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GREEN STURGEON

Evidence of spawning by green sturgeon, *Acipenser medirostris*, in the upper Sacramento River, California

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Abstract This study reports the only direct evidence of spawning of green sturgeon, *Acipenser medirostris*, in the upper Sacramento River, CA. Two green sturgeon eggs were collected with substrate mats immediately below Red Bluff Diversion Dam. One green sturgeon larva was collected with a larval net at Bend Bridge. We concluded that green sturgeon spawn in the upper Sacramento River, both above and below RBDD. Temperature ranges in the study area (10–15°C) are similar to conditions used in successful artificial rearing of green sturgeon and do not appear to be a limiting factor to successful spawning of green sturgeon; however, suitable habitat upstream of RBDD is inaccessible when dam gates are lowered.

Keywords Artificial substrates · Larval nets · Rotary-screw traps · Migration · Red Bluff Diversion Dam

Introduction

The green sturgeon, *Acipenser medirostris*, is the most widely distributed member of the sturgeon family (Moyle et al. 1992). Despite its wide geographic distribution in the northern Pacific Ocean, the green sturgeon is considered a rare or vulnerable species in the United States and Canada (Birstein 1993; Moyle et al. 1994; Cambell 1997). The green sturgeon is identified as a species of special concern by California Department of Fish and Game (CDFG) and a species of concern by the U.S. Fish and Wildlife Service (USFWS). The only known spawning populations in North America are in the Klamath, Rogue, and Sacramento rivers, all of which have flow regimes that are affected by water projects (Moyle et al. 1994). The operational regime of Red Bluff Diversion Dam (RBDD), an agricultural diversion structure located on the Sacramento River, consists of closing the RBDD gates in spring and opening them in the fall started in 1987. Current operation dates are: gates-in 15 May, gates-out 15 September. Once the gates are in place, up-stream passage is limited to a fish ladder engineered for salmonids. No sturgeon has been observed to pass through this structure since dam operations began in 1966. The start of the irrigation season and the operation of the dam roughly coincide with the spring spawning up-migration, which occurs in April and May (data from Rogue River, Erickson & Webb this issue). An unknown portion of the adult green sturgeon population are able to migrate past Red Bluff and spawn upstream prior to the dam operation period,

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whereas passage of fish migrating after 15 May is blocked. River out-migration is thought to occur in early winter coinciding with the first winter storms (Erickson et al. 2002), and thus should not be impeded by the dam operations.

Observations of adult green sturgeon in a 16-km reach below RBDD after the annual spring lowering of the dam gates suggest spawning takes place below the dam (Moyle et al. 1995). Rotary screw traps, attached to RBDD just beyond the hydraulic boil caused by the bottom discharge gates, captured 517 sturgeon larvae from 15 July 1994 to 30 June 1995 (Johnson and Martin 1997) and 1 291 sturgeon larvae ranging from 20 to 40 mm total length RBDD between 1996 and 2000 (Table 1) (Gaines and Martin 2001). Subsamples of the 1996–2000 year-class larvae, raised at the U.C. Davis Center for Aquatic Biology and Aquaculture (CABA) and identified as green sturgeon, confirmed that spawning occurs upstream of RBDD. The objective of this study was to identify green sturgeon spawning locations and dates in the upper Sacramento River. This is a report of my findings during the year of 2001.

Study area

The river below Shasta Dam can be divided into three reaches. The upper river is defined as the reach from Shasta Dam river kilometer (rkm) 505 to Colusa (rkm 231) with pool-riffle-and run characteristics. The middle reach is Colusa (rkm 231) to the mouth of the Feather River (rkm 128) that includes some spawning areas of white sturgeon. The lower river is defined as the reach from Verona (rkm 128) to San Francisco Bay. The section of the upper Sacramento River examined for use by spawning green sturgeon adults ranged from rkm 383 to rkm 425 (Fig. 1). This reach is generally not leveed and can be considered stable. Near Redding, the river is broader and slower, but below Jelly's Ferry (rkm 429) it enters Iron Canyon and forms a series of rapids, becoming a bedrock stream controlled by the underlying geology (Reynolds 1990). At Red Bluff the river enters the valley proper. Despite agricultural and urban development, the upper river remains mostly in a natural state supporting areas of riparian vegetation.

River flows on the upper Sacramento River within the study area are influenced by releases from Shasta dam. During winter and early spring, flows can fluctuate significantly due to accretion from tributaries or flood-control releases. Flows in the study area generally range from 169 $m^3 s^{-1}$ during non-flood periods to 1,415 $m^3 s^{-1}$ during flood events. When the dam gates are lowered at RBDD, flows are controlled to meet irrigation needs from May through September and range from 283–425 $m^3 s^{-1}$.

Methods

I used artificial substrate mats of furnace filter material bolted to 86 cm × 60 cm angle-iron frames (McCabe and Beckman 1990) to sample for green sturgeon eggs. Mats were held in position on the river bottom by a cement filled PVC anchor with three metal flukes. A 9.5 mm-diameter buoy line with a numbered float was attached to the anchor to mark the location of each substrate. Float line length varied with the depth and velocity. I selected sampling areas based on observations of adult sturgeon by river guides and USFWS field crews. I selected locations upstream of deeper holes in higher velocity water using a depth finder. Coordinates for each site were recorded using a portable GPS. I placed artificial substrates at depths of 1.5–3.6 m. I examined the mats twice weekly, cleaned them of sediment, and replaced them. I sorted samples recovered from

Table 1 Summary of green sturgeon captured in rotary-screw traps at Red Bluff Diversion Dam 1995–2000

	Year					
	1995	1996	1997	1998	1999	2000
Number captured	414	1363	355	350	78	97
Mean total length (mm)	33	34	30	26	26	31

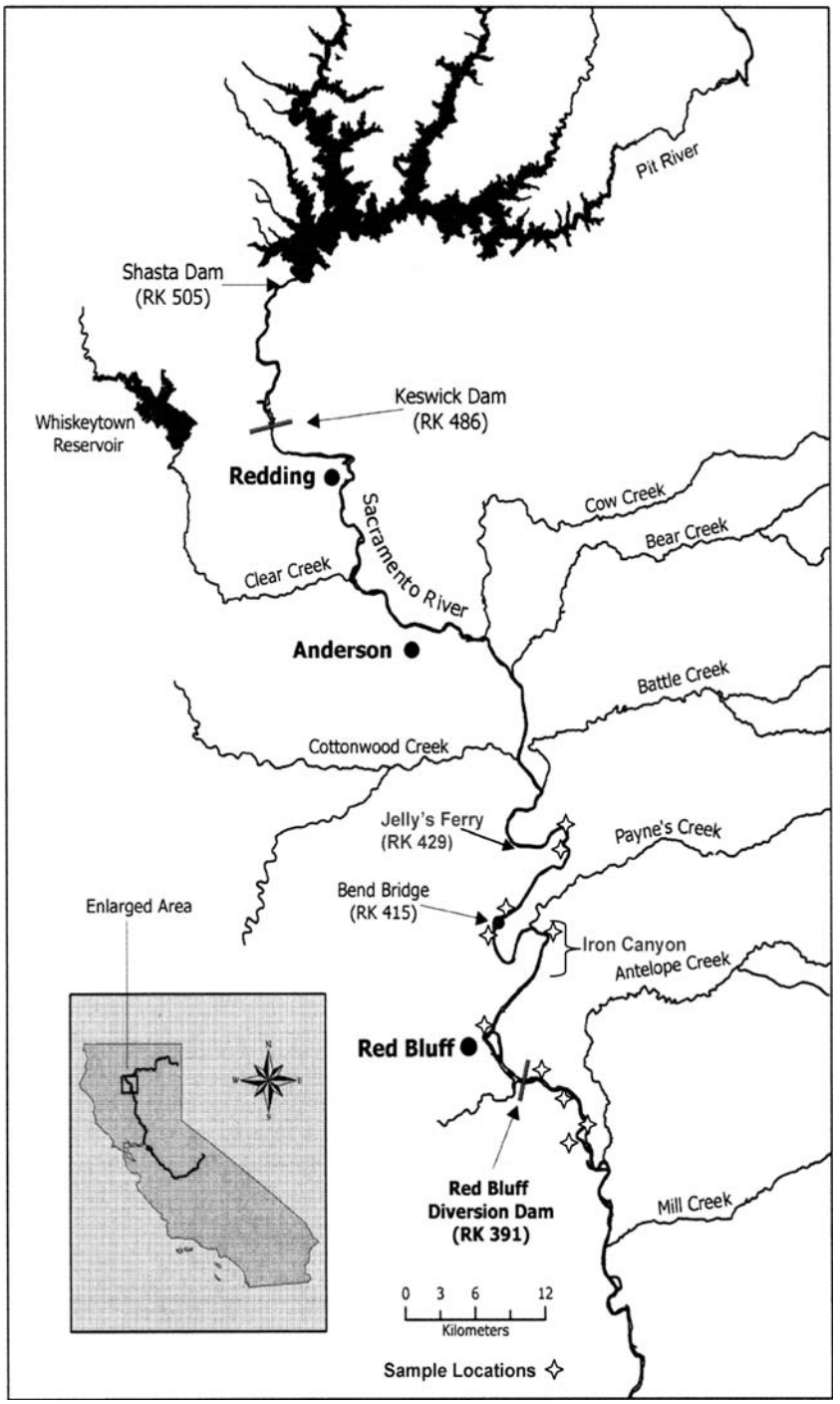

Fig. 1 Area view of northern California showing the location of Red Bluff Diversion Dam (RBDD) and the study area rkm 383–425

the mats in the field and preserved them in 70% ethyl alcohol.

On 21 March 2001, three to five substrate mats were placed at nine locations from rkm 383 to rkm 425, with a total of 28 mats deployed. Due to time constraints, only 22 mats were deployed through mid-May. Three mats at RBDD were removed during the period when

gates were being lowered. On 17 May two mats were replaced along the right bank and two along the left bank below RBDD. An average of 23 substrate mats were deployed per day for 15 weeks until 16 July, when spawning was thought to have ended.

Larvae sampling began 26 June and continued twice weekly until 24 July, using a cone shaped net constructed of 1.2 mm polyester square mesh netting similar to that used for collection of sturgeon larvae in the Sacramento River (Kohlhorst 1976). The net was deployed for a total of 21 h. To facilitate safe navigation, night sampling was limited to three sites located near boat ramps. The boat was secured to a structure in the river when possible or held stationary by the boat operator. Sampling with the larval net lasted up to 30 min. Because green sturgeon larvae are active in darkness (Van Eenennaam et al. 2001) sampling took place twice weekly during evening and pre-dawn hours for all sites. Evening sampling usually began at 17:00 h and extended to 22:00 h. Pre-dawn sampling began at 04:00 h and ended at 08:00 h. I sampled 18 times at RBDD (rkm 390), three times at Dog Island (rkm 396) and nine times at Bend Bridge (rkm 415). Two additional sites were chosen for post-dawn sampling; Supan Riffle (rkm 406) which was sampled ten times and Salmon Hole (rkm 424) was sampled three times. Samples for both techniques were sorted in the field and specimens preserved with 70% EtOH.

Results

Flow and temperature

During the only significant rainfall event (5 March, 2001) flows as high as 1,500 m^3 s^{-1} were recorded at Bend Bridge. Flows during the last week of March through mid-May ranged from 198–306 m^3 s^{-1}. Average daily flows measured by the California Department of Water Resources at Bend Bridge were 200 m^3 s^{-1} when substrate mats were first deployed on 21 March (Fig. 2). River temperatures are required to remain below 13.3°C at Bend Bridge to provide for successful incubation of winter-run chinook salmon, *Oncorhynchus tshawytscha*, eggs. This temperature regime is maintained by controlled releases from Shasta Dam. Daily temperatures upstream of RBDD ranged from 10.7 to 15.8°C. Daily temperatures below RBDD ranged from 8.3 to 15.1°C. Average daily temperatures measured by the California Department of Water Resources at RBDD ranged from 8.3 to 15.1°C (Fig. 3).

Artificial substrate sampling

Two sturgeon eggs were found on one of the mats, river left, immediately below RBDD 14 June. The eggs were identified as green sturgeon by the UC Davis Genome Lab (Josh Israel, personal communication). No other sturgeon eggs were collected from mats at other sites. The

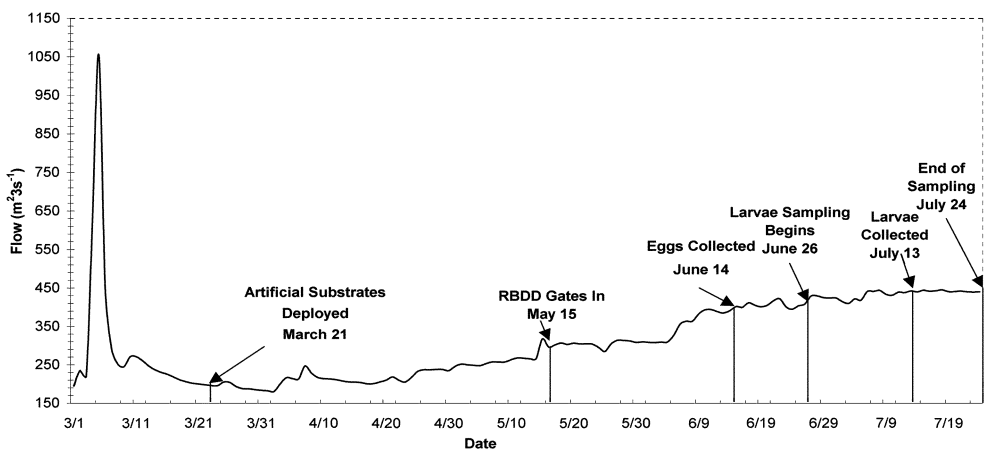

Fig. 2 Daily river flows recorded at Bend Bridge from 1 March to 24 July 2001

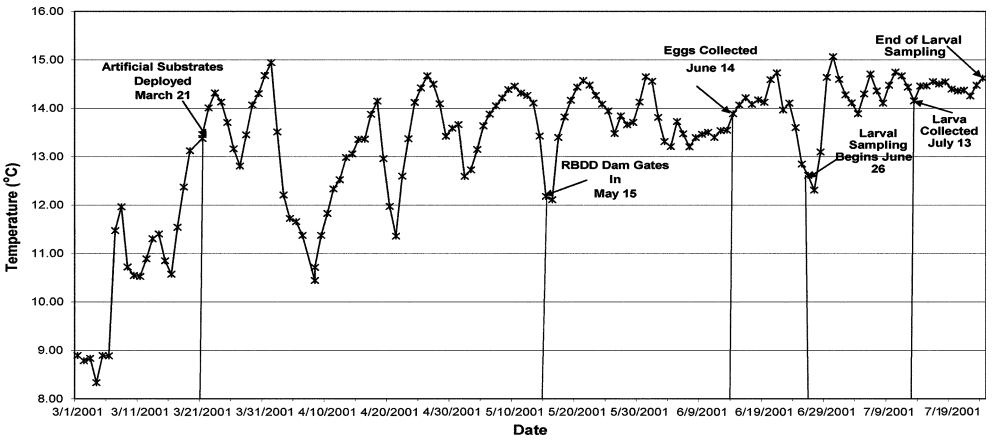

Fig. 3 Average daily river temperatures at Red Bluff Diversion Dam 1 March to 24 July 2001

spawning dates of these eggs, estimated by UCD CABA based embryonic development, suggested that they were spawned on 11 June. Adult green sturgeon were observed periodically through June by FWS personnel immediately below RBDD after gates were lowered on 15 May.

Larvae sampling

One 24-mm total length sturgeon larva was captured during the pre-dawn hours on 13 July at Bend Bridge, and was identified as a green sturgeon by the UC Davis Genome Lab. Based on the stage of development, the larva was estimated to be 13 days post-hatch. Assuming an incubation period of 6 days, it would have been spawned on 24 June. Discussions with river fishing guides revealed observations of adult sturgeon at two locations upstream of the study area.

Discussion

The collection of two sturgeon eggs and one larva is the only direct evidence of green sturgeon spawning in the Sacramento River that permit us to estimate dates and general locations of spawning. The capture of larvae between 1994 and 2000 (Gaines and Martin 2001) (Fig. 4) also corroborate this; however, these samples were collected in large rotary screw traps and were not examined for stage of development, and thus do not provide any indication of spawning location or date.

This study was originally designed in 1997 using the prevalent methodology at that time, e.g.; artificial substrate mats, for the capture of eggs and larvae of white sturgeon. Later findings from artificial spawning and larval rearing of green sturgeon (Van Eenennaam et al. 2001) indicated that green sturgeon eggs may be less adhesive than eggs from other acipenserids, possibly reducing the effectiveness of artificial substrates. This knowledge prompted the subsequent decision to use net sampling at night.

Information is lacking regarding spawning migrations, spawning or nursery habits of green sturgeon in the upper Sacramento River. In the Klamath River, the spawning period is March–July, with a peak from mid-April to mid-June (Emmett et al. 1991). This time period (April to June) is comparable with the observations of adult green sturgeon at RBDD (personal observations).

The estimated spawning dates of the eggs and larva (11 June and 24 June, respectively) fall within the spawning period of late April through July as suggested by the rotary screw trap data at RBDD from 1994 to 2000 (Fig. 4). The habitat requirements of green sturgeon are poorly known; however, the comparatively large egg size, thin chorionic layer on the egg and other characteristics of green sturgeon eggs indicate that cold (8–14°C), clean water is required for spawning (S. Doroshov, personal communications). Preferred spawning substrate is likely large cobble, but can range from clean sand to bedrock

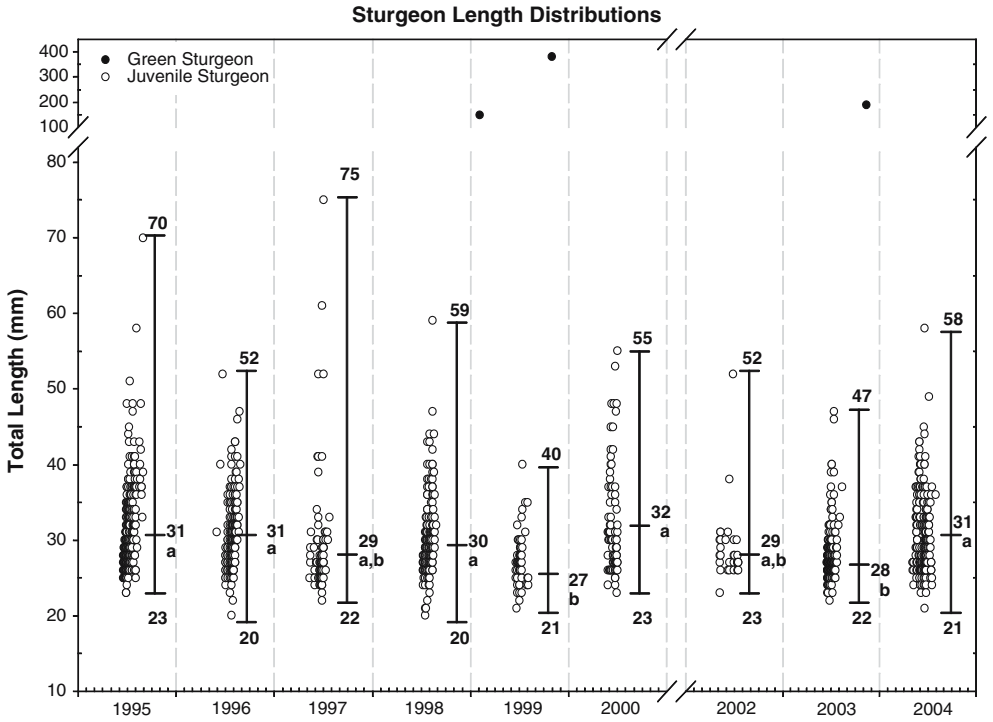

Fig. 4 Length distributions for juvenile white and green sturgeon captured by rotary-screw traps at Red Bluff Diversion Dam summarized from January 1995 through June 2000 and April 2002 through December 2004. In 1996 and 1997, 124 juvenile sturgeon were grown to the size of juveniles and identified as green sturgeon, *Acipenser medirostris*. The yearly mean total lengths with common letters were not significantly different (Tukey HSD, $P > 0.05$)

(Moyle et al. 1995). Substrate immediately below RBDD, where the eggs were collected, is mainly composed of large cobble. Substrate above Bend Bridge, where the larva was collected, is a combination of gravel and bedrock. Substrate and temperature are consistent with expectations at sites where eggs and larva were found.

Cold water releases from Shasta Dam (since 1988), intended for incubation of winter-run Chinook eggs may also provide optimal temperatures for green sturgeon spawning and egg incubation. Temperature ranges within the study area are similar to conditions used in successful artificial rearing of green sturgeon and do not appear to be a limiting factor to successful spawning.

The raised position of the RBDD gates during the first portion of the upstream migration of adults provides access to additional and possibly better spawning habitat; however, this habitat becomes inaccessible when dam gates are lowered. The size of upstream migrating adult sturgeon precludes the use of existing fish ladders at RBDD. No sturgeon has been known to pass the ladders since RBDD went into operation in 1966.

We concluded that green sturgeon spawn in the Sacramento River above RBDD and that suitable habitat and conditions exist. However, the extent of these conditions is unknown. Further studies to evaluate habitat and larval sampling are needed to determine the extent of these conditions above and below RBDD and whether the operation of RBDD affects the timing of adult migration.

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