampling period	statistic	1992	1993
August 1-6	mean sample size Standard Deviation	98.6 5 13.4	89.5 4 7.04
August 7-13	mean sample size Standard Deviation	124.0 6 13.32	94 2 14.14
August 14-20	mean sample size Standard Deviation	123.0 14 13.87	
August 21-28	mean sample size Standard Deviation	122.0 12 24.5	126.6 124 15.5
August 29- September 5	mean sample size Standard Deviation	124.5 4 17.9	
September 7-11	mean sample size Standard Deviation		137.0 49 19.32
September 20-26	mean sample size Standard Deviation		138.6 16 18.66