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Native Fish Response to Nonnative Fish Removal From 2005-2008 in the Middle Green River, Utah

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Young-of-year, Green River, Colorado pikeminnow, roundtail chub, *Gila* spp., bluehead sucker, flannelmouth sucker, speckled dace, backwater habitat, seine, smallmouth bass removal.

EXECUTIVE SUMMARY

The introduction of nonnatives, extirpation of natives and habitat alterations that serve as a catalyst for both, have been identified as one of the leading causes of homogenization of fish populations across the United States (Rahel 2000). Nonnative smallmouth bass have been identified as one of the main predatory threats to native fishes in the middle Green River, mainly due to predation upon early life-stages. In response to population expansion throughout the upper Colorado River basin, intensive smallmouth bass removal efforts were initiated in 2004 and continued through 2008. During this time, focus areas and level of mechanical removal effort within the middle Green River has fluctuated greatly.

The desired outcome of nonnative fish removal in the middle Green River and elsewhere in the upper Colorado River basin is to reduce predacious threats and recover native fish populations. The first response of native fishes to nonnative predator removal will likely be detected by an increase in the abundance of small-bodied nonnative fishes and early life-stages of the native fish community (Bestgen et al. 2007). In order to detect a response by small-bodied nonnative fishes and young-of-year (YOY) native fish to nonnative fish removal, three backwater habitats were sampled in each five-mile sub-reach of the middle Green River from 2005-2008. The fish community and catch rates were evaluated to investigate if a response occurred. Catch-per-unit-effort (CPUE) was used to evaluate native (bluehead sucker *Catostomus discobolus*, flannelmouth sucker *Catostomus latipinnis* and *Gila* spp.) and nonnative (sand shiner *Notropis stramineus,* red shiner *Cyprinella lutrensis*, and fathead minnow *Pimephales promelas*) fish species during pre- (2000-2003) and post-removal (2004-2008) periods using regression analyses. Native species distribution was also evaluated by river mile between pre- and post-treatment periods.

Results indicated that smallmouth bass removal did not produce a definitive response in YOY native fishes or small-bodied nonnatives. Since 2000, native fishes have not exceeded 3% of the total community composition, but did increase slightly in 2008, mostly attributed to a larger proportion of bluehead sucker. Bluehead sucker catch rates consistently hovered around zero prior to 2006, but in 2007 and 2008, CPUE was higher than most years, which could indicate the only potential positive response to nonnative fish control. Regression analyses indicated no significant differences between pre- and post-removal periods for native and nonnative fishes. Distribution of native fish between pre- and post-removal periods demonstrated that *Gila* spp. CPUE was sporadic in all sections, whereas bluehead and flannelmouth sucker had higher post-treatment CPUE in upstream reaches. However, all other reaches demonstrated sporadic patterns for pre- and post-treatment catch rates.

Native fish YOY catch did not increase concomitantly with increased removal of nonnative fishes, which may have several potential explanations. One potential hypothesis is that the duration of the project may be too limited for a response to occur, demonstrated by all regression models failing our power analyses. Another hypothesis is that smallmouth bass removal effort was insufficient to generate a response by the native fish community, which is supported by the inconsistent nature of smallmouth bass removal in the middle Green River and the fact that we did not observe a decrease is smallmouth bass CPUE. In addition, the current study design is limited temporally (i.e., snapshot in time each year), thus native-nonnative interactions could be occurring in backwater habitats, yet they may go undetected. We recommend continuing to monitor small-bodied nonnative and YOY native fishes in the middle Green River through this project to increase the sample size necessary for a robust analysis. However, we suggest that the development of a new study design specifically targeted on determining native-nonnative species habitat overlap on a temporal scale is necessary to provide a better understanding of species interactions (competition and predation) and whether native fishes are positively responding to nonnative fish control.

INTRODUCTION

The proliferation of nonnatives, decline of the natives and habitat alterations that exacerbates both trends, serve to homogenize fish communities across the United States (Rahel 2000). The Colorado River basin is no exception to the profound consequences of nonnative invasions, determined as one of the most altered fish assemblages in the United States (Fuller et al. 1999; Tyus and Saunders 2000). In addition, habitat alteration, largely due to water manipulation in the Southwestern United States, has accelerated nonnative invasions (Minckley and Deacon 1968). As a result, Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, humpback chub *Gila cypha*, and bonytail *Gila Elegans*, have been federally listed under the Endangered Species Act (USFWS 2002; Jelks et al. 2008). By the early 1980's, 42 nonnative fish species had been introduced into the upper Colorado River basin (Tyus et al. 1982). In the Green River drainage, Flaming Gorge Dam operations have greatly altered environmental conditions, shifting discharge, sediment transport, and temperature regimes allowing nonnative species to proliferate in the middle Green River (Muth et al. 2000). Negative impacts to native fish populations vary, but generally result from competitive and predatory interactions between native and nonnative species (Taylor el al. 1984; Haines and Tyus 1990; Karp and Tyus 1990; Tyus and Saunders 2000).

Although several nonnative species are present in the middle Green River (Skorupski and Breen 2011), predation by smallmouth bass *Micropterus dolomieu* and northern pike *Esox Lucius* are of particular concern because they often prey on age-0, small-bodied and juvenile native fish (Hawkins and Nesler 1991; Johnson et al. 2008). Although these species were prevalent in other drainages of the upper Colorado River basin (e.g., Yampa River; Anderson 2005), they did not become established in the middle Green River until 2000. Thereafter, abundance and distribution increased resulting in mechanical removal efforts starting in 2001 for northern pike and 2004 for smallmouth bass. Mechanical removal was effective at reducing northern pike after 2001 (Monroe and Hedrick 2008), which remained suppressed after that, only requiring maintenance level removal to maintain low numbers. During the first three years of smallmouth bass mechanical removal (2004-2006), effort was relatively low with three removal passes in the middle Green River from the Split Mountain boat ramp (river mile [RM] 319.3) to Sand Wash (RM 215.5) (Christopherson et al. 2004 and 2005; Hedrick and Monroe 2006). However, models simulating effort scenarios indicated that smallmouth bass exploitation rates resulting from these levels of effort were insufficient to have a negative effect on the population (Haines and Modde 2007). It was estimated that a minimum exploitation rate of 60% is necessary to result in a smallmouth bass population crash (Haines and Modde 2007), thus effort was increased in the middle Green River beginning in 2007. Removal passes were conducted from Split Mountain boat ramp to the confluence of the Duchesne River (RM 249) and included eight and 11 passes in 2007 and 2008, respectively (Hedrick and Monroe 2007; Monroe and Hedrick 2008).

The desired outcome of nonnative fish removal in the middle Green River and elsewhere in the upper Colorado River basin is to reduce predacious threats and recover native fish populations. The first response of native fishes to nonnative predator removal will likely be detected by an increase in the abundance of small-bodied nonnative fishes and early life-stages of the native fish community (Bestgen et al. 2007). For example, bluehead sucker, flannelmouth sucker, speckled dace *Rhinichthys osculus,* and *Gila* spp., all of which are consistently present in the middle Green River (Breen et al. 2011), can serve as surrogates of the response anticipated for endangered fish species occupying similar habitats (e.g., Colorado pikeminnow).

Determining the response of the native fish community is critical to evaluate whether mechanical removal of nonnative predators is an effective control measure aiding in the recovery of endangered fishes. Thus, the goal of this project is to determine if there is a native species response to mechanical removal of nonnative predator species in the middle Green River.

GOALS AND OBJECTIVES

Goal: To estimate the response of the native fish community to nonnative predator removal.

Objective: Estimate the response of small-bodied nonnative fishes and early life-stages of native fish to removal of northern pike and smallmouth bass in the middle Green River.

STUDY AREA

Our study reach included the middle Green River from the Split Mountain boat ramp in Dinosaur National Monument (RM 319.3) to Sand Wash (RM 215.5; Figure 1). Removal of smallmouth bass (2004-2008) and northern pike (2001-2008) occurred throughout this reach, thus providing an opportunity to evaluate the response of native fish to nonnative fish removal. However, it is important to note that smallmouth bass removal effort (i.e., number of passes) and sample reaches differed between years (Figure 2).

The middle Green River was divided into four sections based on differences in habitat and smallmouth bass removal effort between years. More specifically, sections were separated at the Duchesne River confluence because nonnative removal below this point did not occur in all sampling years (Figure 2). The four sections are as follows: Split Mountain boat ramp to three miles below the Ashley Creek confluence (RM 319-297), three miles below the Ashley Creek confluence to the Stirrup floodplain (RM 296-273), the Stirrup floodplain to the Duchesne River confluence (RM 272-249), and the Duchesne River confluence to Sand Wash (RM 248-

215.5). The first section is characterized by steep gradients and an abundance of cobble and gravel substrates (including within backwater habitats). The second and third sections are characterized by larger backwaters, with more sand and silt substrates. Backwaters in the lower reach are dominated by silt substrates that increase in depth towards Sand Wash.

METHODS

Field sampling. — This study was modeled after the ISMP (Interagency Standardized Monitoring Protocol) sampling (project # 138) that began in 1986 (USFWS 1987). For ISMP sampling, the middle Green River was sectioned into five-mile reaches and the first two backwaters within each five-mile reach were seined using the following standard protocol: (1) all post-larval monitoring was accomplished between 20 September and 10 October using a 0.3 cm ace mesh seine (4.57 x 1.22 m), (2) backwaters were at least 30 m^2 and at least one ft deep at the deepest point, and (3) suitable backwaters were sampled with a minimum of two non-overlapping seine hauls (preferably parallel to one another and perpendicular to the main axis of the backwater) to encompass at least 25% of the backwater, avoiding the mouth of the backwater and the shallow, upper end. All identifiable Colorado pikeminnow and other native fish species collected in all seine hauls were measured (total length = TL, in mm) and released. Nonnative fish captured in the first seine haul for each backwater were enumerated (USFWS 1987; McAda 1989; McAda et al. 1994).

Beginning in 2005, one additional backwater per five-mile reach was added to the study design, but the backwater selection requirements were relaxed for an acceptable backwater with the idea that Colorado pikeminnow were no longer the primary target. The only difference in sampling for the third backwater habitat was that additional seine hauls were taken in any part of the backwater, including the mouth and/or shallow tail end.

Native fish species captured in the first seine haul that were large enough to identify were measured (TL) and released, whereas all nonnative fish were identified, enumerated, and removed. In the second and any subsequent seine hauls, all identifiable native fish were measured (TL) and released. Common small-bodied, nonnative cyprinids (sand shiner, red shiner and fathead minnow) were not counted after the first seine haul. However, less common nonnatives (i.e., smallmouth bass, common carp *Cyprinus carpio*, green sunfish *Lepomis cyanellus*, channel catfish *Ictalurus punctatus*, black bullhead *Ameiurus melas*, gizzard shad *Dorosoma cepedianum*, and white sucker *Catostomus commersonii* in the second and subsequent seine hauls were counted and measured (TL). Fish that were too small to reliably identify (usually smaller catostomids and *Gila* spp.) and/or new species occurrences (plains killifish *Fundulus zebrinus*, in 2008) were preserved and sent to the Larval Fish Laboratory at Colorado State University for identification.

In addition to fish measurements, the overall length (m), width (m), maximum depth (cm), and temperature (ºC) of each backwater and associated mainchannel area were recorded. Each seine haul was measured for length (m) and width (m). The depth of each seine haul (cm) was taken at three locations: one at its maximum depth and at two points midway between that point and each shoreline. Predominant substrates (silt, sand, gravel [3–76 mm], cobble [76–305 mm], or boulder [>305 mm]) were also identified at each depth measurement location. River mile, UTM coordinates, and time of sampling were also recorded at each backwater sampled.

Data Analysis. — CPUE and total catch served as metrics to compare trends in native and nonnative YOY and small-bodied fishes collected during pre- (2000-2003) and post-removal (2004-2008) periods. We relied on this approach because pre-removal is when smallmouth bass became abundant, but mechanical removal was not yet initiated, whereas intense smallmouth bass removal had been in place during the post-removal period. Both metrics were calculated for each species from 2000 to 2008, but CPUE was the primary metric used to account for differences in sampling effort starting in 2005 (Figure 3). We calculated CPUE as the number of fish collected/area sampled in m^2*100. Unknown *Gila* spp. and roundtail chub *Gila robusta,* were combined as *Gila* spp. for all years due to the difficultly in identifying YOY chubs to species. Unknown minnow spp. were recorded in 2006 due to overwhelming abundances (i.e., hundreds to thousands in most seine hauls). Therefore, within-year ratios of fathead minnow (4%), red shiner (88%), and sand shiner (7%) were used to estimate the total number of each species.

Analytical Procedures. — Simple linear regressions were performed for the top three most abundant native species (bluehead sucker, flannelmouth sucker, and *Gila* spp.; speckled dace were excluded due to low numbers caught, Figure 4) and the three most dominant nonnative cyprinids (fathead minnow, red shiner and sand shiner) to determine if a significant response (i.e., a change in CPUE over time within each period) occurred for pre- and post-removal years. An independent regression was applied to each period (pre- and post-removal) and each species. The crux of the analysis is to test if there is a significant response during the pre-removal (no nonnative removal) and post-removal period, when nonnative predator removal occurred. Power tests were performed for each regression analysis to determine if the model adequately describes the relationship of the variables.

Presence/absence, community composition, species richness and species diversity indices (Shannon and Evenness; Krebs 1989) were used to compare fish community structure in backwaters from 2000-2008. High values of Shannon diversity index represent a more diverse community and Evenness measures how the abundance of the species is distributed among all species, with higher values representing a more even community. Presence/absence was mainly used to view historical trends since 1985. These methods allowed us to examine the fish community as a whole to indentify if any major shifts were observed before and after smallmouth bass removal was implemented.

Data were also analyzed by river mile sections of the middle Green River study area. We investigated the distribution of native species within each section by plotting CPUE for pre- and post-removal periods. Several reasons delineate the importance of determining if a variable response is observed in different sections of the middle Green River. First, to determine potential community shifts based on habitat conditions and differences in smallmouth bass removal effort by section. For example, the most consistent and intense removal effort was within the upper three sections of the middle Green River and the greatest CPUE of smallmouth bass occurred below the Duchesne River in 2004 (Christopherson et al. 2004). In addition, smallmouth bass removal has occurred from Echo Park to Split Mountain from 2004 to 2008 (Jones et al. 2010). In the middle Green River, CPUE decreased in 2005 and mechanical removal did not occur below the Duchesne River in 2007 and 2008 (Figure 2). Thus, differences in smallmouth bass removal effort may have resulted in a differential response in YOY native species in different sections of the middle Green River. In addition, there are vital recruiting populations of bluehead sucker, flannelmouth sucker, and *Gila* spp. within Dinosaur National Monument (e.g., Breen and Hedrick 2010; Breen and Hedrick In Press). Therefore, if a positive native fish response were to occur, it would be intuitive that the response would most likely occur in the uppermost sections.

RESULTS

Fish community trends. —The native and nonnative fish community has and continues to change from historical conditions, specifically within the pre- and post-removal periods (Tables 1-2). From 2000-2008, bluehead sucker, flannelmouth sucker, *Gila* spp., and speckled dace have all been represented by low numbers caught and catch rates, none of which exceeded 2.1 fish/100m^2 (Figures 4-5). *Gila* spp. had relatively higher catch rates in 2001 but thereafter they were represented by low CPUE (Figure 5). Flannelmouth sucker were the only native species consistently present in the middle Green River (Table 1) with sporadically higher catch rates (2001 and 2003-2004), but do not appear to have a positive response due to smallmouth bass control (Figure 5). Since 2000, native fishes have not exceeded 3% of the total community composition, but did increase slightly in 2008, mostly attributed to a larger proportion of bluehead sucker (Figure 6). Bluehead sucker catch rates consistently hovered around zero prior to 2006, but in 2007 and 2008, CPUE was higher than most years, which could indicate the only positive response to nonnative fish control (Figure 5).

The number of nonnative fish species present in backwaters has increased from five to 15 species from 1985 to 2008, including three new species observations since 2006 (Table 2). Observations occurred for black bullhead in 1986, black crappie *Pomoxis nigromaculatus*, and white sucker *Catostomus commersoni* in 1994, smallmouth bass in 1995, and bluegill *Lepomis macrochirus* in 2006 (Table 2). Although not as abundant as other nonnative fish species, these five species have been collected from backwaters regularly since their presence and represent potential predatory and hybridization (white sucker) threats on native fishes; particularly, smallmouth bass which were more sporadic prior to 2004 (Table 2). Elevated levels of nonnative species were observed in 2000, 2002, and 2006, with CPUE over 1000 (fish/100m^2)

when combined (Figure 7). However, catch rates have decreased since 2000, particularly for red shiner, and were at their lowest in 2008 (Figure 7). CPUE of less common small-bodied nonnative fishes in backwater habitats shifted from 2000 to 2003 (pre-removal) and 2004 to 2008 (post-removal) (Figure 8). Presence and CPUE appears to increase during the post-removal period. Common carp was the only species whose CPUE increased or stayed the same in pre- and post-removal periods (Figure 8). Although community composition has become more species-rich over time (Table 2), we observed a decline in catch rates for the three most abundant nonnative cyprinids (Figure 7). As a result, richness, Shannon diversity and Evenness indices including all native and nonnative species were highest in 2008 (Table 3).

Native fish pre vs. post analysis. — Linear regressions on the pre-removal sampling period (2000-2003) were negatively sloped for bluehead sucker and *Gila* spp. and positively sloped for flannelmouth sucker (Figures 9-11). Although native species demonstrated a response prior to nonnative removal no significant differences were observed for flannelmouth sucker ($r^2 = 0.07$, $P = 0.73$), bluehead sucker ($r^2 = 0.44$, $P = 0.34$) or *Gila* spp. ($r^2 = 0.05$, $P = 0.77$) and did not pass the power test due to small sample sizes and large variability. Linear regressions during post-removal (2004-2008) were negatively sloped for flannelmouth sucker and *Gila* spp. and positively sloped for bluehead sucker (Figures 9-11). Again, no significant differences were observed for flannelmouth sucker ($r^2 = 0.37$, $P = 0.28$), bluehead sucker ($r^2 = 0.29$, $P = 0.35$) or *Gila* spp. ($r^2 = 0.69$, $P = 0.08$) and did not pass the power test due to small sample sizes and large variability. Post-hoc analyses to test for differences between pre- and post-removal slopes were not possible given that significant differences were not detected for individual models. Although the test has merit to determine a response before and after smallmouth bass control, results should be interpreted with caution. More specifically, the possibility of a type-II error is high for all species (i.e., decreased ability to detect a difference when one actually occurs). When considering they were absent in 2001-2002 (Table 1; Figure 4), high CPUE in 2007-2008 (Figure 5) could represent an important positive response.

Native fish pre vs. post trends by river mile section. — Bluehead sucker had the highest pre-removal CPUE for RM 296-273 and 272-249, with a catch rate of zero in the upper most section (Figure 12). Conversely, bluehead sucker had relatively high CPUE in all river mile sections except 296-273 during post-removal. High catch rate in RM 319-297 could be a function of consistent smallmouth bass removal since 2004, but does not explain the increase in the lower most section where removal was discontinued from 2007-2008 (Figure2). For flannelmouth sucker, pre-removal CPUE was high for RM 296-273 and 248-215 (Figure 13), whereas post-removal only had high CPUE in RM 319-296.

Nonnative fish pre vs. post analysis. — Linear regressions on the pre-removal (2000-2003) sampling period were negatively sloped for red shiner, fathead minnow and sand shiner (Figures 15-17); however, no significant differences were observed for red shiner (r^2 = 0.45, P = 0.33), fathead minnow (r^2 = 0.39, P = 0.38) and sand shiner (r^2 = 0.61, P = 0.22) and did not pass the power test due to small sample sizes and large variability. Linear regressions during the post-removal (2004-2008) sampling period were negatively sloped for red shiner and fathead minnow and positively sloped for sand shiner (Figures 15-17). Likewise, no significant differences were observed for red shiner (r^2 = 0.18, P = 0.48), fathead minnow (r^2 = 0.00, P = 0.96) and sand shiner (r^2 = 0.01, P = 0.84). In addition, post-removal regressions did not pass the power test due to small sample sizes and large variability. Results should be interpreted with caution because of the low power of the model.

DISCUSSION

Smallmouth bass removal did not produce a definitive response in age-0 native fish species. CPUE of flannelmouth sucker and *Gila* spp. decreased over the course of the study, whereas, bluehead sucker was the only native species to demonstrate any level of a positive post-removal response. Pre- and post-removal regression analyses were not significantly different for the three native species; however, the power of the analysis was reduced due to the limited extent of the project (i.e., only occurred for a few years). Regardless of the shortcoming of the test and its interpretation, the continuation of the study, which will increase the period of record, could only benefit native species analyses. This is particularly true for bluehead sucker that had a positive post-treatment response (Figure 10), which was also supported by the greatest percent composition and CPUE in 2008 (Figures 5-6). When considering these metrics, the positive response demonstrated by bluehead sucker could indicate some degree of a native fish community response from nonnative fish removal, but without statistical power and other potential environmental causes for increase, interpretation is difficult and conclusions should be cautionary. However, a differential response could have occurred due to differences in smallmouth bass removal effort (Christopherson et al.2004; Hedrick and Monroe 2007; Monroe and Hedrick 2008).

A response would be expected where nonnative removal effort has been the most consistent and concentrated (Figure 2). The highest abundance of smallmouth bass were observed below the Duchesne River confluence in 2004 (Christopherson et al. 2004); however, removal effort did not occur below this point in 2007 and 2008. Alternatively, effort increased in the three upper sections (Hedrick and Monroe 2007; Monroe and Hedrick 2008). Thus, it would be expected that the greatest potential for a response would likely occur in sections above the

Duchesne River confluence. Unfortunately, a definitive pre- and post-removal response by river mile section was not observed for all native species, mostly because pre-removal CPUE was similar to or greater in many river mile sections. Flannelmouth and bluehead sucker did have higher post-removal catch rates in section 319-297, with CPUE being zero for bluehead sucker during the pre-removal period (Figure 5). In addition, bluehead sucker CPUE was higher during post-removal below the Duchesne River, which one could hypothesize that the White River sucker population contributes to YOY in the Green River. The high catch rate for flannelmouth in RM 319-297 could be a function of consistent smallmouth bass removal similar to bluehead sucker, but two sections had high catch rates during pre-removal, which does not reflect poor conditions prior to smallmouth bass removal. *Gila* spp. had higher catch rates for pre-removal, which is likely due to the 2001cohort (Figure 5) and post-removal catch rates were relatively low; however, regardless of sample period, CPUE was higher in the upper sections (Figure 14). Breen and Hedrick (2010, In Press) have determined that healthy bluehead sucker populations persist in the White River, with successful annual reproduction indicated by high YOY catch rates relative to the Green River. Similarly, high post-removal catch rates for flannelmouth sucker, bluehead sucker and *Gila* spp. (both pre- and post-treatment), could be a result of successful recruitment in Dinosaur National Monument (Vanicek and Kramer 1969; Breen and Hedrick 2010, In Press). Although results were not strikingly definitive spatially among river sections, it could be hypothesized that if a response were to occur it would be within close proximity to recruiting populations where YOY are more likely to be abundant. Additionally, smallmouth bass removal has been most consistent in this area, thus it is possible this is the first sign of a positive response in age-0 native species. In general, results demonstrate that bluehead sucker, flannelmouth sucker and *Gila* spp. are influenced by Dinosaur National Monument populations, but they do not definitively indicate a post-removal response to smallmouth bass removal. Even though we have not observed a definitive positive response to nonnative predator removal, it is important to recognize that the fish community in the middle Green River has been in constant flux, thereby providing a complex set of interactions, potentially masking a response if there is in fact one.

Fish community structure has shifted considerably over the past three decades in the middle Green River. In 1985, only five nonnative species were present and by the end of this study in 2008, 15 nonnative fish species were present in backwaters of the middle Green River. Research has shown that distribution of many cosmopolitan fish species has increased because of intentional and unintentional introductions of nonnative fish (Rahel 2000). In the middle Green River, nonnative species diversity has increased, as well as abundance primarily from fathead minnow, red shiner and sand shiner in backwaters. These three small-bodied cyprinids are resilient species, which can spawn multiple times, and over an extended period from spring into fall, and produce a large number of offspring (Pflieger 1975), facilitating their high catch rates. What is also alarming is speckled dace have not been observed in the fish community since 2005 (Figure 4).

One hypothesis when intense removal of nonnative fish began was that abundance of nonnative small-bodied cyprinids would increase as potential predators (e.g., smallmouth bass) decreased. However, a decline has been observed in red shiner, fathead minnow and sand shiner, and 2008 marked the lowest CPUE since 2000, while fish community composition has become more diverse and even (Table 3). It seems that some mechanism is allowing for diversification of the community, which was most apparent in 2007 and 2008 (Table 3). For example, Huston's (1979) dynamic equilibrium hypothesis demonstrates that certain levels of competitive displacement and frequency, (either being direct competition, predation or environmental), relates to species diversity. This hypothesis could explain the response in nonnative catch rates and diversity observed in 2007 and 2008; yet, regressions were not significantly different for the top three cyprinids pre- or post-removal of smallmouth bass.

Poor native fish response. — A number of possibilities could explain why a definitive positive response in native fishes was not observed over the study period. One potential hypothesis is that the duration of the project may be too limited for a response to occur, supported by all regression models failing the power analyses. In addition, Haines and Modde (2007) estimated that with a 60% exploitation rate for smallmouth bass, it could potentially take 20 years of removal efforts to cause a population crash. This leads us to believe that our data supports the conclusions of Haines and Modde (2007). More specifically, within the time frame of this project (5 years of removal) not enough time has elapsed to negatively influence the smallmouth bass population, thus a response in the native fish community would not be expected.

Another potential hypothesis is that smallmouth bass removal effort in the middle Green River is insufficient from one year to another to generate a response by the native fish community. Although removal has been conducted for a number of years, no abrupt reduction has been observed in smallmouth bass catch rates (Figure 2). From 2004-2006, removal effort was minimal (three passes), and was determined to be insufficient to crash the smallmouth bass population (Haines and Modde 2007). Even though effort increased in 2007 and 2008 (Hedrick and Monroe 2007; Monroe and Hedrick 2008), smallmouth bass removal only extended to the Duchesne River, adding more inconsistency within the study period. This is supported by exploitation rates only approaching 60% in 2004 and 2008 (Christopherson et al. 2004 and 2005;

Hedrick and Monroe 2006 and 2007; Monroe and Hedrick 2008). In addition, while smallmouth bass were found in low abundance in backwaters, they were only sporadically found prior to 2004 (Table 2). Evidence suggests a greater interaction of age-0 smallmouth bass and natives in backwater habitats since 2005. This leads us to believe that other potential interactions were not being captured under this study design.

Bestgen et al. (2007) demonstrates that there is a negative association between age-0 native species and age-0 smallmouth bass when YOY smallmouth bass are present in the same habitats. However, habitat complexity is limited in the middle Green River (largely an alluvial reach) relative to other systems such as the Yampa River (e.g., Bestgen et al. 2007), thus age-0 smallmouth bass likely utilize different habitats at various life stages (i.e., they may move out of backwater habitats upon achieving a certain size). In contrast to our study, native fish response in the Yampa River is measured throughout summer, whereas we only have one sampling event in the early fall, after potential age-0 smallmouth bass may have utilized backwater habitats (i.e., post-interaction of competitive and predatory pressure). This is supported by 2011 sampling results that indicated that higher abundances of age-0 smallmouth bass were present in backwaters following an extended high flow regime that likely postponed smallmouth bass spawning activities (Skorupski et al. 2011). Backwater habitats would have to be sampled over a broader temporal scale to answer this hypothesis.

CONCLUSIONS

- We did not observe a definitive positive response by YOY native fishes between pre- and post-removal periods or by river mile section, however bluehead sucker potentially demonstrated a positive post-removal response.

- Community composition trends are complex; richness and diversity indices have increased since 2000 mostly attributed to decreases in red shiner, fathead minnow and sand shiner catch rates and an increase in less common nonnative species diversity. Fish community interactions potentially masked a nonnative removal response and/or make it difficult to detect one.
- Bluehead sucker potentially demonstrated a positive post-removal response. Native fishes did not exceed 3% of the total community composition since 2000, but did increase slightly in 2008, mostly attributed to a larger proportion of bluehead sucker. Bluehead sucker catch rates consistently hovered around zero prior to 2006, but in 2007 and 2008, CPUE was higher than most years, which could indicate the only potential positive response to nonnative fish control.
- Smallmouth bass effort and the area of removal was inconsistent making it difficult to detect a YOY native fish response.

RECOMMENDATIONS

- Continue to monitor small-bodied nonnative and YOY native fishes in the middle Green River through this project to increase the sample size necessary for a robust analysis. Additional evaluations of relationships between nonnatives and natives will provide a better understanding of species interactions (competition and predation) and habitat overlap.

- Determine whether data collected through this project is sufficient for evaluating YOY native fish response to nonnative predator control measures in the middle Green River. The timing of ISMP and Native Fish Response sampling (late September), is likely limiting our ability to detect habitat overlap between YOY native fishes and early life-stages of nonnative predators in the middle Green River in comparison to other reaches in the upper Colorado River basin where native fish response is being assessed (e.g., Yampa River; Bestgen et al. 2007).

- We suggest that a separate study is necessary that focuses on investigating if there is overlap with YOY native species and YOY nonnative predators on a temporal scale to determine whether detrimental interactions are occurring when they are most crucial (i.e., nonnative predators potentially utilizing the same habitats).

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Table 1. Presence/absence of bluehead sucker (BH), *Gila* spp. (CH), Colorado pikeminnow (CS), flannelmouth sucker (FM), razorback sucker (RZ), and speckled dace (SD) in backwaters in the middle Green River. Data prior to 2005 were part of the ISMP sampling effort, which is provided for historical species trends.

Year	BH	CH	CS	FM	RZ	SD
1985	X	X	X	X		X
1986	X	X	X	X		X
1987	X	X	X	X		X
1988	X	X	X	X		X
1989	X	X	X	X		X
1990	X	X	X			X
1991		X	X			
1992	X	X	X	X		X
1993	X	X	X	X		X
1994	X	X	X	X		X
1995	X	X	X	X		X
1996	X	X	X	X		X
1997	X	X	X	X	X	X
1998	X	X	X	X	X	X
1999	X	X	X	X		X
2000	X	X	X	X	X	X
2001		X	X	X		
2002		X		X		X
2003	X	X	X	X		
2004	X	X	X	X		X
2005	X	X	X	X		X
2006	X		X	X		
2007	X	X	X	X		
2008	X	X	X	X		

Table 2. Presence/absence of fathead minnow (FH), red shiner (RS), sand shiner (SS), black bullhead (BB), channel catfish (CC), common carp (CP), green sunfish (GS), northern pike (NP), black crappie (BC), white sucker (WS), smallmouth bass (SM), redside shiner (RD), gizzard shad (GZ), bluegill (BG), and plains killifish (PK) in backwaters of the middle Green River. Data prior to 2005 were part of the ISMP sampling effort, which is provided for historical species trends.

Year	FH	RS	SS	BB	CC	CP	GS	NP	BC	WS	SM	RD	GZ	BG	PK
1985	X	X	X			X						X			
1986	X	X	X	X	X	X	X	X							
1987	X	X	X	X	X	X									
1988	X	X	X	X	X	X	X								
1989	X	X	X		X	X	X								
1990	X	X	X		X	X									
1991	X	X			X	X	X								
1992	X	X	X	X	X	X	X								
1993	X	X	X		X	X	X								
1994	X	X	X			X	X		X	X					
1995	X	X	X		X	X	X				X				
1996	X	X	X		X	X	X								
1997	X	X	X	X		X	X		X	X	X				
1998	X	X	X	X	X	X	X	X		X		X			
1999	X	X	X	X		X	X	X	X		X	X			
2000	X	X	X	X		X	X		X						
2001	X	X	X	X	X	X			X		X				
2002	X	X	X			X	X		X	X					
2003	X	X	X			X			X						
2004	X	X	X		X	X	X		X	X	X				
2005	X	X	X	X	X	X	X		X	X	X				
2006	X	X	X	X		X	X		X	X	X		X	X	
2007	X	X	X	X	X	X	X		X	X	X		X	X	
2008	X	X	X	X	X	X	X		X	X	X		X		X

Table 3. Species richness and diversity indices of young-of-year and small-bodied fish community from 2000 to 2008. Analysis includes total catch of all species observed in backwater habitat.

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Richness	13	11	11	9	14	16	14	18	17
Shannon	0.92	0.66	0.63	0.27	0.76	0.74	0.47	0.97	1.46
Evenness	0.24	0.19	0.18	0.08	0.20	0.19	0.12	0.23	0.37

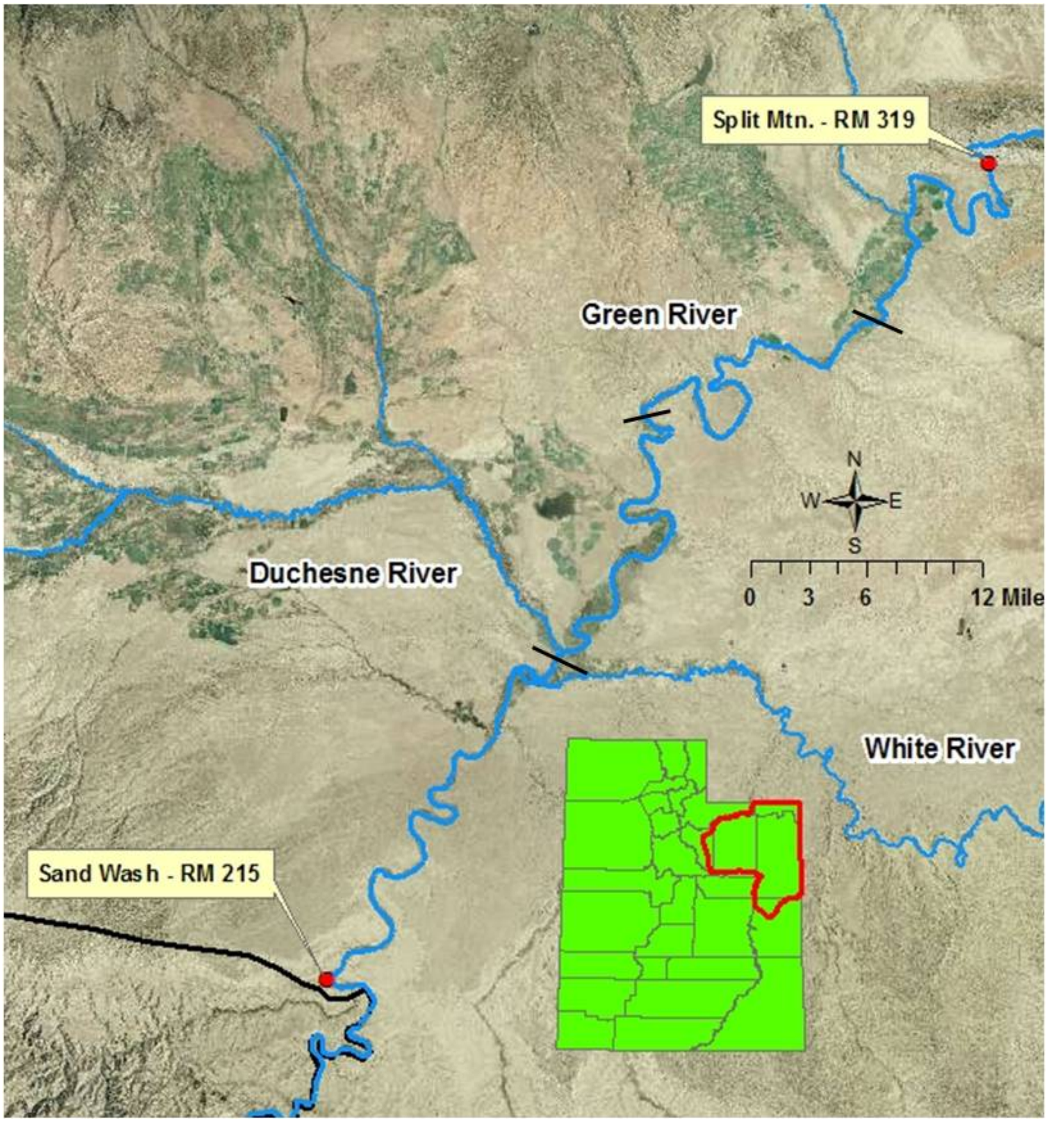

Figure 1. Middle Green River backwater sampling from Split Mountain Boat Ramp to Sand Wash. Black dashes represent the separation point of the four sections established for analysis in the middle Green River.

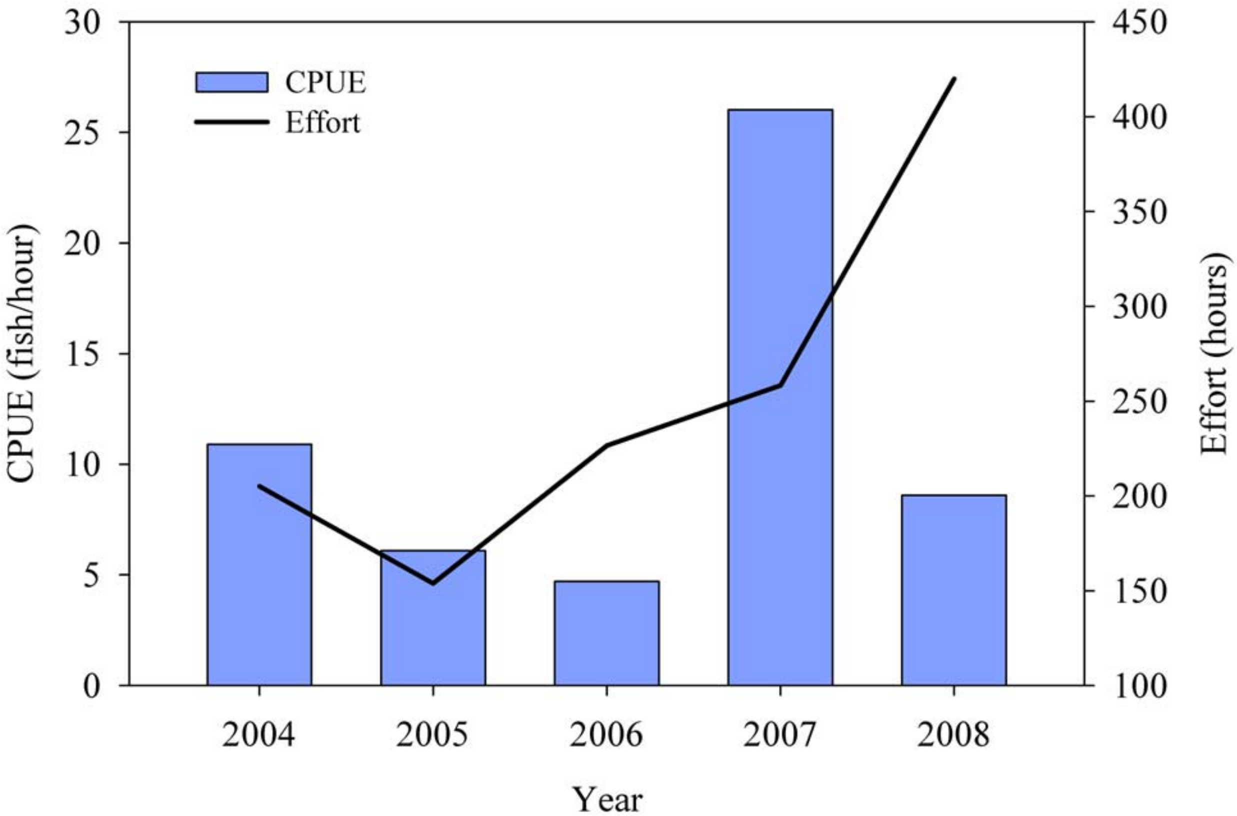

Figure 2. Catch-per-unit-effort (CPUE) and effort for smallmouth bass removal from 2004-2008 in the middle Green River. Effort in 2004-2006 was conducted from Split Mountain boat ramp to Sand Wash (103.8 total miles), whereas 2007-2008 was from Split Mountain boat ramp to the Duchesne River confluence (71.3 total miles).

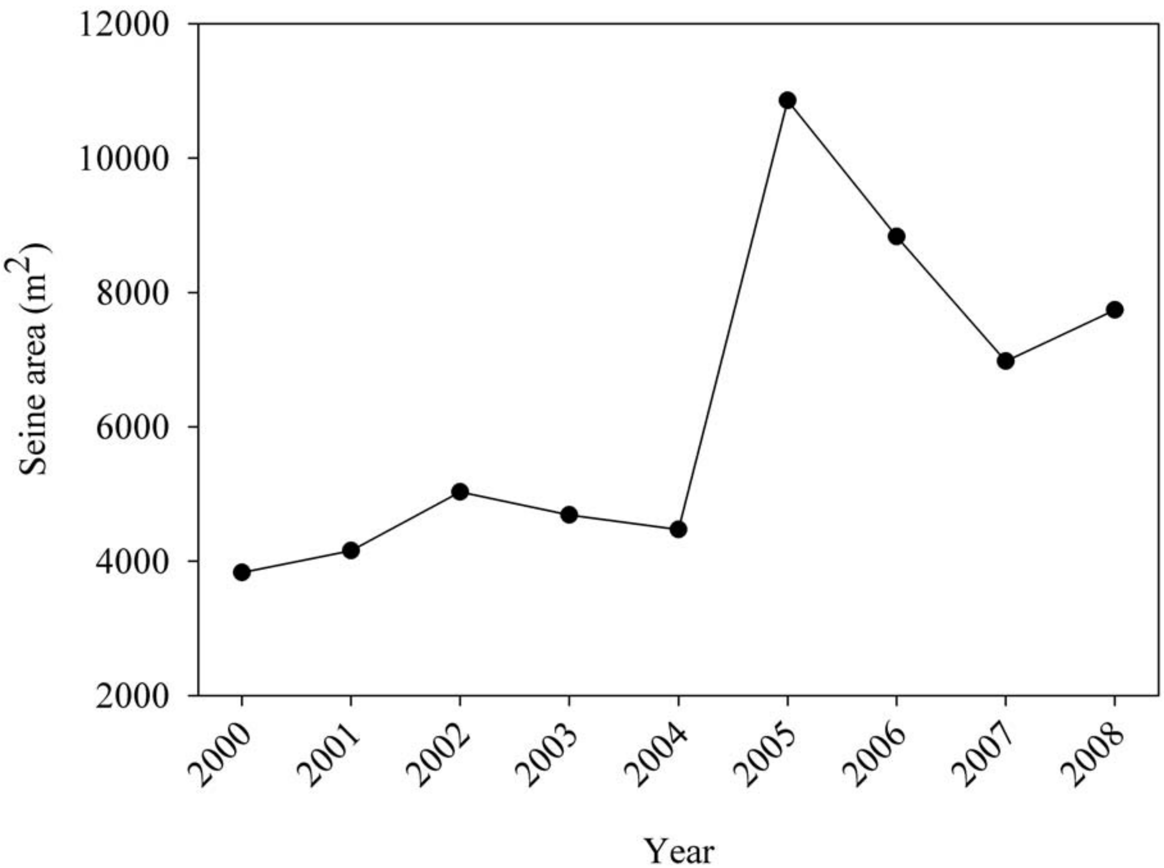

Figure 3. Total area sampled for young-of-year native fishes in the middle Green River from 2000-2008. Increased effort beginning in 2005 reflects the addition of a third backwater habitat sampled for native fish response.

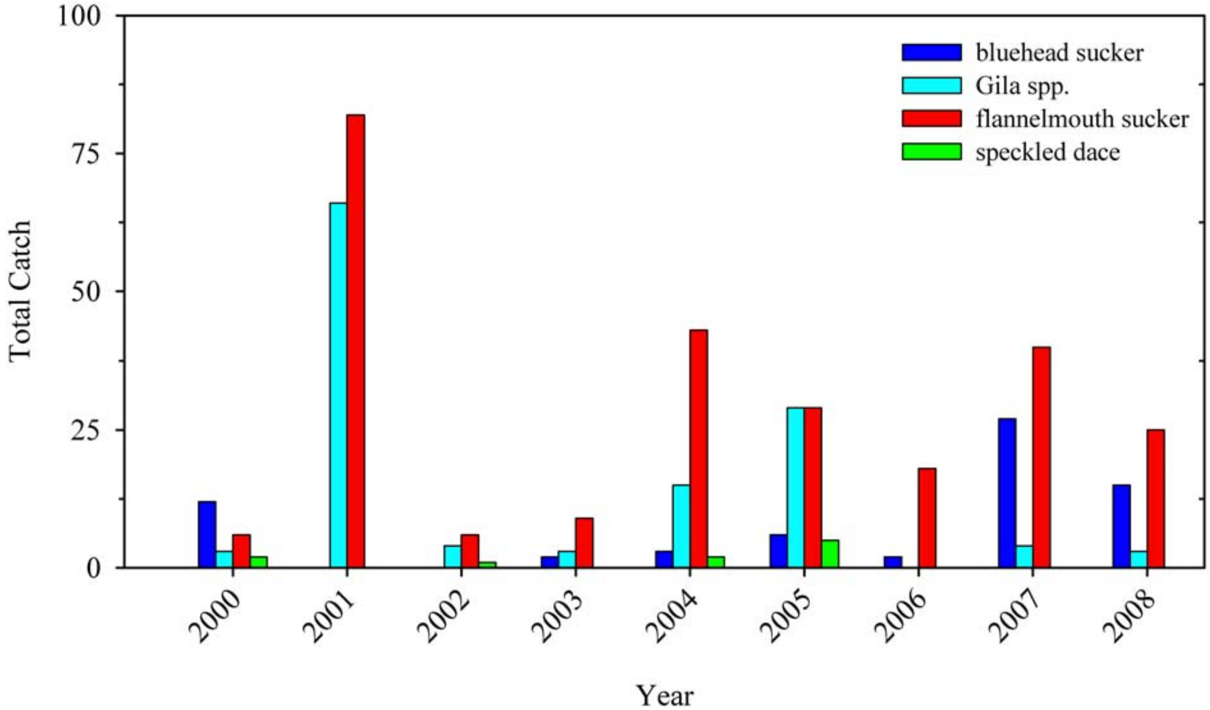

Figure 4. Total catch of young-of-year native fishes collected from all backwaters of the middle Green River.

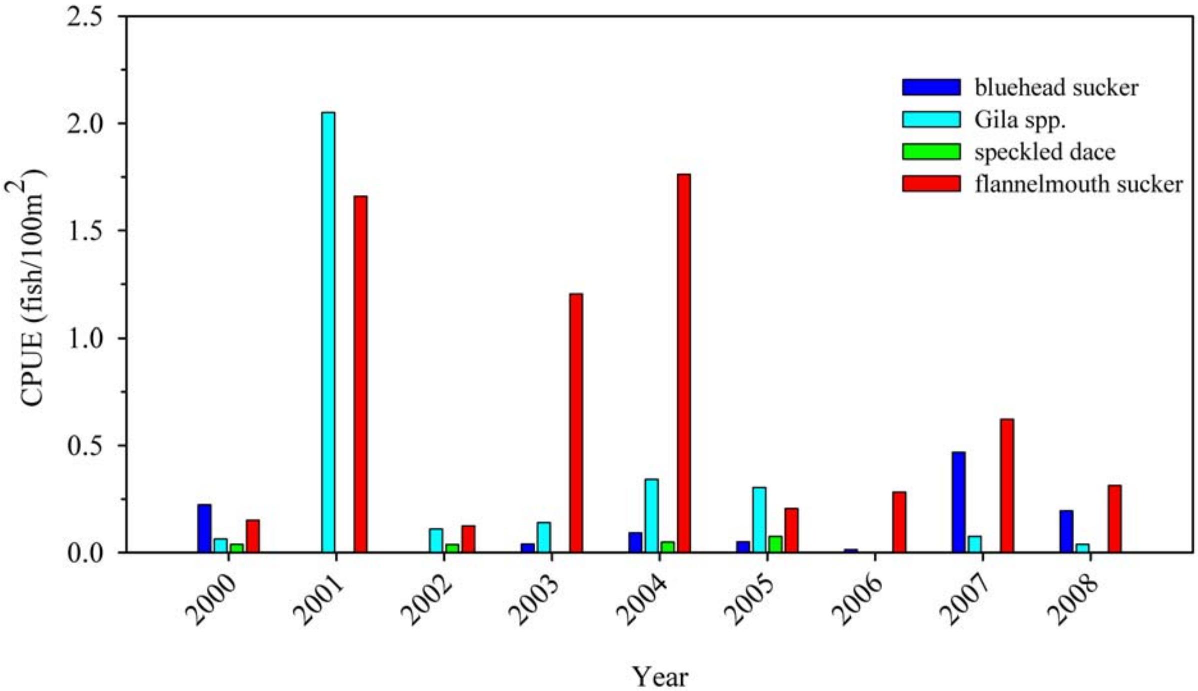

Figure 5. Catch-per-unit-effort (CPUE) of young-of-year native fishes collected from all backwaters of the middle Green River.

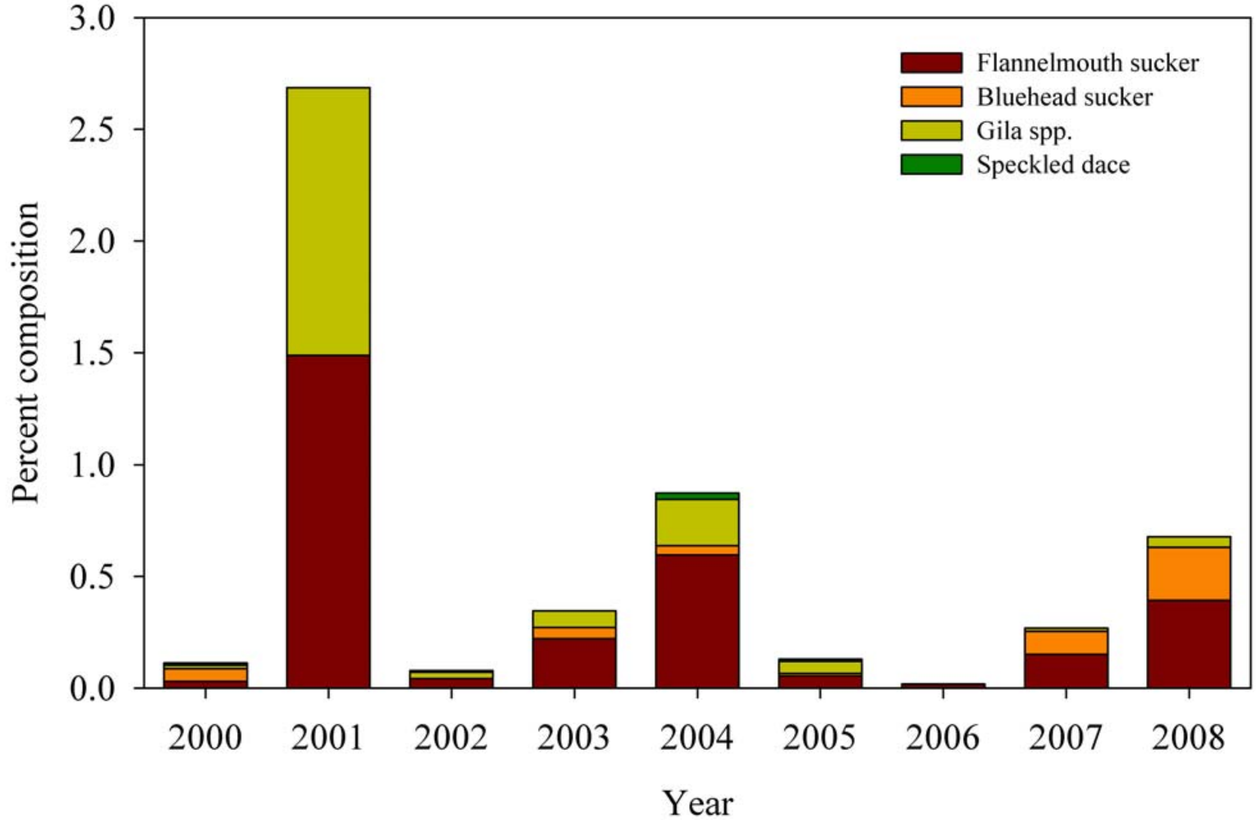

Figure 6. Percent composition of young-of-year from all 2000 to 2008 backwater sampling in the middle Green River.

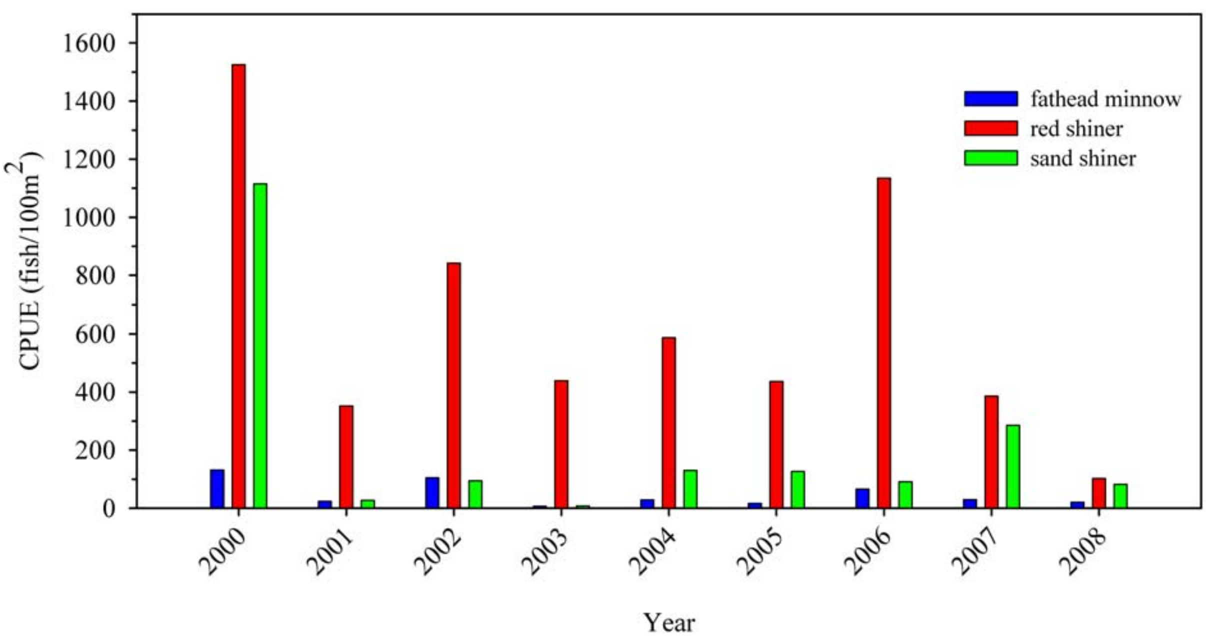

Figure 7. Catch-per-unit-effort (CPUE) of the most prolific nonnative cyprinids collected from first seine hauls of all backwaters in the middle Green River.

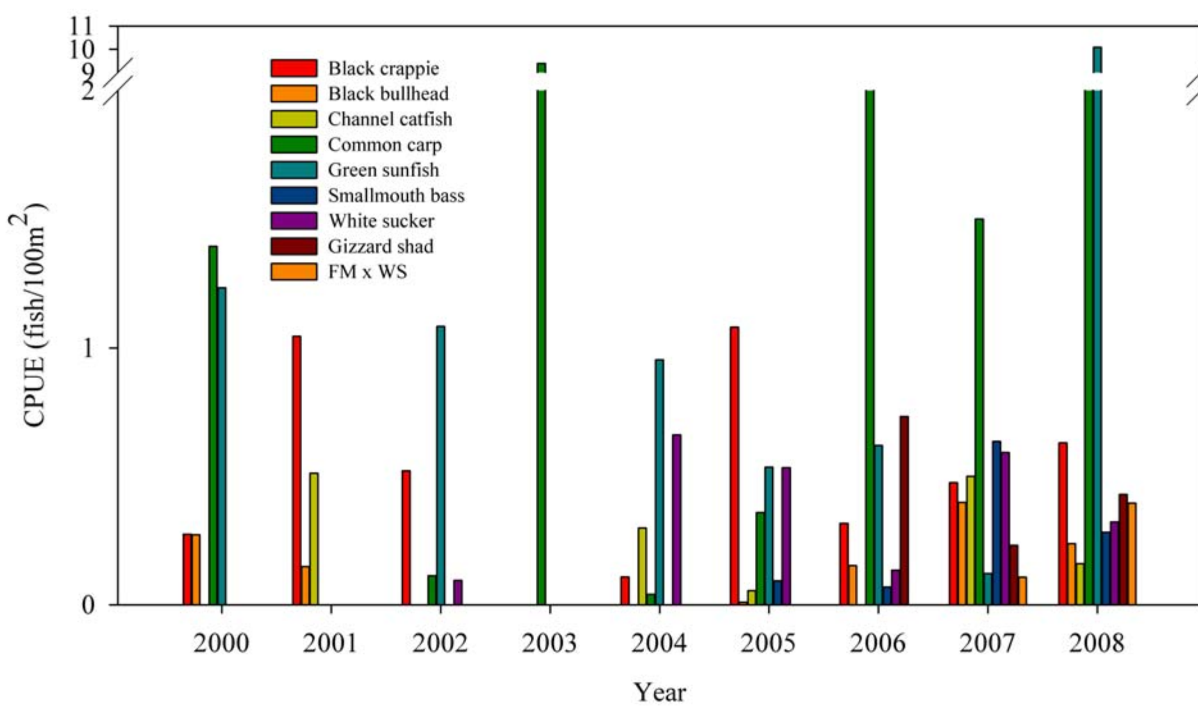

Figure 8. Catch-per-unit-effort (CPUE) of nonnative fishes collected from 2000-2008 in backwaters of the middle Green River. FM x WS were the hybridized form of flannelmouth and white sucker.

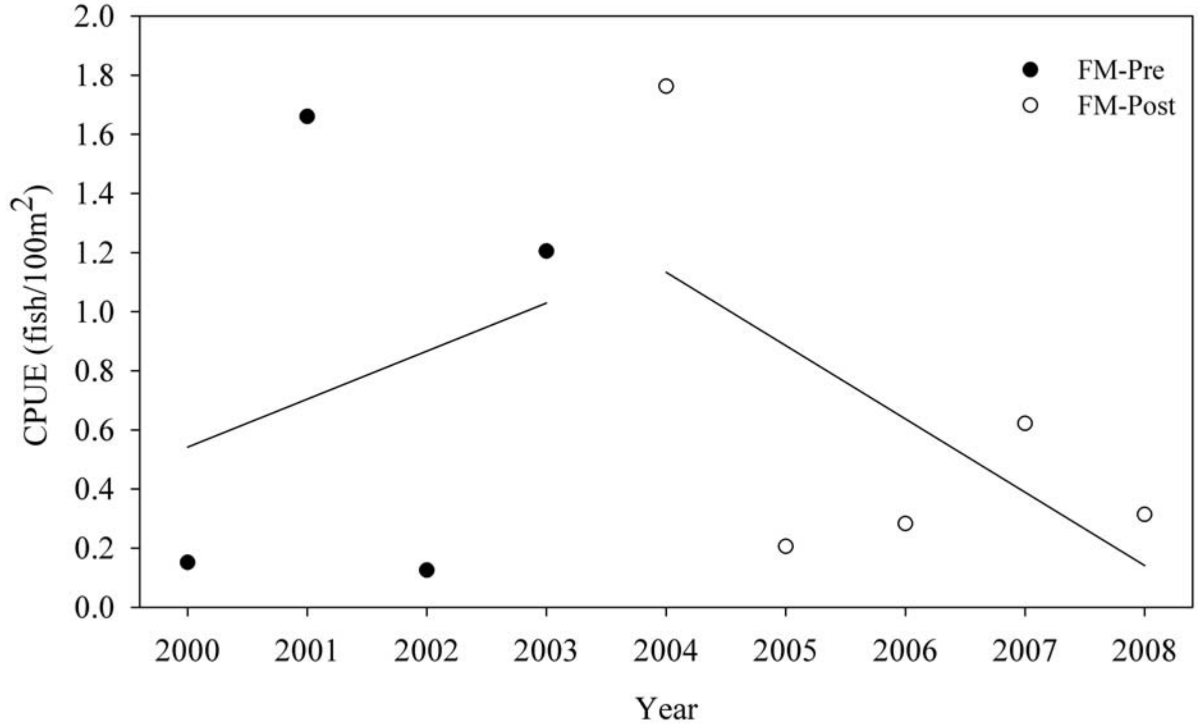

Figure 9. Linear regressions of catch-per-unit-effort (CPUE) of young-of-year flannelmouth sucker (FM) for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.

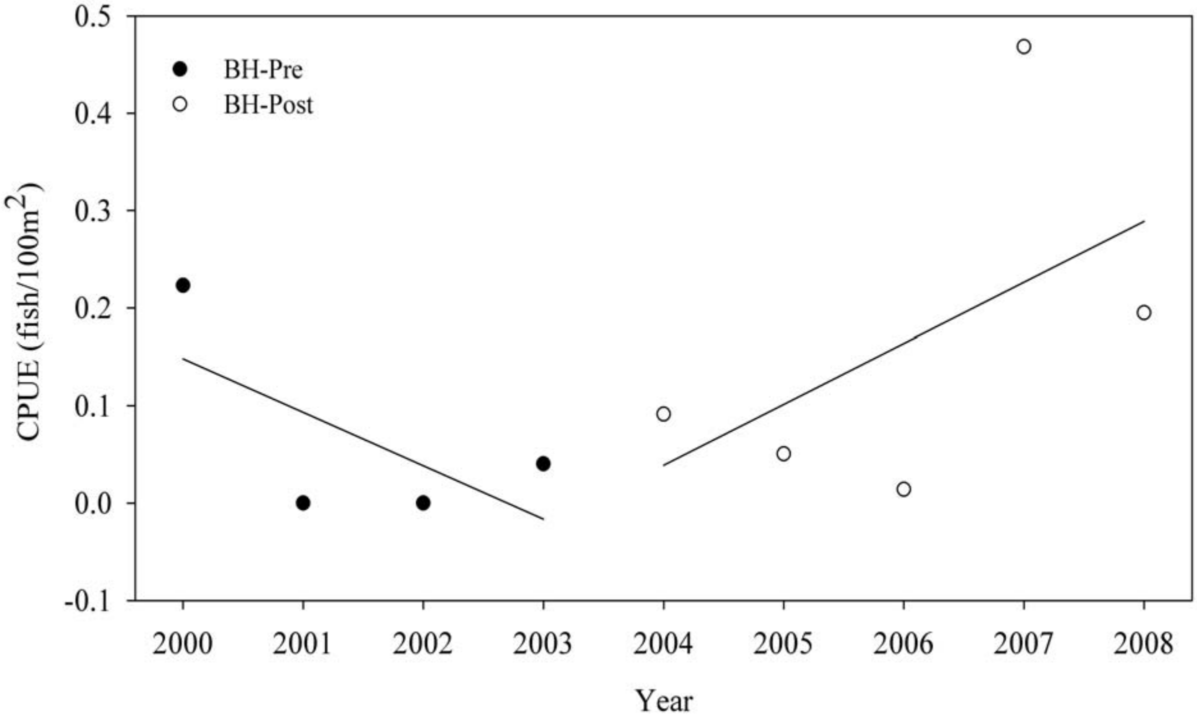

Figure 10. Linear regressions of catch-per-unit-effort (CPUE) of young-of-year bluehead sucker (BH) for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.

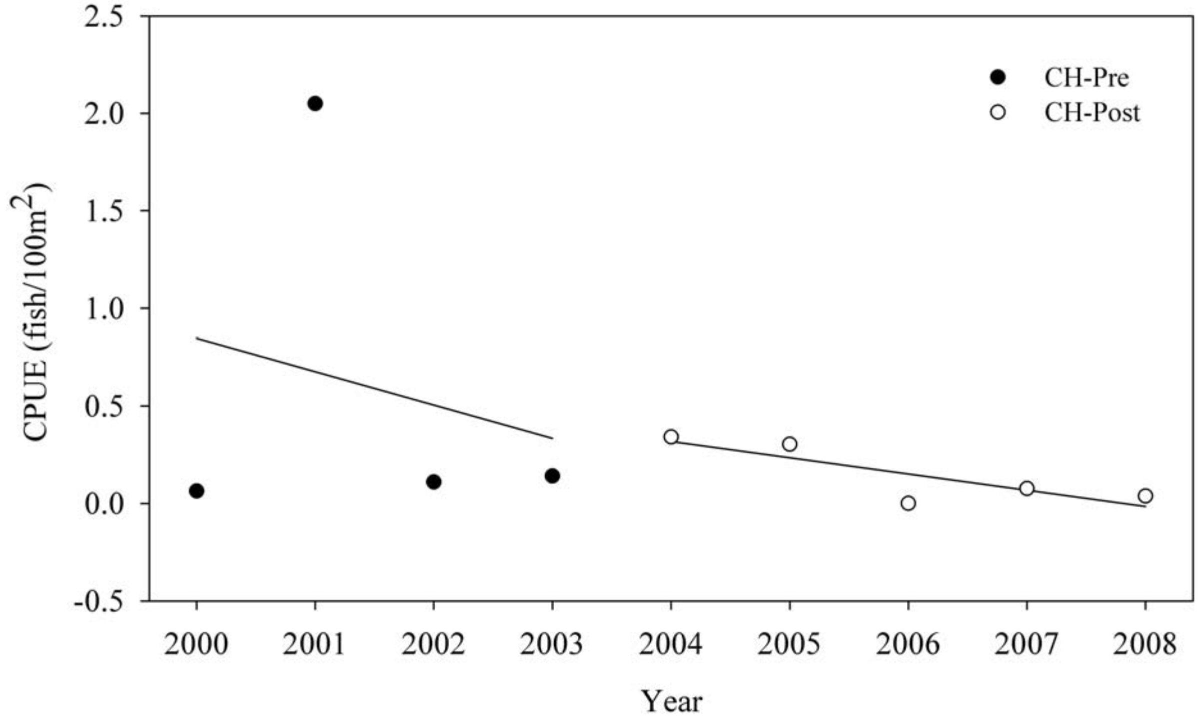

Figure 11. Linear regressions of catch-per-unit-effort (CPUE) of young-of-year *Gila* spp. (CH) for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.

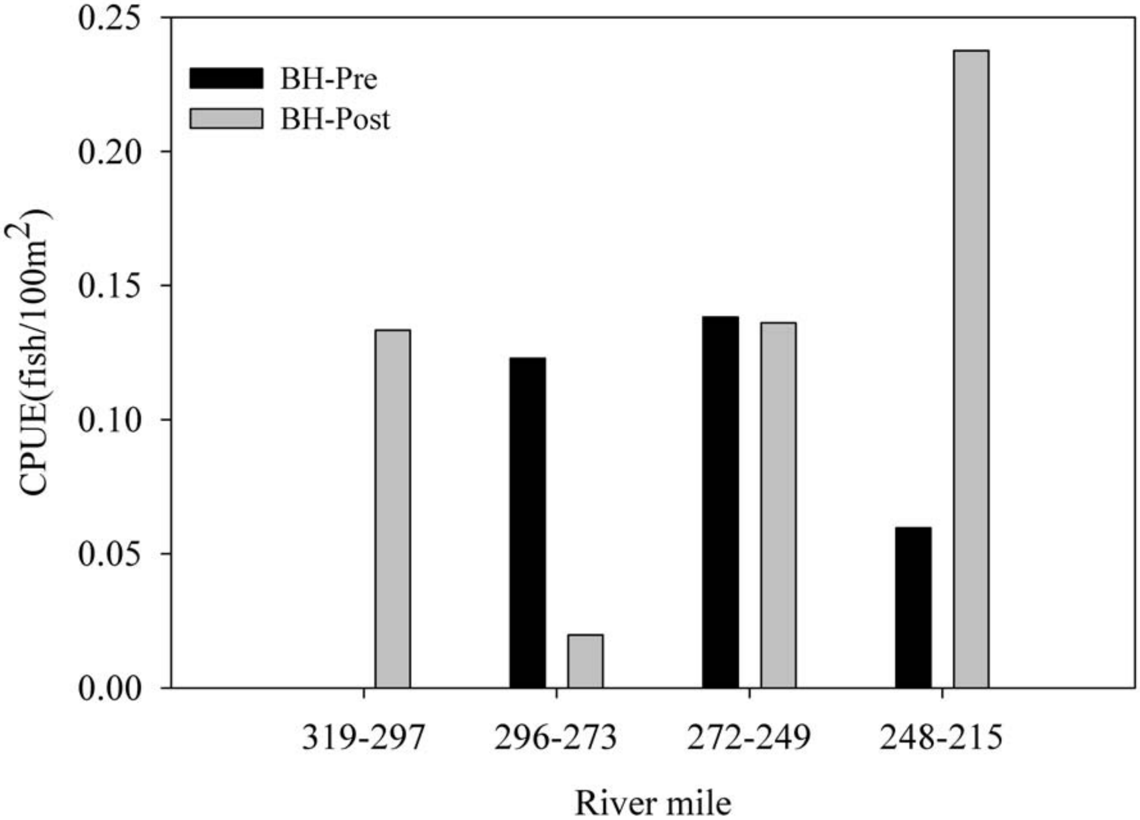

Figure 12. Catch-per-unit-effort (CPUE) of young-of-year bluehead sucker (BH) collected from backwaters of the middle Green River collected during pre-removal (2000-2003) and post-removal (2004-2008) sampling years within four river mile sections.

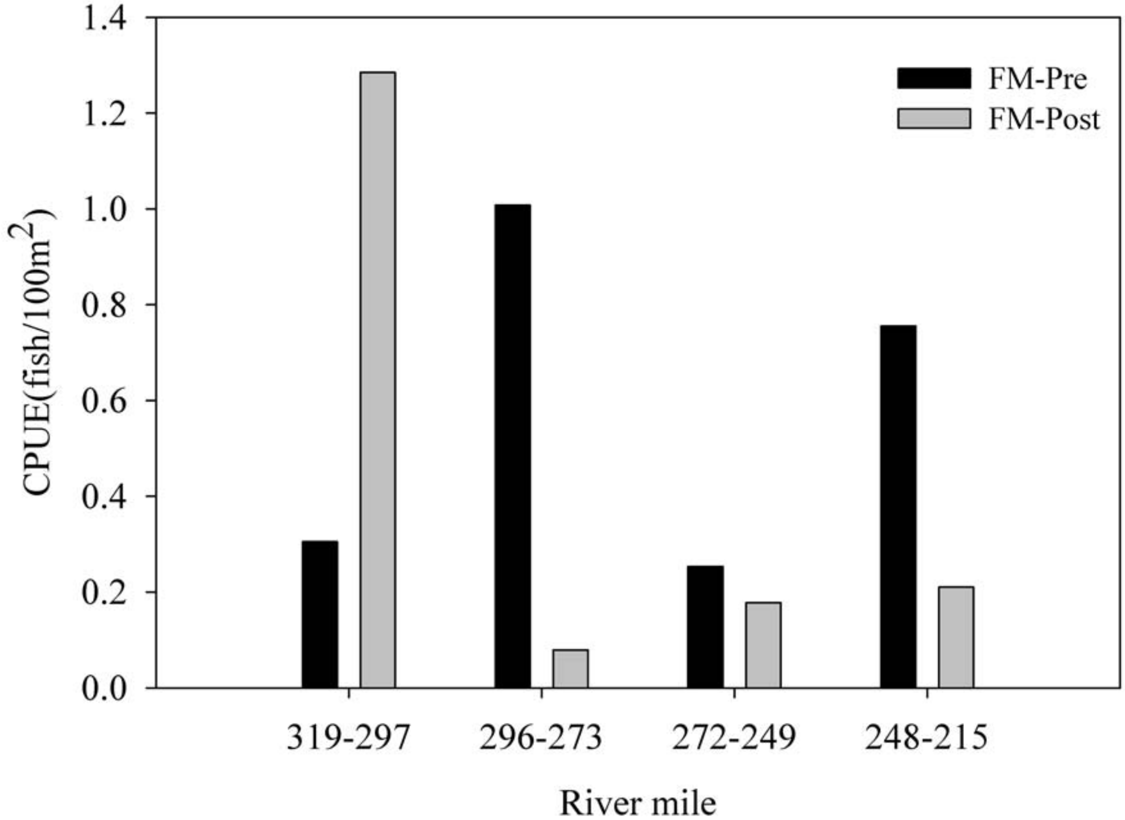

Figure 13. Catch-per-unit-effort (CPUE) of young-of-year flannelmouth sucker (FM) collected from backwaters of the middle Green River collected during pre-removal (2000-2003) and post-removal (2004-2008) sampling years within four river mile sections.

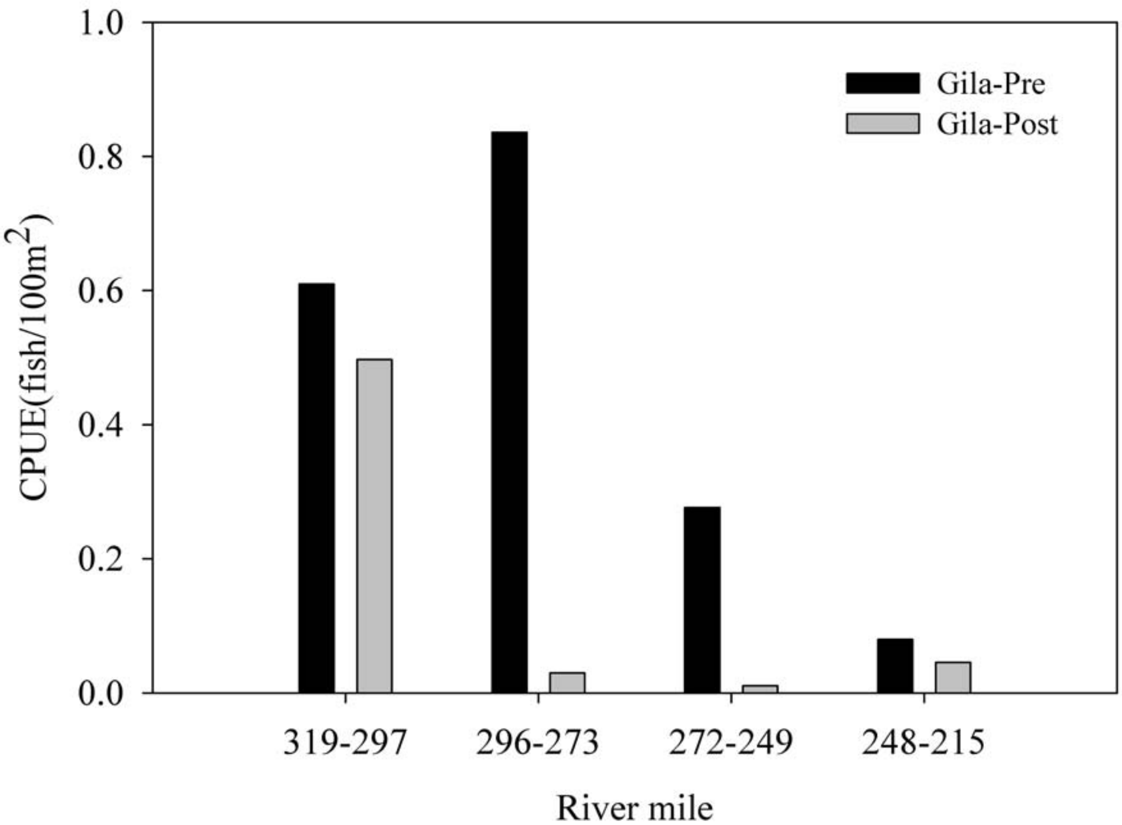

Figure 14. Catch-per-unit-effort (CPUE) of young-of-year *Gila* spp. collected from backwaters of the middle Green River collected during pre-removal (2000-2003) and post-removal (2004-2008) sampling years within four river mile sections.

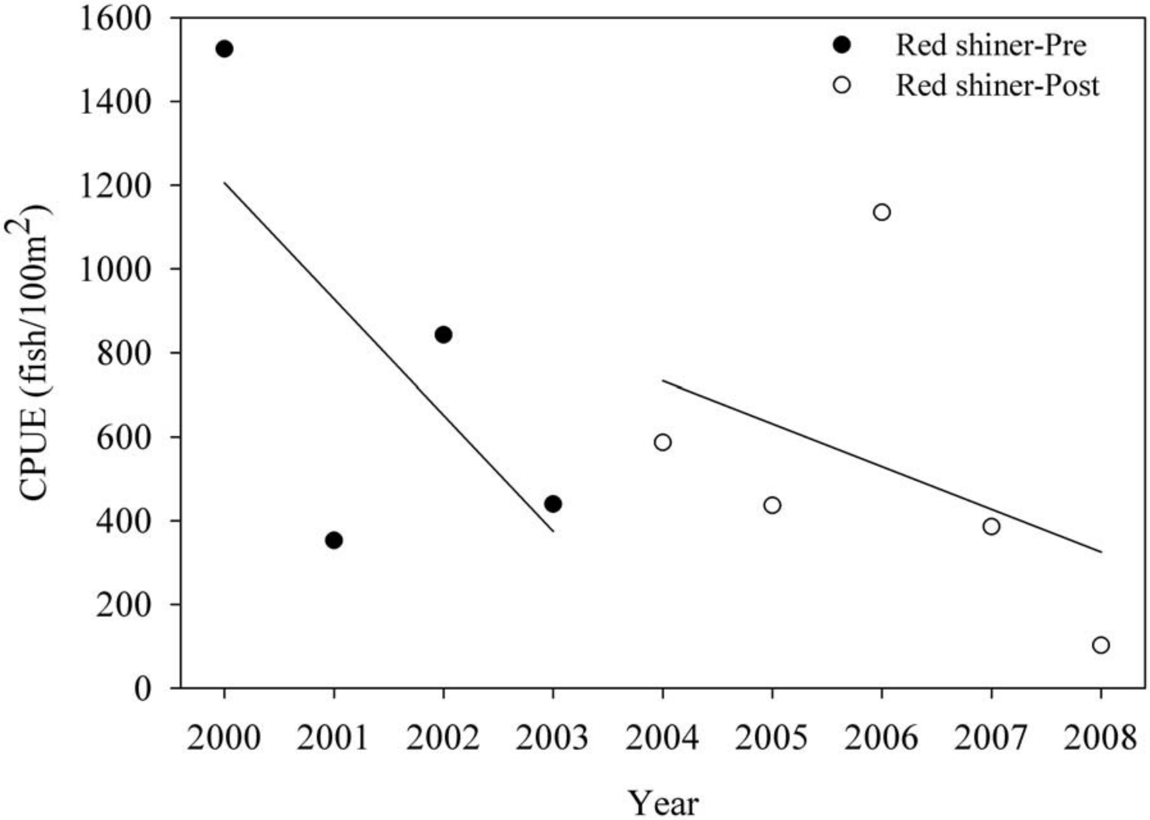

Figure 15. Linear regressions of catch-per-unit-effort (CPUE) of red shiner for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.

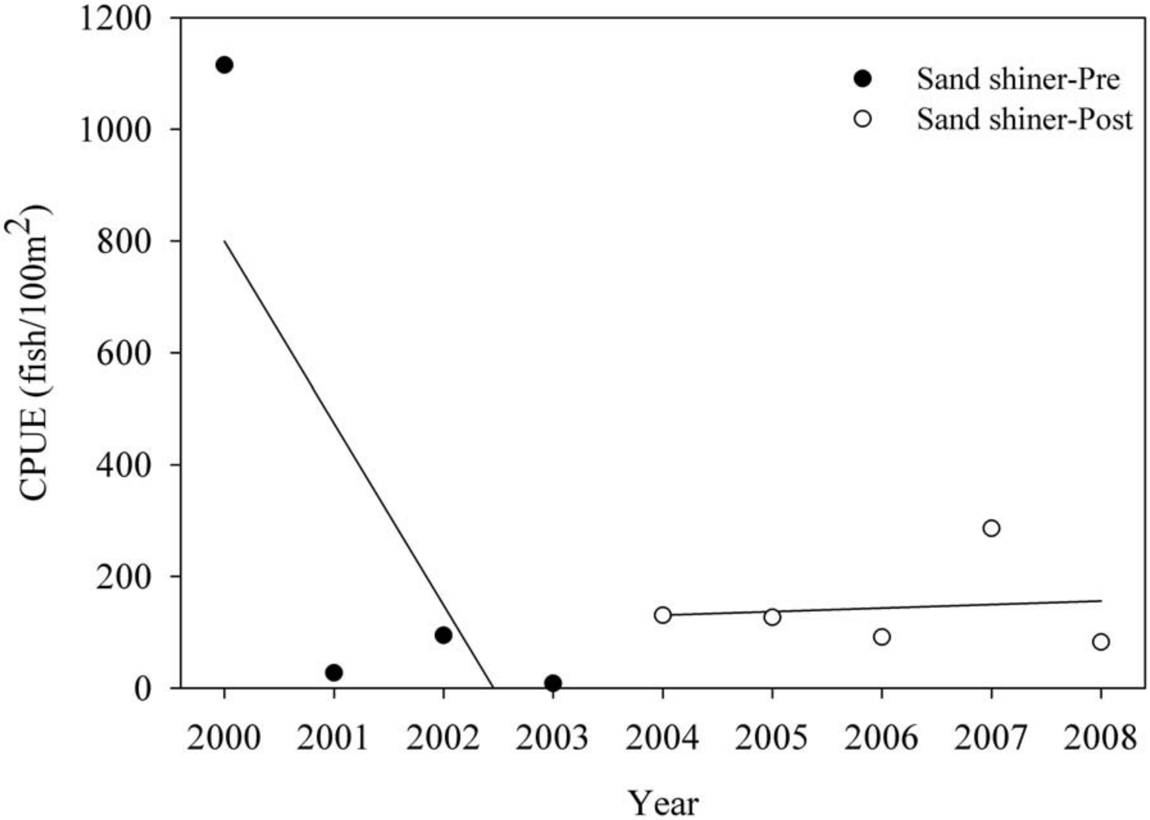

Figure 16. Linear regressions of catch-per-unit-effort (CPUE) of sand shiner for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.

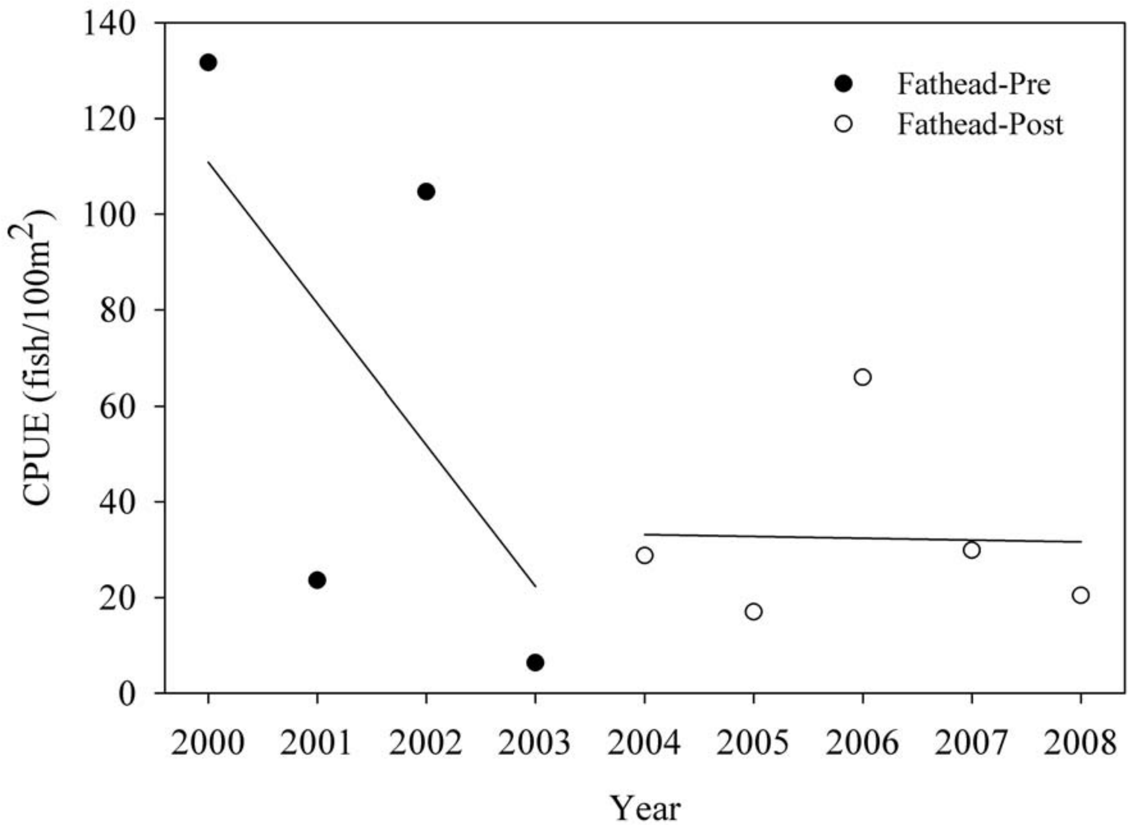

Figure 17. Linear regressions of catch-per-unit-effort (CPUE) of fathead minnow for pre-removal (2000-2003) and post-removal (2004-2008) sampling years from backwaters of the middle Green River.