Northern pike management studies in the Yampa River, Colorado, 1999-2002

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Contribution 137 of the Larval Fish Laboratory, Colorado State University

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Disclaimer

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EXECUTIVE SUMMARY

Northern pike *Esox lucius* is a nonnative species that invaded the Yampa River, located in northwestern Colorado, in the late 1970s and they now occupy the mainstream river and several connected reservoirs. Northern pike are considered a predatory threat to Colorado pikeminnow *Ptychocheilus lucius,* a federally endangered species with critical habitat in the lower half of the Yampa River. We evaluated mechanical removal of northern pike primarily from a 75-mile portion of the Yampa River within critical habitat with the following objectives: 1) Remove juvenile and adult northern pike from critical habitat reaches in the Yampa River, 2) Relocate northern pike from the Yampa River to isolated ponds or reservoirs in or near the Yampa Valley that conform to Nonnative Fish Stocking Procedures and are accessible to anglers, and 3) Determine effectiveness of removal in reducing the number of northern pike of all sizes or reducing the number of large northern pike. All objectives were met.

A presumed northern pike spawning area upstream of critical habitat near Hayden, Colorado and a major portion of critical habitat for Colorado pikeminnow were sampled with boat electrofishing, fyke nets, and seines between 1999 and 2002. During four years, 1042 northern pike were removed and translocated to Yampa State Wildlife Area ponds or Rio Blanco Reservoir. Lengths of northern pike ranged from 28 to 1015 mm. Collection of young-of-year northern pike confirmed spawning and nursery areas in the Hayden Reach in 1999. Downstream movement of juvenile and small adult northern pike into critical habitat was supported by the distribution and abundance of small adults that were captured predominantly in the most upstream

reach in critical habitat. As distance increased downstream the number of small adults declined. Large northern pike were distributed throughout the river.

Although removal was considered effective at reducing the number of northern pike, removal effects varied by reach. After initial declines from 2000 to 2001 in all reaches, northern pike numbers continued to decline at Lily Park and increased at Juniper and Maybell in 2002. Removal was most effective at Lily Park apparently because fish were removed at a greater rate than the rate of immigration and recruitment. Reduced immigration at Lily Park was attributed to upstream removals that relieved competitive pressures that would increase downstream dispersal. Reduced recruitment at Lily Park was attributed to the absence of a local source of small fish and the distant source of potential recruits far upstream. Catch rate increases in Juniper and Maybell in 2002 were proportional to an increase in the number of small adults in each reach, with the largest number of small adults in Juniper. For removal to be effective, fish must be removed at a rate greater than the rate of replacement from immigration or recruitment. Effective removal will require increased effort (i.e. more sampling occasions) and removal in areas upstream of critical habitat to reduce immigration into downstream critical habitat reaches.

Northern pike occurred in concentration areas immediately downstream of Juniper and Cross Mountain canyons and in spring backwaters throughout the river. Concentration areas were sinks for northern pike and were recolonized by northern pike between sampling trips. Removal effectiveness could increase by increasing effort in concentration areas and habitats that attract northern pike.

There was evidence of northern pike predation attempts on Colorado pikeminnow as large as 799 mm TL. Injuries attributed to northern pike were observed on 18% of all Colorado pikeminnow handled and injury rate of newly handled fish increased each year. Prey removed from live northern pike included roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis*, and bluehead sucker *C. discobolus*. Prey consumed by northern pike were as large as 72% of the predator length.

Conclusions

- Objective 1 was accomplished. Northern pike juveniles and adults were captured using electrofishing and fyke nets and removed from the Yampa River.
- Objective 2 was accomplished. Northern pike were moved to ponds in the Yampa River drainage and a reservoir in the White River Valley and mortality of handled fish was very low (4%).
- Objective 3 was accomplished. Effectiveness of removal in reducing the number of northern pike of all sizes or reducing the number of large northern pike was evaluated.
- Removal was most successful in Lily Park, the most downstream reach, apparently because the reach was located the farthest from upstream sources of reproduction and recruit-sized fish.

- In Lily Park, removal was effective at reducing numbers of large northern pike $\geq$ 600 mm.
- Removal was initially effective in all reaches, but was least effective in Maybell and Juniper reaches, apparently due to the proximity of each reach to a source of recruiting and immigrating fish.
- In Juniper and Maybell, the number of large northern pike $\geq$ 600 mm was apparently sustained in 2002 by recruitment of a strong cohort to that length.
- Northern pike densities were highest in concentration areas and northern pike recolonized these areas after removal.
- Northern pike outnumbered Colorado pikeminnow in the river and in several backwaters.
- Changes in length-frequency distributions of northern pike over time were attributed to growth of strong cohorts and not a result of removal.
- There were strong cohorts of juvenile and small adult northern pike that apparently entered critical habitat through Juniper, the most upstream reach in critical habitat.
- Northern pike consumed prey that were up to 72% of their body length.
- Colorado pikeminnow were subject to northern pike predation attempts as evidenced by attack injuries.
- Northern pike attack injuries were observed on 18% of Colorado pikeminnow and annual injury rate increased over time.
- Northern pike preyed on other native fishes such as roundtail chub, flannelmouth sucker, and bluehead sucker.

Recommendations

- Increase number of northern pike removed annually in critical habitat
  - Increase the number of riverwide removal occasions each year.
  - Increase the number of samples in high density areas on each sample occasion.
  - Extend removal to other seasons.
- Reduce immigration from areas upstream of critical habitat:
  - Expand juvenile and adult removal to areas upstream of critical habitat.
  - Tag northern pike in Elkhead and Catamount reservoirs to determine relative levels of escapement of adults to the river and if necessary, focus control measures such as screening on the reservoir with the greatest level of escapement.
- Reduce recruitment from areas upstream of critical habitat
  - Identify concentrations of young-of-year (YOY) northern pike to determine the relative contribution of young from reservoir and riverine spawning areas. This could be accomplished by sampling for young fish in the river from Catamount Reservoir to the Green River confluence.
  - Identify and confirm spawning sites associated with YOY concentrations.
  - Prioritize and direct management at high production areas.
  - Investigate and implement techniques that limit access of spawning adults to high production spawning areas.
  - Block escapement of YOY or eliminate YOY from high production spawning areas.

- Identify riverine and reservoir environmental conditions associated with strong cohorts and evaluate the potential to negatively manage these conditions to reduce cohort strength.
- Conduct periodic abundance estimates of northern pike to measure removal effect.
- Develop bioenergetic models that help define the level of removal necessary to benefit native and endangered fishes.

INTRODUCTION

Project background— This project implemented nonnative fish management in the Yampa River with a goal to improve the survival of endangered fishes in the Yampa River by reducing the number of adult northern pike *Esox lucius* in critical habitat. Northern pike was ranked as one of six nonnative piscivorus species of greatest concern by biologists in the Upper Colorado River Basin based on their potential for predation of endangered and other native fishes (Hawkins and Nesler 1991). Northern pike occupy portions of the Yampa and Green rivers identified as critical habitat for endangered Colorado pikeminnow *Ptychocheilus lucius*, humpback chub *Gila cypha*, razorback sucker *Xyrauchen texanus*, and bonytail *G. elegans*. Northern pike, also pose a predatory and competitive threat to other native species such as roundtail chub *G. robusta*, bluehead sucker *Catostomus discobolus*, and flannelmouth sucker *C. latipinnis* (Martinez 1995).

The Upper Colorado River Endangered Fish Recovery Program (Recovery Program) determined that control of nonnative fishes was necessary for recovery of the endangered fishes in the Upper Basin. The Colorado Division of Wildlife (CDOW), a Recovery Program participant, developed an Aquatic Wildlife Management Plan for the Yampa River Basin (Yampa Aquatic Plan) which included management of northern pike and other nonnative species (CDOW 1998). The Yampa Aquatic Plan recommended active trapping and translocation of northern pike, smallmouth bass *Micropterus dolomieu*, channel catfish *Ictalurus punctatus*, and white sucker *C. commersoni*, from portions of the Yampa River that contain critical habitat for endangered fish. In addition to the priority of enhancing survival of endangered fishes, the Yampa Aquatic Plan acknowledged the importance of continuing to provide fishing opportunities for anglers and recommended that gamefish removed from critical habitat be translocated to nearby, isolated waters. This project initiated northern pike removal as recommended by the Yampa Aquatic Plan with the following objectives:

1. Remove juvenile and adult northern pike from critical habitat reaches in the Yampa River.
2. Relocate northern pike from the Yampa River to isolated ponds or reservoirs in or near the Yampa Valley that conform to Nonnative Fish Stocking Procedures and are accessible to anglers.
3. Determine effectiveness of removal in reducing the number of northern pike of all sizes or reducing the number of large northern pike.

Historical background of northern pike in the Yampa River— The northern pike is a coolwater species with a circumpolar native distribution that extends from northwestern Europe across northern Asia to northern North America. In North America, its native range includes most of Canada, Alaska, New England, and states around and west of the Great Lakes; however, it has been widely introduced as a gamefish and its current range now extends far south into waters outside its native range. In Colorado, northern pike were first introduced by private fish culturists into waters of the eastern plains in 1874 and by state and federal agencies into northeastern reservoirs in 1956 (Wiltzius 1985). Between 1962 and 1970, the state of Colorado stocked northern pike in several other small reservoirs within the drainages of the Colorado, Gunnison, Dolores, San Juan, and White rivers. In western Colorado, northern pike were first stocked in 1962 by the state wildlife agency in Vallecito Reservoir in the San Juan River drainage near Durango and in Joe Moore Reservoir near the town of Mancos in the Dolores River drainage (Wiltzius 1985).

Wiltzius (1985) in his review of previous gamefish stockings in Colorado, reported only one stocking for northern pike in the Yampa River drainage and that record was inaccurate. Wiltzius (1985) reported that Divide Creek Reservoir received northern pike in 1970 and that this reservoir was in the Yampa River Basin. This was inaccurate because this small reservoir, southwest of Elk Springs, Colorado, is in the White River drainage. Wiltzius (1985) did not report any other records for the Yampa River drainage but records at the CDOW show that 571, 50 to 100 mm long northern pike obtained from Colorado State University were stocked in Elkhead Reservoir by the CDOW in 1977 (P. Martinez, pers. comm.). Presumably, the stocking was to reduce an over-abundance of suckers and fathead minnows (W. Elmblad , pers. comm.). Elkhead Creek is a Yampa River tributary located about 5 miles upstream of Craig and the reservoir dam is about 4 miles up the tributary (Figure 1).

Northern pike were not collected in the Yampa River by researchers until 1979. Prior to that, northern pike were not reported in stream surveys of the Yampa River in the 1950s (Lemons 1954; Klien 1957) and none were captured during intensive sampling from Steamboat Springs to Lily Park between 1975 and 1978 (Carlson et al.

1979; Prewitt et al. 1978; Wick et al. 1979). These investigators captured thousands of fish of all life stages by electrofishing boat, trammel net, gill net, seine, and dipnet, and likely would have collected northern pike unless the species was extremely rare or absent. In October 1979, a 670 mm total length (TL) northern pike that weighed 2270 grams was caught by researchers angling at Lily Park (Wick et al. 1981 and associated field notes). Based on current growth rates for northern pike, the estimated age of this fish was six or seven years old (P. Martinez and K. Rogers, pers. comm.). Adult northern pike continued to be collected in low numbers downstream of Craig, from 1981 through 1984 (Miller et al. 1982; Wick et al. 1985a, 1985b, 1986) and apparently increased in abundance and distribution through 1991 as evidenced by their more frequent occurrence in samples taken by Nesler (1995). From 1986 through 2000, northern pike were caught consistently in critical habitat in the Yampa River as a by-catch of an interagency standardized monitoring program (ISMP) for Colorado pikeminnow and their numbers peaked in 1992 and 1999 (C. McAda, in litt.).

Elkhead Reservoir was widely considered the original source for northern pike in the Yampa River, but unless stocked fish were larger than the sizes reported (50–100 mm), the capture of a 670 mm, six-year-old northern pike in 1979, two years after stocking would refute that claim. If stocking sizes were accurate, then fish stocked in Elkhead Reservoir in 1977 would have been two to three years old by 1979 and could not be as large as the fish captured in 1979. Unless the CDOW stocking records are incomplete or inaccurate, then northern pike did not originate from Elkhead Reservoir and either northern pike originated from another local water or they moved up the Yampa River from the Green River downstream. If records of early stocking are inaccurate there may have been unreported stockings in the Yampa River basin prior to 1977. In 1970, the state of Colorado stocked northern pike in a variety of small impoundments in northwest Colorado and although no specific records appear to exist, it is conceivable that a small reservoir in the Yampa drainage could have received fish in 1970 (P. Martinez, pers. comm.). A reliable angler from Craig recalled northern pike in Ralph White Reservoir located on Fortification Creek north of Craig in the early 1970s; but, no stocking records could be found for northern pike in Ralph White and creel samples of the reservoir from 1973 through 1979 did not report northern pike (S. Hebein, pers. comm.). There are no known reports of northern pike in the Green River until well after they were found in the Yampa River, suggesting that northern pike did not infiltrate from downstream and implying a Yampa River origin. Although there is much speculation, the initial source of northern pike in the Yampa River remains unknown, however their initial increase and range expansion occurred in the 1980s, after their legal introduction into Elkhead Reservoir.

Reconstructing the origin and expansion of northern pike from events that occurred over 25 years ago is problematic; even recent expansions in the Yampa River basin are difficult to document. Northern pike presently inhabit upstream Catamount and Stagecoach reservoirs, and their origin in these waters is undocumented and likely illicit. Catamount Reservoir was filled in 1979 and Stagecoach Reservoir further upstream, was filled in 1989. Northern pike were first observed in Catamount Reservoir in 1995 (K. Rogers, pers. comm.). Although there is speculation that northern pike were in the river upstream of what is now Catamount Reservoir prior to closure of the dam, there is evidence that supports that northern pike were not in the river and instead were illicitly stocked after closure of Stagecoach Reservoir.

The main reason it is unlikely that northern pike were upstream of Catamount Reservoir before closure of the dam is because given the abundant trout forage available in the reservoir soon after closure, a population of northern pike would have surely developed and been observed well before 1995 (K. Rogers, pers. comm.). A more plausible explanation for the occurrence of northern pike in Catamount Reservoir is that the population was founded from individuals escaping from Stagecoach Reservoir located upstream. Northern pike became established in Stagecoach Reservoir by 1994, with numerous small individuals showing up in gill nets set that year (K. Rogers, pers. comm.). In addition, ages from cleithra of large fish captured over the last several years indicate hatching and therefore reproduction in 1993 (K. Rogers pers. comm.); therefore, adult northern pike were probably introduced to Stagecoach Reservoir very shortly after dam closure.

After 1992, northern pike numbers substantially increased in the Yampa River. An event that could be the likely cause of the increase occurred in the fall of 1992, when the City of Craig, which operates Elkhead Dam and its outlets, initiated a rapid, high volume, prolonged drawdown of Elkhead Reservoir to reduce reservoir water levels to survey for potential reservoir enlargement. During the drawdown, a large portion of the reservoir fishery including northern pike and smallmouth bass were transported into Elkhead Creek and the Yampa River. The loss of gamefish from the reservoir into the river was significant enough to be noticed by reservoir anglers. There was a large reduction in catch of these species in the reservoir soon after the event. Further evidence that this event introduced substantial numbers of fish from the reservoir is that prior to 1992 Nesler (1990) found smallmouth bass extremely rare in the Yampa River. Both species increased in the 1990s with peaks of northern pike in 1992 and 1999 as monitored by ISMP (C. McAda, in litt.). Both northern pike and smallmouth bass are now abundant and widespread. Since their introduction, northern pike have increased their distribution and abundance throughout the Yampa River and the species is now a gamefish river wide (Davis 1995; Haggerty 2001). Northern pike currently reproduce within Elkhead, Stagecoach, and Catamount reservoirs and movement of tagged adults from Stagecoach Reservoir to the river was reported by Hill (2004). The volume and timing of movement and the relative contribution of adults or young from these reservoirs is unknown. Hill (2004) also reported spawning near Hayden, in sloughs, backwaters, and gravel pit ponds but the relative contribution of riverine spawning is also unknown.

STUDY AREA

The Yampa River is located in arid, northwestern Colorado and drains from the southern Rocky Mountains to the Green River. Basin size is 3,410 miles^2, average annual discharge is 1.2 million acre feet, and hydrology is snow-melt driven with peak flows occurring in spring. The study area was in the Yampa River within a presumptive spawning area for northern pike near Hayden , Colorado, and within a portion of critical habitat for Colorado pikeminnow in the Yampa River from near Milk Creek (River Mile; RM 120) to the upstream end of Yampa Canyon (RM 45). River miles denote distance upstream from the confluence with the Green River. The study area was divided into four reaches, the Hayden Reach and three reaches in critical habitat. The Hayden Reach was 20 miles long between Highway 40 bridge east of Hayden and the downstream end of Yampa State Wildlife Area (RM 171–151). Reaches in critical habitat were separated by high-gradient, white-water canyons. The Juniper Reach was 30 miles long between Milk Creek and the Maybell Diversion Dam in Juniper Canyon (RM 120–90.5; Figure 1). The upper 17 miles contains higher gradient than the lower portion of the reach and travels through a canyon known locally as either Little Yampa Canyon or Duffy Canyon. The lower 10 miles of the Juniper Reach traverses low-gradient, irrigated, agricultural land. A 1.5-mile, white-water section in Juniper Canyon immediately downstream of the Maybell Diversion dam was not navigable and was not sampled. The Maybell Reach was approximately 28-miles long between the lower end of Juniper Canyon and the upstream end of Cross Mountain Canyon (RM 89–59). It is low-gradient, with irrigated agriculture, and skirts the small town of Maybell, Colorado.

At 10 miles long, the Lily Park Reach was only a third the length of the other reaches and included the area from Cross Mountain Canyon to the entrance of Yampa Canyon (RM 55.5–45.5). Cross Mountain Canyon contains 3-miles of very high-gradient, white-water rapids and was not sampled. The first two miles of the Lily Park Reach were high gradient with cobble substrate originating from Cross Mountain Canyon and numerous riffle-pool sequences. At RM 51, the Little Snake River enters and deposits large amounts of fine sediment, primarily sand, in the remaining 5 miles of this reach. This wide, shallow, sandy channel is often unnavigable except at peak flows.

METHODS

Sampling protocol— Sampling occurred between April and July during runoff when flow was sufficient to navigate the river. The Hayden Reach was sampled only in 1999 and critical habitat was sampled from 1999 through 2002. In critical habitat reaches, there were four sampling occasions each year and each occasion required 10 to 12 continuous days to sample all three reaches. In years when flows declined rapidly, some sections of river within each reach were not navigable by electrofishing boat by the fourth sampling occasion and were not sampled. In 1999, only backwaters were sampled; in later years, both shorelines and backwaters were sampled. Backwaters included flooded ephemeral, tributary washes and irrigation return channels. Shorelines included all habitats associated with water's edge and were sampled by boat electrofishing, starting at the most upstream location and progressively moving downstream about 0.6 to 3.0 m from shore. One electrofishing boat was used in 2000 and two electrofishing boats were used in subsequent years. When two boats were used, both shorelines were sampled simultaneously.

Small backwaters were sampled by electrofishing boat and the sampled included with riverine, electrofishing effort. If a backwater was large enough, it was blocked to prevent escapement of fishes during sampling with a fine-mesh net set at the mouth and a trammel net set about 0.3 m inside the block net. The fine-mesh block net allowed us to work the trammel net between sampling passes without fish escaping. In 1999, backwaters interiors were seined (block-and-seine) for adults and some backwaters were dipnetted for presence of larval fish. From 2000 through 2002, backwater interiors were electrofished (block-and-shock, Nesler 1995) for adult fish. Number of sampling passes ranged from one to five and increased as backwater size and complexity increased. Fish were processed at the end of each sample pass. All passes were conducted on the same day and after the last sampling pass, block nets were removed. In a few larger backwaters, block-and-shock sampling was followed by a 1- to 4-day, fyke-net set. The trap end was set just inside the backwater with the throat facing the backwater mouth. A lead net was extended from the center of the trap to one bank and a single wing net was extended to the other bank so that fish attempting to enter or leave the backwater would be funneled by the nets into the trap.

Fish handling— Fish were processed at the site of capture. Northern pike were measured to the nearest mm total length (TL) and weighed to the nearest 50 gr with 5- or 10-kg, Pesola® spring scales. In 2000, northern pike captured on the first sampling occasion were marked with a dorsal hole punch and returned to the river. On other occasions, northern pike were tagged in the musculature on the left, near the posterior base of the dorsal fin with numbered and colored Floy® tags. Northern pike were tagged primarily for other studies to evaluate potential escapement from receiving waters after translocation and to track growth and angler harvest at translocation sites. Fish severely injured by sampling gear or natural injury were euthanized with an overdose of Tricaine (MS-222).

Pike were visually examined for evidence of consuming large prey, typically by the presence of a caudal fin protruding from the pike's mouth. If a caudal fin was observed, we attempted to identify the species visually. If we were uncertain about the identification, the fish was removed by grasping the prey's tail with pliers and gently encouraging regurgitation by the pike. Prey lengths were used to determine the relationship between predator and prey lengths. We used this relationship to determine the maximum prey size that a northern pike could consume and to identify the minimum length of northern pike that could pose the greatest threat to Colorado pikeminnow recruiting into the Yampa River. Colorado pikeminnow typically recruit into the Yampa River upstream of Yampa canyon when between 425–450 mm TL (Hawkins 1992). We were interested in whether removal reduced the number of large northern pike that had the greatest potential to prey on Colorado pikeminnow.

After processing, northern pike were held alive in holding pens in the river until adequate numbers were obtained for transport to receiving waters. Most fish were held no more than 24 hours and then transported in salted and oxygenated water. Except for some fish marked and released in the river at the Hayden reach in 1999 and in critical habitat reaches in 2000, all northern pike were transported to receiving waters identified by the CDOW. In 1999, northern pike were placed in the Yampa State Wildlife Area ponds between Hayden and Craig and from 2000 through 2002, northern pike were moved to Rio Blanco Reservoir in the White River drainage between Meeker and Rangely. Colorado pikeminnow were photographed, measured (mm TL), weighed (g), scanned for the presence of a PIT tag, and if unmarked, implanted with a PIT tag.

Habitat type, UTM coordinates, and river mile of capture were recorded. If external injuries were present we described their severity, location, size, and whether open or healed. Injuries were categorized as pike attacks, lesions, or injuries of unknown origin. Injuries were attributed to northern pike based on characteristics similar to injuries observed on dead prey removed from northern pike. Only northen pike attributed injuries are reported here.

Removal evaluation— To evaluate the effect of removal over time, we plotted catch-per-unit-effort (CPUE) by year for main-channel electrofishing (EL) over the duration of our study. Evaluation of removal was based on shoreline electrofishing because electrofishing effort was easily quantified and sampling was relatively consistent among years. CPUE standardized samples with different effort. We assumed that CPUE of shoreline electrofishing (EL-CPUE) had a positive relationship with the number of northern pike in each reach; therefore, changes in EL-CPUE values should provide a relative index of changes in abundance of northern pike. EL-CPUE was calculated for each sample as number of fish captured per hour. Duration of electrofishing sampling effort was obtained from a counter on each electrofishing unit that recorded elapsed seconds that electricity was applied to the water. Samples were averaged by reach to obtain mean EL-CPUE for two size classes, northern pike of all sizes and northern pike $\geq$ 600 mm TL. The larger-sized group represented the size of northern pike that had the greatest potential to prey on recruiting Colorado pikeminnow. Linear regression was used to test for statistically significant differences in mean EL-CPUE between sampling periods for each reach. The *ln*EL-CPUE was used because residual plots revealed a better fit than with non-transformed EL-CPUE. A non-significant probability value for the regression relationship (regression slope) of *lnEL-CPUE* as a function of *year*, for each reach, indicated that the slope was not significantly different than zero.

The purpose of backwater sampling was to increase number of adult northern pike removed on each sampling occasion with a minimal amount of additional effort. Block-and-shock CPUE (BS-CPUE) and fyke net CPUE (FY-CPUE) for fish captured in backwaters were plotted by year over the duration of our study to examined for trends in CPUE. To determine trends we examined the relative declines of BS-CPUE and FY-CPUE between 2000 and 2001. We did not perform regression analysis of CPUE with these gears because sampling effort was highly variable within years and because the gears were used only two years. Data from 1999 were excluded from trend analysis because samples were collected by seine and seine effort was not comparable to later samples that recorded electrofishing effort in time. Data from 2002 were excluded because we only had one backwater sample due to the lack of sufficient flow to create backwater habitat.

Abundance estimation of northern pike— Abundance of northern pike was estimated in 2000, prior to large-scale removal to serve as a benchmark of effectiveness. In 2000, on the first sampling occasion, northern pike were marked with a dorsal hole punch and released at site of capture. Northern pike abundance was estimated from the proportion of marked and unmarked fish captured on the second sampling occasion using program CAPTURE (White et al. 1982).

Interactions between Northern pike and Colorado pikeminnow— Annual injury rate of Colorado pikeminnow measured the percent of Colorado pikeminnow with northern pike injuries as a proportion of those handled for the first time each year. Annual Injury rate included only fish handled in the year of original capture. Recaptured fish handled previously in this study were not included in annual injury rate. This avoided counting injured fish more than once and inflating annual injury rate. To account for recaptured fish that received an injury after their initial handling we calculated cumulative injury rate. Cumulative injury rate described the percentage of individual fish with injuries in proportion to the number of unique fish handled at the end of each year. Cumulative injury rates included recaptured fish in the cumulative number of injured fish only if the recaptured fish obtained an injury after the year they were initially handled.

We also examined the ratio of northern pike to Colorado pikeminnow captured in three selected backwaters from 1988 through 2001. The sites were Morgan Gulch (RM 103.4) in the Juniper Reach, Spring Creek (RM 81.6) in the Maybell Reach, and a backwater upstream of the Little Snake River (RM 51.4) at Lily Park. These sites were selected because there was a long history of sampling using similar techniques at each site. We reported the number of fish captured only with block-and-seine or block-and-shock techniques on each sampling occasion. Pre-1999 data were interpreted from figures 35, 37, and 38 in Nesler (1995).

RESULTS

Removal evaluation based on EL-CPUE— Mean EL-CPUE generally declined during the removal period suggesting that removal was effective at reducing the number of resident northern pike. The greatest declines in EL-CPUE occurred between 2000 and 2001 when EL-CPUE declined 73% for northern pike of all sizes and 67% for northern pike ≥ 600 mm TL (Table 1; Figure 2). After initial declines in catch rate from 2000 to 2001 in all reaches, EL-CPUE for both size groups continued to decline at Lily Park and increased in Juniper and Maybell in 2002. The EL-CPUE increases from 2001 to 2002 were greatest in Juniper where EL-CPUE for northern pike of all sizes rose to 73% of their original rate in 2000 and EL-CPUE for northern pike ≥ 600 mm increased to a level higher (120%) than observed at the start in 2000 (Table 1; Figure 4). Negative slopes of regression relationships for most fish-size and reach combinations for the three year period support that northern pike abundance declined over time; but, slopes varied by reach. Rate of decline (slope) was lowest at Juniper, moderate at Maybell, and steep at Lily Park, suggesting that declines were least sustained at Juniper and more likely to be sustained as distance increased downstream of Juniper (Table 1). Only northern pike ≥ 600 mm at Juniper, the most upstream reach, had a slightly positive regression slope suggesting an increase or at least a constant number of large northern pike in that reach during the three years (Table 1). From 2000 to 2001, the largest rate of decline in EL-CPUE for northern pike of all sizes was at Lily Park, followed by Maybell, and Juniper; however, declines were not statistically significant except for northern pike of all sizes at Lily Park, the most downstream reach ($P=0.01$; Table 1; Figure 3).

Except for Lily Park, regression trends in other reaches were likely not statistically significant because catch rates increased from 2001 to 2002. More important, the small sample size (3 years) provided low statistical power and the ability to detect only the largest declines.

At the start of removal in 2000, capture rates showed large differences in density among reaches. Greatest capture rate was at Lily Park (10 fish/hr), followed by Maybell (5 fish/hr), and Juniper (3 fish/hr; Figure 3). Densities of northern pike $\geq$ 600 mm also varied by reach. Lily Park had the highest capture rate (5.8 fish/hr), followed by Maybell (2.2 fish/hr), and Juniper (0.5 fish/hr; Figure 4). By 2002, EL-CPUE was less variable among reaches suggesting that northern pike densities were more similar among reaches after a few years of removal.

Changes in backwater CPUE— Mean BS-CPUE and FY-CPUE declined for northern pike of all sizes from 2000 to 2001 further supporting that removal reduced resident population size. Mean BS-CPUE declined more than 50%, from 22.5 fish/hour in 2000 to 12.9 fish per hour in 2001 (Figure 5). Block and shock was a very effective sampling technique, capturing many fish in a short period of time. Total block-and-shock effort was 17.2 hours (Table 2). Total effort was low because it required very little electrofishing time for each sample. Most fish were captured by the electrofishing gear used in the backwater rather than in trammel block nets, but block nets were instrumental in increasing capture rates by preventing fish from escaping the backwater.

Fyke net CPUE (FY-CPUE) for northern pike also declined more than 50% from 0.13 fish/hr in 2000 to 0.05 fish/hr in 2001 (Figure 6). In 2002, fyke nets were not set because discharge was too low to flood backwaters. FY-CPUE appeared low (<1 fish/hour) because fyke nets accumulated many hours during their continuous, multiple day, sets. Total fyke net effort for 2000 and 2001 was 848 hours (Table 2). Even with low catch-rates, fyke nets were very efficient considering their working time was far greater than the minimal time required to set up and monitor the gear.

Abundance estimate of northern pike— At the start of removal in 2000, we estimated that 1,277 (95% profile likelihood interval 801–2345; CV, 27%) northern pike lived in the study area based on 11 recaptures on the second sampling occasion of 83 marked fish. Eight additional recaptures on the third sampling occasion were not used in the analysis. Capture probability was 13%. From 2000 through 2002, we removed 928 northern pike or 73% of the estimated population size.

Number and biomass of northern pike removed— In the Hayden Reach, 114 northern pike (biomass 184.4 kg) were captured and 72 (145 kg) were released alive at site of capture, 19 were translocated, 4 died during holding, and 19 young-of-year were preserved as voucher specimens (Table 2). There were 1000 northern pike removed from critical habitat reaches between 1999 and 2002; 956 were translocated and 44 (4%) either died during transport or were euthanized due to severe injury. Total biomass removed from critical habitat was 1,288 kg and total electrofishing effort was

405 hours (Table 2). The majority of northern pike and most of the biomass of northern pike of all sizes were removed from main channel compared to backwater areas (Table 3). Electrofishing in the main channel of critical habitat captured 67% of all northern pike removed and numbers removed increased each year (Table 3). In critical habitat, sampling gears used in backwaters captured 32% of all northern pike (Table 3). Most fish (25%) were captured by block-and-seine and block-and-shock and 7% were captured by fyke and trammel nets. Number and biomass of northern pike removed from backwaters declined in years after 2000 due to lower effort in 2001 and almost no effort in 2002 due to low water conditions that did not create backwaters (Table 3). The fewest northern pike were captured in 1999 when sampling was limited to backwaters and the most were caught in 2000, the first year of river-wide electrofishing (Table 3). For all years combined, the greatest biomass of northern pike was removed from Juniper (510.9 kg), followed closely by Maybell (480.p kg), and Lily Park (295.5 kg; Table 4). Biomass removed from Lily Park was almost 60% of the biomass removed from Juniper; however, the area sampled at Lily Park was only a third the size of the area sampled in each of the other reaches. On a per mile basis, the biomass at Lily Park (29 kg/mile) was almost double the biomass in Juniper (17 kg/mile), indicating a concentration of large fish in the short Lily Park reach. Northern pike $\geq$ 600 mm TL were considered large enough to be a predatory threat to Colorado pikeminnow and fish of this size comprised 38% of all fish removed and 65% of the total biomass removed in all years (Table 4). At least one northern pike stocked in Yampa Wildlife Area ponds in 1999 escaped or was purposefully moved and was recaptured by an angler about one mile downstream of the ponds in the spring of 2000.

Length frequency of northern pike— Total length of northern pike ranged from 28 to 953 mm TL in the Hayden Reach and from 110 to 1,015 mm TL in critical habitat reaches. Modal length-group of fish captured generally increased each year from 1999 through 2002 (Figure 7). We did not age fish, but we did use a length-at-age relationship developed by another researcher who aged cleithra from several hundred northern pike captured upstream of our study site (K. Rogers, in litt.):

$$\text{Total length} = 239.066 \times \text{Ln(Age)} + 245.96.$$

Based on this relationship, northern pike would average 419 mm TL at age 2, 520 mm TL at age 3, 591 mm TL at age 4, and 647 mm TL at age 5. These lengths-at-age were similar to modal length-groups of northern pike captured from 1999 to 2002. Increased catch rates of northern pike $\geq$ 600 mm in Juniper and Maybell in 2002 were attributed to a strong cohort in 2001 that grew to a length over 600 mm in 2002 (Figures 10 and 11). New recruits into critical habitat were observed in a modal length-group between 350 and 450 mm representing a strong cohort of 2 year olds in 1999 which grew each year to lengths that corresponded with the length-at-age relationship (Figure 7). In 2002, another abundant cohort of small northern pike between 350 and 450 mm were collected primarily in the Juniper Reach (Figures 7 and 11).

Spawning occurred in the Hayden Reach based on collection of young northern pike, 28 to 70 mm TL on June 4 and 11, 1999. Some of those young were captured in Yampa State Wildlife Area ponds in the Hayden Reach. Most larger juveniles and small adults were captured in Juniper, the most upstream reach in critical habitat, and number of small fish decreased as distance increased downstream. Of 51 northern pike < 350 mm TL captured in critical habitat reaches, 80% were from Juniper, 20% were from Maybell, and none was from Lily Park (Figures 7–11). Small adults showed a similar trend of increasing abundance in upstream reaches. Of 195 northern pike between 350 and 450 mm TL captured in critical habitat reaches, 75% were from Juniper, 21% were from Maybell, and 4% were from Lily Park (Figures 7–11). Modal length-groups were generally similar among reaches each year if fish < 450 are excluded from length-frequency distributions (Figures 8–11).

Density of northern pike — Northern pike captured in the main channel by electrofishing were concentrated in high densities in two short river reaches just downstream of high-gradient canyons (Figure 12). Concentration areas were downstream of Juniper Canyon (RM 90–85) and downstream of Cross Mountain Canyon (RM 55.5–52.5) with highest densities in the first mile downstream of each canyon. High density of northern pike in the upper section of the Juniper Reach in 2002 was primarily due to a large number of fish <450 mm (Figures 11 and 12).

Northern pike and Colorado pikeminnow ratios in selected backwaters, 1988–1991 and 1999–2001— During this study, from 1999 through 2001, three backwaters were sampled in a manner similar to the way they were sampled from 1988 through 1991 by Nesler (1995). Generally the frequency of northern pike in samples increased and the frequency of Colorado pikeminnow declined in samples of these backwaters between the two time periods (Figure 13). Northern pike were much more abundant in samples from Morgan Gulch (RM 103.4) and Spring Creek (RM 81.6) between 1999 and 2001 than they were prior to 1991. Backwaters were generally depleted of northern pike after each sample, yet they re-colonized backwaters by the next sampling occasion. Colorado pikeminnow were usually absent from samples with large numbers of northern pike.

Northern pike predation and maximum prey length— Caudal fins of large prey fish were observed protruding from the mouth of some northern pike and these prey items were usually removed to identify species and length. Seven prey species were extracted from northern pike: roundtail chub, flannelmouth sucker, bluehead sucker, rainbow trout *Oncorhynchus mykiss*, white sucker, northern pike, and black bullhead *Ameiurus melas*. Most prey were at least partially digested indicating predation was not recent and that prey were not likely consumed during our electrofishing.

The largest prey removed from a live northern pike was 457 mm TL, 72% of the northern pike's 635 mm length. Prey removed from live northern pike averaged 54% (range 42–72%) of predator length (Table 5). Prey length and prey-length to predator-length ratio provided a measure of the maximum prey size that northern pike consume. Based on consumption of prey up to 72% of their length, we estimated that northern pike 600 mm TL would pose a predatory threat to Colorado pikeminnow with a length of 425 mm, the size they typically recruit into the Yampa River upstream of Yampa Canyon (Hawkins 1992). We evaluated metrics and CPUE for northern pike $\geq$ 600 mm TL because this size range was considered the greatest predatory threat to Colorado pikeminnow in the Yampa River.

Dead prey often had external injuries from the initial predation attack. These injuries were usually located on both lateral surfaces of the mid-section and were characterized by lacerations that formed striations or crescent-shaped puncture wounds on opposing sides with a pattern characteristic of pike dentition. Characteristics of these injuries were similar to injuries observed on some live Colorado pikeminnow, roundtail chub, flannelmouth sucker, bluehead sucker, white sucker, and northern pike. Injuries observed on live fish ranged in severity from minor scrapes to potentially life-threatening gashes. Conspecific attack injuries were observed on 12 northern pike ranging from 360 to 683 mm TL.

Predation attempts by northern pike on Colorado pikeminnow— Annual injury rate of Colorado pikeminnow with injuries attributable to predation attempts by northern pike increased from 9% in 1999 to 26% in 2002 (Table 6). By the end of 2002, 18% (n = 39) of the 221 unique Colorado pikeminnow handled had accumulated injuries. Cumulative injury rate increased each year indicating that rate of negative interactions between Colorado pikeminnow and northern pike increased over time. Of all Colorado pikeminnow captured in each reach, 20% at Juniper had injuries, 15% at Maybell had injuries, and 8% at Lily Park had injuries. These cumulative injury rates were positively correlated with the total number of northern pike captured in each reach over the three year period, i.e. injury rate was highest in reaches with the most northern pike.

Length of 221 Colorado pikeminnow handled ranged 442 to 799 mm TL and length of 39 fish injured by northern pike ranged from 468 to 647 mm TL. Pike induced injuries did not increase as size decreased. Injuries to Colorado pikeminnow were observed in 19% of fish 450–499 mm TL, 25% of fish 500–549 mm TL, 19% of fish 550–599 mm, and 15% of fish 600–650 mm TL. Injuries were not observed on the one Colorado pikeminnow $<$ 450 mm nor on any of the 20 Colorado pikeminnow $\geq$ 650 mm. Wounds were located in all body regions, but most typically along the mid-section and were similar to injuries observed on dead prey removed from northern pike. Injuries ranged from minor to severe lacerations, with varying degrees of infection and healing.

DISCUSSION

Effects of removal— Northern pike numbers declined in critical habitat from 2000 through 2001 based on declining catch rates in all three reaches, Juniper, Maybell, and Lily Park. We attribute the decline to our removal efforts in critical habitat. From 2001 to 2002, number of northern pike continued to decline only at Lily Park. Removal was most effective at Lily Park because fish were removed at a rate greater than the rate of immigration and recruitment. Reduced immigration of northern pike into Lily Park was attributed removals in upstream Maybell and Juniper reaches which reduced the number of potential immigrants and reduced downstream dispersal by reducing competitive pressures in those reaches. Reduced recruitment at Lily Park was attributed to the absence of a local source of small, recruit-sized fish and the longer distance of Lily Park from the source of young recruits from within and upstream of the Juniper reach.

Declines in EL-CPUE were not sustained at Maybell and Juniper in 2002 due to immigration and recruitment into those reaches. Catch rate increases of northern pike at Juniper and Maybell in 2002 were proportional to an increase in the number of small adults in each reach, with the largest number of small adults at Juniper and only a few at Maybell. This distribution suggests that those small fish most likely immigrated into critical habitat from upstream of Juniper. Number of small northern pike decreased as distance increased downstream from Juniper, further supporting that reproduction occurred within or upstream of Juniper, the most upstream reach. Few small fish

(350–450 mm TL) were captured in Juniper in years prior to 2002, suggesting that small fish did not recruit from local stocks but rather moved in from other locations. Spawning was either absent or negligible in critical habitat suggesting that northern pike in critical habitat were sustained by production upstream of critical habitat, such as at the Hayden Reach where spawning was documented based on collection of young-of-year northern pike in 1999. Presence of larvae in Hayden, and juveniles and small adults in Juniper, suggest downstream dispersal of small fish from the Hayden Reach into critical habitat.

An open population in the study site was further supported by comparing the number of northern pike removed from the initial abundance estimate. After three years, 928 northern pike were removed from the study site. If the northern pike population in the study site was closed to immigration and recruitment, then only 349 northern remained of the initial population after 2002 sampling; yet, in 2003 we handled almost 300 northern pike and in 2004 approximately 350 northern pike were removed from this area (Hawkins unpublished data). Northern pike were apparently replenished at a rate similar to removal. Alternatively, an imprecise abundance estimate that grossly underestimated the number of northern pike might explain the lack of a measurable removal effect in 2002. The best measure of effectiveness of removal would be before and after estimates of abundance. Periodic and precise abundance estimates of northern pike would be much better for determining absolute effects of removal on the population. To increase precision in abundance estimates will require tagging large numbers of northern pike with individually identifiable tags, returning these fish to the river alive after capture, and having at least two recapture occasions.

Northern pike and Colorado pikeminnow interactions— Colorado pikeminnow and northern pike were syntopic in the main channel and in backwaters. During runoff, northern pike were commonly captured in backwaters traditionally used by Colorado pikeminnow. Colorado pikeminnow tend to seek out backwaters in the spring because they have warmer water than the river and traditionally these backwaters have abundant small prey, creating ideal conditions for Colorado pikeminnow seeking to build energy reserves prior to migration in the spring. Colorado pikeminnow were often absent or few and northern pike were often present and numerous in backwaters during our sampling. High densities of northern pike in backwaters increase their encounter rates with Colorado pikeminnow; however, it is unknown whether Colorado pikeminnow were absent from many backwaters due to predation, avoidance of predation, harassment, or increased competition that reduced the prey-base and therefore the value of backwater habitat. Loss of these valuable habitats may reduce fitness and reproductive success for Colorado pikeminnow.

In addition to high densities in backwaters, northern pike also had high densities in the river below Cross Mountain and Juniper canyons, two areas historically used by Colorado pikeminnow (Wick et al. 1985a and 1985b). High northern pike densities at those locations are problematic for Colorado pikeminnow that attempt to reside in these areas or that move through them during spawning migration. Encounters probably increase at these locations in late summer during Colorado pikeminnow return migrations when flows are reduced further concentrating northern pike into pool habitat. Colorado pikeminnow that live in the Juniper Reach must pass both high density areas twice during each spawning run thus increasing their potential encounters with northern pike. Lily Park poses the highest threat because it has maintained the highest densities of large northern pike ≥ 600 mm even after intensive removal. Control measures should exploit behavior that concentrates northern pike in high density areas and habitats described above. Concentration areas act as sinks for northern pike which re-colonize these areas within weeks after depletion sampling. For the greatest removal effect, these areas should be sampled intensively and repeatedly.

Predation of Colorado pikeminnow by northern pike is likely occurring in the Yampa River as evidenced by failed predation attacks on Colorado pikeminnow and consumption of fish the same size as adult Colorado pikeminnow by northern pike. Injuries on Colorado pikeminnow were potentially severe enough to reduce their fitness and for some fish were life threatening. We documented that northern pike could consume prey items up to 72% of their body length which was much larger than the literature reported. Bioenergetic models should include this information in future analyses. Annual increases in the percentage of adult Colorado pikeminnow with injuries were attributed to increases in the percentage of large northern pike and to declines in the number of small-sized, fish prey causing northern pike to shift to larger prey.

Interestingly, small Colorado pikeminnow had a lower percentage of attack injuries than larger fish, but this may reflect more successful predation of smaller Colorado pikeminnow, resulting in fewer small Colorado pikeminnow alive with injuries.

Our studies considered northern pike larger than 600 mm as the greatest threat in our study site because they can potentially consume Colorado pikeminnow that recruit into this area when about 425 mm; however, Colorado pikeminnow as small as 380 mm also occur in this area (Hawkins, unpublished data). Colorado pikeminnow this size could be consumed by northern pike even smaller than 600 mm.

Predation potential is even greater downstream of our study site in Yampa Canyon where smaller Colorado pikeminnow, humpback chub, razorback sucker, and recently stocked bonytail reside. In Yampa Canyon, juvenile Colorado pikeminnow as small as 280 mm have been captured (McAda, *in litt.*). Colorado pikeminnow this small are vulnerable to predation by northern pike as small as 390 mm, a size that includes almost all northern pike that live in Lily Park. Removal efforts upstream of Yampa Canyon, primarily reduce predation pressures on adult Colorado pikeminnow residing in that area; but just as important, upstream removals also reduce the number of northern pike that move downstream into canyon areas where other, smaller, endangered fishes reside.

Successful reduction of northern pike in critical habitat requires reducing or eliminating reproduction, especially in years that produce abundant cohorts. Reducing recruitment requires knowledge of which spawning locations produce the most young northern pike. Places that could support northern pike spawning include reservoirs, man-made ponds, and natural sloughs and backwaters. Northern pike spawning areas should be located and ranked based on their production of young. The best technique to locate spawning areas would be to longitudinally sample the river for young-of-year northern pike in the late summer. Concentrations of young northern pike would reveal nearby spawning areas. Mapping relative abundance of young-of-year northern pike longitudinally down the river would identify river sections that have the greatest production of northern pike. Relative abundance of young northern pike immediately downstream of reservoirs compared to riverine abundance would assist in determining if young are escaping reservoirs in significant numbers. Control efforts may vary depending on each place or location, but should focus on those that produce the most young northern pike. Specifically, reproduction should be reduced by physically removing local or immigrating adult northern pike, blocking entry of adult northern pike into spawning areas, or preventing the exit of young northern pike to the river.

Ultimately, successful control of northern pike in critical habitat will require a large-scale, basinwide approach that focuses primarily on reducing reproductive success and restricts downstream movement of northern pike at the earliest possible life stage. Recent projects have extended removal into areas upstream of critical habitat and there was at least one attempt to screen movement into presumed reproductive habitats (Hill 2004). To obtain a sufficient removal effect within a specific area such as critical habitat will require either more efficient sampling or more than four sampling occasions. Maintaining a smaller population of northern pike in critical habitat requires removal at a rate greater than the rate of immigration and recruitment and this apparently happened from 2000 to 2001, but not in 2002. To maintain a reduced population of northern pike in critical habitat will also require removal of northern pike from areas upstream of critical habitat so that numbers removed from critical habitat are not replenished by immigration or recruitment from those upstream reaches.

CONCLUSIONS

- Objective 1 was accomplished. Northern pike juveniles and adults were captured using electrofishing and fyke nets and removed from the Yampa River.
- Objective 2 was accomplished. Northern pike were moved to ponds in the Yampa River drainage and a reservoir in the White River Valley and mortality of handled fish was very low (4%).
- Objective 3 was accomplished. Effectiveness of removal in reducing the number of northern pike of all sizes or reducing the number of large northern pike was evaluated.
- Removal was most successful in Lily Park, the most downstream reach, apparently because the reach was located the farthest from upstream sources of reproduction and recruit-sized fish.
- In Lily Park, removal was effective at reducing numbers of large northern pike $\geq$ 600 mm.
- Removal was initially effective in all reaches, but was least effective in Maybell and Juniper reaches, apparently due to the proximity of each reach to a source of recruiting and immigrating fish.
- In Juniper and Maybell, the number of large northern pike $\geq$ 600 mm was apparently sustained in 2002 by recruitment of a strong cohort to that length.
- Northern pike densities were highest in concentration areas and northern pike recolonized these areas after removal.
- Northern pike outnumbered Colorado pikeminnow in the river and in several

backwaters.

- Changes in length-frequency distributions of northern pike over time were attributed to growth of strong cohorts and not a result of removal.
- There were strong cohorts of juvenile and small adult northern pike that apparently entered critical habitat through Juniper, the most upstream reach in critical habitat.
- Northern pike consumed prey that were up to 72% of their body length.
- Colorado pikeminnow were subject to northern pike predation attempts as evidenced by attack injuries.
- Northern pike attack injuries were observed on 18% of Colorado pikeminnow and annual injury rate increased over time.
- Northern pike preyed on other native fishes such as roundtail chub, flannelmouth sucker, and bluehead sucker.

RECOMMENDATIONS

- Increase number of northern pike removed annually in critical habitat
  - Increase the number of riverwide removal occasions each year.
  - Increase the number of samples in high density areas on each sample occasion.
  - Extend removal to other seasons.
- Reduce immigration from areas upstream of critical habitat:
  - Expand juvenile and adult removal to areas upstream of critical habitat.
  - Tag northern pike in Elkhead and Catamount reservoirs to determine relative levels of escapement of adults to the river and if necessary, focus control measures such as screening on the reservoir with the greatest level of escapement.
- Reduce recruitment from areas upstream of critical habitat
  - Identify concentrations of young-of-year (YOY) northern pike to determine the relative contribution of young from reservoir and riverine spawning areas. This could be accomplished by sampling for young fish in the river from Catamount Reservoir to the Green River confluence.
  - Identify and confirm spawning sites associated with YOY concentrations.
  - Prioritize and direct management at high production areas.
  - Investigate and implement techniques that limit access of spawning adults to high production spawning areas.
  - Block escapement of YOY or eliminate YOY from high production

spawning areas.

- Identify riverine and reservoir environmental conditions associated with strong cohorts and evaluate the potential to negatively manage these conditions to reduce cohort strength.
- Conduct periodic abundance estimates of northern pike to measure removal effect.
- Develop bioenergetic models that help define the level of removal necessary to benefit native and endangered fishes.

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Table 1–Mean catch-per-unit-effort of northern pike captured by shoreline electrofishing (EL-CPUE) in the Yampa River and analysis of variance (ANOVA) for *lnEL-CPUE* as a function of *year* captured. Probability value tests whether the slope is significantly different than zero. CI is confidence interval and SE is standard error.

	mean EL-CPUE (95% CI)			ANOVA			
Reach	2000	2001	2002	*y*-intercept (SE)	slope (SE)	r^2	*P*
Northern pike of all sizes							
all reaches combined	4.8 (2.6–7.0)	1.3 (0.8–1.8)	1.9 (1.5–2.3)	907 (947)	-0.45 (0.47)	0.45	0.51
Juniper	3.0 (2–4)	0.7 (0.3–1.1)	2.2 (1.6–2.8)	313 (1560)	-0.16 (0.78)	0.04	0.87
Maybell	5.1 (1.0–9.2)	1.4 (0.8–2.0)	1.6 (0.9–2.3)	1122 (854)	-0.56 (0.43)	0.63	0.41
Lily Park	10.1 (0–20.9)	3.9 (1.4–6.4)	1.5 (0.8–2.2)	1887 (30)	-0.94 (0.02)	0.99	0.01
Northern pike $\geq$ 600 mm total length							
all reaches combined	1.8 (0.5–3.1)	0.6 (0.4–0.8)	0.8 (0.5–1.1)	826 (749)	-0.41 (0.37)	0.55	0.47
Juniper	0.5 (0.2–0.8)	0.3 (0.2–0.4)	0.6 (0.2–0.8)	-294 (810)	0.15 (0.40)	0.12	0.78
Maybell	2.2 (0–4.7)	0.6 (0.2–1.0)	0.9 (0.6–1.2)	852 (979)	-0.43 (0.49)	0.43	0.54
Lily Park	5.8 (0–7.1)	2.2 (1.1–3.3)	1.2 (0.6–1.8)	1553 (240)	-0.78 (012)	0.98	0.10

Table 2—Sampling effort by gear during sampling in the Yampa River, 1999–2002.

	No. of days	No. of electro-fishing boats	Shoreline Electrofishing (hrs)	Block & shock (hrs)	Fyke Net (hrs)	Trammel Net (hrs)	Block & Seine (# samples)
Hayden Reach							
1999	15	1	4	0	530	2.5	18
Critical habitat reaches							
1999	10	1	0	7	0	0	35
2000	35	1	57	7	569	14	0
2001	35	2	182	3	279	0.4	0
2002	32	2	166	0.2	0	0	0
Critical habitat total		–	405	17.2	848	14.4	35

Table 3–Number and biomass (kg, in parentheses) of northern pike removed from main channel and backwaters in the Yampa River. Mortalities reported in footnotes include fish that died during holding and fish euthanized due to severe injuries.

	1999	2000 [a]	2001	2002	Total (all years)
Hayden Reach					
backwaters	42 [b] (39)	–	–	–	42 (39)
Critical habitat reaches					
main channel	0	158 (215.1)	217 (305.9)	299 (363.2)	674 (884.2)
backwaters	72 (72.8)	201 (245.3)	52 (84.4)	1 (1.2)	326 (403.7)
Total from all habitats in critical habitat	72 [c] (72.8)	359 [d] (460.4)	269 [e] (390.3)	300 [f] (364.4)	1000 (1287.9)

a Does not include 83 fish captured and released on the first sampling occasion.
b Does not include 72 fish released alive at site of capture, 3 mortalities, and 19 young of year preserved as voucher specimens.
c Includes 4 mortalities and 8 yearling fish preserved as voucher specimens.
d Includes 12 mortalities.
e Includes 8 mortalities.
f Includes 12 mortalities. Does not include one tagged fish that escaped to the river (Floy tag # 521- color white).

Table 4–Number and biomass (kg, in parentheses) of northern pike removed from critical habitat reaches in the Yampa River, 1999–2002.

Reach	1999	2000[a]	2001	2002	Total all years
Northern pike of all sizes					
all reaches combined	72 (72.2)	359 (460.4)	269 (390.2)	300 (364.0)	1000 (1287.3)
Juniper	37 (30.4)	195 (222.3)	97 (129.6)	161 (128.7)	490 (510.9)
Maybell	29 (37.8)	94 (124.2)	111 (164.2)	99 (154.7)	333 (480.9)
Lily Park	6 (4.5)	70 (113.9)	61 (96.4)	40 (80.6)	177 (295.5)
Northern pike ≥ 600 mm total length					
all reaches combined	20 (47.0)	111 (262.2)	128 (263.1)	121 (260.7)	380 (833.0)
Juniper	7 (16.5)	47 (114.6)	25 (61.6)	36 (71.4)	115 (264.1)
Maybell	11 (27.8)	32 (73.9)	88 (171.5)	53 (117.6)	184 (390.7)
Lily Park	2 (2.8)	32 (73.7)	15 (30.1)	32 (71.7)	81 (178.2)

a In 2000 83 fish were captured, marked and released on the first sampling occasion and released at site of capture; 19 of those fish were recaptured. The numbers in the table do not include 64 marked fish that were released but never recaptured.

Table 5— Total length (TL) and species of prey extracted from northern pike captured in the Yampa River.

prey species	prey TL (mm)	northern pike TL (mm)	prey length: predator length ratio	prey extracted from
rainbow trout	457	635	0.72	live fish
bluehead sucker	420	712	0.59	live fish
northern pike	389	696	0.56	stomach of dead fish
flannelmouth sucker	450	808	0.56	live fish
roundtail chub	434	785	0.55	stomach of dead fish
bluehead sucker	360	664	0.54	live fish
bluehead sucker	350	660	0.53	live fish
bluehead sucker	375	724	0.52	live fish
roundtail chub	430	908	0.47	live fish
roundtail chub	339	815	0.42	live fish
white sucker	203	575	0.35	stomach of dead fish

Table 6— Number and percentage of unique Colorado pikeminnow from the Yampa River with injuries from pike predation attempts.

	1999	2000	2001	2002
Number of unique fish handled each year [a]	22	81	99	19
Number of fish with pike-attack injuries	2	9	19	5
Annual injury rate	9 %	11 %	19 %	26 %
Cumulative number of unique fish	22	103	202	221
Cumulative number of unique fish with pike-attack injuries [b]	9	11	32	39
Cumulative injury rate	9 %	11 %	16 %	18 %

a Unique fish were those not handled previously during this study.
b Cumulative number of unique fish with injuries includes recaptured fish that received injuries after the year of initial handling, including 2 fish in 2001 and 2 fish in 2002

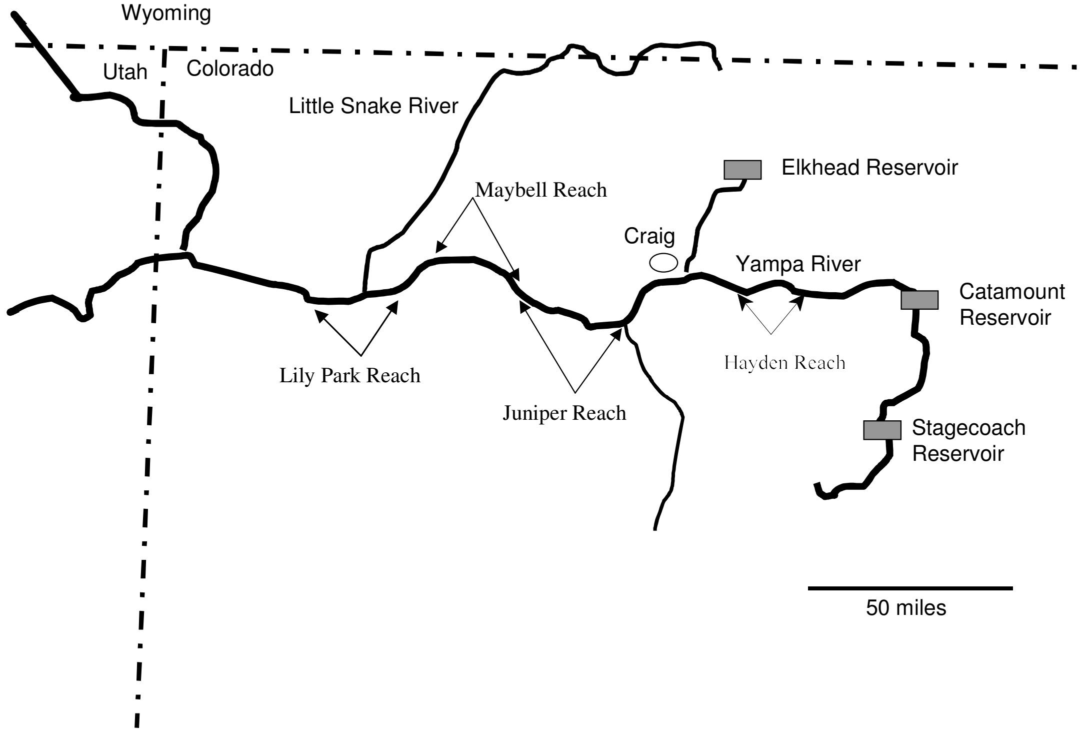

Figure 1–Map of northern pike study reaches in the Yampa River, Colorado.

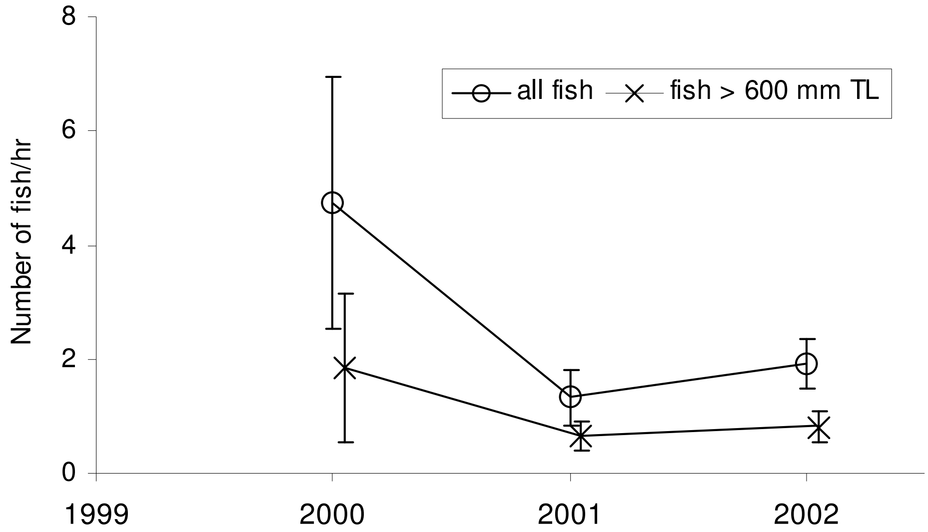

Figure 2— Mean annual electrofishing CPUE and 95% confidence interval of northern pike captured in the Yampa River, 2000--2002.

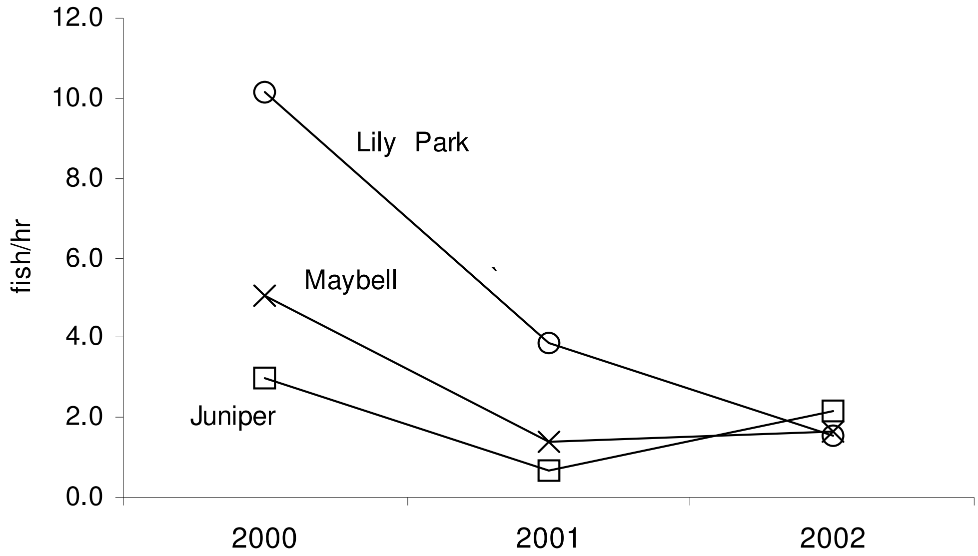

Figure 3— Mean annual electrofishing CPUE of northern pike of all sizes captured in each reach of the Yampa River, 2000-2002.

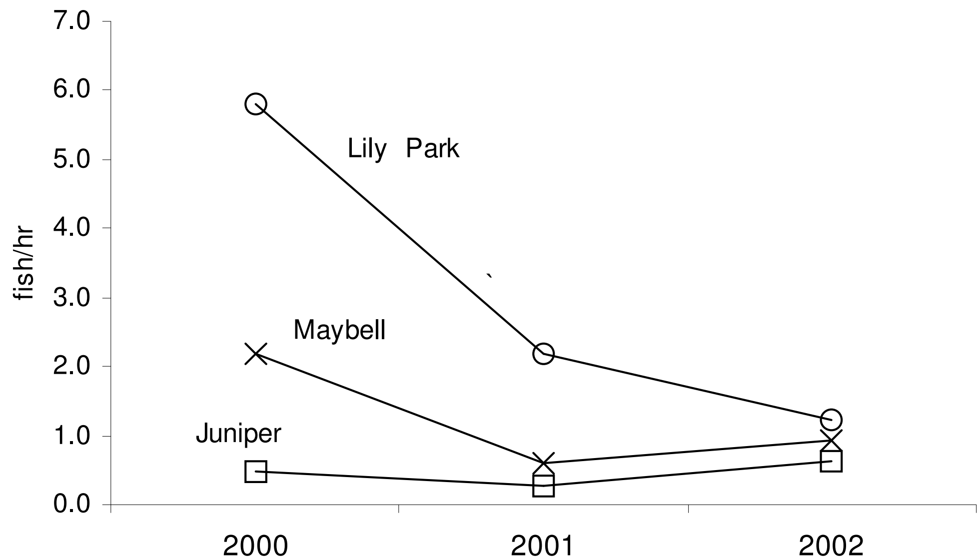

Figure 4— Mean annual electrofishing CPUE of northern pike ≥ 600 mm TL captured in each reach of the Yampa River, 2000-2002.1

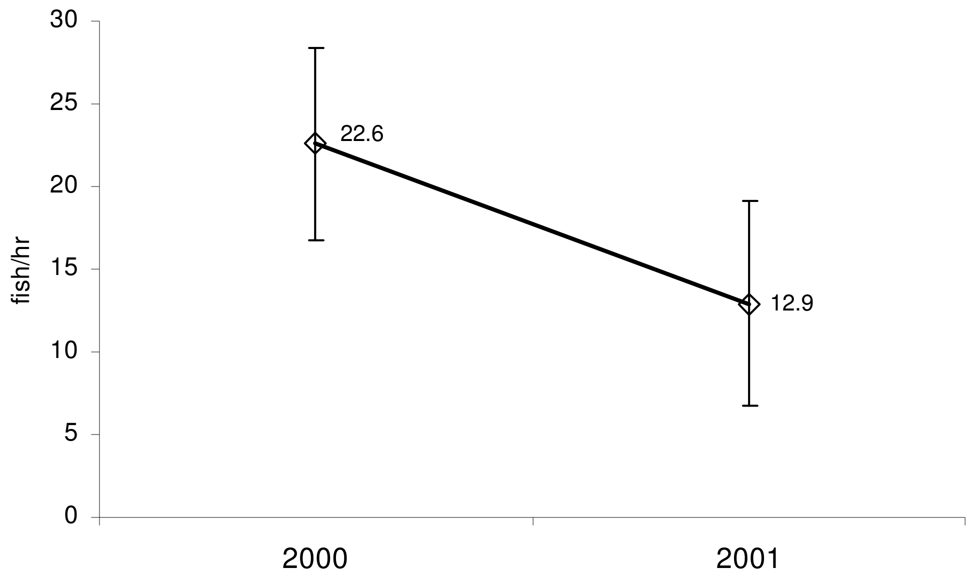

Figure 5— Mean annual block-and-shock CPUE and 95% confidence interval of northern pike of all sizes captured in all reaches of the Yampa River, 2000–2001.

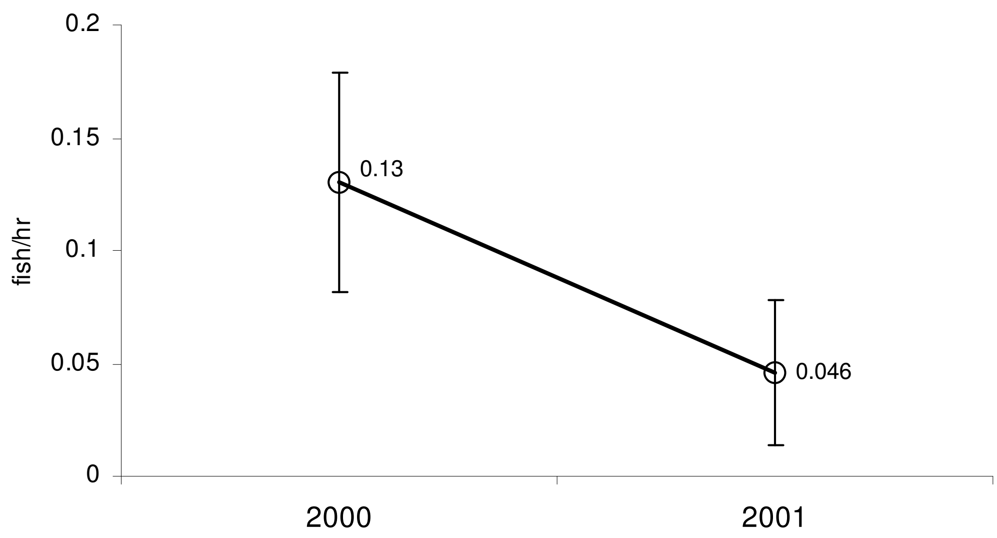

Figure 6— Mean annual fyke-net CPUE and 95% confidence interval of northern pike of all sizes captured in all reaches of the Yampa River, 2000–2001.

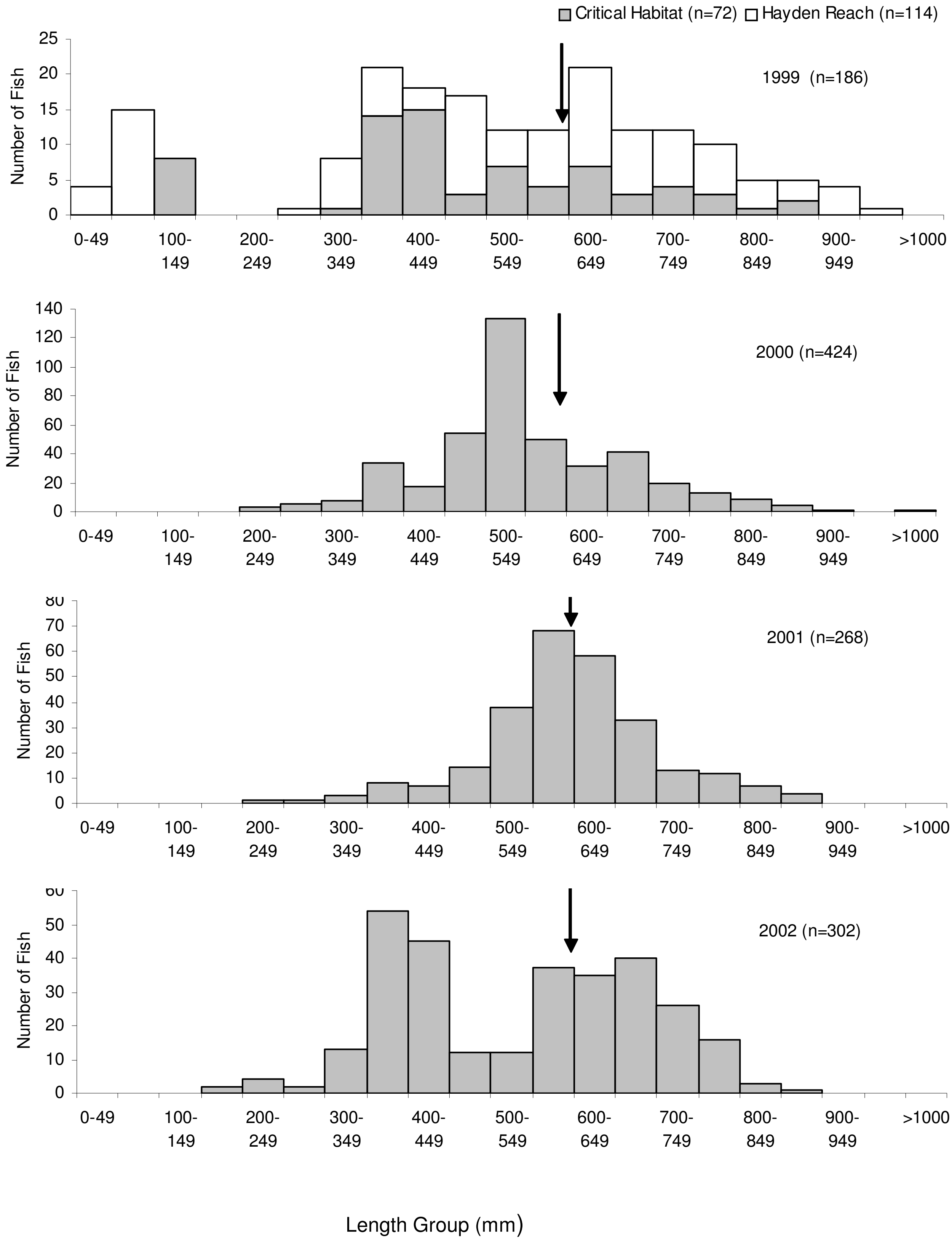

Figure 7— Length-frequency of northern pike captured in critical habitat (solid bars) and Hayden reaches (open bars) in the Yampa River, 1999–2002. Hayden reach was sampled only in 1999. Arrows denote location of 600 mm length for reference.

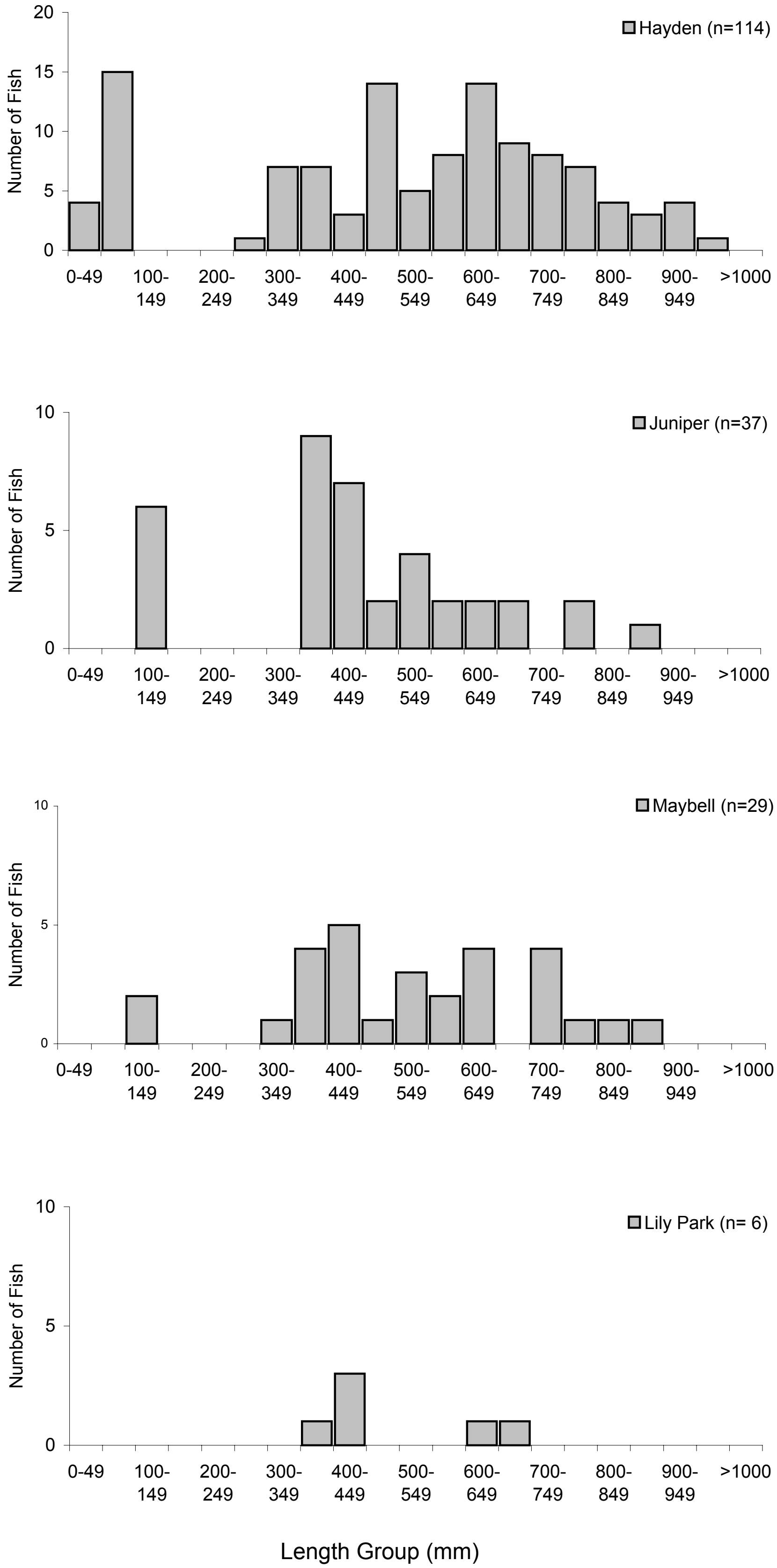

Figure 8---Length-frequency of northern pike captured by all gears in each reach of the Yampa River, 1999.

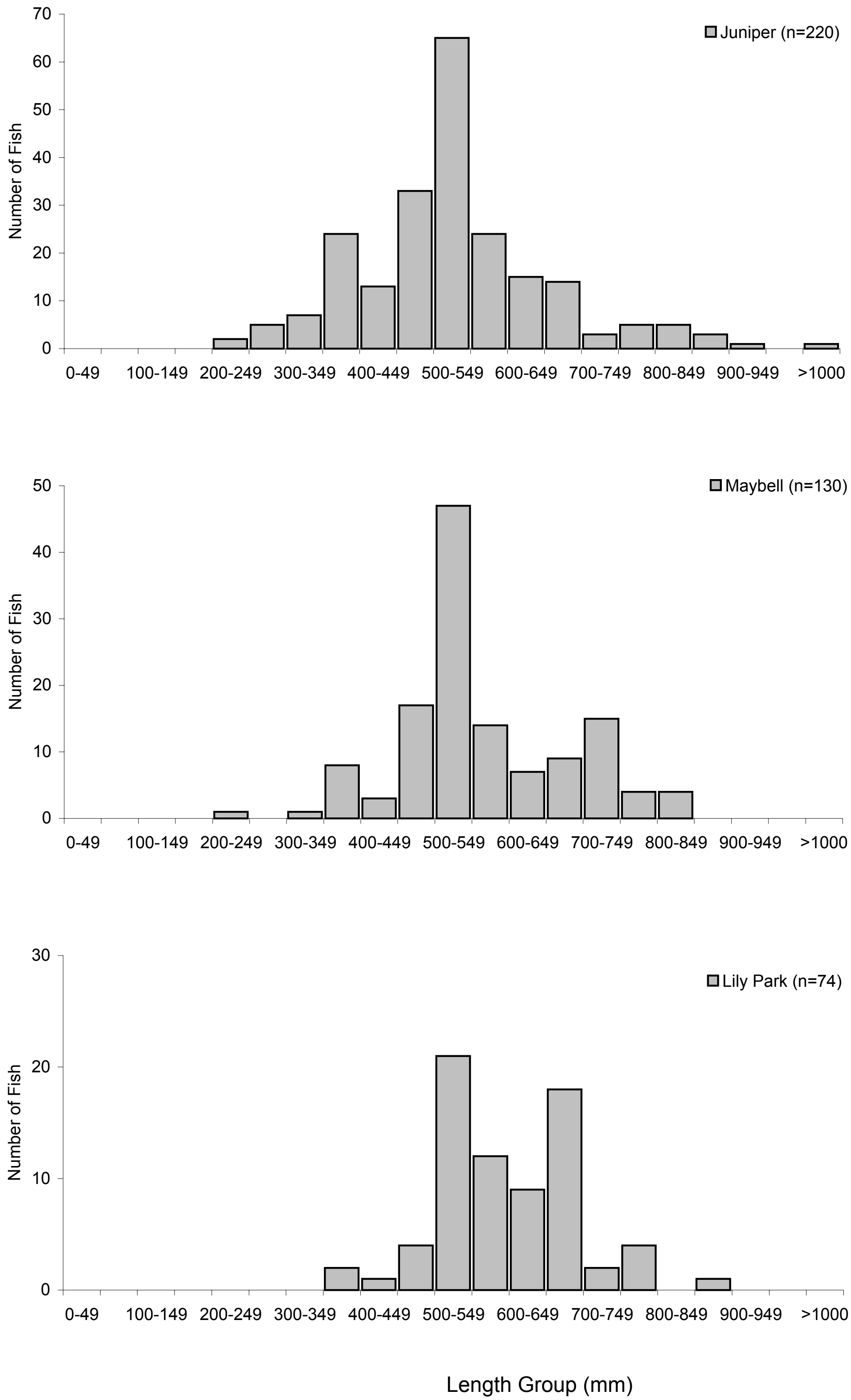

Figure 9---Length-frequency of northern pike captured by all gears in each reach of the Yampa River, 2000.

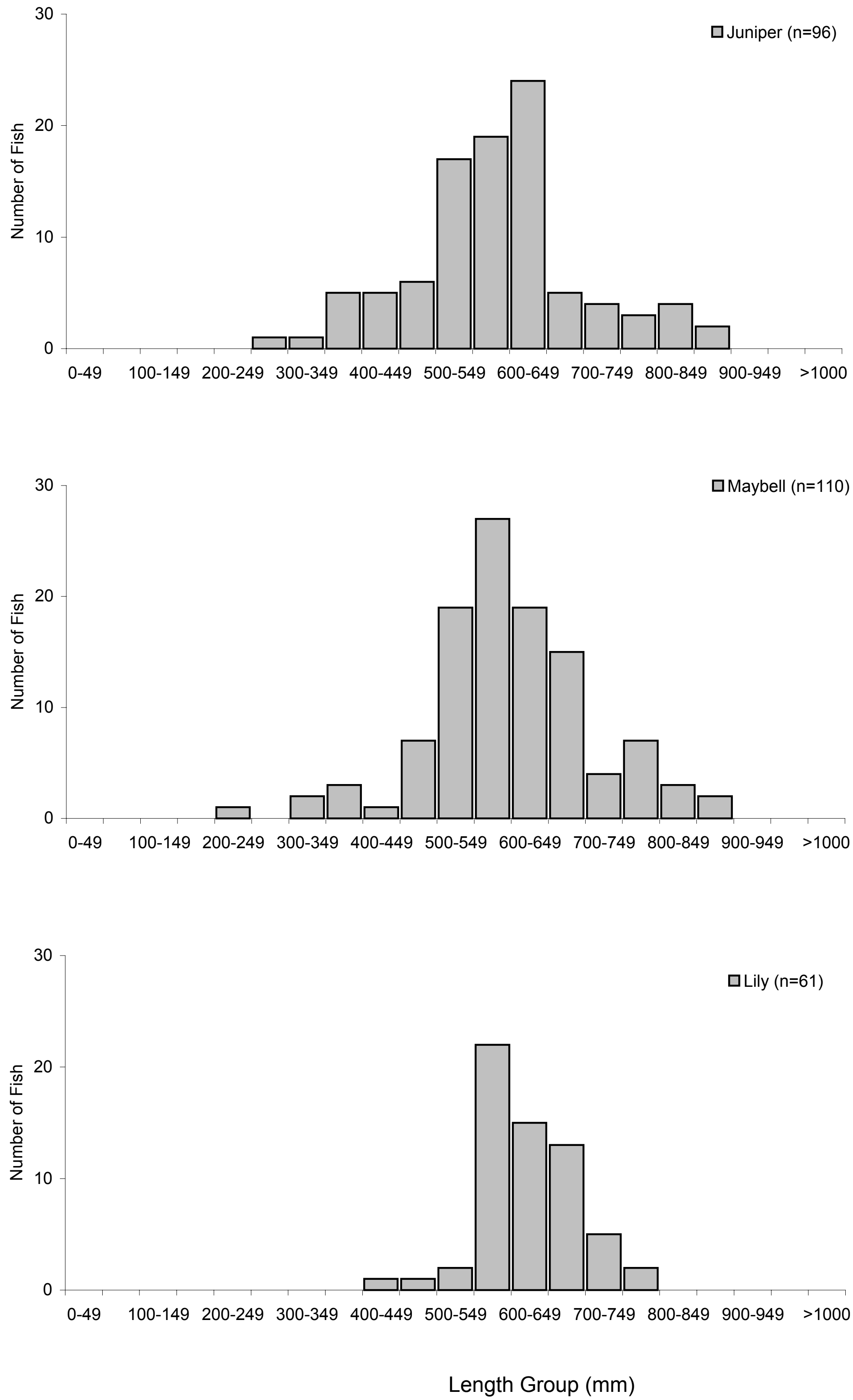

Figure10---Length-frequency of northern pike captured by all gears in each reach of the Yampa River, 2001.

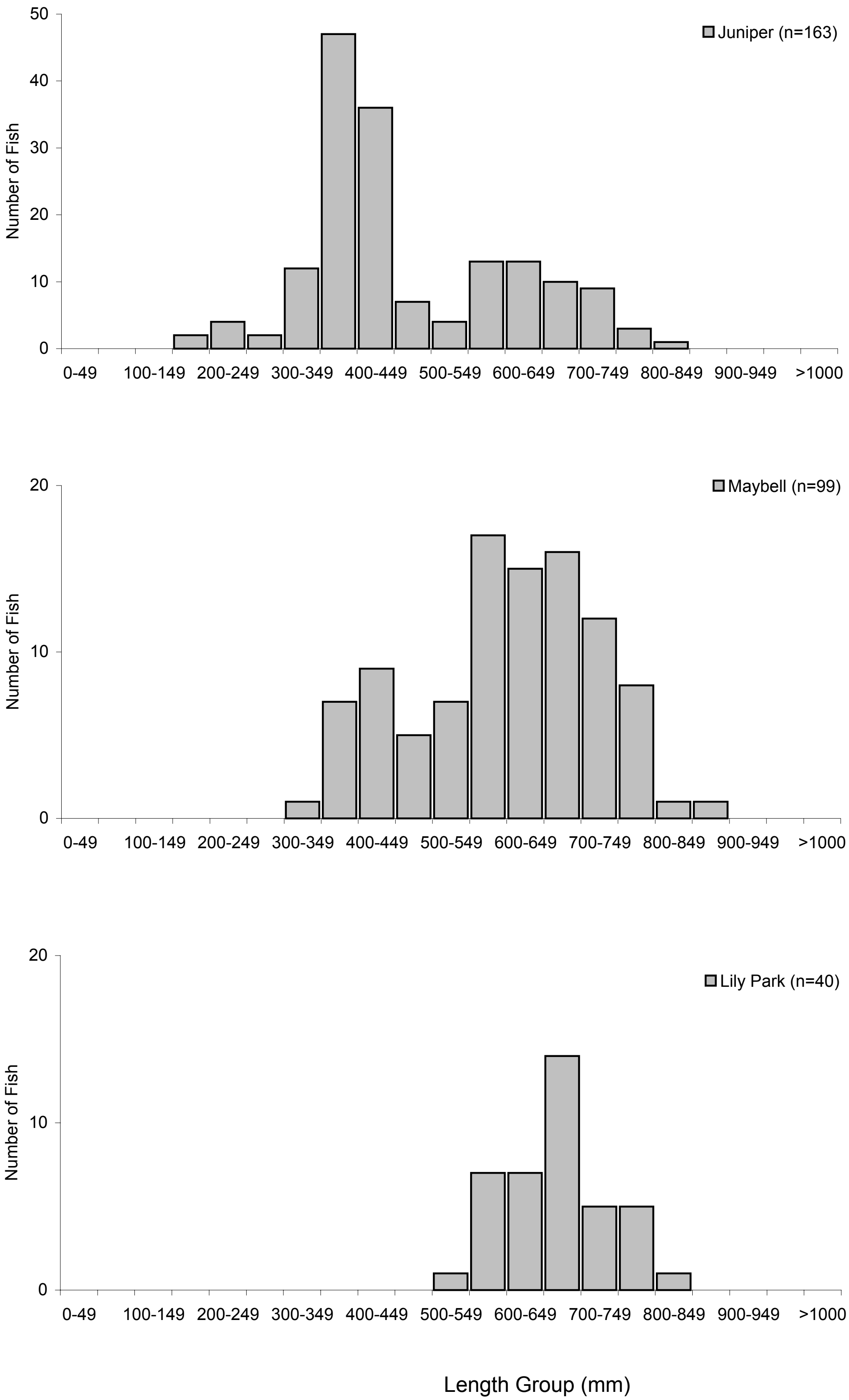

Figure 11---Length-frequency of northern pike captured by all gears in each reach of the Yampa River, 2002.

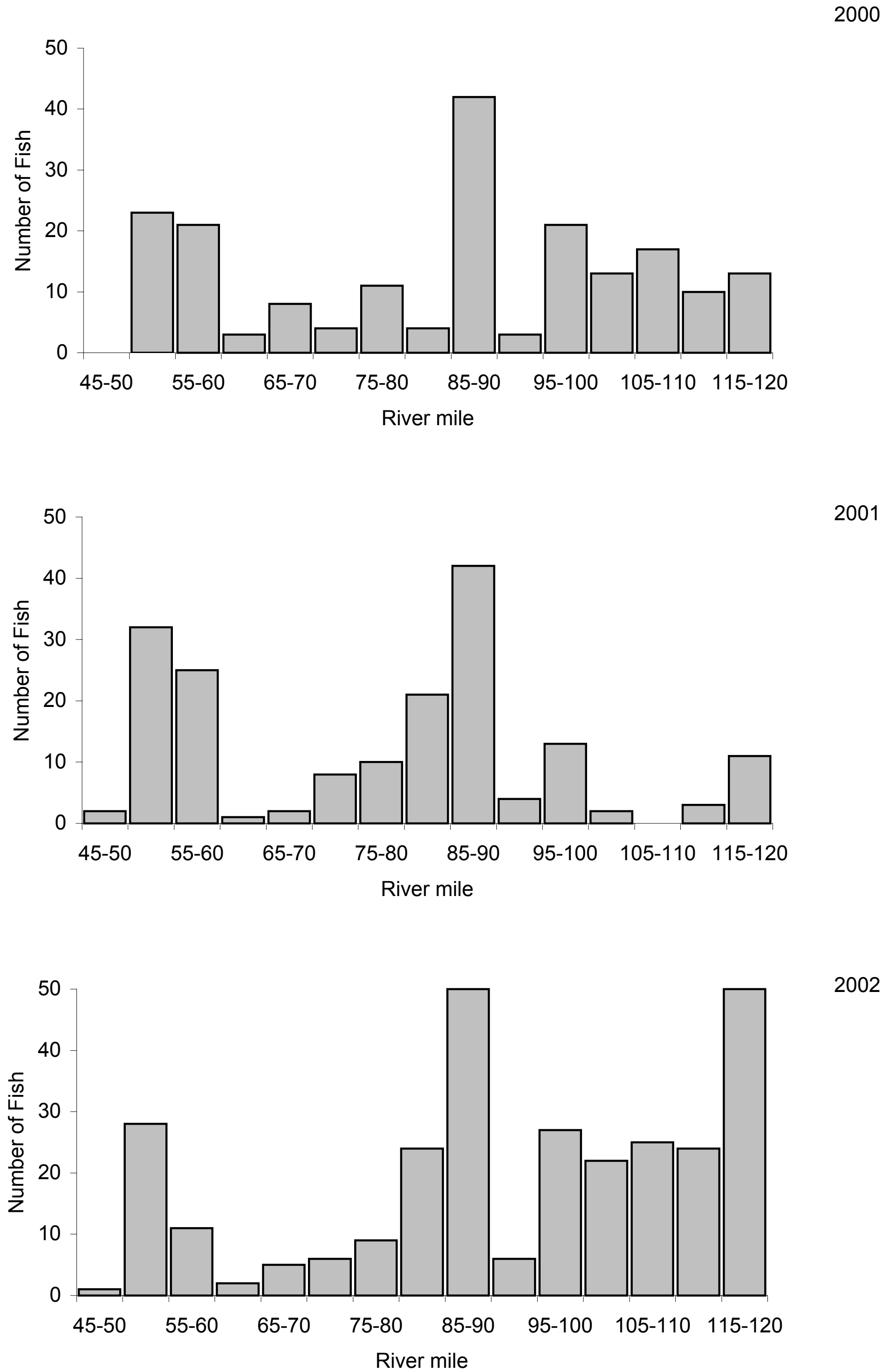

Figure 12---Density of northern pike captured by electrofishing shorelines in the Yampa River, 2000--2002. One boat was used in 2000 and two boats were used in 2001 and 2002.

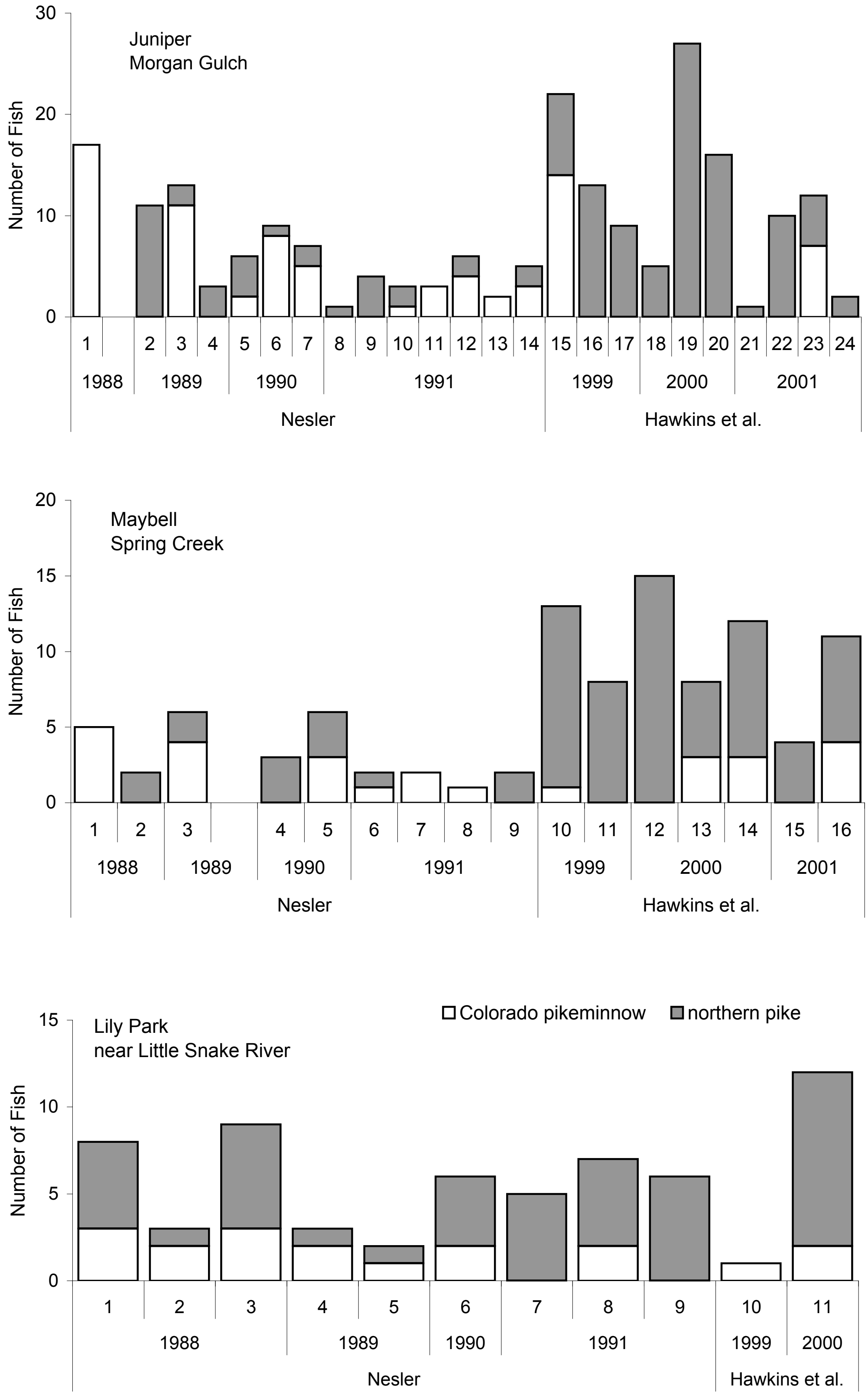

Figure 13---Number of northern pike and Colorado pikeminnow captured in a selected backwater in each reach with block-and-shock or block-and-seine techniques. Sampling techniques are described in the text. Pre-1999 data were from Nesler (1995; Figures 35, 37, and 38).