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Estimating the annual spawning run-size and population size of the Southern Distinct Population Segment of Green Sturgeon *Acipenser medirostris*

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<A>Abstract

The Southern Distinct Population Segment of Green Sturgeon spawns in the Sacramento River, California and is listed as a Threatened Species by the Federal Endangered Species Act. We estimated the spawning run and population size in 2010 – 2015 using Dual Frequency Identification Sonar (DIDSON) sampling, underwater video camera species identification, and acoustic tag detections. Spawning run-size varied from 336 to 1,236 individuals. We estimated total population size to be 17,548 individuals (95% confidence interval = 12,614 – 22,482). We estimated the number of adults to be 2,106 (1,246 –2,966), the number of juveniles to be 4,387 (2,595 – 6,179) and subadults to be 11,055 (6,540 – 15,571). This study provides the first estimate of Sacramento River Green Sturgeon run-size and initiates a time series of abundance that can inform Endangered Species Act recovery processes. Furthermore, these absolute abundance estimates provide a context for evaluating the significance of impacts, such as bycatch in coastal fisheries or entrainment in water diversions, where the number of impacted individuals is known.

<A>Introduction

Green Sturgeon *Acipenser medirostris* are anadromous fish which spawn in three major river systems in California and Oregon (NMFS 2006). The species is separated into two distinct population segments (Israel et al. 2004), which are managed separately by the National Marine Fisheries Service. The Northern Distinct Population Segment (NDPS) consists of individuals that spawn in the Rogue River in southern Oregon and the Klamath River in northern California while individuals in the Southern Distinct Population Segment (SDPS) spawn in the Central Valley, California. The SDPS was designated as a Threatened Species by the National Marine Fisheries Service in 2006 (NMFS 2006). The NDPS was designated a Species of Concern (NMFS 2006) but the concern for NDPS abundance was buffered by the presence of two separate spawning stocks. Loss of spawning habitat is considered a detriment to a sustained population of Green Sturgeon in the Central Valley, California (Adams et al. 2007).

The amount of historical habitat available to Green Sturgeon varies by population. The NDPS currently has access to 100% of historically accessible habitat. Spawning in the NDPS consistently occurs in the main stems of the Rogue and Klamath rivers; however, spawning has also been documented in the Trinity and Salmon rivers, tributaries of the Klamath River (Benson et al. 2006). In contrast, the SDPS consists of individuals that spawn almost entirely within a 160 km (100-mile) segment of the Sacramento River below Keswick Dam, which forms a barrier to passage (Adams et al. 2007). In addition, SDPS spawning was documented in the Feather River during June, 2011 (Seesholtz et al. 2015) indicating that Green Sturgeons can spawn in major Sacramento River tributaries. It is probable that the SDPS historically spawned in currently inaccessible portions of rivers above dams in the American, Feather and Yuba rivers. Today, flow regulation and habitat fragmentation likely constrain their current spawning distribution (Mora et al. 2009).

NMFS (2006) identified a lack of information describing the total number of individuals in each of the populations as a potential risk factor for both populations. At that time, no direct estimates of population abundance of either DPS existed and status designations were prompted by a decline in other indicators of abundance. These indicators include 1) indirect abundance estimates based on the proportion of Green Sturgeon caught with White Sturgeon (*Acipenser transmontanus*) by the California Department of Fish and Wildlife 2) annual catch in the Yurok tribal Green Sturgeon fishery on the Klamath River, and 3) catch per unit effort estimates from a commercial Columbia River sturgeon fishery. White Sturgeon coexist with Green Sturgeon in the Sacramento River but White Sturgeon are much more abundant (Moyle 2002). While there is a body of knowledge about the life history and potential demographic structure of the species (Beamesderfer et al. 2007), DPS-specific estimates of adult abundances necessary to facilitate future status assessments have yet to be produced. Thus, the objectives of this study were to estimate the number of annually migrating SDPS Green Sturgeon and to estimate the SDPS population size. We also produce estimates of sub-adult life stages that may be useful for evaluating impacts on those life stages where the number of impacted individuals is known. Estimates of adult abundance will allow the status of SDPS Green Sturgeon to be evaluated relative to recovery criteria.

<A>Methods

<B>Study Site

The Sacramento River is the largest river in California, draining the northern 71,000 km^2 of the Central Valley. Our study took place within a 155 km reach between the Anderson-Cottonwood Irrigation District Dam at river kilometer (rkm) 570 and the Highway 32 overcrossing (rkm 415) during the months of June and July of 2010 through 2015 (Figure 1). We calculated rkm as the distance upstream from the Golden Gate Bridge.

Our sample sites consisted of the 125 locations deeper than 5 m described in Thomas *et al.* (2014), identified based on a meso-habitat survey by the U.S. Bureau of Reclamation beginning in January of 2008 and completed May 2010. In the Rogue River, NDPS Green Sturgeon congregate in locations greater than 5 m deep (Erickson et al. 2002). Thus, Thomas *et al.* (2014) and our study chose a 5 m depth criterion to identify potential congregating locations within the Sacramento River. The Bureau of Reclamation survey identified 125 discrete habitat units fulfilling this criterion, a portion of which were occupied by Green Sturgeon carrying acoustic tags (Thomas et al. 2014). A subset of these surveyed sites were confirmed as spawning locations by Poytress *et al.* (2013).

<B>Run-Size Estimate

<C>*Estimating abundance with DIDSON*.– We modified the presence-absence and abundance estimation methods described by Mora *et al*. (2015) to annually estimate the abundance of migrating Green Sturgeon in the Sacramento River. Our modification was that we first censused the sample sites to determine the presence or absence of sturgeon using Dual Frequency Identification Sonar (DIDSON) [Sound Metrics, Belleview WA]. DIDSON is an acoustic camera that operates like a medical ultrasound, allowing researchers to see video-like images of ensonified fish, submerged objects, and substrate. The presence-absence surveys were initiated during the first week of June, generally lasted two weeks and systematically occurred moving upstream from the most downstream sample site. We then estimated the abundance of sturgeon at each of the occupied locations over one to three days. Depending on the year, the DIDSON surveys were either performed by one or two teams working concurrently. However, video camera sampling (See *Estimating species proportion* below) was always performed by a single team. Our other modification from the methods of Mora *et al.*(2015) allowed us to account for some of the potential bias inherent in the movement of individual sturgeon during the sample period (See *Estimating migration patterns with telemetry* below).

<C>*Estimating species proportion*.– Both Green Sturgeon and White Sturgeon spawn in the Sacramento River (Kohlhorst 1976). Even though migration studies suggest their spawning habitats are separated in time and space (Miller 1972, Shaffter 1997, Heublein et al. 2008), we wanted to be sure that the detected sturgeon were the target species as these two species are indistinguishable in DIDSON images. We used underwater video camera transects to estimate the relative proportions of Green and White Sturgeon at locations of detected sturgeon presence to correct for this potential bias. To gather visual sturgeon detections for species identification, we towed an underwater video camera (Splash Cam Deep Blue Pro, Ocean Systems, Inc., Everett, WA) attached to a 10 kg sounding weight at locations where sturgeon densities were sufficiently high enough to ensure detections (Groves and Garcia 1998). The standard definition (720p) video feed from the camera was recorded onto DVD (2010, 2011) or digital video tape (2012 – 2015) for later analysis, and viewed real-time aboard the survey boat to avoid collisions

with sturgeon. During 2012 – 2015 we fitted the towed cameras assembly with a high definition (1080p) underwater video camera (GoPro Hero2, GoPro, Inc., San Mateo, CA) to record a greater field of view and image quality compared to the standard definition image from the Deep Blue Pro. These species proportion surveys occurred the week after the abundance surveys.

We reviewed the video files, tallied the number of sturgeon detections and assigned them as Green Sturgeon, White Sturgeon, or Undetermined Species. Our criteria for identifying sturgeon species are listed in order of decreasing precedence in Table 1 (Moyle 2002).

For each year of the survey, we estimated the proportion of detected sturgeons that were Green Sturgeon as a binomial proportion ($\hat{P}_G$) of the number of sturgeon-camera interactions identified as Green Sturgeon (N_G) to the number of sturgeon-camera interactions identified to species (N_c). For each year, we pooled all samples within the study area. A binomial distribution is the distribution of the number of success resulting from *n* independent trials all experiencing the same probability of success *p*. Thus, for each year we assumed that the proportion of green sturgeon (*p*) was uniform within the study area and stable throughout the sample period. Furthermore, we assume that the results of each trial (each sturgeon-camera interaction [*n*]) are spatially and temporally independent of each other. We calculated $\hat{P}_G$ as:

EQ(1) $$\hat{P}_G = \frac{N_G}{N_c}$$

with variance:

EQ(2) $$\hat{V}(\hat{P}_G) = \frac{\widehat{P_G}(1 - \widehat{P_G})}{N_c}$$

<C>*Estimating migration patterns with telemetry data*.– Individual Green Sturgeon migrate into and out of the survey area at varying times during each spawning year, so during any given survey the entire spawning run may not be in the survey area. Mora *et al.* (2015) described

assumptions of our abundance estimation technique that, when violated, will impart bias to the final estimate. They recommended using individual based information describing migration patterns to correct for these potential sources of bias. To account for the effects of this bias on our abundance estimates, we relied on detections of acoustically tagged Green Sturgeon in the study area. Tagged individuals (n = 288) (Heublein et al. 2008, Vogel 2008, Lindley et al. 2011, Thomas et al. 2014) were detected by an array of ultra-sonic tag detecting hydrophones maintained by the Biotelemetry Laboratory of the University of California, Davis (UCD). We utilized these apparent migration patterns to estimate the quantity of two groups of individuals not detected during our DIDSON surveys: 1) the proportion of annual migrants that exited the study area prior to our abundance estimate, and 2) the daily average proportion of individuals migrating between units during our study period in June and July of each year. Here we assume that the mechanisms that influence migration are experienced and acted upon uniformly for all individuals in the study area. That is, *p* from the binomial distribution example above is the same for all individuals. Further, we assume that each migrant makes the decision to migrate independently of others, *n* from the binomial example above. There may be reasons to suspect that migration has a behavioral component and thus may be a contagious dependent process (Lindley et al. 2011), however we lack the mechanisms to assess how this violation biases our estimate of migration timing.

<C>*Proportion of annual migrants that had exited the study area*.– To estimate the proportion of annual migrants that had exited the study area prior to our abundance estimate, we summarized individual Green Sturgeon detections by week and coded them as either present or having already exited the study site. This was determined for individuals not tagged in the same spawning year as being summarized with the exception of 2011 when only two previously tagged fish entered the study area. For the year 2011, we included the exit dates of 22 individuals tagged during that spawning year (Thomas et al. 2014). For all years, the estimate of proportion of individuals that had exited the study system before our abundance estimate occurred was calculated as a binomial proportion ($\hat{P}_P$) of the number of individuals that had exited the study system by the week of our abundance surveys (N_s) to the number of total annual migrants detected on the hydrophone array that year within the study area (N_M):

EQ(3) $$\hat{P}_P = \frac{N_S}{N_M}$$

with variance:

EQ(4) $$\hat{V}(\hat{P}_P) = \frac{\hat{P}_p(1 - \hat{P}_p)}{N_M}$$

We then utilized the total number of detected sturgeon from the DIDSON transects ($\widehat{T}$, from Mora *et al*. 2015, equation 5.) to estimate the total number of individuals that had exited our study system before our abundance surveys ($\widehat{N}_E$) as:

$EQ(5)$ $$\widehat{N}_E = \left(\frac{\widehat{T}}{1 - \widehat{P}_P}\right)\widehat{P}_P$$

The variance of $\widehat{N}_E$ was calculated using the Delta Method as in Mora *et al.* (2015):

EQ(6) $$V\left(\widehat{N}_E\right) = \left[(\hat{P}_P)^2 \cdot \hat{V}\left(\hat{T}\right)\right] + \left[(\hat{T})^2 \cdot \hat{V}\left(\hat{P}_P\right)\right] + \left[\hat{V}\left(\hat{P}_P\right) \cdot \hat{V}\left(\hat{T}\right)\right]$$

Equations 5 and 6 result in an annual estimate of the total number of annual migrants that had exited the study area prior to our sampling, and the estimated variances of these totals.

<C>*Number of individuals migrating between habitat units*.– To estimate the daily average number of individuals migrating between habitat units in the study area during June and July of each year, we queried the UCD Laboratory database for Green Sturgeon detections occurring during these months, between the hours of 0700 hours and 1900 hours (the daily time period of sampling) and only at hydrophones not located directly in the sample sites. We estimated a daily quantity ($\widehat{P}_I$) as a binomial proportion of the number of unique individuals detected, and assumed to be migrating between units (N_D), to those present in the study area and not detected during that day and thus assumed to be within the habitat units (N_M).

EQ(7) $$\hat{P}_I = \frac{N_D}{N_M}$$

with variance:

EQ(8) $$\hat{V}(\hat{P}_I) = \frac{\hat{P}_I(1 - \hat{P}_I)}{N_M}$$

To estimate the annual average proportion of individuals that were moving between units during our sample period, we calculated the average ($\overline{P}_I$), of the daily estimates $\hat{P}_I$ as:

EQ(9) $$\overline{P}_I = \sum_i^n \frac{\hat{P}_I}{n}$$

With variance:

EQ(10) $$V(\overline{P}_I) = \sum_i^n \frac{\hat{V}(\hat{P}_I)}{n^2}$$

Then for each year, we calculated the total number of individuals that were transiting between sample sites during our abundance surveys ($\hat{N}_T$) as:

$EQ(11)$ $$\hat{N}_T = \left(\frac{\hat{T}}{1 - \overline{P}_I}\right)\overline{P}_I$$

The variance of $\hat{N}_T$ was calculated using the Delta Method as in Mora et al. (2015):

EQ(12) $$V(\hat{N}_T) = \left[(\hat{P}_I)^2 \cdot \hat{V}(\hat{T})\right] + \left[(\hat{T})^2 \cdot \hat{V}(\hat{P}_I)\right] + \left[\hat{V}(\hat{P}_I) \cdot \hat{V}(\hat{T})\right]$$

Equations 11 and 12 result in annual estimates of the total number of individuals migrating between units during our annual sample periods and the estimated variances of these totals.

The means and variances of these three estimated annual quantities ($\hat{T}, \hat{N}_E, \hat{N}_T$) were then summed to represent the total number of Green Sturgeon that migrated during each year and the estimated variances of those totals.

<B>Population Estimate

To estimate the number of mature adults in the SDPS we first had to estimate two quantities: the mean and variance of run-sizes over a six-year period and the distribution of interannual spawning frequencies.

Green Sturgeon are iteroparous and individuals do not make spawning migrations every year. To estimate the distribution of temporal intervals between spawning migrations from repeat spawners we again turned to the detection record of acoustically tagged Green Sturgeon. The detection database was queried for all Green Sturgeon performing a spawning migration. Individuals were considered to have completed a spawning migration in a given year if they were detected by a tag detecting monitor in our study area that year. We then calculated the interval, in years, between spawning migrations for 41 individuals that had spawned more than once. The identified distribution was used as an estimate of SDPS spawning periodicity. The mean, $\bar{S}_{GS}$ and variance of this distribution is V($\bar{S}_{GS}$) were calculated using the standard estimators for a sample mean and variance.

$EQ(13)$ $$\bar{S}_{GS} = \frac{1}{n}\sum_{i}^{n} x_i$$

$EQ(14)$ $$V(\bar{S}_{GS}) = \frac{1}{n-1}\sum_{i}^{n} (x_i - \bar{x})^2$$

We then estimated the average run-size of SDPS Green Sturgeon by calculating the six-year geometric mean of our run-size estimates using the following equations. The average run-size ($\bar{T}_G$) was calculated as:

EQ(15) $$\bar{T}_G = \sqrt[6]{\prod_i^6 \hat{T}}$$

with variance:

EQ(16) $$V(\bar{T}_G) = \sum_i^6 \frac{\hat{V}(\hat{T})}{6^2}$$

We estimated the total number of adults in the SDPS ($\hat{N}_A$) by multiplying the average run-size ($\bar{T}_G$) by the estimated average spawning periodicity ($\bar{S}_{GS}$).

EQ(17) $$\hat{N}_A = \hat{S}_{GS}\,\bar{T}_G$$

The variance of $\hat{N}_A$ was calculated using the Delta Method as in Mora *et al.* (2015):

EQ(18) $$V[\hat{N}_A] = (\hat{S}_{GS})^2\hat{V}[\bar{T}_G] + (\bar{T}_G)^2\hat{V}[\hat{S}_{GS}] + \hat{V}(\bar{T}_G)\hat{V}(\hat{S}_{GS})$$

Beamesderfer and Simpson (2007) determined that given multiple assumptions about population characteristics, the SDPS Green Sturgeon population would have an expected life stage distribution of 25% juveniles, 63% sub-adults and 12% adults. The juvenile life history stage was defined by Beamesderfer and Simpson (2007) as “fish during freshwater rearing prior to migration to the ocean (generally one to three years of age and 0 – 60 cm in length).” Adults were defined by the authors as “fish larger than the median size and age of female maturation (approximately 165 cm and 20 years of age).” The sub-adult life history stage refers to individuals between these two age classes. Combining the proportions provided by Beamesderfer and Simpson (2007) with our estimate of the number of adults in the SDPS, we estimated the number of individuals in the juvenile and sub-adult life history classes.

<A>Results

Abundance sampling occurred over one to three days from mid-June to early July each year (Table 2). The number of days required to sample the occupied habitat units varied between years due to the number of cumulatively occupied units and the varying number of sampling teams. During 2010, 2011 and 2012 two crews worked together to sample different units concurrently; however, in 2013 through 2015 sampling was performed by one crew.

Table 2 displays the estimates of the total number of sturgeon present considering only the DIDSON transect estimate of abundance. As estimates of run-size for each year, these values are uncorrected for the bias imparted due to species proportion, migration timing and individual movement between sample sited during our surveys (Mora et al. 2015). We detected an average of 346 sturgeon each year ranging from 220 in 2011 to 526 in 2014.

Annual estimates of the proportion of Green Sturgeon in our study area calculated from video camera transects ranged from 0.98 to 1 (Table 3). Of the 699 sturgeon observed on video, 390 were identifiable to species and of those, only two were White Sturgeon. These two White Sturgeon observations occurred during one year and were captured on the same day in the same location on the same video camera transect. We classified sturgeon as Unidentifiable usually due to a blurred image resulting from the combination of distance and turbidity or unidentifiable due to limited viewing time after the fish was startled and quickly swam away. Otherwise, it is apparent that the majority of sturgeon detected in our study area were Green Sturgeon.

The estimated proportion of annual migrants that had left the study area before our abundance surveys were performed averaged .33 and ranged from 0.00 to 0.57 (Table 4). 2013 was an outlier with 0 individuals leaving the study area before our abundance surveys.

The estimated proportion of Green Sturgeon in transit between sample sites during DIDSON surveys averaged .013 and ranged from 0.004 to 0.017 (Table 5).

The estimates of annual run-size accounting for the proportion of sturgeon transiting between sites or out of the study area are shown in Table 6. These values represent the total number of adult Green Sturgeon that entered our study area each year. These values do not include the number of migrants that entered tributaries of the Sacramento River such as those documented by Seesholtz *et al.* (2015). The average run-size was calculated to be 571 with the 95% confidence limits of 529 and 613.

The detections of 42 repeat migrations of 41 individuals displayed a spawning interval of two to six years. The mean spawning periodicity was 3.69 years with a variance of 0.56 (Figure 2).

We directly estimated the number of adults in the SDPS to be 2,106 within the 95% confidence limits of 1,246 and 2,966. Applying the life history proportions of Beamesderfer and Simpson (2007), we estimated there to be 4,387 juveniles within the 95% confidence limits of 2,595 and 6,179, and 11,055 sub-adult within the 95% confidence limits of 6,540 and 15,571, for a total population estimate of 17,548 SDPS Green Sturgeon within the 95% confidence limits of 12,614 and 22,482 individuals.

<A>Discussion

We estimate that during each year of the study there were between 1,246 and 2,966 SDPS Green Sturgeon in the reproductive portion of the population. We regard this as a fairly reliable estimate of SDPS Green Sturgeon population size because it overcomes two issues that hampered earlier estimates: a limited sample region (Israel and May 2010), and estimating the abundance of Green Sturgeon based on the ratio of Green to White sturgeon numbers in a White Sturgeon sampling study (U.S Fish and Wildlife Service 1995, Adams et al. 2007). Israel and May (2010) used genetic techniques to estimate effective population size during the years 2002-2006. Their study sampled out-migrating juveniles at Red Bluff Diversion Dam, potentially omitting the contribution of individuals spawned downstream of this location. Their estimates of effective population size contributing to their samples ranged from 10-28 spawners. These results are not surprising given two facts. First, effective population size is often smaller than census population size. Second, their sampling occurred during a time when Red Bluff Diversion Dam operated as a temporal barrier to Green Sturgeon spawning, likely reducing the numbers of spawners upstream of this point and thus reducing the spawners contributing to their sample (Heublein et al. 2008). U.S. Fish and Wildlife Service (1995) estimated the number of adult (> 101.6 cm) Green Sturgeon present in the Sacramento-San Joaquin Estuary for eight years throughout the interval between1967 and 1990. A direct estimate using capture-recapture estimation was not possible as no recaptures of individual occurred during their sampling. Those authors estimated the mean number of Green Sturgeon adults to be 983 resulting in a doubling goal of 1,966 individuals. The results of our study suggest that the doubling goal set by the Central Valley Project Improvement Act has been met. Our study, if anything, likely underestimates the SDPS abundance because it did not include the recently documented spawners in the Feather River, as determined from a collection of thirteen eggs from Green Sturgeon (Seesholtz et al. 2015). Future population estimates of adult SDPS Green Sturgeon should coordinate DIDSON sampling in the mainstem Sacramento with concurrent sampling in other Central Valley tributaries.

Our estimates of juvenile, subadult, and total SDPS green sturgeon numbers are less reliable because they are based on the ratios in Beamesderfer and Simpson's (2007) modeling study which combines data from the NDPS and SDPS. Their estimate of percentage of juvenile sturgeon is particularly uncertain because so little is known about this life stage. Additionally, their model requires four assumptions that are admittingly rarely met:

> "*constant recruitment, population equilibrium, stable size and age structure, and a lack of density dependence*" (Beamesderfer et al. 2007).

However, this study provides a rough estimate of total abundance suitable for assessing impacts of take, such as those that are observed in coastal trawl fisheries and at large water diversions.

The Demographic Recovery Criteria, under development by NMFS as part of the SDPS Green Sturgeon Recovery Plan, contain quantitative targets of population size used to determine if significant threats to the recovery of a population are alleviated. The draft criterion requires an estimated adult population of 3,000 individuals (J. Heublein, NMFS Green Sturgeon Recovery Coordinator, personal communication). Our results show that the population is not far below the desired 3000 spawning adults in the population. The Demographic Recovery Criteria states that 'each annual spawning run must be comprised of a combined total, from all spawning locations, of at least 500 adult fish.' That recovery target was met during four of six years of our survey; however the criterion provides no guidance on the interpretation of confidence intervals. For example the 2011 estimate of 334 adult spawners has a 95% confidence interval spanning 273 – 395 adults, clearly not reaching the 500 adult fish criteria. A less clear result occurred in 2012 when 597 adult spawners were estimated to have migrated into the study area. The 95% confidence intervals of that estimate span 499 – 695 adults, almost entirely within the desired draft criteria. The draft Demographic Recovery Criteria could be clarified to specify if just the point estimate of adult run-size and population size, the entire confidence interval, or just a majority of the confidence interval is used to satisfy the recovery criteria.

It is clear that further implementation of DIDSON based surveys that measure the abundance and distribution of Green Sturgeon during their spawning period will provide information crucial to the evaluation of SDPS Green Sturgeon status. Two of the five draft Demographic Recovery criteria describe criterion based on either abundance (annual run-size, total population size) or distribution (successful spawning in at least two rivers within their historical range). Spawning has been recently detected in the Feather River (Seesholtz et al. 2015) and future coordinated DIDSON surveys of the Feather and Sacramento Rivers is planned.

This study provides additional evidence that sturgeon in the study area during June and July are almost entirely Green Sturgeon. The only exception to this expectation was the two White Sturgeon detected in 2013. Given the findings of Miller (1972) and Shaffter (1997), this pattern was not surprising; however, we had expected a larger proportion of the detected sturgeon to be White Sturgeon based on self-reporting by recreational fishermen to the California Department of Fish and Wildlife. Other evidence provides support for Green Sturgeon prevalence. For example, all sturgeon larvae and juveniles that were captured in a screw trap operated at Red Bluff Diversion Dam were identified as Green Sturgeon (Poytress et al. 2014). In addition, initial results of Green and White Sturgeon migration studies by the UCD Biotelemetry Laboratory support our findings (E. Miller, UCD, personal communication).

The high run-size estimate from 2014 stands out as an obvious outlier. The sampling for the 2014 estimate occurred roughly two weeks later in the spawning season than the other annual estimates. Otherwise, all aspects of the study design were the same during 2014 as they were during previous years. For 2014, two components of the estimate of run-size were the greatest for any year of our study: the total number of sturgeon detected via DIDSON transects and the proportion of individuals that had left the study system before our DIDSON sampling began. These two factors clearly combined to inflate the estimate of run-size but we consider their estimated values as valid because measurements from all years were performed uniformly. It is worth noting that the 2014 and 2015 spawning seasons occurred during a major drought in California although it is unknown how environmental factors, such as reduced flow, influence run-size and Green Sturgeon spawning migrations. As our study continues and our time series expands, we plan to investigate these questions.

Finally, because our model is reliant on individual based migration information, it is crucial that tagging of individuals with long lasting acoustic tags continue to be conducted to inform population monitoring efforts into the future. Population monitoring of the SDPS of Green Sturgeon is crucial to understand the status of the species. DIDSON sampling and acoustic tagging appear to be the most efficient and least invasive methods to track the SDPS Green Sturgeon status. It would be important to know, for example, if the greater numbers of adults observed in 2014 represents a reproductive cohort or a response to environmental changes.

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Indicator	Green Sturgeon	White Sturgeon
Dorsal Scutes	8-11	11-14
Lateral Scutes	23-30	38-48
Post-Dorsal Scute Present	Yes	No
Ventral Green Stripe	Yes	No

Lateral Green Stripe Present	Yes	No

Table 1. Criteria used to identify sturgeon to species. If none of the criteria were discernable, we assigned “Undetermined Species”.

Year	Sample Dates	N	± 95% CI
2010	6/17	245	63

2011	6/16	220	41
2012	6/14, 6/15	329	56
2013	6/10, 6/11, 6/12	338	61
2014	6/30, 7/1, 7/2	526	64
2015	6/24, 6/25, 6/26	423	59

Table 2: The dates when the abundance estimating surveys occurred and the estimated total number of sturgeon resulting from the DIDSON transects, uncorrected for bias due to violations of assumptions.

Year	N (Green)	N (White)	Unknown	P (Green)	Variance
2010	76	0	47	1.00	0.0000
2011	39	0	40	1.00	0.0000
2012	50	0	57	1.00	0.0000
2013	88	2	87	0.98	0.0002
2014	100	0	64	1.00	0.0000
2015	37	0	26	1.00	0.0000

Table 3: The number of Green and White Sturgeon detected on video camera and the mean and variance of the estimated species proportions.

Year	N (Migrants)	N (Exited)	Proportion Not In River	Variance
2010	9	5	0.56	0.027
2011	24	8	0.33	0.009
2012	18	8	0.44	0.014
2013	14	0	0.00	0.000
2014	14	8	0.57	0.017
2015	32	14	0.44	0.008

Table 4: The number of sturgeons implanted with acoustic tags that were detected as leaving our study area each year before the initiation of our abundance surveys.

Year	Proportion In Transit	Variance
2010	0.004	4.07E-06
2011	0.02	1.37E-05
2012	0.015	7.72E-06
2013	0.013	1.41E-05
2014	0.017	1.66E-05
2015	0.01	4.14E-06

Table 5: The estimated average daily proportion of tagged sturgeon migrating between sample sites during the month of June and July.

Year	N	± 95% CI
2010	552	109
2011	334	61
2012	597	98
2013	335	61
2014	1236	157
2015	756	98

Table 6: The estimated number of Green Sturgeon that migrated into the study area between 2010 and 2015.

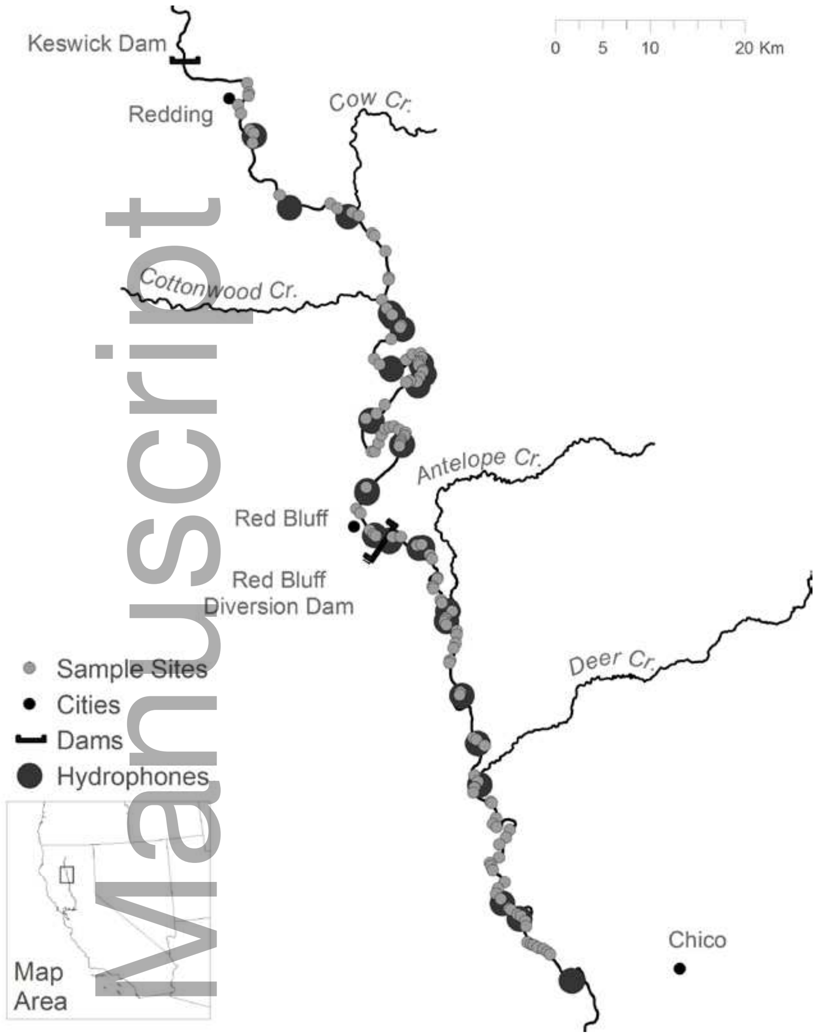


Figure 1: The Sacramento River showing the sample sites as light grey dots and tag detecting monitors as black dots.

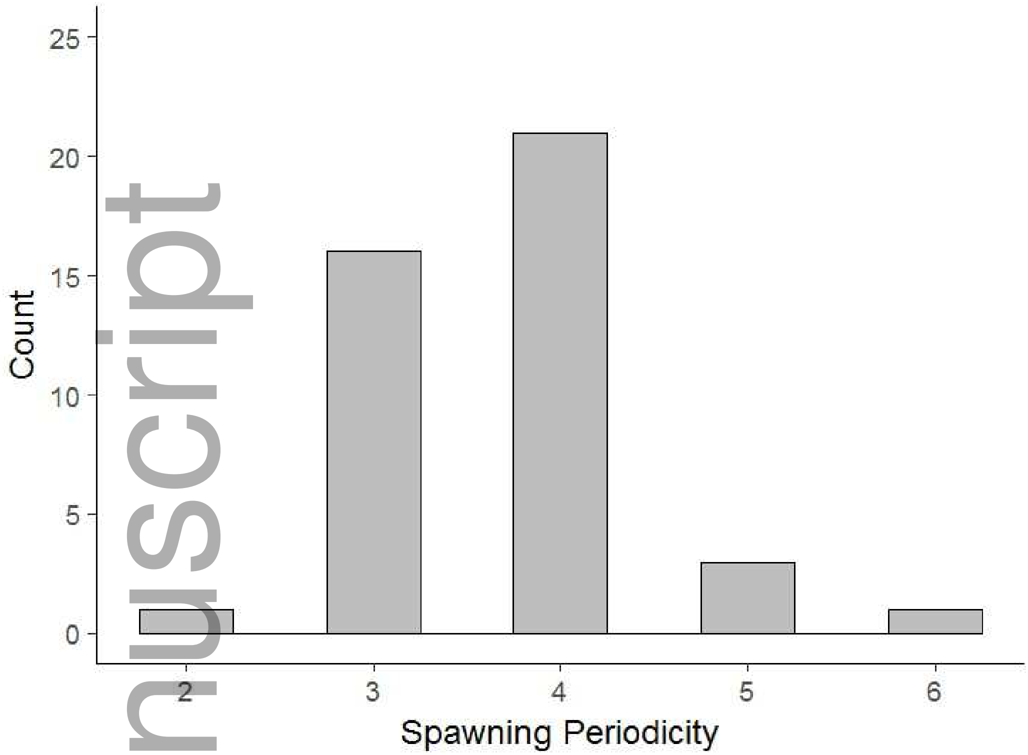


Figure 2: Histogram of spawning periodicity of acoustically tagged Green Sturgeon.

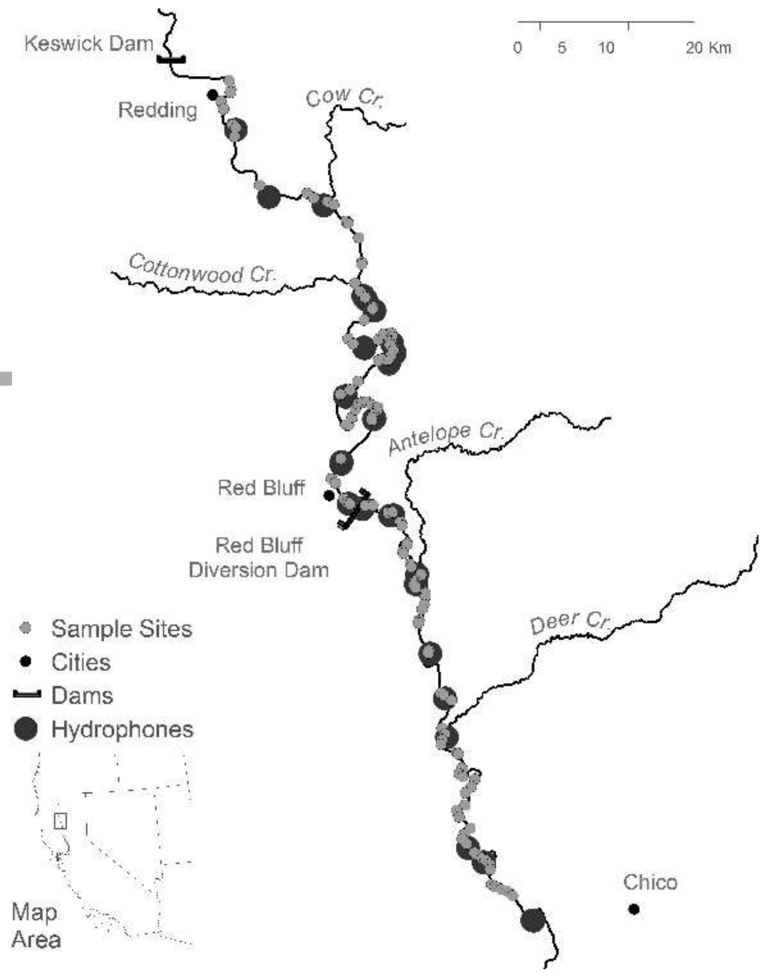
Supplemental Material

GreenSturgeon.wmv

Video showing a typical Green Sturgeon ID. Visible are a lateral green stripe, number of dorsal scutes and the presence of a post-dorsal scute.

WhiteSturgeon.wmv

Video showing one of two identified White Sturgeon. Visible are the lack of a lateral green stripe, number of dorsal scutes and the lack of a post-dorsal scute.



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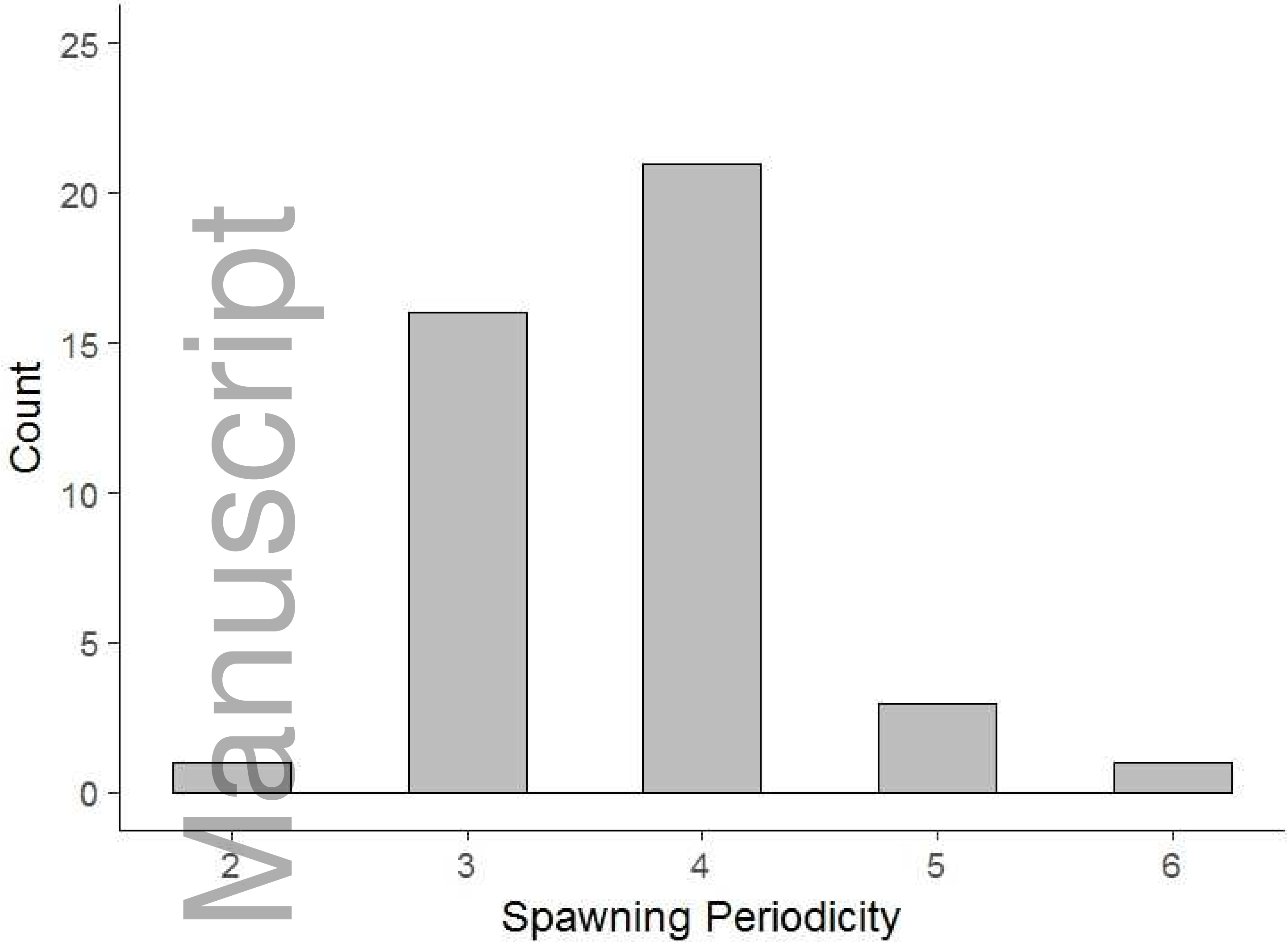

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