CUI-UI REPRODUCTIVE SUCCESS FROM POTENTIAL EGG DEPOSITION TO LARVAL EMIGRATION

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ABSTRACT.—From 1985 to 2006, we tracked cui-ui, *Chasmistes cujus*, survival from potential egg deposition of migrating spawners to emigrating larvae. Tahoe sucker larvae emigrated to Pyramid Lake the same time as cui-ui larvae, but cui-ui was the predominant catostomid larvae we captured. Survival of cui-ui larvae ranged from 0.46% to 21.17%, declining significantly with decreased flow and increased number of spawners ($P < 0.01$). Mean total length of emigrating larvae ranged from 11.5 to 12.6 mm and may have been affected by stream flow. Removal of impediments to upstream migrating cui-ui spawners, along with sufficient stream flows, may enhance early life-stage survival.

RESUMEN.—Desde 1985 hasta 2006, rastreamos la supervivencia de peces cui-ui, *Chasmistes cujus*, de una posible deposición de huevos de hembras migratorias a larvas emigrantes. Las larvas del pez Tahoe sucker emigraron al Lago Pirámide al mismo tiempo que las larvas cui-ui, pero las cui-ui fueron las larvas catostómidas predominantes que capturamos. La supervivencia de las larvas cui-ui varió de 0.46% a 21.17%, y disminuyó significativamente con la reducción del caudal y con el aumento de la cantidad de hembras en desove ($P < 0.01$). La longitud promedio de las larvas emigrantes varió de 11.5 a 12.6 mm en longitud total y pueden haberse visto afectadas por el caudal de la corriente. La remoción de los obstáculos para la migración aguas arriba de peces hembras cui-ui, junto con la provisión de suficiente caudal de corriente pueden mejorar la supervivencia en etapas tempranas de la vida.

Reproductive success is an important metric in assessing population health and in understanding a species' life history strategy and population dynamics (Stearns 1992, Williams et al. 2001). Data needed to estimate reproductive success are, however, difficult to secure (Houde 2002), and consequently, efforts have focused on commercially valuable species (Houde 1997, Hyatt et al. 2005, Landaeta and Castro 2006). There is less information on early life-stage survival for nongame fishes, including federally listed species.

Cui-ui *Chasmistes cujus*, a nongame species endemic to Pyramid Lake, Nevada, was federally listed as endangered because the population declined dramatically as a result of reproductive cycle disruption (U.S. Department of the Interior 1973). Disruption of cui-ui reproduction began in the 20th century when large-scale water diversion from the Truckee River, Pyramid Lake's only perennial tributary, resulted in lake elevation decline and formation of a shallow delta at the river mouth (La Rivers 1962). Cui-ui, which are river spawners, were unable to enter the Truckee River to spawn in many years, and when they did, eggs were often scoured due to an unstable river bottom

(Scoppettone et al. 1986). Cui-ui longevity allowed it to persist more than a decade with little to no recruitment (Scoppettone et al. 1986, 2000, Scoppettone 1988). In the mid-1970s, anthropogenic changes in the lower Truckee River improved cui-ui spawner passage. In late winter to early spring, adult cui-ui migrate to the southern end of Pyramid Lake and await environmental cues triggering their river spawning migration. Cui-ui typically migrate *en masse* and spawn over gravel substrate, with females crudely burying their demersal eggs by moving gravel with the anal fin (Scoppettone et al. 1983, 1986, Scoppettone and Vinyard 1991). The resulting progeny emigrate to Pyramid Lake upon swim-up and primarily at night. In this paper, we estimated run size, egg deposition, and larval survival over a 20-year period to better understand cui-ui reproductive patterns.

METHODS

Description of Area

Pyramid Lake lies within the confines of the Pyramid Lake Paiute Indian Reservation in west-central Nevada, at the western edge of the

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Fig. 1. Marble Bluff Dam and Marble Bluff Fishway in relation to Truckee River/Pyramid Lake. Insets, Truckee River/Pyramid Lake watershed, California and Nevada, and Marble Bluff Fishway in relation to Marble Bluff Dam.

Great Basin. It is a terminal lake with a surface area of approximately 785 km². The main-stem Truckee River originates at Lake Tahoe, California, and flows 192 km before discharging into Pyramid Lake. Its primary water source is snowmelt and rain falling on the east side of the Sierra Nevada. The typical period from adult spawning migration to larval out-migration is April through June; during this study (1985–2006), lower Truckee River flows in these months ranged from about 1 m³ · s⁻¹ to 75 m³ · s⁻¹ (<http://waterdata.usgs.gov/nwis>). Stream flow is regulated, in part, by reservoir releases and water diversions. Since the late 1970s, water has been released from Stampede Reservoir to attract cui-ui spawners, facilitate their upstream river passage, and modify water temperature (U.S. Fish and Wildlife Service 1992). These flow releases have typically augmented natural flows. During 1987, 2003, and 2004, however, virtually the entire Truckee River flow entering Pyramid Lake originated from reservoir releases. Lake levels in

these years were relatively high, and the delta was not an impediment to upstream migrants.

Marble Bluff Dam Complex was constructed to facilitate fish passage over the Truckee River delta. It consists of Marble Bluff Dam (MBD) and Marble Bluff Fishway (MBF); the MBF serves as a 5-km-long canal bypass around the Truckee River delta (Fig. 1). Upstream of Pyramid Lake, MBD prevents erosion associated with declining lake elevations, and it diverts water into the MBF (Glancy et al. 1972). When lake elevation is below 1170 m, cui-ui access the river via the MBF, which flows at about 1.1 m³ · sec⁻¹ and has 4 ice-harbor-type ladders along its course. There is a fish-handling building where fish are monitored, captured, and transported upstream of MBD. When lake elevation is ≥1170 m, cui-ui migrate up the Truckee River, and they are trapped at the base of MBD, transported above the dam, measured, sexed, and released. From 1997 to the end of this study in 2006, the surface elevation of Pyramid Lake was sufficiently high

that the MBF was closed, and cui-ui were trapped at the base of MBD.

Upstream of MBD there are several diversion dams that may impede the migration of spawners. Numana Dam, approximately 12 km upstream of MBD, diverts water to agricultural land on the Pyramid Lake Paiute Indian Reservation. The dam has a fish ladder, but its efficacy in passing cui-ui is untested. Beginning approximately 20 km upstream of Numana Dam, there are 3 rock diversion dams with unknown effects on migrating cui-ui, and Derby Dam (the largest diversion dam along the mainstem Truckee River) is approximately 40 km upstream of Numana. It is believed most cui-ui spawned downstream from Derby Dam, even prior to its completion in 1906 (La Rivers 1962), though they historically were collected at its base (Snyder 1918).

Potential Egg Deposition

We estimated the egg deposition potential for cui-ui females that passed upstream of MBD from 1985 to 2006. There were spawning migrations in 15 of these 22 years. Cui-ui either did not migrate or there were too few females (<100) to warrant monitoring during the remaining 7 years. To estimate total egg deposition, we used spawner counts, sex ratios, and mean size of females passed upstream of MBD (unpublished file data). Since only a fraction of cui-ui were measured and sexed during the run, we estimated total potential egg deposition for a given year as the product of the mean fecundity of measured females and the estimated number of females, based on sex ratios, passed upstream of MBD. The fecundity-size relationship was calculated by Scoppettone et al. (2000). These authors used 2 different regression equations to estimate fecundity: high fecundity following a year of no cui-ui spawning ($y = 3.51x - 4.66$) and low fecundity following a spawning year ($y = 3.07x - 3.51$), where $x = \log_{10}$ fork length of females captured at MBD and $y = \log_{10}$ estimated fecundity.

Larvae Netting and Identification

Because of the tremendous number of emigrating catostomid larvae, we found it practical to fish only 2 nets and often only for brief intervals. Nets were fished 30 m downstream from MBD and were 2.4 m long with a 50-cm-diameter mouth. They had a removable PVC

cylinder (larvae receptacle) 20 cm deep and 8.5 cm wide at the cod end. The net mesh was 800 microns, and the cylinder had 500-micron-mesh fiberglass along its length. Nets were fitted with a General Oceanic Digital Flow Meter and a harness for attachment to a cable extending across the river. The cable and attached nets were moved to and from fishing sites using a pulley system. One fishing site was near the center of the river, 15–20 m from the bank, and the other was 3–10 m from the bank. There were up to 60 exposed baffles equally spaced horizontally and vertically, projecting from the face of MBD. They serve to dissipate energy of the falling water and are assumed to mix larvae throughout the water column, creating the possibility for a single net to capture a representative sample of emigrating larvae passing over the dam (Fig. 2). To test this assumption, we conducted a paired t test to determine if there was a difference in annual catches between nets. In 1985, 1986, and 1987, contents from the 2 nets were mixed and were not used in the test.

Throughout the period of larvae emigration, which ranges from mid-April through the end of July, drift nets were fished Monday, Wednesday, and Friday (beginning near dusk) for 5–20 min at hourly intervals over 4–6 h. The counter number on the digital flow meter was recorded prior to net setting. Immediately after nets were pulled, contents from each of the larvae receptacles were placed in separate 12-L buckets, and the ending count of the digital flow meter was recorded. Captured catostomids were enumerated, and up to 50 randomly selected larvae were placed in a vial of 10% formalin for later species identification. Each vial contained a tag with date and time of capture along with the identifying number of the net.

We conducted diel sampling 1–3 times per season for a total of 24 episodes to determine daily emigration pattern of cui-ui larvae. We followed the same procedures as in our seasonal sampling, but over a 24-h period, collecting a sample once every hour. Preserved catostomids were identified to species using a binocular dissecting scope and a key for catostomid larvae of the Truckee River Basin (Snyder 1983). Number of larvae was counted for each net and each sample hour. From 1994 to 2006, a subsample of at least 10 cui-ui larvae were randomly selected from each vial and

Fig. 2. Marble Bluff Dam showing baffles at the dam face.

measured to the nearest 0.01 mm (total length). The online National Water Information System of the U.S. Geological Survey (<http://waterdata.usgs.gov/nwis>) was used to track daily river flow at the Nixon gaging station, 2 km upstream of the larvae sampling site.

Larvae Estimates

We estimated number of cui-ui larvae emigrating past MBD for a given spawning year by first using the General Oceanic Digital Flow Meter to calculate the volume of water passed through each net for each 5–20 min fishing period and then counting the catostomid larvae in each net sample. In the laboratory, we determined the relative proportion of cui-ui to Tahoe sucker *Catostomus tahoensis* for each net set, and the number of cui-ui larvae captured was extrapolated to one hour. We then estimated number of cui-ui larvae $\cdot \text{m}^{-3}$ passing over MBD during a 24-hour period for each Monday, Wednesday, and Friday of sampling. We used a linear regression equation with the number of cui-ui larvae $\cdot \text{m}^{-3}$ captured over each of 24 diel episodes as the dependent variable, and the average number of cui-ui larvae $\cdot \text{m}^{-3}$ for a given 4–6-h sampling

event as the independent variable. The estimated number of cui-ui larvae that passed MBD on a given day was the product of the number of larvae $\cdot \text{m}^{-3}$ and total m^3 that fell over MBD that day.

We estimated larvae numbers for those days sampled and then extrapolated larvae numbers for the season (estimated number of larvae for sampling days $\cdot$ number of days during emigration/number of sampling days). We typically sampled 29%–44% of the days in a given season. We feel this was a representative sample of larvae migration in a season.

Survival

In this paper, we define larval survival as the quotient of the estimated number of larvae produced in a given year divided by potential number of eggs deposited for that year (Pepin 2002). Regression analysis was used to determine if there was a relationship between survival of each of the sample years and magnitude of stream flow and density (number of male and female spawners passed upstream of MBD). To adjust for nonnormality and heterozygosity, survival was arcsine transformed, and density and flow were converted to a natural-log

TABLE 1. Number of females (F) and males (M) passed upstream of Marble Bluff Dam, female mean length (mm), mean fecundity, expected number of eggs deposited, estimated number of larvae captured, and estimated egg-to-larvae survival over a 22-year sampling period.

Year	Number Passed		Mean FL		Egg estimate $\times 10^8$	Larvae estimate $\times 10^6$	SD $\times 10^6$	Larval survival (%)
	F	M	F	Mean fecundity				
1985	5945	3384	568	87,566	5.2	68.1	—	13.09%
1986	19,409	16,094	567	87,093	16.9	315.2	—	18.65%
1987	3220	2074	572	89,475	2.9	4.8	—	1.67%
1988	—	—	—	—	—	—	—	—
1989	19	52	—	—	—	—	—	—
1990	—	—	—	—	—	—	—	—
1991	—	—	—	—	—	—	—	—
1992	—	—	—	—	—	—	—	—
1993	4842	14,151	528	72,159	3.5	38.6	0.9	11.05%
1994	22,597	43,754	542	75,822	17.1	142.8	15.3	8.34%
1995	37,777	61,316	542	75,822	28.6	606.4	65.4	21.17%
1996	84,771	86,897	542	75,822	64.3	653.8	53.4	10.17%
1997	157,975	149,011	540	74,965	118.4	1164.5	32.1	9.83%
1998	273,268	218,715	541	75,393	206.0	144.1	5.9	0.70%
1999	298,214	284,930	549	78,872	235.2	302.5	16.6	1.29%
2000	83,958	98,185	568	87,566	73.5	171.4	1.5	2.33%
2001	—	—	—	—	—	—	—	—
2002	17,940	20,149	565	86,152	15.5	73.1	0.2	4.73%
2003	76,807	82,695	546	77,555	59.6	138.7	9.8	2.33%
2004	69	100	—	—	—	—	—	—
2005	582,787	772,879	532	71,604	417.3	191.8	6.6	0.46%
2006	478,649	473,972	534	72,435	346.7	160.0	42.9	0.46%

value. Stream flow was measured at the Nixon gage and was the average for April, May, and June for a given year (<http://waterdata.usgs.gov/nwis>). Multiple regression models were ranked according to their AIC_c value (Burnham and Anderson 2002, Motulsky and Christopoulos 2004).

RESULTS

Potential Egg Deposition Larvae Estimates

There was a broad range in potential number of eggs deposited in the 15 years we studied. Estimated egg release varied from 2.9×10^8 eggs in 1987 to 417.3×10^8 eggs in 2005 (Table 1).

Cui-ui were the predominant catostomid larvae captured in our 15 years of sampling (Fig. 3). The relative abundance of Tahoe sucker larvae declined over the course of the study. Annual cui-ui larvae net catches for the 2 nets fished were generally similar over the 12 years of comparison. There was no significant difference ($df = 11$, $t = -0.33$, $P = 0.75$) in numbers of cui-ui larvae captured between the 2 nets.

There was a strong positive relationship between the number of cui-ui larvae $\cdot m^{-3}$ for

each seasonal 4–6-h netting event and the number of cui-ui larvae $\cdot m^{-3}$ for the 24-h periods (Table 2). Estimated number of cui-ui larvae emigrating past MBD ranged from 4.8 million in 1987 to 1.2 billion in 1997 (Table 2). The SD between the 2 nets from 1993 through 2006 ranged from 0.2×10^6 in 2002 to 65.4×10^6 in 1995. Annual mean larval lengths ranged from 11.5 mm TL in 2003 to 12.7 mm TL in 1999, and the mean for all 12 years was 12.4 mm. There was a trend toward increasing larvae length with increasing stream flow, but this relationship was not significant ($R = 0.49$, $df = 9$, $P = 0.070$).

Survival

Survival from potential egg deposition to emigration to MBD ranged from 0.5% in 2005 and 2006 to 21.2% in 1995 (Table 1). The regression model with the lowest AIC_c score (104.9) and highest Akaike weight (0.685) contained both flow and density ($R^2 = 0.5$, $P = 0.01$; Table 3).

DISCUSSION

There was a broad range in survival rate from potential egg deposition of migrating

Fig. 3. Relative percent of cui-ui and Tahoe sucker larvae captured per year in 15 sampling years over a period of 22 years.

TABLE 2. Linear regression between 4- and 6-h sample periods and 24-h diels with R² and probability (*P*).

Years	Sample time	R ²	df	<i>F</i>	<i>P</i>
1993	19:00–00:00	0.97	1, 22	673	<0.001
1993	19:00–01:00	0.98	1, 22	1240	<0.001
1994, 1995, 1996	20:00–23:00	0.91	1, 22	223	<0.001
2005	20:00–02:00	0.98	1, 22	1192	<0.001
1985, 1986, 1996, 1997, 1998, 1999	21:00–01:00	0.97	1, 22	672	<0.001
2002, 2003	22:00–01:00	0.98	1, 22	1077	<0.001

TABLE 3. Values of the Akaike’s information criterion (AIC_c) used to select the best model from 4 candidate models of cui-ui larval survival in the Truckee River, Nevada, 1985–2006. Density is the number of adult cui-ui passed upstream of MBD in a given year. Flow is the average daily flow (m³ · s^{−1}) for April, May, and June of each year measured at the Nixon gaging station. The best model (lowest AIC_c value) is presented first; ΔAIC_c is the difference between AIC_c values of the individual models and that of the best model. Akaike weights (ω) provide a measure of each model’s relative weight or likelihood of being the best model in the data set given. K is the number of parameters in the model.

Model	R ²	df	<i>F</i>	<i>P</i>	AIC _c	ΔAIC _c	ω	K
Density + Flow + Constant	0.514	2, 12	6.351	0.013	104.894	0.000	0.685	3
Density + Constant	0.254	1, 13	4.433	0.055	107.504	2.610	0.186	2
Constant	—	—	—	—	108.724	3.830	0.101	1
Flow + Constant	0.042	1, 13	0.566	0.465	111.266	6.372	0.028	2

spawners to their emigrating progeny. Influencing this range was magnitude of stream flow and number of spawners released upstream of MBD. Survival tended to be greater with higher flows, and we suspect this was due to cooler water temperatures (Scoppetone et al. 1993). Also, high flows can facilitate

egg oxygenation and metabolic waste removal, leading to greater survival (Heard 1991, Greig et al. 2006). Reproductive success as related to water quality may also have a density-dependent influence (Elliott 1990). We suspect that restriction of spawning habitat caused by dams leads to overcrowding in spawning sites,

since lowest survival occurred in years with the greatest number of spawners. As eggs pile on top of each other, there may be insufficient oxygen to accommodate all eggs or later spawners may physically disturb incubating eggs (Pepin 2002).

Other studies tracking catostomid larvae emigration to lake environments (Geen et al. 1966, Modde and Muirhead 1994, Cooperman and Markle 2003) typically have not estimated survival. However, Ellsworth et al. (2010) determined that June suckers, *Chasmistes liorus*, experienced recruitment failure in years of low flow. The MBD Complex allowed us to estimate reproductive potential from the number and mean size of females passed upstream. The estimates are not adjusted for spawner mortality (Scoppettone et al. 2006) or residual egg retention; consequently, our survival estimates from egg deposition to emigrating larvae are likely conservative. The MBD Complex also provided the opportunity to estimate the number of emigrating cui-ui larvae.

This study gives survival estimates from potential egg deposition of spawner to emigrating larvae for an endangered catostomid over a 21-year period. Comparable early life-stage data on population survival are rare because there is typically not the opportunity to sample larvae for most fish populations and systems (Houde 2002). These results may be helpful in understanding the population dynamics of other long-lived western North American lake suckers and may enhance information on conditions affecting cui-ui population dynamics (Emlen et al. 1993). Our study suggests that increasing the amount of spawning habitat (currently restricted by inability of fish to move past dams) and increasing seasonal river flows would increase cui-ui survival from egg to emigrating larvae in this system.

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