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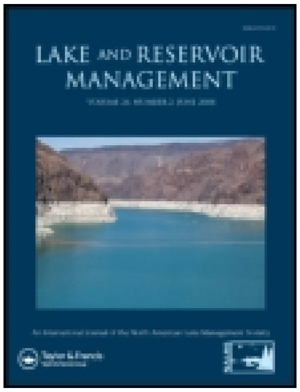

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Growth, condition, diet, and consumption rates of northern pike in three Arizona reservoirs

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Growth, condition, diet, and consumption rates of northern pike in three Arizona reservoirs

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Abstract

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Northern pike (*Esox lucius* L.) introductions are controversial in the western United States due to suspected impacts they might have on established sport fisheries and potential illegal introductions. Three Arizona reservoirs, Parker Canyon Lake, Upper Lake Mary and Long Lake were sampled to examine the diet, consumption dynamics, and growth of northern pike. Northern pike diets varied by season and reservoir. In Parker Canyon Lake, diets were dominated by rainbow trout in winter and spring and bluegill and green sunfish in the fall. In Long Lake the northern pike ate crayfish in spring and early summer and switched to young of the year common carp in summer and fall. Black crappie, golden shiners, and crayfish were the major prey in Upper Lake Mary during spring, but they switched to stocked rainbow trout in the fall. Northern pike growth was in the high range of growth reported throughout the United States. Estimated northern pike specific consumption rate (scr) of rainbow trout ($g/g/d \times 10^{-6}$) was greatest in Upper Lake Mary (scr = 329.1 ± 23.7 $g/g/d \times 10^{-6}$) where stocked fingerling (<120 mm total length [TL]) rainbow trout were most vulnerable to these predators, compared to larger (>280 mm TL) rainbow trout stocked in Long Lake (scr = 1.4 ± 0.1 $g/g/d \times 10^{-6}$) and Parker Canyon Lake (scr = 287.2 ± 15.1 $g/g/d \times 10^{-6}$) where catchable-sized rainbow trout were stocked. Managers should consider the cost-benefits of stocking fish >200 mm TL in lakes containing northern pike.

Key words: Arizona, bioenergetics, introduced fish, northern pike, predation

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Northern pike (*Esox lucius* L.) occur in 45% of the total freshwater area of North America, historically ranging in the north-temperate regions of the Great Lakes basins (Carlander *et al.* 1978). Today, they are found virtually throughout North America due to their legitimate introduction by state agencies to establish sport fisheries and by illegal stocking by misguided anglers (Carlander 1969, Webster *et al.* 1978, McMahon and Bennett 1996). In some cases in the western United States, their negative impact has resulted in lawsuits and eradication programs costing taxpayers millions of dollars (Lee 2001, Hill 2004).

Arizona is the southwestern limit of the current range of northern pike, well outside their native range. Very little is known about the biology of this species in the American Southwest. Northern pike were first introduced into Arizona by government agencies in the late 1960s (Minckley 1973). However, illegal introductions in Arizona have been increasing. Since the 1990s, 4 illegal introductions of northern pike in Arizona reservoirs were reported where they survived and reproduced (Arizona Game and Fish Department, unpublished data). One of these introductions occurred 10 km north of the U.S.-Mexico border, which probably represents the current southern limit of this species range (Crossman 1978). The effects of northern pike predation on other fish in Arizona could be substantial because they are highly piscivorous and can significantly reduce prey density and change fish communities (He and Kitchell 1990). The small number of sport fishing lakes in Arizona, coupled with the threat of more illegal introductions of northern pike, makes it necessary to evaluate their biology and potential impacts on prey fishes, particularly rainbow trout (*Oncorhynchus mykiss*). Rainbow trout are much more popular with Arizona anglers than northern pike and are stocked in many of the same lakes. High consumption of rainbow trout by northern pike may lower return of rainbow trout to the creel and increase the cost of these fisheries considerably.

Lakes and reservoirs in Arizona are under different temperature regimes than lakes in the native range of northern pike,

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and summer water temperatures often exceed optimal temperature (19 °C) for growth (Casselman 1978). Warmer water temperatures result in increased northern pike consumption and could raise predation pressure on existing prey (Headrick and Carline 1993) as well as allow for longer growing seasons than are typical for this species. Arizona also has different prey types and water chemistry than many of the northern regions. These factors could contribute to differences in growth, body condition, and diet.

Studying northern pike in Arizona provides an opportunity to understand the biology of a cool-water species stocked in waters at the southern geographic limit of its range. The goals of this study were to: (1) estimate growth and condition of northern pike in Arizona reservoirs and compare these values to those within their native range; and (2) describe the diet and consumption rates of northern pike in Arizona lakes, particularly the role of rainbow trout.

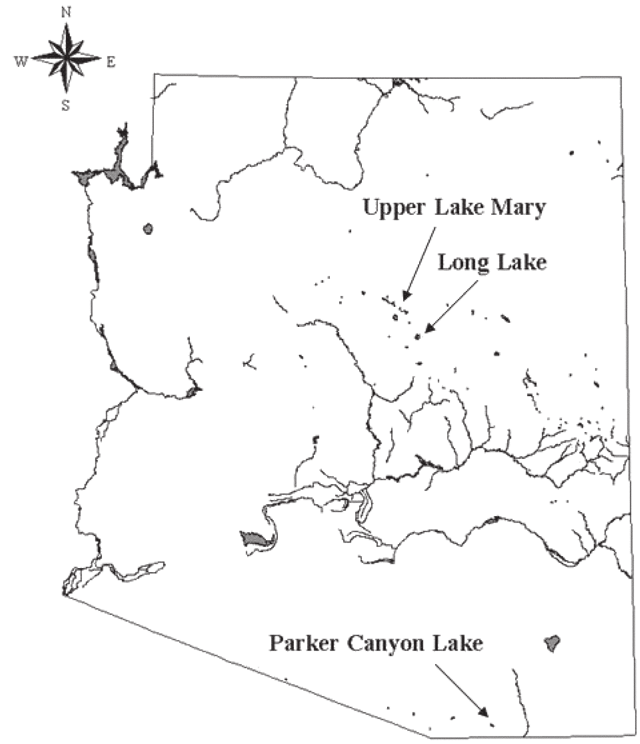

Figure 1.-Lakes sampled for northern pike from August 2001 through December 2002, in Arizona.

Methods

Study sites

This study was conducted in 3 Arizona reservoirs containing northern pike: Long Lake, Parker Canyon Lake, and Upper Lake Mary (Fig. 1). Long Lake is located in north-central Arizona at an elevation of 2,053 m. At full capacity the reservoir's surface area is 108 ha with a maximum depth of 7.6 m. However, in 2002 Long Lake had a surface area of 95 ha and a maximum depth of 1.6 m. The Arizona Game and Fish Department (AGFD) originally stocked Long Lake with northern pike in 1965. The fish community consisted of channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, green sunfish *Lepomis cyanellus*, northern pike, rainbow trout, and walleye *Stizostedion vitreum*. Rainbow trout (mean total length [TL] at stocking = 200 mm) were stocked in the spring strictly as a put-and-take fishery.

Parker Canyon Lake, elevation 1,636 m, is located in southeastern Arizona, about 10 km north of the U.S.-Mexico border. During this study, Parker Canyon Lake was at full capacity, about 50 ha, with a maximum depth of 25 m. Parker Canyon Lake was stocked illegally with northern pike sometime around 1996 (Mitchell and Young 1999). The fish community was composed of black bullhead *Ameiurus melas*, bluegill *Lepomis macrochirus*, channel catfish, green sunfish, largemouth bass *Micropterus salmoides*, northern pike, rainbow trout, and redear sunfish *Lepomis microlophus*. A seasonal rainbow trout fishery was maintained through stocking (mean TL at stocking = 249 mm) from fall into spring.

Upper Lake Mary, elevation 2,081 m, is a long, narrow reservoir above the Mogollon Rim in north-central Arizona. At full capacity the reservoir surface area is 355 ha, with a maximum depth of 12 m. During 2002 the maximum depth was 5.5 m, with 81 ha of surface area. Upper Lake Mary was originally stocked with northern pike in 1969 by the AGFD. The fish community consisted of black crappie *Pomoxis nigromaculatus*, channel catfish, golden shiner *Notemigonus crysoleucas*, northern pike, yellow bass *Morone mississippiensis*, yellow perch *Perca flavescens*, and walleye. Occasionally, AGFD stocked subadult rainbow trout, but did not do so annually. Rainbow trout (mean TL at stocking = 120 mm) were stocked in fall 2002.

Sampling

Sampling was conducted for approximately one year (late September–November 2001 to late November–early January 2002–2003) in all lakes. Sampling was conducted seasonally at each of the lakes. Seasons were defined as: spring (March–May), summer (June–August), fall (September–November), and winter (December–February).

Fish were captured using angling, electrofishing, fyke netting, and gill netting (Ricker 1975). Angling was conducted during all hours with any effective method (*e.g.*, spinners, bait). We used a 5-m Coffelt electrofishing boat containing a Coffelt VVP-15 electrofishing unit set at 8–10 amps pulsed DC current between 100 and 200 volts for electrofishing surveys. Frequency was set at 60 pulses per second and a pulse width

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of 60 percent. Electrofishing began at dusk and ended after one trip around the entire shoreline. The electrofishing boat was slowly driven parallel to the shoreline and current was applied periodically. Fyke nets (13–38 mm bar mesh) were fished in water <2 m deep with leads set perpendicular to shore. All fish were removed daily to minimize post capture digestion and feeding on other fishes in the net. Experimental gillnets were 45.7 m long and consisted of six 7.6-m panels containing bar meshes of 13, 19, 25, 32, 38, and 51 mm. Gillnets were set on the bottom, perpendicular to the shoreline in predetermined random locations for 1 to 2 h. Fish were identified to species, measured to the nearest millimeter (mm) TL, and weighed to the nearest gram (g).

Water quality and thermal experience

Dissolved oxygen (mg/L), temperature (°C), and secchi depths (nearest 0.1 m) were collected monthly in the deepest portion of each lake, with the exception of July in Long Lake and June and July in Upper Lake Mary due to forest closures. Also, no sampling was conducted in the winter when ice was present at Long Lake and Upper Lake Mary. Temperature and dissolved oxygen were collected using a Hydrolab Quanta at 0.5-m increments.

Growth, age, and condition

Growth and age of northern pike were estimated through analysis of cleithra, scales, length-frequency data, and recapture of tagged fish (Ambrose 1983). Cleithra were collected from netting mortalities and from all fish caught during the last sampling event at each lake. Annuli were examined from dried, unmagnified cleithral bones under reflected light (Casselman 1978). Scales were obtained from above the lateral line, just anterior to the dorsal fin (Toner and Lawler 1969). Acetate impressions of scales were read under a microfiche reader and verified by two independent readers. Northern pike were marked by inserting an individually numbered t-bar Floy tag just posterior and ventral to the dorsal fin (Pierce and Tomcko 1993). No anesthetic was used, and only fish able to maintain an upright position in the live well were tagged.

Age-frequency distributions by cohort were developed after aging. From age-frequency distributions, a mean length was calculated for each cohort. Relative weights (W_r = 100 × individual fish weight/standard weight) were calculated seasonally for each northern pike population to assess condition (Anderson and Neuman 1996). Relative weights were calculated with the standard weight (W_s) equation: $\log_{10}(W_s) = -5.437 + 3.096 \log_{10}\mathrm{TL(mm)}$. Relative weights were compared among lake and season using a 2-factor univariate Model I Analysis of Covariance with unequal replication, where lake and season were factors and fish total length was the covariate. Growth was compared among lakes using a one-factor univariate Model I analysis of covariance with unequal replication, where lake was a factor and total fish length was a covariate. Plots of studentized residuals versus predicted values were examined to estimate the appropriateness of each model. Simple main effects for each model were further analyzed by pairwise comparisons.

Diet analysis

Stomach contents of northern pike were collected in the spring, fall, and winter in Parker Canyon Lake and Upper Lake Mary. At Long Lake, stomach contents were collected in the spring, summer, and fall. Stomach contents of live northern pike captured through electroshocking, gillnetting, fyke nets, and angling were removed by gastric lavage and preserved in 95% ethanol (Seaburg 1957, Finnell 1988). Prey items lodged in the mouth or esophagus were removed manually (Finnell 1988). Twenty northern pike collected in Long Lake were dissected to determine the effectiveness of the gastric lavage. Prey items were identified in the laboratory and separated by taxon, blotted, and examined under a dissecting scope. Aggregated proportions were weighed to the nearest 0.01 g, and intact prey were measured (mm TL). Fish prey in advanced stages of digestion were identified by diagnostic bones such as the cleithra, opercles, dentary, and pharyngeal arch (Hansel *et al.* 1988).

Bioenergetics model

Bioenergetics modeling is useful for investigating consumption rates of predators and evaluating impacts to prey populations and estimating forage requirements (Stewart *et al.* 1981, Hartman and Brandt 1995). We used a bioenergetics model to examine the consumption dynamics of northern pike populations in the 3 Arizona reservoirs. The fish bioenergetics-modeling program of Hanson *et al.* (1997) was used for northern pike populations. The model requires specific inputs for the temperature occupied by the predator, caloric content of predator and prey, abundance, growth rates, and diet composition of predators throughout the modeling period. The physiological variables used to model northern pike consumption were those used by Hanson *et al.* (1997). Energy densities of ingested prey items were obtained from the literature and assumed to be constant across seasons for prey and predator (Table 1). Because Upper Lake Mary and Long Lake were shallow, windswept, and only weakly stratified during the study, we averaged temperatures over the entire water column. Water temperature had to be interpolated during months of forest closure in Long Lake and Upper Lake Mary to estimate thermal experience for the missing months. Parker Canyon Lake was stratified from May to November with anoxic conditions in the hypoliminion of the lake. Average temperatures above the hypoliminion were used for the simulations, where suitable dissolved oxygen levels (≥3 mg/L) existed (Headrick and Carline 1993). When

Table 1.-Prey energy densities (J/g wet weight) used in the bioenergetics models.

Prey taxon	Closest Surrogate	Energy density (J/g wet weight)	Source
Black crappie *Pomoxis nigromaculatus*	Bluegill	4186	Kitchell *et al.* 1974
Bluegill *Lepomis macrochirus*		4,186	Kitchell *et al.* 1974
Common carp *Cyprinus carpio*	Cyprinidae	7,524	Cummins and Wuycheck 1971
Golden shiner *Notemigonus crysoleucas*	Emerald shiner	4,983	Kelso 1972
Green sunfish *Lepomis cyanellus*	Bluegill	4,186	Kitchell *et al.* 1974
Largemouth Bass *Micropterus salmoides*		4,186	Rice *et al.* 1983
Northern crayfish *Orconectes virilis*	*Orconectes propinquus*	6,153	Stein and Murphy 1976
Northern pike *Esox lucius*		3,600	Bevelheimer *et al.* 1985
Rainbow trout *Oncorhynchus mykiss*	Steelhead	6,069	Rand *et al.* 1993

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Parker Canyon Lake was not stratified, we used an average temperature of the entire water column for simulations.

Diet compositions were calculated as seasonally aggregated percentages by wet weight of the total diet. When only a few samples (<3) of stomach contents were obtained for an age class during a season, diets were borrowed from available age classes. As a result of forest closures and ice, we were unable to obtain diets for some seasons, and diets were estimated during these seasons by averaging the diets of previous and subsequent seasons. At Parker Canyon Lake, stomach contents collected by AGFD through the winter 1999, 2000, and 2001 (n = 20) were averaged with diet data from this research project to increase sample sizes. Diet items from AGFD were measured using total length (mm) and counted, but not weighed. To compare stomach contents collected by AGFD and the data from this research project, we used the total length of ingested prey items to estimate weight through back calculation of plotted total lengths and weights. In Parker Canyon Lake, rainbow trout were assumed to be in the diets on the first day of stocking, 23 October 2001, until a month after the last rainbow trout stocking, 8 April 2002. Rainbow trout were still being collected frequently in gillnets on 18 April 2002 in Parker Canyon Lake. We averaged spring and fall to estimate summer diets in Upper Lake Mary because we could not access the lake in the summer due to forest fire closures.

The consumption of individual northern pike cohorts was fit to match their growth in each lake. Values of P represent the proportion of maximum consumption achieved by an individual or cohort given the constraints of temperature, predator size, and energy content of predator and prey ingested. Average P values for all size classes combined ranged from 0.22–0.60 in Long Lake, 0.30–0.51 in Parker Canyon Lake, and 0.26–1.00 depending on the season. Consumption of prey items in each lake during each season was compared using a univariate model 1 analysis of variance, where specific consumption (g/g/day) was the dependent variable, and prey was the factor. To stabilize the variance and correct for skewness, data was $\log_{10}(x + 1)$ transformed for specific consumption rates before analysis. For multiple comparisons of specific consumption among lakes, Tamhane's T2 test was used.

Consumption of rainbow trout was of special interest because they were stocked into the lakes to provide an additional sport fishery. Specific consumption of rainbow trout by northern pike was compared among lakes using a univariate model 1 analysis of variance, where specific consumption of rainbow trout by northern pike (g/g/day) was the dependent variable, and lakes was the fixed factor. To stabilize the variance and correct for skewness, specific consumption data was $\log_{10}(x+1)$ transformed before analysis. For multiple comparisons of specific consumption among lakes, a Tamhane's T2 test was used. Consumption of rainbow trout by different age groups of northern pike and in different seasons was compared using a univariate model 1 analysis of variance for

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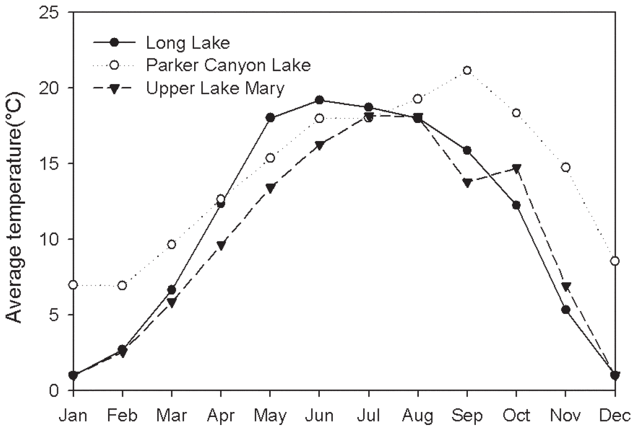

Figure 2.-Thermal experience of northern pike (°C) used in bioenergetics model.

each lake, with log-transformed specific consumption as the dependent variable, and age and season as the fixed-effect factors, respectively. Tamhane's T2 test was used again for examining differences among factors. Data for all tables and figures is presented in its original untransformed state.

Estimated rainbow trout losses

Bioenergetics simulations were used to estimate annual consumption of rainbow trout (g·year^{-1}) by individual northern pike of each age class. To calculate the total number of rainbow trout consumed per year by an individual northern pike, annual consumption of rainbow trout (g·year^{-1}) was divided by the average weight of rainbow trout stocked in each lake.

We also evaluated the effects of northern pike predation on various sizes of stocked rainbow trout by estimating the number of rainbow trout from each size group that could be consumed by a range of different-sized northern pike populations. Currently, little information on northern pike densities in the southwestern United States is available; however, these data are common in other areas. Population density in the upper Midwest ranged from 2.8–7.1 fish/ha (Priegel and Krohn 1975, Mosindy *et al.* 1987, Margenau *et al.* 1998) to 38.0–59.0 fish/ha (Snow and Beard 1972, Pierce *et al.* 1995, Margenau *et al.* 1998, Pierce *et al.* 2003). Therefore, we examined the effect of a typical low density (3.0 fish/ha) and high-density (60.0 fish/ha) population of northern pike on rainbow trout in each lake. Population age structure data collected during our study was used to calculate age-specific consumption rates of northern pike on rainbow trout. These projections provide a range of possible predation losses of different-sized rainbow trout to northern pike predation in the three Arizona reservoirs.

Results

Sampling

We attempted to sample each of the lakes seasonally; however, due to drought and forest fires, each lake was closed for part or all of summer 2002. As a result, sampling was restricted, and Long Lake was the only lake where northern pike were collected for a portion of the summer. Ice covered Long Lake and Upper Lake Mary from December to February 2001–2002, and no sampling was conducted during this period.

Water quality

Parker Canyon Lake was the warmest of all study lakes, with an average high temperature of 21.1 °C in September (Fig. 2). Average temperature profiles were similar at Long Lake and Upper Lake Mary from July to February in 2002. The highest temperatures recorded in Long Lake and Upper Lake Mary were 19.2 °C in June and 18.1 °C in August, respectively. Average temperatures ranged from 1.0 to 19.2 °C in Long Lake, 7.0 to 21.1 °C in Parker Canyon Lake, and 1.0 to 18.2 °C in Upper Lake Mary

Parker Canyon Lake was anoxic from May to November below 8–12 m, with the peak occurring in August when it was anoxic below 6 m. Dissolved oxygen in the epilimnion ranged from 5.2 to 8.6 mg/L during this period. When the lake was not stratified (December–April) dissolved oxygen ranged from 4.5 to 11.6 mg/L. Both Long Lake and Upper Lake Mary were shallow and weakly stratified and never fell below 5.0 mg/L of dissolved oxygen. Dissolved oxygen throughout the year in Long Lake and Upper Lake Mary ranged from 5.1 to 12.0 mg/L and 5.7 to 16.9 mg/L, respectively.

Upper Lake Mary was most turbid, with secchi depth averaging 0.3 m (SE ± 0.03 m), while Parker Canyon Lake was clearest with secchi depth averaging 3.5 m (SE ± 0.26 m). The average secchi depth for Long Lake was intermediate at 2.0 m (SE ± 0.20 m).

Age and weight

Northern pike growth slowed with age and varied among lakes. Northern pike in Long Lake grew fastest, while those in Upper Lake Mary grew slowest (Fig. 3). Mean lengths at age for 1-, 2-, 3-year-old fish in Long Lake were 473 mm, 702 mm, and 771 mm, respectively. In Parker Canyon Lake mean lengths at age for 1-, 2-, 3-, 4-, 5-, and 6-year-old fish were 449 mm, 593 mm, 698 mm, 784 mm, 857 mm, and 922 mm, respectively. Mean lengths at age for 1-, 2-, 3-, 4-year-old fish in Upper Lake Mary were 475 mm, 594 mm, 693 mm, and 763 mm, respectively. Age and corresponding length of northern pike was most similar to maximum values reported from North America and Europe (Carlander 1969, $P > 0.35$). Maximum age of northern pike in Long Lake was 3 years, 6 years in Parker Canyon Lake, and 4 years in Upper Lake Mary.

Relative weights, adjusted for total length, were higher for northern pike in Long Lake ($P < 0.001$; Fig. 4) than Parker Canyon Lake and Upper Lake Mary, which were not different ($P = 0.274$). Long Lake northern pike were generally above the rangewide 75 percentile weight, and Parker Canyon Lake and Upper Lake Mary fish were just below this standard. Relative weight of northern pike was highest in summer and spring and lowest in winter and fall ($P < 0.06$). Relationships between relative weight and total length by season were generally positive in Parker Canyon Lake and Long Lake, and negative in Lake Mary (Fig. 4).

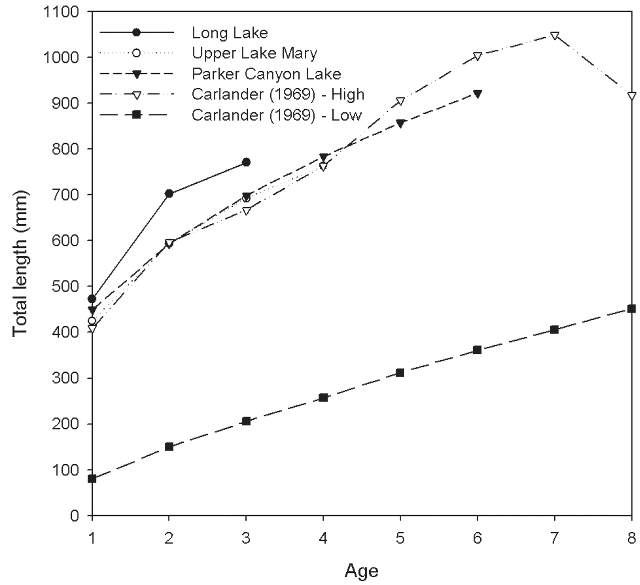

Figure 3.-Average total-lengths-at-age of northern pike from Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, from August 2001 through December 2002 and the reported high and low in North America and Europe by Carlander (1969). Total lengths at age of northern pike from the three Arizona reservoirs were not different ($P < 0.001$) than the highest reported by Carlander. Growth of northern pike in Arizona is among the fastest in the species' range.

Diet analysis

Stomach contents were obtained from northern pike in Long Lake ($n = 69$), Parker Canyon Lake ($n = 22$), and Upper Lake Mary ($n = 34$). Stomach contents with prey that could not be identified because of advanced digestion were eliminated from analysis. However, the number of stomachs containing contents that could not be identified was low (*i.e.*, Long Lake, $n = 4$; Parker Canyon Lake, $n = 1$; Upper Lake Mary, $n = 1$). No stomachs samples were collected in the winter due to ice at Long Lake. Also, diets of age-2 northern pike in Long Lake were assumed to be the same as age-1 because no stomach samples were successfully collected from age-2 northern pike. Northern pike consumed crayfish, common carp, northern pike, and rainbow trout in Long Lake (Fig. 5). Crayfish were the dominant prey in spring (100%) and early summer (60%) and were replaced by common carp fry through summer (37%) and fall (82%). Some cannibalism occurred in summer (3%) and fall (17%). Rainbow trout were found in stomachs only in fall (1%).

Northern pike prey in Parker Canyon Lake consisted of bluegill and green sunfish, largemouth bass, northern pike, and rainbow trout. Small sunfish were difficult to identify to species and as a result were grouped. Rainbow trout were the dominant prey in the winter (87%) and spring (80%) with smaller numbers of northern pike (3%) and largemouth bass (9%) comprising their diet. Bluegill and green sunfish were the only prey found during the fall.

Upper Lake Mary's northern pike ate black crappie, crayfish, golden shiners, and rainbow trout. In spring, black crappie (29%), golden shiners (57%), and crayfish (14%) were the major prey and in the fall and winter stomachs contained rainbow trout (99 and 70%, respectively), black crappie (0 and 28%, respectively) and golden shiners (1%).

Bioenergetics model

Model simulations indicated that consumption of prey by northern pike varied seasonally by age class, lake, and available prey (Fig. 6). Northern pike in Long Lake had the highest specific consumption rates [$\log_{10}$(g prey/g predator/day + 1)] on crayfish in the spring ($P < 0.001$). In the summer, northern pike consumed common carp at the highest rates followed by crayfish ($P < 0.001$). In fall, common carp continued to be consumed at higher rates than other prey items, followed by other northern pike ($P < 0.001$). In the winter, crayfish were the most highly consumed item, followed by common carp ($P < 0.001$).

Northern pike in Parker Canyon Lake had the largest specific consumption rates on rainbow trout in the spring followed by bluegill/green sunfish and largemouth bass. In the summer, northern pike consumed bluegill/green sunfish at the highest rates followed by largemouth bass. In fall, bluegill/green sunfish were consumed at higher rates than other prey items, followed by largemouth bass then rainbow trout. In winter, rainbow trout became the most highly consumed item once stockings were started, followed by bluegill/green sunfish ($P < 0.001$).

Northern pike in Upper Lake Mary had the highest specific consumption rates on golden shiner in both the spring and summer, followed by black crappie and crayfish ($P < 0.001$).

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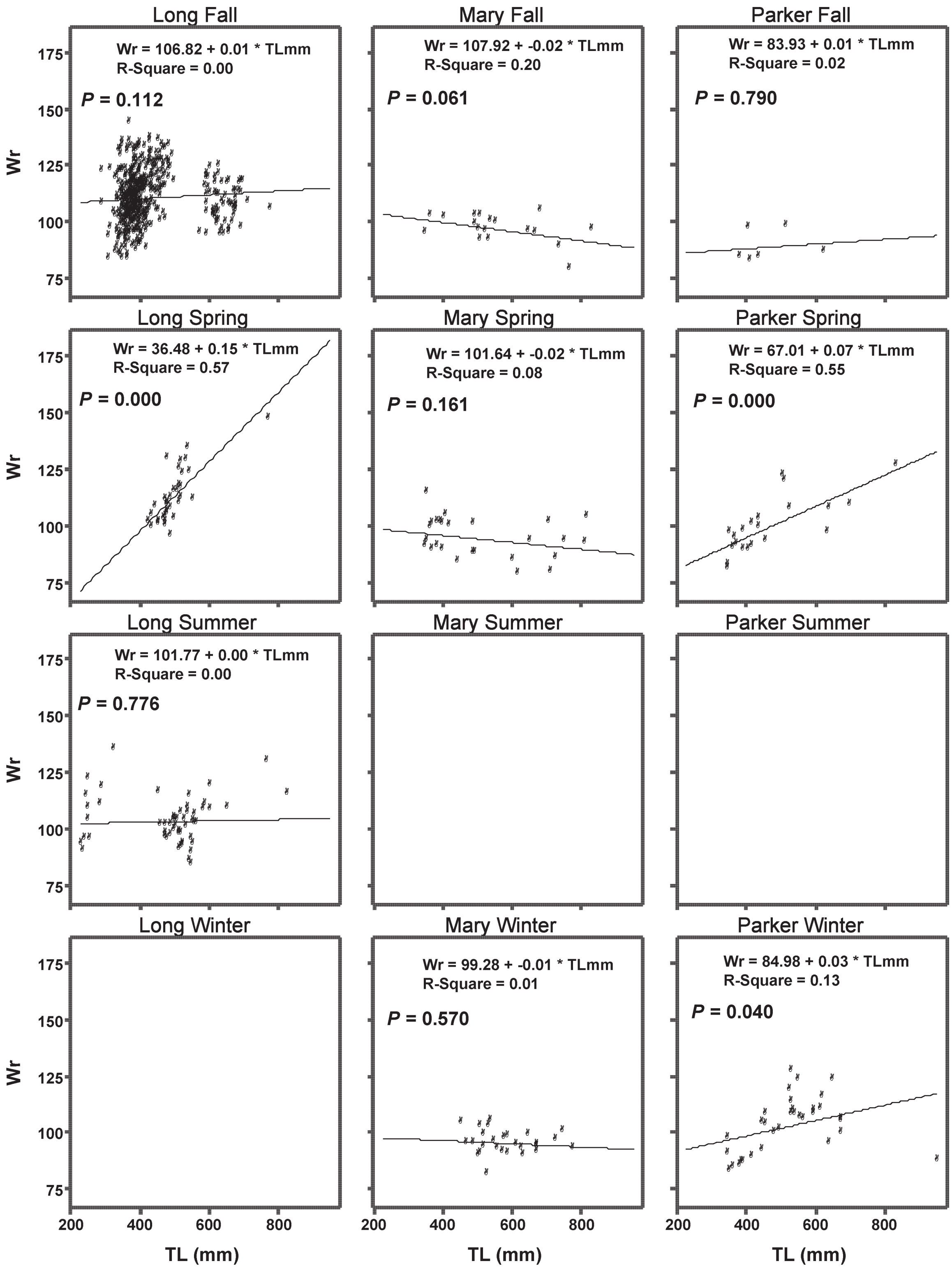

Figure 4.-Relative weights (W_r) by season of northern pike collected in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, August 2001 to December 2002.

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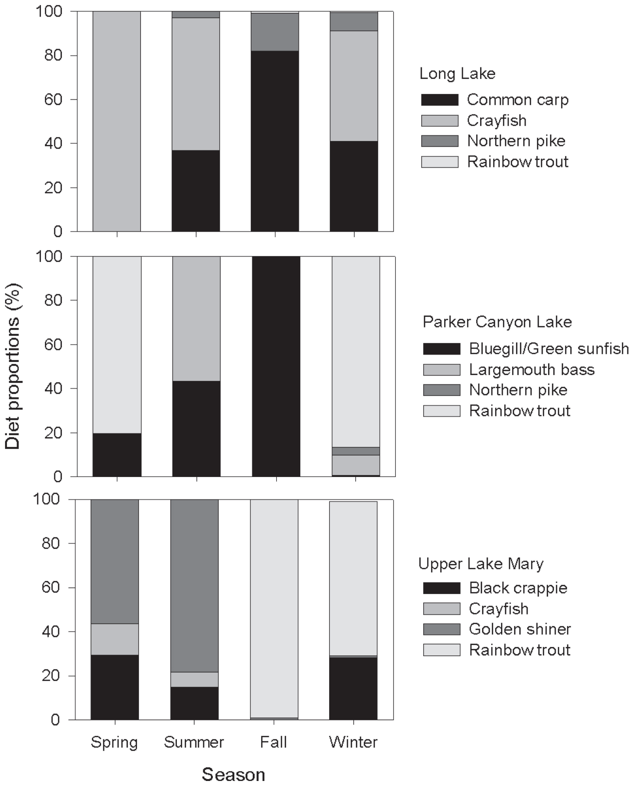

Figure 5.-Proportion by weight of prey items used in a bioenergetics model for pike in 2002 at Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona.

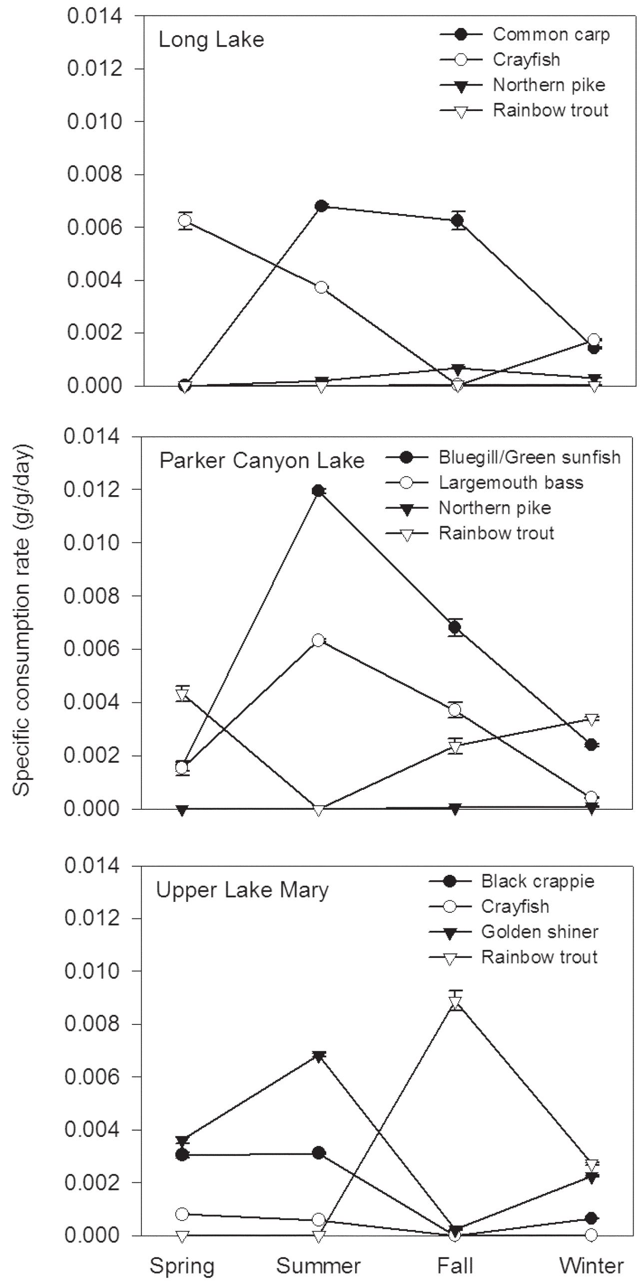

Figure 6.-Specific consumption rates (grams/gram/day) by prey type (± SE) for Long Lake, Parker Canyon Lake, and Upper Lake Mary.

In fall, rainbow trout were the most highly consumed item ($P < 0.001$). In the winter, rainbow trout continued to be the most highly consumed item, followed by golden shiner and black crappie ($P < 0.001$).

Specific consumption of rainbow trout by northern pike differed by lake ($P < 0.001$; Table 2). Specific consumption was highest in Upper Lake Mary followed by Parker Canyon Lake and finally Long Lake. In Long Lake, specific consumption of rainbow trout was highest in the fall, followed by the winter ($P < 0.001$). In Parker Canyon Lake specific consumption of rainbow trout was highest in the spring, then winter, and then fall ($P < 0.001$). In Upper Lake Mary, northern pike consumption of rainbow trout was highest in the fall, followed by the winter ($P < 0.001$). In both Long Lake and Upper Lake Mary, age-1 northern pike had the highest specific consumption rate of rainbow trout followed by age-2, then older (ages 3–6) fish ($P < 0.04$). Age-0 fish had the lowest consumption of rainbow trout. In Upper Lake Mary, age-0 northern pike had a much higher specific consumption rate of rainbow trout than older age groups ($P < 0.001$).

Estimated trout losses

Parker Canyon Lake received the most stocked rainbow trout, 96.4 kg·ha^{-1}·yr^{-1} (27,076 rainbow trout·yr^{-1}), during the study, while Long Lake received 8.8 kg·ha^{-1}·yr^{-1} (10,000 rainbow trout·yr^{-1}) and Upper Lake Mary received 2.5 kg·ha^{-1}·yr^{-1} (11,752 rainbow trout·yr^{-1}). Long Lake and Upper Lake Mary were stocked once per year with rainbow trout on 4 March 2002 and 24 September 2002, respectively. Parker Canyon

Table 2.-Hatchery reared rainbow trout stocking history, average total length (mm) and weight (g) at stocking, estimated pike specific consumption rate of rainbow trout (g/g/d × 10^{-6}) in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona from October 2001 to November 2002.

Body of water	Stocking dates	Number stocked	Average TL and Wt.	Average (± SE) specific consumption rate (g/g/d × 10^{-6}) Age 0	Age 1	Age 2	Age 3	Age 4	Age 6
Long Lake	Mar 3, 2002	10,000	200 mm 84 g	0.58 (± 0.05)	2.17 (± 0.17)	1.75 (± 0.12)	1.26 (± 0.10)	—	—
Parker Canyon Lake	Oct 23, 2001 to Apr 8, 2002	27,076	249 mm 178 g	—	381.80 (± 20.09)	306.76 (± 16.03)	—	244.64 (± 12.80)	215.41 (± 11.29)
Upper Lake Mary	Sep 24, 2002	11,752	120 mm 17 g	813.63 (± 61.07)	237.49 (± 18.16)	220.90 (± 14.46)	194.20 (± 12.77)	179.21 (± 11.82)	—

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was stocked with rainbow trout on several events beginning on 23 October 2001 and ending 8 April 2002.

Individual consumption of rainbow trout by northern pike increased as age class increased in all lakes. Annual consumption of rainbow trout by individual northern pike was lowest in Long Lake where age-0, -1, -2, and -4 pike consumed <1, 13, 20, and 20 g·year^{-1}, respectively. Northern pike in Parker Canyon Lake had the highest consumption of rainbow trout where age -1, -2, -4, and -6 individuals consumed 1,455; 2,334; 4,096; and 5,920 g·year^{-1}, respectively. Consumption of rainbow trout by northern pike in Upper Lake Mary was 378; 931; 1,595; 1,867; and 2,295 g·year^{-1} for individuals age-0, -1, -2, -3, and -4, respectively. The number of rainbow trout consumed per year in Long Lake by individual northern pike belonging to any age class was <1. In contrast, an individual 6-year-old northern pike in Upper Lake Mary, where the average weight and size of rainbow trout is lower compared to the other lakes, consumed 135 rainbow trout per year. The total number of rainbow trout consumed by an individual in the other age classes in Upper Lake Mary was estimated to be 22, 55, 94, and 110 by age-0, -1, -2, and -3, respectively. Consumption at Parker Canyon Lake was intermediate, with the annual number of rainbow trout consumed by age-1, -2, and -4 individuals equaling 8, 13, 23, and 33, respectively.

Assuming the northern pike densities in Arizona were in the range reported by Margenau *et al.* (1998) and Pierce *et al.* (2003), their predation would have consumed 0–2% (10 to 200 individuals) of the stocked rainbow trout in Long Lake and 3–63% (800–17,000 individuals) of the fish in Parker Canyon Lake. In Upper Lake Mary all the rainbow trout (>100%; 15,000 to >300,000 individuals) would have been consumed.

Discussion

Growth, age, and condition

Northern pike in Arizona grew quickly compared to most populations (Carlander 1969). The exceptionally high growth rates in the 3 Arizona lakes probably resulted from optimal water temperatures for northern pike feeding (19–21 °C) over much of the year (Casselman 1978), and availability of soft-rayed prey fishes at optimum densities (18.7–115.4 kg/ha) and sizes (Beyerle 1978).

Northern pike in Upper Lake Mary exhibited the lowest condition and growth of the 3 populations. Secchi depths of Upper Lake Mary during our study (0.3 m) were much lower than those in Parker Canyon Lake (3.5 m) or Long Lake (2.0 m). Northern pike are visual feeders, and predation is hampered by turbid water (Carlander 1969, Craig and Babaluk 1989). Thus, northern pike foraging in Upper Lake Mary may have been limited by the ability to locate prey, reducing growth and condition. The positive relationship between total length and northern pike condition (W_r) in Parker Canyon and Long Lakes may reflect the availability of catchable-sized rainbow trout (>200 mm TL) to the larger fish. For example, in Parker Canyon Lake, relative weights of northern pike <450 mm TL averaged 91, while northern pike ≥450 mm TL averaged 108.

Diet and specific consumption of northern pike

Age-0 common carp (mean TL = 47 mm; TL range 21−118 mm) comprised most of the northern pike forage in Long Lake. Mauck and Coble (1971) determined that common carp >110 mm TL were not vulnerable to northern pike ≤316 mm TL, and that common carp likely outgrow northern pike predation in 1 or 2 years. The rapid growth and high specific consumption rates of northern pike on common carp indicate that northern pike may be able to prey more effectively on common carp in Arizona than in other North American areas. Crayfish were second only to common carp

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in their importance to northern pike, especially in the spring and beginning of summer, which was similar to findings of Pierce *et al.* (2003) who also found them a valued prey item. Growth rates of tagged northern pike declined from May to June, when their primary diet was composed of crayfish. Thus, crayfish may not have contributed to the growth of northern pike in Long Lake, but may have sustained them until age-0 common carp were available later in the summer and positive growth rates of tagged northern pike occurred. Cannibalism occurred only in northern pike >587 mm TL, suggesting larger northern pike were limited by availability of suitably sized forage (Diana 1987). We were unable to obtain diet samples immediately after or during the rainbow trout stocking at Long Lake, so the peak of predation may have been missed, and subsequently our rainbow trout consumption estimates are underrepresented to some degree. Nevertheless, northern pike consumed rainbow trout at a low rate, probably resulting from several factors. Large, catchable-sized rainbow trout were stocked; the northern pike population in Long Lake was comprised of a high proportion (77.1%) of age-0 individuals that could not effectively consume catchable-sized (> 280 mm TL) rainbow trout; and there was adequate food for this most numerous size group (crayfish and age-0 common carp).

Bluegill, green sunfish, largemouth bass, and rainbow trout were dominant prey in Parker Canyon Lake. Northern pike typically act as a top-down predator that influences fish communities (Casselman and Lewis 1996). In sympatric populations of largemouth bass and northern pike in Nebraska's Sandhill lakes, the relative abundance of largemouth bass was reduced when compared to lakes where northern pike were absent (Paukert and Willis 2003). These reductions were either due to direct predation or competition with largemouth bass for similar food resources. In Parker Canyon Lake, northern pike consumed similar prey as largemouth bass, bluegill, and green sunfish; thus, competition between northern pike and largemouth bass may have occurred if the prey base was limited. We also found northern pike consume largemouth bass (Gurtin *et al.* 1996, Soupir *et al.* 2000, Paukert and Willis 2003). However, studies on the food habitats of northern pike in other areas have found that centrarchids are not a preferred prey (Beyerle 1971, Mauck and Coble 1971, Weithman and Anderson 1977), but are usually eaten when other more preferred prey are unavailable. Beyerle and Williams (1968) found that soft-rayed fishes were selected over centrarchids by northern pike, and northern pike of all sizes selected the smallest centrarchid possible.

Catchable rainbow trout stocked into Parker Canyon Lake were too large to be eaten by a majority of the northern pike population. Age-0 northern pike in Parker Canyon Lake averaged 408 mm TL and did not feed effectively on the stocked rainbow trout. Northern pike are able to consume soft-rayed fishes up to 45% of their own total length (Hart and Hamrin 1988). The average total length of rainbow trout stocked was 249 mm TL. Thus, only northern pike, >553 mm TL, could consume rainbow trout stocked into Parker Canyon Lake. The relative weight of large northern pike was much higher than that of smaller cohorts, indicating that sufficient forage was available to them, probably rainbow trout. Arizona Game and Fish Department personnel are currently using gill nets to cull large northern pike that would exert the highest consumptive demand on catchable-sized rainbow trout. If culling efforts of large northern pike do not continue, one would expect the consumption of rainbow trout by northern pike to increase.

Stocking of rainbow trout increased the prey base in the lake. Thus, reduction in the stocking of rainbow trout, particularly in Parker Canyon Lake where a high annual biomass of rainbow trout is stocked annually, may increase predation pressure on other prey, particularly bluegill and largemouth bass. Soft-rayed fishes such as golden shiner and rainbow trout were most highly consumed by northern pike in Upper Lake Mary, and rainbow trout stocked at a size (120 mm TL) that could be effectively consumed by age-0 northern pike were rapidly removed.

Management implications

Sport fishery potential for northern pike in Arizona seems limited by lack of angler interest. A statewide angler survey conducted in 1999 by AGFD revealed that only 0.3% of Arizona anglers listed northern pike as their favorite fish to catch. Trout and largemouth bass were the favored targets of 38% and 28% of the anglers, respectively (T. Pringle, Arizona Game and Fish Department, unpublished data). Although some lakes in Arizona might develop northern pike fisheries equivalent to those in their native range, past trends in Arizona statewide creel surveys suggest that angler preference is unlikely to significantly change (Pringle 1994). The high growth of northern pike in Arizona allows them to reach "stock size" (>35 cm) by age-1; however, the valuable trout and warmwater fisheries lost as a result of northern pike predation may outweigh any angling benefit.

Similar to the results of others, we found that small hatchery-reared rainbow trout ($\leq$120 mm TL), were particularly vulnerable to northern pike, while those >200 mm were less susceptible to predation. An evaluation of stocking rainbow trout at various sizes in Seminoe Reservoir, Wyoming, found an increase in creel return rates for larger fish ($\geq$210 mm TL) because smaller fish (<210 mm TL) were susceptible to predation by walleye (Wiley *et al.* 1993). Yule *et al.* (2000) suggested that in the presence of established walleye populations, rainbow trout needed to be stocked at sizes >208 mm TL to maintain viable rainbow trout fisheries. Our results show that even the lowest density of northern pike would have been able to remove all of the small rainbow trout

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from Upper Lake Mary. In Arizona, rainbow trout grown to 200 mm TL are 34 times more expensive than those grown only to 120 mm TL. Further studies need to be conducted to determine if "swamping" lakes with small fish would be as cost effective as stocking catchables.

Lakes containing northern pike provide a source population for future illegal introductions. In addition, large northern pike are able to feed effectively on large rainbow trout. Therefore, culling northern pike by mechanical means, as well as stocking catchables may provide a higher return to the creel. Culling efforts by mechanical means in Yellowstone Lake for introduced lake trout, *Salvelinus namaycush*, have been found to be effective (Ruzycki *et al.* 2003). In 1996, shortly after the discovery of lake trout in Yellowstone Lake, the Park Service initiated culling efforts for their removal, principally through intensive gill-netting throughout the lake and at known spawning locations. Three years after the mechanical removal began, consumption of indigenous cutthroat trout (*Oncorhynchus clarki bouvier*) by lake trout had been reduced by an estimated 43%. If no culling efforts had occurred, lake trout predation of cutthroat trout during 1999 would have increased an estimated 32% from the 1996 levels (Ruzycki *et al.* 2003). However, the disadvantage with culling efforts by mechanical means in such a large lake such as Yellowstone lake (34,100 ha), is that it can be labor intensive and incur a substantial cost (Stapp and Hayward 2002). In Arizona where reservoirs containing northern pike are smaller (<355 ha), effective culling efforts may be more feasible given the expected lower costs and labor intensity. However, total removal of northern pike by piscicide in areas where local opposition is low and costs are reasonable may eliminate a source population for future introductions and allow for future reintroductions of trout.

We have shown that northern pike at the southern extent of their distribution exhibited high growth rates when compared to northern latitudes. Also, we found that bioenergetics modeling could serve as a framework to assess the potential predation impacts of northern pike in Arizona reservoirs. Our findings indicate that rainbow trout losses to northern pike predation can be considerable, especially when stocked rainbow trout are small. Managers could potentially increase survival of rainbow trout by stocking larger rainbow trout that could escape predation by the smaller predators. However, the cost of implementing these strategies must be weighed in terms of their ability to decrease mortality. Bioenergetics simulations can be effective in evaluating the trade-offs of various management strategies and can provide a means of validating these actions to anglers.

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