LFL contrib. #100

Effectiveness of Light Traps

For Capture and Retention of Larval and Early Juvenile *Xyrauchen texanus* and Larval *Ptychocheilus lucius* and *Gila elegans*

Final Report

Submitted to

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30 September 1997

LFL Contribution 100

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Effectiveness of Light Traps For Capture and Retention of Larval and Early Juvenile *Xyrauchen texanus* and Larval *Ptychocheilus lucius* and *Gila elegans*[1]

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Abstract

Light traps are used to capture the larvae of many fishes. To assess potential of floating, low-intensity, quatrefoil-style light traps for capture of the larvae or early juveniles of endangered Colorado River Basin fishes, provide guidelines for trap use, and better interpret field results, we conducted experiments in 1.2-m diameter tanks under light-excluding tents. For each capture trial, 50 laboratory-reared larvae or (for razorback sucker *Xyrauchen texanus* only) 25 juveniles were released into a tank and allowed to acclimate through simulated daylight, dusk, and full darkness before traps were set for 1, 4, or (for razorback sucker larvae only) 8 h. In corresponding retention experiments, fish were placed in trap catch basins and allowed to calm before traps were placed in tanks. Mean capture percentages (MCPs) for larvae in 1 and 4-h trials were 13 to 36% for razorback sucker (33 to 44% in 8-h trials), 3 to 16% for Colorado squawfish *Ptychocheilus lucius*, and 5 to 30% for bonytail *Gila elegans*. MCP usually, but not always, increased with set duration for larvae. For early juvenile razorback sucker, maximum MCP, 51%, occurred within 1 h. Once in the trap, most larvae stayed; mean retention percentages (MRPs) were 85 to 99% for razorback sucker in 1, 4, and 8-h trails, and 95 to 99% for Colorado squawfish larvae in 1 and 4-h trials (bonytail were not tested for retention). Retention of juvenile razorback sucker was notably less with MRPs of 65 to 73%. For fish in close proximity to the trap, these results suggest that the light traps

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[1] This is the combined final report for a series of laboratory light-trap experiments sponsored by the National Park Service in 1993 and 1994 under cooperative CA1268-2-9004 (work orders CSU-21 and CSU-48, respectively): "Efficiency of Light Traps for Capture of Razorback Sucker Larvae," ". . . Early Juvenile Razorback Suckers," ". . . Colorado Squawfish Larvae," and ". . . Bonytail Larvae."

tested are at least moderately effective in clear water for the capture and retention of razorback sucker and bonytail larvae and even better for capture of early juvenile razorback sucker.

Additional experiments were conducted with razorback sucker. With trap lights off, few or no fish were captured and MRPs were lower, strikingly so for protolarvae with only 16% retention in 4-h trials. Light is critical for the effective capture and retention of fish larvae. Under simulated dusk, 1-h MCPs were lower than during night trials, but not significantly different. Setting traps prior to night fall might increase the ultimate number of fish collected but reduce catch per unit time. Under simulated dawn, 1-h MRPs dropped to 69% for protolarvae but remained 99% for postflexion mesolarvae. Traps should probably be retrieved before dawn to avoid significant losses of at least small larvae. In 1-h turbid water trials, MCPs were 2.6 to 2.8 times greater for larvae but 70% less for juveniles in 50 to 75 FTU water than in clear water. For fish in close proximity to the trap, effectiveness significantly increases for larvae in turbid water but decreases for early juveniles. Although maximum body width of the larger postflexion mesolarvae approximated 2 mm, MCP and MRP for those larvae did not change significantly when 4-mm slit traps were used instead of 2-mm traps. However early juveniles were unable to enter 2 mm traps. Maximum total length for capture of razorback sucker by 2-mm-slit traps is between 20 and 27 mm. MCP for postflexion mesolarvae did not change significantly when tested in a comparable trap with 300 times greater light intensity at trap perimeter. MCPs for early juveniles dropped by over two-thirds to 19% in trials using a larger three-lobed light trap with comparable low-light intensity and to just 8% with 500 times greater light intensity. Dramatically increasing trap light intensity did not affect the capture of postflexion mesolarvae but significantly reduced the catch of early juveniles. Differences in trap design can affect the number of early juveniles captured.

Introduction

Light traps have been reported to be effective for capturing positively phototactic larvae and early juveniles of many marine and freshwater fishes (e.g., Faber 1982, Floyd et al. 1984b, Muth and Haynes 1984, Gregory and Powles 1985, Doherty 1987, Gehrke 1994, Kelso and Rutherford 1996). Fortunately, positive phototaxis at night or in dark environments appears to be characteristic of larvae beyond just-hatched stages and early juveniles for most freshwater fishes. Captured specimens are usually alive and in good condition unless predators are also collected or anoxic conditions develop in overcrowded traps deployed for too long a period of time (R. T. Muth, personal communication[2]). Fish or other organisms larger than desired can be excluded from collections by using light traps with sufficiently narrow entry slits. Light traps are most appropriate for night-time sampling in habitats with very little to no current (except in some marine investigations), often including habitats difficult to sample by other means. Most light traps are relatively easy to use, although night-time setting and retrieval of traps can be hazardous and inconvenient.

In the Lower Colorado River Basin, razorback sucker *Xyrauchen texanus*, a federally endangered species, has been observed to spawn and successfully produce larvae near shore in Lake Mohave, but with rare exceptions, researchers have been unable to document natural survival beyond the first several weeks of life (Bozek et al. 1984, Bestgen 1990). Predation, particularly by introduced fishes, is strongly suspected as the most likely cause (Minckley et al. 1991). To help circumvent this problem, lower basin researchers have developed a successful program of attracting wild razorback sucker larvae to submerged white lights, capturing them with large dip nets, stocking them in rearing enclosures, and subsequently releasing them back to the lake at much larger sizes less vulnerable to predation (Burke 1995). Mueller et al. (1993) modified and experimented with a quatrefoil-style light trap for collecting razorback sucker larvae but found that although the traps might be useful for assessing relative abundance and thereby spawning success, they captured too few larvae to supplant collection by submerged light and dip nets for the rear-and-release program.

In the Upper Colorado River Basin (UCRB), razorback sucker populations also continue to decline and show very little evidence of recruitment. The first evidence of successful reproduction in the upper basin in recent decades was the collection of razorback sucker larvae in 1984 by fine-mesh seine in the middle Green River, Utah, below suspected spawning grounds (Tyus 1987). In 1992, researchers began a concerted drift-net and fine-mesh seine collection program for razorback sucker larvae below one of these spawning grounds and confirmed successful reproduction (Muth 1995). With that confirmation, UCRB researchers planned and implemented expanded investigations of razorback sucker production including experimental use of light traps. If light traps proved sufficiently successful for capture of razorback sucker larvae in quiet nearshore and backwater habitats of the upper basin, researchers planned to use them along with other gear to: (1) monitor reproductive success, (2) assess downstream transport, (3) identify nursery backwaters, (4) verify utilization of restored floodplain habitats, and (5) otherwise document spatial and temporal distribution. If enough wild razorback sucker

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[2] U.S. Fish and Wildlife Service; 145E, 1300S; Suite 404, Lincoln Plaza; Salt Lake City, Utah 84115.

larvae could be collected and effectively separated alive from the larvae of other fishes, light-trap collections might be used to stock enclosures or ponds for a trial rear-and-release program similar to that in the lower basin. If larvae of other species of concern including the federally endangered Colorado squawfish *Ptychocheilus lucius*, humpback chub *Gila cypha*, and bonytail *Gila elegans* are sufficiently susceptible, light traps might be similarly incorporated in associated investigations and monitoring programs.

In preparation for initial field investigations by the National Park Service (NPS) and participants in the Colorado River Fishes Recovery Program (CRFRP) in 1993, the NPS Cooperative Parks Study Unit asked the Larval Fish Laboratory to investigate the various types of light traps available and recommend a design and source. The earliest light traps reported for capturing larval and early juvenile fishes in North America were adaptations of cylindrical, wire-screen, minnow traps (Paulson and Espinosa 1975; Kindschi et al. 1979) and a rectangular Plexiglas trap with inward, wedge-shaped entry ports on each side (Faber 1981, 1982). We focused our attention on variations of a design we believe to be more effective, the Quatrefoil Light Trap initially designed and used by Floyd et al. (1984a). The basic design is that of four clear-plastic, cylinders with about a quarter of their circumference removed, arranged between flat top and bottom plates in a four-lobed pattern so as to provide four full-height, smoothly funneling entry slits to the middle enclosure (Figure 1). The original design features a central, full-height, spiral-scored light rod; a lamp housed in a metal tube fitted to the top of the light rod; a 3-volt battery pack (two D-cell flashlight batteries), which is suspended above the water from the same support as the trap (e.g., tripod or overhanging limb); and a convenient stainless-steel "mixing bowl" catch basin with screened bottom.

The version of Quatrefoil Light Trap we finally recommended for use by UCRB researchers is commercially produced by Southern Concepts. The trap is compact, 32-cm tall by 24-cm in diameter, and constructed of plexiglass with a four-lobe assembly 14 cm tall and 19 cm in overall diameter (Figure 1). It features a 5-cm thick styrofoam top to float the trap and anchor tabs extending 4 cm from top and bottom plates with holes to allow the trap to slide up and down a vertical rod planted in shallow water or to be tied to an anchor or nearby structure in deeper water. Like the original quatrefoil trap this unit has a central, spiral-scored light rod and integrated lamp and power supply (two D-cell batteries in series). However, this version has the battery holder attached to the top of the trap and uses a lens-focusing lamp positioned immediately above the light rod. It also has a unique voltage-limiting circuit (2 volt) that provides a constant intensity of about 2 lux of warm, white light to the perimeter of the trap and about 0.1 lux at a distance of 0.5 m from it's center (measurements in air). The voltage-limiting circuit also extends useful life of a pair of alkaline batteries to about 40 h of constant-intensity illumination. Traps can be ordered with entry slits widths specified by the customer (e.g., 2, 4, or 6 mm). At our request, the easily removed catch basin was modified with a series of fine-mesh, Nitex-screened ports on one side rather than the bottom to allow a pool of water to be retained in the basin for holding live larvae after trap retrieval. Current refinements of the trap are advertised as the *Edlite* and sell for over $300.

Our primary concern about use of the Southern Concepts Trap was that output light intensity might not be enough to attract razorback sucker larvae. However, the

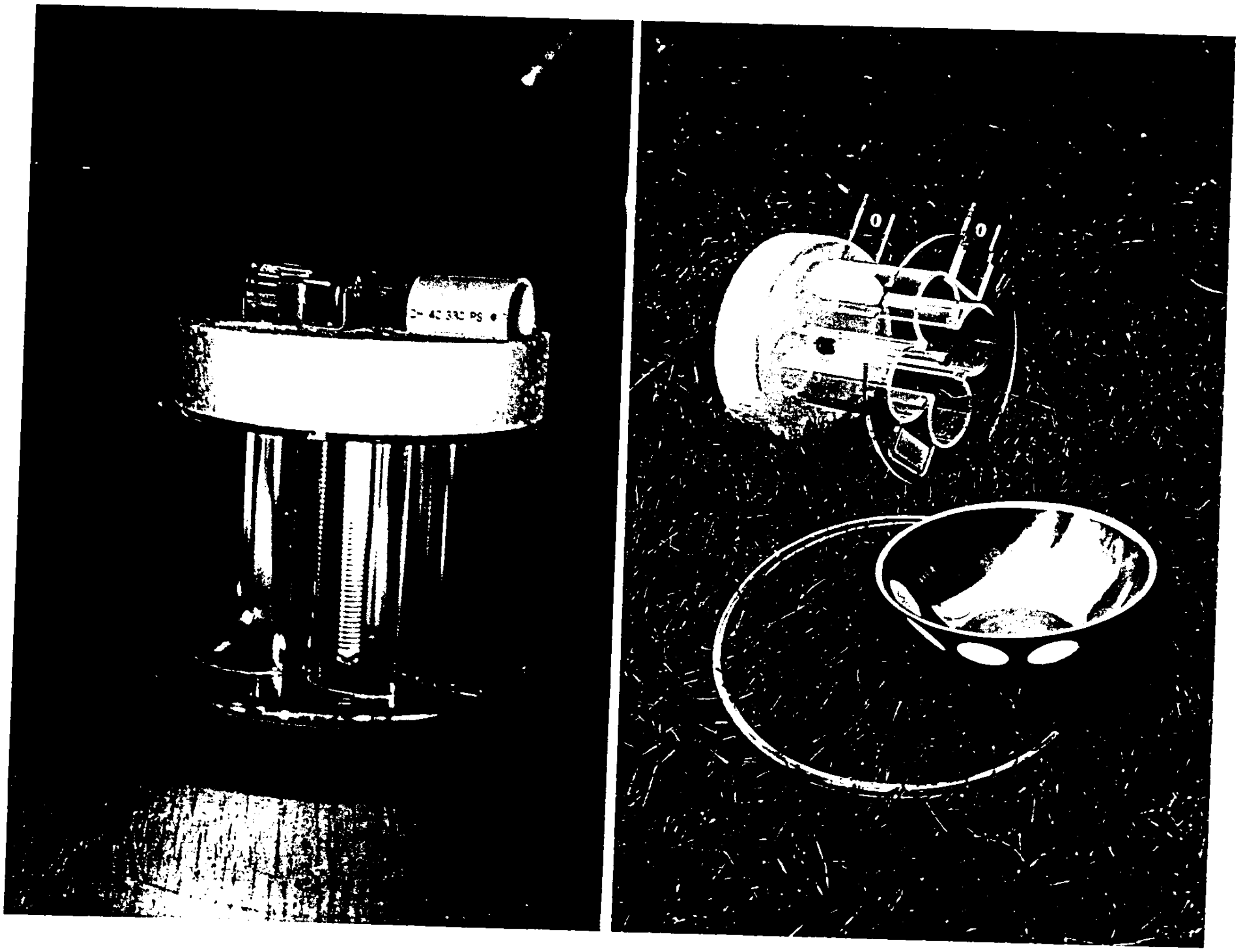


FIGURE 1.–Low-light intensity quatrefoil-type light trap produced by Southern Concepts of Birmingham, Alabama, and used for all but alternative trap and high-light-intensity experiments; assembled on left, catch basin removed on right.

biologist who designed and manufactures the trap, E. Tyberghein (personal communication[2]), assured us that the light intensity is adequate to attract and collect large numbers of fish larvae representing a very wide variety of species including catostomids. In his investigations, he had found the light traps more effective than alternative collection techniques for fish larvae and has been using them exclusively for nearshore and backwater sampling. When set in moderately turbid waters (e.g., ~0.5 m secchi-disk readings), he reports easily seeing the glow of the traps from shore as much as 15 m away (we've observed likewise in the field). He also noted that doubling intensity would not double the range of visibility in very turbid waters and that too much intensity might repel some larvae when they get close to the trap.

Objectives

As we and other researchers prepared to use the traps in the field in spring 1993, we felt a need for controlled experiments to assess capture and retention efficiencies for razorback sucker larvae relative to: (1) set duration, (2) dusk and dawn, (3) water turbidity, and (4) trap characteristics. In addition, we expected the results of these experiments to be useful in developing guidelines for optimizing use of the traps and interpreting field results. In spring 1994, we repeated some capture and retention efficiency experiments with early juvenile razorback sucker and larval Colorado squawfish and bonytail to assess effectiveness of the traps for collection of somewhat older razorback sucker and larvae of other endangered species.

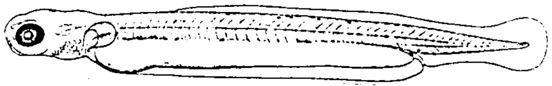
Methods

The larval and early juvenile fish tested were reared and the experiments conducted in the indoor facilities of Colorado State University's Aquatic Research Laboratory. Fertilized eggs for each species were obtained from Dexter National Fish Hatchery and Technology Center in New Mexico. The fish were reared under a diel cycle of artificial lighting at a relatively constant water temperature of 18°C. Larvae were fed brine shrimp nauplii initially and later switched to dry food. In spring 1993, we tested razorback sucker as 10 to 11-mm-TL (total length) protolarvae (swimup, just beginning to feed), 12 to 13-mm flexion mesolarvae, and 15 to 20-mm postflexion mesolarvae and metalarvae (for convenience, hereafter often referred to only as postflexion mesolarvae) (Figure 2). In spring 1994, we tested 27 to 35-mm early-juvenile razorback sucker and 8 to 9-mm protolarvae and 11 to 13-mm postflexion mesolarvae of both Colorado squawfish and bonytail.

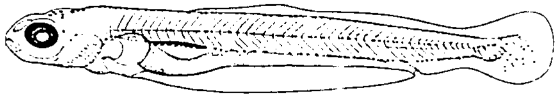
Experiments were conducted in 1.2-m-diameter, green, fiber-glass tanks. Each tank was covered by a light-excluding tent of black plastic. A dimmer-controlled flood lamp a meter above one side of each tank was used to simulate daylight, dusk, and dawn inside the tent (Figure 3). Water in each tank was maintained at a depth of 45-cm and a temperature of 18 to 20°C. Except for light-intensity, slit-width, and alternative-trap-design trials, all experiments utilized Southern Concepts Traps (Figure 1) with 2-mm slits for larval-fish trials or 6-mm slits for early juvenile trials.

Most experiments consisted of treatments with triplicate trials. Fifty larvae or 25 early juveniles were used for each capture ordesired set period for each trial, the trap was retrieved by slowly lifting it from the water, the catch basin was removed, and the fish captured or retained in the trap were anesthetized with an

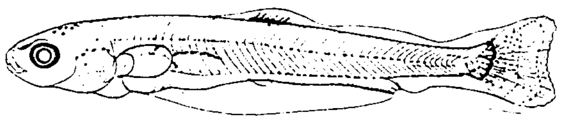
DEVELOPMENTAL INTERVALS TESTED
Xyrauchen texanus



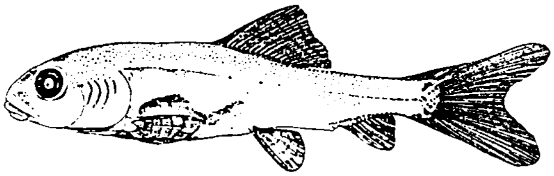
Late Protolarvae, 10-11 mm TL



Flexion Mesolarvae, 12-13 mm TL



Postflexion Mesolarvae, 15-20 mm TL



Early Juveniles, 27-35 mm TL

FIGURE 2.–Developmental intervals of razorback sucker used in light-trap experiments.

FIGURE 3.–Experimental set up with light trap secured in the middle of a 1.2 m diameter tank under a light excluding tent.

overdose of tricaine methanesulfonate, counted, and preserved in formalin. All fish that remained in or escaped to the tanks were netted and similarly anesthetized, counted, and preserved. If any fish could not be recovered, the experimental tank was drained and refilled prior to the next trial. No fish were used for more than one trial.

Data were recorded as percentage captured or retained and tabulated with treatment means and 95% confidence intervals. Differences between specific means are considered statistically significant (α = 0.05) if their associated confidence intervals do not overlap. Statistical significance among comparable means was also assessed by analysis of variance (ANOVA) using arcsine-transformed data. If a significant difference in multiple comparisons was detected, the Student-Newman-Keuls range test was used to confirm which means are significantly different.

Capture and Retention by Set Duration

For simulated-night (full darkness) capture experiments, we released fish into a circular tank and allowed them to acclimate under successive 0.5-h periods of simulated daylight (floodlamp fully on), dusk (gradual dimming of floodlamp to full darkness), and full darkness. A trap was then secured in the middle of the tank and it's lamp switched on for a set period of 1 h (all species and tested developmental intervals), 4 h (all except razorback sucker flexion mesolarvae), or 8 h (razorback sucker protolarvae and postflexion mesolarvae only).

For simulated-night retention experiments, the fish were placed in a pool of water in the bottom of a light-trap catch basin and the basin was reattached to the trap. After allowing time for the fish to calm, the trap was secured in the middle of a tank, and its lamp switched on for a period of 1 h (all but razorback sucker flexion mesolarvae and bonytail), 4 h (same), or 8 h (razorback sucker protolarvae and postflexion mesolarvae only).

Several supplemental experiments with razorback sucker were run with the trap light off. These experiments included both capture (single 1-h trial with flexion mesolarvae, triplicate 1-h trials with early juveniles, and single 8-hr trial with postflexion mesolarvae) and retention (triplicate 4-h trials with protolarvae and postflexion mesolarvae, and single 1-h and 4-h trials with early juveniles).

Dusk, Dawn, and Daylight Experiments

Simulated dusk-capture and dawn-retention experiments were conducted only with razorback sucker. For simulated-dusk capture trials, protolarvae or postflexion mesolarvae were acclimated to 0.5 h daylight before a trap was set in the tank for a period of 0.5 h daylight plus 0.5 h gradual dimming to full darkness (1 h sets). For simulated-dawn retention trials postflexion mesolarvae were allowed to calm in a trap before it was set in a tank for a period of 0.5 h gradual brightening to full daylight followed by 0.5 h of daylight.

Two single 1-h trials were run under simulated daylight with early juvenile razorback sucker. One was a capture trial the trap light off and the other retention trial with the trap light on.

Turbid-Water Experiments

For turbid-water trials, which were conducted only with razorback sucker, bentonite clay suspensions were maintained at 50 to 75 FTU (Formazin Turbidity Units) for flexion mesolarvae, postflexion mesolarvae, and early juveniles, and 20 to 30 FTU for

TABLE 1.–Comparative summary of selected features and specification of light traps used for light-intensity, entry slit-width, and trap design experiments.

Trap (source):	Mueller	Southern Concepts			Jennings (prototype)	
Basic Design:	Quatrefoil	Quatrefoil			Trefoil	
Total height:	22 cm	30 cm			50 cm	
Total diameter:	35 cm	25 cm			41 cm	
Tube/slit height:	20 cm	14 cm			21 cm	
Catch container:	Basin[a]	Basin with screened windows			Screw-on bottle	
Lamp/power:[b]	7-W bulb 120-V	2.25-V bulb, 2 D-cells in series, constant-intensity (voltage-limiting) circuit			2.25-V bulb, etc.	6-W bulb 120-V line
Light distribution:[b]	Lamp in jar	Threaded plastic light rod down middle			Light rod	Lamp in jar
Light intensity:	High	Very low			Very low	High
at perimeter:	300 lux	2 lux			0.5 lux	160 lux
0.5 m from center:	30 lux	0.1 lux			0.1 lux	50 lux
1 m from center:		0.05 lux			0.05 lux	15 lux
Entry slit width:	10 mm	2 mm [c]	4 mm	6 mm[c]	6-8 mm	6-8 mm

[a] Design lacks catch container; attached catch basin from Southern Concepts Trap for this experiment.

[b] Mueller and Jennings Traps lack built-in lamps and power supplies–110-V lamps were sealed in jars and suspended in middle of trap for high light-intensity experiments; Southern Concepts Trap lamp, rod, and power supply were adapted to the Jennings trap for low light-intensity comparison.

[c] Standard traps for all other experiments with larvae (2-mm slit width) and juveniles (6-mm slit width).

single trials with flexion mesolarvae and early juveniles. The higher turbidity levels were maintained by bubbling air from the bottom of the tanks.

Alternative Light-Intensity, Entry Slit-Width, and Trap-Design Experiments

Light-intensity, entry slit-width, and alternative-trap experiments were conducted only with razorback sucker in 1-h trials using: (1) a Southern Concepts Trap with 4-mm slits (capture and retention, postflexion mesolarvae), (2) a Southern Concepts Trap with 2-mm slits (single capture trial, early juveniles), (3) a slightly larger, non-commercial, quatrefoil-type trap used in the Lower Colorado River Basin by Mueller et al. (1993) and hereafter referred to as the Mueller Trap (capture, postflexion mesolarvae), and (4) a larger prototype light trap designed and constructed for juvenile fish by D. Jennings[3] and hereafter referred to as the Jennings Trap (capture trials with early juveniles). Light intensity for all traps was measured in air at the perimeter of the trap and 0.5 and 1.0 m from the trap's center using a Science and Mechanics Darkroom Model A-3 Photo Meter. Selected features and specifications for the traps used in these experiments are compared and summarized in Table 1.

The Mueller Trap is essentially the simplified quatrefoil-type trap illustrated by Killgore (1991) but modified with 10-mm slits, removable floats under the corners of top plate, and top and bottom plates painted black to block upward and downward directed light. Unlike Southern Concepts Traps, the Mueller Trap lacks a light rod, integrated lamp and power supply, and collection container. Chemical light sticks or other sources of illumination are usually suspended through a

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[3] U.S. Fish and Wildlife Service, Denver, Colorado

stoppered hole in the top plate. For our experiment with the trap (high light intensity only), we sealed a 7-W lamp in a small jar, suspended it in the middle of the trap, and connected it to a 120-V electrical outlet. Because the Mueller Trap lacks a catch container, we removed the stopper from the center of the bottom plate (floor) and clipped on the catch basin from a Southern Concepts Trap.

The Jennings Trap is a floating "trefoil" (three-lobe) design with adjustable slits, a catch bottle connected to a hole in the middle of the bottom plate and the light rod, lamp, and power supply adapted from a Southern Concepts Trap. For our experiments with the trap, entry slits were adjusted to 6 to 8 mm. Trials were run using both the low-intensity Southern Concepts Trap lighting and a substituted high-intensity arrangement similar to that devised for the Mueller Trap but with a 6-W lamp. The low-intensity version of this trap produced in the same light intensity as that of Southern Concepts Traps except at trap perimeter where, due to the Jennings Trap's greater diameter, intensity was just 0.5 lux.

To prevent larvae from draining back out the slits as we slowly lifted Mueller and Jennings Traps from the water, we first sealed their entry slits with strips of plastic foam. After retrieval, we carefully scanned the inside floor of the traps and foam strips for stranded fish that had not drained into the catch containers. Sealing the entry slits was considered unnecessary with Southern Concepts Traps because the entire inside portion of the bottom plate (floor) is cut-away and opens directly to the catchment basin. However, the screened ports on the sides of the catch basin significantly limit the rate of drainage through the catch basin and Southern Concepts Traps also had to lifted very slowly from the water.

Results

Night-time Capture Relative to Set Duration

Under our test conditions, all tested life stages of razorback sucker were at least moderately susceptible to capture by Southern Concepts Traps (Table 2). Mean capture percentages (MCPs) ranged from 13 to 44% for larvae and 47 to 51% for early juveniles. For protolarvae, MCP increased progressively with set duration from 18% (1 h sets) to 44% (8-h sets), although the difference between means for 1-h and 4-h sets was not significant. For postflexion mesolarvae MCP increased only between 1 and 4-h sets and for early juveniles there was no difference between 1 and 4-h MCPs (no 8-h sets). Interestingly, 1-h MCP was notably, but not quite significantly, greater for flexion mesolarvae (27%) than either earlier or later larvae. Unfortunately, flexion mesolarvae were not tested for longer sets.

For comparable developmental intervals (protolarvae and postflexion mesolarvae) and set durations (1 and 4-h), razorback sucker and bonytail larvae were very similar in their susceptibility to capture by light traps, whereas Colorado squawfish larvae were generally less susceptible (Table 2). For Colorado squawfish postflexion mesolarvae, the 4-h MCP (3%) was particularly notable as the lowest MCP recorded for full-darkness capture experiments with the trap light switched on, regardless of species, developmental interval, or set duration and including their own 1-h MCP (8%).

Illumination from the trap is critical for captures. Capture percentages for various developmental intervals of razorback sucker ranged from 0 to 4% in several trials run with the trap light switched off (Table 2).

TABLE 2.–Capture by light traps relative to set duration. Percentages of 50 larval razorback sucker, Colorado squawfish, or bonytail or 25 juvenile razorback sucker captured per 1, 4, or 8-h trial by floating, low-light-intensity, quatrefoil-style traps (Southern Concepts; 2-mm entry slits for larvae, 6-mm for juveniles) in clear water in 1.2-m diameter tanks under light-excluding tents; three trials per treatment. Differences between specific means are statistically significant if their associated 95% confidence intervals (CI) do not overlap.

Developmental Interval	Duration of Trap Sets		
	1 hour	4 hours	8 hours
	Razorback sucker		
Protolarvae (10-11 mm TL)			
Mean (CI):	18 (11-25)	25 (18-32)	44 (33-55)
Ordered data:	14 18 22	22 22 30	36 38 58
Flexion mesolarvae (12-13 mm TL)			
Mean (CI):	27 (21-34)		
Ordered data:	24 26 32		
Postflexion mesolarvae[a] (15-20 mm TL)			
Mean (CI):	13 (5-22)	36 (29-43)	33 (23-43)
Ordered data:	6 14 20	32 34 42	26 28 44
Early juveniles (27-35 mm TL)			
Mean (CI):	51 (40-62)	47 (39-54)	
Ordered data:	44 44 64	40 48 52	
	Colorado squawfish		
Protolarvae (8-9 mm TL)			
Mean (CI):	7 (1-14)	16 (6-26)	
Ordered data:	4 6 12	6 18 24	
Postflexion mesolarvae (11-13 mm TL)			
Mean (CI):	8 (1-15)	3 (0-9)	
Ordered data:	4 8 12	2 2 6	
	Bonytail		
Protolarvae (8-9 mm TL)			
Mean (CI):	23 (14-32)	23 (17-29)	
Ordered data:	14 24 30	20 24 26	
Postflexion mesolarvae (11-13 mm TL)			
Mean (CI):	5 (0-13)	30 (20-40)	
Ordered data:	0 6 10	22 26 42	
	Razorback sucker with trap lights off		
Flexion mesolarvae (12-13 mm TL)			
Single trial:	0		
Postflexion mesolarvae[a] (15-20 mm TL)			
Single trial:			4
Early juveniles (27-35 mm TL)			
Mean (CI):	3 (0-8)		
Ordered data:	0 4 4		

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[a] Also recently transformed metalarvae

TABLE 3.–Retention by light traps relative to set duration. Percentages of 50 larval razorback sucker or Colorado squawfish or 25 juvenile razorback sucker retained per 1, 4, or 8-h trial by floating, low-light-intensity, quatrefoil-style traps (Southern Concepts; 2-mm entry slits for larvae, 6-mm for juveniles) in clear water in 1.2-m diameter tanks under light-excluding tents; three trials per treatment. Differences between specific means are statistically significant if their associated 95% confidence intervals (CI) do not overlap.

Developmental Interval	Duration of Trap Sets								
	1 hour			4 hours			8 hours		
	Razorback sucker								
Protolarvae (10-11 mm TL)									
Mean (CI):	85	(77-92)		81	(69-92)		93	(85-100)	
Ordered data:	80	84	90	68	82	92	86	96	98
Postflexion mesolarvae[a] (15-20 mm TL)									
Mean (CI):	99	(94-100)		97	(92-100)		99	(94-100)	
Ordered data:	98	100	100	96	96	98	98	100	100
Early juveniles (27-35 mm TL)									
Mean (CI):	73	(63-83)		65	(55-75)				
Ordered data:	64	72	84	56	64	76			
	Colorado squawfish								
Protolarvae (8-9 mm TL)									
Mean (CI):	96	(89-100)		95	(89-100)				
Ordered data:	92	96	100	92	96	96			
Postflexion mesolarvae (11-13 mm TL)									
Mean (CI):	98	(93-100)		99	(94-100)				
Ordered data:	96	98	100	98	100	100			
	Razorback sucker with trap lights off								
Protolarvae (10-11 mm TL)									
Mean (CI):				16	(6-26)				
Ordered data:				8	12	28			
Postflexion mesolarvae[a] (15-20 mm TL)									
Mean (CI):				84	(71-97)				
Ordered data:				72	80	100			
Early juveniles (27-35 mm TL)									
Single trials:	68			40					

[a] Also recently transformed metalarvae

Night-time Retention Relative to Set Duration

The number of fish collected by a light trap depends not only on the number of fish entering the trap but also how many find their way back out. Retention was good for razorback sucker larvae through 8 h, but only fair for early juveniles, even after 1 h (Table 3). Mean retention percentages (MRPs) ranged from 81 to 93% for protolarvae and even better, 97 to 99%, for postflexion mesolarvae (means are significantly different for 1 and 4-h sets but not 8-h sets–the comparison between 4-h means is significant based on ANOVA and Student-Newman-Keuls range test criteria but not on confidence intervals). MRPs were significantly lower, 65 to 73%, for early juveniles (1 and 4 h sets only). Within each developmental interval tested, there were no significant differences

TABLE 4.–Capture by light traps relative to water turbidity. Percentage of 50 larval or 25 juvenile razorback sucker captured per 1-hour trial by floating, low-light-intensity, quatrefoil-style traps (Southern Concepts; 2-mm entry slits for larvae, 6-mm for juveniles) in clear or turbid water in 1.2-m diameter tanks under light-excluding tents; three trials per treatment. Differences between specific means are statistically significant if their associated 95% confidence intervals (CI) do not overlap.

	Water Turbidty						
Developmental Interval	Clear			50-75 FTU			20-30 FTU
Flexion mesolarvae (12-13 mm TL)							
Mean (CI):	27	(21-34)		71	(65-78)		48[b]
Ordered data:	24	26	32	68	70	76	48
Postflexion mesolarvae[a] (15-20 mm TL)							
Mean (CI):	13	(5-22)		36	(20-52)		
Ordered data:	6	14	20	24	24	60	
Early juveniles (27-35 mm TL)							
Mean (CI):	51	(40-62)		15	(7-22)		12[b]
Ordered data:	44	44	64	8	16	20	12

[a] Also recently transformed metalarvae.
[b] Single trial

among the means with respect to set duration.

Comparable sets of 1 and 4-h trials for Colorado squawfish larvae revealed that retention was as good or better than that for razorback sucker (Table 3). MRP was 95 to 96% for protolarvae and 98 to 99% for postflexion mesolarvae. No retention trials were conducted for bonytail.

In a limited set of razorback sucker trials with trap lights off, we found light was also critical for retaining protolarvae and at least helpful in retaining older fish (Table 3). MRP for protolarvae dropped from 81% for 4-h trials with the trap lamp switched on to 16% for a comparable set of 4-h trials with the trap lamp switched off. In a similar comparison for postflexion mesolarvae, MRP dropped from 97% with light to 84% without light, but the difference was not quite statistically significant. For early juveniles, single 1-h and 4-h trials conducted without light resulted in 68% and 40% retention, respectively, as compared with ranges of 64 to 84% and 56 to 76%, respectively, for trials with light.

Night-time Capture in Turbid Water

All other experiments in this investigation were conducted in clear water, but in the field, waters are often quite turbid. Based on 1-h trials, razorback sucker mesolarvae were nearly three times more susceptible to light traps set in moderately turbid water than in clear water (Table 4). For flexion mesolarvae, MCP increased from 27% in clear water to 71% in bentonite clay suspensions of 50 to 75 FTU. For postflexion mesolarvae, MCP increased from 13% in clear water to 36% in 50-to-75-FTU water.

In contrast to the larvae, early juvenile razorback sucker were much less susceptible to traps in turbid water. MCP dropped by more than two-thirds from 51% in clear water to 15% in 50-to-75-FTU water.

Single trials were conducted with razorback sucker flexion mesolarvae and early juveniles in water of intermediate turbidity, 20 to 30 FTU (Table 4). Percent capture was 48% for the mesolarvae, precisely intermediate

TABLE 5.–Capture and retention by light traps relative to skylight. Percentage of 50 larval or 25 juvenile razorback sucker captured or retained per 1-hour trial by floating, low-light-intensity, quatrefoil-style traps (Southern Concepts; 2-mm entry slits for larvae, 6-mm for juveniles) in clear water in 1.2-m diameter tanks under light-excluding tents; three trials per treatment. Dusk capture trials were conducted under 0.5 hour of full daylight simulated by a 150 W floodlamp and 0.5 hour of gradual dimming to full darkness; sequence was reversed for dawn retention trials. Differences between specific means are statistically significant if their associated 95% confidence intervals (CI) do not overlap.

	Simulated Skylight Conditions		
Developmental Interval	Night	Dusk/Dawn	Daylight
	Capture (dusk or daylight)		
Protolarvae (10-11 mm TL)			
Mean (CI):	18 (11-25)	13 (7-19)	
Ordered data:	14 18 22	10 12 16	
Postflexion mesolarvae[a] (15-20 mm TL)			
Mean (CI):	13 (5-22)	5 (0-12)	
Ordered data:	6 14 20	0 4 10	
Early juveniles (27-35 mm TL)			
Mean (CI):	51 (40-62)		8[b]
Ordered data:	44 44 64		8
	Retention (dawn or daylight)		
Protolarvae (10-11 mm TL)			
Mean (CI):	85 (77-92)	69 (64-74)	
Ordered data:	80 84 90	68 68 70	
Postflexion mesolarvae[a] (15-20 mm TL)			
Mean (CI):	99 (94-100)	99 (93-100)	
Ordered data:	98 100 100	96 100 100	
Early juveniles (27-35 mm TL)			
Mean (CI):	73 (63-83)		68[b]
Ordered data:	64 72 84		68

[a] Also recently transformed metalarvae.

[b] Single trial

between MCPs for clear and 50-to-75-FTU water. Percent capture for early juveniles, 12%, was similar to the MCP for 50-to-75-FTU trials and likewise much lower than the MCP for comparable clear water trials.

Dusk Capture, Dawn Retention, and Daylight

Dusk capture and dawn retention experiments were conducted for both razorback sucker protolarvae and postflexion mesolarvae. MCPs for simulated 1-h daylight through dusk trials with razorback sucker, 13% for protolarvae and 5% for postflexion mesolarvae, were lower, but not significantly less than for comparable 1-h night-time captures (18% and 13% respectively; Table 5). MRP was significantly lower for protolarvae in 1-h simulated dawn through daylight trials (69%) than for night-time retention trials (85%) but remained the same for postflexion mesolarvae (99%).

For early juvenile razorback sucker, we ran a single 1-h, simulated-daylight capture trial

TABLE 6.–Capture and retention by light traps relative to trap design, slit width, and light intensity. Percentage of 50 larval or 25 juvenile razorback sucker captured or retained per 1-hour trial by floating traps in clear water in 1.2-m diameter tanks under light-excluding tents; three trials per treatment. Differences between specific means are statistically significant if their associated 95% confidence intervals (CI) do not overlap. See Table 1 for comparative summary of trap features and specifications.

Trap (source):	Mueller	Southern Concepts			Jennings	
Basic Design:	Quatrefoil	Quatrefoil			Trefoil	
Light intensity:	High	Very low			Very low	High
Entry slit width:	10 mm	2 mm [a]	4 mm	6 mm[a]	6-8 mm	6-8 mm
			Capture			
Postflexion mesolarvae[b]						
Mean (CI):	10 (3-17)	13 (5-22)	15 (5-24)			
Ordered data:	6 10 14	6 14 20	6 14 24			
Early juveniles (27-35 mm TL)						
Mean (CI):		0[c]		51 (40-62)	19 (12-26)	8 (1-15)
Ordered data:		0		44 44 64	16 16 24	4 8 12
			Retention			
Postflexion mesolarvae[b]						
Mean (CI):		99 (94-100)	93 (86-100)			
Ordered data:		98 100 100	90 90 100			

[a] Standard traps for all other experiments with larvae (2-mm slit width) and juveniles (6-mm slit width).
[b] 15-20 mm TL; also recently transformed metalarvae.
[c] Single trial.

with the trap light off and a single 1-h, daylight retention trial with the light on. Daylight capture percentage with trap light off was just 8% as compared with MCPs of 51% at night with trap light on and 3% at night with the trap light off (Tables 2 and 5). In contrast to daylight capture, daylight retention with trap light on, 68%, was similar to MRPs for night retention trials with the light on (73% for 1-h and 65% for 4-h trials) and matched the retention percentage for a single 1-h night retention trial with the light off (Tables 2 and 5).

Light-Intensity, Slit-Width, and Trap-Design

To address our concern about the low light intensity of the Southern Concepts, we conducted a set of high-intensity trials for razorback sucker postflexion mesolarvae using the high-intensity Mueller Trap (Table 1). Despite a light intensity 150 times greater than that of the Southern Concepts Trap at trap perimeter, the MCPs for razorback sucker postflexion mesolarvae using the high-intensity Mueller Trap (10%) and the low-intensity Southern Concepts Traps (13 and 15%) were nearly the same (Table 6).

We also conducted two sets of trials for early juveniles using both low-intensity and high-intensity versions of the prototype Jennings Trap (Table 1). Light intensity at trap perimeter for the high intensity version was 320 times greater than for the low-intensity version. The MCP for the high-intensity configuration of the Jennings Trap, 8%, was less than half the MCP for the low-intensity version of the same trap, 19%, but the means were not statistically different (Table 6).

Postflexion mesolarvae (and early metalarvae) of razorback sucker were large enough to approach, and sometimes exceed, the size limit for passage through the 2-mm slits of Southern Concepts Traps used for most other experiments. To determine whether slit width affected the MCP or MRP for these fish, we conducted a corresponding set of 1-h, night-time trials with a 4-mm slit trap (Table 6). The MCP, 15%, was not significantly different from that for the same trap with 2-mm slits (13%); nor did either MCP differ significantly from that for the high-intensity Mueller trap which had 10-mm slits. The 93% MRP for the 4-mm trap was lower but not significantly different than the 99% MRP for comparable trials using a 2-mm slit trap.

As a check on the above results with postflexion mesolarvae, we ran a single 1-h night-time trial with early juveniles (27-35 mm TL) using a 2-mm-slit Southern Concepts Trap (Table 6). No fish were captured. The 2-mm slits were too narrow to allow passage.

The Southern Concepts, Mueller, and Jennings Traps are all traps consisting of adjacent, vertical, clear-plastic tubes which smoothly funnel organisms attracted to the inside illumination through narrow but full-height entry slits. However, the two former traps are more similar in that both use four tubes in a quatrefoil pattern whereas the latter uses three tubes in a trefoil pattern. The MCPs for early juvenile trials using both the low-intensity and high-intensity configurations of the 6-to-8-mm-slit Jennings Trap were much lower than the 51% MCP for comparable juvenile fish trials with a 6-mm slit Southern Concepts Trap (Table 6). Irrespective of trap illumination, the prototype Jennings Trap, was much less effective for capturing early juvenile razorback suckers. A low-intensity configuration of the Mueller Trap was not tested, but MCPs for capture of postflexion mesolarvae by the high-intensity configuration of this trap were similar to those for the low-intensity Southern Concepts Traps. If there was a trap design effect between these traps, it was hidden by a confounding interaction with the Mueller Trap's greater light intensity.

Discussion

Capture Effectiveness

Based on our experiments, some but not all razorback sucker larvae and early juveniles that come into close proximity of a light trap are likely to be captured and retained in that trap, probably 15 to 50% depending on life stage and set duration in relatively clear water, and perhaps up to 70% (or more) for larvae in moderately turbid water (Tables 1-3). Bonytail larvae were generally as responsive to light traps as razorback sucker, but Colorado squawfish larvae were generally, and unexpectedly, less susceptible (results for Colorado squawfish should be verified by repeating experiments with another brood of larvae).

Although the effectiveness of light traps for capture of razorback sucker, bonytail, and especially Colorado squawfish larvae confined in close proximity to the trap was much less than hoped for, the results of our experiments (Table 2) are generally comparable to those for somewhat similar experiments reported by others using different species and trap designs. Secor et al. (1992) and Zigler and Dewey (1995) both conducted capture experiments with floating variations of the quatrefoil light trap using Cyalume Lightsticks as the source of illumination. Secor et al., using green or white light sticks, ran a set of three 1-hr trials in tanks larger than ours with 100 8-d-old striped bass *Morone saxatilis* (probably 6 to 7 mm protolarvae or flexion mesolarvae) per tank. The MCP was 30%, a figure comparable to our 1-h results for protolarvae of bonytail and flexion mesolarvae of razorback sucker, but better than for protolarvae of razorback sucker and especially Colorado squawfish (Table 2). In a single 8-h (overnight) trial, Secor et al. captured 57% of the striped bass larvae, a value within the range for our 8-h trials with razorback sucker protolarvae. Zigler and Dewey, using yellow light sticks, conducted three 2-h trials per week for five weeks in a small raceway (2.9 x 0.7 x 0.3 m) stocked with northern pike *Esox lucius* larvae at an initial density of 3,927/m^3. Despite much higher densities of closely confined larvae, their MCPs for trials with protolarvae and mesolarvae (11-20 mm TL) during the first three weeks ranged from about 18 to 37% and were comparable to many of our own results for 1 and 4-h trials with larvae, especially razorback sucker and bonytail (Table 2). However, the MCP for their first week of trials with early juveniles remained in the same range at about 29%, a figure notably less than for our razorback sucker juveniles (although our ranges for individual trials did overlap). In a later week of trials with larger northern pike, MCP dropped to about 8%, probably, as Zigler and Dewey suggested, because many pike had grown too large to slip through the 5-mm slits of their trap.

The size of fish potentially admitted to light traps is limited largely by body width. Based on body-width measurements at the origin of the pectoral fin (Snyder and Muth 1990), and assuming the pectoral fins are folded against the body, 2, 4, and 6-mm entry slits should be able to accommodate razorback sucker larvae up to at least 17, 28, and 40 mm in TL, respectively. Accordingly, we expected the 2-mm slit width of our standard Southern Concepts Traps to make passage into and out of the trap difficult or impossible for at least some postflexion mesolarvae (and early metalarvae) measuring up to 20 mm TL. However, as evidenced by the lack of any significant difference between corresponding MCPs and MRPs for trials with 2 and 4-mm slit traps, and a similar MCP for trials using a Mueller Trap with 10-mm slits, most of these fish were still small enough to slip or squeeze through a 2-mm slit and having considerably wider openings did not encourage significantly more fish to pass in or out of the trap. A single capture trial with early juvenile razorback sucker demonstrated that the size limit for fish passing into a trap with 2-mm slits was less than 27 mm TL.

Light is a critical element in light-trap capture and, especially for smaller larvae, retention. Unlit traps capture very few fish (Table 2, Kindschi et al. 1979, Faber 1982, Secor et al. 1992, Mueller et al. 1993, Gehrke 1994, and Zigler and Dewey 1995). If trap light is extinguished well after sampling has begun, substantial numbers of fish, especially small larvae such as the razorback sucker protolarvae (Table 3), may escape. For early juveniles, however, retention at least during the first hour is similar whether the trap light is on or off. For battery-powered light traps, only batteries certain to last through the sampling period should be used to avoid loss of trap light (for Southern Concepts Traps, useful alkaline-battery life is about 40 hours).

Set Duration

The results of our experiments comparing set durations of 1, 4, and sometimes 8 h, suggest that the response of razorback sucker to light traps tended to stabilize more rapidly as the fish grew and developed (Table 2). For protolarvae, MCP increased significantly between 4 and 8-h trials, whereas for postflexion mesolarvae, it increased significantly between 1 and 4 h, then remained stable through 8-h, and for early juveniles, it appeared to stabilize by the first hour. However, no 8-h trials were conducted with the juveniles to follow the trend beyond 4 h. Except for postflexion mesolarvae of Colorado squawfish, trends for 1 and 4-h MCPs for Colorado squawfish and bonytail were similar to those for corresponding developmental intervals of razorback sucker, but again, 8-h trials were not conducted. These results suggest that in a static setting, an equilibrium develops between the density of fish inside and immediately outside the trap and that the equilibrium varies with species, life stage, and other factors. However, if this were true, we would have expected MRPs in our retention experiments to drop over time to corresponding equilibrium levels. Instead, MRPs remained at the same very high levels for larvae regardless of set duration. Only for early juvenile razorback suckers did MRPs approach MCPs. Perhaps passage through the slits of a trap is a learning experience, and fish, especially larvae, that have first passed through entry slits into a trap, are more likely to find their way back out.

In an open environment, larvae are not confined near the trap as in our experiments, and with time, water currents and fish movement continuously change the number and distribution of fish within the effective range of light traps. Even as fish continue to move into the trap, densities immediately around the trap may be restored or even increase. If a program goal is to capture as many specimens as possible, and we assume an emptied trap will capture more fish per unit time than one partially full prior to the ensuing portion of the sampling period, periodically retrieved overnight sets will be most effective. Also, if light traps are likely to capture moderate to large numbers of organisms in short periods of time, or even a few voracious predators (e.g., odonate nymphs–Mueller et al. 1993; larger fish), traps should be checked and emptied frequently to avoid anoxic conditions due to overcrowding and minimize predation.

Using simple light traps to collect zooplankton, Ervin and Haines (1972) reported that although catch increased with set duration, the greatest proportion of organisms were caught in the first half hour of sampling (traps were initially deployed 2 h after sunset). Short, consistently deployed sets (perhaps even less than an hour in duration) may be more appropriate than longer sets for indices of relative abundance, assessments of point distribution, and investigations of micro-habitat utilization (e.g., Floyd et al. 1984b, Gregory and Powles 1988). Traps used for such purposes should have comparable light output and differences in developmental-interval susceptibility and water turbidity should be taken into account. However, after 5 years of study on Coosa River, Alabama, E. Tyberghein (personal communication^3) concluded that light traps are good qualitative but poor quantitative tools.

Once the effective range for the various life stages of a target species is known, it might be possible to use light traps to approximate larval or early juvenile fish density or abundance. Secor et al. (1992) noted that depending on night conditions (e.g., moonlight) and water clarity, chemical lightstick traps used in their experiments illuminated radial distances as great as 3 m. Still, we have no idea about the size of a light trap's sphere of influence–the distance from which various fishes and life stages might be attracted towards the glow of a light trap. These and other questions might be at least partially addressed through controlled experiments in large pools or ponds.

Turbid Water

Increases in water turbidity not only reduce the maximum distance from which fish are drawn towards light traps, but also impact the effectiveness of traps for capture of fish in close proximity. Our results suggest that moderate levels of turbidity significantly increase effectiveness of traps for capture of larvae but decrease effectiveness for early juveniles. Differences in water turbidity will confound catch-per-unit effort comparisons. Consistent measures of water turbidity should be recorded for each collection to help interpret and perhaps (based on additional controlled experiments) normalize results.

The nearly three-times greater mean catch of razorback sucker larvae in turbid rather than clear water was particularly unexpected (Table 4). However, the results are supported by field observations of greater catches of fish larvae in Alabama's Tallapoosa River under turbid conditions (E. Tyberghein, personal communication[3]). In the only published account we found of light trap capture experiments in turbid water, Gehrke (1994) reported MCP's considerably lower (up to 12%) than ours for razorback sucker larvae, but experimental conditions (larger tank, much greater density of larvae, 12-h overnight sets, simultaneous sampling with multiple traps in the same tank, no clear-water trials for comparison), trap design (small, acrylic, cylindrical minnow trap with apertures of inward funnel on each end narrowed to 10 cm), trap illumination (12-h Cyalume Lightsticks of different colors), and species (golden perch *Macquaria ambigua*) were all quite different.

The very strong but opposite responses of razorback sucker larvae (nearly 3 times greater MCP) and juveniles (MCP less than a third) to light traps in turbid as compared to clear water (Table 4) might reflect developmental differences in optimal light intensities for phototaxis. Our experiments suggest there may also be another factor impacting effectiveness of light traps for juvenile fish in close proximity to the trap. Additional experiments are needed to confirm and perhaps identify this factor. For larvae, the results might be at least in part an artifact of experimental conditions. In clear water, the tank walls, which were only a little over 0.5 m from the center of the trap, were well-illuminated, and visually limited larvae, unlike early juveniles, may have been just as happy associating or orienting with the tank walls as with the trap, thereby precluding or delaying movement by some larvae towards the trap. In turbid water, tank walls were poorly illuminated and perhaps not readily distinguishable from the turbid water itself; this would have made the trap the only illuminated object for phototactic response or visual orientation.

If this hypothesis is true, surfaces such as banks, rocks, vegetation, or even shallow bottom substrate in relatively clear waters could be well illuminated by a trap light and might provide fish larvae with attractive alternatives to the trap itself. When possible, it might be wise to avoid setting traps immediately adjacent to such structures or at least take this hypothesis into account when evaluating collection results. Field tests of the hypothesis would certainly be warranted. On the other hand, highly structured or well-vegetated environments are often the habitats of interest or the likely location of target fish for light-trap sampling (Gregory and Powles 1985, Zigler and Dewey 1995). Even if the hypothesis is true, fish larvae frequently aggregate in or near such structure or cover and light traps deployed in close vicinity usually yield the greatest catches (R. Muth, personal communication;[2] E. Tyberghein, personal communication[3]).

Dusk, Dawn, and Skylight

It is often convenient and safer to set traps before nightfall and retrieve them after dawn. However, Ervin and Haines (1972) reported that their best results for collection of zooplankton by light traps were obtained beginning 2 h after sunset. Many researchers apparently suspect the same for fish larvae and prefer to wait an hour or two after sunset to deploy traps as well as conclude sampling well before sunrise (e.g., Gregory and Powles 1985; Doherty 1987; Kissick 1993). These measures might be particularly justified if collections are to be compared on a catch-per-unit-effort basis, e.g., number per hour or standardized overnight set.

The MCPs for our dusk capture trials with razorback sucker larvae were lower than for corresponding night-time trials, but not significantly different (Table 5). Secor et al. (1992), using chemical light sticks in quatrefoil-type traps in hatchery ponds, recorded their smallest average catch for 1-h collections of 12-d-old striped bass larvae during dusk, but night-time catches three nights before and two nights later were not significantly different. If traps are set before nightfall, researchers should expect some captures before full darkness and take this into account in evaluating results, especially catch-per-unit-effort comparisons.

Our 1-h daylight capture trial with early juveniles (Table 5), those of Paulson and Espinosa (1975) for juveniles, and those of Gehrke (1994) for larvae resulted in very few captures with or without lights switched on. Accordingly, we expect the 0.5-h dusk (dimming to full darkness) portion our trials to be the effective portion of our trials for capture of larvae.

Relative to corresponding night-time trials, dawn retention trials resulted in a significant loss of protolarvae but no change in the extremely high retention of postflexion mesolarvae (Table 5). To avoid potentially significant losses of small fish larvae, traps should be retrieved before dawn.

Apparently even moonlight can affect light-trap captures. Gregory and Powles (1985) reported that sampling during a full moon reduced the number of light-trap captures. Secor et al. (1992) recorded their greatest catches of larvae in total absence of moonlight (new moon).

Light-Intensity

Higher light-trap intensities penetrate water a greater distance from the trap, thereby increasing it's effective range and the potential number of fish attracted to vicinity of the trap. However, for razorback sucker confined close to the trap, our experiments revealed that substantial increases in trap light intensity (e.g., from 2 lux to 160 or 300 lux at trap perimeter in air) decreased MCP slightly for postflexion mesolarvae and by more than half for early juveniles, but the differences between corresponding low and high-intensity MCPs were not significant (Table 6).

These results are contrary to expectations based on light-intensity experiments by others, but perhaps the intensity of our high-intensity traps was simply not high enough. Gehrke (1994), for example, conducted light gradient experiments at initial intensities of 8.3, 83, and 830 lux and found that 10 to 12-d old larvae of golden perch and silver perch *Bidyanus bidyanus* tended to aggregate in the most intense portion of the gradient for each initial intensity level and that for wavelengths of 496 and 601 nm the response was increasingly stronger at the higher intensity levels. Bulkowski and Meade (1983) conducted light intensity preference experiments (2, 4, 7, 13, 34, and 7,800 lux) with walleye *Stizostedion vitreum* larvae and early juveniles. Larvae 1 to 3 weeks old (9-12 mm TL) showed a marked preference only for the extreme brightest light (27-52%) versus a more-or-less even distribution of less than 10% under each much lower light intensities. Larvae and early juveniles 4 to 7 weeks old (15-30 mm) still showed a preference for the brightest light but the strength of the response dropped considerably (13-16%).

Mueller et al. (1993) compared overnight field capture rates of razorback sucker larvae for Mueller Traps illuminated by green Cyalume Lightsticks (initial intensity of 11 lux at 20 cm, but rapidly decreasing with time) versus similar traps illuminated by 200 and 400 times brighter white light from 12 and 55-W bulbs (2,100 and 4,500 lux at 20 cm, respectively). A subsample of the larvae measured 10 to 13 mm TL. Mean capture rates were 70 to 200 times greater for traps with the 12 and 55-W bulbs than those with light sticks–3, 6, and 0.03 larvae/h, respectively, for traps in a highly productive cove and 30, 14, 0.2 larvae/h for traps in a less productive bay. Mueller et al. (1993) suggested that the lower capture rates for larvae in the highly productive cove were due to dense swarms of zooplankton and macroinvertebrates attracted to the traps which in turn reduced light transmission. However, they didn't mention the possibility that many fish larvae entering those traps were consumed by larger numbers of odonate nymphs that were also collected in the highly productive cove. Regarding the extremely poor catches by traps with light sticks, if the light had very much diminished or effectively extinguished by the time traps were retrieved, our retention experiments with trap lamps switched off (Table 3) suggest that many early-stage razorback sucker larvae would likely have escaped before retrieval.

Contrary to Mueller et al.'s (1993) findings relative to razorback sucker, chemical light sticks have been reported to be simple, convenient, and dependable light sources that do attract fish larvae (Dewey and Jennings 1992; Secor et al. 1992; Kissick 1993; Gehrke 1994; R. Wallus, personal communication[4]). The most serious problems with light sticks are their relatively short life, 3 to 24 hours, rapidly decreasing output (50-60% during the first hour), and the effect of temperature on that output (Kissick 1993, Gehrke 1994).

Mueller et al. (1993) also suggested that razorback sucker larvae might avoid light intensities exceeding 4,500 lux. With respect to their 55-W traps in the less productive bay, they noted that "many larvae were attracted to the brighter halogen lights, but from observations of larvae observed around the traps compared to capture counts, we estimate that in some cases fewer than 20% actually entered the traps." However, Mueller et al. retrieved their traps with large fine-mesh dip nets and would have simultaneously captured at least some of the larvae immediately around the trap, as well as those in or draining from the trap. If in our experiments, even our-300 lux (trap perimeter) version of the Mueller Trap was bright enough to elicit some avoidance, perhaps more larvae were similarly attracted to it than our low-intensity Southern Concepts Trap, but a lesser percentage actually entered or remained in it. In the field, substantially greater light intensity would be

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[4] Tennessee Valley Authority, Water Resources, Chattanooga, Tennessee.

expected to significantly increase the effective range of a light trap and therefore the number of fish potentially susceptible to the trap, but if a lesser percentage of the fish are likely to enter or remain in that higher-intensity trap, the benefit of greater range may be lost.

Early juvenile razorback sucker in very close range of the traps were either less attracted to, or perhaps even repelled by, the higher intensity light (Table 6). Such was the case for juvenile walleye in Bulkowski and Meade's (1983) intensity preference experiments where walleye older than 8 weeks (32-40 mm TL) aggregated most under the lowest intensity lights (2 and 4 lux).

Field Experience and Applications

Floating, low-but-constant-intensity, quatrefoil-type light traps (i.e, Southern Concepts Traps with 4-mm slits) were experimentally used by the U.S. Fish and Wildlife Service, National Park Service, Utah Division of Wildlife Resources, and Larval Fish Laboratory in 1993 and 1994 to assess razorback sucker production and larval distribution in the middle and lower Green River and Colorado River inflow to Lake Powell (CRLP), Utah (Muth and Wick 1997). Despite the generally low to moderate capture percentages in our laboratory investigations, these light traps were considered quite successful. For capture of razorback sucker larvae, light trapping in still backwater and shoreline areas (often where seining was difficult or impossible), was at least as effective as daytime seining in backwaters and along shores, and more effective than drift netting in main or side-channel currents. Of nearly 62,000 larval and early juvenile fish taken in 253 light-trap collections in 1993 (mostly overnight sets), 350 were razorback sucker larvae (Muth and Wick 1997 and unpublished data). In 1994, 1,293 razorback sucker larvae were taken in 284 collections (Muth and Wick 1997). Consequently, these light traps have been included in an extensive monitoring program for the species (Muth 1995).

Experimental efforts in the UCRB to capture and rear razorback sucker larvae to a less vulnerable size have encountered difficulties with survival during transport and initial rearing (Muth and Wick 1997). Perhaps the most difficult problem in this effort will be capturing and effectively separating enough larvae at one time to warrant the effort, even with light traps. Night-time seining or dip netting with lights, as is successfully conducted in the Lower Colorado River Basin, might warrant consideration for qualitative collections and comparison with light traps.

The light traps tested in our laboratory experiments were at least as effective for capture of larval *Gila* (represented by bonytail) as for razorback sucker and somewhat less effective for capture of Colorado squawfish larvae (Table 2). However, and as expected, very few larvae of either *Gila* species or Colorado squawfish were taken by light traps in 1993 or 1994 field investigations (Muth and Wick 1997). Those investigations targeted razorback sucker larvae and were well underway or nearly completed before many *Gila* and especially Colorado squawfish larvae were likely to be present. The larvae and early juveniles of these species have been effectively monitored and studied with drift-net and fine-mesh seine collections for many years, but in quiet-water habitats, light traps might be sufficiently effective to be considered as an alternative or complementary sampling technique for these species as well as razorback sucker.

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