INTERACTIONS OF PREDATION AND HYDROLOGY ON NATIVE SOUTHWESTERN FISHES: LITTLE COLORADO SPINEDACE IN NUTRIOSO CREEK, ARIZONA

John N. Rinne[1]

Non-native fish introductions in the southwestern United States have resulted in the reduction in and replacement of many native species. Interspecific interactions may come either singularly or as a combination of competition, hybridization, or predation (Rinne 1994). Competition between non-native, introduced species and native southwestern species is not easily or well documented (Douglas et al. 1994). The mechanism of hybridization is best documented for introduced salmonids and southwestern native trouts (Rinne 1985, 1988, 1994; Rinne and Minckley 1985). Predation by introduced species as a mechanism of interaction and impact on native species is increasingly being demonstrated as an important factor in the reduction and replacement of native fishes.

Minckley (1982) first suggested that the decline of the threatened razorback sucker, *Xyrauchen texanus*, resulted from predation on its eggs and fry by introduced species. Meffe (1985) demonstrated that the introduced western mosquitofish, *Gambusia affinis*, was an effective predator on the native endangered Gila topminnow, *Poeciliopsis occidentalis*. Marsh and Brooks (1989) reported the marked effect of ictalurid catfish predation on the young of the introduced razorback sucker. Blinn et al. (1993) reported that rainbow trout, *Oncorhynchus mykiss*, has a significant impact on the distribution and abundance of the native threatened Little Colorado spinedace, *Lepidomeda vittata vittata*. Rinne and Alexander (in press) examined further the role of salmonid predation on not only spinedace but the native Apache trout (*O. apache*). They concluded, based on laboratory and field studies, that predation by introduced rainbow trout and brown trout (*Salmo trutta*) is a major contributor to the decline in both numbers and range of these two native threatened species.

In addition to the biotic impacts of introduced species, habitat alteration and loss have contributed to the decline of native fish species in the Southwest (Rinne 1994). Habitat alteration has come largely through groundwater mining, damming, and diversion of streams and rivers. Many artificial lakes occur in upper elevation montane streams above the Mogollon Rim in Arizona. These impoundments are stocked with introduced salmonids for sport fishing. Rinne and Janish (1995) reported that over 69 million non-native fishes were stocked into the watersheds of the Little Colorado and Black rivers between 1930 and 1991. Ninety percent were stocked in lakes and reservoirs that are positioned in the headwaters of these two major river systems. Accordingly, they serve as a constant potential source of input for non-native fishes into downstream creeks and rivers. The objectives of this paper are to examine the relative roles of biotic (predation) and abiotic (water quality, hydrology, and its modification) factors in one montane stream in east-central Arizona, and also to expand results from Nutrioso Creek to river systems and other native species in general.

Study Area

Nutrioso Creek heads near 2700 m and flows north toward Springerville, Arizona (Figure 1). It is joined by Paddy Creek at about 2500 m and then passes through the town of Nutrioso. The reach above Nutrioso (ca. 7 km) has a higher gradient (> 5%) than the downstream reaches, with substrates mostly of cobble and boulder. From the confluence with Paddy Creek to several kilometers downstream it passes through a montane meadow. At base flows the waters are

[1]Rocky Mountain Forest and Range Experiment Station, Southwest Forest Science Complex, Flagstaff, AZ

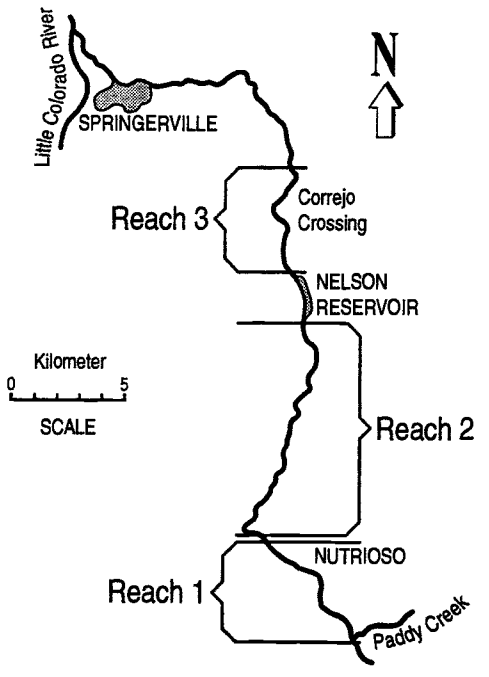

Figure 1. Map of Nutrioso Creek indicating reaches and Nelson Reservoir (modified from Blinn and Runck 1990).

clear (< 10 NTUs; HACH spectrophotometer) and cold (< 20°C) and contain adequate dissolved oxygen (7–9 mg/l; Blinn and Runck 1990). Below the town of Nutrioso the stream passes through another montane meadow that lies between Nutrioso and Nelson Reservoir about 12 km to the north (Figure 1). This reach is mostly privately owned and is subjected to grazing and agriculture. It is lower in gradient (2–5%) with gravel-sand to silt substrates. The stream channel is deeply incised (3–4 m) at many points and waters are diverted for irrigation (Marsh and Young 1988). Waters are only slightly warmer, dissolved oxygen is adequate, and turbidity is 20–25 NTUs. The third and final reach (Figure 1) lies below Nelson Reservoir, which was constructed in the 1950s. This reach also lies within montane meadow vegetation type, but the stream is characteristically deeply incised (1–3 m) into meadow substrates. Similar to Reach 2, its gradient is low (≤ 2%) and its substrate is primarily silt sand with pebble-cobble riffles. Turbidity is significantly higher, ranging from 100 (Rinne and Alexander in press) to over 250 NTUs (Blinn and Runck 1990) during the summer months. Oxygen can be reduced at night (< 2.0 mg/l), but it is adequate for both trout and spinedace during daylight hours (7 mg/l). Finally, Nelson Reservoir provides sport angling for residents of Springerville, Nutrioso and Alpine, Arizona and is periodically stocked with primarily rainbow trout. Between 1958 and 1991 over 3 million rainbow were stocked on 106 different occasions (Rinne and Janisch 1995).

Reach 1 contains almost exclusively rainbow x Apache trout hybrids with speckled (*Rhinichthys osculus*) being uncommon. Spinedace have only been reported in the lowermost portion of this reach at the town of Nutrioso (Highway 180/191 bridge; Marsh and Young 1988). Reach 2 contains rainbow, spinedace, two suckers (bluehead [*Catostomus discobolus*] and flannelmouth [*C. latipinnis*]), and another native cyprinid (speckled dace [*Rhinichthys osculus*]; Marsh and Young 1988). In addition to the above species, both brown and brook trout (*Salvelinus fontinalis*), which are introduced into Nelson Reservoir for sport fishing (Rinne and Janisch 1995), and fathead minnow (*Pimephales promelas*), which is a bait species, occur in Reach 3. In summary, there are four native and four introduced fish species occurring in Nutrioso Creek.

Materials and Methods

Hatchery-reared juveniles (60–100 mm, TL) of the native Apache trout, *Oncorhynchus apache*, were used in laboratory experiments. This species was used because it was readily available from the Williams Creek National Fish Hatchery (U.S. Fish and Wildlife Service). Further, potential predation effects on this species in the wild could be estimated. Finally, because of morphology and observed behavioral traits we used the Apache trout as a "surrogate" for the much rarer and difficult to obtain spinedace. Because introduced trouts and the native spinedace occur in the same reaches of the stream, a final objective was to determine the roles of turbidity and cover as factors in reducing introduced trout predation on the spinedace. Brown, rainbow, and hybrid (Apache x rainbow) trout were used as predators.

Predation relative to turbidity was conducted under field conditions in net enclosures constructed of 3.1 mm (1/8 inch) mesh and 1.5 m x 3.0 m in size. Nets were deployed in Nutrioso Creek (see Blinn et al. 1993) below Nelson Reservoir in summer for periods of 7 to 12 days. Mean turbidity (NTUs) was estimated from water samples taken at surface, mid-water, and bottom at three locations within each cage and analyzed

with a Hach turbidity meter. Spinedace (the prey) and trout (the predator) were measured, counted, and placed in the cages. At the conclusion of the experiment, all remaining fishes were removed and counted to determine the percent predation.

Laboratory studies were designed to permit controlled and elevated levels of turbidity in artificial, circular raceways (Frigid Units) 3–7 m in length. Fines (< 2 mm) used in studies were sieved from substrate materials collected in streams from the White Mountain region where all species occur in the wild. Water temperature was controlled by a Frigid Units chiller at 10–13°C. Water was circulated by a 1 HP pump to sustain turbidity. At the conclusion of the experiments, predator and prey were enumerated to permit calculation of percentage predation over the duration of the experiment. Additional laboratory studies were conducted in the presence of the abiotic influence of cover and with neither cover nor turbidity present. Cover comprised stream cobble (150–300 mm) placed in raceways. Percent cover was calculated as the percentage of surface area of the cobble relative to that of the total experimental area.

Laboratory Predation Study Results

Laboratory experiments indicated that two rainbow and brown trout could reduce Apache trout juveniles from 60 to 68 percent (mean = 60%) in a period of 24 hours (Table 1). Similar results occurred using brown trout as the predator; however, brook trout reduced Apache trout numbers by only 30 percent in days.

Similar experiments using brown trout as the predator with artificially high turbidities (>195 NTU) showed a somewhat reduced average loss of prey species (Apache trout; mean 60–45%) in a 3–4 day period (Table 2).

By comparison, artificially imposed 13–35 percent cover did not reduce the predation efficiency of either brown or rainbow trout (Table 3). In fact, mean loss (77%) was greater than in clear waters with no cover (mean 60%; Table 1).

Field Predation Study Results

Blinn et al. (1993) reported on the results of enclosure studies from Reach 1, the upper clear-water reach of Nutrioso. Rainbow trout (190–270 mm TL) in the presence of an adequate invertebrate food supply were effective and efficient predators on spinedace (40–65 mm TL). One 185 mm TL trout was reported to consume 4 spinedace in one 16-hour period. In addition, the presence of the rainbow predator affected the behavior of spinedace. Spinedace are trout like and utilize undercut banks for cover in absence of vegetation, boulders, or deeper water. In the absence of rainbow trout in enclosures, the spinedace used undercuts significantly more than in enclosures containing this non-native predator. Conversely, in the presence of rainbows, spinedace were forced into open waters,

Table 1. Results of laboratory predation studies using introduced salmonids (> 175 mm) as the predator species and hatchery-reared Apache trout (*Oncorhynchus apache*) as the prey.

Predator	No.	No. of Prey		% Loss	Duration (days)
		Start	End		
Rainbow	2	25	9	64	1
Rainbow	2	25	8	68	1
Rainbow	2	25	10	60	1
Rainbow	2	25	10	60	1
Rainbow	2	25	9	64	1
Rainbow	2	25	8	68	1
Brown	2	25	10	60	1
Brown	2	25	10	60	1
Brook	2	10	6	30	3

Table 2. Results of laboratory predation studies with brown trout (*Salmo trutta*; > 200 mm) and Apache trout (*Oncorhynchus apache*; 75–100 mm) at varying artificially created turbidities.

No. of Predator	No. of Prey		% Loss	Duration (days)	Turbidity (NTUs)
	Start	End			
4	40	15	66	4	214
4	40	30	25	3	200
2	20	6	70	3	195
2	45	35	22	4	200–300

Table 3. Results of laboratory predation studies using brown and rainbow trout (> 175 mm) as predators and Apache trout juveniles as prey and in varying percentages of cover.

Predator	No.	No. of Prey		% Loss	Duration (days)	% Cover
		Start	End			
Rainbow	2	14	1	93	3	13
Rainbow	2	14	4	71	3	25
Brown	2	25	8	68	4	15
Brown	2	25	6	76	3	35

rendering them vulnerable to other visual predators such as great blue herons and garter snakes.

Field experiments using rainbow trout, hybrid Apache x rainbow trout, and brown trout in the presence of turbidity indicated that as turbidity increased, the percentage loss of prey decreased (Table 4). Compared to lab experiments conducted for about half the time period (4 vs. 8 days) and at lower turbidities (mean; 85 vs. 200 NTU), there was no difference in the comparative loss of prey species to predation. This assumes that there is no difference in prey response (Apache trout vs. spinedace) to the predator (brown trout).

Table 4. Results of field predation studies in cage enclosures using introduced salmonids (>175 mm, TL) and their hybrids as predators and Little Colorado spinedace (*Lipidomeda vittata vittata*; 40–60 mm, TL) as prey. Studies were conducted at naturally occurring turbidities in Nutrioso Creek on the Apache Sitgreaves National Forest.

		No. of Prey				Turbidity
Predator	No.	Start	End	% Loss	Duration (days)	(NTUs)
Rainbow	0	40	27	33	10	no data
Rainbow	4	35	3	89	10	no data
Rainbow	4	35	1	97	10	no data
Rainbow	2	20	9	55	7	13
Rainbow	2	20	14	30	12	82
Rainbow	4	20	20	0	9	103
Hybrid	2	20	2	90	7	9
Hybrid	2	20	3	85	12	63
Hybrid	2	5	2	60	9	82
Brown	2	20	8	60	7	18
Brown	2	20	9	55	12	76
Brown	4	10	7	30	9	160

Discussion and Conclusions

Results of both field and laboratory predation studies indicated that predation as a mechanism of interaction with non-native trout is significant in the reduction and replacement of the threatened Little Colorado spinedace. Turbid waters exist below Nelson Reservoir in Nutrioso Creek where introduced trouts and spinedace co-occur. These turbidities may reduce predation effectiveness; however, potential loss to predation is yet significant (ca. 60% in a week to 10 days). Similarly, cover up to 35 percent in laboratory experiments did not effectively reduce predation efficiency of either rainbow or brown trout. Elevated turbidities may reduce predation but will not eliminate it. Indeed, sustained elevated turbidities is not a management option and may ultimately have negative effects on the native spinedace.

The presence of Nelson Reservoir and the continued stocking of salmonids for sport fishing is a major impediment to security of spinedace in Nutrioso Creek. Similar stocking in reservoirs in the East Clear Creek drainage further impacts the spinedace. Such stocking ensures a continued source of predators to the downstream, turbid, warmer, and often low dissolved oxygen reach where these salmonids would through time most likely be eliminated because of unsuccessful reproduction. Elevated turbidity and temperature below Nelson Reservoir have undoubtedly favored the spinedace more than the introduced trouts, thus sustaining populations of the native cyprinid. The middle reach (2) of Nutrioso is not optimum trout habitat. Even in the event of upstream migration of trout from Nelson Reservoir, they would not become established because of reduced habitat quality in the form of dewatering from irrigation and increased water temperature during summer months.

Stream renovation to remove non-native salmonids followed by reintroduction of native salmonids is a well-developed and often used technique in upper elevation streams (Rinne and Turner 1991). It might be suggested as an approach to remove introduced trout from the headwaters of Nutrioso Creek. Because the native Apache trout has occurred in the headwaters of Nutrioso Creek (Rinne 1985; Dowling and Childs 1992), it would be conceivable to reintroduce this species. The question is "Did the native trout and spinedace co-occur in the headwaters of this creek?" Relevant to this question are (a) whether spinedace occurred in the upstream, higher gradient colder waters, and (b) if native trout consume the spinedace as the introduced trouts do.

Preliminary experiments relative to the first question indicate that sustained spinedace populations never occurred in the upper portions of Reach 1. Two hundred spinedace were captured from Reach 3 and introduced to Reach 1 in October 1992. Rainbow trout were removed from a 200 m reach of the stream to remove the predation influence. In May of 1993 no spinedace were located in either the introduction pools or downstream for a half kilometer. An additional 50 adult spinedace (> 60 mm TL) were introduced on June 16 1993. Revisitation and sampling with electrofishing gear 5 weeks later revealed no

spinedace in the introduction pool. Only a half dozen were captured about 200 m downstream where movement was impaired by a hardware cloth barrier. Beaver dams in this reach historically may have permitted spinedace to penetrate further into the headwaters of Nutrioso. Presently, they are found only up as far as the town of Nutrioso where beavers persist today.

With regard to predation by native trout, laboratory experiments indicate that Apache trout smaller than 225 mm TL do not prey upon spinedace. Two dozen spinedace (40–60 mm TL) were placed in a living stream (Frigid Units) with a dozen wild caught Apache trout (90 to 225 mm) for a period of 2 weeks. No spinedace were lost. However, when two large (400 mm TL) hatchery-reared Apache trout were similarly placed in this same environment with two dozen spinedace, most were consumed within an hour. Because the maximum size of Apache trout is limited by physical habitat to 250 mm or less in upper Nutrioso Creek, predation by the native if spinedace co-occurred with it would probably be minimal.

Altered stream hydrology through dams, which provides habitat for introduced sport fishes in situ and alters flow regimes ex situ or downstream, is a major contributing factor to the decline of the Little Colorado spinedace. As such, dams present both an abiotic and biotic impact on the spinedace and other native fishes. Many other species of native fishes depend on natural hydrographs for their life history requirements (Meffe and Minckley 1987; Rinne and Minckley 1991). Disturbance events such as floods stimulate native fishes to spawn (Mueller 1984) while at the same time reducing or removing non-native species (Meffe and Minckley 1987; Stefferud and Rinne in press). On the other hand, dams alter, control, and stabilize flow regimes, rendering them more favorable habitat for many introduced species, primarily from the Mississippi River Basin.

Co-occurrence of native and non-native fishes in the same reaches of a stream or river greatly reduces the chances of native species surviving through time. If natural hydrographs are present, then the periodic, abrupt flooding characteristic of the Southwest streams may favor sustainability of the natives. In contrast, controlled streams below lakes and reservoirs ameliorate these events and lower the probability of sustaining native fish faunas. The upper Verde and Gila rivers may yet sustain native fish faunas because they are not dammed (Propst et al. 1986, 1987; Stefferud and Rinne 1995).

Ideally, exclusion of non-natives is necessary if native species are to persist. This approach has been used widely in upper elevation montane streams such as Nutrioso Creek and many others in the White Mountains of east-central Arizona (Rinne and Turner 1991) and continues to the present (Rinne and Janisch 1995). In larger lower elevation streams in the Southwest logistics prevent this approach. One approach to sustaining native fishes is securing habitats for them by purchase. This has been done for the spinedace through purchase of real estate encompassing tributaries and the mainstream Little Colorado River (Rinne and Janisch 1995). Watersheds can be managed as special areas for native species.

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