Western North American Naturalist 79(1), © 2019, pp. 110–123

Size-specific fate and survival of June Sucker *Chasmistes liorus mictus* in Utah Lake, Utah

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ABSTRACT.—The June Sucker *Chasmistes liorus mictus* is a large-bodied catostomid endemic to Utah Lake, Utah. It is a federally listed endangered species, and one component to its recovery is a stocking program with a target of releasing 2.8 million fish averaging 200 mm long. Because size is implicated as a factor in poststocking survival of western native fishes, particularly in the presence of nonnative fishes, over a 4-year period a combination of telemetry and remote sensing was used to demonstrate size-specific poststocking survival of June Sucker in Utah Lake. A total of 88 June Sucker were released with acoustic tags to estimate short-term survival, and remote PIT scanners were deployed to examine long-term survival. Survival of telemetry fish varied from 0.0 to 0.83, with larger fish exhibiting the greatest survival in the final year. Size-specific survival was most evident in the analysis of PIT scanning data in which survival ranged from 2% for fish shorter than 200 mm to 90% for fish stocked at 300 mm. The causes of mortality are unknown, but likely culprits are nonnative fish and piscivorous birds. Both are well documented preying on June Sucker and similar species. Controlling predation may be impractical, but releasing fewer numbers of larger fish presumably will increase or maintain the population and be more cost effective than the current strategy. Overall, conservation and recovery of June Sucker will be a challenging endeavor going forward.

RESUMEN.—El catostómido June Sucker *Chasmistes liorus mictus* es pez de gran cuerpo, endémico de Utah Lake (Utah), considerado en peligro de extinción a nivel nacional. Un aspecto fundamental para su recuperación consiste en un programa de almacenaje enfocado en la liberación de 2.8 millones de peces con una longitud promedio de 200 mm. Debido a que el tamaño es un factor que influye en la supervivencia posterior al almacenaje de los peces nativos occidentales (particularmente en presencia de peces no nativos), durante un período de 4 años se usó una combinación de telemetría y teledetección para demostrar la importancia del tamaño en relación con la supervivencia posterior al almacenaje de los peces June Sucker en Utah Lake. En total fueron liberados 88 peces June Sucker con etiquetas acústicas para estimar su supervivencia a corto plazo, para evaluar la supervivencia a largo plazo y se emplearon escáneres remotos PIT. La supervivencia de los peces evaluados por telemetría varió de 0.0 a 0.83, siendo los peces más grandes los que exhibieron mayor supervivencia en el último año. La supervivencia relacionada con el tamaño fue más evidente en el análisis de los datos de escaneo PIT donde la supervivencia varió de un 2% en los peces de 200 mm a un 90% en los peces de 300 mm. Las causas de mortalidad son desconocidas, aunque las posibles causas de la mortalidad sean la presencia de peces no nativos y aves piscívoras. Ambos, peces no nativos y aves piscívoras han sido registrados como depredadores de los peces June Sucker y de otras especies similares. El control de la depredación puede resultar poco práctico, pero la liberación de una menor cantidad de peces grandes posiblemente aumente o mantenga la población y sea más rentable que la estrategia actual. En general, la conservación y el rescate de los peces June Sucker será una labor desafiante para el futuro.

June Sucker *Chasmistes liorus mictus* is a large-bodied catostomid endemic to Utah Lake, Utah; it is federally listed as endangered. Unlike many members of the family Catostomidae, June Sucker is one of 4 members characterized as lake suckers that possess a terminal, rather than inferior, mouth position (Miller and Smith 1981). This is an adaptation to feeding on plankton in the water column of pelagic zones, instead of bottom feeding. Adults are long lived, with sexual maturation between 5 and 10 years of age (Belk 1998). Mature adults participate in an annual spawning migration into tributaries of the lake, with peak activity in June (Modde and Muirhead 1994). Postemergence larvae

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drift downstream and occupy pool habitats before returning to the lake.

Historically, June Sucker numbered in the millions (Jordan 1891), but numbers declined drastically, and fewer than 1000 wild individuals were estimated to persist into the latter 1990s (USFWS 1999). Population decline is attributed to multiple factors including overharvest, habitat degradation, and negative interactions with nonnative species. Annual spawning migration occurs in 3 major tributaries (Hobble Creek, Provo River, and Spanish Fork River), but anthropogenic disturbances (i.e., altered flow regimes, river impoundments, and habitat degradation) have restricted spawning aggregates predominantly to the lower Provo River (UDWR 2014b). These disturbances and the introduction of a suite of nonnative species have resulted in June Sucker recruitment failures (Modde and Muirhead 1994, Belk et al. 2001).

A recovery plan (USFWS 1999) includes creating a refuge population, improving habitats, monitoring annual population, and augmentating the wild population using hatchery-reared fish. Recruitment bottlenecks have inhibited natural population growth, despite successful spawning. Therefore, augmentation became an important recovery plan component, and more than 350,000 individuals longer than 200 mm total length (TL) have been stocked into the lake with a target of stocking 2.8 million June Sucker (USFWS and URMCC 1998). However, sampling efforts in the past decade using traditional methods (larval light traps, trammel nets, trap nets, etc.) have not recorded juvenile fish in Utah Lake and its tributaries (UDWR 2014b), and fates of stocked June Sucker were and are mostly unknown (USFWS 1999, UDWR 2011, 2014a, 2014b).

A previous study estimated June Sucker poststocking survival at 5%, noting that survival was strongly correlated to rearing site and size at release (Rasmussen et al. 2009). Billman et al. (2011) reported several factors correlated with poststocking survival: size at release, rearing site, condition, season, and release site. However, both studies derived survival estimates from fish that had already successfully recruited to the adult population and thus did not capture short-term survival of juvenile fish; this approach may have been biased due to the time it takes for juveniles to reach maturity, potential site fidelity, and a sampling regime with unequal distribution of sampling effort (Billman et al. 2011).

This study was initiated in 2013 to evaluate poststocking survival of juvenile June Sucker. The study was two-fold: (1) immediate poststocking survival of hatchery-reared June Sucker was estimated using acoustic telemetry, and (2) longer-term survival of the augmented population was evaluated using a mark-recapture analysis of passive integrated transponder (PIT) data. These results contribute to a better understanding of the June Sucker augmentation program as well as the challenges faced in regard to conservation and recovery of the species.

METHODS

Survival estimates and movement patterns for captive-reared June Sucker were obtained from intensive acoustic telemetry and remote PIT-scanning studies conducted on Utah Lake. Each discrete segment of the telemetry study covered one of 3 seasons (early summer [June and July], late summer [July, August, and September], and early autumn [September, October, and November]) and provided short-term (9-week) survival rates. A total of 88 June Sucker were implanted with acoustic tags (see *Surgical Method* below), and 6600 additional fish were implanted with 134.2-kHz PIT tags prior to release into the lake. The first 3 years of study entailed 2 stockings and tracking periods per year, while the final year only required one. All June Sucker used for this study were raised at the Fisheries Experiment Station (FES), a UDWR facility in Logan, Utah. June Sucker at the FES are spawned by artificial crosses of an active brood stock held at the facility (Andersen et al. 2006). They are raised on commercial feed in circular fiberglass tanks, grown for approximately 1 year, and released into the lake at approximately 200 mm.

Study Area

Utah Lake is one of the largest freshwater lakes west of the Mississippi River and is situated on the eastern edge of the of Great Basin physiographic province (Fuhriman et al. 1981). The lake is a natural lacustrine system, encompassing a surface area of 38,400 ha, and it has a relatively uniform contour with an average depth of 2.8 m and a maximum depth of 4.2 m (Fuhriman et al. 1981). The climate is semiarid and the area receives little annual rainfall, resulting in a large net evaporation. Historically, Utah Lake's fish assemblage comprised 13 native fishes but is now reduced to 2 native species, June Sucker and Utah Sucker *Catostomus ardens*. Contemporary fish community composition is predominantly nonnatives, all of which negatively interact with native suckers (Radant and Hickman 1985, Belk et al. 2001).

Surgical Method

All surgeries followed established procedures (Mueller et al. 2000, Karam et al. 2008). Fish were implanted with model PT-4 acoustic transmitters (Sonotronics Inc., Tucson, AZ), which are small (25 mm long; weight in air 4.1 g) and reliable, and which have a minimal battery life of 90 d and a nominal range of 300 m. Before surgery, each individual was anesthetized by immersion in a dark container with approximately 16 L of fresh water and tricaine methanesulfonate (MS-222; 125 mg/L). A successfully anesthetized fish was indicated by lack of opercular movement, weak muscular movements, and cessation of fin movements. Once these criteria were met, the fish was removed from the container, measured (TL, mm), weighed (g), and scanned for a 134.2-kHz PIT tag. The fish then was placed on a surgery cradle ventral side up and covered in a wet towel to eliminate desiccation. Anesthesia was maintained by gently pumping MS-222 solution across the gills via the mouth with a small tube (4.77 mm diameter) for the remainder of the surgical procedure. A short (<2 cm) ventral incision was made slightly anterior to the left pelvic fin and an acoustic transmitter sanitized in 70% ethanol was inserted into the abdominal cavity. Fish absent a PIT tag were implanted with a 134.2-kHz tag via the incision. The incision was closed with 2–3 knots using 4-0 absorbable, braided, coated suture and an RB-1 (CV-23) 17-mm, ½-taper needle (AD Surgical, Sunnyvale, CA). Postsurgery fish were given an injection of a 10 mg/kg dosage of antibiotic Baytril® (enrofloxacin), and the incision was swabbed with betadine, both to aid in preventing infection (Martinsen and Horsberg 1995). Fish were then placed into an oxygenated recovery tank and monitored until tag retention was confirmed and full recovery was achieved, indicated by return of full motor function in the recovery tank (usually <15 min).

Stocking of PIT-tagged and telemetry-tagged fish followed standard protocols performed by FES in typical stocking events. Fish were tempered at a rate of 1 °C per hour to within 2 °C of lake water temperature. Fish were released during daytime into the Provo River mouth (Fig. 1). If water was too shallow in the mouth, fish were transported to deeper water for stocking.

In years 2013 and 2014, a total of 40 June Sucker at 244 mm mean TL (SD 11 mm, range 225 to 275 mm) were implanted with PT-4 tags at the release site: 10 on 29 July 2013 (late summer 2013), 10 on 17 September 2013 (early autumn 2013), 10 on 2 June 2014 (early summer 2014), and 10 on 31 July 2014 (late summer 2014). In 2013 an additional 10 June Sucker were implanted with PT-4 "dummy" tags, which are the same weight and size as the live tags. The purpose of the "dummy" tags was to evaluate the surgical technique in a controlled environment. Because of differences in conditions between lake and hatchery (i.e., water temperature, water chemistry, food availability, etc.), direct comparisons in survival could not be made between tagged and untagged fish. Therefore, the "dummy" tagged fish were held simultaneously with a control group of 10 untagged fish at FES for 60 d to make these direct comparisons.

In 2015 a total of 24 June Sucker (250 mm mean TL, SD 15 mm, range 224 to 288 mm) were implanted with PT-4 tags. The methodology was altered to address concerns about the recovery period of tagged fish. In addition, acoustic tags were modified to increase acoustic output and thereby increase detection range, which resulted in minor reduction in battery longevity. Nominal battery life was still longer than each tracking period (9 weeks). To maximize survival during the early summer period, 10 fish were surgically implanted with acoustic tags, PIT-tagged at FES, and held for 2 weeks (released on 22 June 2015). Acoustic tags were activated after implantation on the stocking date to ensure maximum battery life. In the early autumn stocking (31 August 2015), a total of 14 fish were implanted with PT-4 tags. Seven were held at FES for 2 weeks and stocked alongside 7 additional fish that were implanted lakeside and released the same day. The reasoning was to directly compare fish that were given a 2-week recovery period with fish that were released immediately following surgery.

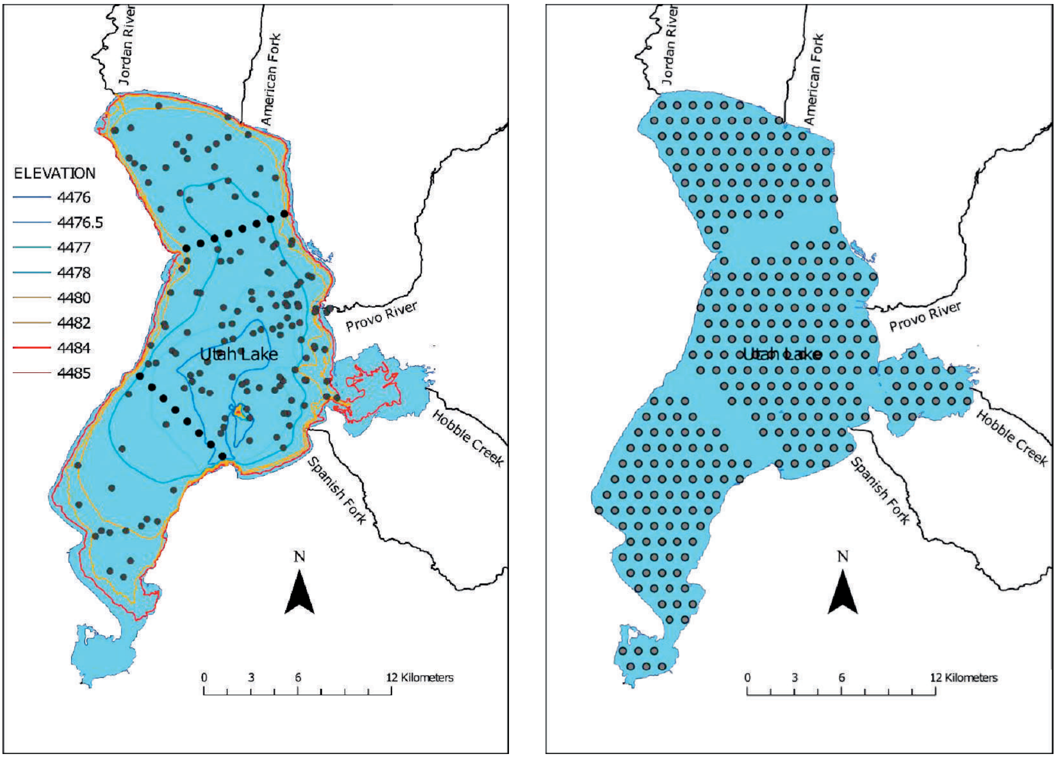

Fig. 1. Map of Utah Lake, Utah: SUR placements (left) and tracking points (right). Black circles represent the permanent SUR gates, and gray circles represent the randomly deployed SURs. SUR = submersible ultrasonic receiver. Elevation is given in feet (1 foot = 0.305 m).

In 2016, the primary objective was to directly compare survival between age-1 and age-2 fish. Twenty-four June Sucker (12 age-1 mean TL 212 mm, SD 12 mm, range 190 to 235 mm; 12 age-2 mean TL 311 mm, SD 16 mm, range 295 to 348 mm) were surgically implanted with model PT-4 acoustic transmitters and PIT-tagged. All surgeries were done at FES, and fish were held in separate tanks for 2 weeks prior to stocking; acoustic tags were activated after implantation on the stocking date (6 June 2016) to maximize battery life.

Passive Tracking

Each year prior to stocking, 20–22 submersible ultrasonic receivers (SURs) equipped with weights and buoys were deployed throughout the lake in permanent locations as a method of passive tracking. Initial trials indicated a PT-4 tag detection range of approximately 500 m from an SUR. Based on this distance, 16 SURs were used to section the lake into 3 zones with 8 SURs deployed 1000 m apart across the lake along 2 transect lines. Two SURs also were placed at the mouth of Provo Bay: one was placed in the mouth of Provo River and one was placed approximately 0.5 km upstream in Provo River to detect movement into and out of these areas. Each year an additional 4–5 SURs were deployed and moved around the lake in random locations generated with ArcGIS (Fig. 1). SUR data were downloaded weekly, and any fish detected within 12 h of the download time was manually tracked using active methods outlined below.

Active Tracking

Active tracking was conducted weekly for each 60-d tracking period over 4 study years using a directional or omnidirectional hydrophone connected to a programmable ultrasonic tracking receiver (Sonotronics DH-4 and USR-08, respectively). Detection trials for directional and omnidirectional hydrophones were conducted at 50-m intervals, indicating detection ranges of 400 m for directional and 300 m

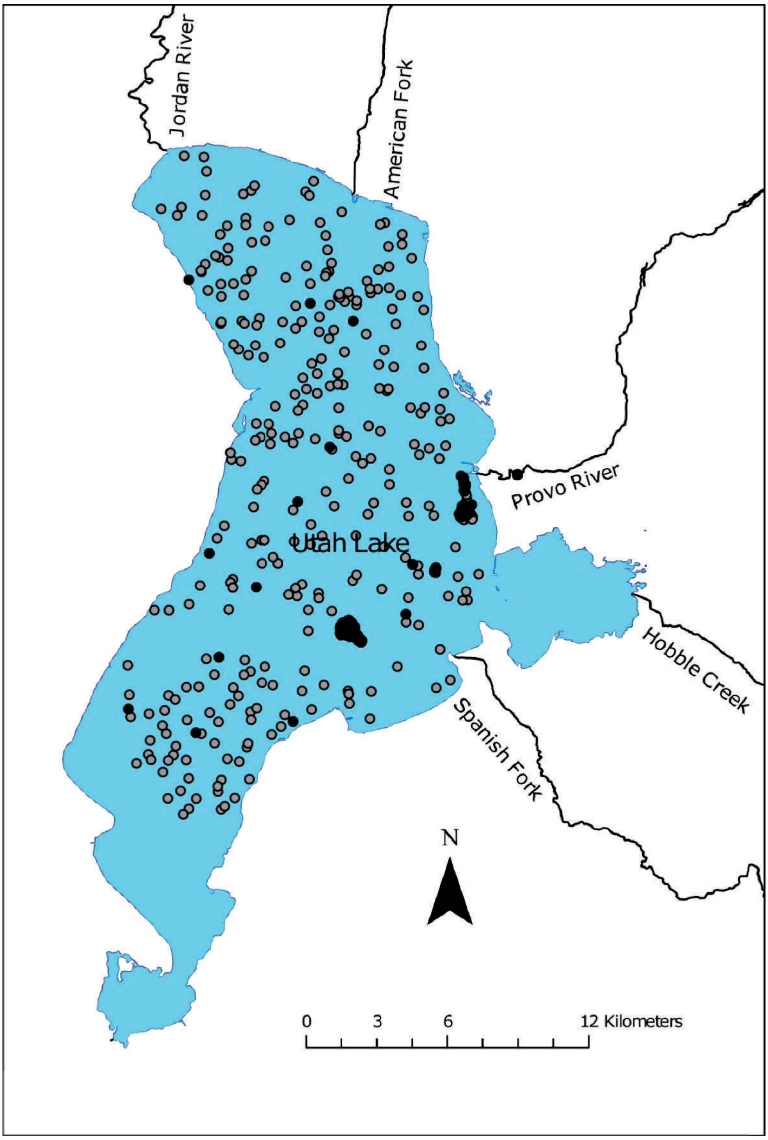

Fig. 2. Locations of all remote PIT-scanner deployments over the 4-year study period in Utah Lake, Utah. Gray circles represent deployments that did not contact any fish, and black circles represent deployments that contacted at least one fish.

for omnidirectional hydrophones. A nominal target was established to contact every fish once per day during the tracking period. At 1 week poststocking, SURs were downloaded to determine whether any fish had left the central zone. Up to 316 manual tracking points (1000 m apart) were visited weekly using a directional hydrophone, and the towable hydrophone was used to laterally transect the lake in search of fish between manual tracking points (Fig. 1). However, water levels were significantly lower in 2015 and 2016 compared to previous years, and many tracking points were inaccessible, especially in areas such as Goshen and Provo Bays.

Fish were considered missing if they were not contacted during the week. SUR data were incorporated to find fish that were not detected with active tracking. A search was initiated in the zone beyond the SUR transect

TABLE 1. Summary of remote PIT scanning deployments over the study period.

Year	Number of deployments	Hours of scanning	Number of contacts	Number of unique contacts
2013	136	3385	69	58
2014	144	4148	477	263
2015	336	14713	2274	773
2016	623	25843	1767	742

where the fish was last contacted. A search of the entire lake was initiated if a fish was missing for 3 tracking periods. A fish contacted in the same location for 3 subsequent tracking periods was considered a mortality and revisited periodically for confirmation. All individual fish contacted were triangulated using the directional hydrophone, and locations were identified and recorded by Universal Transverse Mercator (UTM) coordinates in a boat-mounted Global Positioning System (Garmin GPSMAP® 531s). Location and tag information were recorded, and data were incorporated into a database to facilitate data analysis and provide a history of each acoustic-tagged fish.

PIT Scanning

Portable remote PIT scanners were deployed in Utah Lake in order to contact juvenile PIT-tagged June Sucker released during this study and to supplement contact data for adult June Sucker already collected by UDWR. These data were used to assess poststocking and adult survival of PIT-tagged June Sucker. Remote PIT scanners initially were deployed at localities where June Sucker congregations were reported by UDWR and commercial fishers, or detected in past remote PIT-scanning studies (Ehlo et al. 2015a, 2015b). PIT scanners thereafter were deployed around the lake to examine June Sucker distribution in the lake proper.

PIT scanners were constructed of watertight PVC in 2 sizes: large PIT scanners (1.2 × 0.8 m) and small PIT scanners (0.8 × 0.8 m). These units housed internal components including a scanner, a logger, and a 10.4- or 20.8-amp-hour battery lasting up to 72 h or 120 h, respectively. Some PIT scanners were made to be neutrally buoyant, while others were negatively buoyant. Because June Sucker are midwater planktivores, PIT scanners were deployed in an upright position within the water column to increase contacts. This was achieved by adding weight to the bottom of neutrally buoyant units and adding foam "pool noodle" material to the top of negatively buoyant antennas. Read range typically was 25 to 30 cm when a PIT tag was parallel to the field (fish swimming over the antenna), and about 46 cm when a PIT tag was perpendicular to the field (fish swimming through the antenna).

The number of submersible PIT scanner antennas was increased in each year of study from 5 units in 2013 to as many as 30 in 2016. In total, PIT scanners were deployed 1269 times and accumulated 48,132 h of scanning time (Fig. 2). Altogether, remote PIT scanning made 4587 contacts, of which 1464 were unique PIT tags (fish that were contacted multiple times were only counted once) (Table 1). Most (1120) of the unique contacts represented encounters with June Sucker tagged at capture, June Sucker tagged at release or capture with incomplete information, or other PIT-tagged species (e.g., Utah Sucker, hybrid suckers). June Sucker with a poststocking or incomplete tagging recorded could not be used to assess poststocking survival because these individuals had already survived the poststocking period or the release period was unknown. After those records were excluded, 344 unique June Sucker stocked since 2007 with a 134.2-kHz PIT tag remained. June Sucker stocked in 2011 represented 64% of the fish within this stocking group (220 of 344 fish), with a mean TL at stocking of 309 mm (SD 39 mm, range 205 to 435 mm), and most scanned fish were released at >250 mm (Fig. 3).

Prior to and during this study, the UDWR maintained fixed-position multiplexing arrays (mux) installed on tributaries of Utah Lake to detect PIT-tagged spawning fish, including June Sucker. The first mux unit was installed on the Provo River in 2008, after spotlighting and netting surveys indicated that most of the June Sucker population spawns there (UDWR 2014b). Additional mux units were installed in other tributaries: Spanish Fork River, in 2009,

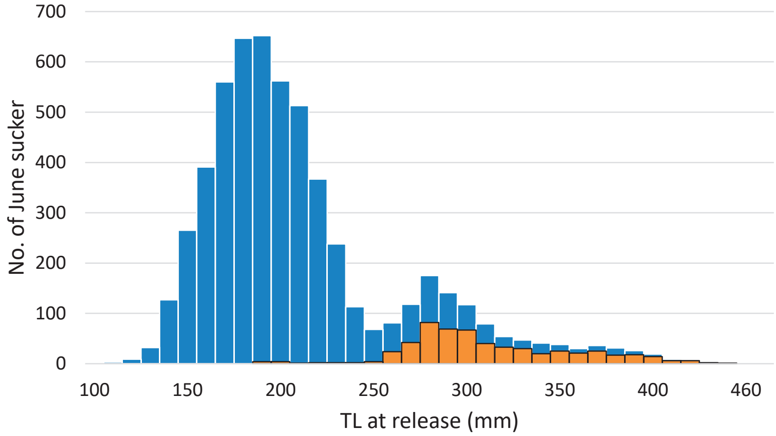

Fig. 3. Length frequency of June Sucker stocked in Utah Lake since 2010 with a 134.2-kHz PIT tag (blue bars) and length frequency (at release) of those fish encountered at remote PIT scanners (orange bars). PIT-scanning contacts of June Sucker within the same calendar year as release were excluded.

and Hobble Creek, in 2010. Data from these units were provided by the UDWR for inclusion in the mark-recapture model. No data were collected in Spanish Fork River in 2014 and 2015 due to equipment failure.

A total of 49,492 contacts representing 3163 unique individuals were recorded by UDWR PIT scanning efforts from 2011 through 2016. As with remote PIT scanners, most (2616) unique contacts were excluded due to timing of the tagging event or incomplete information (see above paragraph). After these records were removed, a total of 547 unique June Sucker remained (stocked with 134.2-kHz PIT tags and contacted by UDWR PIT scanners from 2011 through 2016). There were 237 June Sucker contacted by both remote and stationary scanners, resulting in 654 unique June Sucker encountered during the 6 years of scanning, and 581 individuals from this group were released in 2011 or later.

Data Analysis

Short-term survival estimates using active and passive tracking techniques were derived from hatchery-reared June Sucker using methods described by Kaplan and Meier (1958). To estimate survival, every individual was assigned to one of 3 fates: (1) fish died before end of study, (2) fish survived study, or (3) fish was lost to study (lost signal); every individual was assigned a fate for each week of study. Several scenarios were presented and addressed using the same methods. A fish lost but later found dead (after 3 subsequent tracking periods) was presumed alive up to the point that it was found dead. A fish lost to study and not contacted within the 60-d tracking period was determined lost the last time it was contacted (i.e., censored the week after last contact). Lost fish were not assumed to be mortalities because year-to-year differences in amount of trackable shoreline resulted in differences in contact probability among studies. In 2016, lake level was below 1367 m elevation, 1.5 m lower than in 2014. The lowered lake level reduced the total area that could be accessed via boat. The amount of shoreline habitat available to fish but not available to boats increased when the lake levels were low, increasing the probability that live sonic-tagged June Sucker could avoid detection. If all lost fish were assumed dead, then estimates of mortality would be influenced by the changing probability of detection due to shifting lake levels. Mortalities were designated to have occurred on the first date that a fish was contacted at the same location for 3 consecutive tracking events. Active and passive tracking data both were used to determine at what date a fish was permanently lost to study.

The Cormack–Jolly–Seber (CJS) mark-recapture model for live-encounter data was selected as the best overall model to assess poststocking survival of June Sucker. Most data for the model were contacts with spawning June Sucker from mux units. Remote PIT scanning conducted in the lake proper was

TABLE 2. Model comparisons from Program MARK for the mark-recapture models based on 134.2-kHz PIT-tagged June Sucker released in 2011 and 2013 and encountered from 2011 through 2016. Models provided in this table are not the complete set of models tested.

Model	QAICc	QAICc weights	Model likelihood	Parameters	QDeviance
$\Phi_{3\text{ age + Time + TL(age 1\&2)}}\ P_{3\text{ age + Time + TL(age 1\&2)}}$	2424.20	0.502	1.000	17	2390.00
$\Phi_{3\text{ age + Time+ TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1\&2)}}$	2424.27	0.485	0.967	16	2392.09
$\Phi_{3\text{ age + TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1\&2)}}$	2432.44	0.008	0.016	13	2406.32
$\Phi_{3\text{ age + TL(age 1\&2)}}\ P_{3\text{ age + Time + TL(age 1\&2)}}$	2434.22	0.003	0.007	14	2406.08
$\Phi_{2\text{ age + Time + TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1\&2)}}$	2435.52	0.002	0.004	15	2405.37
$\Phi_{3\text{ age + Time + TL(age 1\&2)}}\ P_{2\text{ age + Time + TL(age 1)}}$	2445.97	0.000	0.000	15	2415.81
$\Phi_{3\text{ age + Time + TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1)}}$	2446.69	0.000	0.000	15	2416.53
$\Phi_{3\text{ age + Time + TL(age 1\&2)}}\ P_{3\text{ age + Time + TL(age 1)}}$	2447.57	0.000	0.000	16	2415.39
$\Phi_{3\text{ age + Time + TL(age 1)}}\ P_{2\text{ age + Time + TL(age 1)}}$	2454.92	0.000	0.000	14	2426.78
$\Phi_{2\text{ age + Time + TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1)}}$	2455.44	0.000	0.000	14	2427.30
$\Phi_{3\text{ age + TL(age 1)}}\ P_{3\text{ age + Time + TL(age 1)}}$	2456.39	0.000	0.000	12	2432.29

used to supplement mux data, increasing the likelihood that all adult June Sucker had an equal probability of being encountered regardless of spawning behavior. Although the intent of in-lake scanning was to contact juvenile June Sucker released during the study period, most contacts in the lake were with adult June Sucker concentrated at a few locations. These locations may represent in-lake spawning sites or staging areas.

The computer program MARK was used to estimate apparent poststocking survival and encounter probability for the CJS model (White and Burnham 1999). Records for June Sucker stocked with a 134.2-kHz PIT tag into Utah Lake from 2011 to 2015 were initially considered for inclusion in the model. Few fish were released with a 134.2-kHz tag prior to 2011, and PIT scanning, which considerably increases probability of encounter, was implemented in all tributaries by 2011. Remote PIT scanning data collected during this study and PIT scanning and capture records provided by UDWR biologists were used to derive encounter histories. Encounter histories based on combined (remote and stationary) PIT scanning data and capture data from netting and spotlighting activities during the spawning period were annualized, with 1 to indicate a release or encounter at any time during a calendar year and 0 to indicate no encounter or release.

The CJS live-recaptures model within MARK contains 2 parameter groups: apparent survival (Φ) and encounter probability (P). Each parameter can be modeled to vary with time and age. Because of the limited number years of data available, age structure for both parameter groups was limited to a maximum of 3. Total length at release was added as an individual covariate to apparent survival and encounter probability for up to 2 years poststocking. The global model consisted of 16 parameters; apparent survival and encounter probability were structured as a 3–age class model in which the first 2 age classes (first and second poststocking years) covaried with size at release and both parameter groups varied with time (year). Size at release, time, and age were modeled as additive factors on apparent survival and encounter probability:

$$\Phi_{3\text{ age+Time+TL(age 1\&2)}}\,P_{3\text{ age+Time+TL(age 1\&2)}}$$

A complete model set list was developed using every combination of age structure equal to or less than 3 ages, with inclusion or exclusion of time and TL, resulting in a total of 121 models. Models were grouped by the survival parameterization (11 groups of 11 models) and were run sequentially, starting with the most complex model in the most complex model set (i.e., the global model). All 11 models in the first set were run, 8 from the second, 3 from the third, and so forth. The number of models run in each set was based on rankings of the most complex model in the set. It was assumed that models within one set that ranked lower than models in other sets with the same parameterization of recapture would likely continue to rank lower. In total, 37 models were run in MARK, and the top models are represented in Table 2.

TABLE 3. Fate of telemetry-tagged June Sucker stocked into Utah Lake, Utah, throughout the 4-year study.

	Week									
	1	2	3	4	5	6	7	8	9	Total
Late summer 2013										
Survivors	10	8	8	7	5	5	5	4	4	4
Mortalities	0	2	0	1	1	0	0	0	0	4
Lost fish	0	0	0	0	1	0	0	1	0	2
Early autumn 2013										
Survivors	8	6	5	5	4	2	2	2	2	2
Mortalities	0	0	1	0	0	1	0	1	0	3
Lost fish	2	2	0	0	1	0	0	0	0	5
Early summer 2014										
Survivors	9	2	2	2	2	2	1	1	0	0
Mortalities	1	5	0	0	0	0	1	0	1	8
Lost fish	0	2	0	0	0	0	0	0	0	2
Late summer 2014										
Survivors	7	1	1	0	0	0	0	0	0	0
Mortalities	3	0	0	1	0	0	0	0	0	4
Lost fish	0	6	0	0	0	0	0	0	0	6
Early summer 2015										
Survivors	10	8	6	6	6	6	6	6	6	6
Mortalities	0	1	2	0	0	0	0	0	0	3
Lost fish	0	0	1	0	0	0	0	0	0	1
Early autumn 2015										
Survivors	14	14	12	8	8	8	7	6	3	3
Mortalities	0	0	0	1	0	0	0	1	2	4
Lost fish	0	0	2	3	0	0	1	0	1	7
Age 1 2016										
Survivors	12	11	11	11	8	5	1	1	0	0
Mortalities	0	0	0	0	0	1	2	0	0	3
Lost fish	0	1	0	0	3	2	2	0	1	9
Age 2 2016										
Survivors	12	11	9	9	8	5	5	5	5	5
Mortalities	0	0	0	0	0	1	0	0	0	1
Lost fish	0	1	2	0	1	2	0	0	0	6

Models were ranked within MARK based on Akaike's information criterion (AIC) score (Akaike 1974). This value reported in MARK is a modified value (AICc) that adjusts for small sample sizes (Burnham and Anderson 2002). The value of $\hat{c}$ was 1.835 based on the Fletcher $\hat{c}$ estimator reported in MARK for the global model (Fletcher 2012). This estimate of $\hat{c}$ was used to adjust AICc values (QAICc). Reported parameter values were based on model averaging of all models with a QAICc weight of at least 0.01 (Johnson and Omland 2004).

There were 5605 PIT tag release records initially considered for the mark-recapture model (released between 2011 and 2015). Only 6 fish were released in 2012, too small a number to be useful in the model. More than 3000 June Sucker were released in 2014 and 2015, but few fish from these years have been reencountered, only 10 from 2014 and 5 from 2015. Mean TL at release was shorter in 2014 and 2015 compared to 2011 and 2013, and survivors among these smaller fish may take several years to reach maturity. Because most reencounters occurred during spawning activity, lack of contact with fish from 2014 and 2015 may be due to lack of maturity. Mean length at release in 2011 and 2013 was longer than in other years, but range was broad in both years (198 to 435 mm TL and 105 to 464 mm TL, respectively). Fish released in 2011 had up to 5 years to reach maturity during our study, and those from 2013 had 3 years. Therefore, the mark-recapture analysis was restricted to these 2 release years. All reencounters (release was considered as the first encounter in the model) with these fish from 2012 through 2016 were included. Although this reduced the number of released June Sucker evaluated in the model from 5605 to 2208, the number of reencounters was only slightly reduced from 598 to 576. Effective sample size for the mark-recapture model (initial release encounters + reencounters between 2012 and 2016) was 3057.

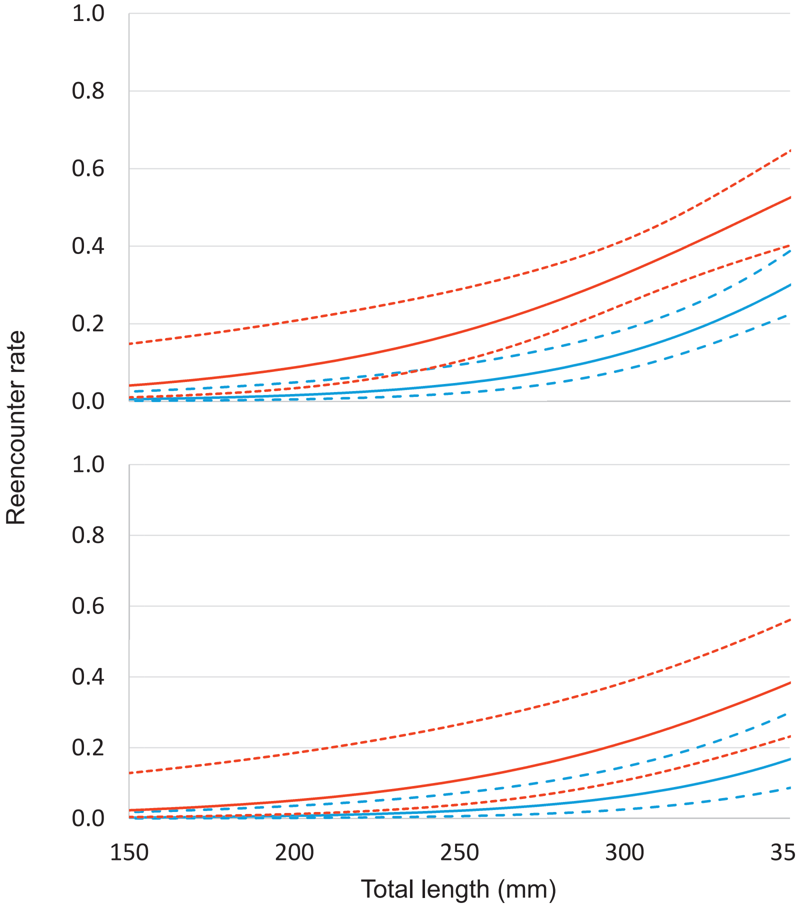

Fig. 4. Reencounter rate by remote PIT scanning of June Sucker stocked in 2011 (top) and 2013 (bottom). Solid blue lines indicate age-1 fish, with dotted blue lines depicting the 95% confidence interval. Solid red lines indicate age-2 fish, with dotted red lines depicting the 95% confidence interval.

Results

SURs continuously scanned for all seven 60-d tracking periods and recorded 133,726 contacts representing 86 of the 88 acoustic-tagged fish throughout the 4 study years. Manual tracking efforts resulted in 300 contacts representing 73 of 88 acoustic-tagged fish (Table 3).

In 2013, 18 of 20 acoustic-tagged fish were contacted by active and passive tracking. Kaplan–Meyer survival estimates were higher for late-summer fish (0.58; 95% CI 0.27 to 0.86) than early-autumn fish (0.42; 95% CI 0.15 to 0.74). However, overlapping confidence intervals indicate that estimates were not significant. In addition, there was no mortality of either "dummy" tagged fish or untagged fish in the controlled settings, validating the surgical technique and telemetry tag selection. In 2014, 20 of 20 telemetry fish were contacted by active and passive tracking. Survival estimates for early-summer fish decreased steadily from 0.90 (95% CI 0.54 to 0.99) in week 1 to 0.40 (95% CI 0.14 to 0.73) in weeks 2–6 to 0.20 (95% CI 0.04–0.56) in weeks 7 and 8 and finally to 0.00 (95% CI 0.00–0.34) in week 9. Kaplan–Meier estimates were not calculated for late-summer fish due to censoring of the majority (6 of 10) of fish after the first week of tracking. In 2015, 24 of 24 telemetry fish were contacted by active and passive tracking. Early summer survival estimates were 0.67 (95% CI 0.33 to 0.91), while survival estimates for early autumn were not calculated because the fates of half the fish released were unknown (lost

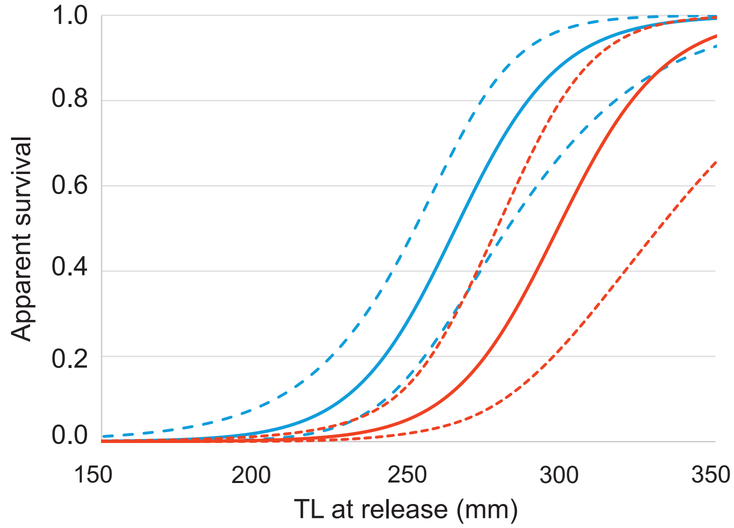

Fig. 5. Relationship between size at release and first-year apparent survival for June Sucker stocked into Utah Lake in 2011 (blue) and 2013 (red). Dashed lines represent 95% confidence intervals. The relationship was estimated from model-averaged results of a mark-recapture model assessed in MARK based on encounter data from 2011 through 2016.

fish). As a result, differences between hard and soft releases could not be determined. In 2016, 24 of 24 telemetry fish were contacted by active and passive methods. Age-1 survival estimates were not calculated due to the lack of any survivors and the number of lost fish. The age-2 survival estimate was 0.83 (95% CI 0.51 to 0.97).

All models with a QAICc weight of more than 0.001 had TL as a covariate for apparent survival and reencounter rate (Table 2), indicating a significant influence of size at release on both poststocking survival and reencounter rate. Reencounter rate estimates were size specific for the first 2 years after release, and different among release cohorts (Fig. 4). Adult reencounter rates were estimated for the 2011 release cohort at 0.618 (95% CI 0.530 to 0.699) for 2014 and 0.612 (95% CI 0.519 to 0.697) for 2015. The reencounter rate in 2016 was confounded with survival due to time-varying survival and reencounter rates in all models used for model averaging.

Apparent first-year survival for June Sucker stocked at 200 mm TL was 0.020 (95% CI 0.005 to 0.078) for fish stocked in 2011 and 0.003 (95% CI 0.001 to 0.012) for fish stocked in 2013 (Fig. 5). Estimated apparent survival of a June Sucker at 300 mm increased with size (TL): 0.898 (95% CI 0.695 to 0.971) for fish stocked in 2011 and 0.555 (95% CI 0.241 to 0.830) for fish stocked in 2013 (Fig. 5). Estimates of apparent survival also increased with age. Model-averaged estimates of second-year apparent survival for 2011 and 2013 were 0.737 (95% CI 0.411 to 0.919) and 0.714 (95% CI 0.324 to 0.928), respectively, and third-year survival for a 2011 stocking was 0.888 (95% CI 0.782 to 0.946). The top 4 models, with nearly 98% of the QAICc weight, differed only in factors influencing apparent survival; number of ages influenced by size at release (age-1 and age-2, with TL as a covariate), and presence or absence of time.

DISCUSSION

Nine-week poststocking survival of hatchery-raised June Sucker is low (only 20 of the 88 fish survived the 9-week telemetry tracking period), small sample size and low statistical power notwithstanding. There was also a high number of fish lost to the study, and these lost fish could represent either mortalities (i.e., tags deposited on land or another place where acoustic telemetry was ineffective) or survivors (i.e., fish that persisted in shallow water that was not effectively trackable). Kaplan–Meier survival estimates would increase or decrease depending on which fate the lost fish actually experienced. Even with strong statistical power, it would be difficult to extrapolate 9-week

Kaplan–Meier estimates because environmental variability could affect the population over the year (e.g., changing water chemistry, water depth, etc.). Regardless, mark-recapture analysis reinforces short-term results based on PIT-tag scanning data, and despite temporal variation, the analysis shows that the probability of surviving the first year poststocking is <2% for small (200-mm) June Sucker.

While the main causes of mortality are not known, predation by nonnative fishes is well documented and has exacerbated the decline of southwestern native fishes (Minckley and Deacon 1991), with June Sucker being no exception. A suite of nonnative species has been established in Utah Lake, species which prey on and compete with every life stage of June Sucker. White bass *Morone mississippiensis* readily consumes larval June Sucker (Belk et al. 2001), but its small size likely precludes predation on larger individuals. However, larger carnivores such as walleye *Sander vitreus*, largemouth bass *Micropterus salmoides*, and northern pike *Esox lucius* are capable of preying on all but the largest adult June Sucker (UDWR 2014a). In addition, piscivorous birds play a role in June Sucker survival. Ehlo et al. (2015b) visually observed and documented California Gull *Larus californicus* preying on June Sucker immediately poststocking. American White Pelican *Pelecanus erythrorhynchos* also occurs in large numbers on Utah Lake and is capable of ingesting June Sucker regardless of stocking size. In fact, Evans et al. (2016) documented predation by American White Pelican on a 730-mm Lost River Sucker *Deltistes luxatus*, a species closely related to June Sucker. Scoppettone et al. (2014) estimated that pelican predation on Cui-ui *Chasmistes cujus*, another similar species, resulted in 90% mortality in Pyramid Lake, Nevada. While bird predation, particularly by California Gull and American White Pelican, is naturally occurring, it likely exacerbates effects of nonnatives on June Sucker. There is no evidence that other important sources of mortality (e.g., disease, old age, pollution, fishing) account for lost fish or the low survival estimated during the time frame of this study.

Conclusively, size at release is one of the most significant factors dictating poststocking survival of June Sucker. This result is most evident in the mark-recapture analysis. Survival was as low as 0.02 in 2011 and 0.03 in 2013 for 200-mm fish and as high as 0.90 in 2011 and 0.59 in 2013 for 300-mm fish (Fig. 5). Although statistical power was low for the telemetry portion of the study, in the final year all smaller fish were either mortalities or lost to the study, compared to larger fish, of which almost half survived the 9-week study (Table 3). These results mirror findings by Billman et al. (2011) and Rasmussen et al. (2009), who both concluded that size at release was an important determinant of June Sucker survival. This relationship also is documented for other large-bodied desert suckers: for example, there is a strong positive relationship between size at release and survival of Razorback Sucker *Xyrauchen texanus* (Minckley et al. 2003, Marsh et al. 2005, Zelasko et al. 2010).

The current June Sucker population of a few thousand individuals is maintained largely by an augmentation program that has stocked more than 350,000 individuals. Our data indicate that releasing fewer numbers of larger fish (300 mm) will increase or maintain the population at the same size and presumably be more cost effective than continued release of large numbers of smaller fish (200 mm). Increasing size at release should alleviate predation on June Sucker by smaller predators. Still, the species continues to show little evidence of natural recruitment within Utah Lake, presumably because of negative interactions with nonnatives (Belk et al. 2001). Exclusion of nonnative fishes has been successful in maintaining populations of endangered fishes in the southwestern United States by allowing them to survive, reproduce, and recruit. An example is Cibola High Levee pond, where native Bonytail *Gila elegans* (a cyprinid) and Razorback Sucker both reproduce and recruit successfully (Mueller 2006). However, Utah Lake is a large body of water, and removal and exclusion of nonnative fish on that scale may not be a feasible option. Potential loss of recreational fishing opportunities presents another impediment (Clarkson et al. 2005). Minckley et al. (2003) outlined a plan to construct isolated backwaters along the lower Colorado River to provide nonnative free habitats and aid in recovery of endangered big river fishes. Modeling this plan, modest-sized ponds could be constructed adjacent to Utah Lake to provide this essential nonnative-free habitat for June Sucker to reproduce, recruit, and grow out for eventual repatriation. Finally, fish derived from natural spawning may have higher survival than hatchery-produced individuals (e.g., Anderson et al. 2013), so management strategies that increase natural recruitment could be developed and implemented to benefit the species. Overall, continued conservation and recovery of June Sucker will be a challenging endeavor moving forward.

ACKNOWLEDGMENTS

This work was funded by the June Sucker Recovery Implementation Program. M. Mills, Local Coordinator, facilitated an agreement in behalf of the program, which also provided PIT tags for the study. Care and use of fish in this study was approved by the Institutional Animal Care and Use Committee of Arizona State University, protocol numbers 11-1149R and 13-1318R. We thank M. Mills, S. Seegert, D. Tinsley, R. Mellenthin, D. Routledge, J. Reynolds, J. Watson, G. Howes, M. Fullmer, D. Wiley, C. Crockett, K. Patterson, J. Wisenall, S. Gehrke, A. Burgad, and S. Hannam for assistance with tagging, surgery, and fieldwork. We also thank Utah Lake State Park for storage and lodging accommodations.

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Received 24 February 2018
Revised 2 August 2018
Accepted 10 December 2018
Published online 22 April 2019