BULLFROG TADPOLE (RANA CATESBEIANA) AND RED SWAMP CRAYFISH (PROCAMBARUS CLARKII) PREDATION ON EARLY LIFE STAGES OF ENDANGERED RAZORBACK SUCKER (XYRAUCHEN TEXANUS)

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NOTES

CAVERNICOLOUS MISSOURI TRICLAD (PLATYHELMINTHES: TURBELLARIA) RECORDS

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ABSTRACT—Dendrocoelopsis americana is reported for the first time in Missouri. Sphalloplana evaginata is reported from central Missouri and extends the range of this species by 280 km.

Dendrocoelopsis americana (Hyman, 1939) inhabits subterranean streams and springs in Oklahoma and Arkansas (Hyman, 1939a, 1939b; Kenk, 1973; Darlington and Chandler, 1979; Kawakatsu et al., 1995) and a single well in northeastern Texas (Kawakatsu and Mitchell, 1984). Sphalloplana evaginata Kenk, 1977 is known from 4 caves in Perry County, Missouri (Kenk, 1977; Peck and Lewis, 1978).

While conducting biological inventories in several Missouri caves, we fixed flatworms in Bouin’s fluid and transferred them to 75% ethanol. For identification, RS prepared 8-μm thick histological sections stained in Mallory-Cason. The Zoological Museum Amsterdam (ZMA) retains all material.

We collected 2 specimens of D. americana (Hyman, 1939) from Stadin Elbow Cave, McDonald County, Missouri, on 21 November 2002 (ZMA V.Pl. 982.1, sagittal sections on 6 slides). They occurred in a pool 5 cm wide by 8 cm long by 2.5 cm deep approximately 20 m within the cave. The pool contained no obvious organic material such as plant debris or bat guano. This locality is 45 km north of the other known locations for this species and the first record for Missouri. Other aquatic fauna present include Caecidotea stiludactyla (Isopoda: Asellidae) and Stygobromus (Amphipoda: Grangonyctidae).

We identified S. evaginata Kenk, 1977 from specimens collected in Moles Cave, Camden County, Missouri on 1 September 2001 (1 individual) by Lawrence Ireland and 27 January 2003 (3 individuals) by MES (ZMA V.Pl. 983.1, sagittal sections of anterior end on 28 slides and horizontal sections of posterior end on 20 slides; V.Pl. 983.2, sagittal sections on 25 slides). Flatworms occurred approximately 20 m inside the cave in a section of stream 2 to 5 cm deep that was flowing out of the cave. This portion of the stream received organic input from a maternity colony of gray bats (Myotis grisescens) roosting upstream and partially over the stream. We saw 17 of the flatworms: 11 on guano in a section of stream with gravel substrate; 4 on guano in an area of stream with solid bedrock bottom and no gravel; and 2 on gravel substrate in a section of stream directly upstream from the bat guano pile. These collections represent a range extension of 280 km to the west for this species, which remains a Missouri endemic. Other aquatic fauna present included Caecidotea and 2 amphipods (Grangonyctidae), Bactrurus and Grangonyx forbesi.
The distribution of planarians in Missouri caves is poorly known. Species such as *Macrocoeloma glandulosa* Hyman, 1956 and *M. lewisi* Kenk, 1975 occur in a single cave and 2 caves, respectively (Hyman, 1956; Kenk, 1975; Peck and Lewis, 1978). Our new records for *D. americana* and *S. evaginata* suggest that the known distribution of cave planarians in Missouri reflects collecting effort. Difficulties associated with preserving specimens, lack of sexually mature individuals, and limited access to taxonomic experts also compound the problem. Indeed, we collected planarians from several additional caves that were inadequate for identification.

We thank J. George and N. Murray of Missouri Department of Conservation and A. Leary and T. Miller of Missouri Department of Transportation for assistance during collection of specimens. We thank G. Graening, C. Melhart, and S. Taylor for assistance with manuscript preparation. V. Carmona generously translated the abstract.

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**RARE EGG CAPSULE PRODUCTION IN THE INVASIVE TERRESTRIAL PLANARIAN *BIPALIUM KEWENSE***

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Abstract—The invasive terrestrial planarian *Bipalium kewense* is found worldwide in tropical and warm temperate zones. The rate of spread and ecological impact of the flatworm will depend in part on its reproductive strategies. Members of this species reproduce primarily by fission of posterior body fragments. Herein we report, for only the second time in over 120 years of international study, the production of a fertile egg capsule by *B. kewense*. The capsule was produced by a flatworm from Texas, hatched in 21 days, and it contained 7 juveniles. Although the capsule structure, incubation period, and litter size were similar to those characteristic of the sexual species, *B. adventitium*, the *B. kewense* capsule was larger (112 mg) and produced larger offspring.
Because invasive terrestrial planarians are now present in many countries worldwide (Hyman, 1940; Winsor, 1983; Ogren and Kawakatsu, 1998; Sluys, 1999) and because their predatory habits might alter ecosystems (Blackshaw and Stewart, 1992; Christensen and Mathew, 1995), efforts to better understand the ecology of these animals have increased greatly in recent years (Mather and Christensen, 1998; Ducey et al., 1999; Boag and Yeates, 2001; Zaborski, 2002; Fiore et al., 2004). Although many species of planarians are now present in the United States, 2 species apparently predominate in distribution and local abundances: Bipalium adventitium Hyman, 1943 in the north and Bipalium keiwense Moseley, 1878 in the south (Ogren and Kawakatsu, 1998).

Bipalium keiwense has been found in dozens of tropical and subtropical countries in both the Northern and Southern Hemispheres (Dendy, 1892; Hyman, 1943, 1954; Winsor, 1983; Ogren and Kawakatsu, 1998) and might have the broadest distribution of any terrestrial planarian (Sluys, 1999). The species is believed to be native to Southeast Asia (Hyman, 1943; Winsor, 1983) and has been inadvertently spread by humans moving plants and soil (Winsor, 1983; Ogren, 1985). Since the first published record of the species in North America in 1891 (Ogren, 1985), B. keiwense has been recorded living outdoors in most southern states as far north as central California, Missouri, Kentucky, and Virginia (Ogren, 1985; Ogren and Kawakatsu, 1998).

The ecological impact of B. keiwense on native and agricultural landscapes in the United States will depend on its ecological interactions and reproductive strategies. Terrestrial planarians are, in general, hermaphroditic and use allo-sperm to create embryos that are grouped within egg capsules (Hyman, 1943; Ball and Reynolds, 1981; Ogren, 1985). Although dissections of specimens of B. keiwense from around the world have revealed mature gonads and copulatory organs, Hyman (1943) and Winsor (1985) suggested that this species reproduces only by asexual fission outside of tropical areas, and only a single study (Connell and Stern, 1969) documented egg capsule production by live individuals from anywhere in the world. As part of larger research program studying flatworm-earthworm interactions in the United States, we captured and raised many B. adventitium and B. keiwense. Herein, we report for only the second time the production of a fertile egg capsule by B. keiwense.

Our research team and members of the general public collected B. adventitium and B. keiwense from human-dominated landscapes and natural areas around North America. The B. keiwense were from California, Georgia, Missouri, North Carolina, and Texas. In the laboratory, we kept each flatworm individually in plastic containers (590 to 780 cm³) filled with moist paper towels and held at 18 to 22°C. We fed earthworms to both flatworm species. Egg capsules, offspring hatching from the capsules, and fragments produced by asexual fission were weighed and held separately from the parental flatworms. Between 1994 and February 2005, we raised or handled 311 B. keiwense, including 192 individuals raised following asexual fission.

One moderately sized B. keiwense was received in November 2004 as part of a shipment of 8 flatworms collected by a citizen in Cypress, Texas, and on 21 January 2005, this B. keiwense produced an egg capsule. As is the case with other terrestrial planarians, the capsule was initially bright red and turned black within 14 hours. Egg capsule mass (112 mg) was considerably larger than the masses of egg capsules produced by B. adventitium (mean = 22.5 mg; Ducey and Noce, 1998; Ducey et al., 2005). While in captivity, the parent flatworm also
produced 7 fragments via asexual fission, including one fragment 10 days prior to, and another fragment 5 days after, egg capsule production. The *B. keowiense* egg capsule hatched 21 days after deposition, exactly the same number of days reported by Connella and Stern (1969) for their one capsule, and similar to the mean incubation time of 23 days for *B. adventitium* (Ducey et al., 2005). Seven offspring emerged from the capsule, with the mean individual offspring mass of 11.7 mg (*SE* = 1.0 mg; range = 7.5 to 14.7 mg). These offspring were about twice as large as *B. adventitium* hatchlings (mean ± *SE* = 5.16 ± 0.33 mg; *n* = 98; Ducey et al., 2005). Although Connella and Stern (1969:309) described their juveniles as “replicas of adult worms,” ours were not. The juveniles that hatched in our study had the same dark collar and 2 dark medio-lateral stripes on the body as on adults, but only 3 of the 7 offspring showed the median dorsal stripe, and none showed the 2 distal-lateral stripes characteristic of adults. The juveniles also had lightly colored heads ringed by a dark border, in contrast to the generally darker heads of adults.

In their reviews of the species, Hyman (1940, 1943) and Winsor (1983) suggested that reproduction in *B. keowiense* in temperate regions was strictly via asexual fission. Specimens that possessed mature gonads and copulatory organs have been identified from many countries (Winsor, 1983), but only a single published study documented egg capsule production by living members of this species (specimen from Louisiana; Connella and Stern, 1969). Our egg capsule represents the fourth capsule ever reported for *B. keowiense* and only the second capsule ever hatched for this species. This paucity of other records is not due to these animals having escaped scientific scrutiny. Adult *B. keowiense* have been observed in nature, and raised and studied in laboratories, for over 120 years (e.g., Dendy, 1892; Morgan, 1900; Barnwell, 1969), and asexual fission has been frequently observed (Fletcher, 1887; Richters, 1887; Chandler, 1976; Neck, 1987). The fact that egg capsules are easily seen in nature for some other terrestrial planarians (e.g., *Artioposthia triangulata*; Christensen and Mather, 1997) or frequently recorded for captured specimens (e.g., *B. adventitium*, Ducey et al., 2005) suggests that sexual reproduction and egg capsule production are indeed rare in *B. keowiense*. Although fragmentation might be more efficient at converting resources into offspring (Calow et al., 1979), rare occurrences of sexual reproduction enhance genetic exchange and variability in other, primarily asexual species of planarians (D’Souza et al., 2004).

We thank the many people who have provided specimens from around the country (especially G. Anderson, M. Birk, B. Del Maio, B. B. Ducey, F. Johnson, M. Hamerslough, D. Hodgson, K. Mason, and J. Rapier) and helped maintain the animals in the laboratory (notably J. Dawson, C. Fiore, R. Getzke, L. Lacey, G. Shaw, and J. Tull).

**LITERATURE CITED**


D’SOUZA, T. G., M. STORHAS, H. SCHULENBURG, L. W.
BEUKERBOOM, AND N. K. MICHELS. 2004. Occasion- 
al sex in an ‘asexual’ polyploid hermaphrodite. 
Proceedings of the Royal Society of London B 

DUCEY, P. K., M. MESSERE, K. LAPOINT, AND S. NOCE. 
1999. Lumbricid prey and potential herpetofaun-
al predators of the invading terrestrial flatworm 
Bipalium adventitium (Turbellaria: Tricladida: Ter-
ricola). American Midland Naturalist 141:305– 
314.

DUCEY, P. K., AND S. NOCE. 1998. Successful invasion 
of New York State by the terrestrial flatworm, Bi-
palium adventitium. Northeastern Naturalist 5: 
199–206.

DUCEY, P. K., L-J. WEST, G. SHAW, AND J. DELISLE. 
2005. Reproductive ecology and evolution in the 
invasive terrestrial planarian Bipalium adventitium 

FIORE, C., J. L. TULL, S. ZEHNER, AND P. K. DUCEY. 
2004. Tracking and predation on earthworms by 
the invasive terrestrial planarian Bipalium adve-
ntitium (Tricladida, Platyhelminthes). Behavioural 

FLETCHER, J. J. 1887. Remarks of an introduced spe-
cies of land-planarian apparently Bipalium ke-
wense, Moseley. Proceedings of the Linnean Society 
of New South Wales 2:244–249.

HYMAN, L. H. 1940. Native and introduced land pla-

HYMAN, L. H. 1943. Endemic and exotic land pla-
narians in the United States with a discussion of 
necessary changes of names in the Rhynchodem-

HYMAN, L. H. 1954. Some land planarians of the 
United States and Europe, with remarks on no-
mencature. American Museum Novitates 1667: 
1–21.

MATHER, J. G., AND O. M. CHRISTENSEN. 1998. Behav-
ioural aspects of the ‘New Zealand flatworm’, Ar-
tioposthia triangulata, in relation to species spread. 
Pedobiologia 42:520–531.

MORGAN, T. H. 1900. Regeneration in Bipalium. Ar-
chiv fur Entwicklungsmechanik der Organismen 

NECK, R. W. 1987. A predatory terrestrial flatworm, 
Bipalium kewense, in Texas (USA): Feral popula-
tions and laboratory observations. Texas Journal 

OGREN, R. E. 1985. Exotic land planarians of the ge-
nus Bipalium (Platyhelminthes: Turbellaria) from 
Pennsylvania and the Academy of Sciences, Phil-
adelphia. Proceeding of the Pennsylvania Acad-
emy of Sciences 58:193–201.

Nearctic and Neotropical land planarian (Tri-
cladida: Terricola) faunas. Pedobiologia 42:441– 
451.

RICHERS, F. 1887. Bipalium kewense Mosley, eine 
Landplanarie des Palmenhauses zu Frankfurt. 
Der Zoologische Garten 28:231–234.

SLUYS, R. 1999. Global diversity of land planarians 
(Platyhelminthes, Tricladida, Terricola): a new 
indicator-taxon in biodiversity and conservation 
studies. Biodiversity and Conservation 8:1663– 
1681.

WINSOR, L. 1983. A revision of the cosmopolitan land 
planarian Bipalium kewense Moseley, 1878 (Tur-
bellaria: Tricladida: Terricola). Zoological Jour-
nal of the Linnean Society 79:61–100.

ZABORSKI, E. R. 2002. Observations on feeding be-
havior by the terrestrial flatworm Bipalium adven-
titium (Platyhelminthes: Tricladida: Terricola) 
from Illinois. American Midland Naturalist 148: 
401–408.

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NEW RECORDS OF CICADAS FROM MEXICO 
(HEMIPTERA: CICADOIDEA: CICADIDAE)

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ABSTRACT—I report on specimens that represent the first records of 7 cicada species in 5 genera 
found in Mexico. This is the first report of a Beameria species in Mexico.

RESUMEN—Reporto los primeros registros de siete especies de chicharra de cinco géneros en 
México. Este es el primer registro de una especie de Beameria en México.
The Central American cicada fauna has received little study since the landmark Biologia Centrali-Americana (Distant, 1881, 1883, 1900, 1905). Davis (e.g., 1919, 1928, 1936, 1941, 1944) added significantly to the Mexican cicada fauna by describing new genera and species. Other than the general review by Moore (1996), little has been done on the Mexican cicada fauna until the recent description of 2 new Mexican species (Sanborn et al., 2005).

A search of the Cicadoidea bibliographies (Metcalf, 1963a, 1963b, 1963c; Duffels and van der Laan, 1985) and Sanborn et al. (2005) identified 87 cicada species inhabiting Mexico. I have located several species in the Instituto de Biologia, Universidad Nacional Autonoma de Mexico (UNAM), University of Nebraska State Museum (UNSM), Texas A&M University (TAMU), Louisiana Arthropod Museum, Louisiana State University (LSUC), University of Nebraska State Museum (UNSM), Texas A&M University (TAMU), Louisiana Arthropod Museum, Louisiana State University (LSUC), Utah Museum of Natural History (UMNH), Carnegie Museum of Natural History (CMNH), Philadelphia Academy of Natural Sciences (ANSP), Natural History Museum of Los Angeles County (LACM), Monte L. Bean Life Science Museum, Brigham Young University (BYUC), and the Bohart Museum of Entomology, University of California (UCDC) that represent the first records for 7 additional species of the Mexican cicada fauna. Original specimens are housed in the collections above, with vouchers in the collection of the author.

Family Cicadidae Leach, 1815

Subfamily Tibiceninae Atkinson, 1886

Tribe Zammarini, Distant, 1905

Odopea diriangani Distant, 1881. There are specimens from the UNAM collected at Querétaro. Km 8 Neblinas-Aqua Zarca, 21°15′14″N, 99°4′58″W, 23 June 1998 and 21 August 1998. Specimens from UNSM were collected at Hidalgo, Chapulhuacan, 26–27 July 1981. Odopea diriangani has previously only been reported from Nicaragua (Distant, 1881, Metcalf, 1963a). This represents a northern expansion for the species.

Zammara calochroma Walker, 1858. Specimens in the UCDC were collected at Chihuahua, Colonía Dublán, 21 August 1957. As the species name suggests, this organism has a broad distribution. It is found across the southwestern United States from Arizona to Texas and north to Kansas.

Tribe Tibicenini Distant, 1889

Diceroprocta eugraphica (Davis, 1916). Specimens in UNAM were collected at Chihuahua, Colonía Dublán, 21 August 1957. This species has a broad distribution. It is found across the southwestern United States from Arizona to Texas and north to Kansas.

Tibicen parallelus Davis, 1923. Specimens in the UCDC were collected at Chihuahua, Temoris, 11–24 August 1969, and 2 miles south of Temoris, 22 August 1968. Tibicen parallelus is found north into Arizona and New Mexico. I have collected specimens not far north of the border of Arizona and Sonora.

Tribe Fidicinini Distant, 1905

Beameria venosa (Uhler, 1888). Specimens in BYUC were collected at Chihuahua, Colonía Dublán, 21 August 1957.

Beameria wheeleri Davis, 1934. Specimens in the ANSP were collected in Chihuahua, Estación Conchos, 1,219 m, 22 July 1988. These specimens represent the first representatives of the genus Beameria to be reported from Mexico.

There are probably many other species present in Mexico that await discovery and addition to the cicada fauna. The inclusion of a number of cicada genera from northern temperate as well as tropical regions and the relatively small number of species per genus in Mexico suggests that there are many species...
remaining to be found (Moore, 1996). I have identified several new species from museum collections and have begun to publish species descriptions (Sanborn et al., 2005).

Corrigenda to Sanborn et al. (2005). The type location for Neocicada mediamexicana Sanborn should be Hwy 120 km 223, 43 km E Jalpan near La Sierrita, 21º16’25”N, 99º12’51”W, 1,510 m. The allotype and paratype location should read Tlamaya Falls, Los Pozas, 3 km E Xilitla near La Conchita, Hwy 120 km 265, 21º23’45”N, 98º59’48”W, 595 m.

I thank J. Brambila of the Florida State Collection of Arthropods, H. Brailovsky (UNAM), S. Clark (BYUC), B. Ratcliff (UNSM), E. Riley (TAMU), C. Carlton (LSUC), G. Bills and E. Rickart (UMNH), R. Davidson (CMNH), J. Weintraub and D. Azuma (ANSP), W. Xie (LACM), and S. Heydon (UCDC) for assistance while visiting collections or for providing specimens. D. Yanega kindly provided the information for the corrigenda.

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BULLFROG TADPOLE (RANA CATESBEIANA) AND RED SWAMP CRAYFISH (PROCAMBARUS CLARKII) PREDATION ON EARLY LIFE STAGES OF ENDANGERED RAZORBACK SUCKER (XYRAUCHEN TEXANUS)

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ABSTRACT—Bullfrog tadpoles (Rana catesbeiana) and red swamp crayfish (Procambarus clarkii) are widespread introduced taxa that are problematic throughout the western United States. Their impact on native amphibians and crustaceans is well documented, but less is known regarding their influence on native fishes. Predator-prey tank tests showed both species consumed eggs and larvae of the endangered razorback sucker (Xyrauchen texanus) in a laboratory setting. Tadpoles consumed 2.2 razorback sucker eggs/d and 1.4 razorback sucker larvae/d, while crayfish ate 6.0 eggs/d and 3.5 larvae/d. Relatively high densities of bullfrog tadpoles and crayfish in razorback sucker spawning areas suggest that these nonnative taxa might pose a threat to the recruitment success of this and other imperiled native fish.

RESUMEN—Los renacuajos de la rana toro (Rana catesbeiana) y una especie de cangrejo de río (Procambarus clarkii) son taxa no nativos problemáticos con una distribución geográfica amplia en el oeste de los Estados Unidos. Su impacto sobre anfibios y crustáceos nativos está bien documentado, pero su influencia sobre peces nativos es casi desconocida. Pruebas en tanques de depredador-presa mostraron que ambas especies consumieron huevos y larvas del matalote jorobado (Xyrauchen texanus), una especie amenazada. Los renacuajos consumieron 2.2 huevos de X. texanus/día y 1.4 larvas/día, mientras los cangrejos comieron 6.0 huevos/día y 3.5 larvas/día. Las densidades relativamente altas de los renacuajos de R. catesbeiana y P. clarkii en zonas del desove de X. texanus sugieren que estas especies no nativas tal vez sean una amenaza al éxito de reclutamiento de éste y otros peces nativos amenazados.

Razorback sucker (Xyrauchen texanus) is endemic to the Colorado River. Dramatic declines in their number and range caused it to be federally listed as endangered in 1991 (56 FR 54957). The absence of young in the wild has been attributed to predation by nonnative fish (Minckley et al., 1991; Tyus and Sanders, 2000; Minckley et al., 2003). Recruitment levels necessary to sustain populations have only occurred in recent years in isolated ponds where nonnative fishes are absent (Minckley et al., 1991; Minckley et al., 2003; Marsh and Pacey, 2005).

Cibola High Levee Pond (Cibola HLP) is a 2.3-ha human-made oxbow located on the lower Colorado River along the Arizona–California border and represents one isolated location where sustainable recruitment has occurred; however, survival of young razorback suckers is intermittent. Nonnative fish are rare (Mueller et al., 2005), suggesting other predators or factors might be responsible for the periodic absence of young fish. For instance, Horn et al. (1994) illustrated that razorback sucker larvae are highly susceptible to odonate nymphs and suggested they might also be vulnerable to other nontraditional predators. Our discovery of bullfrog (Rana catesbeiana) tadpoles and red swamp crayfish (Procambarus clarkii) among spawners prompted our curiosity whether these introduced taxa could also threaten early life stages of native fishes.

Laboratory Tests—Large numbers of bullfrog tadpoles and sexually ripe razorback suckers were collected at Cibola HLP during routine sampling in 2003. Several hundred eggs dis-
covered in a tub where razorback sucker were held prior to data processing were used in a preliminary experiment, rather than being discarded. One hundred eggs were put into each of 4, 38-L, aerated aquarium tanks in the laboratory. Subsequently, 25 bullfrog tadpoles were added to each of 3 tanks, leaving one tank holding only fish eggs. The tanks were allowed to sit unattended over the weekend and were examined after 72 h. The fish eggs were completely absent in tanks containing tadpoles and were all present in the control tank.

Based on these preliminary results, we designed a more structured and expanded series of tests to examine whether bullfrog tadpole and crayfish would eat razorback sucker eggs, larvae, and fry. Additional bullfrog tadpoles and crayfish were collected from Cibola HLP, and razorback sucker eggs, larvae, and fry were provided by Willow Beach National Fish Hatchery. Experiments were conducted in 38-L, aerated aquariums that were equipped with separation screens that initially isolated predators from prey. Substrate and cover were not provided to allow accurate counts of the number of eggs and larvae remaining after a 24-h exposure experiment.

Tanks contained either 4 tadpoles, 2 crayfish, or no predators (control) and 20 razorback sucker eggs or larvae. Controls were used to measure natural mortality of larvae and visibility or deterioration of eggs, because these factors could influence consumption rates. The number of tests and size of test organisms was dictated by their availability. Shortages of larvae made it necessary to use larger (>14 mm) fry for some crayfish experiments. Predators and prey were measured for total length (fish, tadpoles) and cephalothorax length (crayfish) (Table 1). Separating screens were gently removed to start the experiment, and remaining prey were counted at the end of 24 h. These 24-h experiments indicated that tadpoles consumed an average of 2.2 eggs/d (n = 6 tests) and 1.4 larvae/d (n = 7 tests), while crayfish ate an average of 6.0 eggs/d (n = 8 tests) and 3.5 larvae/d (n = 12 tests) (Table 1). Only 3 of 200 control fish died during the experiments (n = 10 tests).

Field Monitoring—Spawning activities of razorback sucker and bonytail (Gila elegans), another native fish found in the Cibola HLP, were recorded using underwater video equipment. During this monitoring, bullfrog tadpoles and crayfish were commonly observed feeding among spawning fish. These filming sessions were expanded to gain a better understanding of the relative abundance of bullfrog tadpoles and crayfish among spawners.

Two 12-volt (VDC), black-and-white, underwater video cameras were mounted on small submersible tripods and aimed at the bottom. These cameras were linked to surface monitors and VHS recorders. Four areas were filmed: a razorback sucker spawning area, a bonytail spawning area, and 2 areas that were randomly chosen that were not being used by spawners. Recordings were reviewed using a VHS film editor and stopped at precise 5-minute intervals to count tadpole and crayfish observed in that single frame. Density estimates were calculated from the number of organisms observed divid-

### Table 1—Size of prey and predators (diameter of fish egg, total length of fish larva and tadpole, and cephalothorax length of crayfish) and predation rates (number of individuals consumed/day) of bullfrog (Rana catesbeiana) tadpoles and red swamp crayfish (Procambarus clarkii) preying on razorback sucker (Xyrauchen texanus) eggs and larvae in laboratory tank experiments.

<table>
<thead>
<tr>
<th>Test</th>
<th>Prey size (mm) mean (range)</th>
<th>Predator size (mm) mean (range)</th>
<th>Tests n</th>
<th>Number consumed mean (95% CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg—Tadpole</td>
<td>3.2 (2.7–3.5)</td>
<td>100 (84–116)</td>
<td>6</td>
<td>2.2 (1.2–2.9)</td>
</tr>
<tr>
<td>Egg—Crayfish</td>
<td>3.2 (2.9–3.5)</td>
<td>32.8 (26.3–40.6)</td>
<td>8</td>
<td>6.0 (2.7–9.4)</td>
</tr>
<tr>
<td>Larvae—Tadpole</td>
<td>11.5 (10.1–12.5)</td>
<td>100 (83–115)</td>
<td>7</td>
<td>1.4 (0.8–2.0)</td>
</tr>
<tr>
<td>Larvae—Crayfish</td>
<td>18.5 (13.3–27.6)</td>
<td>48.5 (33.9–65.4)</td>
<td>12</td>
<td>3.5 (1.9–5.1)</td>
</tr>
<tr>
<td>Controls*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>3.2 (2.7–3.5)</td>
<td></td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>Larvae</td>
<td>15.0 (10.1–27.6)</td>
<td></td>
<td>10</td>
<td>0.1 (0.0–0.3)</td>
</tr>
</tbody>
</table>

* Mortality only.
ed by a size estimate of the viewing area (the viewing area varied due to camera angle). Average densities were multiplied by the total area of the pond to develop a simple estimate of population size.

Twelve video sessions (2 h each) taken during daylight hours from 18 February to 17 April 2003 were analyzed for the presence of bullfrog tadpoles and crayfish. Bullfrog tadpole densities \( n = 286 \) frames averaged 2.1 tadpoles/m\(^2\), with densities increasing \((0.9 \text{ to } 3.7 \text{ tadpoles/m}^2)\) during the course of the study. Adult crayfish densities averaged \(<0.1\text{ crayfish/m}^2\) \((0.0 \text{ to } 11.1 \text{ crayfish/m}^2)\) during the same period. The tadpole and crayfish community was estimated at approximately \(>48,000\) tadpoles and \(>2,000\) crayfish.

Given that bullfrog tadpoles and crayfish consumed razorback sucker eggs and larvae under laboratory conditions, their abundance and presence among spawners at Cibola HLP suggests they might pose a threat to native fish eggs and larvae if their densities are relatively high. The intermittent recruitment of razorback sucker at Cibola HLP might be attributable to bullfrog tadpole and crayfish predation, because nonnative fish predators were rare \(<0.1\%\) of the 3,760 fish sampled (Mueller et al., 2005).

Introduced bullfrogs and crayfish are widespread and abundant not only in the wild, but also in many culturing facilities (Bills and Marking, 1988; Kane et al., 1992). Bullfrog tadpole predation of eggs and larvae of native anurans and salamanders is well documented (Ehrlich, 1979; Kiesecker and Blaustein, 1997; Murray et al., 2004), but their threat to native fish is less recognized (Kane et al., 1992). Boyd (1975) suspected tadpole predation on fish, but Nguenga et al. \((1997, 2000)\) were the first to document and measure toad predation of eggs and newly hatched larvae of African catfish \((Heterobranchus longifilis)\). They found fish larvae were most vulnerable prior to developing fins \(<6\) d.

Crayfish predation on eggs of recreational and native fishes is well documented (Horns and Magnuson, 1981; Dorn and Mittelbach, 2004). Evidence of crayfish feeding on live fish larvae is less common. In laboratory settings, crayfish fed on young lake trout \((Salvelinus namaycush)\); Savino and Miller, 1991) and juvenile Gila chub \((Gila intermedia)\), suckers \((Catostomus)\), and speckled dace \((Rhinichthys osculus)\) (Carpenter, 2000). Gut content analyses provided evidence of \(P. clarkii\) consuming Gambusia in a freshwater marsh (Gutiérrez-Yurrita et al., 1998). Introduced crayfish negatively impacted several benthic fish communities in British rivers via competition and predation (Guan and Wiles, 1997).

Predator removal programs aimed at restoring razorback sucker recruitment within the Colorado River basin have typically focused on the removal of large, nonnative fish predators (Mueller, 2005). When large predators that depress nontraditional predators \((i.e.,\) predaceous insects, crustaceans, and amphibians) are removed, the latter typically increase in abundance (Horn et al., 1994; Mueller and Burke, 2005). These cause-and-effect reactions deserve closer scrutiny in predator control programs, because of the potential negative effects the nontraditional predators might pose to the early life stages of fish.

**Literature Cited**


Horn, M. J., P. C. Marsh, G. Mueller, and T. Burke. 1994. Predation by odonate nymphs on larval r-


