*North American Journal of Fisheries Management* 23:503–511, 2003


# Effects of Flooding on Abundance of Native and Nonnative Fishes Downstream from a Small Impoundment

ANDREW A. SCHULTZ,*[1] O. EUGENE MAUGHAN, AND SCOTT A. BONAR

*Arizona Cooperative Fish and Wildlife Research Unit,*
*U.S. Geological Survey,*
*University of Arizona,*
*104 Biosciences East, Tucson, Arizona 85721, USA*

WILLIAM J. MATTER

*School of Renewable Natural Resources,*
*University of Arizona,*
*325 Biosciences East,*
*Tucson, Arizona 85721, USA*

*Abstract.*—Flooding can benefit native fishes in southwestern streams by disproportionately displacing nonnative fishes. We examined how the presence of an upstream impoundment affected this relationship in lower Sonoita Creek, Arizona. Nonnative species not found in the reservoir decreased in abundance in lower Sonoita Creek after flooding. The catch and relative abundance of some nonnative species found in both the reservoir and the creek increased in lower Sonoita Creek after flooding. Movement of nonnative fishes out of the reservoir via the spillway during periods of high water probably contributes to the persistence and abundance of these species downstream. Both preventing nonnative fishes from escaping reservoirs and the release of flushing flows would aid conservation of native southwestern fishes downstream.

Many species of fish native to the American Southwest have decreased to the extent that they are now federally listed as threatened or endangered (Minckley and Deacon 1991). Loss and modification of aquatic habitats (Miller 1961; Hendrickson and Minckley 1984; Rinne 1992; Rinne et al. 1998) and negative interactions with introduced species (Meffe 1985; Marsh and Brooks 1989; Douglas et al. 1994; Marsh and Douglas 1997; Dudley and Matter 2000) are primarily responsible for these declines.

In the Southwest, flooding has been shown to benefit native fishes by disproportionately displacing nonnative fishes (Meffe 1984; Minckley and Meffe 1987; Rinne and Stefferud 1997; Rinne et al. 1998). This is not surprising because fishes native to the Southwest have evolved in arid systems where precipitation is often torrential and localized, and runoff is often abrupt through channels that may be narrow, of high gradient, canyonlike, and lacking dense vegetative cover. Discharge may increase by three or more orders of magnitude in seconds. In comparison, many of the fishes introduced to the Southwest evolved in mesic systems, where channels meander, having low gradients and broad floodplains, and floods build over periods of hours to days (Minckley and Meffe 1987). The disproportionate displacement of nonnative fishes by flooding is theorized as a factor that allows long-term coexistence of some native and nonnative fishes (Meffe 1983, 1984; Minckley and Meffe 1987).

Reservoirs often alter downstream discharge regimes and habitat conditions, provide habitat for nonnative fishes and an impetus for stocking them, and subsequently affect fish assemblages downstream (Vanicek et al. 1970; Edwards 1978; Ward and Stanford 1979; Clarkson and Childs 2000). The impact of regulation may be enhanced in dryland streams because the regulated regime often is drastically different from natural flow conditions (Davies et al. 1994). Our objectives were to quantify the effects of flooding on the fish assemblage of a southwestern stream below an impoundment and identify management strategies that would favor native fishes in these types of systems.

## Study Area

Lower Sonoita Creek begins downstream of Patagonia Lake, a 101-ha impoundment that is primarily used for recreation. About 6.9 km of lower Sonoita Creek are perennial, but short reaches are

* Corresponding author: andrew_a_schultz@hotmail.com
[1] Present address: School of Renewable Natural Resources, University of Arizona, 325 Biosciences East, Tucson, Arizona 85721, USA.

Received July 30, 2001; accepted August 14, 2002

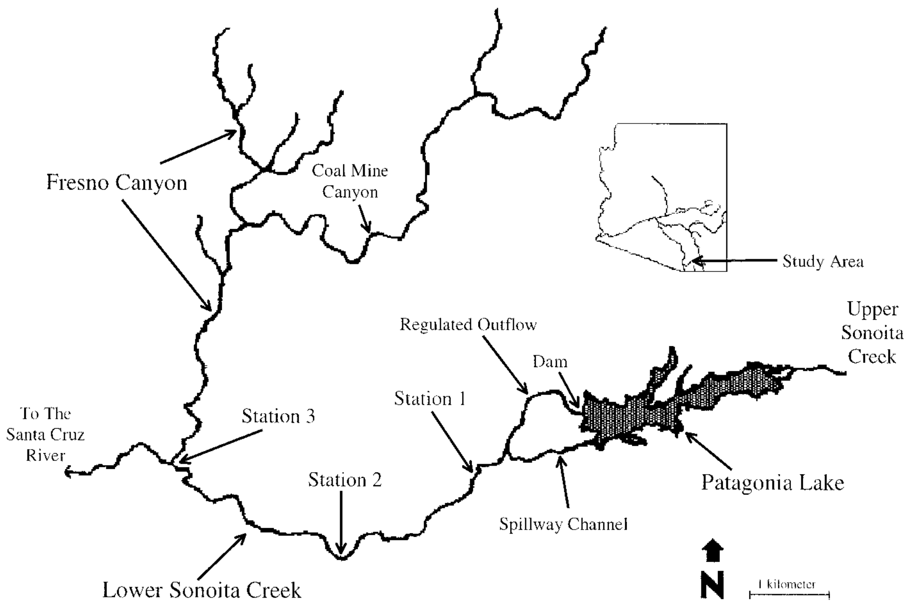


FIGURE 1.—Map showing the locations of lower Sonoita Creek, Arizona, and sampling stations along it.

seasonally intermittent (Figure 1). Discharge in lower Sonoita Creek consists of outflow through the dam, spillway overflow, and groundwater influx. Average discharge (taken 7.6 km southwest of Patagonia, Arizona) during 40 years of record-keeping was 0.23 m/s; median yearly mean discharges was 0.18 m/s (USGS 1972) and the maximum recorded discharge was 623 m/s (from a stage–discharge relationship; S. Ince, University of Arizona, Tucson, personal communication). Most years have periods of no flow (USGS 1972). Flooding is common during the monsoon season (July–September) and is followed by a period of relatively stable flow until the dry season (May–July). Normally, surface flow in lower Sonoita Creek ceases about 7–8 km upstream from its confluence with the Santa Cruz River and reaches the Santa Cruz River only during floods. The mean elevation and mean stream gradient from Patagonia Lake Spillway to the confluence with Fresno Canyon (Figure 1) are 1,117 m and 9.2 m/km, respectively. Sixty-two percent of the drop in elevation occurs from Patagonia Lake Spillway to its confluence with the outflow from Patagonia Lake Dam, a distance of only 17% of the stream length used to calculate the gradient. Fresno and Coal Mine canyons, tributaries to lower Sonoita Creek (Figure 1), are intermittent. Surface flow connects Fresno Canyon to lower Sonoita Creek only during floods. Average yearly precipitation at Patagonia Lake (1980–1994) is 48.8 cm/year, 42% of which occurs in July and August (Arizona State Parks Department, unpublished data).

Historically, seven species of fish were native to the Sonoita Creek basin (Minckley 1969). Currently, lower Sonoita Creek harbors four species of native fish (longfin dace *Agosia chrysogaster*, desert sucker *Catostomus clarki*, Sonora sucker *C. insignis*, and Gila topminnow *Poeciliopsis occidentalis*) and at least eight species of nonnative fish. Two species of nonnative fish (red shiner *Cyprinella lutrensis* and yellow bullhead *Ictalurus natalis*) are found in lower Sonoita Creek but not in Patagonia Lake. The other six species of nonnative fish (mosquitofish *Gambusia affinis*, channel catfish *I. punctatus*, green sunfish *Lepomis cyanellus*, bluegill *L. macrochirus*, largemouth bass *Micropterus salmoides*, and flathead catfish *Pylodictis olivaris*) are present in both lower Sonoita Creek and Patagonia Lake (Schultz 2000). Fresno and Coal Mine canyons combined contain two species of native and three species of nonnative fish (D. Weedman, Arizona Game and Fish Department, personal communication).

Land adjacent to lower Sonoita Creek is used primarily for livestock grazing, low-density residential development, and recreation. Vegetation along lower Sonoita Creek is classified as Sonoran Riparian and Oasis Forests, Cottonwood-Willow Series-224.53 (McGann and Associates 1997).

We established three permanent sampling stations along lower Sonoita Creek (Figure 1). The stations consisted of a connected pool, run, and riffle and were of roughly similar size. We designated macrohabitat types as pool, run, or riffle based on criteria in McMahon et al. (1996). Stations 1 and 2 were located about 1.8 and 4.1 km downstream of Patagonia Lake Spillway, respectively. Station 3 was located at the confluence of Fresno Canyon and lower Sonoita Creek, about 6.7 km downstream of Patagonia Lake Spillway. Stations were chosen on the basis of their permanence of surface flow, equidistance from each other, macrohabitat structure (a connected pool, run, and riffle), property ownership, and proximity to access roads.

## Methods

*Sampling of fish*.—We sampled each station 11 times from March 1998 through September 1999. The mean interval between sampling trips was 54 d; the intervals ranged from 31 to 79 d. We used a combination of electrofishing and netting methods to capture fish, passing over the station three times alternately with each method. Stations were sampled with equal effort per unit area. Block nets (3-mm mesh) were used to prevent emigration and immigration when discharge was low enough for nets to remain in place. When possible, stations were sampled on consecutive days. We used an 8-m × 1.5-m haul seine with 5-mm mesh for seining. Where seining was impractical, we used a long-handled dip net with 5-mm mesh. We used a Smith-Root Type VII backpack electrofisher on trips 1–3 and a Smith-Root 12-B POW backpack electrofisher on trips 4–11. We identified captured fish to the lowest practical taxon. Most fish smaller than 20 mm total length (TL) were not identified beyond the family level. We detained fish in aerated buckets and in instream live cars until sampling and measurements were completed and then returned them to the macrohabitat from which they were captured.

*Discharge*.—We derived estimates of total discharge by combining the outflows from the spillway and the dam outlet located at the base of Patagonia Lake Dam. A meter at the dam outlet estimated discharge. Discharge flowing over the spillway (a broad-crested weir) was calculated with the following equations (S. Ince and D. Scheall, Department of Hydrology, University of Arizona, Tucson, personal communication):

$$\text{Discharge } (\text{m}^3/\text{s}) = 348 \cdot h^{1.5} \quad \text{for } h \leq 0.15 \text{ m}, \quad \text{and}$$

$$= 1{,}200 \cdot h^{1.5} \quad \text{for } h \geq 0.15 \text{ m},$$

where $h$ = head in meters from a lake-level recorder.

When the lake-level recorder was inoperable, discharge was taken from a discharge recorder located in lower Sonoita Creek just downstream of Fresno Canyon (standardized to the equation above). We defined sampling dates for when the stream had been exposed to previous flooding as those where a discharge greater than or equal to 1.81 m/s (10 times the historical daily median of yearly discharges and about a bank-full flood in lower Sonoita Creek) had occurred within 30 d before that sampling date.

*Data management and analysis*.—We calculated the total catch and relative abundance (% of the number caught) by station and date for each species, all native fishes combined, all nonnative fishes found in both lower Sonoita Creek and Patagonia Lake combined, and all nonnative fishes found only in lower Sonoita Creek. Catch and relative abundance data were transformed using a natural logarithm and arcsine square root, respectively, to normalize data for analysis. If a data set contained zeros, 1.5 was added to all data in the set to code for analysis (Zar 1984). Station was used as a blocking factor for all two-way analysis of variance (ANOVA) tests. Because of their rarity, flathead catfish and the hybrids Sonora suckers × desert suckers and green sunfish × bluegills were included in group analyses only. We used two-way ANOVA to compare mean relative abundance and catch for each species between sampling dates with and without previous flooding.

## Results

### *Discharge*

Flooding 30 d before the initial sampling dates (i.e., 19–21 March 1998) to 18 September 1999 occurred on 54 d at Station 3 (median = 7.15 m/s) and on 53 d at Stations 1 (median = 6.27 m/s) and 2 (median = 6.57 m/s). The maximum discharge of 114.78 m/s occurred on 31 August 1999. Equipment failure was responsible for gaps in discharge measurements from 24 July to 5 August 1998 and from 1 November 1998 to 25 April 1999. After studying rainfall data for these dates, we concluded that flooding in lower Sonoita Creek probably occurred on no more than 2 to 3 d. We designated 5 of 11 sampling trips (19–21 March 1998, 11–13 August 1998, 2–4 October 1998; 7 and 13 July 1999 [only Stations 2 and 3]; and 24–26 September 1999) as having had prior flooding.

TABLE 1.—Mean relative abundance (%) and catch (fish/sampling date) of species (organized by origin and distribution groups) from sampling periods with and without prior flooding in lower Sonoita Creek, Arizona. The *F*-statistics (df = 1, 32) and probabilities (*P*) are from a two-way analysis of variance comparing sampling dates (*N* = 33) with and without prior flooding.

| | Mean relative abundance with and without prior flooding | | | | Mean catch with and without prior flooding | | | |
|---|---|---|---|---|---|---|---|---|
| Species | With | Without | *F* | *P* | With | Without | *F* | *P* |
| **Native fishes** | | | | | | | | |
| Longfin dace | 10.2 | 22.2 | 2.69 | 0.11 | 41.3 | 152.6 | 4.05 | 0.05 |
| Desert sucker | 4.5 | 7.4 | 1.41 | 0.24 | 19.0 | 44.1 | 3.42 | 0.07 |
| Sonora sucker | 1.0 | 1.6 | 0.65 | 0.42 | 2.6 | 3.2 | 0.60 | 0.44 |
| Gila topminnow | 28.9 | 23.9 | 0.03 | 0.87 | 141.7 | 264.2 | 3.80 | 0.06 |
| **Nonnative fishes found in lower Sonoita Creek only** | | | | | | | | |
| Yellow bullhead | 2.3 | 5.4 | 2.61 | 0.11 | 7.3 | 13.8 | 1.54 | 0.22 |
| Red shiner | 0.5 | 3.4 | 8.80 | <0.01 | 3.1 | 15.9 | 7.94 | <0.01 |
| **Nonnative fishes found in both lower Sonoita Creek and Patagonia Lake** | | | | | | | | |
| Mosquitofish | 50.3 | 33.6 | 8.21 | <0.01 | 146.5 | 96.7 | 0.42 | 0.51 |
| Channel catfish | 0.2 | 0.1 | 0.48 | 0.49 | 0.8 | 0.4 | 0.42 | 0.52 |
| Green sunfish | 0.2 | 1.3 | 5.88 | 0.02 | 0.5 | 2.4 | 10.03 | <0.01 |
| Bluegill | 0.1 | 0.8 | 2.88 | 0.10 | 0.2 | 1.2 | 3.41 | 0.07 |
| Largemouth bass | 1.6 | 0.2 | 7.40 | 0.01 | 5.0 | 0.6 | 6.22 | 0.01 |

### *Relationship between Flooding and Fish Abundance*

Both the mean catch and mean relative abundance of most native fishes were lower after periods of flooding in lower Sonoita Creek (Table 1). For mean catch, this trend was at least moderately significant for three of the four species of native fish (longfin dace, desert sucker, and Sonora sucker). Despite the trend, none of the native species showed a significant difference in relative abundance between periods with and without flooding.

As with most native fishes, both the mean catch and mean relative abundance of nonnative fishes found only in lower Sonoita Creek were less after periods with flooding (Table 1). However, this trend was significant for red shiners only.

Unlike with the two previous groups, both the mean catch and mean relative abundance for three of the five nonnative fishes (mosquitofish, largemouth bass, and channel catfish) found in both lower Sonoita Creek and Patagonia Lake were greater after periods with flooding (Table 1). For mean catch, this trend was significant for both mosquitofish and largemouth bass, the two most abundant species within this group. However, only largemouth bass showed a significant increase in relative abundance after flooding. In visual terms, largemouth bass were conspicuously more abundant throughout lower Sonoita Creek after certain periods of flooding. A trend similar to the previous two groups was noted for both green sunfish and bluegill (Table 1). Green sunfish and bluegill showed an at least moderately significant decrease in both mean catch and mean relative abundance after periods with previous flooding.

When catch data for each species group (native fishes, nonnative fishes found in lower Sonoita Creek only, and nonnative fishes found in both Lower Sonoita Creek and Patagonia Lake) were plotted against flood peaks over time (Figures 2−4), the group trends mentioned above were also generally apparent and consistent at each individual sampling station, but especially so at Stations 1 and 2.

## Discussion

Nonnative fishes found only in lower Sonoita Creek decreased in abundance after most floods. These results are similar to those of previous studies of nonnative fishes in southwestern streams (Meffe 1984; Minckley and Meffe 1987; Rinne and Stefferud 1997). However, some nonnative fishes found in both Patagonia Lake and lower Sonoita Creek increased in abundance after most floods. The increase in abundance of these nonnative fishes probably was caused by dispersal from Patagonia Lake into lower Sonoita Creek during periods of increased discharge that topped the spillway. Movement of fish over reservoir spillways can be substantial (Clark 1942; Louder 1958; Elser 1960; Lewis et al. 1968).

Even if floods substantially displace nonnative fishes in lower Sonoita Creek, input of new indi-

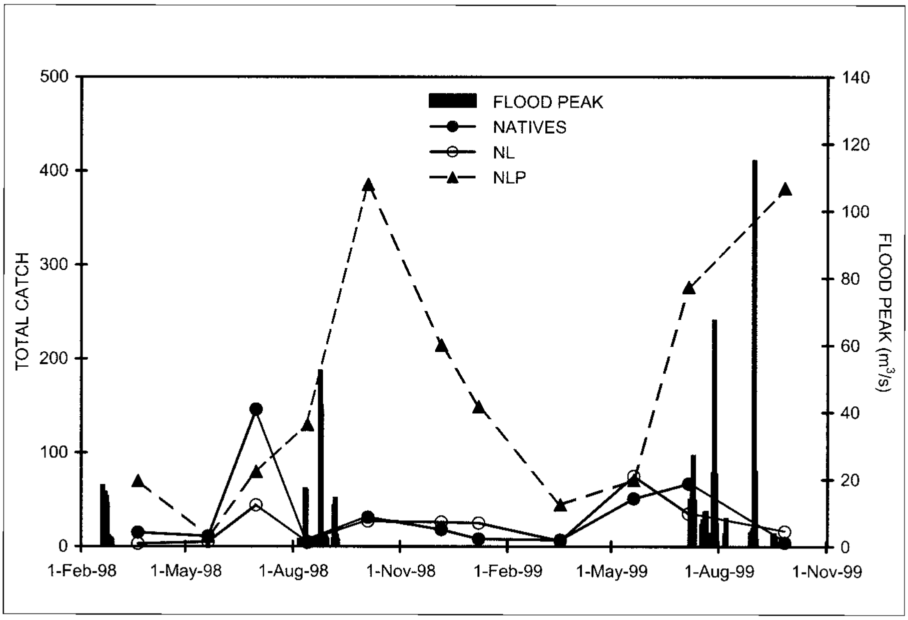


FIGURE 2.—Variation in the catch ($N$ = 11) of native fishes combined, nonnative fishes found in lower Sonoita Creek only (NL), and nonnative fishes found in both lower Sonoita Creek and Patagonia Lake (NLP) in response to flood peaks ($N$ = 53) at Station 1, lower Sonoita Creek.

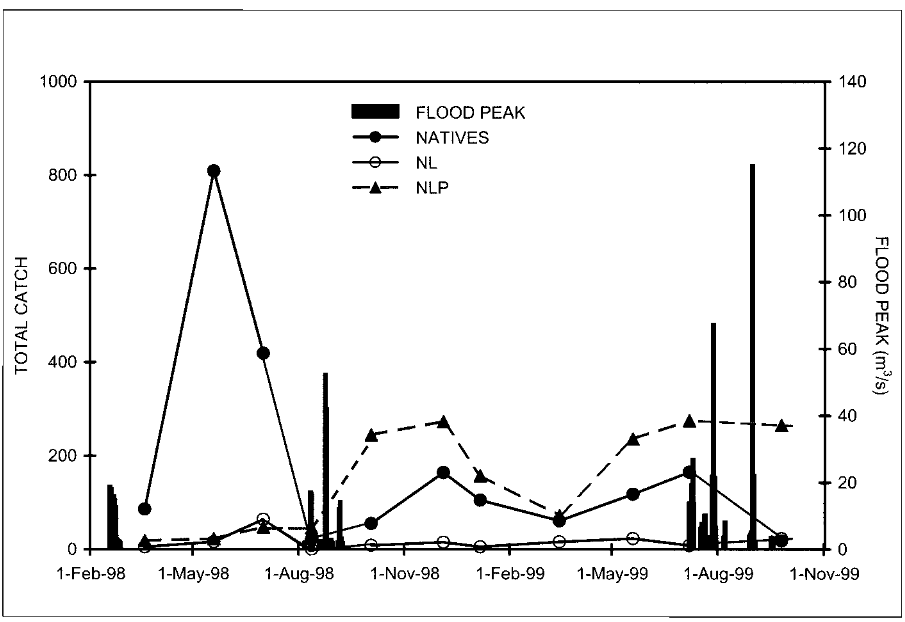


FIGURE 3.—Variation in catch ($N$ = 11) of native fishes combined, nonnative fishes found in lower Sonoita Creek only (NL), and nonnative fishes found in both lower Sonoita Creek and Patagonia Lake (NLP) in response to flood peaks ($N$ = 53) at Station 2, lower Sonoita Creek.

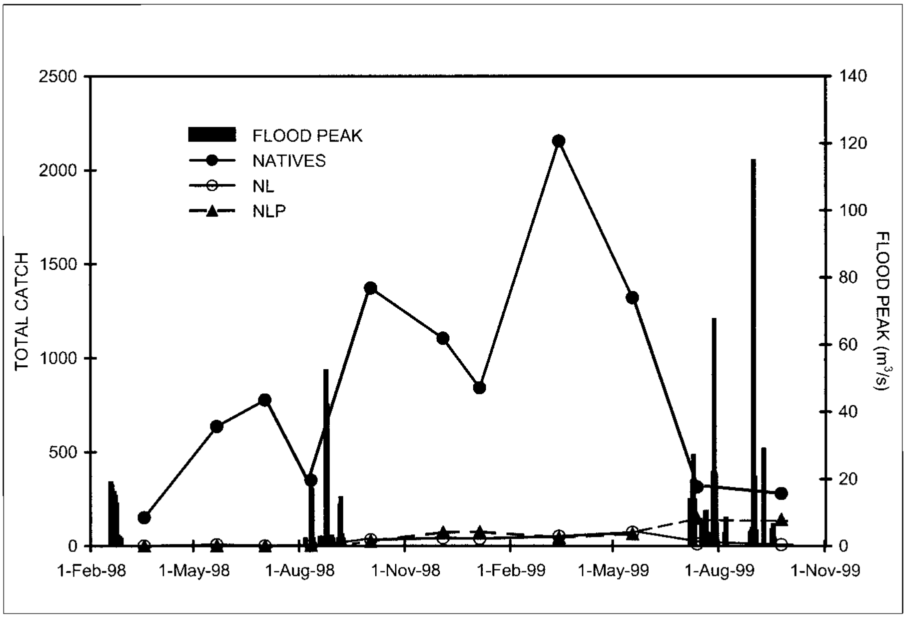


FIGURE 4.—Variation in catch ($N$ = 11) of native fishes combined, nonnative fishes found in lower Sonoita Creek only (NL), and nonnative fishes found in both lower Sonoita Creek and Patagonia Lake (NLP) in response to flood peaks ($N$ = 54) at Station 3, lower Sonoita Creek.

viduals from Patagonia Lake may mask losses. Because no small young of the year (<37 mm TL) of species found in both Patagonia Lake and lower Sonoita Creek (except mosquitofish) were collected in lower Sonoita Creek, recruitment within lower Sonoita Creek probably cannot account for the increase in certain nonnative fishes after periods with flooding. Repeated input of nonnative fishes to lower Sonoita Creek from Patagonia Lake may sustain certain nonnative fishes in lower Sonoita Creek that otherwise might be unable to successfully reproduce or recruit at a rate capable of maintaining populations in the creek. These species are unlikely to be sustained by movement of individuals upstream during the brief connection of lower Sonoita Creek with the Santa Cruz River during or briefly after flooding in lower Sonoita Creek.

Historical data corroborate our belief that the reservoir contributes to the persistence and increased abundance of nonnative fishes downstream. Before completion of Patagonia Lake Dam in 1968, only a single nonnative fish (goldfish *Carassius auratus*) was collected from Sonoita Creek (Minckley 1969), despite the presence of at least seven species of nonnative fish within the basin and extensive modification of the stream from its original condition (Minckley 1969). After the dam was completed, nonnative fishes quickly spread throughout Sonoita Creek. At least nine species of nonnative fish have been documented in mainstream Sonoita Creek since completion of the dam (Schultz 2000). During our study, nonnative fishes accounted for about 29% of the fish captured in lower Sonoita Creek and 85% of the fish captured at the sampling station closest to Patagonia Lake (Station 1; Schultz 2000).

The spread and occasional dominance of nonnative fishes downstream of impoundments is a well-known pattern (Vanicek et al. 1970; Holden 1979; Walker 1979; Stanford and Ward 1986). The most conspicuous examples of this scenario usually involve large-scale hydroelectric dams, which radically alter hydrologic and thermal regimes, often for great distances downstream (Vanicek et al. 1970; Holden 1979; Stanford and Ward 1986). However, Martinez et al. (1994) contended that smaller-scale impoundments that do not drastically alter hydrologic or thermal regimes could still have a profound influence on native fishes by facilitating establishment and proliferation of nonnative species. Preimpoundment surveys in the White River, Colorado, showed that native fishes predominated; after completion of a dam, however, nonnative fishes made up roughly 80% of the fish collected in the river below the dam, despite only a subtle change in downstream hydrologic and thermal conditions (Martinez et al. 1994). Lower Sonoita Creek has more in common with the smaller-scale scenario.

The decrease in catch of most native fishes in lower Sonoita Creek after floods of historically average magnitude is unexpected for a stream that is semiregulated and lately not canyon bound. Minckley and Meffe (1987) suggested that when abundance of native fishes declined after flooding, losses occurred primarily in the most canyon-bound streams or stream reaches. The decrease in catch of native fishes in lower Sonoita Creek after flooding may result from increased predatory pressure on native fishes by the increased numbers of nonnative fishes from Patagonia Lake. Most of the nonnative fishes found in both Patagonia Lake and lower Sonoita Creek are known to feed on fish native to the Southwest (Meffe 1985; Marsh and Brooks 1989; Minckley and Deacon 1991; Marsh and Douglas 1997; Dudley and Matter 2000; Rinne 2001). Predation by largemouth bass and mosquitofish was the primary cause leading to extirpation of certain populations of fish native to the Southwest (Minckley and Deacon 1991). In lower Sonoita Creek, we witnessed small shoals of largemouth bass stalking and attacking poeciliids in shallow water.

Many factors have been hypothesized to allow the persistence of native fishes in the presence of nonnative fishes (Minckley et al. 1977; Rinne and Stefferud 1997; Minckley 1999), but in most situations exact mechanisms remain unclear (Rinne and Stefferud 1997). The disproportionate displacement of nonnative fishes by flooding often is thought of as a leading candidate in this regard, especially in the Southwest (Meffe 1984; Minckley and Meffe 1987; Rinne and Stefferud 1997). The role of flooding in the apparent coexistence of native and nonnative fishes in lower Sonoita Creek, however, is somewhat contradictory. Although flooding may hinder certain nonnative fishes from establishing or proliferating within lower Sonoita Creek, it may also provide a periodic pulse of nonnative fishes from Patagonia Lake into downstream areas. Furthermore, floods originating in Fresno and Coal Mine canyons (the only tributaries to lower Sonoita Creek) could disproportionately displace nonnative fishes residing below Fresno Canyon. These same floods may facilitate movement of fish from these tributaries to lower Sonoita Creek. In combination with the benefits native fishes receive from a disproportionate decrease in nonnative competitors and predators after floods, postflood changes in stream substrate may be linked to spawning success and recruitment of native fishes in southwestern streams (Rinne and Stefferud 1997; Brouder 2001).

*Management Implications*

Nonnative fishes escaping from reservoirs have the potential to markedly affect populations of native fishes downstream. Removal of reservoirs is rarely feasible; however, several management actions could be taken to reduce their effects. Attempts to remove nonnative fishes from a stream system must include concurrent treatment of reservoirs, lakes, and stock tanks in the watershed upstream (Sponholtz et al. 1998). Nonnative species will rapidly recolonize downstream areas from upstream sites left untreated.

In cases where removal of nonnative fishes is undesirable or unfeasible, screens or barriers could be placed in outflow structures to restrict the downstream movement of nonnative fishes. Powell and Spencer (1979) developed a barrier of parallel bars to prevent loss of harvestable-sized fish over spillways. However, most screens or barriers would not prevent passage of many juvenile fish and are rarely 100% successful in preventing movement of adult fish from lakes and reservoirs into downstream areas. The stocking of sterile or native fishes in upstream reservoirs is a potential option. Loch and Bonar (1999) provide an example of the difficulty in preventing fish from escaping lentic water bodies and the potential importance of stocking sterile fish: they reported the presence and movement of exotic grass carp *Ctenopharyngodon idella* in the Columbia River, even though the fish is permitted only in closed or screened lakes, reservoirs, or canals in the Pacific Northwest.

Water outflow from a dam with deep outlets could be manipulated to prevent discharge from topping a spillway, thus reducing the chances of nonnative fishes dispersing into downstream areas. Additionally, dam outflow could be manipulated to benefit native fishes downstream by disproportionately displacing nonnative fishes. Emergency water releases from reservoirs in central Arizona negatively impacted nonnative fishes in downstream areas in a manner similar to flooding in unregulated southwestern streams (Minckley and Meffe 1987). The potential for dam outflow to negatively impact nonnative fishes is related to downstream channel characteristics and the magnitude and timing of releases. Physical characteristics common to many mesic streams (unconstrained, broad floodplains, low gradients, and perennial downstream reaches and tributaries) will lessen the effect of dam outflows on nonnative fishes (Minckley and Meffe 1987). Harvey (1987) found that susceptibility to displacement rapidly declined with an increase in fish size and that the effects of floods on stream fish communities can depend on small differences in the timing of reproduction. Our study suggests that the potential benefits of flooding to remove nonnative fishes may be compromised if reservoirs located upstream are involved.


## Acknowledgments

We thank Simon Ince and Dennis Scheall for providing hydrologic information. We are grateful to the Arizona State Parks Department and the staff at Patagonia Lake State Park, especially Rick Gagnon, for their assistance and permission to work in the Sonoita Creek State Natural Area. We thank Robert J. Frye for statistical advice. We thank Vicki Gempko, Eddie Moreno, and others for their assistance in the field. We thank the Badillo and Harsh families for their permission and assistance regarding use of access routes into the Sonoita Creek State Natural Area. This study was funded through the Arizona Cooperative Fish and Wildlife Research Unit with support from the Agricultural Experimental Station and the U.S. Geological Survey. This paper is dedicated to the late O. Eugene Maughan.


## References


Brouder, M. J. 2001. Effects of flooding on recruitment of roundtail chub, *Gila robusta*, in a southwestern river. Southwestern Naturalist 46:302–310.

Clark, C. F. 1942. A study of the loss of fish from an artificial lake over a wasteweir, Lake Loramie, Ohio. Transactions of the North American Wildlife and Natural Resources Conference 7:250–256.

Clarkson, R. W., and M. R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River big-river fishes. Copeia 2000:402–412.

Davies, B. R., M. C. Thoms, K. F. Walker, J. H. Okeeffe, and J. A. Gore. 1994. Dryland rivers: their ecology, conservation and management. Pages 484–511 *in* P. Calow and G. E. Petts, editors. The rivers handbook, volume 2. Blackwell Scientific Publications, Oxford, UK.

Douglas, M. E., P. C. Marsh, and W. L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994:9–19.

Dudley, R. K., and W. J. Matter. 2000. Effects of small green sunfish (*Lepomis cyanellus*) on recruitment of Gila chub (*Gila intermedia*) in Sabino Creek, Arizona. Southwestern Naturalist 45:24–29.

Edwards, R. J. 1978. Effect of hypolimnion reservoir releases on fish distribution and species diversity. Transactions of the American Fisheries Society 107: 71–77.

Elser, H. J. 1960. Escape of fish over spillways 1958–1960. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 14(1960):174–185.

Harvey, B. C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. Transactions of the American Fisheries Society 116: 851–855.

Hendrickson, D. A., and W. L. Minckley. 1984. Cienegas-vanishing climax communities of the American Southwest. Desert Plants 6(3):141–175.

Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 57–74 *in* J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Proceedings of the first international symposium on regulated streams. Plenum, New York.

Lewis, W. M., R. Heidinger, and M. Konikoff. 1968. Loss of fishes over a drop-box spillway of a lake. Transactions of the American Fisheries Society 97: 492–494.

Loch, J. J., and S. A. Bonar. 1999. Occurrence of grass carp in the lower Columbia and Snake Rivers. Transactions of the American Fisheries Society 128: 374–379.

Louder, D. 1958. Escape of fish over spillways. Progressive Fish-Culturist 20:38–41.

Marsh, P. C., and J. L. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of introduced razorback suckers. Southwestern Naturalist 34:188–195.

Marsh, P. C., and M. E. Douglas. 1997. Predation by introduced fishes on endangered humpback chub and other species in the Little Colorado River, Arizona. Transactions of the American Fisheries Society 126:343–346.

Martinez, P. J., T. E. Chart, M. A. Trammell, J. G. Wullschleger, and E. P. Bergersen. 1994. Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. Environmental Biology of Fishes 40:227–239.

McGann and Associates, Inc. 1997. Sonoita Creek State Natural Area management plan: background report. Arizona State Parks, Phoenix.

McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83–120 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Meffe, G. K. 1983. Ecology of species replacement in the Sonoran topminnow (*Poeciliopsis occidentalis*) and the mosquitofish (*Gambusia affinis*) in Arizona. Doctoral dissertation. Arizona State University, Tempe.

Meffe, G. K. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. Ecology 65:1525–1534.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: a case study. Southwestern Naturalist 30:173–187.

Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Papers of the Michigan Academy of Science, Arts, and Letters 46:365–404.

Minckley, W. L. 1969. Aquatic biota of the Sonoita Creek basin, Santa Cruz County, Arizona. Ecological Studies 15:1–8.

Minckley, W. L. 1999. Ecological review and management recommendations for recovery of the endangered gila topminnow. Great Basin Naturalist 59: 230–244.

Minckley, W. L., and J. E. Deacon, editors. 1991. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Minckley, W. L., and G. K. Meffe. 1987. Differential selection by flooding in stream fish communities of the arid American Southwest. Pages 93–104 *in* W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Minckley, W. L., J. N. Rinne, and J. E. Johnson. 1977. Status of the gila topminnow and its co-occurrence with mosquitofish. U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Research Paper RM-198, Fort Collins, Colorado.

Powell, D. H., and S. L. Spencer. 1979. Parallel-bar barrier prevents fish loss over spillways. Progressive Fish-Culturist 41:174–175.

Rinne, J. N. 1992. Physical habitat utilization of fish in a Sonoran Desert stream, Arizona, southwestern United States. Ecology of Freshwater Fish 1:35–41.

Rinne, J. N. 2001. Nonnative, predatory fish removal and native fish response, upper Verde River, Arizona: preliminary results. Hydrology and Water Resources in Arizona and the Southwest 31:29–36.

Rinne, J. N. and J. A. Stefferud. 1997. Factors contributing to collapse yet maintenance of a native fish community in the desert Southwest (USA). Pages 157–162 *in* D. A. Hancock, D. C. Smith, A. Grant, and J. P. Beumer, editors. Developing and sustaining world fisheries resources: the state of science and management. Proceedings of the 2nd world fisheries congress. CSIRO Publishing, Collingwood, Australia.

Rinne, J. N., J. A. Stefferud, A. Clark, and P. J. Sponholtz. 1998. Fish community structure in the Verde River, Arizona, 1975–1997. Hydrology and Water Resources in Arizona and the Southwest 28:75–80.

Sponholtz, P. J., D. C. Redondo, B. P. Deason, L. M. Sychowski, and J. N. Rinne. 1998. The influence of stock tanks on native fishes: Upper Verde River, Arizona. Proceedings of a symposium on environmental, economic, and legal issues related to rangeland water developments. Arizona State University, Center for the Study of Law, Science and Technology, Tempe.

Schultz, A. A. 2000. The structure and dynamics of the fish assemblage in lower Sonoita Creek, Arizona. Master's thesis. University of Arizona, Tucson.

Stanford, J. A., and J. V. Ward. 1986. Fish of the Colorado system. Pages 385–402 *in* B. R. Davies and K. F. Walker, editors. The ecology of river systems. Kluwer, Hingham, Massachusetts.

USGS (U.S. Geological Survey). 1972. Water resources data for Arizona. USGS, Surface Water Records Part 1, Tucson, Arizona.

Vanicek, C. D., R. H. Kramer, and D. R. Franklin. 1970. Distribution of Green River fishes in Utah and Colorado following closure of Flaming Gorge Dam. Southwestern Naturalist 14:297–315.

Walker, K. F. 1979. Regulated streams in Australia: the Murray-Darling river system. Pages 143–163 *in* J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Proceedings of the first international symposium on regulated streams. Plenum, New York.

Ward, J. V., and J. A. Stanford, editors. 1979. The ecology of regulated streams. Proceedings of the first international symposium on regulated streams. Plenum, New York.

Zar, J. H. 1984. Biostatistical analysis, 2nd Edition. Prentice-Hall, Englewood Cliffs, New Jersey.