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Survival of Young Razorback Sucker in Relation to Stocking Rates (fish/ha) and in the Presence or Absence of Predator Communities in Lake Mohave, Arizona-Nevada.

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Abstract–Razorback suckers *Xyrauchen texanus* successfully spawn in Lake Mohave and while viable larvae are produced, no recruitment has been detected for 30 years. Wild razorback sucker larvae were stocked at rates ranging from 3,125 to 22,200 fish/ha in ephemeral habitats located adjacent to Lake Mohave from 1993 through 1995. Suckers survived 14 of 17 stockings (82%) producing 20+ cm juveniles with survival averaging 23%. There was no correlation between survival and stocking rates ($R^2 = 0.06$). Similar survival occurred in a permanent pond that had been recently renovated, but survival declined (91.5%, 12.1%, to 1.6%) each consecutive year (1993-1995) there after. Escalating losses were attributed to odonate nymph and crayfish competition or predation.

Non-native fish were mechanically removed from a 1.3 ha cove to determine if predator densities could be mechanically reduced to a level which would enhance stocking survival. Resident predator biomass was reduced an estimated 58% (-1,554 fish/ha, -45 kg/ha) or to 30-35 kg/ha prior to stocking 10,000 juvenile (68 mm) razorbacks. In spite of their size advantage and considerable predator reductions, only 9 (0.09%) of the initial 10,000 suckers were recovered. Our stocking rate of 7,600 juveniles/ha was effectively consumed by nonnative predators within a few weeks.

Extent of the stocking loss was sobering and exemplifies threats to naturally produced larvae throughout the Colorado River basin. Natural spawned larval in some areas of Lake Mohave may reach densities >20 larvae/m^2, however, larvae rapidly disappear and suckers >2 cm are seldom found. The rate of disappearance suggests predation may be virtually complete within 50 days and be accomplished by small or medium sized predators (cyprinids and sunfish).

Mechanical predator removal appeared to target larger predators. Largemouth bass biomass (16.9 to 7.8 ka/ha) had not fully recovered at the time of rotenoning, however, during this same period bluegill biomass may have more than doubled (20.4 to 64.9 ka/ha). Large predator removal may inherently increase small and medium sized predator standing to crop and possibly even further escalate predation pressure for larval fishes. Survival of early life stages appears to depend on the long-term availability of predator free nurseries. Direct manipulation of nursery habitats to artificially reduce or eliminate resident predators may be the only recourse to provide some chance for natural recruitment.

Introduction

It's well documented that both habitat degradation and introduction of nonnative fishes have led to the demise of endemic fish communities (Ona et al. 1983, Minckley and Deacon 1991). The extent that nonnatives may actually retard recruitment or suppress stocking efforts is obvious in the lower basin (Pacey and Marsh 1998). Little research has been directed at predator-prey interaction, however, there have been numerous cases illustrating the effectiveness of nonnative predators. For instance, razorbacks have been producing millions (est. 20 million/yr) of larvae in Lake Mohave for 30 year with no sign of recruitment. Also over 12 million razorback fry were stocked in Arizona streams and numerous other stockings in the Colorado River without any appreciable survival (Langhorst 1988, Mueller 1989, Minckley et al. 1991).

Predator removal in the mainstem Colorado River has not been seriously considered in the lower basin. However, nearly a million dollars a year is being spent by the upper basin recovery programs for that purpose (USFWS 1997, Brooks and Smith 1998). Nonnative fish removal programs have targeted the San Juan, Gunnison, Colorado, Green, and Yampa Rivers (McAda 1997, USFWS 1997 & 1998, Brooks and Smith 1998). Unfortunately, activities are primarily focused at removing nonnatives and not examining what level of reduction may actually be necessary. Nonnative fish removal is being justified on the premise that any reduction is beneficial or that salvaged fish can benefit other recreational

programs (Brooks and Smith 1998). It's not known whether endemics would respond to a 10, 20, 40, or 80% reduction in nonnatives.

These actions appear to represent a philosophical departure from the belief that some form of habitat manipulation is the only alternative for recovery (Hawkins and Nesler 1991). There is a slow, but growing acceptance, that a more proactive management philosophy may be necessary to prevent extinction in the upper basin (Wydoski and Wick 1998).

A management approach was adopted by the Native Fish Work Group (NFWG) on Lake Mohave in 1989. Activities are focused at simply preventing extirpation rather than habitat restoration. The group is repatriating 50,000 young adults to replace old individuals that are dying of old age (NFWG 1990 & 1994. Mueller 1995). Various methods of collecting wild larvae, culturing young, and reintroducing them back into the wild are being attempted; those that work are pursued, those that don't are quickly modified or dropped. While not true research, the experiences gained through active culturing and management have provided new insights into the biology and ecology of these unique fish. The following discussion provides information on sucker survivalship in regards to stocking rates and in the presences or absence of uonnative predators.

Methods

Razorback suckers were reared in both ephemeral and permanent pouds located along the shore of Lake Mohave. These pouds were formed by wave induced beach erosion that deposited sand across cove entrances. Some of the naturally deposited berms were heightened to permanently isolate coves from high reservoir elevations. While the ponds were physically isolated to fish, they remained hydraulically connected by ground water exchange.

The ephemeral ponds were small, averaging slightly more than 0.13 ha (0.05 to 0.17 ha) at reservoir elevation 195 m (640 ft M.S.L.). Yuma Cove is the only pond that doesn't entirely dry up (<0.1 ha) when the reservoir drops to elevation 192 m (M.S.L.). The cove's berm was mechanically heightened in 1990 to permaneutly isolate it from the reservoir. Surface area averaged 0.82 ha (0.1 to 1.47 ha).

Newly hatched suckers are phototaxic and the NFWG developed methods of collecting naturally spawning young before they're eaten (Mueller et al. 1992, Mueller et al. 1993, Marsh 1993). Larvae were collected between the months of January and April and then transported to hatchery facilities. When fry reached an average total length of 15 to 25 mm (30-60 days) they were redistributed to rearing ponds. Fish growth was rapid and by late summer, the majority of razorback suckers exceeded 30 cm TL. The reservoir is typically lowered (3-4 m) by October for routine maintenance which in turn slowly drains the ponds and aids in fish recovery. Suckers >30 cm are stocked back into the reservoir while smaller suckers are transported to other permanent ponds (Yuma and Davis Covers) for further growth.

Davis Cove was chosen as a permanent rearing location due to its size (1.3 ha), depth (7 m), and narrow (<50 m) entrance which could be closed by net or earthen berm. Located on the Arizona shoreline just 2 km south of Catherine's Landing. it was ideally located for stocking access. Its entrance was blocked with a 8 mm meshed, custom built barrier uet (50 x 7 m) on 4 February, 1992. The net was secured by steel cable, continuous floatation boom, and was anchored with continuous concrete parking bumpers. Small (>20-30 mm) fish could swim through the net, but it was believed resident predators could be controlled through mechanical removal.

Fish were mechanically removed from Davis Cove using electrofishing, gill nets, fyke nets, seining, and angling dnring the second week of June 1992. The cove was interlaced with gill and trammel nets and then electrofished for fonr consecutive nights. Captured fish were weighed, measured and then relocated uuharmed to the reservoir.

Two sizes of razorback suckers were stocked. Ten thousand, small (68 mm) suckers (Year class 1991-Dexter National Fish Hatchery) and 167 larger (17-30 cm) suckers, representing 1992 ephemeral pond production were stocked from 24 June through 28 September. Larger fish were PIT tagged prior to being stocked. The barrier net was inspected and fish growth was monitored biweekly using seines, fyke and trammel nets. All nonnatives and razorback suckers >30 cm were released into the reservoir.

Scuba surveys were conducted bimonthly to measure relative abundance (fish/10 min.) and to uote fish growth. behavior, and habitat use. Divers followed four permanently mounted rope transects along the bottom of Davis Cove to uote fish locations, numbers, effort (fish/10 min), and associated habitat types (Mueller and Marsh 1993).

Net breaches were discovered in January and April 1993 and repaired. Sand would deposit on the net and when the reservoir rose, the weight of the sand caused the net to pull away from the floatation collar. This became problematic by the end of 1993 and plans were made to replace the net with an eartheu barrier. An earthen berm was constructed in August 1995 and following installation, the cove was rotenoned and all fish were recovered, identified, counted and weighted. Additional fish were collected the following day as warm

temperatures caused morbid fish to swell and rise to the surface, allowing a complete fish recovery.

Results

Ephemeral Ponds (Seasonal)

Environmental conditions (i.e. water quality, temperature, DO) within the small ephemeral ponds were greatly influenced by reservoir elevation and storms events. Reservoir elevation and fluctuations determined pond depth and water exchanges. Typically, the shallow habitats were highly productive supporting lush stands of aquatic macrophytes and algae. Summer storms would occasionally import sediment and organic material, often covering vegetation and perpetuate turbid conditions that could persist for weeks. Summer heat would cause thermal and chemical stratification, resulting in anoxic conditions (<1 mg/L) that could trigger fish kills if habitats were disturbed (i.e.. sampling or wadding). Motitoring was typically reduced or totally suspended through July and August and fish recovery began in September.

Larval (15-25 mm) razorback suckers were stocked into ephemeral ponds on 17 separate occasions during the springs of 1993 to 1995. Larvae were typically stocked at a rate of 5,000 fish/ha but rates did range from 500 to 20,000 fish/ha. A comparison of survival with stocking rate showed no correlation (R2 =0.06) and suggests more eminent localized factors (i.e. water quality, DO, temperature, and avian/invertebrate predation) influenced survival. Fish were recovered from 14 of the 17 stockings (82%) and exhibited an average survival rate over the 3 years of 23% (Table 1).

Yuma Cove (Permanent/no predator fish)

Resident fish were removed with rotenone in 1990 and 1991. Sexually mature razorbacks were stocked in 1991 and 1992 to determine if fish would naturally spawn. Spawning did occur both years, but recruitment failed in 1991 and only 296 young razorbacks were recovered in 1992 (Horn and Marsh 1993. Pacey and Marsh 1998). Poor production prompted the NFWG to suspend using in-cove spawning and instead collect and transplant wild reservoir larvae. Wild sucker larvae were stocked in 1993 (500 larvae/ha), 1994 (3,600 larvae/ha), and 1995 (6,900 larvae/ha). Recovery rates declined each year; 91.5 % of the fish reclaimed were in 1993, 12.1% in 1994, and only 1.6% in 1995. After 1996, razorback suckers were stocked at a larger size (>50 mm) and survival increased substantially. The reason for the poor larval survival was never fnlly determined, but it was suspected that predatory odonates and crayfish were contributing factors (Mueller et al. 1992, Horn 1992, Hom et al. 1994).

TABLE 1.–Stocking and survival rates of larval (15-25 mm) razorback suckers stocked into ephemeral ponds adjacent to Lake Mohave, Arizona-Nevada from 1993 through 1995.

Year	Backwater	Total In	Fish/ha*	Recovery	Survival (%)	Avg. Size (mm)
1993	AJ	2,010	11,820	198	10	175
	Willow	500	3,125	26	5	219
	NL	2,000	22,200	250	13	193
	Total/Average	**4,510**	**12,300**	474	**10**	**196**
1994	N. Chem.	1,000	6,250	812	81	194
	Dandy	1,000	———	562	56	198
	NL.	500	5,500	217	43	224
	Sidewinder	500	12,500	201	40	201
	Willow	1,000	6,250	160	16	208
	AJ, NAJ, NNM	2,000	4,000	0	0	0
	Total/Average	**6,000**	**6,900**	**1,952**	**39**	**224**
1995	Sidewinder	500	12,500	186	37	278
	N. Chem.	1,303	8,100	378	29	284
	Willow	500	3,125	76	15	302
	Dandy	1,187	———	442	37	272
	NL.	666	7,400	20	3	342
	AJ.	1,000	5,880	84	8	314
	Total/Average	**5,156**	**7,400**	**1,186**	**22**	**299**

* Surface area @ Lake Mohave elevation 195 m (640 ft).

Data taken from Burke and Mueller 1993, Burke 1994 and other unpublished field data.

TABLE 2.–Comparison of fish standing crop (fish/ha) measurements from Davis Cove, Lake Mohave, Arizona using manual methods (1992) and rotenone (1995).

	(1992-Pre Stocking)			(July-Jan. 1993)			(1995 Renovation)			
	Manual			Manual			Rotenone			
Species	#	kg	(kg/ha)	#	kg	(kg/ha)	#	kg	(kg/ha)	
Largemouth bass*	100	21.5	(16.9)	50	34.8	(27.4)	150	9.9	(7.8)	
Green sunfish*	234	4.7	(3.7)	27	2.6	(2.0)	261	2.9	(2.3)	
Bluegill*	1,440	25.9	(20.4)	260	25.4	(20.0)	1,700	82.4	(64.9)	
Yellow bullhead*	6	5.4	(4.3)	7	2.1	(1.7)	13	3.2	(2.5)	
Carp	191	172.3	(135.7)	33	55.0	(43.3)	224	427.7	(336.8)	
Razorback sucker	——						3	12.3	(9.7)	
Total Predators*		57.5	(45.3)		64.9	(51.1)		98.4	(77.5)	(-58.5%)
Total Fish	1,971	229.8	(180.9)	377	119.9	(94.4)	2,348	538.4	(424.0)	(-42.7%)

Davis Cove Reduced Predator Fish

Two weeks prior to stocking (June, 16-24, 1992) over 1,900 (1,550 fish/ha) resident fish weighing a total of 230 kg (181 kg/ha) were removed from Davis Cove (Table 1). Subsequent monthly (July 1992-January 1993) efforts raised the total number and biomass of fish removed to nearly 2,350 and 350 kg (1,849 fish/ha & 276 kg/ha). Prestocking efforts removed 57.5 kg (45 kg/ha) of known predator species (largemouth bass, green sunfish, bluegill, bullhead) and follow-up efforts removed an additional 64.9 kg (51 kg/ha) during the following 6 months. Fish biomass was dominated by carp (73%) and numerically by centrarchids (82%).

Species composition was similar for both the mechanical and rotenone removal efforts. Initial removal of largemouth bass (16.9 kg/ha) was greater than the rotenone (7.8 kg/ha) effort. Cove renovation removed 98.4 kg (77.5 kg/ha) of known predators and 538.4 kg (424.0 kg/ha) of total fish biomass. (Table 2).

Recapture of Razorback Suckers- The 10 months provided razorback suckers sufficient time to reach 20 cm. By April 1993, suckers originating from Dexter averaged 263 mm (Table 3). Four sampling trips from January through April, 1993 recovered a total of 14 of the Dexter fish (0.14%). Nine (0.09%) were over 22 cm and released back into Lake Mohave. Of the original 167 larger suckers, 28 were captured (17%).

TABLE 3.–Recapture and growth rates of the initial 10,000 razorback suckers stocking in Davis Cove on June 24, 1992 and supplied by Dexter National Fish Hatchery, New Mexico

Date	Av. Length (mm)	Number	Range (mm)
24-June	68.1	65	48-82
09-July	74.6	31	59-93
15-July	79.3	51	64-115
22-July	78.6	25	62-96
06-August	87.4	14	75-105
20-August	100.9	15	97-163
10-September	127.9	9	97-163
12-January	150.0	4	106-190
17-February	105.0	1	105
28-April	263.1	9	220-280

Miscellaneous Observations- Indirect evidence through seining and trapping, along with direct observations by snorkel and SCUBA indicated young suckers were nocturnal. Young suckers hid in aquatic vegetation and other forms of cover during daylight hours but were found on sandy substrates bordered by dense vegetation at night (Mueller 1993, Mueller and Marsh 1998). Suckers were distributed throughout the cove after dark regardless of depth (0.3-10 m). Five SCUBA surveys conducted in July, September, November (1993), March, and May, 1993 revealed sucker abundance decreased with time. Relative sucker abundance declined from 6.1 suckers/10 min to; 3.2, 0.4, 1.2, and 0.4 respectively. Removal of a majority of largemouth bass coincided with an impressive increase in abundance of large crayfish. By October 1993, crayfish predation of net-captured fish complicated barvest efforts.

Larger razorback suckers were PIT tagged prior to release into Davis Cove. Ont of curiosity, we scanned the large predators taken from the cove and found several largemouth bass contained PIT tags that had been used to mark razorback suckers. One largemouth bass contained 6 PIT tags in its digestive track.

Discussion

Disappearing Young? Razorback suckers have been spawning in Lake Mohave for decades but natural recruitment has not been documented for nearly 30 years (Marsh and Minckley 1989, Minckley et al. 1991, Pacey and Marsh 1998). Adults successfully spawn in a wide range of habitats, their eggs hatch, and while emerging larvae are initially abundant, they quickly disappear. Larval densities during Lake Mohave spawning may approach 200.000 larvae/ha (Mueller 1989) an estimate

that may actually be conservative. Three biologists recently (March 1999) individnally dipped 11,000 razorback larvae in a 4 hour period from a single, small cove (0.25 ha).

Symptoms of their decline are similar basin wide. In the upper basin, razorback larvae have been collected in the Green and lower Colorado River but juveniles are all but absent (Gutermuth et al. 1994, Muth et al. 1998, USFWS 1998b). Juveniles have been reported throughout the basin (Modde et al. 1996, Guthermuth et al. 1994, Mueller 1996, Holden et al. 1997), however, their collection is extremely rare suggesting there's little or no recruitment to old, relic populations (Minckley et al. 1991, USFWS 1998b).

Predation by non-native fishes appears to be the primary factor limiting razorback recruitment (Minckley et al. 1991, Pacey and Marsh 1998). There is ample evidence showing that when placed in new or unoccupied habitats, razorback survival and recruitment commonly occurs (Minckley et al. 1991, Pacey and Marsh 1998). Young and adult suckers do extremely well when placed by themselves in lakes, stock tanks, municipal golf course ponds, and there are some instances of natural recruitment (Mueller 1995, Mueller and Wick 1998, Pacey and Marsh 1998). However, predators come in many forms and are rapid colonizers.

We learned two lessons by stocking razorback larvae in Yuma Cove. First, we can alter aquatic communities, and second, we have far less control of long-term changes. The stockings were successful and initial survival was high (91%), but dropped each consecutive year to unacceptable levels (1.6%). By removing predator fish. the backwater was rapidly colonized by odouate nymphs and crayfish. These large invertebrates became extremely abundant and are known to compete with, or feed upon, native fishes (Mueller et al. 1992, Horn et al. 1994, Carpenter and McIvor 1999). Crayfish also became a problem in Davis Cove. Initial survival was improved by stocking larger suckers, but unfortunately, crayfish inflicted high fish mortality and mutilations during routine netting. In response, a specially designed crayfish trap was developed that would only capture crayfish and not fish (Kevin Morgan personal communique). These traps are typically in continuous use to control crayfish numbers.

Mechanical Predator Removal- Our attempt to mechanically remove fish predators was approacbed with over optimism and some degree of arrogance. We were confident predators could be mechanically removed from a small, 1.3 ha cove, to levels that would iusure survival. Sampling efforts were intensive but techniques were selective toward larger fish due to intrinsic biases of electrofishing and gill netting. We feel a high percentage of larger predators such as largemouth bass were indeed removed. An estimated 58% of the predator biomass (181 kg/ha) was removed prior to stocking. Based on the rotenone data, we suspect predator standing crop had been reduced to 30 to 35 kg/ha at the time of stocking and this community was made up primarily of small and medium sized sunfish. Razorbacks were actually stocked at a higher biomass rate of 37.8 kg/ha (7,600 fish/ha).

It's doubtful all the razorbacks were recovered. Three razorbacks were recovered in 1995, but their origin was unknown due to the fact that other razorbacks were stocked after June 1993. Regardless, diving observations and recapture evidence strongly suggests survival was indeed poor. Schooling juvenile suckers were continuously harassed by sunfish and largemouth bass that had evaded capture. Divers observed many suckers with obvious predator wounds such as frayed fins and abraded caudal peduncles. Only 9 of the original 10.000 stocked were harvested. Recovery of larger (>17 cm) suckers was higher (17%) and when considering size, similar to the estimated survival (57%) of suckers released into Lake Mohave (Marsh 1997). However, the rate was still substantially below survival (>80%) rates for predator free environments.

Razorback sucker is not the only native that has low tolerance for predators. Osmundson (1986) observed similar predation when Colorado pikeminnow *Ptychocheilus lucius*) were stocked over nonnative fish populations in gravel-pits near Grand Junction, Colorado. Pikeminnow were stocked in three sizes (50-65 mm, 75-90 mm, and 100-120 mm) and by 28 weeks survival had dropped to 0.3%. Largemouth bass initially selected smaller pikeminnow and preferred them over some resident prey species. Mortality was also high in ponds believed to have low predator densities and it was speculated losses might be attributed to; starvation, winter stress, and parasitism. It's interesting to note that crayfish were reported present but not listed as a possible predator.

The Few and the Lucky- There is ample evidence showing the importance of predator control and the benefits of ephemeral habitats (Valdez and Wick 1981, Minckley et al. 1991, Mueller 1995, Burdick et al. 1997). Documentation of natural recruitment anywhere in the basin has been extremely rare, but when it has occurred it has been typically associated with ephemeral or newly created habitats where predators were absent (e.g., irrigation canals and supply ponds (St. Amant et al. 1974, Ulmer and Anderson 1985, Marsh and Minckley 1989, Minckley et al. 1991, Mueller 1996, Pacey and Marsh 1998).

Modde (1997) recently reported similar recruitment from Old Charley Wash, Green River, Utah. Old Charley wetland was manually manipulated through a series of drainages and inundations from the river in 1994, 1995 and 1996. The wetland was partially drained in 1994, removing a large portion of the resident fish community. Nonnative fish were removed at a rate of 12.6 kg/ha, of

TABLE 4.–Standing crop (kg/ha) of known predator fish (year class =>1) and razorback suckers harvested from Old Charley Wash, Utah during the fall of 1994, 1995, and 1996.*

Species	1994	1995	1996
All fish	1,006.7* (12.6)	10,133.7 (126.7)	5,710.4 (71.4)
Channel catfish	38.4* (0.5)	90.3 (1.1)	57.2 (0.7)
Black bullhead	189.9* (2.4)	16.8 (0.2)	10.4 (0.1)
Green sunfish	1.0* (<0.01)	125.7 (1.6)	0
Total	229.3* (2.9)	232.8 (2.9)	67.6 (0.9)
Razorback sucker	0	28	45
Harvest Rate (fish/ha)		(0.35)	(0.56)

Incomplete harvest* Data taken from Modde 1997.

which, 2.87 kg/ha where known predators (Table 4). The wetland was inundated the following spring and was completely drained the following fall. The reestablishing fish community was dominated by carp and expanded to 126.7 kg/ha which included 2.91 kg/ha of predators. The salvage effort also discovered 28 juvenile razorback suckers which represented the largest number of naturally spawned juveniles recently collected in the upper basin. The wetland was reflooded in the spring of 1996. Salvage operations that fall removed 71.4 kg/ha of total fish biomass and 0.85 kg/ha of known predators along with an additional 45 juvenile razorbacks. The ephemeral nature of this backwater produced 73 juvenile razorback suckers.

Predators undoubtedly invaded the wetland during spring flooding, however, the fall renovations suggest the spring influx (biomass) was actually low. Predator biomass decreased (>2.87, 2.91, to 0.85 kg/ha) each consecutive year as numbers of salvaged razorbacks increased. Low predator levels, combined with turbid waters, debris, and masked by thousands of small fish, presented conditions which allowed larval razorback sucker to survival. These same mechanisms periodically result in the recovery of juvenile razorbacks from seasonally drained irrigation canals (St. Amant et al. 1974, Mueller 1996, Pacey and Marsh 1998).

Management Implications- The key to native fish survival is directly linked to extremely low or absent predation pressure. Removal of 58% (-45 kg/ha) of the predator standing crop in Davis Cove was insufficient to insure the survival of 68 mm razorbacks stocked at a rate of 7,600/ha. It's speculated predator biomass reductions closer to 90-95% may have been necessary for survival rates >10%. This would equate to predator thresholds below 5 kg/ha. Evidence suggests even more radical reductions might be necessary to insure some degree of larval survival. Data collected by Modde (1997) at Old Charley Wash suggests acceptable predator thresholds for natural recruitment in the Green River may be well below 1 kg/ha.

The concept of restricting the establishment of resident predators in nursery habitats is not new. Nearly 20 years ago Valdez and Wick (1981) recommended the creation or maintenance of seasonal backwater nurseries, that would seasonally drain, preventing nonnative proliferation. This management concept involves the inundation of backwaters during spring runoff for a period of 8 to 10 weeks which is insufficient for any meaningful growth. Expected growth would be minimal (10-15 mm), raising the question if 25-35 mm suckers could avoid predators once forced back into the river (Burdick et al. 1997). Evidence from 3 decades of stocking literally millions of small suckers would indicate no (Minckley et al. 1991). Reported occurrences of natural recruitment, suggests survival may actually be less likely in natural settings than for manipulated habitats such as canals, new habitats, or Old Charley Wash.

It's often speculated that predation pressure is more severe in the lower basin due to reservoirs and large backwater complexes. However, possibly more important is the role of a system's carrying capacity combined with the ability of nonnatives to rapidly invade with numerical superiority. Modde (1997) and Burdick et al. (1997) reported nonnative fish invasion rates ranging from 7,900 to 15,700 fish/ha in a single flooding event. These rates are nearly an order of magnitude greater than densities measured in Davis Cove (1,800 fish/ha). Mechanical removal methods (electrofishing, nets) may be relatively effective for larger predators such as northern pike, channel catfish, and largemouth bass in small systems (McAda 1997, Jim Brooks personal communique) however, we believe this practice is not only ineffective, but may actually create conditions more detrimental toward natural recruitment.

Large predator removal may enhance the reintroduction of larger fish, however, benefits may be short-lived and have other ramifications. There is growing evidence the removal of larger predators increases the overall abundance of younger or smaller predators. A 50% removal of largemouth bass in Davis Cove may have resulted in a doubling (+285%) of sunfish biomass. Similar increases in small channel catfish resulting from the removal of larger individuals have been reported for

the channel catfish removal program on the San Juan River (Jim Brooks and Dale Ryden personal communique). If natural recruitment of razorback sucker is being completely suppressed, within a few weeks after spawning, an increase in small predator densities may actually worsen conditions. If nonnative predation can't be controlled in the mainstem river, the question then becomes: How, or possibly more importantly, WHERE can we insure survival and growth?

Modde (1997) presented a concept for manipulated or managed nursery habitats which would provide fish longer periods for growth (4-6 months). The concept involved the construction of backwaters with drainage and inflow structures which would allow flood waters to be artificially impounded for longer durations. The Old Charlie Wash experiments from 1994 through 1996 illustrated that the concept did work. While major construction may be suited for large backwaters like Old Charlie Wash (80 ha) this approach may not be economical feasible for smaller nursery areas. Other researchers have suggested using chemical renovation or drainage to establish similar nursery or rearing ponds (Osmundson 1986, Langhorst 1988, Mueller 1995, Burdick et al. 1997, Wydoski and Wick 1998). Unfortunately, this direct managemeut approach is not widely accepted by the recovery programs.

The USFWS and BR are developing an artificial ecosystem program for the explicit use of endangered fishes in the lower basin (USFWS 1997b, Minckley unpublished material). This program proposes to construct 270 ha of refugia habitat adjacent to the river and be designed to regulate nonuative encroachment. Communities of nonnative fishes would be stocked and managed and larger individuals would be occasionally removed and stocked into the river.

Similar opportunities exist in the upper basin. Currently, 246 ponds have been identified in the 10-50 year floodplain and targeted for reclamation (Martinez and Martinez 1998). The primary goal is to reduce the influx of nonnative fishes. As pointed out by Burdick (et al. 1997), Wydoski and Wick (1998) these habitats could provide an opportunity to establish resident, native fish communities. If stocked, native species would acclimate to local conditions, grow to adulthood, possibly produce offspring. and eventually repatriate the river during flood flows. Periodic (2-5 years) reclamation and restocking could provide not only additional native fish influx, but also predator free nursery habitats that might expedite natural recruitment.

However, before any of these theories can be tested, its essential that core populations of sexually mature fish be reestablished. As illustrated by what many might cousider ideal conditions at Old Charlie Wash in 1995 and 1996, natural survival of young razorbacks was <1 sucker/ha of nursery habitat. Low densities probably reflect relatively low larval production from an adult population possibly numbering less than 250 fish (Modde et al. 1996). Unfortunately, the reestablishment of breeding populations may take 5 to 10 years to accomplish.

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