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Biology and Foraging Demands of Northern Pike in Three Arizona Reservoirs and Their Distribution and Status in the Southwestern United States

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Fisheries Research Report 03-04

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Executive Summary

Northern pike are a highly piscivorous member of the Esocidae family, native to north temperate Canada and the United States. In the 1960's and 1970's Northern pike were brought into the Southwestern United States to diversify angler sportfishing opportunities. More recently, the range of northern pike has expanded into other lakes and ponds throughout the southwest due to illegal introductions. Top predators, such as northern pike, can be troublesome for managers given their ability to exert top-down effects and alter fish communities. Northern pike have the potential to affect existing warmwater and trout fisheries, threaten native fishes in adjacent areas, and be difficult to control for both political and logistical reasons. At the request of Arizona Game and Fish Department managers, we conducted this study to investigate the biology, foraging demand, current range of northern pike in the Southwest, and their benefits and drawbacks as a sportfish. Our major findings are as follows:

- As of 2003, northern pike occur in one lake in California, four lakes and in the Humboldt River in Nevada, the Green, and Colorado Rivers and two reservoirs in Utah, nine lakes in Arizona, eight lakes and the Rio Grande River in New Mexico.
- Illegally introduced northern pike in Lake Davis, California cost the State of California approximately $15 million in control efforts and compensation to adjacent communities.
- Northern pike in southwestern river systems can migrate long distances (e.g. 110 km in the Green River in one year).

- Colorado researchers found bite wounds from northern pike on 9% of native Colorado pikeminnows in the Yampa River, Colorado.
- Northern pike have an upper lethal incipient temperature of 29.4 C with optimal growth occurring at 19-21 C. Therefore water temperatures in lower elevation desert lakes, reservoirs, streams, and rivers in the Southwest are probably to high to allow northern pike to survive.
- Some rivers in Arizona contain water temperatures suitable for northern pike survival. These include the Colorado, upper Verde, and the Salt River. However, factors such as strong current and absence of spawning habitat often preclude northern pike from developing large populations in fast-moving rivers without adjacent backwaters and nursery areas. Between 1968 and 1970, 571 Northern pike were stocked into the Verde River, but populations did not develop. Temperatures in the lower Verde and Gila Rivers approach or exceed the upper lethal temperature of northern pike.
- Only 0.3% of Arizona anglers preferred to fish for northern pike compared to 37.8% for black bass, and 28.4% for trout respectively.
- The sportfish most likely to be impacted by northern pike predation in the Southwest are trout, given the overlap in water temperatures between the two species.
- In some lakes in Arizona and New Mexico, agencies no longer stock trout or reduce stockings because predation from northern pike results in a negligible return to the creel.

- We studied the biology and foraging demands of northern pike in Long Lake, Arizona; Upper Lake Mary Lake, Arizona; and Parker Canyon Lake, Arizona.
- In Parker Canyon Lake, Upper Lake Mary, and Long Lake, Arizona, northern pike standing crops were highly variable: 1.0 kg/ha, 1.8 kg/ha and 49.3 kg/ha respectively. In their native range northern pike standing crops range from 3.6 to 11.5 kg/ha.
- Growth of northern pike in all three Arizona lakes was high compared to other areas of the United States. Fish reached stock size (i.e. >35 cm) by age-1.
- Age 1 northern pike in all three Arizona lakes had the highest prey consumption.
- Northern pike consumed crayfish, common carp, northern pike, and rainbow trout in Long Lake. Crayfish were the dominant prey item in early spring and summer until carp fry hatched in July or August. Carp fry remained the dominant prey throughout the rest of the summer and fall. In Parker Canyon Lake, northern pike ate bluegill, green sunfish, largemouth bass, northern pike, and rainbow trout. During spring and winter, rainbow trout were the dominant food item. In summer, panfishes and largemouth bass dominated the diet. In Upper Lake Mary, northern pike ate black crappie, golden shiners, and crayfish in the summer. In the fall and winter, the vast majority of the diet was rainbow trout.
- Northern pike consumed 64.3 kg/ha common carp, 25.26 kg/ha crayfish, 4.98 kg/ha northern pike, and 0.25 kg/ha rainbow trout in Long Lake; 1.39 kg/ha bluegill/green sunfish, 1.23 kg/ha largemouth bass, 0.01 kg/ha northern pike, and 1.22 kg/ha rainbow trout in Parker Canyon Lake; 1.29 kg/ha black crappie, 0.27

kg/ha crayfish, 1.61 kg/ha northern pike and 1.60 kg/ha rainbow trout in Upper Lake Mary.

- Northern pike consumed 2.9%, 1.2%, and 63.2% of the total number of rainbow trout stocked in Long Lake, Parker Canyon Lake, and Upper Lake Mary, respectively. Average sizes of trout stocked into these lakes were 200 mm, 249 mm, and 120 mm respectively. Therefore stocking catchable trout (i.e. put and take), rather than fingerling or fry (i.e. put, grow, and take) may substantially increase their survival in Arizona lakes containing northern pike.
- Mechanical removal provides mixed results as a control option for nuisance populations of northern pike. In many sites mechanical removal only partially removes northern pike and provides only temporary improvement. Results from Lake Davis, California suggest angler harvest has done little to reduce the northern pike population. After 3.5 years of mechanical removal in this lake, the population of northern pike has increased. However, the standing crop of northern pike in Parker Canyon Lake was very low (1.0 kg/ha). It is unknown if this was the result of insufficient habitat, culling efforts by the Arizona Game and Fish Department, or a combination of the two.
- Chemical treatment or draining is often the most effective method for northern pike control.
- Northern pike sportfishing diversifies angling opportunities in Arizona. However given the very low standing crops northern pike developed in two of the three lakes we studied; and their predatory impact on largemouth bass, panfishes and

rainbow trout, which develop more popular, valuable fisheries; sportfishing potential of northern pike in Arizona appears limited.

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CHAPTER A

Biology and foraging demands of northern pike in three Arizona reservoirs

Biology and foraging demands of northern pike in three Arizona reservoirs

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Abstract

Northern pike were first introduced into Arizona in the 1960s to provide sport-fishing opportunities. Recently, the range of northern pike in Arizona has expanded due to illegal introductions. The small number of sport fishing lakes in Arizona coupled with illegal introductions of northern pike raised questions about their potential predation impacts to the prey base. We sampled three Arizona reservoirs containing northern pike to quantify their consumption dynamics using bioenergetics modeling and estimate potential predation impacts upon the prey base. Growth rates, diets, and abundance estimates of northern pike were also obtained along with temperature profiles from each of the reservoirs. Northern pike in Long Lake had the highest consumption rates of the three reservoirs (94.8 kg/ha) and common carp was the highest consumed prey item in Long Lake (64.3 kg/ha). In Parker Canyon Lake, bluegill and green sunfish were the prey most consumed by northern pike at 1.4 kg/ha. Rainbow trout and golden shiners were the prey most widely utilized by northern pike in Upper Lake Mary with both consumed at 1.6 kg/ha throughout the year. Growth of northern pike was high compared to northern pike throughout the U.S. Abundances of northern pike in Arizona reservoirs were highly variable with extremely low densities in Parker Canyon Lake and Upper Lake Mary (1.0 to 1.4 fish/ha) to extremely high density in Long Lake (76.3 fish/ha). Biological information (i.e., growth rates, abundance, diets) gathered in this study should be useful for managing northern pike fisheries in similar systems along southern distribution of the species range.

Introduction

Northern pike *Esox lucius* now occur throughout North America in shallow vegetated areas of lakes, marshes, backwater sloughs, and slow moving rivers (Crossman 1978). Northern pike is a common and abundant species, found in 45% of the total freshwater area of North America (Carlander et al. 1978). Historically, the range of northern pike in North America was in north temperate regions (Crossman 1978). However, the development of impoundments primarily in the West, has allowed northern pike to expand their range (McCarraher 1961; Carlander et al. 1978). The distribution of northern pike distribution has expanded from the Mississippi River basin and portions of the Great Lakes basins to virtually all of the United States, except southern regions too warm to support the species. This range expansion has resulted primarily through introductions to provide sportfishing opportunities (Carlander 1969; Anderson 1973; Webster et al. 1978). Introductions have been conducted legally by government agencies as well as illegally by anglers (Carlander 1969, McMahon and Bennett 1996).

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, three illegal introductions of northern pike were reported in Arizona reservoirs where the species survived and reproduced (Arizona Game and Fish Department, unpublished data). One of these introductions occurred 10 km north of the U.S.-Mexico border, likely representing the southern limit of the range of this species (Crossman 1978).

Northern pike is regarded as a top predator in most aquatic systems (Casselman 1978). Understanding the foraging demand of a top-level predator is essential to managing fish communities that include popular sport fishes. The effects of northern pike predation on other fish in Arizona lakes and reservoirs could be substantial (Mitchell and Young 1999). Northern pike is highly piscovrous and has been shown to significantly reduce prey density and, potentially, cause large-scale changes in 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 make it necessary to evaluate their biology and potential impacts on forage fishes. Lakes and reservoirs in Arizona also are under different temperature regimes than lakes in the native range of northern pike. Water temperatures often exceed optimal temperatures for growth of the species during summer. At higher temperatures, consumption rates must increase to compensate for increases in metabolic rate or growth will decrease. Higher consumption rates may place an increase of predation pressure on the existing fish populations than what is typical for this species in northern regions. Also, Arizona has different prey species and water quality than in northern states and provinces where northern pike are native. These factors may contribute to differences in growth, standing crops, body condition, and food habits of northern pike in Arizona. 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. In addition, an understanding of the potential effects of northern pike dispersal from reservoirs into desert river systems containing native and typically threatened and endangered Arizona fishes is needed to provide important information for conservation of native fish species.

The goals for this study were to: (1) estimate growth, condition, and abundance of northern pike in Arizona reservoirs and compare these values to those within their native range; (2) examine the foraging demand of northern pike in Arizona lakes and implications to existing fish communities; and (3) evaluate the potential threat of northern pike to native fish within Arizona.

Methods

Study sites. This study was conducted in three Arizona reservoirs containing northern pike: Long Lake, Parker Canyon Lake, and Upper Lake Mary (Figure 1). Long Lake and Upper Lake Mary were originally stocked with northern pike in 1965 and 1969, respectively. Parker Canyon Lake was recently stocked with northern pike illegally sometime around 1996 to 1997 (Mitchell and Young 1999). We selected sites that were accessible by boat and represented historical and illegally introduced northern pike populations.

Long Lake is located in north-central Arizona in Coconino County, at an elevation of 2,053 m and is 72 km southeast of the city of Flagstaff. In 1941, Long Lake was created when a canal was built connecting the natural basin of Long Lake from Solders Annex Lake. Long Lake receives water from the Solider Annex system only when it overflows, releasing water into the canal. At full capacity the surface area is 108 ha with a maximum depth of 7.6 m. However, during 2002 Long Lake had a surface area of 95 ha and a maximum depth of 1.6 m. The surrounding terrain is rolling and dominated by pinyon-juniper woodland intermixed with grasses. Northern pike were first stocked in Long Lake by the Arizona Game and Fish Department (AGFD) in 1965 and were last stocked in 1967. Fish species present in Long Lake were channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, green sunfish *Lepomis cyanellus*, northern pike, rainbow trout *Oncorhynchus mykiss*, and walleye *Stizostedion vitreum*. Rainbow trout are maintained entirely through stocking.

Parker Canyon Lake, elevation 1,636 m, is located in southeastern Arizona in Santa Cruz and Cochise counties, 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. Water levels were maintained by precipitation runoff from a 23-km^2 watershed above the lake. The dominant watershed vegetation near the lake vicinity was oak-juniper woodland; however, Mexican manzanita *Arctostaphylos pungens*, and pinyon pine *Pinus edulis*, were abundant in higher and exposed areas above the lake. Fish present were black bullhead *Ameiurus melas*, bluegill *Lepomis macrochirus*, channel catfish, green sunfish, largemouth bass *Micropterus salmoides*, northern pike, rainbow trout, and redear sunfish *Lepomis microlophus*. Northern pike were illegally introduced into Parker Canyon Lake sometime during 1996-1997 (Mitchell and Young 1999). A put-and-take rainbow trout fishery was maintained through stocking efforts beginning in the fall and continuing into the spring with only a few rainbow trout surviving through the summer.

Upper Lake Mary, elevation 2,081 m, is a long, narrow reservoir above the Mogollon Rim in north-central Arizona, approximately 16 km southeast of the city of Flagstaff. The surrounding vegetation consisted mainly of ponderosa pine *Pinus ponderosa*, scrub oak *Quercus spp*., and short grasses. An earthen dam constructed in 1941 formed Upper Lake Mary. Tributaries to the lake generally flowed only during spring snowmelt. 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. Fish present were black crappie *Pomoxis nigromaculatus*, channel catfish, golden shiner *Notemigonus crysoleucas*, northern pike, yellow bass *Morone mississippiensis*, yellow perch *Perca flavescens*, and walleye. From 1969 until 1980 northern pike were stocked into Upper Lake Mary by AGFD. Occasionally, AGFD stocks sub-adult rainbow trout, but does not do so on an annual basis.

Sampling. Sampling was conducted on a seasonal basis at each of the lakes. Seasons were defined as: spring (March-May), summer (June-August), fall (September-November), and winter (December-February). However, during the summer of 2002 each lake was closed for part of the summer due to forest fires. As a result sampling was restricted in the summer and Long Lake was the only lake where northern pike were collected during the summer. Ice existed on Long Lake and Upper Lake Mary from December to February 2001-2002, and no sampling was conducted.

We used several techniques to capture fish to minimize size biases from sampling gear including angling, electrofishing, fyke netting, and gill netting. Angling was conducted during all hours with any effective method (e.g., spinners, bait). We used a 5-m Coffelt electrofishing boat connected to a Coffelt VVP-15 electrofishing unit set at 8 to 10 amps pulsed DC current between 100 to 200 volts for electrofishing surveys. Frequency was set at 60 pulses per second and a pulse width of 60 percent. Electrofishing usually began at dusk and ended after one trip around the entire shoreline. The electrofishing boat was slowly driven parallel to the shoreline. Current was applied periodically. All fish were netted and placed in a live well. Total lengths (mm) and weights (g) were taken on all fish. Fyke nets (13-38 mm stretched mesh) were fished in water less than 2 m deep with leads perpendicular to shore. All fish were removed daily to minimize post capture digestion and feeding. Experimental gillnets were 45.7-m in length and consisted of six 7.6-m panels containing bar measure meshes of 13, 19, 25, 32, 38, and 51 mm. Gillnets were set during daylight hours for about 2 h. Sets were along the bottom, perpendicular to the shoreline in predetermined random locations. All fish were identified to species and measured to the nearest millimeter total length and weighed to the nearest gram.

Water quality and thermal experience. Dissolved oxygen, pH, temperature (°C), and specific conductance (µS) were collected monthly throughout the year at Parker Canyon Lake. At Long Lake, water quality information was collected monthly, except in July due to forest closures and when ice was present from December to February. Water quality information was collected monthly at Upper Lake Mary except during June and July because of forest closures and when ice was present from December to February.

Data were obtained in the deepest portion of each lake at 0.5-m increments using a Hydrolab Quanta.

Abundance. Abundance of northern pike in Long Lake and Parker Canyon Lake was estimated using the Schumacher and Eschmeyer multiple mark-recapture procedure. The Peterson single mark-recapture procedure was used to estimate northern pike abundance in Upper Lake Mary (Ricker 1975). Population estimates were conducted during October and November of 2002 in Long Lake. Parker Canyon Lake population estimates were conducted from November to February 2001-2002. Upper Lake Mary population estimates were conducted in November and December of 2002. Northern pike biomass (kg) was calculated as the product of the estimated number of fish and their average weight. Biomass was then divided by surface area to obtain a standing crop estimate (kg/ha). Mark and recapture efforts were conducted in the fall and winter when water temperatures were low to reduce mortality (Finnell 1988). Northern pike were marked by inserting a numbered 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. A sub-sample of ten tagged northern pike were placed in a net pen for 14 h to estimate short-term mortality due to tagging.

Growth, age, and condition. Growth and age of northern pike were estimated through analysis of cliethra, length-frequency, recapture of tagged fish, and scales (Ambrose 1983). Cleithra were collected from northern pike that appeared injured as a result of gillnetting and from the last sampling event at each lake. Annuli were examined from dried, unmagnified cleithral bones under reflected light (Casselman 1978). Scales were collected 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 by two independent readers. Aging northern pike using scales and cliethra at Parker Canyon Lake was difficult because annular pattern were indistinct. Therefore, northern pike growth was calculated from the change in weight of tagged individuals between mark and recapture dates. Length-frequency distributions by cohort were formulated after aging. From length-frequency distributions, a mean length was calculated for each cohort. Relative weights (W_r) were calculated seasonally for each northern pike population to assess condition (Anderson and Neuman 1996).

Sport fishing potential of the lakes was determined by comparing the standing crop (kg/ha) and fish densities (fish/ha) of northern pike in Arizona to lakes common in their native range (Scott and Crossman 1973; Margenau et al. 1998). Growth rates were also compared among Arizona lakes and to lakes in other regions to determine age when stock size (>35 cm) northern pike would be available to anglers.

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, trapnetting, and angling were removed by gastric lavage (Seaburg 1957, Finnell 1988). Prey items lodged in the mouth of northern pike were pulled manually from the esophagus (Finnell 1988). Stomach contents were preserved in 100 % ethanol. A sub sample of 20 northern pike was dissected to ensure all contents had been removed by 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 when possible, prey lengths were measured to the nearest total length (mm). Fish prey in advanced stages of digestion were identified by diagnostic bones such as cliethra, opercal, dentary, and phyranageal arch (Hansel et al. 1988). Some contents had only sections of vertebrae and were grouped as unknown fish prey. Those fish that could not be identified because of advanced digestion were eliminated from analysis because they comprised only a miniscule amount of all stomach contents (Long Lake, $n = 4$; Parker Canyon Lake, $n = 1$; Upper Lake Mary, $n = 1$). Crayfish were not identified to species.

Bioenergetics model. Bioenergetics modeling is useful for investigating the relationship between predator demand and prey supply (Stewart et al. 1981; Labar 1993; Hartman and Brandt 1995), and allows fisheries managers the ability to estimate forage requirements needed to support an introduced fish population. We used a bioenergetics model to examine the consumption dynamics of northern pike populations in three Arizona reservoirs. The fish bioenergetics-modeling program of Hanson et al. (1997) was used to estimate the number of prey consumed by the three northern pike populations. Hanson et al. (1997) is based upon the balanced energy equation (Winberg 1956):

$$G = C - R - (F + U) - SDA;$$

where G = growth, C = consumption, R = respiration, F = egestion, U = excretion, and SDA = specific dynamic action. 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 (Table 1). The thermal experience for northern pike was determined through personal observation of the depth at which fish were collected. We assumed that northern pike to be in water containing 3 mg/L of oxygen or greater (Headrick and Carline 1993) and below 29.4 °C in water temperature, their upper incipient lethal temperature (Casselman 1978). Energy densities were assumed to be constant across seasons. Mortality was assumed to be negligible for all populations simulated. Diet composition was calculated as seasonally aggregated percentages by wet weight of the total diet. When there were only a few samples of stomach contents for a period, diets were assumed to be the same as the previous season. Diets of northern pike in winter, when sampling did not occur, were assumed to be the same as in the fall in Long Lake (Figure 2). Diets of age-2 northern pike were assumed to be the same as age-1 because no stomach samples were successfully collected from age-2 northern pike. At Parker Canyon Lake, stomach contents collected by AGFD through the winter of 1999, 2000, and 2001 (n = 20) were combined with diet data from this research project. 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. Diets from age-0 fish from the fall and winter samples were combined at Parker Canyon Lake. Due to the low number of stomach samples for age-2, age-4, and age-6 fish, diet information was combined across all seasons. Trout were assumed to be in the diets on the first day of stocking, on October 23, 2001 until a month after the last trout stocking on April 8, 2002. Rainbow trout were still being collected frequently in gillnets on April 18, 2002. We assumed summer and spring diets of northern pike in Upper Lake Mary were the same because we could not access the lake in summer due to forest closures. Diets were also combined in the simulations for northern pike age-0 and age-1.

Determining predation of northern pike on rainbow trout was possible because stocking records supplied dates and total number of fish stocked and the cost of transporting and raising the fish. Rainbow trout loss was estimated by comparing the number stocked (g/ha) with bioenergetics model estimates (g/ha) for the various lakes. However, estimating predation on other prey species in the reservoirs was difficult because we did not have accurate estimates of abundance for other prey. Thus, prey biomass was evaluated by examining the mean and range of standing crop estimates from Carlander (1955) for lakes and reservoirs in the United States. However, the confidence inters on estimates of standing crops were wide. *P*-values derived from bioenergetics model simulations can be an indicator of prey fish abundance and were determined by age of northern and delineated season in each lake. These *P*-values represent the proportion of maximum consumption achieved by a cohort given the constraints of temperature, predator size, and energy content of predator and prey ingested. *P*-values generated by the bioenergetics model may provide a more detailed measure of prey availability than standing crops presented by Carlander (1955).

Threat to native fish. To assess the threat of illegally introduced northern pike to waters containing native fish and determine their potential to survive we compared the maximum water temperature of rivers containing native fish in Arizona against the upper lethal incipient temperature of northern pike 29.4 °C (Casselman 1978). Temperature data was obtained from USGS real-time data and represented the daily maximum temperatures for 2002 for the Colorado River at Lees Ferry and Bright Angles Landing. Temperature profiles for the Salt and Gila rivers were obtained from the Research Branch of AGFD. Data loggers were placed in various sites on both rivers. The site for the Salt River was the Water Users Boat Ramp located below Saguaro Lake and was recorded in 1999. Temperature data were recorded daily from February 27, 1997 to August 14, 1997 from three sites along the Gila River, Dripping Spring Wash, Kelvin, and Ashurt Hayden Dam. Verde River temperature profiles were obtained from Leslie (2003).

Results

Water quality and thermal experience. Parker Canyon Lake had the highest mean temperatures of all study lakes (Figure 3). Temperature profiles were similar at Long Lake and Upper Lake Mary from July to February. Long Lake had warm temperatures from March to June. However, during June and July, no temperature data were collected in Upper Lake Mary and in July, no temperature data was collected at Long Lake as a result of forest closures. Thus, mean temperatures were interpolated between the existing data. Parker Canyon Lake was anoxic from May to November below 8 to 12 m, with the peak of anoxic conditions occurring in August below 6 m. We assumed northern pike were utilizing the thermocline in summer given the cooler water temperatures and adequate oxygen supply. In August of 2002, AGFD collected two northern pike for mercury testing at depths near the thermocline. Thus, northern pike were assumed to occupy the thermocline from May to November. During winter, when Parker Canyon Lake was not stratified, we assumed that northern pike occupied the entire water column. Northern pike caught in gillnets were collected mostly in shallow, vegetated areas along the shoreline. However, an occasional northern pike was collected at the far end of the gillnet, suggesting some northern pike may utilize the pelagic zone of the lake. Long Lake and Upper Lake Mary were shallow and weakly stratified. Thus, in Long Lake and Upper Lake Mary, northern pike were assumed to occupy the entire water column and were not restricted to any zone throughout the study.

Abundance. Estimates of abundances were calculated from five separate marking events in Long Lake. During the marking period, 591 northern pike were marked and released at a variety of locations throughout Long Lake and 18 were recaptured. Gillnetting (n = 607) was the most effective method for capturing northern pike and angling (n = 2) was the second most effective. Electrofishing was not tested in Long Lake because the water level was too low to allow launch access for the electrofishing boat. The estimated number of northern pike in Long Lake was 7,246 (95% C.I. 4,651 to 11,971). The percentage of age-0 and age-1 was 77.1% and 22.2% (Figure 4). Average total length and weight of northern pike was 425 mm TL and 648 g, respectively, with a standing crop of 49.3 kg/ha and 76.3 fish/ha as the estimated density of adult northern pike.

In seven marking events, 23 northern pike were marked and released at the point of capture in various locations around Parker Canyon Lake. Four northern pike were recaptured during sampling. Gillnetting (n = 21) was more effective for capturing pike than angling (n = 1) or electrofishing (n = 1). Trapnets were found to be ineffective due to steep canyon walls of the lake. The estimated number of northern pike was 54 (95% C.I. 23 to 168) in Parker Canyon Lake. The percentages and ages of northern pike collected were age-0, 33.3%; age-1, 58.8%; age-2, 3.9%; age-4, 2.0%; and age-6, 2.0% (Figure 4). The average total length and weight of northern pike was 482 mm and 965 g. Biomass and adult densities of northern pike in Parker Canyon Lake was estimated to be 1.0 kg/ha and 1.0 fish/ha, respectively.

Abundance estimates at Upper Lake Mary consisted of two events and of the 38 northern pike marked, two were recaptured. Gillnets (n = 37) collected the majority of northern pike followed by trapnets (n = 3). Electrofishing was ineffective in Upper Lake Mary due to low water visibility (>0.1 m). The estimated number of northern pike in Upper Lake Mary was 117 (95% C.I. 40 to 585). The percentage of age-0, age-1, age-2, age-3, and age-4 was 19.4%, 45.8%, 20.8%, 11.1%, and 2.8%, respectively (Figure 4). The average total length and weight of the northern pike was 546 mm and 1,222 g. Northern pike biomass and adult densities was estimated to be 1.8 kg/ha and 1.4 fish/ha, respectively, for Upper Lake Mary. Smaller mesh sizes (13 and 19 mm bar size) primarily captured larger (> 650 mm TL) northern pike by entangling their teeth or mandibles in all of the lakes.

Growth, age, and condition. Growth of northern pike differed among lakes and was high when compared to populations in other areas of the United States (Carlander 1969) (Figure 5). Analysis of scales (Long Lake, *n* = 64; Parker Canyon Lake, *n* = 22; Upper Lake Mary, *n* = 50), cliethra (Long Lake, *n* = 20; Parker Canyon Lake, *n* = 5; Upper Lake Mary, *n* = 14), and length-frequency distributions of the populations collected were of northern pike up to 3 years of age in Long Lake, 6 years of age in Parker Canyon Lake, and 4 years of age in Upper Lake Mary.

Relative weights were highest for northern pike in Long Lake and did not differ among seasons (Figure 6). Northern pike showed an increase in relative weight in Parker Canyon Lake near 450 mm TL in total length. Relative condition of northern pike in Upper Lake Mary was the lowest of the three lakes.

Diet analysis. Stomach contents were extracted and examined from 69 northern pike in Long Lake, 22 in Parker Canyon Lake, and 34 in Upper Lake Mary. Northern pike consumed crayfish, common carp, northern pike, and rainbow trout in Long Lake (Figure 7). Crayfish were the dominant prey item in early spring and beginning of summer until carp fry hatched in July or August. Carp fry remained the dominant prey item throughout the rest of the summer and fall. Some cannibalism occurred in summer and fall. Rainbow trout were found in stomachs only in fall.

In Parker Canyon Lake, prey found in the stomach contents of northern pike were bluegill and green sunfish, largemouth bass, northern pike, and rainbow trout. Bluegill and green sunfish found in stomachs were difficult to identify to species because of their small sizes and were referred to as bluegill/green sunfish. During spring and winter, rainbow trout were the dominant prey item. Northern pike and largemouth bass also were found in stomachs in winter at Parker Canyon Lake. Bluegill/green sunfish were the only prey found in northern pike stomach contents during the fall.

Prey items of northern pike in Upper Lake Mary were black crappie, crayfish, golden shiners, and rainbow trout. In spring, black crappie, golden shiners, and crayfish were the major prey items. The vast majority of stomach contents in the fall consisted of rainbow trout, with a few golden shiners. Rainbow trout continued to comprise the majority of the diet during winter. Black crappie and golden shiners were also important in the diet.

Bioenergtics model. Model simulations indicated that consumption of prey fishes by northern pike varied by lake (Figure 8), prey species (Figure 9), and season (Table 2). Age-1 northern pike in all of the lakes had the highest prey consumption.

Northern pike in Long Lake exerted the highest consumption on crayfish in summer and northern pike, common carp, and rainbow trout in the fall. Age-1 northern pike had the highest consumption on crayfish, northern pike, and rainbow trout. Age-0 northern pike consumed the most common carp. In the spring, summer, fall, and winter across all age classes, *P*-values averaged 0.26, 0.22, 0.30, and 0.60, respectively (Table 3).

Consumption of bluegill/green sunfish and largemouth bass in Parker Canyon Lake occurred during summer. In winter, northern pike and rainbow trout were consumed. Bluegill, largemouth bass, and rainbow trout in Parker Canyon Lake were consumed primarily by age-1 northern pike, while most northern pike were consumed by age-6 northern pike. *P*-values for all the age classes for the spring, summer, fall, and winter averaged 0.33, 0.34, 0.30, and 0.51, respectively.

Northern pike in Upper Lake Mary consumed black crappie, crayfish, and golden shiners in the summer. Rainbow trout were consumed most heavily in fall when stockings occurred. Black crappie, golden shiners, and rainbow trout were eaten largely by age-1 northern pike, and crayfish were eaten primarily by age-2 northern pike. Average *P*-values for all age classes were 0.45, 0.25, 0.33, and 1.01 for the spring, summer, fall, and winter, respectively.

Northern pike consumed 2.9%, 1.2%, and 63.2% of the total number of rainbow trout stocked in Long Lake, Parker Canyon Lake and Upper Lake Mary, respectively (Table 4). The average cost per rainbow trout stocked at Long Lake, Parker Canyon Lake, and Upper Lake Mary was $0.69, $1.52, and $0.02, respectively. Parker Canyon Lake received the most stocked rainbow trout with 96,391 g/ha, while Long Lake received 8,842 g/ha and Upper Lake Mary 2,466 g/ha of stocked fish. Carlander (1955) reports that the average standing crop per ha in the United States for black crappie, bluegill, common carp, golden shiner, largemouth bass, and northern pike is 15.48 kg/ha, 47.45 kg/ha, 82.23 kg/ha, 48.13 kg/ha, 21.54 kg/ha, and 9.2 kg/ha, respectively (Figure 10). The following amount of prey was consumed for the entire year in the corresponding lakes: Long Lake, common carp 64.3 kg/ha, crayfish 25.26 kg/ha, northern pike 4.98 kg/ha, rainbow trout 0.25 kg/ha; Parker Canyon Lake, bluegill/green sunfish 1.39 kg/ha, largemouth bass 1.23 kg/ha, northern pike 0.01 kg/ha, rainbow trout 1.22; Upper Lake Mary, black crappie 1.29 kg/ha, crayfish 0.27 kg/ha, northern pike 1.61 kg/ha, and rainbow trout 1.60 kg/ha.

Threat to native fish. Native fish found in Colorado, Gila, Salt, and Verde rivers are: bluehead sucker *Catostomus discobolus*, Colorado pikeminnow *Ptychocheilus lucius*, desert sucker *Catostomus clarki*, flannelmouth sucker *Catostomus latipinnis*, humpback chub *Gila cypha*, longfin dace *Agosia chrysogaster*, razorback sucker *Xyrauchen texanus*, roundtail chub *Gila robusta*, sonora sucker *Catostomus insignis*, speckled dace *Rhinichthys osculus*. The maximum temperature recorded in Colorado River at Bright Angles landing occurred in September and was 14.8 °C, well below upper lethal incipient temperature of northern pike (Figure 11). The Colorado River at Lees Ferry was on average colder than Bright Angles landing and experienced the highest maximum temperature in December at 10.3 °C. The Salt River at the Water Users Boat Ramp site experienced the highest temperature in August at 24.2 °C. Water temperature at the Dripping Spring Station site of the Gila River was above the upper lethal incipient temperature of northern pike in both July (29.75 °C) and August (30.31 °C). Gila River temperatures at the sites Kelvin and Ashurt Hayden Dam were approaching upper lethal in July at 28.97 and 29.01 °C, and may have exceeded the temperatures in August. The highest water temperatures of the Verde River occurred in August in section IV at the Fort McDowell (33 °C) and Beeline Highway (33 °C) sites where water temperatures exceeded the upper lethal limit of northern pike. In the upper sections of the Verde River, the high temperature of 28^{o}Cs occurred in June at Perkinsville Bridge and Perkins Property sites in August.

Discussion

Abundance, growth, and condition.

Abundances of northern pike were extremely low in Parker Canyon Lake and Upper Lake Mary (1.0 to 1.4 fish/ha) to extremely high in Long Lake (76.3 fish/ha), when compared to abundances in their native range. Populations with low densities in Wisconsin and Ontario were in the range of 2.8-7.1 fish/ha (Priegel and Krohn 1975; Mosindy et al. 1987; Margenau et al. 1998) and high density populations in Minnesota and Wisconsin were in the range of 38.0-59.0 fish/ha (Snow and Beard 1972; Scheirer 1988; Pierce et al. 1995; Margenau et al. 1998; Pierce 2003).

Major factors that affect the standing crop of northern pike are habitat availability and the suitability of forage (Inskip 1982). The low densities of northern pike in Parker Canyon Lake are probably a result of culling efforts by AGFD personnel along with lack of suitable habitat during summer. Personnel from AGFD have gillnetted annually since 1997, except during this study, and removed northern pike in an attempt to reduce predation on stocked rainbow trout. Thus, the abundance estimate of northern pike may be lower due to the suppression of the population. Also, gillnetting may be targeting larger individuals and the estimate of abundance represents smaller sized fish. The amount of suitable habitat for northern pike occurs from May to November because the lake is anoxic below 8 to 12 m and surface temperatures, range from 19-21^{o}C, above temperature for optimal growth. (Casselman 1978). Thus, northern pike are restricted to a 2 to 3 m zone near the thermocline. Headrick and Carline (1993), also found habitat compression in summer due to warm temperatures in surface waters and low oxygen in cooler bottom waters, severely constrained summer growth of northern pike in Ohio reservoirs. Limitation of growth may have influenced reproductive success of female northern pike, consequently limiting their densities. In Upper Lake Mary water levels probably inhibit the densities of northern pike. Water levels and temperature are the main abiotic factors influencing year-class strengths of northern pike (Casselman 1996). Strong year classes of northern pike are associated with rising water levels and flooded terrestrial vegetation during spawning (Johnson 1957; Beckman and Elrod 1971). Likewise a reduced spawning area caused by lower water level results in a reduction in the number of recruits (Autko 1964). In 2002, Upper Lake Mary was only at 13.2% of the storage capacity of the reservoir at full level and during the last 5 years has decreased in capacity 18.3% as a result of drought. Decreasing water levels also inhibit macrophyte growth, which is essential spawning habitat for northern pike (InSkip 1982; Raat 1988; Casselman and Lewis 1996). Macrophytes in Upper Lake Mary also were limited by low transparency (Secchi depth <0.1 m), which can reduce light penetration, inhibiting their growth (Casselman 1996). High density and production of northern pike in Long Lake seems to be supported, in large part, by the primary prey item, common carp. A study conducted in Camerton Lake, Minnesota, located in the native range of northern pike that contained a high density population (59 fish/ha) found that the primary prey item, yellow perch, was the major reason for the high annual production (Pierce et al. 2003).

Northern pike in Arizona had high growth rates when compared to northern pike in their native range (Carlander 1969). Length-at-age for Long Lake, Parker Canyon Lake, and Upper Lake Mary averaged 14.0%, 0.2%, and 1.8% higher, respectively, than highest reported by Carlander (1969). Scott and Crossman (1973) described an inverse relationship between growth rate and longevity related to increasing latitude. The rapid growth rates of northern pike in Arizona populations probably limits longevity. The exceptionally high growth rates in the three populations is probably the result of a combination of optimal water temperatures (19-21°C) over a large portion of the year (Casselman 1978), and availability of large soft-rayed prey fishes at optimum sizes and densities (Beyerle 1978). Northern pike in Upper Lake Mary exhibited the lowest condition and growth of the three populations and also contained the lowest secchi depths (< 0.1 m) of all the lakes, Parker Canyon Lake and Long Lake contained secchi depths of 2.5 - 4 m and 1.5 – 2.5 m, respectively, throughout 2002. Northern pike are visual feeders, and predation is facilitated by clear water allowing higher food consumption and growth rates. However, high turbity inhibits growth of this sight feeding fish (Carlander 1969; Craig and Babaluk 1989). Thus, it appears the ability of northern pike to forage effectively was limited by the ability to visually locate prey in this lake, reducing growth and condition. Differences in northern pike condition (W_r) among size-groups in Parker Canyon Lake may reflect the availability of numerous rainbow trout, averaging 249 mm

TL (230-260 mm TL), to the larger fish. Relative weights for northern pike < 450 mm TL averaged 91, while northern pike ≥ 450 mm TL averaged 108.

Predatory impacts

Northern pike in Long Lake had the highest consumption rates of the three populations and common carp made up most of the forage fish consumed. The summer and fall peak of common carp in diets of northern pike consisted entirely of age-0 fish (47 mm TL; Range 21-118 mm TL), that were present in shallow water at the time. Mauck and Coble (1971) determined that common carp > 110 mm TL were not vulnerable to northern pike ≤ 316 mm TL and that carp likely outgrow northern pike predation in 1 or 2 years. Northern pike growth was extremely fast in Long Lake. The high consumption rates of northern pike on common carp coupled with high growth rates indicate that northern pike may be able to exert more of an influence on common carp populations than in other North American areas. The bioenergetics simulations indicated that age-1 northern pike accounted for the largest portion of prey consumption in the population. Crayfish were a fairly large food item and were second only to common carp in their importance to northern pike, especially in the spring and beginning of summer. Growth rates of tagged northern pike declined from May to June. Thus, crayfish may not be contributing to growth of northern pike, but may be sustaining the population until common carp fry are of adequate size for northern pike to begin actively foraging on them. Crayfish have been found to be important in the diet of northern pike in other environments (Pierce and Tomcko 1998; Pierce et al. 2003). Simulations indicated that cannibalism comprised 10.1% of consumption by northern pike. Cannibalism occurred in northern pike > 587 mm TL and may suggest northern pike larger than 587 mm TL limited by availability of suitably-sized forage fishes (Diana 1987). About 2.9% of stocked rainbow trout were consumed by northern pike. No diet samples were obtained shortly after or during the rainbow trout stocking at Long Lake, so the peak of predation may have been missed. Estimates of consumption of rainbow trout are probably underrepresented in Long Lake. The population of northern pike is heavily skewed towards age-0 fish. Age-0 northern pike made up 77.1% of the population. Potential causes of for high numbers of age-0 northern pike are exploitation of large northern pike (Bagenal 1977), recruitment of large numbers of small northern pike (Kempinger and Carline 1978), a lack of prey fish of appropriate size (Snow 1978; Diana 1987), and lake characteristics such as abundance of aquatic vegetation providing refugia for YOY (Grimm 1981; Jacobson 1992). The northern pike in Long Lake is likely skewed towards age-0 as a result of a combination of factors, but most probably because there appears to be few prey of adequate size for larger individuals to meet the metabolic demands of larger northern pike, as indicated by the cannibalism (Diana 1987).

Bluegill, greensunfish, largemouth bass, and rainbow trout were the fish species most widely utilized as prey in Parker Canyon Lake. The total number of rainbow trout consumed represented 1.2% of the trout stocked. This low number of trout consumed was unexpected given that soft-rayed fish are often preferred by northern pike (Beyerle and Williams 1968). However, culling efforts by AGFD personnel have reduced the number of large northern pike that would exert the highest consumptive demand on catchable-sized 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 in Parker Canyon Lake. Age-0 northern pike in Parker Canyon Lake averaged < 408 mm TL and comprised 33% of population. If culling efforts do not continue, consumption of trout by northern pike will significantly increase since culling efforts have abundance of northern pike large enough to consume rainbow trout. Stocking of rainbow trout increases the food base in the lake. Thus, reduction in the stocking of rainbow trout, particularly in Parker Canyon Lake, may increase predation pressure on remaining prey, particularly bluegill and largemouth bass, and reduce recruitment and condition of northern pike. Other studies have shown that northern pike consume largemouth bass (Gurtin et al. 1996; Soupir et al. 2000; Paukert and Willis 2003), and 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). In the same populations, predation on bluegills and yellow perch occurred suggesting that northern pike used the same food resources as largemouth bass. In this study northern pike consumed the same prey species, bluegill and greensunfish, as largemouth bass in Parker Canyon Lake and competition may have occurred if the prey base was limited. Studies on the food habitats of northern pike have found that centrarchids are not a preferred prey (Seaburg and Moyle 1964; Beyerle 1971; Mauck and Coble 1971;

Weithman and Anderson 1977). In a small pond stocked only with bluegills and northern pike, Beyerle (1971) found that, despite the higher availability of bluegills, northern pike consumed tadpoles more often than they did bluegills. Growth of northern pike was slow, and Beyerle (1971) suggested that bluegills were not suitable food for northern pike. 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.

Despite the low abundance of northern pike in Upper Lake Mary, modeling indicated that northern pike consumed a large proportion of stocked rainbow trout (63%) along with black crappie and golden shiners. Stocked rainbow trout averaged 120 mm TL and were the smallest sized trout stocked in the three lakes. Thus, northern pike consumption of rainbow trout appears highest for fish < 120 mm TL.

Determining the impacts of predation by northern pike on other prey species in was difficult because we did not have accurate estimates of abundance for prey. Thus, we compared consumption rates to the average standing crops of each prey species compiled by Carlander (1955). Standing crop estimates had large confidence intervals due to the distribution and various sampling techniques used to collect fish. Thus, Carlander (1955) provides a coarse estimate of standing crops for prey species in Arizona. The model consumption estimates and the mean standing crops reported in Carlander (1955) northern pike consumed 68% of the common carp in Long Lake, 3% of the bluegill and 6% of the largemouth bass in Parker Canyon Lake, and 8% of the black crappie and 3% of the golden shiner in Upper Lake Mary. Thus in 2002, northern pike appeared to be exerting a significant impact on only common carp of Long Lake and not the other prey species found in the lakes.

Threat to native fish

The potential threat of northern pike that are introduced to or escape into rivers containing native fish indicates northern pike may survive based on temperature. However, temperature alone does not dictate whether northern pike could become established in Arizona rivers. The factor that most often excludes northern pike from successfully becoming established is the presence of suitable spawning habitat (Inskip 1982). Spawning habitat for northern pike is shallow vegetated areas, such as flooded marshes and terrestrial vegetation or weedy bays (Raat 1988). The absence of inundated vegetation can inhibit or delay spawning (Casselman and Lewis 1996). Also, northern pike are not adapted for bodies of water with strong currents (Inskip 1982). Throughout their range, northern pike occur more frequently in lakes than in rivers (Crossman 1978) and commonly inhabit backwaters and pools of rivers (Inskip 1982). Temperatures in the Colorado River below Glen Canyon Dam (8-10 °C) are tolerated by northern pike, but optimal temperature for growth is 19-21 °C (Casselman 1978). Temperatures in the upper reaches of the Verde River appear suitable for northern pike introductions. Macrophyte growth also is common in this stretch of the river, providing suitable spawning conditions. Lower sections of the Verde River at the Beeline Highway and Fort McDowell areas were too warm to allow northern pike to survive. Although northern pike would be able to survive in certain sections the lower Verde River in summer, the population would be restricted to narrow sections of the river and probably be limited to pools containing cooler water. However, a total of 571 northern pike were stocked three separate times in the Verde River at the Camp Verde Reach from 1968 to 1970 and a population never became established. Thus, some abiotic factor other than temperature may limit them in the system and we assume northern pike would not become established in river in the future. Temperatures in the Gila River approach or exceed the upper lethal temperature of northern pike. Therefore, northern pike would not be able to survive in the lower Gila River. Temperatures in the Salt River at the water users boat ramp are within the temperature tolerance of the northern pike with near optimal temperatures for growth (19-21 °C) occurs through February and August (Casselman 1978). Although northern pike can survive in some sections of rivers in Arizona, other abiotic factors such as strong currents, lack of spawning habitat, or below optimal water temperatures, may limit their distribution and ability to pose a serious threat to native fishes.

Management Implications

Sport fishery potential for northern pike in Arizona seems limited, given the lack of angler interest and low density populations of northern pike. The average density found in nineteen lakes in northern Wisconsin was 16.1 fish/ha and contained a range of 2.8-38.0 fish/ha (Margenau et al. 1998). Scott and Crossman (1973) reported the range of standing crops for northern pike as 3.6 to 11.5 kg/ha. Parker Canyon Lake (1.0 kg/ha and 1.0 fish/ha) and Upper Lake Mary (1.4 fish/ha and 1.8 kg/ha) were well below the average in their native range and would be expected have low catch rates for northern pike. Also, the low water transparency in Upper Lake Mary would make fishing for a visual predator difficult. However, the high density of northern pike in Long Lake (49.3 kg/ha and 76.3 fish/ha) should provide high catch rates of age-0 fish given the higher than normal density and skewed population structure towards age-0 northern pike. 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 most sought after fish by anglers and comprised 37.8% and 28.4%, 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 benefits to stocking northern pike in Arizona lakes.

The low consumption of northern pike on larger rainbow trout (>200 mm TL) compared with the high consumption of smaller sized rainbow trout (≤120 mm TL) indicate that Arizona lakes containing northern pike should be managed as a put-and-take trout fishery. An evaluation of stocking rainbow trout at various sizes in Seminoe Reservoir, Wyoming, found an increase in creel return rates of for larger fish because smaller fish were susceptible to predation by walleye (Wiley et al. 1993). The bioenergetics modeling demonstrated that hatchery-reared rainbow trout, ≤ 120 mm TL, are particularly vulnerable to northern pike predation. The average *P*-value for the age classes increased for each northern pike in Upper Lake Mary from 0.33 in the fall to 1.01 in the winter when rainbow trout, 120 mm TL, were stocked. This dramatic increase in *P*-value suggests that rainbow trout were heavily utilized as a prey fish for the northern pike. An increase in *P*-value also occurred in Parker Canyon Lake in the fall when rainbow trout, 249 mm TL, were stocked, but the increase was not as drastic. *P*-value was 0.30 in the fall and increased to 0.60 in the winter. Stocking of rainbow trout at the maximum size possible will minimize predation impacts. However, fewer larger fish can be stocked than small fish because large fish cost more to produce. Given the high predation impacts on smaller stocked rainbow trout, a put-grow-and-take fishery would sustain heavy predation losses and may not return to the creel in acceptable numbers.

Since northern pike consumed a high proportion of carp fry based on model simulations they may be useful tool for rough fish control in Arizona lakes. Historically, northern pike have been used as rough fish control in some western states (Bergersen 2001). In addition, the rapid growth rates of northern pike in this climate give it a great foraging demand. However, given the potential predation threat this species may represent to Arizona's lake sport fishes coupled with possibility of illegal or escapement into an adjacent body of water, a sterile hybrid species such as tiger muskellunge (female muskellunge *Esox masquinongy* x male northern pike *E. lucius*) may be better suited for rough fish control (Hesser 1978).

This study has shown that bioenergetics modeling can serve as a framework to assess the potential predation impacts northern pike may exert on reservoirs in Arizona.

In the future accurate lake wide biomass estimates of the prey and predators will be essential for evaluating predator-prey dynamics and developing management strategies. Bioenergetics simulations can be used to evaluate the trade-offs of various management strategies and can provide a means of validating these actions to anglers.

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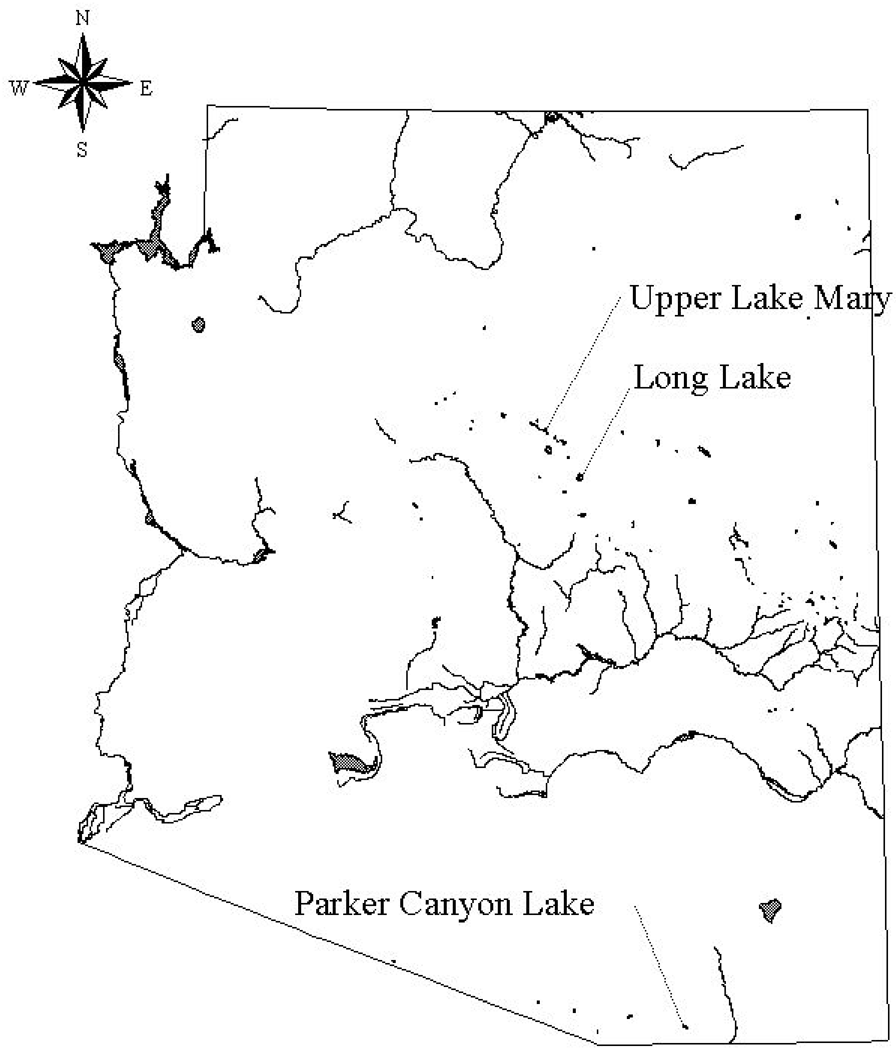


Figure 1.- Lakes sampled for northern pike from August 2001 through December 2002, in Arizona.

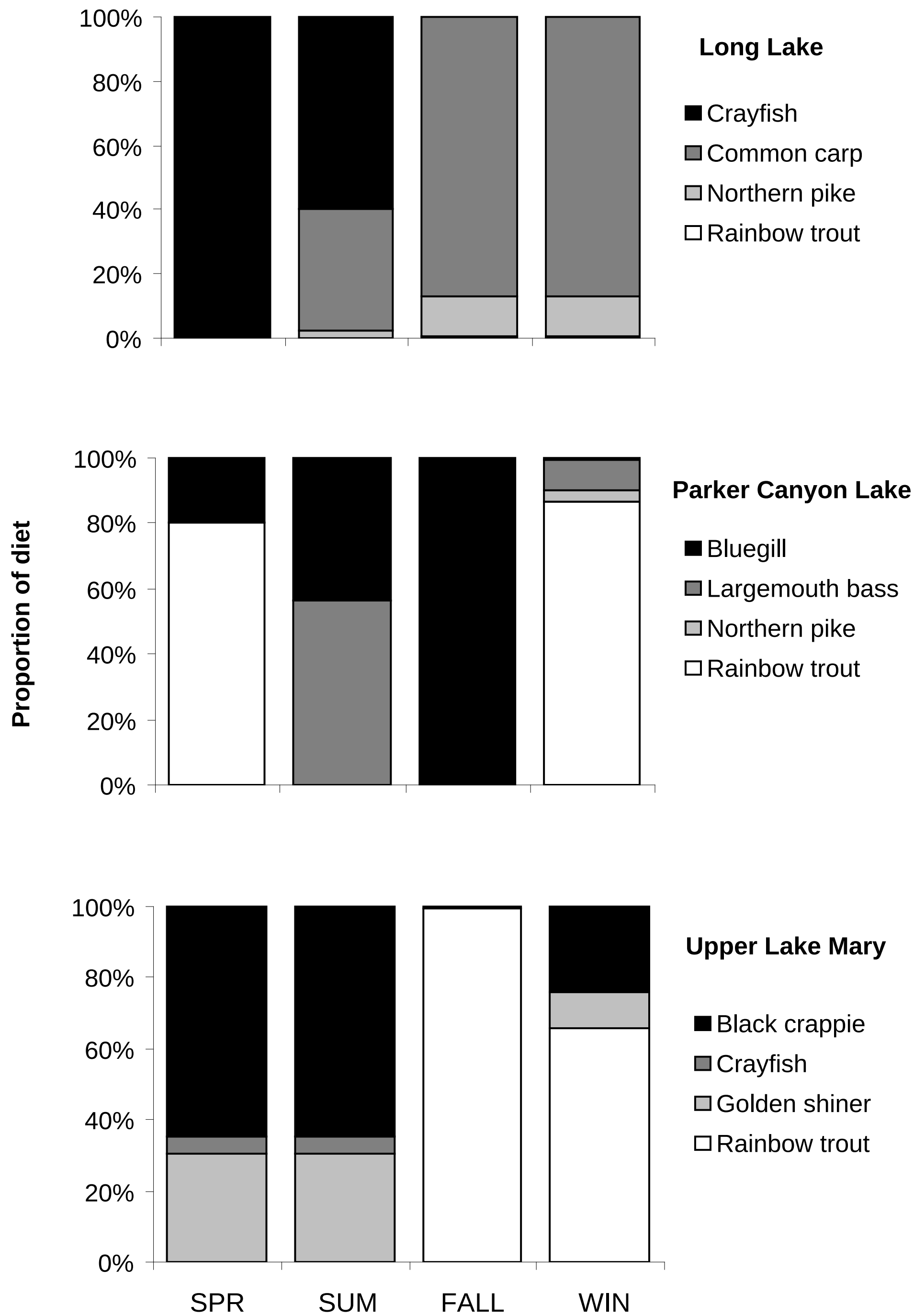


Figure 2.- Proportion of prey items used in a bioenergetics model for northern pike in 2002 at Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona.

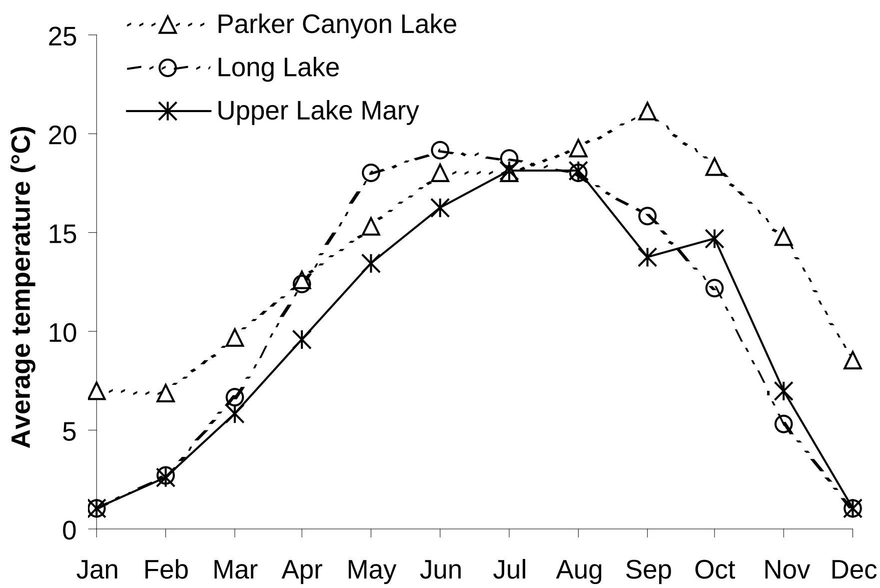


Figure 3.- Average temperature (°C) profile used in a bioenergetics model with temperature interpolated between months.

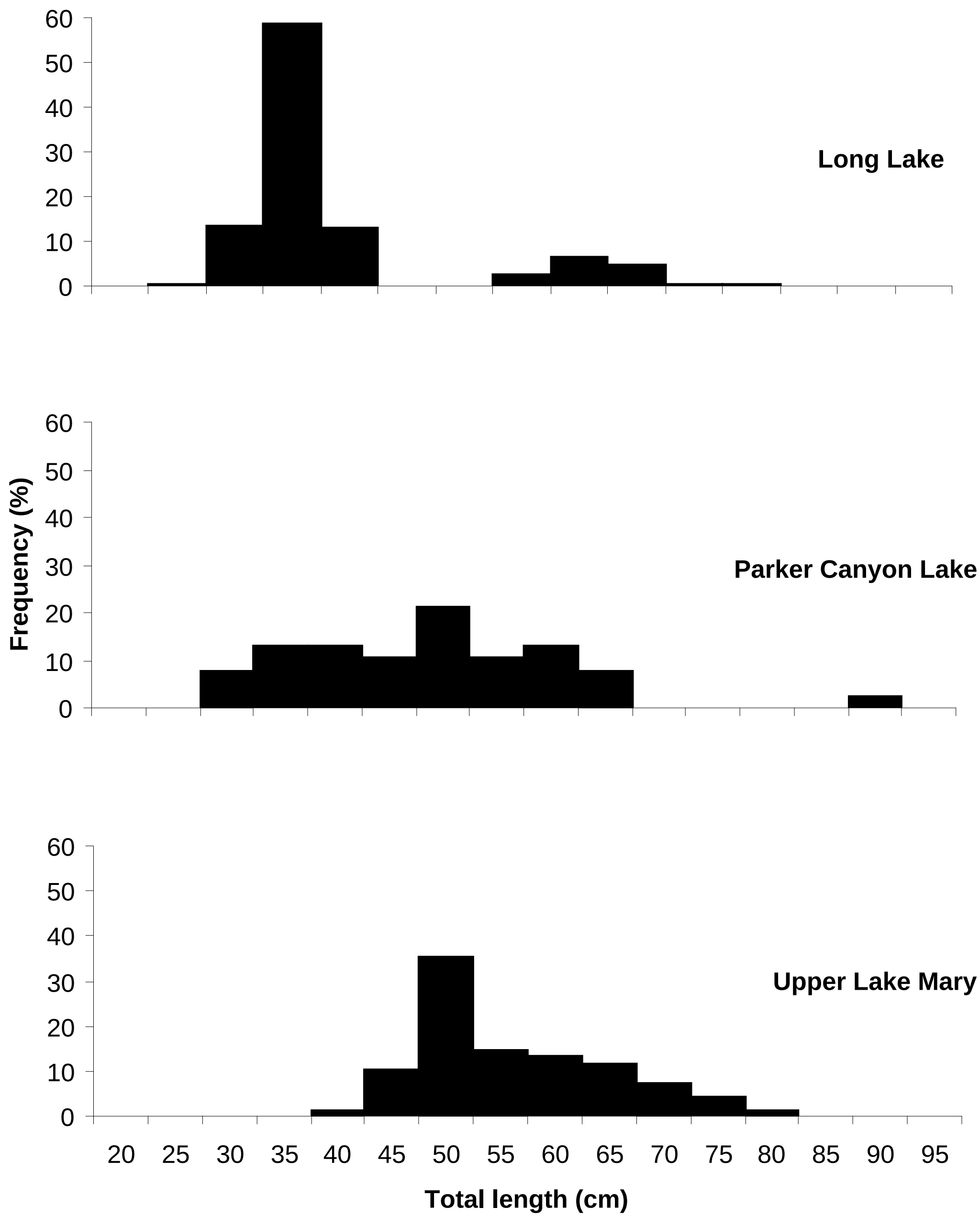


Figure 4.- Length-frequency (total length) histograms for northern pike captured during abundance estimates in fall and winter from Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona.

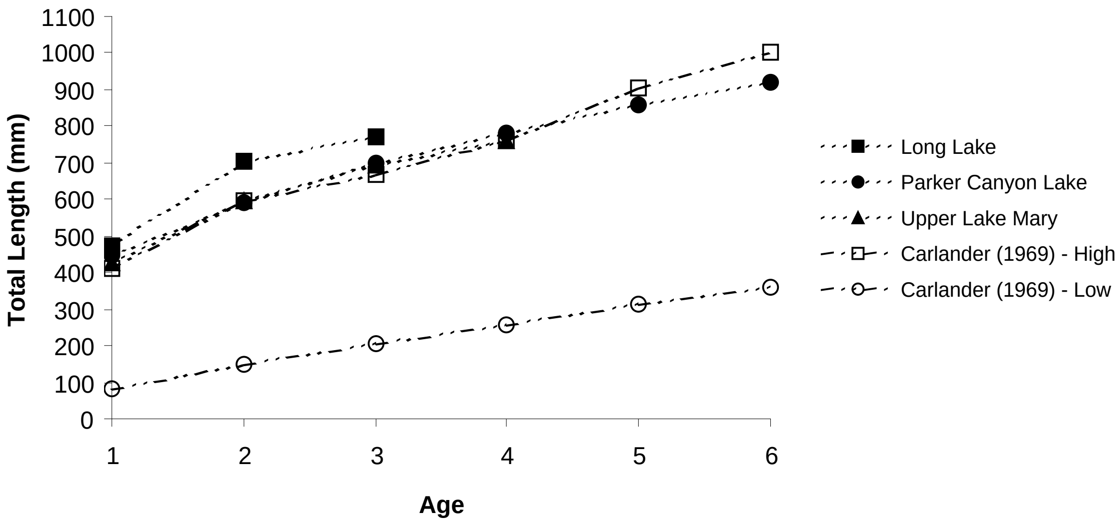


Figure 5.- Total-lengths-at-age of northern pike from Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, from August 2001 through December 2002 and the reported high and low in North America and Europe by Carlander (1969).

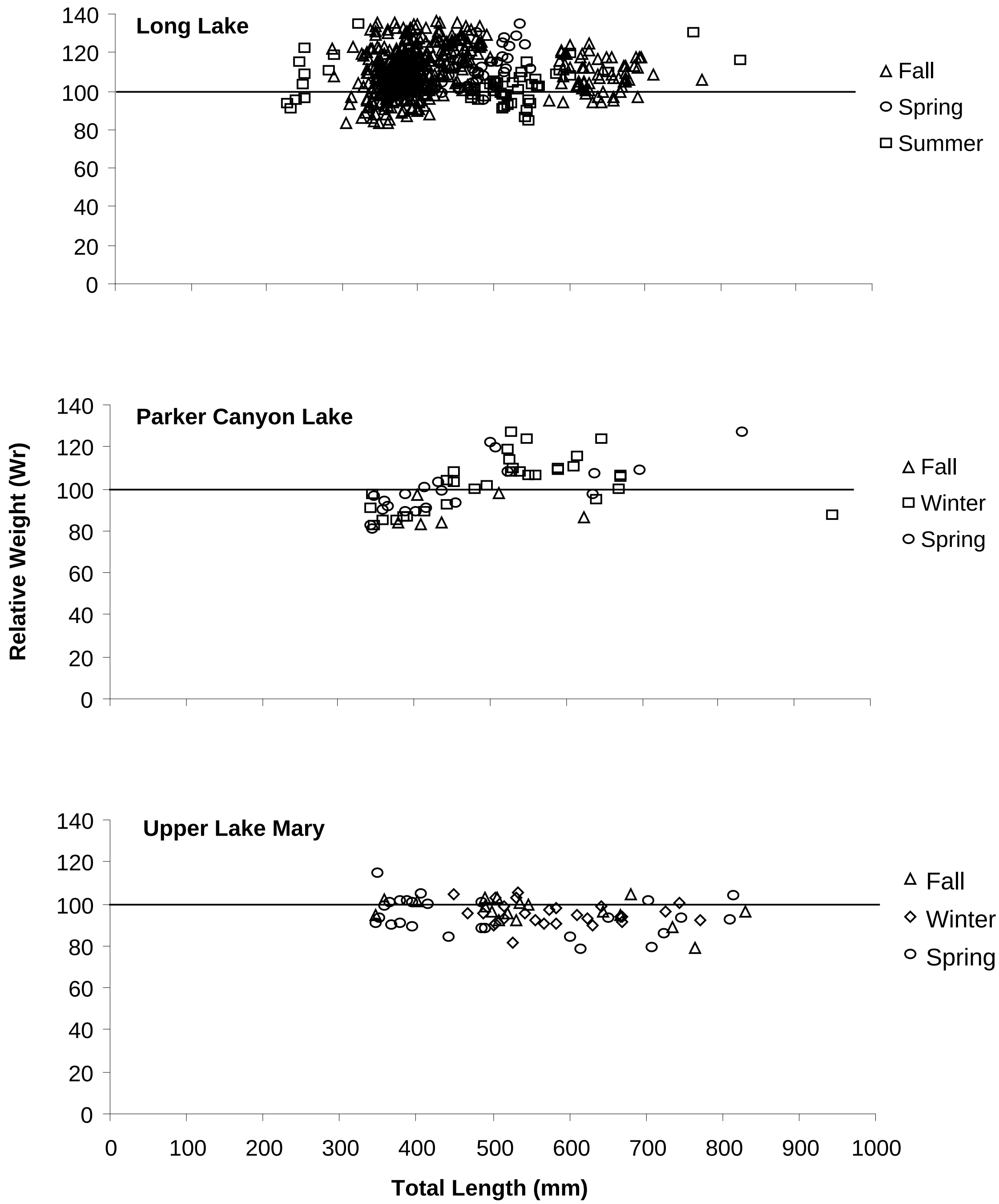


Figure 6.- Relative weights (W_r) by season of northern pike collected in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, August 2001 to December 2002.

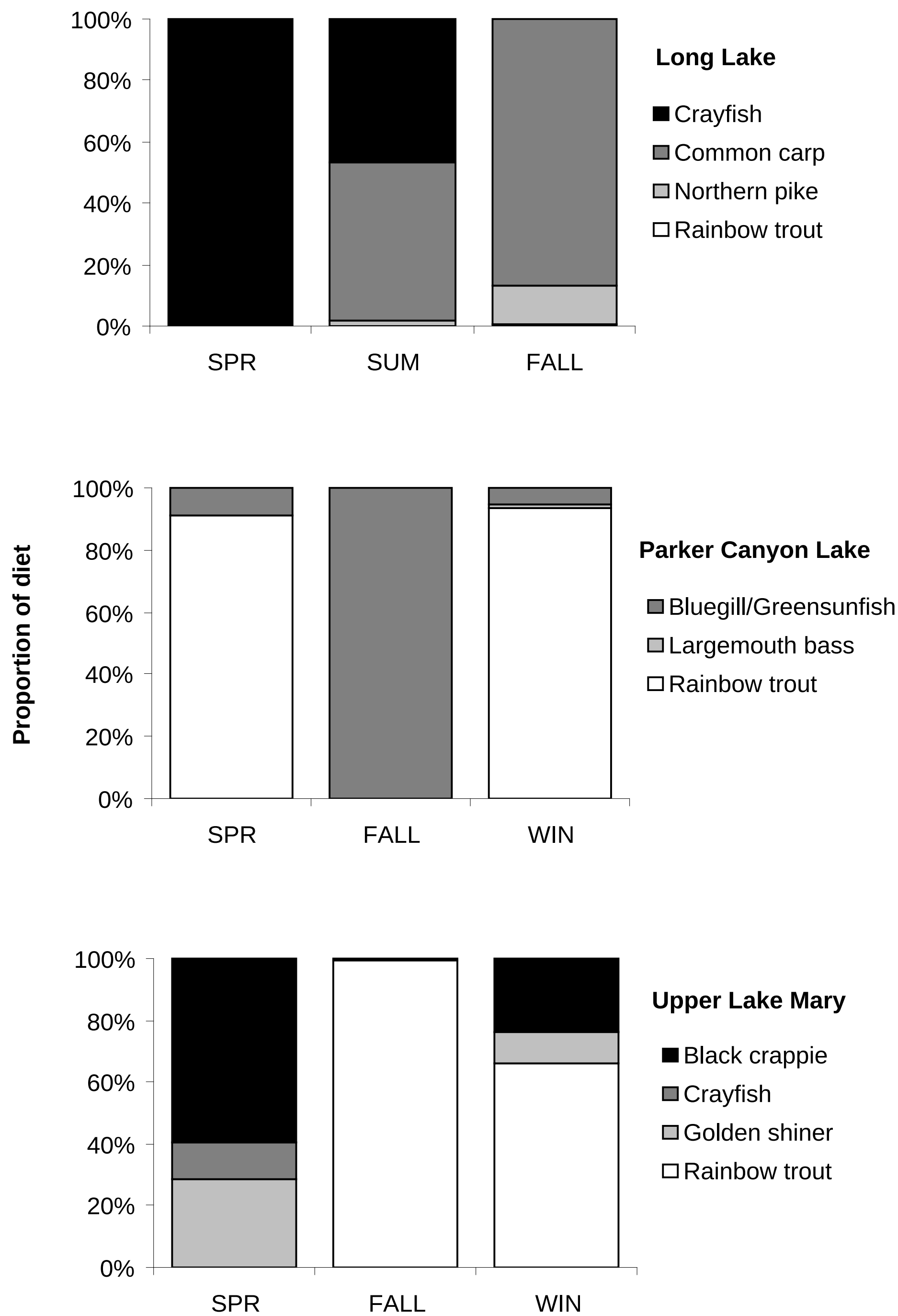


Figure 7.- Proportion of prey items found in northern pike collected from August 2001 through December 2002 in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona.

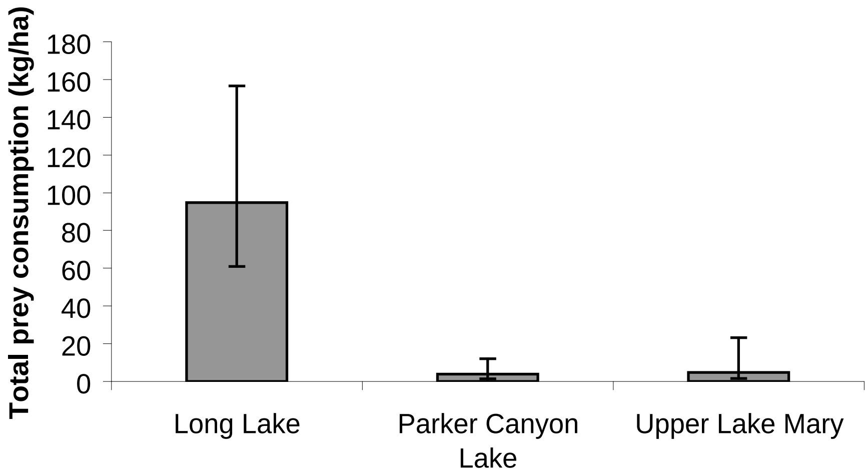


Figure 8.- Total prey consumption (kg/ha) by northern pike as estimated by a bioenergetics model in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona for 2002.

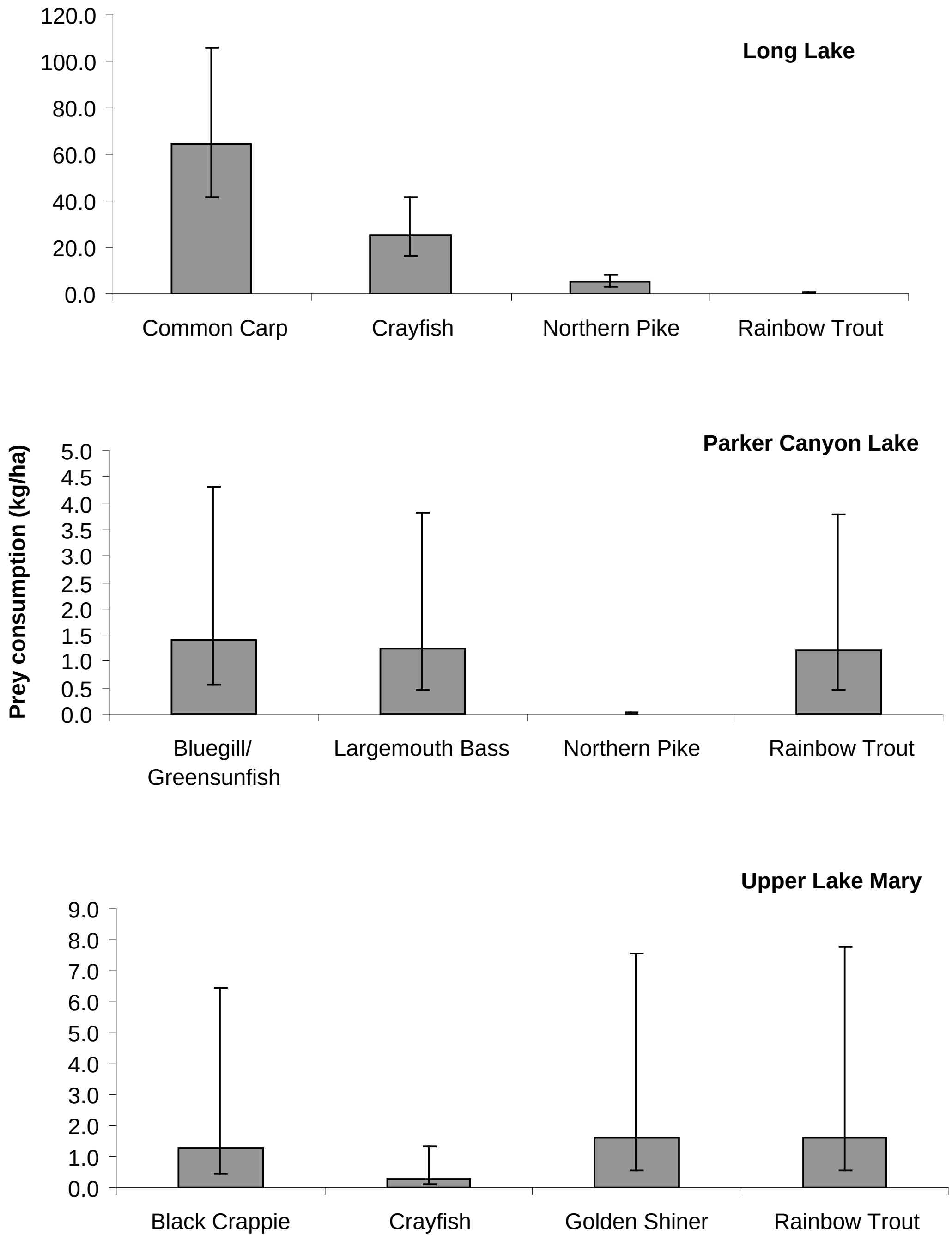


Figure 9.- Total prey consumption (kg/ha) by northern pike by species of prey in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, as estimated by a bioenergetics model.

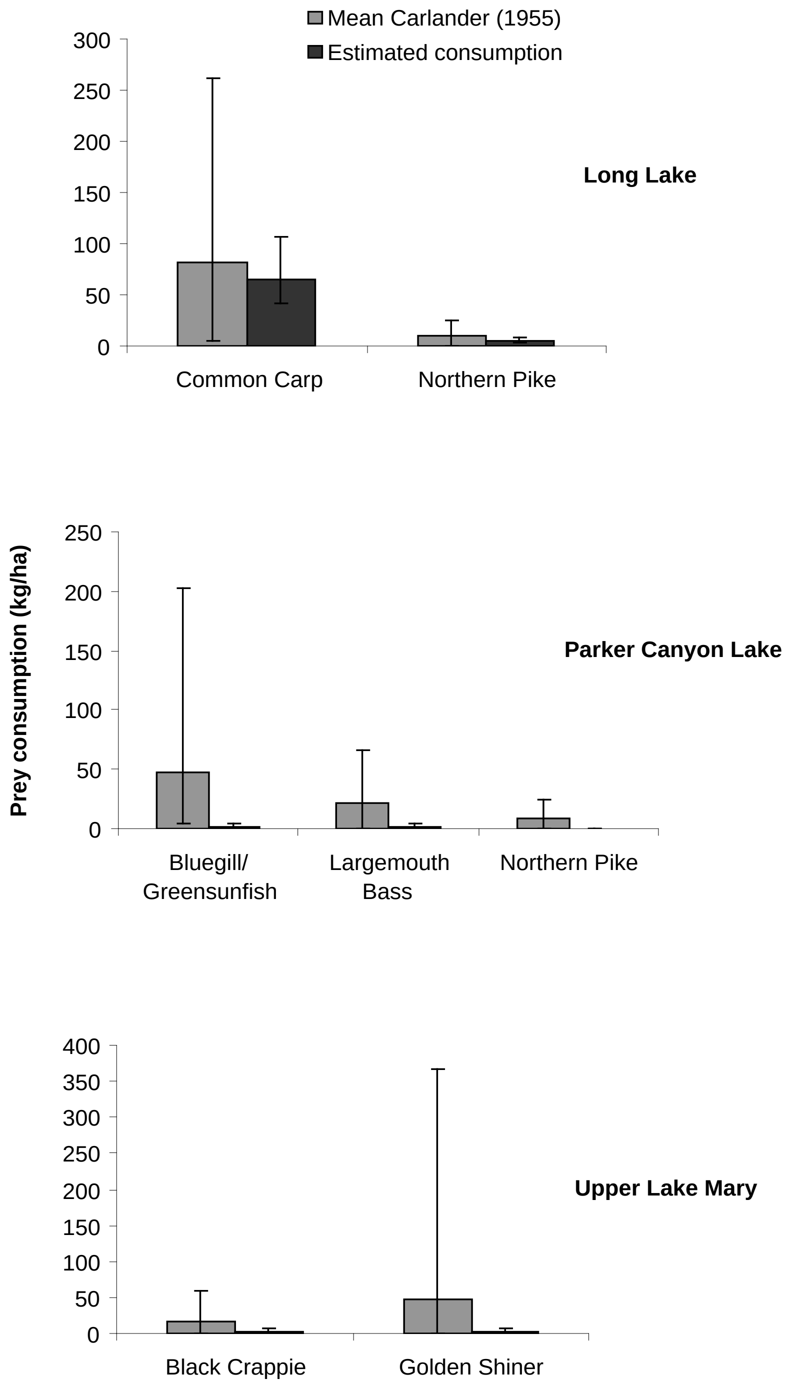
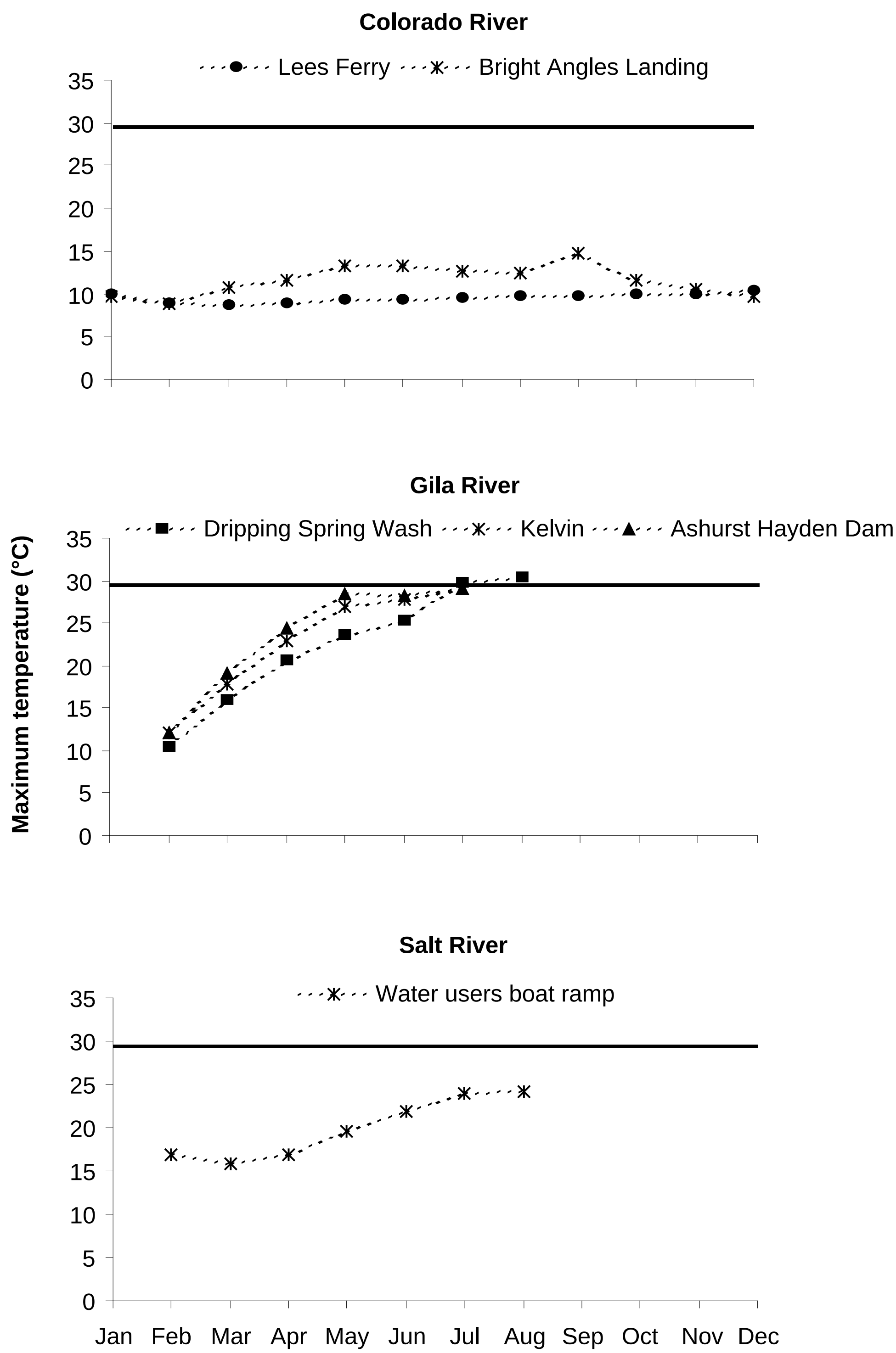


Figure 10.- Total prey consumption (kg/ha) by northern pike for species of prey in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, as estimated by a bioenergetics model and compared to the estimated average standing crop in the United States (Carlander 1955).


Colorado River
Lees Ferry
Bright Angles Landing
Gila River
Dripping Spring Wash
Kelvin
Ashurst Hayden Dam
Maximum temperature (°C)
Salt River
Water users boat ramp
0
5
10
15
20
25
30
35
Jan
Feb
Mar
Apr
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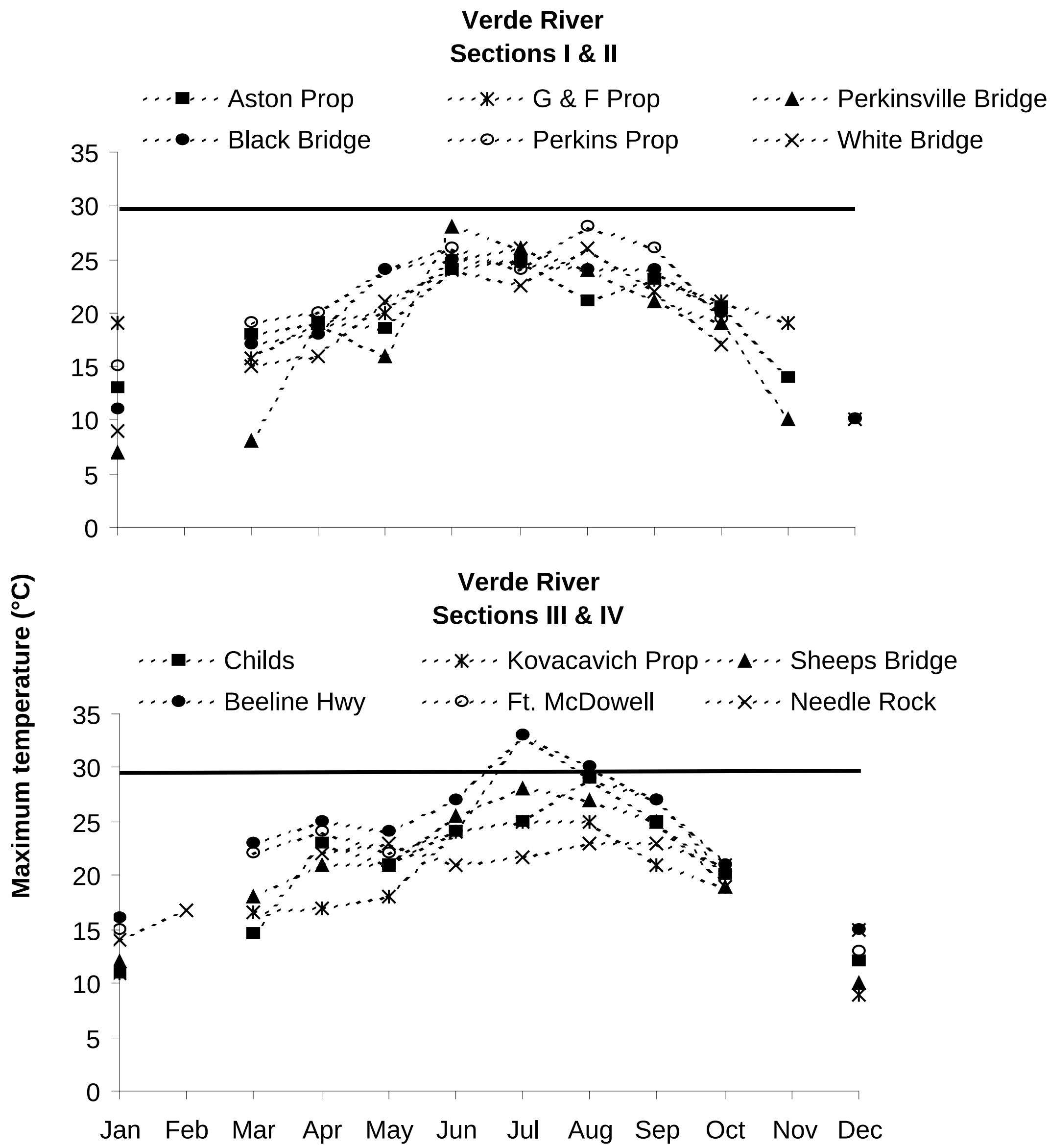

Figure 11.- Monthly maximum water temperatures (°C) for the Colorado River, Gila River, Salt River, and Verde River, Arizona, compared to the upper lethal incipient temperature of northern pike (29.4 °C).

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	Bluegill	4186	Kitchell et al. 1974
Pomoxis nigromaculatus			
Bluegill		4,186	Kitchell et al. 1974
Lepomis macrochirus			
Common carp	Cyprinidae	7,524	Cummins and Wuycheck 1971
Cyprinus carpio			
Northern crayfish	*Orconectus propinquus*	6,153	Stein and Murphy 1976
Orconectes virilis			
Golden shiner	Emerald shiner	4,983	Kelso 1972
Notemigonus crysoleucas			
Greensunfish	Bluegill	4,186	Kitchell et al. 1974
Lepomis cyanellus			
Largemouth Bass		4,186	Rice et al. 1983
Micropterus salmoides			
Rainbow trout	Steelhead	6,069	Rand et al. 1993
Oncorhynchus mykiss			

Table 2.- Seasonal consumption (g of prey) of northern pike by age in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona, January 2002 to December 2002.

Long Lake

Age (Years)	Season	Prey Species: Common Carp	Crayfish	Northern Pike	Rainbow Trout
0	Summer	988,354	0	0	0
	Fall	1,760,633	17,784	0	0
	Winter	579,855	5,857	0	0
1	Spring	0	953,359	0	0
	Summer	790,068	1,281,192	64,060	0
	Fall	1,547,711	0	320,867	18,875
	Winter	315,588	0	65,427	3,849
2	Spring	0	29,331	0	0
	Summer	14,706	23,848	1,192	0
	Fall	25,612	0	5,310	312
	Winter	12,856	0	2,665	157
3	Spring	0	50,986	0	0
	Summer	24,777	40,178	2,009	0
	Fall	37,849	0	7,847	462
	Winter	20,407	0	4,231	249

Parker Canyon Lake

Age (Years)	Season	Prey Species: Bluegill	Largemouth Bass	Northern Pike	Rainbow Trout
0	Summer	2,253	279	0	0
	Fall	10,646	1,316	0	0
	Winter	9,099	1,125	0	0
1	Spring	4,819	4,840	0	11,831
	Summer	16,941	23,395	0	0
	Fall	12,489	15,273	0	12,867
	Winter	2,429	0	0	21,865
2	Spring	521	515	0	1,335
	Summer	1,789	2,471	0	0
	Fall	1,117	1,612	42	1,286
	Winter	0	111	67	2,046
4	Spring	489	478	0	1,281
	Summer	1,655	2,285	0	0
	Fall	1,000	1,442	37	1,125
	Winter	0	92	55	1,691
6	Spring	724	706	0	1,914
	Summer	2,444	3,375	0	0
	Fall	1,462	2,108	53	1,629
	Winter	0	129	77	2,376

Upper Lake Mary

Age (Years)	Season	Prey Species: Black Crappie	Crayfish	Golden Shiner	Rainbow Trout
0	Summer	1,166	96	650	0
	Fall	0	0	184	5,936
	Winter	0	0	5,136	2,766
1	Spring	25,205	2,066	14,049	0
	Summer	33,752	2,767	18,813	0
	Fall	0	0	1,204	38,932
	Winter	0	0	21,099	11,361
2	Spring	7,559	3,649	14,858	0
	Summer	10,661	5,147	20,955	0
	Fall	0	0	258	25,501
	Winter	5,297	0	183	12,786
3	Spring	5,246	2,533	10,312	0
	Summer	7,558	3,649	14,855	0
	Fall	0	0	175	17,344
	Winter	3,422	0	118	8,259
4	Spring	1,434	692	2,819	0
	Summer	2,098	1,013	4,124	0
	Fall	0	0	48	4,708
	Winter	901	0	31	2,176

Table 3.- Bioenergetics model predictions mean proportion of maximum ration (*P*-values) for the respective age-classes of northern pike by season in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona.

Long Lake			Parker Canyon Lake			Upper Lake Mary		
Age (year)	Season	P-value	Age (year)	Season	P-value	Age (year)	Season	P-value
0	Summer	0.26	0	Summer	0.54	0	Summer	0.18
	Fall	0.40		Fall	0.46		Fall	0.58
	Winter	0.46		Winter	0.84		Winter	1.72
1	Spring	0.27	1	Spring	0.38	1	Spring	0.57
	Summer	0.26		Summer	0.33		Summer	0.32
	Fall	0.32		Fall	0.29		Fall	0.31
	Winter	0.59		Winter	0.48		Winter	1.01
2	Spring	0.28	2	Spring	0.33	2	Spring	0.44
	Summer	0.19		Summer	0.30		Summer	0.26
	Fall	0.25		Fall	0.27		Fall	0.27
	Winter	0.82		Winter	0.44		Winter	0.83
3	Spring	0.22	4	Spring	0.30	3	Spring	0.40
	Summer	0.16		Summer	0.28		Summer	0.24
	Fall	0.21		Fall	0.25		Fall	0.25
	Winter	0.52		Winter	0.40		Winter	0.76
			6	Spring	0.29	4	Spring	0.39
				Summer	0.27		Summer	0.24
				Fall	0.25		Fall	0.24
				Winter	0.38		Winter	0.73

Table 4.- Hatchery reared rainbow trout stocking history, estimated northern pike consumption of rainbow trout, and the cost of rainbow trout lost to predation in Long Lake, Parker Canyon Lake, and Upper Lake Mary, Arizona from October 2001 to November 2002.

Lake	Stocking dates	Number stocked	Average TL & Wt	Number consumed	Percent consumed	Cost of trout consumed
Long	3/4/2002	10,000	200 mm	290 trout	2.9%	$199.02
			84 g	(95 % C.I. 180 - 470)	(95% C.I. 1.8 – 4.7%)	(95% C.I. $123.53 – 322.56)
Parker Canyon	10/23/2001 - 4/8/2002	27,076	249 mm	335 trout	1.2%	$510.18
			178 g	(95 % C.I. 139 – 1,059)	(95% C.I. 0.5 – 3.8%)	(95% C.I. $211.70 – 1,612.86)
Upper Mary	9/24/2002	11,752	120 mm	7427 trout	63.2%	$123.72
			17 g	(95 % C.I. 2,444 – 36,137)	(95% C.I. 20.8 – 307.5%)	(95% C.I. $197.48 – 2,919.87)

CHAPTER B

Distribution and status of northern pike in the southwestern U.S.

Distribution and status of northern pike in the southwestern U.S.

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Key Words: northern pike, Southwest, illegal, introductions, distribution, impacts

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Abstract

Northern pike were primarily brought into the southwestern U.S. in the 1960s and 1970s as reservoirs were developed and government agencies sought a species with sportfishing qualities to diversify angler opportunities. Non-native populations of northern pike currently exist in all the southwestern states and some states have seen a rise in illegal introductions by anglers. Top predators, such as northern pike, can be troublesome for managers given the ability of northern pike to exert top-down effects and alter fish communities. In California, an attempt to eradicate a population of northern pike using a piscicide application following an illegal introduction into Lake Davis cost roughly $15 million. Introductions of northern pike have had undesirable consequences on both existing warmwater and trout fisheries, and have threatened native fishes in adjacent areas. Few control options for northern pike exist and mechanical removal for reducing or controlling northern pike has not been successful in the Southwest. Once northern pike become established, little besides chemical treatment has been effective, for eradication.

Introduction

Northern pike, *Esox lucius*, are picivorous top predators that have the ability to tolerate a wide range of environmental conditions (Casselman 1996). They are common inhabitants of many lakes throughout the United States, inhabiting 45% of the total area of freshwater of North America (Carlander et al. 1978). The historic range of northern pike in North America was in north temperate regions and comprised 23 states in the U.S (Crossman 1978). However, the distribution of northern pike has expanded and non-native records exist in 38 states (Fuller et al. 1999). Currently northern pike exist in all of the southwestern states, now the southern limit of its range in the United States (Crossman 1978). The development of impoundments and the sport fishing qualities of northern pike provided the catalyst for this expansion. Unfortunately, several southwestern states have reported illegal introductions of northern pike. Expansion of the range of northern pike in northwestern states via illegal introductions also has been a problem (McMahon and Bennett 1996). Northern pike is an easy species to become established in the event of an illegal introduction due to their high fecundity (2-44 eggs per g of body weight) and ability to spawn with few individuals (Spanovaskaya and Soloninova 1984). Also, illegal introductions have become easier given the modern convenience of live wells in most boats (McMahon and Bennett 1996). There is growing concern among managers in the Southwest about the potential top-down effects northern pike might exert on prized trout fisheries, warmwater fisheries, or native fishes. Top predators, such as northern pike, can be troublesome given their ability to alter fish communities (He and Kitchell 1990). Also, illegally introduced northern pike create undesirable source populations for other introductions and often lead to large financial expenditures for eradication and control. We review the general history, effects, and management of northern pike stocked in the American Southwest. We also discuss two case histories of northern pike introductions into this region and their repercussions.

Present distribution

The first reported introduction of northern pike in the Southwest may have occurred in California in 1891 by the United States Fish Commission (Dill and Cordon 1997). However, there is confusion concerning the exact identity of the species. It may have been grass pickerel, *Esox americanus*. The species never became established in California. Northern pike were not reported from California until 1988 when an angler captured one in Frenchman Reservoir. California Department of Fish and Game (CDFG) confirmed in the fall of 1989 that northern pike were present in significant numbers after an illegal introduction into the reservoir. In 1991 and 1992 CDFG successfully eliminated northern pike from Frenchman Reservoir, the Middle Fork Feather River below the reservoir, and nearby streams, using a piscicide. Northern pike were thought to be no longer present in the state. However, in 1994, northern pike were found in nearby Lake Davis and probably originated from Frenchman Reservoir as a result of an illegal stocking several years earlier (Table 1). In 1997, Lake Davis was treated, but the treatment did not remove all northern pike from the lake, and they were rediscovered in 1999. Currently, Lake Davis supports the only population of northern pike in California (Figure 1).

In the 1960s, Nevada Department of Wildlife (NDOW) stocked northern pike for sportfishing. Northern pike were stocked in Bassett Lake, Commins Lake, Dakes Lake, and JD Reservoir (Deacon and Williams 1984; Sigler and Sigler 1987). In the 1980s, state officials successfully treated Commins Lake to remove the northern pike and restore a trout fishery. However, in the late 1990s, anglers reintroduced northern pike illegally and probably brought them over from Bassett Lake (B. Layton, Nevada Division of Wildlife, personal communication). Northern pike also exist in a section of the Humboldt River below JD Reservoir as a result of the dam being washed out.

Officials with the Utah Division of Wildlife (UDWR) first introduced northern pike to Utah in Redmond and Yuba reservoirs in 1978. Currently both reservoirs support self-sustaining populations. Other populations of northern pike are known to occur in the Green River below Flaming Gorge Reservoir. Northern pike were first reported in this section of Green River in 1981, the result of downstream movement from the Yampa River in Colorado (Tyus et al. 1982). Northern pike were introduced into Elkhead Reservoir, Colorado, an impoundment on the Yampa River drainage in 1977. In 1979, northern pike were collected in the mainstem of the Yampa River, where their numbers increased in the early 1980s (Wick et al. 1985). Northern pike may spawn in the mainstem of the Green River, but recruitment is low within the river (Tyus and Beard 1990). Northern pike can also be found in the Colorado River (Bergersen 2001) and an occasional adult may move into Lake Powell where only one was collected by UDWR in the last 25 years (W. Gustavason, Utah Division of Wildlife, personal communication).

Successful reproduction of northern pike is highly unlikely in Lake Powell given its steep canyon walls, lack of macrophytes, and high water temperatures in shallow nursery areas.

The Arizona Game and Fish Department (AGFD) first introduced northern pike into Arizona in 1965 when four lakes were stocked to provide sportfishing opportunities. Overall, 13 lakes or reservoirs were stocked with northern pike from 1965 to 1974. Northern pike were able to reproduce and establish populations in Long Lake, Lower Lake Mary, Mormon Lake, Upper Lake Mary, Stoneman Lake, and Soliders Lake. Recent drought conditions in the state caused Stoneman Lake, Mormon Lake, and Lower Lake Mary to dry. Northern pike were also introduced into the Verde River from 1968-1970, but did not establish. Northern pike presumably were introduced around the same time period, (i.e., late 1960s to early 1970s), in McNary Mill Ponds on the White Mountain Apache Indian Reservation. Big Bear and Little Bear lakes, located on the Reservation, contained northern pike, but were renovated to remove northern pike (K. Meyers, Arizona Game and Fish Department, personal communication). Currently, four lakes in Arizona support populations of northern pike established through illegal stockings. Northern pike were illegally stocked in Ashurt Lake in the 1990s, and they moved into Coconino Lake. Two illegally stocked northern pike about 1.8 kg in weight, were captured in Fools Hollow Lake in 2003. It is unknown whether northern pike established a self-sustained population. Parker Canyon Lake was illegally stocked with northern pike, sometime between 1996-1997 (Mitchell and Young 1999). Parker Canyon Lake is 10 km north of the U.S.-Mexico border and probably is the limit of southern distribution of northern pike in the United States.

In New Mexico, northern pike were stocked during the 1970's by New Mexico Game and Fish (NMGFD). Springer Lake, Miami Lake, Cochi Lake, Navajo Lake, and Farmington Lake were stocked. Since then, northern pike from Cochi Lake have moved up the Rio Grande River past the Colorado stateline. Within the Rio Grande River, the major concern is possible predation by northern pike on the trout fishery and on native fishes. Although no active management has been directed to remove northern pike, fly fishing groups have targeted northern pike in attempts to reduce their numbers in the Rio Grande River. The Rio Grande River is home to native fish such as Rio Grande chub *Gila pandora*, Rio Grande sucker *Catostomus plebeius*, and Rio Grande cutthroat trout *Oncorhynchus clarki virginalis*. Currently the only body of water actively managed for northern pike in New Mexico is Springer Lake. Rainbow trout were stocked in Springer Lake many years prior to 1993, but predation on rainbow trout by northern pike was high and stockings ceased. Shortly after 1993, the condition of northern pike dramatically dropped and the population dynamics have become more cyclical (E. Fry, New Mexico Game and Fish Department, personal communication). No illegal introductions of northern pike have been reported in New Mexico.

Southwestern case studies

The most famous example of northern pike in the Southwest occurred in Lake Davis, California. The illegal introduction of northern pike in 1994 to Lake Davis caused alarm among managers due to predation threat of northern pike to the popular trout fishery and the possible escape or introduction into the Sacramento-San Joaquin Delta containing a valuable salmon fishery and two endangered native fishes, Sacramento winter-run Chinook salmon *Oncorhynchus tschawytscha*, and delta smelt *Hypomesus transpacificus*. In 1995, eradication using chemical toxicants was determined to be necessary to protect the trout fishery and prevent the illegal and migratory spread of northern pike to other waters. A similar conclusion was reached by CDFG in 1988 when northern pike were discovered in Frenchmen Reservoir and was successfully chemically treated in 1991. The trout population in Lake Davis was severely reduced as result of northern pike predation and only trout greater than seventeen inches in length were surviving (Lee 2001). Prior to the treatment of Lake Davis the local community of Portola began expressing and organizing opposition to the chemical treatment, the community's source of drinking of water. Nevertheless, CDFG cleared the legal channels and treatment began on October 15, 1997. The threat of violence against CDFG was so high California Highway Patrol were called to assist in the delivery of 60,000 lbs of powdered rotenone and 16,000 gals of Nusyn-noxfish to state property (Lee 2001). The lake was restocked with trout and the state compensated Portola and Plumas County with $9.1 million for an alternate drinking water source and lost fishing and tourist business. Two years later northern pike were rediscovered in Lake Davis. Today, CDFG have begun working closely with local community members and has been experimenting with various new techniques in an attempt to suppress the northern pike population. Thirteen ideas were discussed on a panel set up in 2000 and ideas ranged from detonation cord to blocking of coves with nets to contain the northern pike population. Illegally introduced northern pike at Lake Davis have cost the state of California an estimated $15 million dollars. Clearly northern pike are a highly undesirable species for the state given their high predation rates on trout and threat to a variety of other sportfishes in Lake Davis. Also, northern pike escapement into other streams and reservoirs through immigration or illegal stockings by anglers could disrupt California's salmon and trout fisheries and further endanger various other native fishes.

In Arizona, northern pike were illegally introduced to Parker Canyon Lake, a popular trout fishing site along the U.S.-Mexico border, around 1996 to 1997. The nearest northern pike population to Parker Canyon Lake is at least a six-hour drive away. Winter surveys conducted by AGFD in 1999, 2000, and 2001 found rainbow trout were in 65 percent of northern pike stomach contents (D. Mitchell, Arizona Game and Fish Department, unpublished data). In research we conducted the wet weight of rainbow trout comprised 94 percent of the diets of northern pike in the winter. Prior to the discovery of northern pike, AGFD was researching the limnology of the lake to determine the feasibility of creating a put-grow-and-take trout fishery rather than a put-and-take, to save on the cost of stocking rainbow trout. However, with the discovery of northern pike, that management option became unfeasible due to the high predation threat of northern pike on smaller trout. Also, the threat of continued illegal introductions from Parker Canyon to other bodies of water in the area remains real. Native fish reside in streams and rivers near Parker Canyon Lake and temperature profiles of the nearby creeks contain pools with adequate temperatures for northern pike (Mitchell and Young 1999). The total estimated cost of chemically treating Parker Canyon Lake at full capacity is $582,650.00 (Mitchell and Young 1999). Similar to Lake Davis the cost and threat of illegally introduced northern pike is high. Chemical treatment of northern pike in Parker Canyon Lake appears to be the only option to restore the trout fishery and remove the source population as a means for introductions to other waters.

Popularity with anglers

Fishing preference for northern pike by anglers appears low in the Southwest. A nationwide angler survey conducted in 2001 found anglers fishing for northern pike, pickerel, muskie, or muskie hybrids comprised 7% of the total anglers surveyed within the U.S. Whereas, anglers fishing for black bass, panfish, and trout comprised 38%, 28%, and 28%, respectively, of the species sought after by anglers (USFWS 2001). In the Southwest where northern pike populations are less abundant than in the northern states, such as Minnesota and Wisconsin, anglers fishing for northern pike should be lower given the lack of accessibility to the lakes. A statewide survey conducted in Arizona conducted in 1999 where anglers were asked what fish they prefer to fish for, northern pike comprised only 0.3% of the respondents (T. Pringle, unpublished). Trout and largemouth bass were the two species most preferred by anglers and comprised 37.8% and 28.4%, respectively.

Although exact numbers spent on northern pike fishing in the Southwest do not exist, combining data from nationwide and statewide surveys can provide a general estimate for Arizona. In 2001 anglers in Arizona spent $336 million dollars overall on fishing (USFWS 2001). If northern pike expenditures were assumed to be 0.3% based on Arizona statewide surveys then expenditures would be approximately $1 million dollars per year. Similar values could be used on states where anglers surveyed in California spent $2,029,581,000, Nevada $216,721,000, New Mexico $176,476,000, and Utah $392,617,000.

Impacts to sport and native fishes

The sportfish most likely to be impacted by northern pike predation in the Southwest are trout, given the overlap in the water temperatures between the two species and the prey preference of northern pike for soft-rayed fish (Beyerle 1973). Rainbow trout numbers have been reduced in southwestern lakes where northern pike exist (CDFG 2003). In some lakes in Arizona and New Mexico, agencies no longer stock trout or reduced stockings because predation from northern pike results in a negligible return to the creel (E. Fry, New Mexico Game and Fish, personal communication; K. Meyers, Arizona Game and Fish, personal communication). Hatchery-reared salmonids are particularly vulnerable to northern pike predation. For example, 20 to 70-cm northern pike ate large numbers of newly released salmon smolts in the Keret River, northern Russia (Pervoszyvankiy and Bugayev 1992). Areas where a potential trophy trout fishery could exist become marginal trout fisheries at best when northern pike are present (Bergensen 2001). Stocking of larger trout in an attempt reduce predation increases the costs of the states to raise large fish in hatcheries.

Another popular sportfish affected by northern pike predation are largemouth bass, which are found in some of the waters containing northern pike in the Southwest. While food habitat studies of northern pike have found that centrarchids are not a preferred food of northern pike (Beyerle 1971; Mauck and Coble 1971), some studies have shown that northern pike consume largemouth bass (Gurtin et al. 1996; Soupir et al.

2000; Paukert and Willis 2003). In sympatric populations of largemouth bass and northern pike in Nebraska's Sandhill lakes the abundance of largemouth bass was reduced (Paukert and Willis 2003). In the same study, predation on the prey species, bluegills and yellow perch occurred, suggesting that northern pike compete for the same food resources as largemouth bass in these lakes.

Potential predation effects of northern pike on native fish in the Southwest are largely unknown. The current distribution of northern pike in the Southwest is primarily in reservoirs where native fish are not found. However, populations of northern pike found in southwestern rivers of the Green River, Colorado River, and Rio Grande River are mostly likely the waters where native fish may be "threatened". Within these river systems northern pike can move long distances. For example, a tagged northern pike migrated 110 km in the Green River during one year (Tyus and Beard 1990). Thus, even if northern pike may not be able to reproduce in certain sections of the river they still possess the ability to migrate throughout rivers stretches predating upon native fish. A study conducted by Colorado State University researchers found bite wounds from northern pike on 9 percent of the native Colorado pikeminnows *Ptychocheilus lucius* collected in 2000 in the Yampa River, a tributary to the Green River (USFWS 2002).

Northern pike is a coolwater species and has an upper lethal incipient temperature of 29.4 ºC with optimal growth occurring at 19-21 ºC. Thus, lower elevation desert lakes, reservoirs, streams, and rivers containing native fish in the Southwest probably contain water temperatures to high to allow northern pike to survive. Native fish found in the lakes, reservoirs, streams, and rivers at higher elevations would be the most susceptible to northern pike introductions.

Control options

Few "control options" for northern pike exist. Only piscicide applications or complete dewatering can eradicate an entire population of undesirable fish (Schnick 1974). Currently no piscicide is available that selectively kills northern pike and desired fish species may take years to reach carrying capacity after complete eradication of a population (Finlayson et al. 2000). Other methods for reducing or controlling fish communities include: modification of angling regulations to promote or favor overharvest, mechanical removal techniques (i.e., gillnets, electrofishing, fyke nets), biological control techniques (i.e., predators, pathological reactions), drainage of marsh areas in lakes, or reservoir drawdown (Nelson 1978; Finlayson et al. 2000).

Most methods for reducing or controlling northern pike have not been successful. Angler harvest is generally inadequate and often ineffective to alter population structures or densities in northern latitudes (Goeman et al. 1993; Pierce et al. 2003). Results from Lake Davis suggest angler harvest has done little to reduce the northern pike population (CDFG 2001). Biological control of a top-predator like northern pike is highly unlikely unless a pathogen is released. However, pathogens released in the environment often have unpredictable side effects (Finlayson et al. 2000). Mechanical removal of northern pike in the Southwest may not be a viable method for control of the species and has not been successful in Lake Davis. Following the rediscovery of northern pike in 1999, a team was developed several options to remove northern pike and the plan was carried out in 2000. The results from 3 1/2 years of implementing 13 control and containment techniques for northern pike in Lake Davis was evaluated in June 2003 after 28,100 (1,928 kg) northern pike were removed (CDFD 2003). Four criteria were selected to determine if mechanical removal using various techniques were successful: 1) Changes in the northern pike density; 2) Impact to the trout fishery; 3) Changes in the risk of northern pike escaping; and 4) Changes in the risk of human movement of northern pike. However, since the 3 ½ years of mechanical removal, the population of northern pike has increased, trout densities have decreased partly due to northern pike predation coupled with a decrease in stocking numbers, and risk of northern pike escaping or human movement has increased due to the higher density population. The high fecundity of northern pike and favorable environmental conditions for fry in Lake Davis may offset the high mortality resulting from mechanical removal (CDFG 2003). Water levels and temperature are the main abiotic factors influencing year-class strengths of pike. Strong year classes of pike are associated with rising water levels and flooded terrestrial vegetation during period of spawning (Beckman and Elrod 1971). A reduced spawning area caused by the lowering of the water level results in a reduction in the number of recruits (Autko 1964). Since northern pike require vegetation to spawn, drainage of marsh areas in lakes, or large fluctuations in reservoirs water levels eliminate spawning areas for these fish (Hassler 1970; Nelson 1978). However, drawdown also adversely impacts other spring spawners in the reservoirs through loss of habitat or morality to eggs or larvae (Heman et al. 1969; Ploskey 1986). Thus, it appears mechanical removal would only partially remove northern pike and provide only temporary improvement because of their prolific nature. Northern pike would likely soon return to maximum carrying capacity once mechanical treatment stops.

Conclusions

Once northern pike become established, little besides chemical treatment has been effective for removal. Managers are faced with the dilemma of determining whether the costs and impacts of from predation are high enough to justify removal of northern pike. Often options for the fisheries managers are reduced with illegal introductions of northern pike (McMahon and Bennett 1996). Hatchery-reared trout stockings may be halted or reduced in lakes containing northern pike due to high predation losses. As stockings are halted, the northern pike population crashes and condition decreases as the main forage base is removed (E. Fry, New Mexico Game and Fish Department, personal communication). A “no-management” option has often been used to provide fishery opportunities in southwestern lakes where northern pike exist. In these situations, managers allow northern pike populations to exist unhampered in the lake, and reduce their emphasis on trout fisheries. Managers then put management efforts on lakes where active management is beneficial. However, lakes containing northern pike provide a source population for future illegal introductions. Removal of northern pike in areas were local opposition is low and costs are not prohibitive may minimize the predation threat of northern pike in the lake and adjoining waters and eliminate a source population for future introductions. Northern pike do provide sportfishing opportunities for anglers in the Southwest, and this was the primary reason they were introduced (Casselman 1978). In some areas, the presence of northern pike has diversified angling opportunities, especially for anglers from the midwestern United States where northern pike are native, familiar, and create enjoyable fisheries. However, in the process of creating diversified sport fishing opportunities, introductions of northern pike have had undesirable consequences on both existing warmwater and trout fisheries and have threatened native fishes in adjacent areas.

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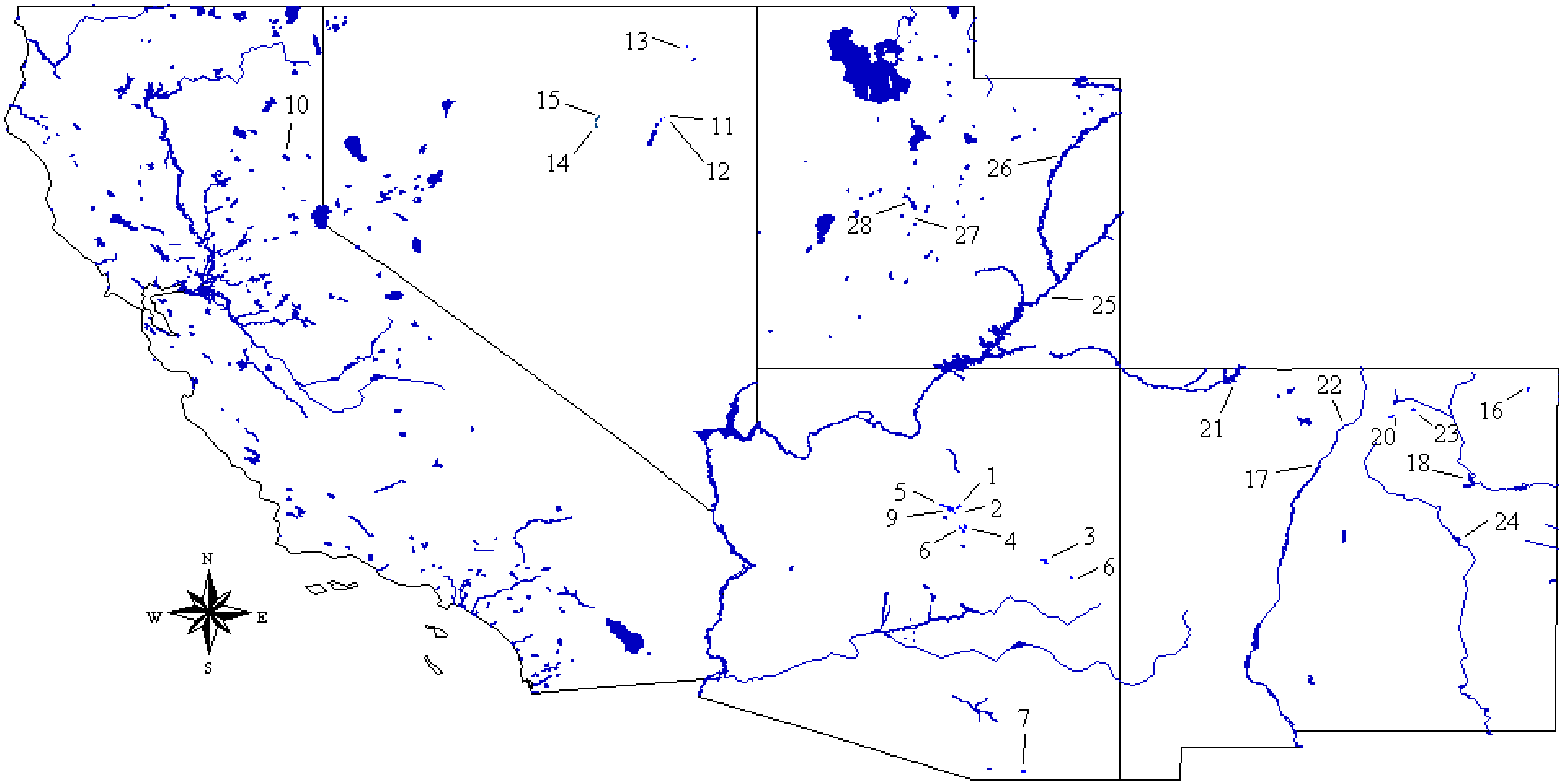

Figure 1.- Map depicting the current range of northern pike in the southwestern states. Numbers correspond to the body of water listed in Table 1.

Table 1.- Lakes, reservoirs, and rivers in southwestern states containing northern pike, with the source of the population defined as an invasion (IN), illegal introduction (IL), and legal stocking (S).

State	Location	Source
Arizona	1. Ashurt Lake	IL
	2. Cocinino Lake	IN
	3. Fools Hollow Lake	IL
	4. Long Lake	S
	5. Lower Lake Mary	S
	6. McNary Mill Ponds	S
	7. Parker Canyon Lake	IL
	8. Soldiers Annex Lake	S
	9. Upper Lake Mary	S
California	10. Lake Davis	IL
Nevada	11. Bassett Lake	S
	12. Comins Lake	IL
	13. Dakes Lake	S
	14. Humbolt River	IN
	15. JD Reservoir	S
New Mexico	16. Clayton Lake	S
	17. Cochiti Lake	S
	18. Conchas Reservoir	S
	19. Farmington Lake	S
	20. Miami Lake	S
	21. Navajo Lake	S
	22. Rio Grande River	IN
	23. Springer Lake	S
	24. Sumner Reservoir	S
Utah	25. Colorado River	IN
	26. Green River	IN
	27. Redmond Reservoir	S
	28. Yuba Reservoir	S