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Population dynamics of introduced flathead catfish in Lake Mitchell, South Dakota

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ABSTRACT

The introduction of flathead catfish (*Pylodictis olivaris*) into Lake Mitchell presented a unique opportunity to study the population dynamics of this species in a South Dakota impoundment. We collected flathead catfish using daytime, low-frequency electrofishing during June 2013, 2014, and 2015 and July, August and October of 2014 to examine population characteristics including abundance, recruitment, mortality, growth, condition, and diet. The flathead catfish population in Lake Mitchell was estimated at 1348 individuals (95% CI = 459–1455; density = 4.97/ha) in 2014 and 1197 individuals (95% CI = 931–1461; density = 4.42/ha) in 2015. Individuals from 11 year classes ranging from 1 to 13 years old were present. The population exhibited consistent recruitment, and annual mortality was estimated at 39%. Flathead catfish grew quickly exceeding stock length at age 3 and quality length at age 5; however, growth slowed in 2015. Similarly, condition of substock and stock-quality length fish declined in 2014 and 2015, respectively. The decline in growth and condition coincided with the recruitment of a large 2012 year class and may be an early indicator of intraspecific competition. Diets of Lake Mitchell flathead catfish primarily consisted of crayfish (*Orconectes* spp.) and fish with flathead catfish shifting to piscivory at approximately 400 mm. The high percentage of centrarchids in flathead catfish diets along with an increase in flathead catfish abundance coinciding with a decrease in bluegill abundance may indicate that flathead catfish are negatively impacting the bluegill population in Lake Mitchell.

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Introduction

Flathead catfish (*Pylodictis olivaris*) have been widely introduced because of their popularity with anglers (Jackson 1999; Kwak et al. 2006; Kaeser et al. 2011). They are renowned for their aggressive behavior, fighting ability when hooked, palatability, and potential to reach a large size (Jackson 1999). Flathead catfish have been stocked for purposes of recreational angling and as a predatory control of stunted or undesirable fish populations (Davis 1985; Haas et al. 2001; Vrtiska et al. 2003). Following introduction, populations often experience steady growth and can obtain a high abundance and biomass (Guier et al. 1981; Quinn 1988; Moser & Roberts 1999; Weller & Geihlsler 1999; Kaeser et al. 2011). However, flathead catfish can impact native fish populations and their introduction into rivers in the eastern United States has resulted in the decline of native bullheads (Guier et al. 1981; Thomas 1993; Moser & Roberts 1999; Kaeser et al. 2011).

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In South Dakota, flathead catfish are native to the Missouri River and its major tributaries, where they provide popular fisheries in the lower portions of the Big Sioux and James rivers (Doorenbos et al. 1996; Doorenbos et al. 1999). In Lake Mitchell, South Dakota, flathead catfish were first sampled in 2007 and were presumed to have originated from an unauthorized introduction from the nearby James River. Nighttime electrofishing catches of 22 and 46 flathead catfish in 2011 and 2012, respectively (T. M. Stevens, Minnesota Department of Natural Resources, unpublished data), provided evidence of natural recruitment and an established population.

Information on the food habits of flathead catfish in reservoirs and their impact on the fish community is relatively scarce (Turner & Summerfelt 1970; Layher & Boles 1980; Haas et al. 2001; Vrtiska et al. 2003; Katt 2016b). The diets of smaller flathead catfish (<500 mm) commonly consist of invertebrates including crayfish (*Orconectes* spp.) and smaller fish, while larger individuals are primarily piscivorous. Highly abundant forage fish, such as gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Amploplites grunniens*), and white perch (*Morone americana*) were the most common food items in flathead catfish in Great Plains reservoirs (Turner & Summerfelt 1970; Layher & Boles 1980; Vrtiska et al. 2003) while flathead catfish introduced into a Minnesota lake primarily consumed common carp (*Cyprinus carpio*) and black bullheads (*Ameiurus melas*) (Davis 1985). Flathead catfish appear to be opportunistic feeders typically consuming the most abundant and easily-accessible prey items (Layher & Boles 1980; Davis 1985; Haas et al. 2001; Vrtiska et al. 2003; Baumann & Kwak 2011).

Flathead catfish predation has been shown to reduce or nearly eliminate centrarchids in ponds (Hackney 1966; Swingle 1967) and rivers (Evans 1991; Thomas 1993). Herndon and Waters (2002) suggested that based on their high abundance and use of centrarchids as prey, flathead catfish would have an impact on the largemouth bass (*Micropterus salmoides*) and sunfish fishery in Lake Sutton, a cooling reservoir similar in size to Lake Mitchell. South Dakota Game, Fish and Parks (SDGFP) fisheries staff are concerned about the potential negative impact of flathead catfish predation upon bluegill (*Lepomis macrochirus*) and crappie (*Pomoxis* spp.) fisheries in Lake Mitchell. The objectives of this study were to describe the population dynamics (abundance, recruitment, growth, mortality, and condition), and quantify food habits of flathead catfish in Lake Mitchell, South Dakota.

Methods

Lake Mitchell, located in southeastern South Dakota (Davison County), is a 271-ha impoundment with a maximum depth of 8.8 m and mean depth of 3.7 m. The lake was constructed in 1928 by the City of Mitchell to serve as a domestic water supply and regional recreation center. The primary source of water is Firesteel Creek, which contains two main branches and drains a watershed of 93,081 ha extending 80 km above the lake. The lake is owned by the City of Mitchell and the fishery is managed by SDGFP. The City owns and maintains several public access areas and parks around the lake while the remainder of the lakeshore is privately owned and highly developed. About 50% of the shoreline is rocky habitat (mostly rip-rap). The predominant aquatic vegetation in the lake is sago pondweed (*Potamogeton pectinatus*); however, an invasive species, curlyleaf pondweed (*Potamogeton crispus*) has been present since 2012. Lake Mitchell contains a fish community with at least 15 species present. The most abundant game fish include bluegill, black crappie (*Pomoxis nigromaculatis*), white crappie (*Pomoxis annularis*), largemouth bass, channel catfish (*Ictalurus punctatus*), flathead catfish, and walleye (*Sander vitreus*). Common non-game fish species include common carp, bigmouth buffalo (*Ictiobus cyprinellus*), smallmouth buffalo (*I. bubalus*), freshwater drum, shorthead redhorse (*Moxostoma macrolepidotum*), white sucker (*Catostomus commersoni*), and green sunfish (*L. cyanellus*).

We collected flathead catfish using daytime low-frequency electrofishing (LFE) with a Smith-Root (7.5 GPP) electrofishing boat using low-pulse frequency (7.5–15 pulses/s) and direct current (2–3 A, 500 V). We used a chase boat to assist in netting surfacing fish in 2014 and 2015 (Gilliland 1988; Cunningham 1995), but not 2013. Electrofishing was completed during June of 2013, 2014,

and 2015, and July, August, September, and October of 2014. Total sampling time varied from 130 to 260 min per sampling event; electrofishing was done in 10-min intervals in 2014 and 2015 and 20-min intervals in 2013. Flathead catfish relative abundance was quantified as mean catch per hour of electrofishing (CPUE) of all sizes of fish and was compared between sampling events with a one-way analysis of variance (ANOVA). Tukey's honestly significant difference (HSD) test was employed to determine where differences existed when the ANOVA was significant.

We measured (total length, mm), weighed (g), removed adipose fins, and determined gender through external characteristics (with the exception of 2013) of all flathead catfish. We compared the proportion of males to females collected between months using chi-square analysis. We extracted pectoral spines from a subsample of 10 fish per 10-mm group for age and growth analysis. We prepared spines according to Koch and Quist (2007) and sectioned them at both the articulating process and the basal recess with a Buehler low-speed isomet saw (Buehler, Lake Bluff, Illinois, USA). We viewed spine sections with a stereo microscope (UNITRON Z850; Commack, New York, USA) using transmitted light through a darkfield attachment and recorded a digital image of each structure from each fish with a Motic 5.0 MP camera (Richmond, British Columbia, Canada) mounted on the trinocular body of the stereo microscope. All spines were aged independently by at least two experienced readers. Any discrepancies in assigned ages were resolved by consensus. The number of visible annuli, the distance from the focus to each annulus (mm), and the radial distance from the focus to the margin (mm) were determined and used to back-calculate length-at-age with the Fraser–Lee direct proportion method (Carlander 1982). Von Bertalanffy growth models

$$L_t = L_\infty [1 - e^{-k(t-t_0)}],$$

where L_t is the predicted total length at time t in years, L_∞ is the theoretical maximum mean total length, e is the base of the natural logarithm, k is the growth coefficient, and t_0 is the hypothetical age at which fish length equals zero were fitted to mean length-at-age data for each population (Ricker 1975) using FAMS 1.64 (Fishery Analysis and Modeling Simulator; Slipke & Maceina 2014).

To test for differences in growth by gender and year, the length increment added in the last year was regressed as a function of initial length (for that year) and analysis of covariance (ANCOVA) was used to compare the regressions. All statistical tests were completed using SYSTAT 13 (SYSTAT Software Inc., Richmond, CA) with a significance level of 0.05.

We developed age–length keys using FAMS 1.64 (Slipke & Maceina 2014) for the 2013–2015 population samples, and then assigned ages to all individuals collected during electrofishing sampling events. The 2013–2015 age frequencies were pooled and \log_e (CPUE) was plotted against age for fish age 2 (the youngest age that appeared fully recruited to the sampling gear) and older in order to estimate instantaneous total mortality rate (Z). Total annual mortality (A) was derived from the formula $A = 1 - e^{-Z}$ (Ricker 1975).

We evaluated condition of flathead catfish using relative weight (W_r). We tested differences in W_r values across years by length categories (Quinn 1989; substock, stock-quality, quality-preferred, preferred and longer) using a one-way ANOVA. In instances when the ANOVA was significant, Tukey's HSD test was used to determine where differences existed.

We used the recruitment variability index (RVI; Guy & Willis 1995) to evaluate variation in recruitment. The RVI employs presence/absence and magnitude of year classes and is sensitive to missing year classes. Values of RVI can range from -1 to 1 with values close to 1 indicating consistent recruitment.

We used single and multiple census mark-recapture models to estimate the flathead catfish population size with corresponding 95% confidence intervals (Ricker 1975). A Schnabel population estimate was obtained in 2014 from recaptures of fish marked during the three consecutive days of sampling. In 2015, the population was estimated using the Petersen method based on fish that were marked with an adipose fin-clip in 2014. Adipose-clipped marks applied in 2014 were easily identifiable in 2015.

We collected up to 25 diets for each 100 mm length group in 2014 using either pulsed gastric lavage (Foster 1977; Waters et al. 2004) or manual extraction. Stomach contents were screened through a 710 μm sieve, fixed in 10% formalin, preserved in 70% ethanol, identified to the lowest possible taxa, counted, and weighed. Stomach contents were further quantified by frequency of occurrence, percent composition by number, and percent composition by wet weight (Bowen 1996; Herndon & Waters 2002). We estimated the shift to piscivory by using logistic regression on the presence or absence of fish prey in diets across length.

Results

A total of 585 flathead catfish were collected during nine sampling events from June 2013 through June 2015. The percentage of male, female, and immature fish collected in 2014 and 2015 was 56%, 38%, and 6%, respectively. The proportion of males to females varied by month ($\chi^2 = 9.14$, $df = 3$, $P = 0.027$) with more males than females collected in June 2014, August 2014, and June 2015, and similar numbers collected in July 2014. Only three flathead catfish (two males and one female) were collected on 13 October 2014 and, therefore, it was not included in the analysis of sex ratio or mean CPUE.

Mean CPUE differed between sampling trips ($F_{3,72} = 4.21$, $P = 0.008$). The mean CPUE on 09 June 2014 (48.8/h) was greater than mean CPUEs for sampling events in July and August (Tukey's HSD, Figure 1). The second highest mean CPUE occurred on the 09 June 2015 sampling event; however, it was not significantly different from any of the others.

In 2015, we recaptured 53 (14.8%) of the 359 fish marked in 2014. The number of flathead catfish in Lake Mitchell was estimated at 1348 individuals (95% CI = 459–1455; density = 4.97/ha) in 2014 and 1197 individuals (95% CI = 931–1461; density = 4.42/ha) in 2015.

The estimated ages of flathead catfish ranged from 1 to 13 years and individuals were collected from 11 year classes (Figure 2). The large 2012 year class comprised 62%, 58% and 49% of the total sample in 2013, 2014, and 2015, respectively. Total annual mortality of fish age 2 and older was estimated at 39%. The population exhibited consistent recruitment with RVI values ranging from 0.45 in 2013 to 0.77 in 2015. There were no missing year classes between 2006 and 2015.

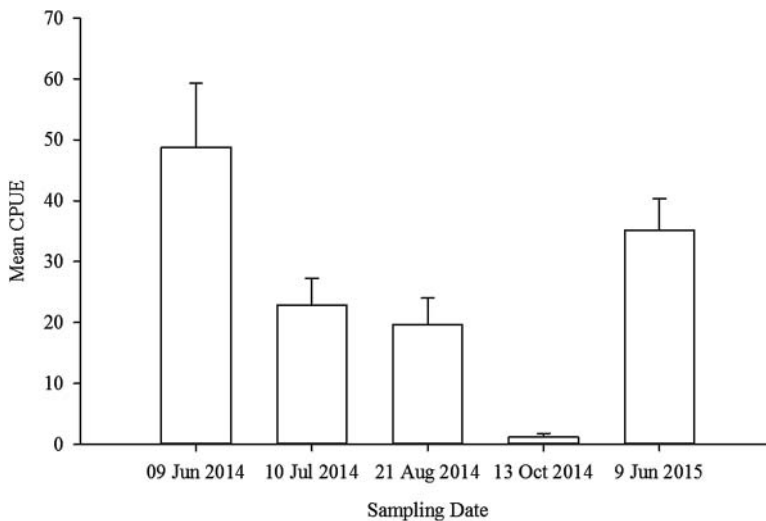


Figure 1. Mean catch per hour (CPUE) of flathead catfish sampled from Lake Mitchell, South Dakota, 2014–2015. Only three flathead catfish were collected on 13 October 2014, so it was excluded from the analysis. Vertical bars represent \pm one SE.

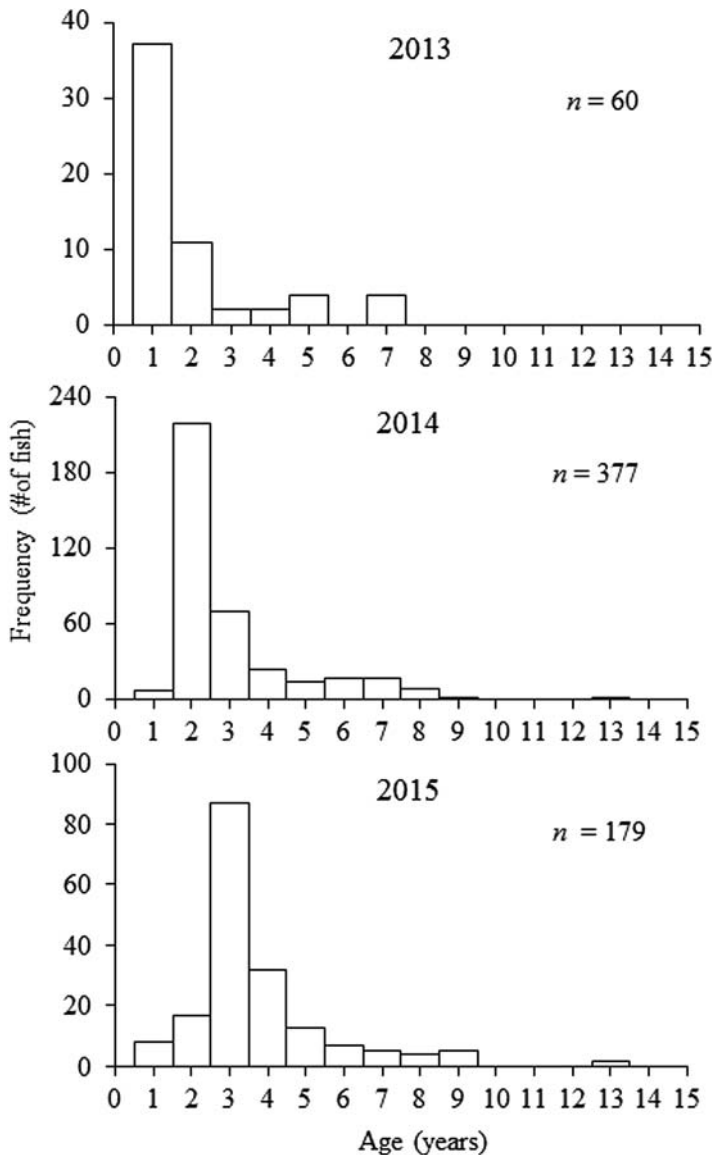


Figure 2. Age frequency distribution of flathead catfish collected from Lake Mitchell, South Dakota, 2013–2015.

Flathead catfish grew quickly exceeding stock length at age 3 and quality length at age 5 (Table 1). Incremental growth was similar in 2013 and 2014 (ANCOVA: slope test, $F_{1,153} = 0.56$, $P = 0.453$; intercept test, $F_{1,154} = 1.74$, $P = 0.190$), but was slower in 2015 than in 2013 (slope test, $F_{1,116} = 27.78$, $P < 0.001$) or 2014 (slope test, $F_{1,209} = 18.13$, $P < 0.001$). Incremental growth was similar for males and females in 2014 (slope test, $F_{1,111} = 1.65$, $P = 0.201$; intercept test, $F_{1,112} = 3.66$, $P = 0.058$), but slower for males in 2015 (slope test, $F_{1,83} = 12.74$, $P = 0.001$).

Von Bertalanffy growth models fit the data well for both males and females ($r^2 = 0.99$; Table 2). Back-calculated and von Bertalanffy modeled growth rates were very similar for males and females from age 1 through age 8 (Figure 3). Modeled growth for males and females began to diverge after age 8 because no fish exceeding age 9 were available for inclusion in the male growth model while the female growth model included two age 13 individuals (Table 1).

Table 1. Mean (\pm 95% C.I.) back-calculated length-at-age (mm) and number of fish at each estimated age for male (M) and female (F) flathead catfish collected from Lake Mitchell, South Dakota, 2013–2015.

Age	2014				2015			
	Male		Female		Male		Female	
	<i>n</i>	Mean	<i>n</i>	Mean	<i>N</i>	Mean	<i>n</i>	Mean
1	77	189 \pm 12	38	180 \pm 19	14	167 \pm 21	19	181 \pm 19
2	77	302 \pm 13	38	306 \pm 18	14	285 \pm 31	19	296 \pm 20
3	34	380 \pm 24	21	390 \pm 26	13	367 \pm 51	17	402 \pm 30
4	21	451 \pm 35	16	441 \pm 22	8	470 \pm 81	15	476 \pm 41
5	16	531 \pm 76	11	529 \pm 32	5	567 \pm 113	11	552 \pm 51
6	15	590 \pm 54	8	608 \pm 63	4	662 \pm 156	8	639 \pm 75
7	8	651 \pm 105	3	646 \pm 99	4	718 \pm 160	6	720 \pm 62
8	2	776	3	687 \pm 100	3	722 \pm 232	5	779 \pm 53
9					1	840	4	805 \pm 64
13			1	968			1	969

Table 2. Flathead catfish age range and growth parameters (95% confidence limits in parentheses) of von Bertalanffy models fitted to mean total length at age data pooled for 2014 and 2015 for males and females collected from Lake Mitchell, South Dakota (L_∞ is the theoretical maximum mean total length, k is the growth coefficient, and t_0 is the hypothetical age at which fish length = 0, and r^2 is the coefficient of determination for model fit with respect to all age classes).

Parameter	Sex	
	Males	Females
Age range (years)	1–9	1–13
L_∞ (mm)	2758	1205
k	0.035	0.111
t_0	–1.129	–0.505
r^2	0.99	0.99

Relative weights differed between years for substock ($F_{2,307} = 8.05, P < 0.001$) and stock-quality ($F_{2,224} = 6.82, P = 0.001$) length categories, but not for quality-preferred ($F_{2,65} = 0.64, P = 0.532$) and preferred ($F_{2,22} = 0.51, P = 0.609$) length categories (Table 3). Condition of substock fish was significantly lower in 2014 than 2013, and the stock-quality length fish exhibited significantly lower

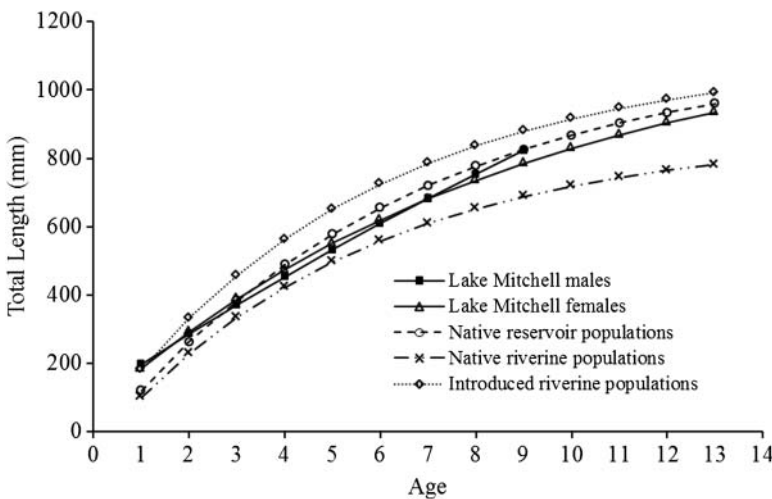


Figure 3. A comparison of von Bertalanffy growth curves for male and female flathead catfish collected from Lake Mitchell in 2014 and 2015 and for native riverine, introduced riverine and native reservoir populations in the USA modeled from length-at-age data summarized by Kwak et al. (2006).

Table 3. Mean relative weight (W_r , SE in parentheses) by length category [substock (SS, > 35 cm), stock-quality (SQ, 35–50 cm), quality-preferred (QP, 51–70 cm) and preferred (P, > 70 cm)] for each year for flathead catfish from Lake Mitchell, 2013–2015. Mean W_r values denoted by different letters (a–c for years, w–z for size categories) were significantly different at $p \leq 0.05$. Differences were not tested for the categories of QP and P in 2013 because sample size was too small ($n < 5$).

Year	Length category			
	SS	SQ	QP	P
2013	97.8 (1.5) ^{a,x}	85.1 (2.4) ^{a,y}	80.9 (0.4)	92.5 (3.5)
2014	90.4 (1.1) ^{b,w}	85.4 (0.9) ^{a,x}	83.9 (1.5) ^{a,x}	94.6 (7.2) ^{a,w,x}
2015	86.4 (1.2) ^{b,w}	81.1 (0.7) ^{b,x}	86.7 (2.6) ^{a,w,y}	100.9 (2.6) ^{a,z}

Table 4. Stomach contents of three sizes of flathead catfish collected in 2014 from Lake Mitchell, South Dakota quantified by frequency of occurrence (FO), percent composition by number (PN), and percent composition by wet weight (PW).

Food item	<300 mm (n = 30)			300–600 mm (n = 77)			>600 mm (n = 7)		
	FO	PN	PW	FO	PN	PW	FO	PN	PW
Centrarchidae	17	14	33	42	43	77	86	86	97
Ictaluridae	7	6	4	3	2	trace	0	0	0
Unidentified fish	7	5	1	7	5	1	14	14	3
All teleostei	27	25	38	49	50	78	100	100	100
<i>Orconectes</i> spp.	67	67	62	55	50	22	0	0	0
Chironomidae	10	8	trace	0	0	0	0	0	0

condition in 2015 than 2014. We also detected significant differences in mean relative weight between length categories within years (Table 3). Mean relative weight differed between the substock and stock-quality length categories in all three years.

A total of 114 diets were collected from flathead catfish; 30 from fish less than 300 mm, 77 from fish 300–600 mm, and 7 from fish over 600 mm (Table 4). Crayfish comprised approximately 67% and 62% of the diets of smaller fish (>300 mm) by number and weight, respectively. Stomachs of 300–600 mm fish contained nearly equal numbers of crayfish and fish; however, fish comprised a substantially higher proportion of the diet by weight (Table 4). Larger flathead catfish (>600 mm) had only fish their diets. Centrarchidae comprised 77% and 97% by weight of fish in diets of 300–600 mm and >600 mm flathead catfish, respectively. Ictaluridae in the diet were all smaller flathead catfish. Chironomidae were found in the diet of three smaller (<190 mm) individuals. The proportion of fish to crayfish in the diet was similar between the months of July and August (Figure 4). Flathead catfish in Lake Mitchell shifted to piscivory at approximately 400 mm. The logistic regression fit the data well (null deviance = 157.48, df = 113; residual deviance = 119.15, df = 112; Figure 5) and few fish over 400 mm had non-fish prey in their diets.

Discussion

Low-frequency electrofishing is the most common gear used to sample flathead catfish (Brown 2009) and a chase boat is often employed when sampling lotic systems (Cunningham 2004). Low-frequency electrofishing appeared to be an effective method for capturing flathead catfish on Lake Mitchell although catch rates commonly fell below the range (38.5–58.0 fish/h) reported for Oklahoma reservoirs (Gilliland 1988; Cunningham 1995, 2000). The relative abundance of flathead catfish in Lake Mitchell was similar to the nearby James River, but higher than that reported for the Big Sioux River in South Dakota (Arterburn 2001). Electrofishing catches for lentic systems on average are higher than for lotic systems (Bodine et al. 2013) and a chase boat was not employed to do the river sampling (Arterburn 2001).

We were most effective at collecting flathead catfish in the month of June. Maximum catch rates in lotic systems have been achieved during summer months, when water temperatures exceed 20 °C and water levels were low (Quinn 1986; Travnicek 2011); however, sampling conditions relative to efficiency have not been evaluated for lentic habitats (Bodine et al. 2013). Although we

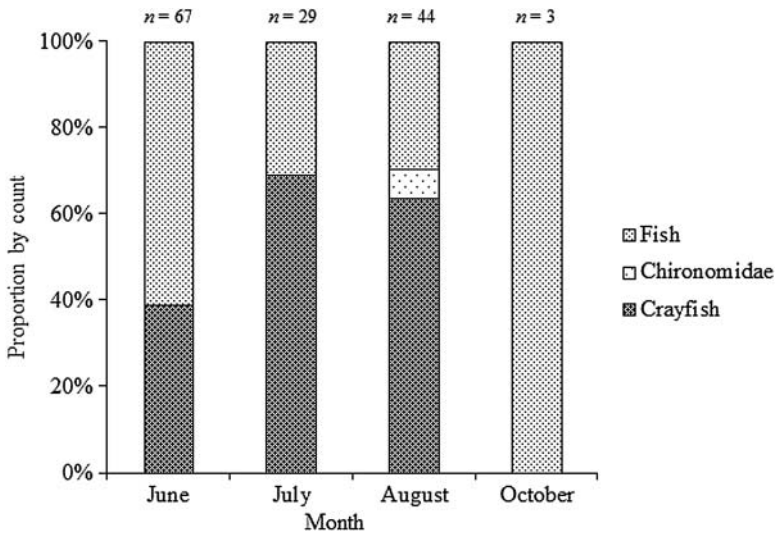


Figure 4. Proportion by number of food items in the stomachs of flathead catfish collected from Lake Mitchell, South Dakota, in 2014.

did not quantify catch by habitat type, a large proportion of the flathead catfish were captured near rocky habitat. Vrtiska et al. (2003) and Katt (2016b) also observed a preference for rocky habitat by flathead catfish in Branched Oak Reservoir, Nebraska. Layher and Boles (1980) caught flathead catfish along the rocky rip-rap of the causeway at Milford Reservoir, Kansas, in July and August and attributed their high abundance at that location to use of rip-rap as spawning, feeding and resting habitat. However, unlike Lake Mitchell, Branched Oak and Milford Reservoir flathead catfish, especially larger fish, were also common in woody habitat.

Estimates of flathead catfish density in lentic waters are scarce, and thus, little is available for comparison with Lake Mitchell. Recent research in Nebraska impoundments yielded estimates of flathead catfish density of 3.4/ha in Pawnee Reservoir, Nebraska (Katt 2016a) and 7.4/ha in

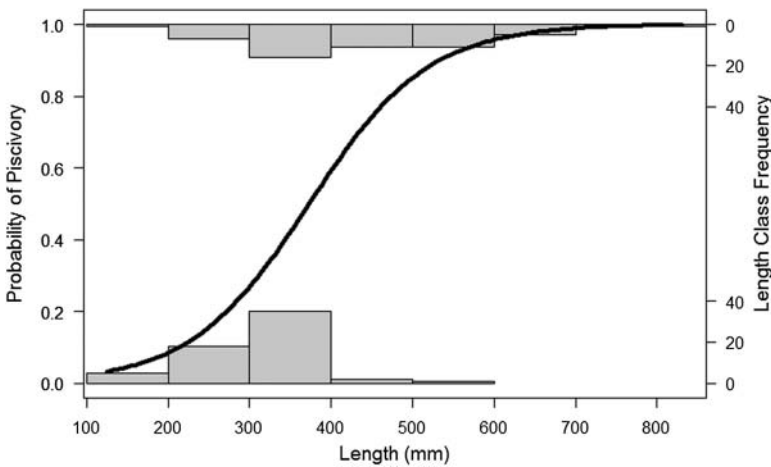


Figure 5. Probability of piscivorous feeding across length classes of flathead catfish in Lake Mitchell, SD, as estimated by logistic regression of diets (presence or absence of fish prey). Frequency of individuals within each size class is shown for piscivorous diets (top) and non-fish diets (bottom).

Branched Oak Reservoir (Katt 2016b). Density in Branched Oak Reservoir was higher than in Lake Mitchell, while Pawnee Reservoir was similar. Density of flathead catfish in lotic systems in the southeastern United States has been estimated at up to 15–18/ha for recently-introduced populations (Quinn 1988; Weller & Geihlsler 1999), but is typically in the range of 1–8/ha for established populations (Kwak et al. 2006; Kaeser et al. 2011).

Flathead catfish in Lake Mitchell are a product of an unauthorized introduction and may still be experiencing population growth as newly-established populations tend to increase rapidly in abundance and biomass (Quinn 1988; Moser & Roberts 1999; Weller & Geihlsler 1999). Accordingly, the Lake Mitchell population appears to be expanding because it is dominated by younger fish recruited from the large 2012 year class. Eventually, this growth phase will culminate at a peak density and biomass, which has been demonstrated to occur at approximately 10 to 15 years for flathead catfish introduced into rivers (Guier et al. 1981; Kaeser et al. 2011). This peak abundance is typically not sustained, but followed by a decline in abundance and growth rate (Kaeser et al. 2011).

Lake Mitchell flathead catfish exhibited consistent recruitment with only two missing year classes within the last 13 years. The limited information available suggests that consistent recruitment in flathead catfish is common in impoundments across the Great Plains (Layher & Boles 1979; Katt 2016a, Katt 2016b). Similar to Lake Mitchell, 13 of 16 year classes (1959–1974) were sampled at Milford Reservoir (Layher & Boles 1979) and 13 of 15 year classes (1997–2011) at Branched Oak Reservoir (Katt 2016b). Researchers attributed missing year classes to periods of low water in both reservoirs. Lake Mitchell has a stable reservoir hydrology (Tanner Stevens, unpublished data) which may help to explain the absence of missing year classes. Relatively consistent recruitment has also been reported for other populations in this area like in the lower unchannelized reach of the Missouri River (Gavin's Point Dam to the confluence with the Big Sioux River; Goble 2011) and the lower end of its South Dakota tributaries (James and Big Sioux Rivers; Arterburn 2001).

Annual mortality of flathead catfish in Lake Mitchell (39%) was at the upper end of the range reported from lentic and lotic systems. The only other estimate of annual mortality for a flathead catfish population in lentic waters came from at Lake Wilson, Alabama (17%; Marshall et al. 2009), and was lower than for Lake Mitchell. Estimates for lotic populations range from about 12%–36% (Daughtery & Sutton 2005; Kwak et al. 2006; Makinster & Paukert 2008; Jolley & Irwin 2011; Kaeser et al. 2011), however, values similar to Lake Mitchell were reported for the Missouri River (34%–59%, Gavin's Point Dam to the Kansas–Nebraska border; Goble 2011) and the Satilla River, Georgia (45%; Sakaris et al. 2006).

The large number of young flathead catfish from the 2012 year class may have inflated our estimate of annual mortality. The dominance of that year class was apparent by its much larger contribution to the total catch at age 1 and age 2 than that of subsequent year classes. Additionally, anecdotal evidence suggests that LFE is selective towards fish less than 600 mm (Brown 2009; Ford et al. 2011); another factor potentially biasing our estimated mortality. We would expect that angler exploitation of flathead catfish is low in Lake Mitchell based upon the observation that reservoir channel catfish fisheries in South Dakota are generally under-utilized and subject to low harvest (Galinat 2004; Stevens 2013; Lucchesi et al. 2015; Potter et al. 2016).

Flathead catfish in Lake Mitchell grew similarly to introduced riverine and native reservoir populations (Kwak et al. 2006) and faster than native riverine populations (Arterburn 2001; Kwak et al. 2006). Lake Mitchell fish also grew faster than fish in the James, Big Sioux and Missouri rivers (Arterburn 2001; Goble 2011). Growth to quality size (510 mm) was reached between age 4 and 5 in Lake Mitchell, but was not reached until nearly age 6 in the James and Big Sioux Rivers and between age 7 and age 8 in the Missouri River (Fort Randall Dam to the Kansas–Nebraska border). Similarly, Lake Mitchell fish reached preferred length (710 mm) between age 7 and 8, while it took between 9 and 10 years for fish in the Big Sioux and James rivers (Arterburn 2001). Lake Mitchell flathead catfish grew faster than fish in Nebraska reservoirs (Katt 2016a, 2016b), possibly because the Lake

Mitchell population was recently introduced while the Nebraska reservoirs contained well-established populations (Kwak et al. 2006; Kaeser et al. 2011).

Mean relative weight of Lake Mitchell flathead catfish was lower than for populations in South Dakota rivers (Arterburn 2001) and Nebraska reservoirs (Katt 2016a, 2016b) and formed a U-shaped pattern relative to length typical of most channel catfish populations (Brown et al. 1995; Doorenbos et al. 1999; Stevens 2013). The lower mean relative weight of stock to preferred length fish relative to other length categories may be related to fish size and a transition from a diet of invertebrates to fish and larger crustacea (Layher & Boles 1980, Jackson 1999, Vrtiska et al. 2003). Higher relative weight of stock to preferred length fish in other reservoir flathead catfish populations was most likely related to extremely abundant fish forage such as age 0 gizzard shad in Milford Reservoir (Layher & Boles 1980) or stunted white perch in Branched Oak Reservoir (Vrtiska et al. 2003). Fish have a higher caloric density than crayfish (Eggleton & Schramm 2002) and stock to preferred length flathead catfish in these reservoirs had a higher percent composition of fish to crayfish in their diets than in Lake Mitchell. High abundance of small forage fish may release fish from density dependence at a smaller size.

In Lake Mitchell, the recruitment of the large 2012 year classes coincided with reduced incremental growth and lower relative weight in 2015 and may suggest that the availability of quality foraging habitat is becoming scarce, and subsequently, the population is approaching carrying capacity. Layher and Boles (1980) postulated that population size in reservoirs may be limited by the availability of suitable habitat for foraging (e.g. interstitial spaces in the rip-rap) rather than the availability of forage. Most of the flathead catfish in Lake Mitchell were concentrated in and around rocky shorelines, rip-rap, and the dam face and had not expanded into woody or open habitats. Kwak et al. (2006) suggests that intraspecific competition and other density dependent factors may slow growth in introduced populations to where it approaches that of native populations. Kaeser et al. (2011) observed not only a decrease in growth rate, but also abundance over time in introduced riverine populations in Georgia.

Centrarchids comprised a larger proportion of the diet of flathead catfish in Lake Mitchell than in many other reservoir populations (Turner & Summerfelt 1970; Layher & Boles 1980; Haas et al. 2001; Jolley & Irwin 2003; Vrtiska et al. 2003). Extremely abundant forage species such as gizzard shad, white perch, freshwater drum or common carp often are the primary food item of reservoir flathead catfish. Although Lake Mitchell does not currently contain gizzard shad, it does support populations of freshwater drum (*Aplodinotus grunniens*), common carp, and black bullhead, important food items of flathead catfish in other lentic systems (Turner & Summerfelt 1970; Davis 1985). However, these fish species were not abundant during the study period (SDGFP, unpublished data) and not found in the diets. Centrarchids have been shown to be a primary food item of reservoir flathead catfish (Edmondson 1974; Herndon & Waters 2002) when extremely abundance forage species like gizzard shad are not available. Edmondson (1974) reported that sunfish were the dominant forage consumed by flathead catfish in Bluestone Reservoir, West Virginia. Centrarchids conservatively comprised 53% of diet items by number in flathead catfish in Lake Sutton, Georgia (Herndon & Waters 2002), and similar to Lake Mitchell, were present in fish of all sizes.

Flathead catfish predation has been shown to reduce or nearly eliminate centrarchids in ponds (Hackney 1966; Swingle 1967) and rivers (Evans 1991; Thomas 1993), but has not been definitively tied to a decline in centrarchids in impoundments similar in size to Lake Mitchell. Herndon and Waters (2002) suggested that flathead catfish would have an impact on the largemouth bass and sunfish fishery in Lake Sutton, a 445-ha cooling reservoir, based on their high abundance and use of centrarchids as prey. Although assessing the impact of flathead catfish predation on bluegill and crappie populations in Lake Mitchell would be difficult as both are cyclical, the recent unprecedented decline in bluegill abundance gives some cause for concern. The four lowest trap-net catches of bluegill in the last 20 years were recorded from 2013 to 2016 (Figure 6; SDGFP, unpublished data). Troughs in

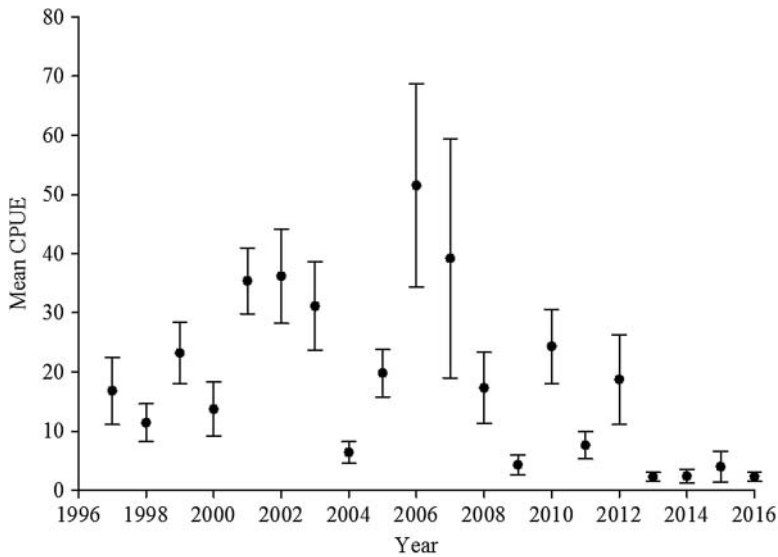


Figure 6. Mean catch per overnight set (CPUE) of bluegills in trap nets on Lake Mitchell, South Dakota, 1997–2016. Vertical bars represent \pm one SE.

bluegill abundance have traditionally lasted for only about a year before the numbers rebound in Lake Mitchell. Thus, the high percentage of centrarchids in flathead catfish diets along with an increase in flathead catfish abundance coinciding with a prolonged decrease in bluegill abundance may indicate that flathead catfish are negatively impacting the bluegill population in Lake Mitchell.

The population parameters estimated in this study most likely characterize the introduced Lake Mitchell flathead catfish population in its growth phase, possibly close to carrying capacity. The recently established population is now successfully reproducing resulting in a population currently skewed toward younger fish. Our assessment may have detected some early signs of intraspecific competition as the population approaches carrying capacity. Moreover, the increase in flathead catfish abundance has coincided with a decrease in bluegill abundance. A follow-up study of population dynamics would be beneficial to determine if Lake Mitchell flathead catfish experience a decline in growth and abundance similar to other introduced populations, and if flathead catfish diets vary over time.

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