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Commercial Harvest of Paddlefish in the Upper Mississippi River

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Abstract—The purpose of this study was to examine spatial and temporal patterns in paddlefish *Polyodon spathula* harvest in the upper Mississippi River (UMR). Specifically, we described trends and evaluated the influence of environmental factors on commercial paddlefish harvest in Pools 9–26 of the UMR between 1953 and 2005. Commercial paddlefish harvest exhibited several peaks, with the highest harvests occurring in the 1950s and 1970s. Pool 19 had the highest harvest among years, while Pools 9 and 11 had the lowest harvest. Total and mean harvest was highest in Pool 13 and Pools 17–19 until the 1990s when the fishery was closed to commercial paddlefish harvest. Since that time, harvest has been restricted to Pools 20–26. Inflation-adjusted prices of paddlefish flesh have continued to decline over the past 50 years. Discharge and temperature characteristics in the spring and winter were not related to paddlefish harvest in any of the study pools; rather, peaks in paddlefish harvest were likely a reflection of the demand and price of roe.

Introduction

The paddlefish *Polyodon spathula* was historically abundant in large streams and rivers throughout the Mississippi River basin and adjacent Gulf coastal drainages, and relict populations occurred in some of the Great Lakes (Lee et al. 1980; Gengerke 1986). However, paddlefish populations in the Great Lakes have been extirpated and nearly all other populations have declined in distribution and abundance (Carlson and Bonislawsky 1981; Unkenholz 1986). Consequently, the paddlefish is now only abundant in parts of the Mississippi River drainage (Bettoli et al. 2009, this volume). The primary factors responsible for declines in paddlefish populations are thought to be habitat alterations, including loss of spawning habitat, channelization and loss of backwater habitat, construction of dams and other barriers to movement, altered flow regimes, and poor water quality resulting from municipal and industrial pollution (e.g., Sparrowe 1986; Unkenholz

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1986). Although habitat modifications have undoubtedly had deleterious effects on paddlefish populations, overharvest is also considered an important factor responsible for the poor status of paddlefish (Gengerke 1986; Pasch and Alexander 1986; Scholten and Bettoli 2005). Moreover, high commercial harvest of paddlefish continues to be a concern for many paddlefish management programs (Hoxmeier and DeVries 1996; Scholten and Bettoli 2005).

Commercial harvest of paddlefish has been highly dynamic in North America over the past century. Although commercial harvesters were present in the Mississippi River basin in the early and mid-1800s (Carlander 1951), paddlefish harvest during that time is largely unknown. Sporadic records have been kept since the 1890s and indicate that paddlefish harvest was high at the turn of the 20th century. High harvest in the 1890s is generally thought to be a response to depleted lake sturgeon *Acipenser fulvescens* and Atlantic sturgeon *A. oxyrinchus* stocks and the need for an alternative source of roe for the caviar market (Carlson and Bonislawsky 1981). For example, approximately 1 million pounds of paddlefish were harvested in 1894 and the largest commercial harvest of paddlefish ever recorded (i.e., 2.4 million lbs) occurred just 5 years later (Coker 1923). Paddlefish were typically harvested for their flesh, particularly for the smoked meat market (Stockard 1907; Carlander 1951). However, roe added considerable economic value to the catch where harvesters in 1898 were reported to receive US$8–9 per pound (0.45 kg; values are inflation adjusted to 2006) of roe (Hussakof 1911). In the following decade, roe prices increased to $32–65 lb (Stockard 1907; Alexander 1914; Coker 1923). Depletion of paddlefish populations, coupled with reduced demand for paddlefish caviar and habitat loss, was likely responsible for the 60% reduction in total harvest observed between 1899 and 1950 (Carlson and Bonislawsky 1981; Gengerke 1986).

Market values have likely had a significant influence on commercial paddlefish harvest, but other factors may also play an important role in the number of harvested paddlefish. In the Mississippi River, construction of the lock and dam system in the 1930s had a substantial influence on paddlefish populations (Carlson and Bonislawsky 1981; Gengerke 1986). Paddlefish often move long distances to reach spawning areas in response to high flow events (e.g., Russell 1986; Paukert and Fisher 2001a; Zigler et al. 1999, 2004). In impounded systems, these movements are often blocked by dams, resulting in high concentrations of fish in tailwater habitats that can be efficiently captured using entanglement gears (Pasch and Alexander 1986; Scholten and Bettoli 2005). Most paddlefish are captured with gill nets, and although high flows may congregate paddlefish in certain areas, high flows hinder the ability of commercial harvesters to deploy and retrieve their gear. Scholten and Bettoli (2005) examined the relationship between discharge and commercial paddlefish harvest in the Tennessee River and found that harvest was strongly related to discharge. Specifically, paddlefish harvest increased as the number of fishable days (i.e., days with flows less than 30,017 ft^3/s) in the season (November–April) increased. In addition to discharge, ice dynamics may also influence harvest where extensive coverage or instream transport of ice prevents harvesters from fishing in lotic systems.

Since the mid-1950s, most states in the Mississippi River basin have maintained excellent records of paddlefish harvest. Small portions of these data sets have previously been reported in the literature (Carlson and Bonislawsky 1981; Gengerke 1986); however, these studies focused on large-scale patterns of harvest across North America and only evaluated harvest into the mid-1970s. No studies have focused on different pools of the upper Mississippi River (UMR), even though this area has historically contributed to a substantial proportion of the paddlefish harvest from the Mississippi River (Gengerke 1986). Therefore, the purpose of this study was to describe spatial and temporal patterns of commercial paddlefish harvest in Pools 9–26 of the UMR between 1953 and 2005. In addition to describing the fishery, we sought to evaluate factors (i.e., discharge, water temperature, and market value) related to paddlefish harvest.

Methods

Commercial paddlefish harvest statistics were obtained from the Upper Mississippi River Conservation Committee (UMRCC). The UMRCC was established in 1943 and is composed of resource managers working on terrestrial and aquatic resource issues in the basin. Although the objectives of the UMRCC are numerous, an important activity of the UMRCC is to collect data on resource use that can be used to guide management and policy decisions in the UMR. Each state in the UMRCC collects monthly or annual commercial harvest data (i.e., pounds harvested) by species and pool. Reporting of commercial harvest data by licensed harvesters is mandatory and all reported data are entered into an electronic database. Prior to this study, the database only included the years 1985 through 2005. Therefore, annual summaries of harvest from 1953 through 1984 were obtained from UMRCC annual reports (e.g., UMRCC 1966). Harvest records are submitted by commercial harvesters who lack sophisticated data collection equipment, but we were primarily interested in broad trends over long-temporal and large-spatial scales. Although nonreporting or underreporting is a concern with these types of data, enforcement has been consistent through time and we are unaware of any activities or factors that might have significantly influenced reporting rates. As such, we assumed that any error and bias was consistent among years. In addition to harvest data, the average market value of harvested fish was also recorded by the UMRCC. Roe prices have been consistently reported for only the past few years; therefore, all economic valuations of the paddlefish fishery presented in the current study represent values associated with the flesh. Although Pools 4–9 (particularly Pool 4) were substantial contributors of commercially harvested paddlefish, pools upstream of Pool 9 have been closed to paddlefish harvest since the 1930s (Gengerke 1978). Consequently, we restricted our analysis to Pools 9–26 (Figure 1).

Total harvest of paddlefish was determined for each pool and year (i.e., 1953–2005) and then summarized by pool (i.e., across years) and by year (i.e., across pools) to provide insight on spatial and temporal harvest patterns. Decadal patterns were also examined for each pool. Market values were examined through time and are presented as inflation-adjusted prices. Inflation-adjusted prices were standardized to 2006 dollars using the consumer price index (Tietenberg 1996). The percentage of total harvest (in weight and economic value) composed of paddlefish was estimated by calculating the total weight and value of all fish species harvested in the study area.

Discharge data were obtained from U.S. Geological Survey and U.S. Army Corps of Engineers gauging stations located at each lock and dam. If data were unavailable for a specific lock and dam, discharge data from the nearest gauging station were used. Air temperature data provided by the National Climatic Data Center (National Oceanic and Atmospheric Administration) were used to evaluate the effects of temperature (e.g., a surrogate measure of ice dynamics) because water temperature and ice coverage records were not available for most areas of the UMR. Similar to

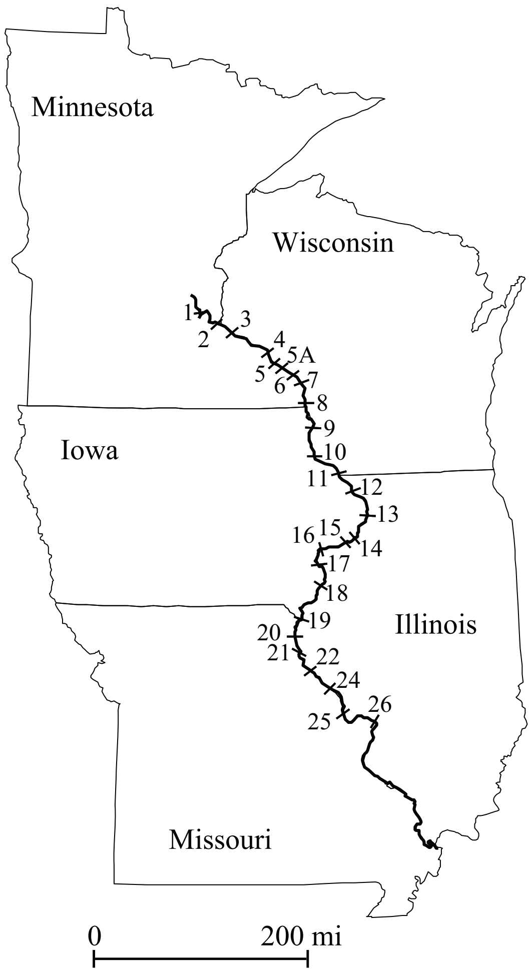

Figure 1. Map of the upper Mississippi River basin. Numbers represent lock and dams. Pools are numbered by the dam forming the pool (e.g., Pool 16 is immediately upstream of Lock and Dam 16).

discharge data, information from the nearest climate recording station was used in the analysis when temperature data were unavailable for a specific pool. Mean and median spring (i.e., March–June) and fall–winter (i.e., September–March) discharge and air temperatures were estimated for each pool. The number of days that exceeded the median discharge (i.e., median of 1953–2005) was also estimated for each pool. Relationships between paddlefish harvest and discharge attributes, air temperature characteristics, and paddlefish flesh prices were examined by first plotting harvest against the independent variables. Relations among discharge, temperature, and paddlefish harvest statistics were analyzed by pool while relations between market values and total harvest were analyzed across pools. Spearman rank correlations were used to explain patterns in paddlefish harvest because the relationships were not linear (Sokal and Rohlf 1995). A Bonferroni adjustment was used to interpret statistical significance (Manly et al. 2002). Specifically, a relationship was not consider significant unless the P-value was less than 0.0029 [α/k; where α was the probability of committing a type I error (α = 0.05) and k was the number of comparisons for each independent variable (k = 17 pools)]. In addition, multiple regression was used to examine whether independent variables (e.g., discharge, market value) interacted to influence harvest.

Results

Mean paddlefish harvest during 1953–2005 varied from less than 1,000 lbs to nearly 12,000 lbs (Figure 2) while total harvest varied from 19,332 to 269,312 lbs (8,768.9–122,157.9 kg; Figure 3) across pools and years. Paddlefish harvest was relatively high in the mid-1950s, peaked in 1958, and then declined in the early 1960s. Harvest began to steadily rise in the mid-1960s and continued to increase over the next decade. Total harvest declined to about 25,000 lbs (11,339.8 kg) in 1981 and then increased to approximately 90,000 lbs (40,823.3 kg) in 1988. Since 1992, total paddlefish harvest from Pools 9–26 has been between 19,000 and 35,000 lbs (8,618.3 and 15,875.7 kg) per year. Market prices for paddlefish flesh were highest in 1956 ($1.24/lb) and lowest in 2000 ($0.29/

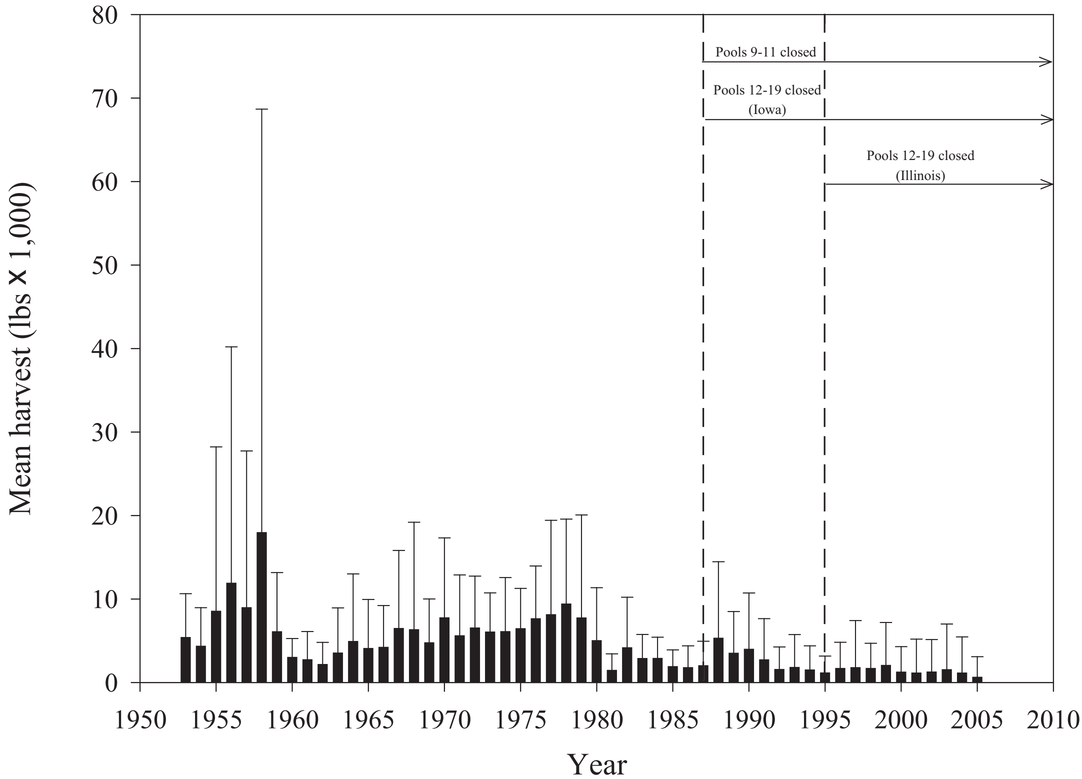

Figure 2. Mean commercial paddlefish harvest from Pools 9–26 of the upper Mississippi River. Error bars represent 1 SD. Vertical dashed lines indicate important changes in commercial harvest regulations: Pools 9–11 were closed in 1987, Pools 12–19 in Iowa waters were closed in 1987, and Pools 12–19 were closed in Illinois waters in 1995.

lb). Unfortunately, similar time series data were unavailable for roe prices.

In addition to temporal variation in harvest, paddlefish harvest also varied among pools. Pools in the lower UMR accounted for the majority of the harvest between 1953 and 2005, with Pools 17–26 accounting for approximately 85% of the total harvest (Figure 4). The highest mean harvest from 1953 to 2005 was observed in Pool 19 (20,386 lbs [9,246.0 kg]), followed by Pools 18 (8,976 lbs [4,071.4 kg]), 26 (8,493 lbs [3,852.4 kg]), 20 (5,059 lbs [2,294.7] kg), and 13 (4,627 lbs [2,098.9 kg]; Figure 4). Total harvest for all years combined was highest in Pool 19 (1,080,447 lbs [490,082.5 kg]), followed by Pools 18 (475,702 lbs [215,774.8 kg]), 26 (450,112 lbs [204,167.4 kg]), 20 (263,088 lbs [119,334.7 kg), and 13 (245,215 lbs [111,227.7]). Pools 9 and 11 had the lowest total (less than 12,000 lbs [5,443.1 kg] each) and mean (less than 230 lbs [104.3 kgk] each) harvest of paddlefish. Several patterns were evident when pools were examined through time (Figure 5). In the 1950s, paddlefish harvest was relatively high in Pools 18 and 19. Harvest in the other pools rarely exceeded 4,000 lbs [1,814.4 kg] per year. Harvest declined in the 1960s, but Pool 19 remained one of the highest producing pools. Similar to the 1950s, harvest in most pools averaged less than 4,000 lbs per year. Nearly all pools exhibited an increase in mean harvest between the 1960s and 1970s where mean harvest increased

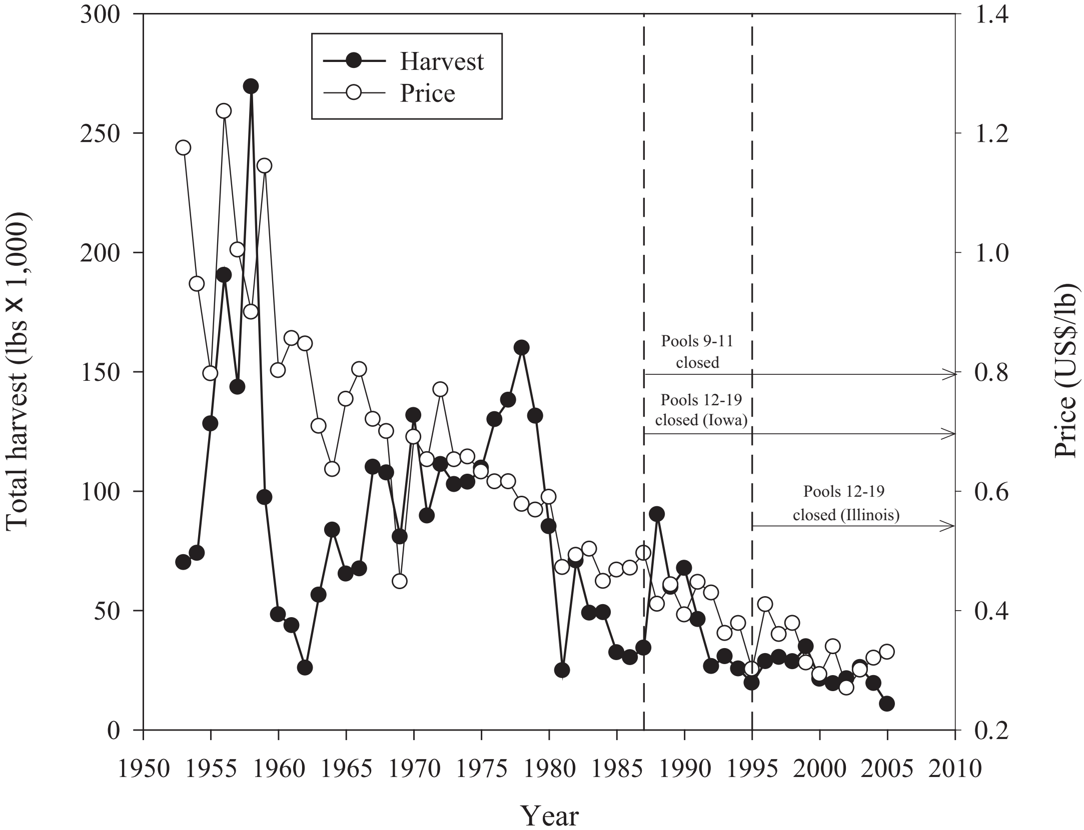

Figure 3. Total harvest and inflation-adjusted price (2006 dollars) of commercially harvested paddlefish from Pools 9–26 of the upper Mississippi River. Vertical dashed lines indicate important changes in commercial harvest regulations: Pools 9–11 were closed in 1987, Pools 12–19 in Iowa waters were closed in 1987, and Pools 12–19 were closed in Illinois waters in 1995.

from 718 to 13,616 lbs (325.7 to 6,176.1 kg; mean ± SD; 3,692 ± 3,621 lbs [1,674.7 ± 1,642.5 kg]) across pools. The only pools that experienced declines in the 1970s were Pools 20 and 21 where mean harvest was about 3,000 lbs (1,360.8 kg) less than in the previous decade. The greatest change in harvest was in Pool 18 where mean harvest increased by almost 14,000 lbs between the 1960s and 1970s. During the 1980s, most paddlefish were harvested from Pools 17–19 and Pool 26. Pools 9–11 were closed to paddlefish harvest in 1987, as were Pools 12–19 in Iowa waters. In 1995, Illinois closed commercial paddlefish harvest from Pools 12–19. As such, most paddlefish harvest has occurred in Pool 20 and Pools 24–26 since 1995.

Discharge characteristics (i.e., mean and median discharge by season, days above median discharge by season) were not significantly correlated with paddlefish harvest in any of the pools (P = 0.70–0.001). The only significant relationship with temperature was in Pool 18, where fall-winter temperature was inversely correlated with harvest (r_s = –0.45, P = 0.001), a pattern inconsistent with our predictions. Across pools, total harvest was positively related to inflation-adjusted flesh prices (r_s = 0.62,

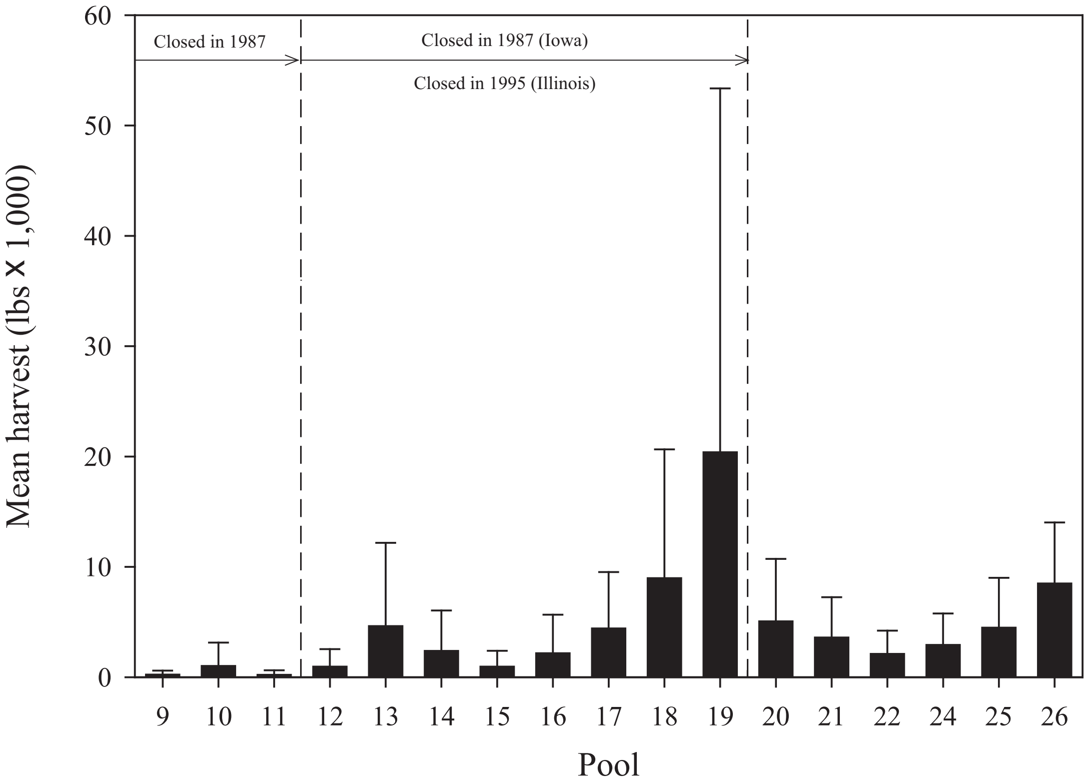

Figure 4. Mean commercial paddlefish harvest from Pools 9–26 of the upper Mississippi River from 1953 to 2005. Error bars represent one standard deviation. Vertical dashed lines indicate important changes in commercial harvest regulations: Pools 9–11 were closed in 1987, Pools 12–19 in Iowa waters were closed in 1987, and Pools 12–19 were closed in Illinois waters in 1995.

$P = 0.0001$). None of the multiple regression models were significant ($P < 0.05$).

Discussion

Like most economic markets, the paddlefish fishery has fluctuated greatly over the past 100 years. The Mississippi River has, at times, been a major contributor to the total U.S. market during those periods, with peak contributions of 77% (1899) and 46% (1950) of the total market (Carlson and Bonislawsky 1981; Gengerke 1986). Since the 1960s, however, the Mississippi River has generally contributed less than 15% of the total harvest. During this time, other systems have dominated the paddlefish harvest, particularly the Tennessee River basin (Carlson and Bonislawsky 1981). Although the impounded portion of the UMR has generally contributed less than 10% of the total U.S. market, it was historically an important proportion of the total Mississippi River harvest. For example, paddlefish from the UMR made up 61% of the entire Mississippi River harvest in 1894, 69% in 1960, and more than 90% of the Mississippi River harvest in 1970 and 1975 (Gengerke 1986).

Three primary peaks in paddlefish harvest seem evident from the literature and this study, including the turn of the 20th century, the 1950s, and the 1970s (Carlson and Bonislawsky 1981; Gengerke 1986; Pasch and Alexander 1986). While the factors influencing these peaks can-

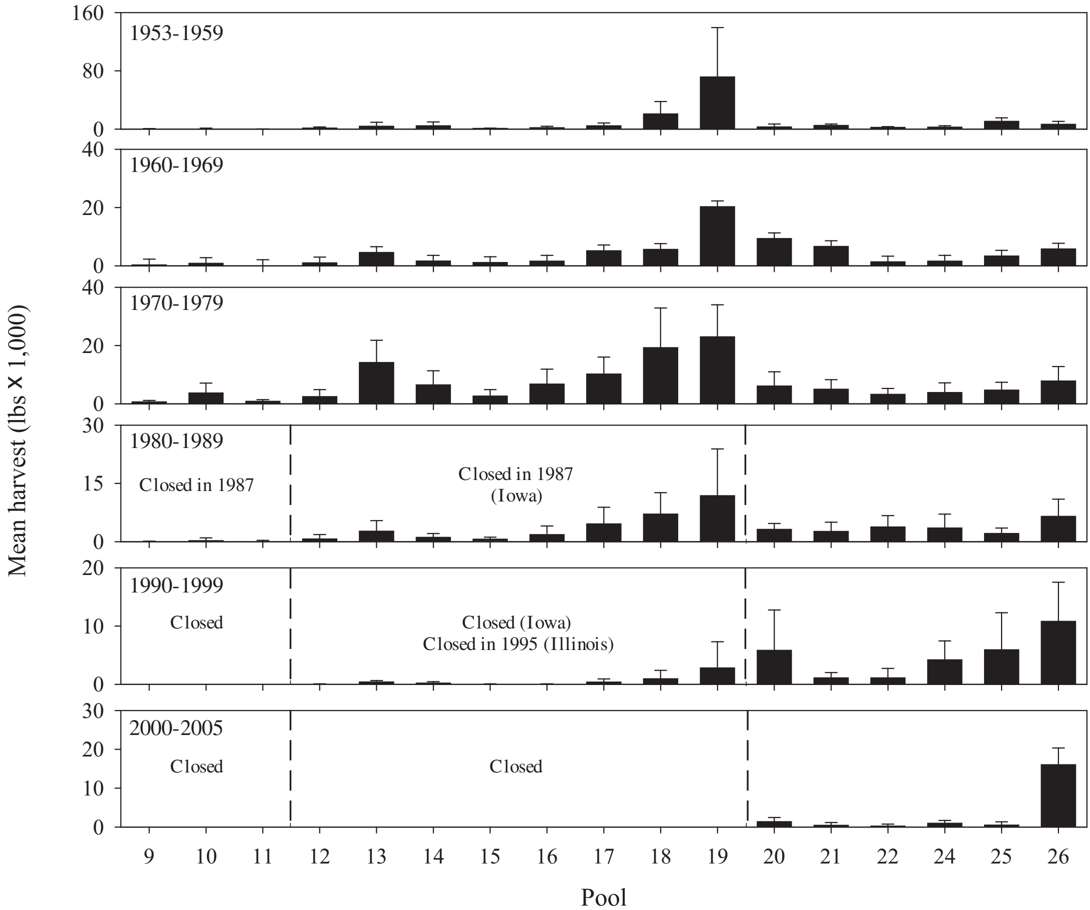

Figure 5. Mean commercial paddlefish harvest from Pools 9–26 of the upper Mississippi River. Vertical dashed lines indicate important changes in commercial harvest regulations: Pools 9–11 were closed in 1987, Pools 12–19 in Iowa waters were closed in 1987, and Pools 12–19 were closed in Illinois waters in 1995.

not be determined using our data, peaks of paddlefish harvest may be due to the demand and value of caviar. Records of roe prices received by commercial harvesters are sporadic, and although time series data are unavailable, peak roe prices have remained similar among time periods. For instance, peak paddlefish roe prices were around $32–65/lb (all prices are adjusted to 2006 dollars and are for unprocessed roe) at the turn of the 20th century (Stockard 1907; Alexander 1914; Coker 1923) and $36–45/lb in 1979 (Pasch and Alexander 1986). High roe prices were, in turn, concordant with increased paddlefish harvest throughout the United States and UMR. When roe prices were around $1–3/lb in the late 1960s and early 1970s (Pasch and Alexander 1986), paddlefish harvest was relatively low. Scholten and Bettoli (2005) reported that 2004 roe prices in Tennessee were around $53/lb. In upper portions of the Mississippi River (i.e., Illinois and Missouri), roe prices were also around $53/lb in 2004, but have recently approached $75/lb (R. Maher, Illinois Department of Natural Resources, personal communication). The history of caviar demand and paddlefish harvest has many fisheries scientists concerned that paddlefish populations will once again experience high exploitation given current roe prices.

Harvest of paddlefish in the UMR has been highly variable among pools, with most harvest occurring in the lower pools in recent years. Prior to the 1990s, Pool 13 and Pools 17–19 generally had the highest harvest. Several factors may be responsible for the high harvest observed in these pools. Aside from Pool 4 (Lake Pepin), Pools 1–13 are characterized by numerous islands and side channels and a narrow river-floodplain (about 1–3 mi [1.6–4.8 km]) that terminates at steep bluffs (USGS 1999). Pools 14–26 are characterized by wider alluvial valleys (approximately 5 mi [8.0 km]) between high bluffs and typically have fewer and larger islands. As such, pools downstream of Lock and Dam 15 are typically more lentic than upstream pools, the only exception being the downstream portion of Pool 13, which is more characteristic of a lentic environment. Paddlefish are generally considered a riverine species but often thrive in reservoir systems when suitable spawning habitats are available (Russell 1986; Paukert and Fisher 2001b). Because most paddlefish are harvested in tailwater habitats or other deepwater habitats when fish are congregated (e.g., downstream of movement barriers, overwinter habitats; Scholten and Bettoli 2005), the observed pattern is unlikely the result of increased capture efficiency in large reservoir habitats. However, reservoirs provide increased habitat area and favorable feeding conditions for paddlefish (Russell 1986; Sparrowe 1986). Standardized paddlefish population data (e.g., catch per unit effort) are currently unavailable for all of the pools used in this study. Thus, it is impossible to determine whether harvest data reflect long-term patterns in paddlefish density. High-harvest pools may contain higher densities of paddlefish or larger paddlefish or may simply reflect congregations of paddlefish resulting from instream barriers to movement (i.e., dams). The observed patterns of harvest may also be a function of where harvesters are located on the river because most commercial harvesters reside in southeastern Iowa, central and southwestern Illinois, and northeastern Missouri (G. Jones, Iowa Department of Natural Resources, personal communication).

Discharge and temperature dynamics were not related to paddlefish harvest in the study pools, except in Pool 18 where fall–winter temperature was inversely related paddlefish harvest. The lack of consistent patterns was surprising given observations of little or no commercial fishing activity during high flow events and poor ice conditions (M. J. Steuck, personal observation). In addition, our results are inconsistent with Scholten and Bettoli (2005), who found that paddlefish harvest increased with the number of fishable days (i.e., based on flow dynamics) in the Tennessee River. The scale of our study may have obscured patterns in the data. For example, few paddlefish may have been harvested in years when prices were low, even though environmental conditions were conducive for capturing paddlefish. Such a situation almost certainly occurred over the past 50 years and would greatly hinder our ability to detect patterns. Also, Scholten and Bettoli (2005) focused on a fishery that had open and closed seasons. In our study, paddlefish could be harvested any time of the year. Even though harvest reports were often collected monthly, we only had annual harvest records available for analysis that were a combination of winter, spring, and fall–winter harvests. The relationship between price and harvest suggests that paddlefish harvest may be a direct result of the market value of their flesh, but this relationship is confounded with harvest regulations placed on the fishery. Paddlefish harvest is undoubtedly related to their market value, but the overall decline in harvest may also be partly due to closure of Pools 9–11 in 1987, Pools 12–19 in Iowa waters in 1987, and Pools 12–19 in Illinois waters in 1995, not necessarily the steady decline in market prices for flesh.

Paddlefish harvest in the impounded portion of the UMR has exhibited high variation among pools during the past 50 years. Although paddlefish harvest was highly correlated with flesh prices, the caviar market and harvest regulations have likely had an important influence on the commercial paddlefish fishery. Three primary peaks in paddlefish harvest have been noted in the UMR, all of which are closely linked with high roe prices associated with the caviar industry. Harvest will likely increase in some portions of the basin given an increase in roe prices over the past 5 years. Future efforts should continue to focus on developing and implementing standard sampling protocols for monitoring paddlefish populations in the UMR and ensuring that commercial harvest data (including roe prices) are rapidly available to natural resource managers for making management decisions.

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