

QUANTIFYING KNOWN GREEN STURGEON, *ACIPENSER*
MEDIROSTRIS AYRES, SPAWNING HABITAT WITHIN
THE UPPER SACRAMENTO RIVER, CALIFORNIA,
USING SIDE SCAN SONAR

A Project
Presented
to the Faculty of
California State University, Chico

In Partial Fulfillment
of the Requirement for the Degree
Master of Science
in
Environmental Science
Professional Science Masters Option

by
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Fall 2015

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Fall 2015

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DEDICATION

I dedicate this project to my wife, Jennifer Gruber, whose capacity for simultaneously dealing with many complex tasks far exceeds that of my own.

During the past three years, she maintained our household through pregnancy and raising our son, Brooks, for the first year and a half of his life when I was busy with work, classes, and my research. While managing all of this, she pursued her profession, providing opportunities to hundreds of CSU, Chico students so they could follow their dreams and study abroad.

Her love and support has made this project come to fruition.



ACKNOWLEDGMENTS

I am grateful to the following people for their support in completing this project.

Randy Senock, my advisor, for his guidance through this program. His experience and direct communication is exactly what I needed to get through this obstacle. Bill Poytress, my supervisor, for allowing me a flexible work schedule so I could attend three years of classes. He requires high standards from me on a daily basis which helped prepare me for this. Amanda Banet and Glen Pearson provided insightful reviews and comments that increased the quality of my project.

To my parents, Cleo and Denny Abel, Deb Davis, and Jeff Gruber, for giving me the never slow down motor, my love for the outdoors, and common sense to navigate through life and the challenges of a career in fisheries. My wife, Jenn, who held down the home front for three years and our son, Brooks, who motivates me every day with his electric smile.

I would like to thank Adam Kaeser and Thomas Litts, creators of the geoprocessing workbook utilized for this project. They produced a document of exceptional quality that allowed me to generate sonar mosaics with no prior experience using ArcMap. They also responded to numerous of my emails, helping me over the hurdles I encountered along the way. If it wasn't for the Geographic Information Systems help provided by Erik Fintel, at the CSU Chico Geographical Information Center I would still be working on this.

Finally, for those who are no longer with us, that provided me with the lifelong role models of how to live a meaningful life: Denny Abel, Arthur Gruber, Doug Gruber, Verna Gruber, Dave Shelby, Warren Shelby, and Alice Weiss

TABLE OF CONTENTS

	PAGE
Publication Rights	iii
Dedication.....	iv
Acknowledgments	v
List of Tables	ix
List of Figures.....	x
Abstract.....	xi
CHAPTER	
I. Introduction	1
Green Sturgeon Status	1
Critical Habitat and Recovery Planning	2
Background Studies.....	3
Methods to Identify Spawning Areas	4
Methods to Identify and Quantify Spawning Habitat Preferences	5
Purpose of the Study.....	7
Scope of the Project.....	8
Significance of the Project.....	8
Limitations of the Study	9
Definition of Terms and Acronyms.....	13
II. Literature Review	15
Current State of Knowledge on Sturgeon Spawning Habitat Preferences.....	15
Evolution of Side Scan Sonar.....	17

CHAPTER	PAGE
III. Methodology.....	20
Study Area.....	20
Egg Sampling	22
Habitat Assessment	23
Suitable Spawning Habitat Criteria	25
Data Analysis.....	26
Quantifying Suitable Spawning Habitat.....	27
IV. Result.....	28
Habitat Assessment	28
Suitable Spawning Habitat Criteria	36
V. Discussion.....	41
Suitable Spawning Habitat Criteria	41
Recovery Plan Implications.....	42
Comparisons of Suitable Spawning Habitat Criteria.....	43
Additional Suitable Habitat Criteria	45
Conclusion and Recommendations	47
References Cited	49

LIST OF TABLES

TABLE	PAGE
1. Green Sturgeon Spawning Habitat Data Collected at the Six Spawning Locations on the Sacramento River, California, During the Spawning Period Between 2008 and 2012.....	10
2. Egg Mat Effort Data Collected on the Sacramento River, California, Between 2008 and 2012.....	12
3. Substrate Classification Scheme and Associated Definitions Used to Delineate Sonar Images.....	26
4. Depth and Velocities Present at the Six Spawning Locations in the Sacramento River, California.....	29
5. Substrate Composition and Number of Occupied Samples by Substrate Type at the Six Spawning Locations.....	39
6. Chi-Square Analysis of the Transferability of the Suitable Spawning Habitat Criteria.....	40
7. Available, Suitable and Percent Suitable Spawning Habitat Quantified Using the Suitable Spawning Habitat Criteria.....	40

LIST OF FIGURES

FIGURE	PAGE
1. Location of Green Sturgeon Eggs Collected at Rkm 426 (a), 424.5 (b), and 377 (c) Using Egg Mats Between 2008 and 2012	11
2. Known Green Sturgeon Spawning Locations on the Sacramento River, California	21
3. Sonar Image from the Upper Sacramento River Delineated to Identify Key Habitat Features	25
4. Depth and Velocities Present at Rkm 426	30
5. Depth and Velocities Present at Rkm 424.5	31
6. Depth and Velocities Present at Rkm 407.5	32
7. Depth and Velocities Present at Rkm 377	33
8. Depth and Velocities Present at Rkm 366.5	34
9. Depth and Velocities Present at Rkm 332.5	35
10. Frequency Distribution of River Depths at Rkm 424.5	36
11. Frequency Distribution of Mean Water Column Velocity at Rkm 424.5	37
12. Frequency Distribution of Substrates at Rkm 424.5	38
13. Depth and Velocity Habitat Suitability Criteria for White Sturgeon	44

ABSTRACT

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Green Sturgeon, *Acipenser medirostris* Ayers, are a long-lived anadromous fish that are being managed as the Northern and Southern Distinct Population Segments based on genetic analysis and spawning site fidelity. Loss of spawning habitat and concern over the concentration of the spawning population into a single watershed were cited as factors for listing the Southern Distinct Population Segment of Green Sturgeon as threatened under the Endangered Species Act on April 7, 2006. Since the Federal listing, adult telemetry data generally indicates the spawning grounds on the Sacramento River extends between river kilometer 324 and 451. Egg mat surveys have documented spawning within six hydraulically-active pools within this reach. Utilizing side scan sonar

technology and Geographic Information Systems, 6.9 hectares of suitable spawning habitat were quantified within the six spawning pools based on the depth, velocity, and substrates type where Green Sturgeon eggs were collected. Methodologies and suitable spawning habitat criteria developed in this project could be used to conduct a complete quantitative habitat assessment to manage critical habitat and guide restoration efforts within and outside the Sacramento River system, providing valuable insight into one of the many biological data gaps recognized during the recovery planning process.

CHAPTER I

INTRODUCTION

Green Sturgeon Status

The North American Green Sturgeon, *Acipenser mediorstris* Ayers, are a long lived anadromous fish, ranging from the Bering Sea, Alaska to Ensenada, Mexico (Moyle, 2002). Conservation organizations, concerned for the species throughout its range, petitioned the National Marine Fisheries Service to list the species as threatened or endangered under the Endangered Species Act (ESA) (Environmental Protection Information Center [EPIC], Center for Biological Diversity, and Water-keepers Northern California, 2001). An initial status review identified that two Distinct Population Segments of Green Sturgeon existed based on spawning site fidelity and genetic evidence; however, neither were listed at the time due to insufficient information (Adams et al., 2002; Israel et al., 2004). Geographically these two populations were separated into the Northern and Southern Distinct Population Segments by the Eel River with the only annual spawning population of Southern Distinct Population Segment (SDPS) (Biological Review Team [BRT] ,2005) occurring in the Sacramento River. Challenges to the initial status review led to a subsequent review and the eventual threatened listing for the SDPS Green Sturgeon in 2006 citing threats of 1) a spawning population with concentrated adults in a single watershed, 2) loss of historical spawning habitat upstream

of Shasta and Oroville Dams, and 3) decreases in juvenile recruitment since 1986 as indicated by state and federal salvage facilities (National Marine Fisheries Service [NMFS] 2006).

Critical Habitat and Recovery Planning

As mandated by the ESA listing, National Marine Fisheries Service published the SDPS Green Sturgeon Critical Habitat Designation in 2009 to identify physical and biological features that are essential to the conservation of the species using the best scientific data available. Overall, it was recognized that relatively little information was available about the early life history and spawning activities of this fish (NMFS 2009b). In total, 524 river kilometers (rkm) of riverine habitat within the mainstem of the Sacramento, lower Feather, lower Yuba, and the lower San Joaquin Rivers were designated as critical habitat for all life stages of SDPS Green Sturgeon.

A secondary mandate of an ESA listing is the development and implementation of a recovery plan in an effort to recover the species to a point where ESA protections are no longer needed. A recovery plan is designed to identify the primary threats to the species, outline recovery actions, and establish criteria to measure the recovery status of the species. To date, a recovery plan has not yet been finalized, although a draft recovery plan (hereafter referred to as the Plan) was completed in 2013. The Plan focuses on conserving existing spawning habitat and restoring historical habitat lost due to the construction of dams. Furthermore, the Plan identifies the need to establish a secondary spawning population outside the Sacramento River, presumably within the

Feather or Yuba Rivers where adults have been known to aggregate during the spawning season (Seesholtz et al., 2015; Cramer Fish Sciences, 2011).

Background Studies

Knowledge of early life history information is critically important when trying to understand the abundance of fish populations and recover a species (Hempel, 1979; Marchant and Shutters, 1996). Therefore, the identification of spawning habitat requirements are key to the restoration, protection, and management of any fish species (Schafter, 1997). For Green Sturgeon, this basic life history information was unavailable at the time of their listing. After the listing, the U.S. Bureau of Reclamation elevated its concern over the spatial and temporal extent of Green Sturgeon spawning within the Sacramento River to help evaluate the impacts of the Red Bluff Diversion Dam (RBDD).

In 2008, the U.S. Bureau of Reclamation funded a five-year egg sampling study conducted by the U.S. Fish and Wildlife Service (USFWS) to identify and characterize spawning habitats through the collection of Green Sturgeon eggs (Poytress et al., 2009-2013). These studies documented spawning over a 94 rkm (rkm 332.5-426) reach of the Sacramento River by collecting 265 eggs and 5 post-hatch larvae within six deep hydraulically active pools and directly below the RBDD. Little information exists on the requirements and availability of spawning habitats utilized by the SDPS of Green Sturgeon beyond Poytress et al. (2009 – 2013; 2015) and Seesholtz et al. (2015).

In conjunction with the USFWS egg studies, the University of California Davis has been conducting adult tracking studies to identify the distribution of adult sturgeon during the spawning season (Heublein et al., 2009; Thomas et al., 2014). These

studies define the putative spawning area as extending approximately 120 river kilometers from rkm 330-451. Additionally, Dual Frequency Identification Sonar (DIDSON) surveys have been used to count the number of spawning adults within aggregation sites in the upper Sacramento River to obtain an SDPS population estimate (E. Mora, unpublished). Results from the DIDSON survey indicate that sturgeon appear to be holding in relatively few pools ($n=22$) within the putative spawning reach (NMFS, 2015). This data indicates that the amount of suitable spawning habitat is much smaller than the 94 or 120 rkm stretch of the upper Sacramento River occupied by adults during the spawning season because spawning appears to be occurring within isolated areas in this stretch of the Sacramento River (Thomas et al., 2014; Poytress et al., 2015; E. Mora, unpublished). In order to correctly define a spawning population metric within the recovery plan, managers need a more refined quantitative assessment of suitable spawning habitat.

Methods to Identify Spawning Areas

Historically, *Acipenser spp.* spawning areas have been documented through the collection of eggs and larvae at or near suspected spawning areas using benthic D-shaped plankton nets (Kohlhorst, 1976; Parsley et al., 1993; McCabe and Tracy, 1994). Although spawning areas can be identified using a plankton net, it requires researchers to be present during the entire sample period. Plankton nets are not identifying the exact location where spawning is occurring as they most readily collected post-exogenous larvae as they distribute from the spawning areas. In 1988, an egg collection device known as an artificial substrate sample (hereafter called egg mat) was developed to take

advantage of the adhesive properties of sturgeon eggs (Wang et al., 1985; McCabe and Beckman, 1990). Egg mats have become the most widely used device to document spawning areas and define habitat characteristics for White, *Acipenser transmontanus* Richardson (Parsley and Beckman, 1994; McCabe and Tracy, 1994; Perrin et al., 2003), Green (Brown, 2006; Poytress et al., 2009 – 2013; Seesholtz et al., 2015), Gulf, *Acipenser oxyrinchus desotoi* Vladykov (Marchant and Shutters, 1996; Fox et al., 2000), and Lake Sturgeon, *Acipenser fulvescens* Rafinesque (Johnson et al., 2006; Chiotti et al., 2008). When compared to plankton nets, egg mats require less effort as they are left unattended for long periods of time and they can be fished in areas that may not be safe or practical for plankton nets (McCabe and Beckman, 1990).

Methods to Identify and Quantify Spawning Habitat Preferences

After identifying spawning areas through the collection of eggs, sturgeon spawning habitat can be described in a variety of ways. In general, these areas have been described as occurring in deep, high velocity or turbulent areas (Parsley et al., 1993; Perrin et al., 2003; Poytress et al., 2009; Seesholtz et al., 2015). More specifically, researchers describe the habitat in terms of river depth, mean column or near bed water velocity, and substrate.

River depth is often collected using a variety of depth sounders (e.g., fish finders) just prior to retrieving egg mats (Perrin et al., 2003; Poytress et al., 2009). This methodology captures information at the exact location of the incubating eggs. Likewise, velocity measurements are measured using hand held or weighted velocity probes (e.g., Marsh-McBirney or Swoffer velocity sensors) at the location of egg mats (Parsley and

Beckman, 1994; Chiotti et al., 2008). Substrates can be visually identified within spawning areas via direct observation utilizing underwater video cameras, visual inspection during low flow periods, or by collecting a physical sample of the substrate (i.e., grab sample; McCabe and Tracy, 1994; Perrin et al., 2003; Chiotti et al., 2008; Poytress et al., 2015).

All of these methodologies have limitations. Individual depth and velocity measurements at the egg collection site helps to identify spawning habitat preferences, but do not help to quantify how much suitable habitat exists. Underwater video and visual inspection surveys are difficult to conduct in deep turbulent waters, which are typically utilized by sturgeon for spawning. Additionally, image distortion makes quantifying substrate difficult because particle size cannot be accurately assessed along the edges of the image (Chiotti et al., 2008). In turbid waters, these types of visual surveys are not beneficial due to restricted visibility (Z. Jackson, United States Fish and Wildlife Service [USFWS], personal communication). Grab samples can be collected, but they require large amounts of time, money, and effort to collect and process, making it difficult to cover sizable sample areas (McCabe and Tracy, 1994).

Understanding what habitat variables are required for spawning is important, but knowing where and how much of that type of habitat exist is equally valuable (Rotenberry et al., 2006). Geographical Information Systems (GIS) allows users to spatially reference and combine multiple data layers (e.g., depth, velocity, and substrate), which can then be used to model the location and availability of specific habitat features (Parasiewicz, 2008). Such information can be used to guide future research, identify habitat restoration options, and predict outcomes to management actions (Parasiewicz,

2001). The use of GIS based technologies for terrestrial landscapes surpasses that used for riverine environments due to the expense, specialized equipment, and logistical challenges (Wiens, 2002; Marcus and Fonstad, 2008).

Recent advances in Side Scan Sonar (SSS) technology has allowed researchers to obtain high resolution, georeferenced images of underwater habitats (Kaesler and Litts, 2010). Coupling SSS technology with Acoustic Doppler Current Profiler (ADCP) technology, I plan to generate georeferenced depth, velocity, and substrate layers throughout the six Green Sturgeon spawning pools identified during the RBFWO egg sampling study (Poytress et al., 2015). Using the GPS coordinates from Green Sturgeon egg collection sites and physical habitat data, I can identify suitable spawning habitat criteria based on the conditions present where spawning was occurring. The suitable spawning habitat criteria can then be used to quantify the amount of suitable habitat that exists within these six areas. The need to protect existing spawning habitat and restore lost spawning habitat was highlighted as a priority in the SDPS Green Sturgeon Draft Recovery Plan and 5-year status review (NMFS, 2013, 2015).

Purpose of the Study

The purpose of this project is to develop methodology to quantify the amount of suitable spawning habitat that exists for SDPS Green Sturgeon within the Sacramento River. This project is a continuation of activities that I have been deeply involved in while working for the U.S. Fish and Wildlife Service throughout my fisheries career. I expect this project will help identify and quantify key habitat features that SDPS Green

Sturgeon utilize for spawning to better evaluate their status and aid in their recovery planning process.

Scope of the Project

This project details the methodology used to define and quantify the amount of suitable spawning habitat contained in the six spawning areas identified by the RBFWO (Poytress et al., 2015). Utilizing the Global Position System (GPS) coordinates of positive Green Sturgeon egg samples, suitable spawning habitat criteria will be defined in terms of river depth, mean column velocity, and substrate type. Based upon the suitable spawning habitat criteria, the amount of suitable spawning habitat contained within six spawning areas identified by the RBFWO will be quantified in hectares (h). Techniques and spawning habitat preferences used within this project are likely applicable within other river systems (e.g., Feather, Yuba, and San Joaquin Rivers) and with other sturgeon species (e.g., White Sturgeon), as the need to quantify spawning habitat is a basis for species management and recovery.

Significance of the Project

Information provided as a direct result of this project will be helpful to the National Marine Fisheries Service in establishing spawning population metrics within the SDPS Green Sturgeon Recovery Plan. Additionally, the benefits may extend to the U.S. Bureau of Reclamation for evaluating the impacts of the Central Valley Project's water management operations for winter run Chinook, *Oncorhynchus tshawytscha* Walbaum, salmon recovery actions. Techniques developed by this project will likely be beneficial to biologists attempting to evaluate spawning habitat for a variety of species.

Limitations of the Study

Compiling Data Over Multiple Years

A primary assumption of this project is that conditions present at the time of the acoustic doppler current profiler [ADCP] (2013) and side scan sonar [SSS] (2014) surveys were consistent with those present when the positive egg samples were collected between 2008 and 2012. Although flows on the Sacramento River are highly regulated by the Central Valley Project for the purpose of flood control, irrigation, and winter run Chinook salmon recovery efforts, egg sampling was conducted over a variety of water year types ranging from critically dry to wet with river discharge ranging from 142 to 690 m³/s, in 2009 and 2011, respectively. In contrast to the wide range of river discharge observed during the egg sampling period, river discharge during the estimated spawning period varied by ~125 m³/s (269 to 396 m³/s; Table 1). At rkm 426, 424.5, and 377 Green Sturgeon eggs were found in a clustered fashion over 3, 4, and 3 years, respectively, documenting numerous spawning events over multiple years and a variety of water year types (Figure 1, Table 2). The assumption that conditions (i.e., depth, velocity, and substrate) were consistent over multiple years is likely untrue. However, the variability in conditions is assumed to be negligible because the eggs were collected in the same general area during a variety of water year types over this multiyear sampling period.

Accuracy of Sonar Imagery Maps

A comparison using SSS imagery to traditional survey methods was done to test the ability to accurately identify five substrate types (sand, rocky fine, rocky boulder, limestone fine, and limestone boulder) in a southwest Georgia stream (Kaesler and Litts, 2010). Sonar maps were highly accurate (69%-83%) and saved a considerable amount of

TABLE 1. GREEN STURGEON SPAWNING HABITAT DATA COLLECTED AT THE SIX SPAWNING LOCATIONS ON THE SACRAMENTO RIVER, CALIFORNIA DURING THE SPAWNING PERIOD BETWEEN 2008 AND 2012

Location	Collected eggs and larvae	Temperature (°C)	Discharge (m ³ /s)	Turbidity (NTU)	Depth (m)	Column velocity (m/s)	Substrate class
rkm 426	26	12.9 ± 0.8	396 ± 115	4.3 ± 1.5	10.1 ± 1.8	0.8 ± 0.4	Gravel/Cobble
rkm 424.5	153	12.9 ± 1.0	275 ± 52	4.7 ± 5.2	6.8 ± 1.8	0.6 ± 0.1	Medium Gravel
rkm 407.5	3	13.9 ± 0.7	269 ± 10	3.8 ± 0.6	6.5 ± 2.9	0.8 ± 0.2	Small Gravel
rkm 377	82	14.1 ± 1.2	311 ± 58	3.8 ± 2.4	4.6 ± 1.2	1.0 ± 0.1	Medium Gravel
rkm 366.5	1	11.8 ± 0.5	290	4.9	6.2	0.3	Medium/Large Gravel
rkm 332.5	4	14.0 ± 1.8	331 ± 87	9.7 ± 11.0	7.3 ± 0.2	1.2 ± 0.5	Small Gravel

Note: Temperature, discharge, turbidity, depth, and column velocity data are mean ± SDs by location during the spawning period. Substrate class denotes median substrate size class where eggs or post-hatch larvae were collected.

Source: Data from Poytress, W. R., J. J. Gruber, J. P. Van Eenennaam, and M. Gard. 2015. Spatial and temporal distribution of spawning events and habitat characteristics of Sacramento River green sturgeon. *Transactions of the American Fisheries Society* 144:1129-1142.

time compared to traditional methods (0.2 hour per kilometer vs 30 hours per kilometer).

Misclassification of substrate type was highest when delineating between rocky and limestone boulders, as these substrates produce similar sonar reflections. Combining these substrate classes increased map accuracy to 92%. Another source of misclassification was transitional areas between substrate types, specifically sand and gravel areas (Kaesler and Litts, 2010). Therefore, users are required to pay close attention to these areas and look for rippled or dune-like patterns typical of sandy areas (Kendall et al., 2005).

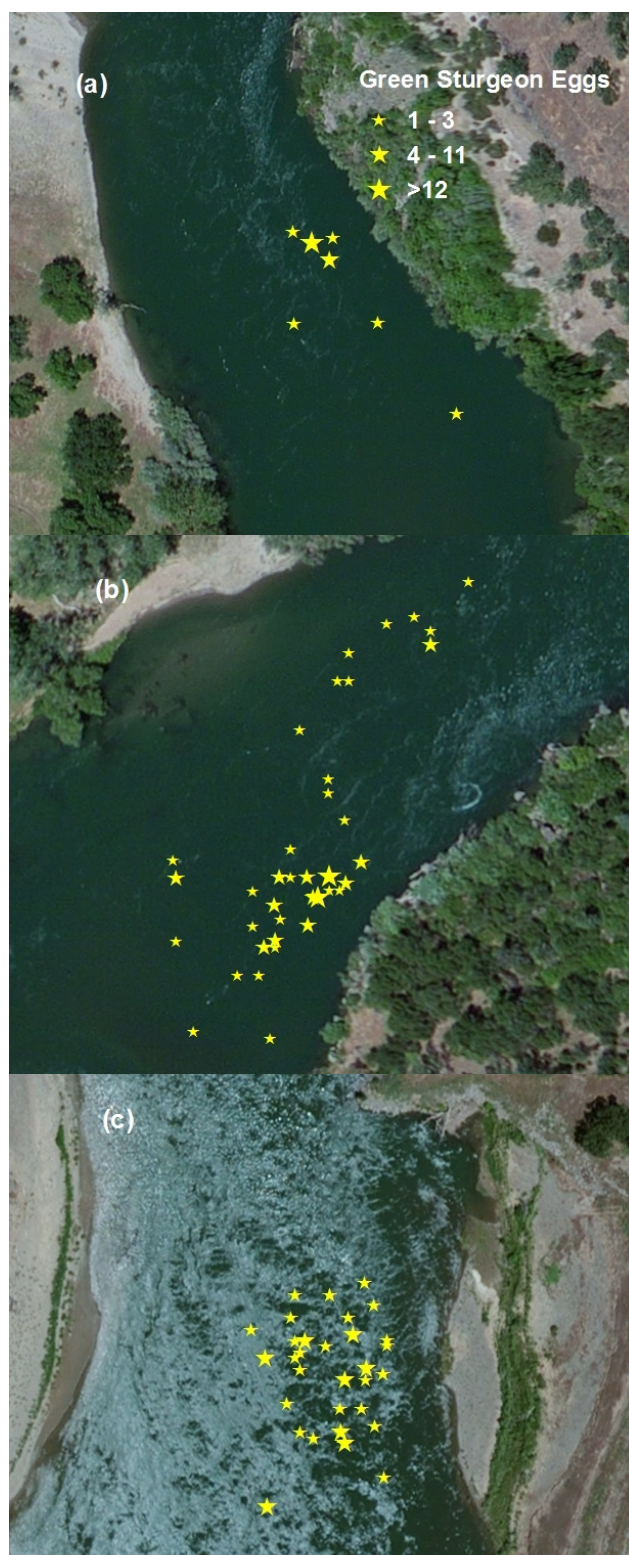


Figure 1. Location of Green Sturgeon eggs collected at rkm 426 (a), 424.5 (b), and 377 (c) using egg mats between 2008 and 2012.

TABLE 2. EGG MAT EFFORT DATA COLLECTED ON THE SACRAMENTO RIVER, CALIFORNIA BETWEEN 2008 AND 2012

Location	Year	Sample period	Collection date(s)	Collected eggs and larvae	Estimated spawning period	Estimated number of spawn events
rkm 426	2010	3/17 – 7/23	5/10	1	5/4	1
	2011	4/12 – 7/18	5/27 – 6/20	8	5/24 – 6/14	3
	2012	4/5 – 7/10	5/11 – 5/14	16	5/10 – 5/14	2
rkm 424.5	2008	4/22 – 8/1	5/2 – 6/13	12	4/30 – 6/10	3
	2009	3/30 – 7/30	4/2 – 5/14	9	4/2 – 4/22	4
	2010	3/17 – 7/23	4/11 – 5/27	93	4/11 – 5/21	8
	2011	4/12 – 7/18	-	0	-	-
	2012	4/5 – 7/10	4/29 – 5/23	40	4/28 – 5/19	4
rkm 407.5	2009	3/30 – 7/30	5/28 – 6/1	2	5/26 – 6/1	2
	2010	3/17 – 7/23	5/18	1	5/18	1
rkm 377	2008	4/22 – 8/1	5/9 – 7/7	29	5/8 – 7/4	7
	2009	3/31 – 7/31	4/24 – 6/23	43	4/23 – 6/20	10
	2010	3/23 – 7/25	4/27 – 6/16	9	4/27 – 6/13	3
rkm 366.5	2010	3/23 – 7/25	5/11	1	5/11	1
rkm 332.5	2011	4/12 – 7/15	5/18	1	5/15	1
	2012	4/6 – 7/14	5/27 – 5/30	3	5/25	1

Source: Data from Poytress, W. R., J. J. Gruber, J. P. Van Eenennaam, and M. Gard. 2015. Spatial and temporal distribution of spawning events and habitat characteristics of Sacramento River green sturgeon. Transactions of the American Fisheries Society 144:1129-1142.

Additional comparisons to classify four substrate types (sand, hard clay, gravel, and exposed bedrock) using SSS was conducted within the Ogeechee River, Georgia (Hook et al., 2011). Similar to other studies, they experienced high levels of map accuracy (85%) and difficulties accurately identifying gravel substrates (39%; Hook et al., 2011). The low accuracy associated with gravel substrates was attributed to the few training opportunities that researchers had to recognize this substrate, as it made up only

10.5% of the sampled area. In contrast, the substrate within the Sacramento River is comprised mainly of a gravel substrate above rkm 324 (Buer et al., 1985; Buer, 2007).

Substrate information for this project was gathered by digitizing maps based on SSS imagery. Funding and staff time did not allow time for additional surveys to validate the accuracy of these maps; however, the prior mentioned published peer reviewed literature has documented the methodology and accuracy of this technique. It should be noted that underwater video surveys conducted in conjunction with egg sampling (Poytress et al., 2009-2012) was referenced during the training and digitization of sonar maps but a comparisons study wasn't conducted.

Definition of Terms and Acronyms

Acoustic Doppler Current Profiler

Acoustic Doppler current profiler (ADCP) is a hydroacoustic current meter that measures water velocity and depth based on the backscatter of sound waves from particles within the water column.

Dual Frequency Identification Sonar

Dual frequency identification sonar (DIDSON) is a high-definition imaging sonar that obtains near-video quality images for the identification of objects underwater (Russell et al., 2003).

Habitat Suitability Criteria

Habitat suitability criteria (HSC) are used to identify spawning habitat preferences for specific physical habitat variables (e.g., depth, velocity, and substrate).

Variables are typically ranked on a scale of 0 to 1, with 0 representing unsuitable conditions and 1 representing suitable habitat (Bovee, 1986).

Side Scan Sonar

Side scan sonar (SSS) produces a photo like image of the substrate using a towfish or transducer to emit and interpret sound waves that reflect off the substrate.

Southern Distinct Population Segment

Southern distinct population segment (SDPS) of Green Sturgeon was established in 2002 when it was recognized that Green Sturgeon spawning in the Sacramento River were genetically different then those spawning in the Rogue and Klamath Rivers (Adams et al., 2002).

CHAPTER II

LITERATURE REVIEW

Current State of Knowledge on Sturgeon Spawning Habitat Preferences

Few studies have been conducted to identify the spawning habitat characteristics utilized by the SDPS of Green Sturgeon and their freshwater life history is among the least understood of any sturgeon species in North America (Kynard et al., 2005). Green Sturgeon spawning was documented within the Sacramento River by the collection of two eggs on egg mats immediately below the RBDD (rkm 391) (Brown, 2006). Similarly, egg mats were used to collect thirteen Green Sturgeon eggs downstream of the Thermalito Afterbay Outlet on the Feather River, California (Seesholtz et al., 2015). The primary objective of both studies was to document spawning, rather than to provide a thorough description of the habitat characteristics present at spawning locations. Habitat characteristics present at these locations may not representative spawning habitat preferences of Green Sturgeon in a natural environment because eggs were collected in areas where aggregations of adult sturgeon exist due to an impassable barrier. The most extensive spawning habitat study for SDPS of Green Sturgeon was conducted by the Red Bluff Fish and Wildlife Office, which is the data utilized to define suitable spawning habitat for this project (Poytress et al., 2015).

White Sturgeon habitat preferences have been well documented and are often used to describe Green Sturgeon spawning habitat (Dees, 1961; Kohlhorst, 1976, Perrin et al., 2003). White Sturgeon spawning temperatures range from 10 to 18 °C and 14 to 16 °C on the Columbia and Sacramento Rivers, respectively (Kohlhorst, 1976; Parsley et al., 1993; McCabe and Tracy, 1994). White sturgeon spawning habitat is generally associated with depths greater than four meters (Parsley and Beckman, 1994; Chapman and Jones, 2010; Paragamian, 2012) containing areas of complex hydraulics with mean column velocities ranging between 1.0 to 2.8 m/s (McCabe and Tracy, 1994; Parsley et al., 1993). Spawning substrates have been described as cobble and boulder (Parsley et al., 1993; Perrin et al., 2003), gravel (Schaffter, 1997) and sand (Paragamian et al., 2001).

Habitat suitability criteria (HSC) are used to identify spawning habitat preferences for a variety of fish species (Conklin et al., 1996). HSC for a physical habitat variable (e.g., depth, velocity, and substrate) are typically ranked on a scale of 0 to 1, with 0 representing unsuitable conditions and 1 representing suitable habitat (Bovee, 1986). HSCs for White Sturgeon suggest suitable habitat be defined as areas with depths ≥ 2 m, velocities ranging from 1.10 to 6.08 m/s, and over a variety of substrate including gravel, cobble, boulder, and bedrock (EA Engineering, 1991; Parsley and Beckman, 1994; Gard, 1996). Due to the lack of data, HSC have not been generated for Green Sturgeon (Gard et al., 2013). Field tests have demonstrated that HSC can be transferred between water sheds, and at times between species, but tests have not validated this for Green and White Sturgeon (Thomas and Bovee, 1993).

Evolution of Side Scan Sonar

Substrate Mapping Options

Habitat mapping, specifically substrate, in large rivers utilized by sturgeon can be challenging due to the size and complexity of the habitats. In clear riverine environments such as the Sacramento River, substrate can be identified visually using underwater video (Gard and Ballard, 2003) or divers (Johnson et al., 2006). In a turbid environment, substrate is identified via grab samples or with a single or multibeam echosounders (McCabe and Tracy, 1994; Paragamian and Rust, 2014). Grab sampling works well for identifying habitat within a small area, but require significant money to implement over larger areas.

Acoustic technology has been used to map aquatic habitat for decades (Kenyon, 1970; Belderson et al., 1972; Ballard and Moore, 1977) and has evolved into three sonar mapping systems: single-beam, multi-beam echo-sounders, and SSS (Blondel, 2009). These systems work on the same basic principle, i.e. that sound waves are projected from a transducer toward the substrate. The signal reflects off of the substrate to the transducer, which interprets the time lag and intensity to determine the location, size, and composition of the substrate (Humminbird, 2009). Single beam echo-sounders distribute a cone-shaped signal directly below the transducer, which identifies the depth while indicating the localized habitat (Heald and Pace, 1996). The footprint of the cone on a single beam echo-sounder is dependent upon on water depth and can be small in a shallow water environment (Blondel, 2009). In comparison to the single beam system, multi-beam echo-sounders incorporate several beams into a single system increasing the field of view. SSS was developed in the 1960's to emit pulses perpendicular to the vessel,

capturing images up to 60 kilometers on either side of the vessel (Fish and Carr, 1990). These pulses are then interpreted by the unit and displayed on a screen as a picturelike image of the substrate. Traditionally, SSS utilized a towfish transducer, which is towed behind a vessel to map areas at sea (Able et al., 1987; Barans and Holiday, 1983; Fish and Carr, 1990) or within deep freshwater environments (Sly, 1983). Unfortunately, the towfish transducer limits the use of SSS to deep water environments, due to the depth at which the towfish travels (Strayer et al., 2006).

Recreational Grade Sonar

Commercial grade SSS operations are expensive, typically exceeding \$40,000 to simply purchase the equipment (Jake Hughes, Idaho Power, personal communication). Fortunately, technology has continued to advance over the last three decades, decreasing the size of the sonar and GPS, allowing for multiple technologies to be coupled into a single inexpensive device. In 2005 and 2009, Humminbird and Lowrance introduced a recreational grade SSS system tailored to the consumer market. Shortly thereafter, researchers found a strong correlation ($r^2=0.85-0.92$) when quantifying deadhead logs and large woody debris using traditional field based methods and SSS (Kaeser and Litts, 2008). Subsequent research compared the accuracy and effort required to conduct SSS surveys against traditional field-based surveys. SSS was found to not only be accurate, (86%) but efficient, requiring one tenth of the time when compared to field based surveys (Kaesar and Litts, 2010). They continued developing the method by creating a step by step sonar imagery geoprocessing workbook and American Fisheries Society workshop, to aid fellow biologists in utilizing these technologies to better manage our natural resources.

Subsequent researchers compared accuracy and effort required to georeference still snapshots against using Dr. Depth software to process raw sonar inputs in the Ogeechee River, GA (Hook, 2011). Overall, both methods provided high levels of accuracy, between 82% and 85%. Differences in effort were noted between the two methods, but Hook (2011) preferred georeferencing sonar imagery using Dr. Depth software due to the speed (22 minutes per rkm) and ease of use. Since the time of Hook's evaluation, additional steps have been automated via ArcMap sonar tools created by Kaeser and Litts narrowing, if not eliminating, advantages of Dr. Depth software observed by Hook. Furthermore, Dr. Depth software is no longer available or supported by its third party creator. Thus for this project, ArcMap sonar tools were used to georeference still sonar snapshots.

CHAPTER III

METHODOLOGY

Study Area

The Sacramento River flows south through 600 kilometers of the state, draining numerous slopes of the Coast, Klamath, Cascade, and Sierra Nevada ranges, and eventually reaches the Pacific Ocean via San Francisco Bay. Since 1943, Shasta Dam and its associated downstream flow-regulating structure, Keswick Dam, have formed a complete passage barrier to upstream anadromous fish at rkm 486, counting upstream from the confluence of the Sacramento and San Joaquin Rivers in Suisun Bay (Moffett, 1949). The 94 rkm reach between Keswick Dam (rkm 486; Figure 2) and RBDD (rkm 391) has narrow bands of intact riparian vegetation encased by tall cliffs of sedimentary and volcanic rocks. The river channel is stabilized by these hard rock surfaces and deposits that erode slowly over time (Buer, 2007).

Egg sampling identified three spawning locations above the RBDD (rkm 426, 424.5, and 407.5) where the river flow is deflected off naturally hard rock surfaces, constricting the river's flow. This constriction increases the water's velocity, creating standing waves and complex hydraulics, which scour out a deep pool within the gravelly substrate. At and below RBDD, the river flows into the Sacramento Valley where its channel meanders through an expanse of alluvial deposit composed mainly of gravel (Buer et al., 1985). Within some sections of this reach, rock levees have been established

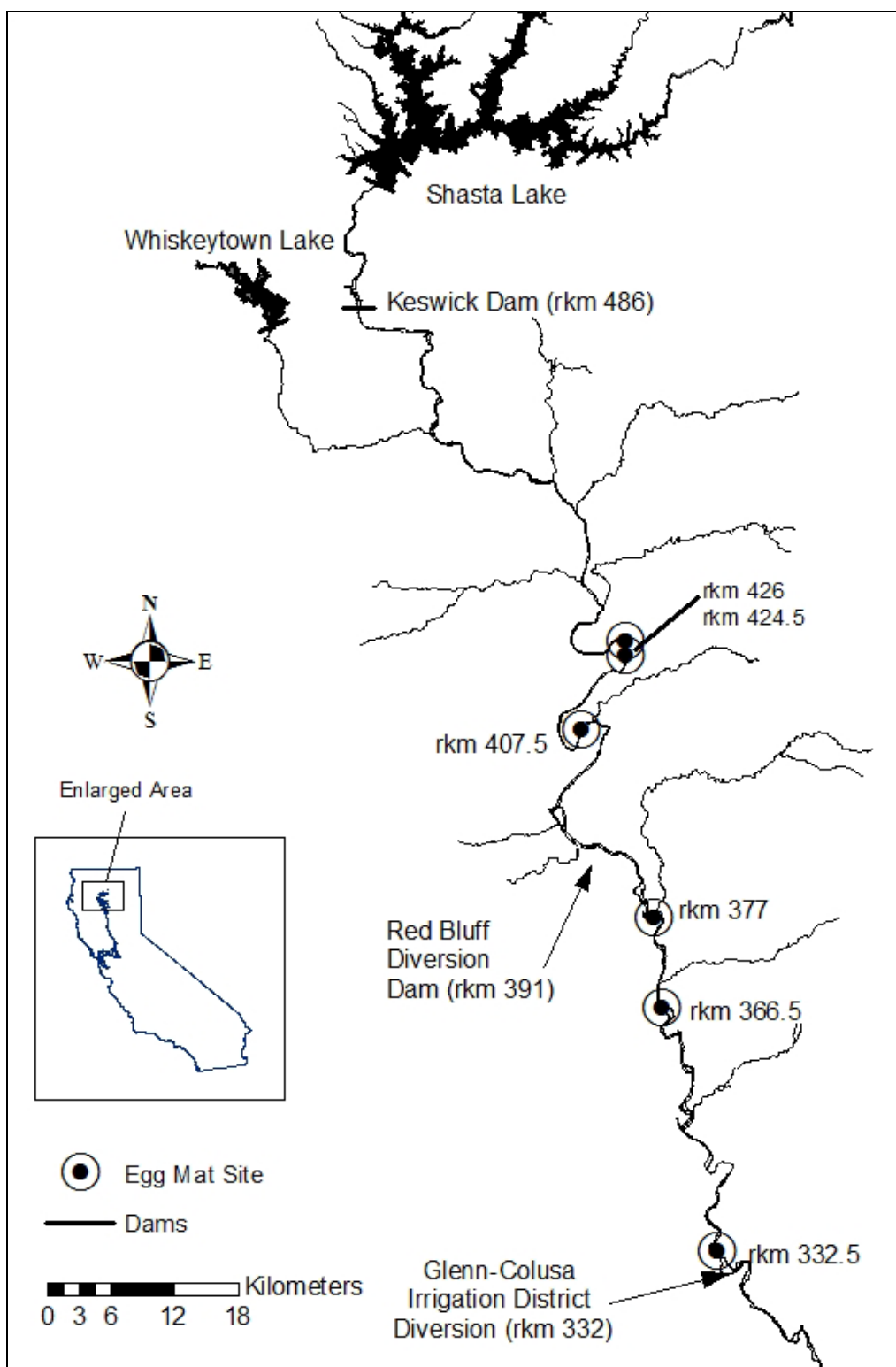


Figure 2. Known Green Sturgeon spawning locations on the Sacramento River, California.

to stabilize the dynamic river channel as it flows south to the Sacramento-San Joaquin Estuary. In this reach egg sampling identified four spawning locations at rkm 391, 377, 366.5, and 332.5. Three of these spawning locations occur as the river flow deflects off the remnants of washed out levees. Similar to the upper spawning locations, the lower locations are locations of deep pools containing complex hydraulics, although standing waves are not present at the lowermost location (rkm 332.5).

Spawning was also documented directly downstream of the RBDD (rkm 391). RBDD is a seasonal impoundment containing eleven moveable dam gates, that when lowered, creates a gravity diversion, blocking upstream passage of Green Sturgeon during their spawning migration. With the gates in the lowered position, un-diverted water was allowed to flow beneath the gates creating water velocities >1.5 m/s and hydraulics similar to that of a low head dam. In 2012, this facility was decommissioned and replaced with a fixed screened pumping plant to improve upstream and downstream passage for salmonids and Green Sturgeon. As such, spawning is no longer occurring at RBDD.

Egg Sampling

Artificial substrate samplers (e.g., egg mats) were used to identify spawning habitat preferences of SDPS Green Sturgeon in the upper Sacramento River. Because egg sampling is not the focus of this project paper, only a general overview of its methods will be given. (For a detailed description see Poytress et al., 2015).

Sampling was conducted from March to July beginning in 2008 through 2012 with varying amounts of effort at the six locations between rkm 426 and 332.5 (Table 2;

Figure 2). Egg mats were deployed in a paired fashion within the pool micro habitat of suspected spawning areas and sampled at approximately 72 hour intervals. Prior to sampling egg mats, waypoints were collected directly above each mat using an external GPS antenna on a Humminbird® 1198C Side Imaging fish finder to record its sampling location. Egg mats were inspected by two field crew members, rinsed, and re-inspected. Eggs were identified to species and Green Sturgeon eggs were preserved in 95% alcohol for laboratory verification and analysis. Because Green Sturgeon eggs are adhesive (Van Eenennaam et al., 2008, 2012) spawning was considered to be occurring in close proximity to where eggs were collected.

Habitat Assessment

Depth and Velocity

At the conclusion of egg sampling, additional surveys were conducted within the known spawning areas to identify river depth, mean water column velocity, and substrate type used by Green Sturgeon for spawning. River depth and mean water column velocity was measured using a ADCP (RD Instruments Workhorse Rio Grande) and a survey grade Real Time Kinematic GPS unit (Topcon HiPer+). ADCP measurements were collected along perpendicular transects throughout the spawning pool at 10 to 20 meter intervals. Transect data was imported into ArcMap to generate a raster dataset by interpolating missing values using ArcTools 3D Analyst. Depth and velocity raster dataset were then exported into individual data layers.

Substrate

Substrate type was identified using a Humminbird® 1198C Side Imaging system and methodology outlined in Kaesar and Litts (2010). The sonar transducer was mounted off the starboard bow of a 6.4 meter inboard jet boat to collect overlapping screen snapshots at 30 second intervals. Sonar's frequency was set to 455 kHz and side beam range varied from 30.5 to 53.3 meters, per side, during the surveys to capture a bank full image of the river substrate. When necessary a second transect was conducted to cover the entire spawning pool. To identify the image capture locations, an external GPS antenna was mounted off the boat's canopy to track the boat's course at five second intervals. User settings were adjusted to "offset" the distance between the transducer and GPS antenna.

Sonar imagery geoprocessing used for this project was completed using methods detailed within Kaeser and Litts, *Sonar Imagery Geoprocessing Workbook* (version 2.1; 2011). Environmental Systems Research Institute's GIS software transformed raw sonar images into sonar image maps with real world coordinates (e.g., Universal Transverse Mercator). ArcMap and IrfanView were used to remove the image collar, crop overlapping sections on consecutive snapshots, and for generation of raw sonar image mosaics. The end result was a continuous mosaic of river bottom consisting of 4-8 individual images, each representing approximately a 200 to 500 meter stream reach within each of the spawning areas.

Sonar mosaics were then saved as new data layer to be delineated based on the substrate's visual texture thus creating a substrate feature class (Figure 3). Five substrate

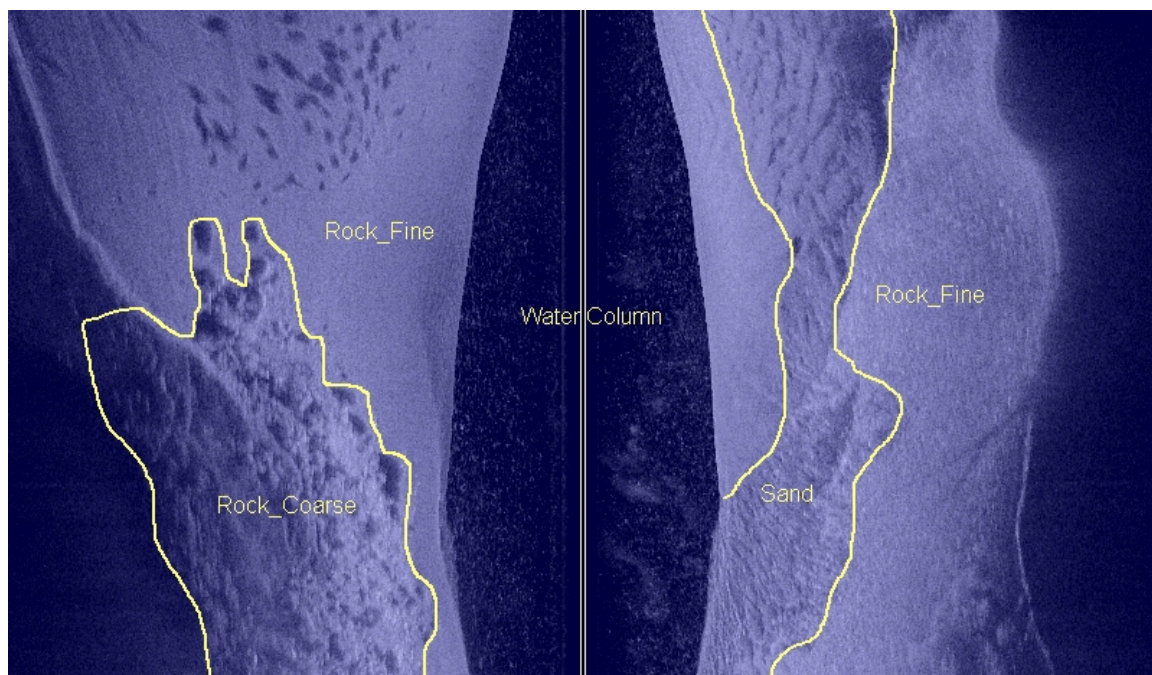


Figure 3. Sonar image from the upper Sacramento River delineated to identify key habitat features. The water column appears as a dark area in the center of the image. Yellow lines have been drawn to illustrate the apparent boundaries between the following substrate classes: Sandy, Rock_Fine, and Rock Coarse. Categories not shown are Large Woody Debris and Unknown substrates.

types were identified: Sand, Rock_Fines, Rock_Course, Large Woody Debris, and Unknown (Table 3)

Suitable Spawning Habitat Criteria

Egg mat samples were separated into two categories based on whether they collected (e.g., occupied) or did not collect (e.g., unoccupied) Green Sturgeon eggs. Using GPS coordinates from where egg mats were retrieved, the depth, velocity, and substrate type for occupied samples at rkm 424.5 were extracted from the three ArcMap data layers to define the range of suitable spawning habitat criteria. Only occupied samples from rkm 424.5 were used to define the suitable spawning habitat criteria

TABLE 3. SUBSTRATE CLASSIFICATION SCHEME AND ASSOCIATED DEFINITIONS USED TO DELINEATE SONAR IMAGES

Substrate Class	Acronym	Definition
Sand	S	< 2 mm (sand, silt, or fine organic matter)
Rock Fine	R_F	>2 mm to 500 mm (gravel to cobble)
Rock Coarse	R_C	> 3 boulders or bedrock outcroppings, each > 500 mm within 1.5 meters of the next boulder
Large Woody Debris	LWD	Submerged trees and bushes covering areas >2.0 m ²
Unknown	UNK	Unclassified areas due to shadows, poor imagery, or unknown substrate

because it contained the highest density of spawning and was sampled all five years during the egg study.

Data Analysis

To determine whether the suitable spawning habitat criteria identified by occupied samples at rkm 424.5 is transferable to the remaining five spawning areas I tested for non-random selection of habitat. To do this I sorted the occupied and unoccupied samples at rkm 426, 407.5, 377, 366.5, and 332.5 into two categories, based on whether they were located in suitable or unsuitable habitat as defined by the suitable spawning habitat criteria. A one sided chi-squared test was used to compare the proportion of occupied and unoccupied sample within suitable or unsuitable categories (Conover, 1971; Thomas and Bovee, 1993). In order for the suitable spawning habitat criteria to be transferable, the occupied samples would have been collected at a higher proportion in areas defined as suitable habitat compared to areas defined as unsuitable habitat. The test statistics (T) were evaluated at the alpha 0.05 and are given as:

$$T = [N^{0.5}(AD-BC)] / [(A+B)(C+D)(A+C)(B+D)]^{0.5}$$

	Suitable	Unsuitable	Total
Occupied	A	B	A+B
Unoccupied	C	D	C+D
Total	A+C	B+D	N

H₀: Egg mats sampled in suitable habitat will be occupied at the same proportion as in unsuitable habitat. (Random; Non-transferable)

H₁: Egg mats sampled in suitable habitat will be occupied at a greater proportion as in unsuitable habitat. (Non-random; Transferable)

Quantifying Suitable Spawning Habitat

The amount of suitable spawning habitat contained within the six spawning areas was quantified by joining the depth, velocity, and substrate raster datasets into a single ArcMap shapefile known as “available habitat.” Using the suitable spawning habitat criteria in a definition query, the “available habitat” shapefile was exported into a new shapefile, “suitable habitat” to identify areas that meet all three suitable spawning habitat criteria. Total area of available and suitable habitat was expressed in hectares.

CHAPTER IV

RESULT

Habitat Assessment

Depth and Velocity

River depth and mean water column velocities surveys were conducted between May 28-31, 2013 with the river discharge between 341.7 and 351.1 m³/s. At the six spawning locations, river depth ranged from 0.9 to 15.7 m and mean water column velocity ranged from 0.01 to 2.30 m/s (Table 4; Figures 4-9). Eggs mats sampled river depths ranging from 1.6 to 13.4 m and mean water column velocity ranged from 0.02 to 1.77 m/s (Figures 10-11).

Substrate

SSS surveys were conducted at the six spawning locations between April 18 to June 13, 2014 with flows ranging from 137.1 to 269.6 m³/s. In total, 13.45 hectares of substrate habitat was mapped. Overall rock_fine substrate consisted of 65% of the mapped habitat but ranged between 41% and 71% within each of the spawning areas (Table 5). Rock_course and sand were the next most abundant substrate at each of the spawning locations making up 13% and 10% of the overall habitat, respectively. Egg mats were sampled in sand, rock_fine, rock_course and large woody debris substrates (Figure 12).

TABLE 4. DEPTH AND VELOCITIES PRESENT AT THE SIX SPAWNING LOCATIONS IN THE SACRAMENTO RIVER, CALIFORNIA

Available habitat							Occupied samples						
Depth (m)				Velocity (m/sec)			Number of samples	Depth (m)			Velocity (m/sec)		
Location	Min	Max	Ave \pm SD	Min	Max	Ave \pm SD		Min	Max	Ave \pm SD	Min	Max	Ave \pm SD
rkm 426	1.0	12.1	5.6 \pm 2.3	0.02	2.30	0.86 \pm 0.45	7	5.0	11.0	8.3 \pm 2.2	0.35	1.28	0.66 \pm 0.34
rkm 424.5	0.9	15.7	5.4 \pm 3.5	0.01	2.17	0.83 \pm 0.43	39	2.8	11.3	7.4 \pm 2.1	0.12	1.11	0.68 \pm 0.24
rkm 407.5	0.9	12.4	7.9 \pm 2.3	0.01	1.80	0.82 \pm 0.39	3	7.4	9.3	8.2 \pm 1.0	0.34	0.94	0.62 \pm 0.30
rkm 377	1.0	11.2	4.4 \pm 2.2	0.04	1.60	0.87 \pm 0.34	34	3.0	7.4	5.0 \pm 0.9	0.69	1.16	0.99 \pm 0.09
rkm 366.5	1.7	7.7	4.7 \pm 1.3	0.02	1.58	0.72 \pm 0.41	1	6.4	6.4	6.4 \pm 0	0.17	0.17	0.17 \pm 0.00
rkm 332.5	1.6	9.2	5.5 \pm 1.6	0.03	1.74	0.66 \pm 0.35	3	7.0	8.4	7.9 \pm 0.8	1.07	1.18	1.13 \pm 0.05

Note: Data is summarized by the available habitat and conditions present where eggs were collected (occupied samples).

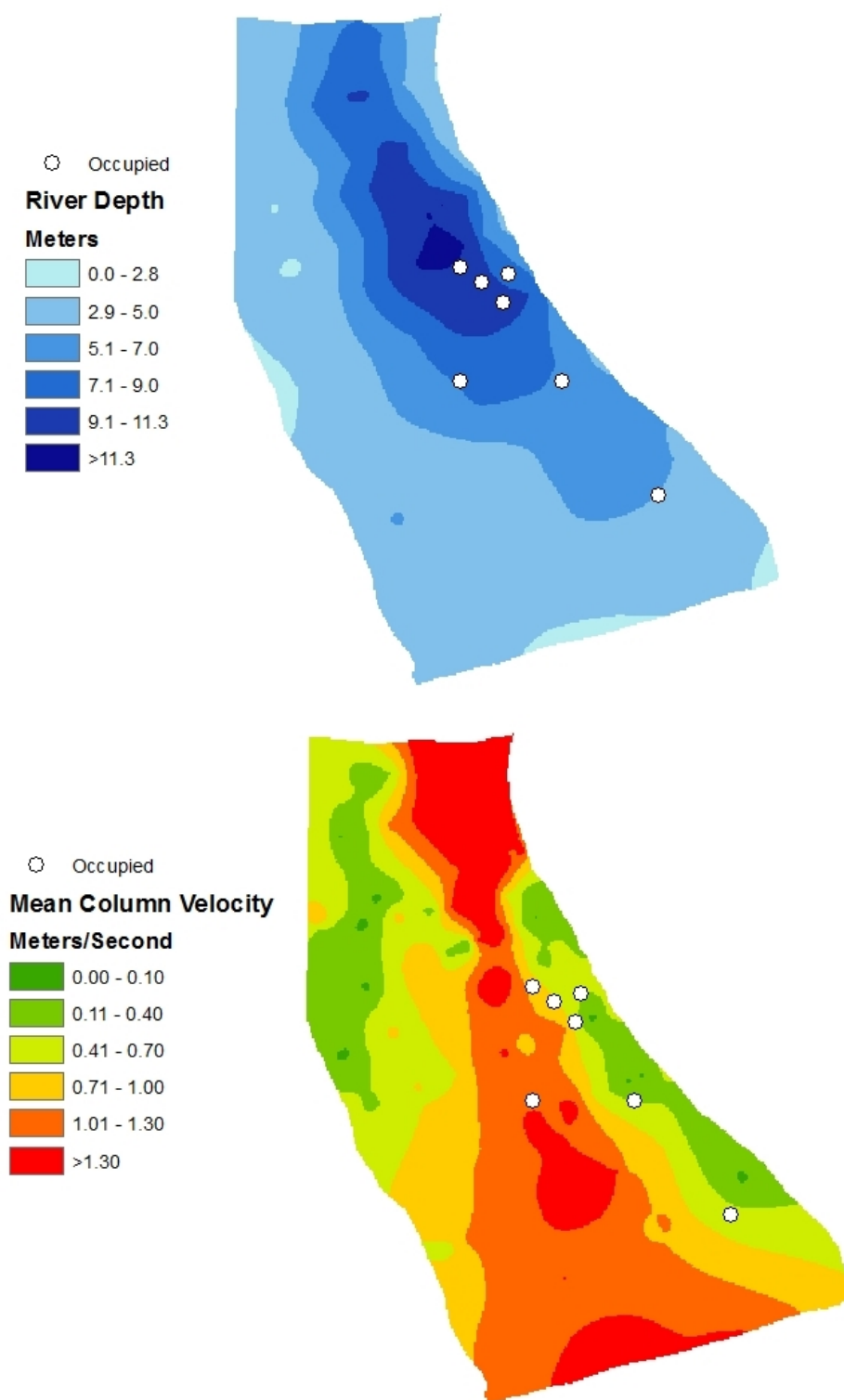


Figure 4. Depth and velocities present at rkm 426. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

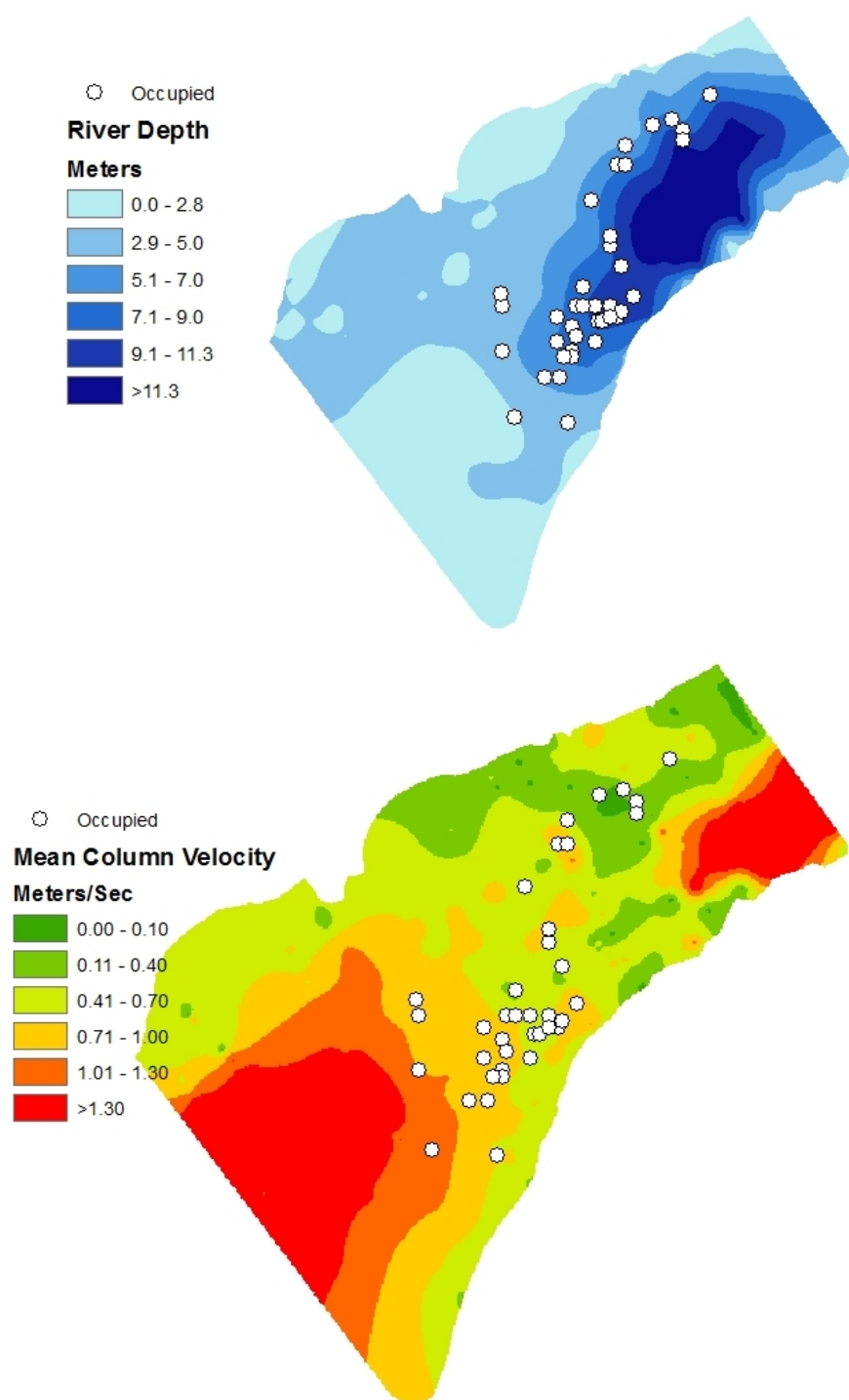


Figure 5. Depth and velocities present at rkm 424.5. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

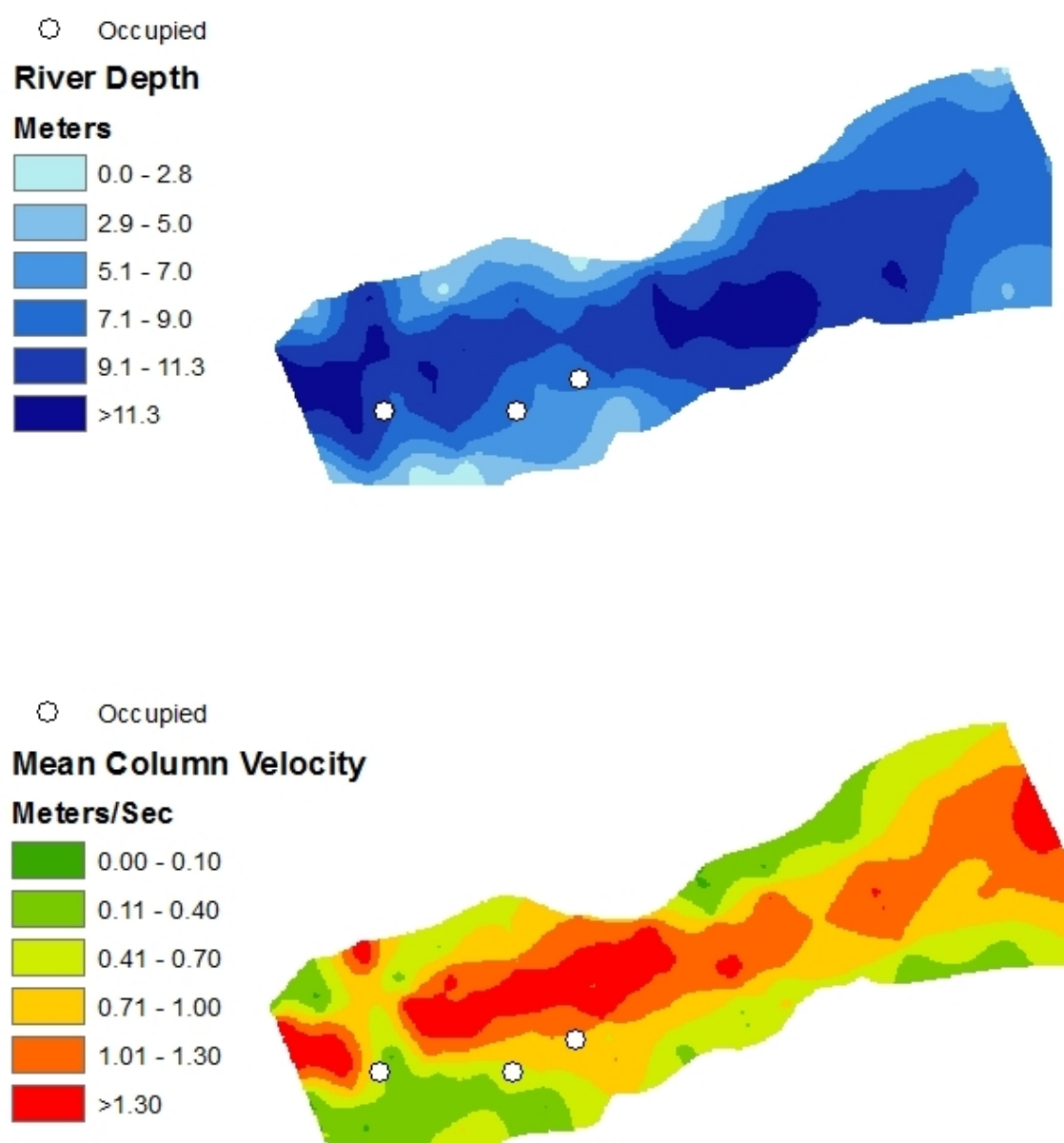


Figure 6. Depth and velocities present at rkm 407.5. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

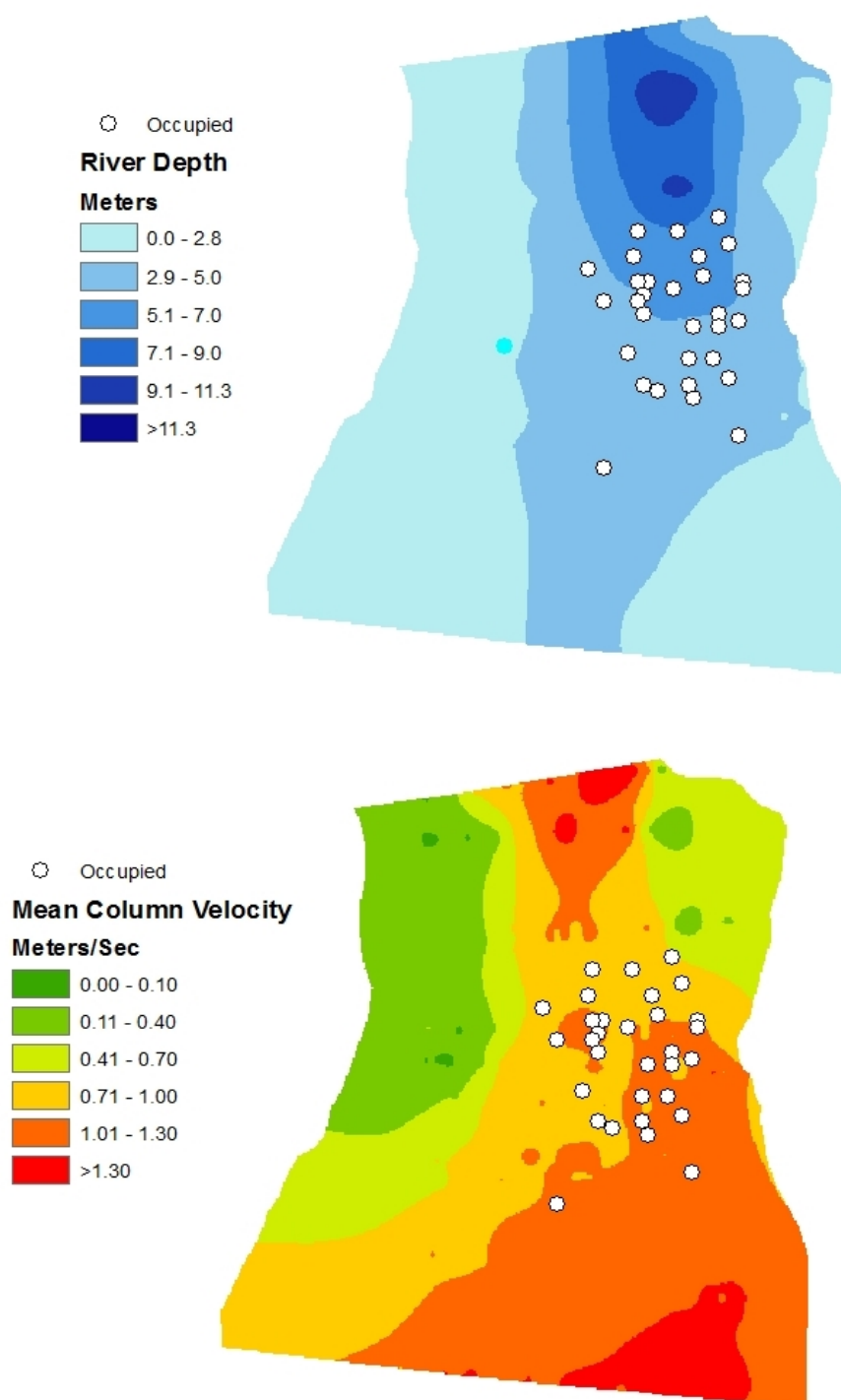


Figure 7. Depth and velocities present at rkm 377. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

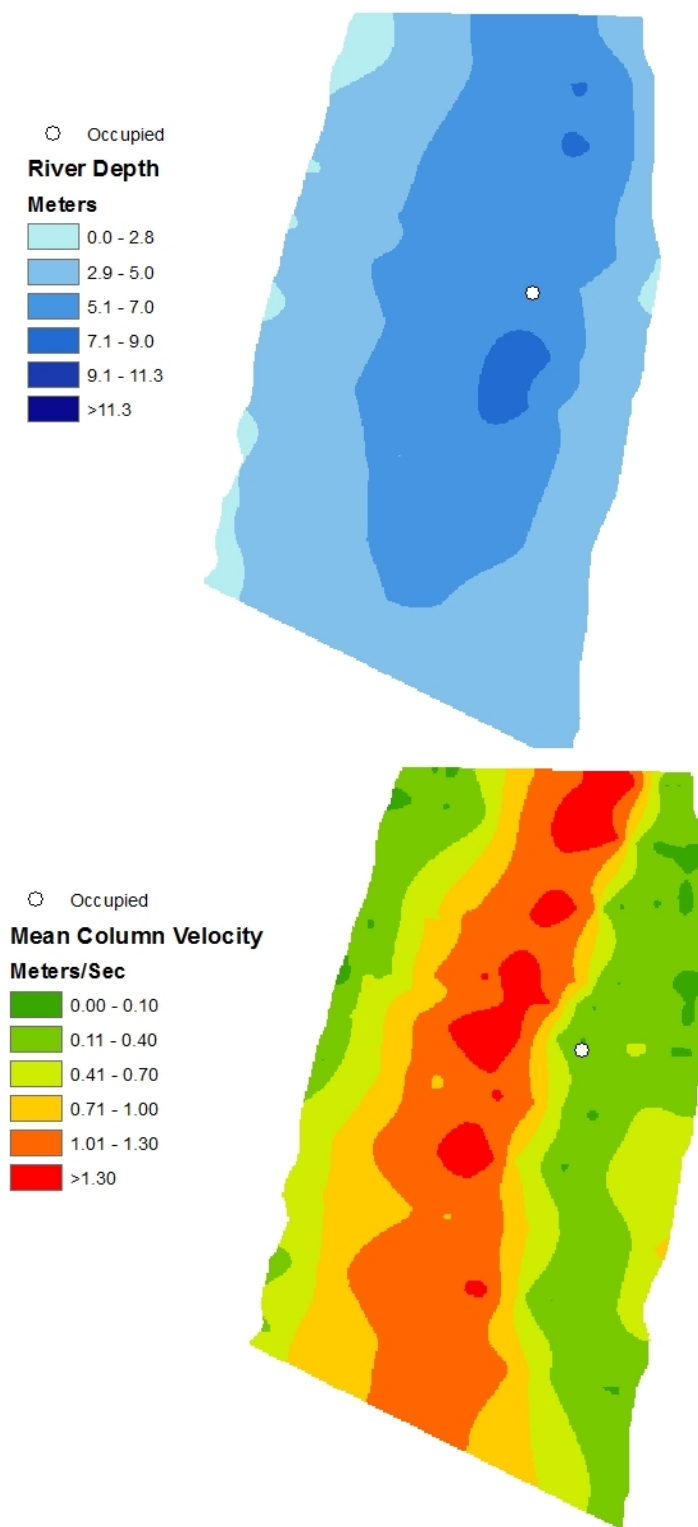


Figure 8. Depth and velocities present at rkm 366.5. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

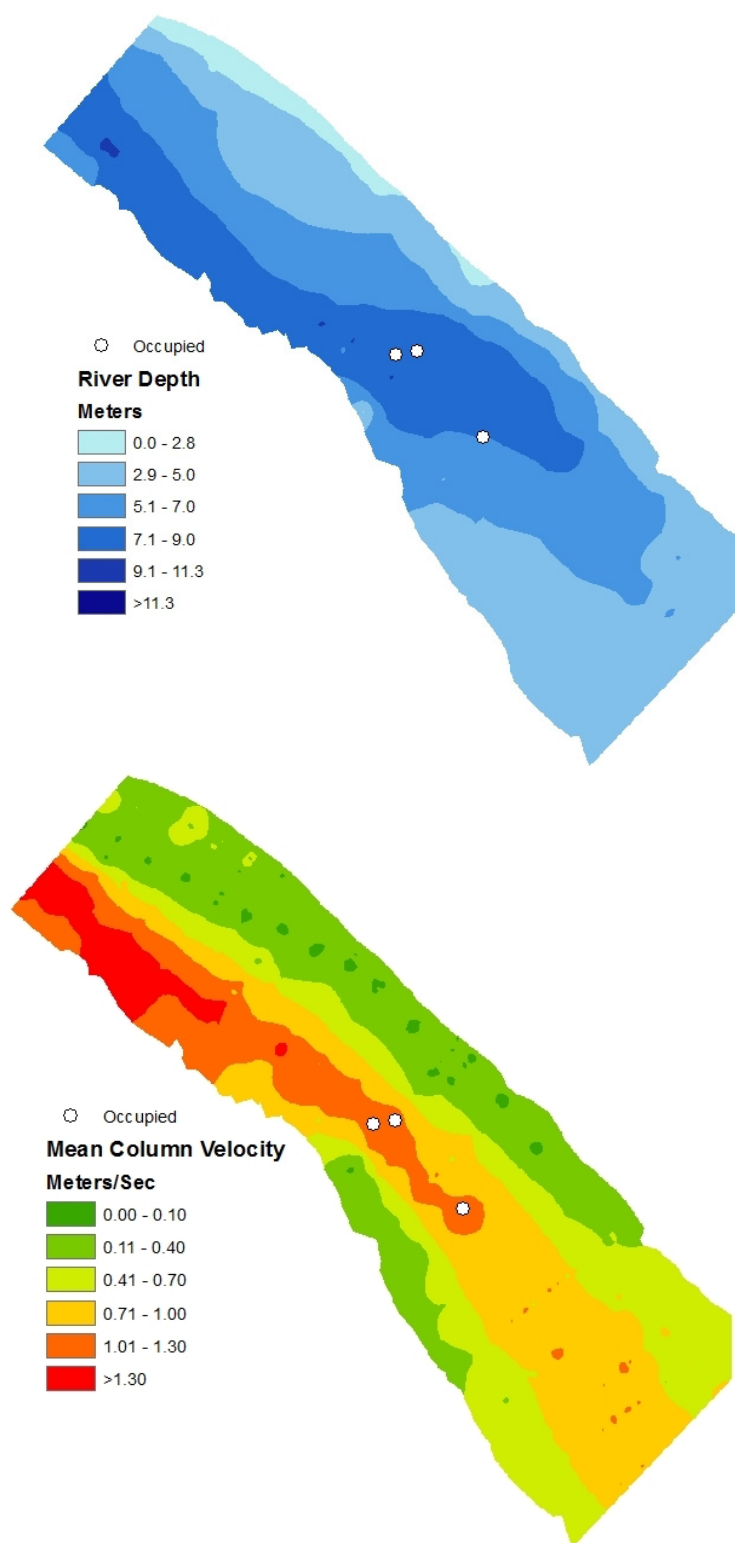


Figure 9. Depth and velocities present at rkm 332.5. White circles indicate the location of egg mat samples that collected Green Sturgeon eggs.

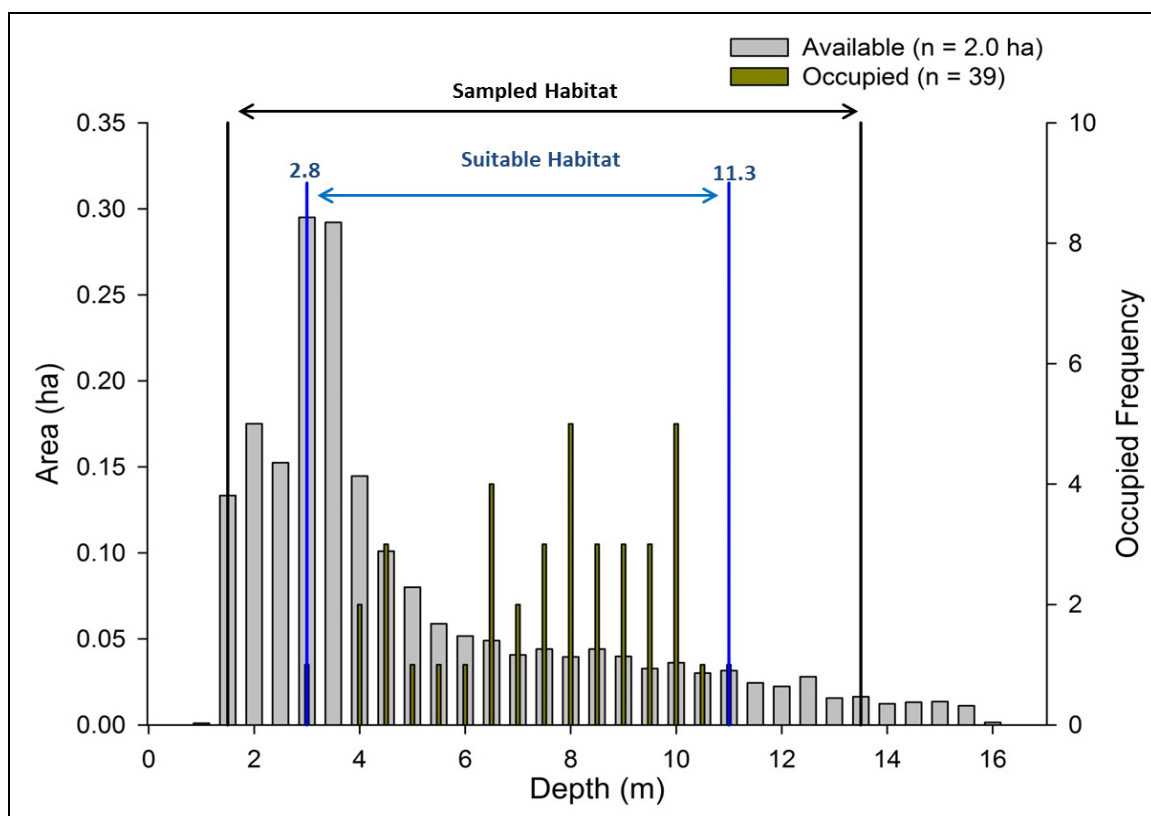


Figure 10. Frequency distribution of river depths at rkm 424.5. The grey bars represent the amount of available habitat and green bars represent the number of egg mats that collected Green Sturgeon eggs (e.g., occupied samples). Black and blue vertical lines represent the range of depths sampled and where Green Sturgeon eggs were collected.

Suitable Spawning Habitat Criteria

Two hundred and sixty-five Green Sturgeon eggs and five post hatch larvae were collected on 87 of the 1793 egg mats that were sampled at the six spawning locations. Occupied samples at rkm 424.5 ($n=39$) were collected at river depths ranging from 2.8 to 11.3 meters, mean water column velocity ranging from 0.12 to 1.11 meters per second and over rock_fine (85%) and sand (15%) substrates (Tables 4-5, Figures 10-12). Chi-square test results rejected the null hypotheses that Green Sturgeon were spawning randomly within the spawning locations ($T=2.1598$; $P=0.0154$; Table 6). Using

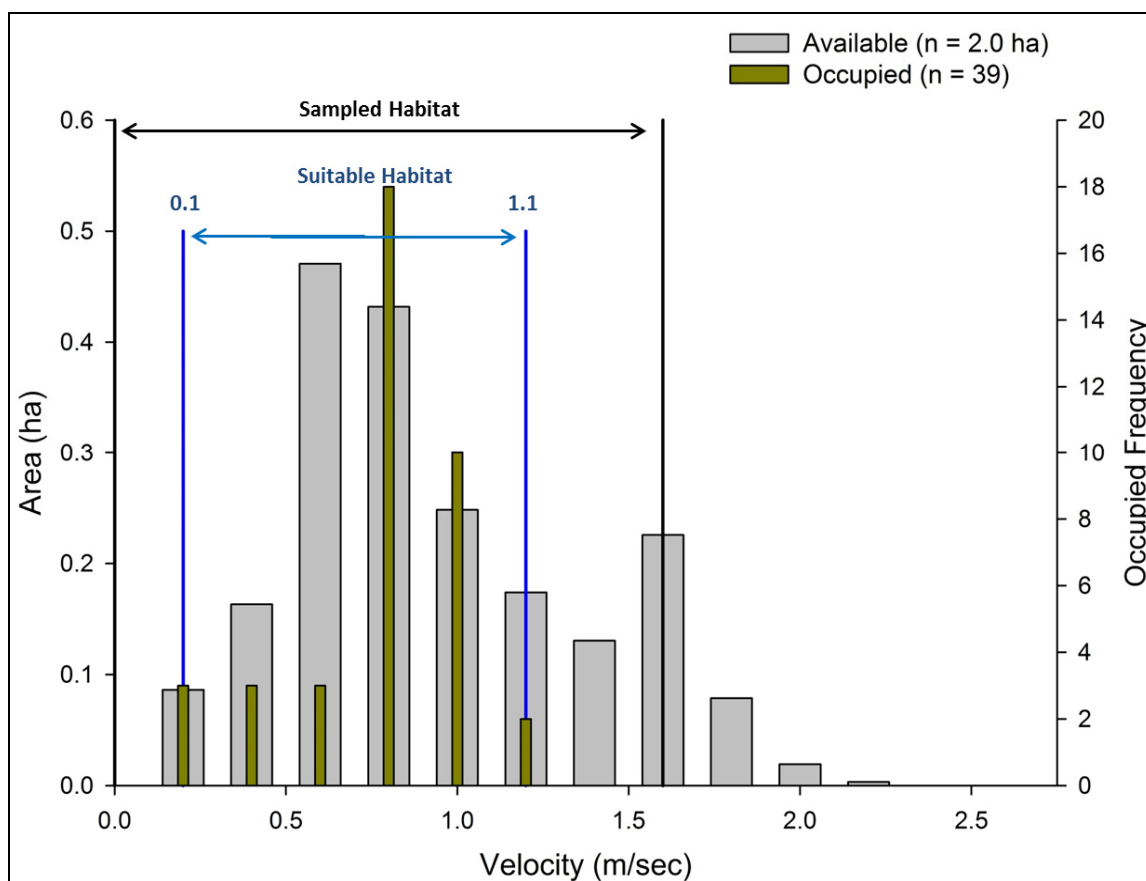


Figure 11. Frequency distribution of mean water column velocity at rkm 424.5. The grey bars represent the amount of available habitat and green bars represent the number of egg mats that collected Green Sturgeon eggs (e.g., occupied samples). Black and blue vertical lines represent the range of velocities sampled and where Green Sturgeon eggs were collected.

the suitable spawning habitat criteria, 6.9 hectares or 51.1% of the 13.45 hectares of available habitat was identified as suitable spawning habitat within the six known spawning areas. Individually the amount of suitable habitat contained within each location ranged from 18.2 to 76.4% (Table 7)

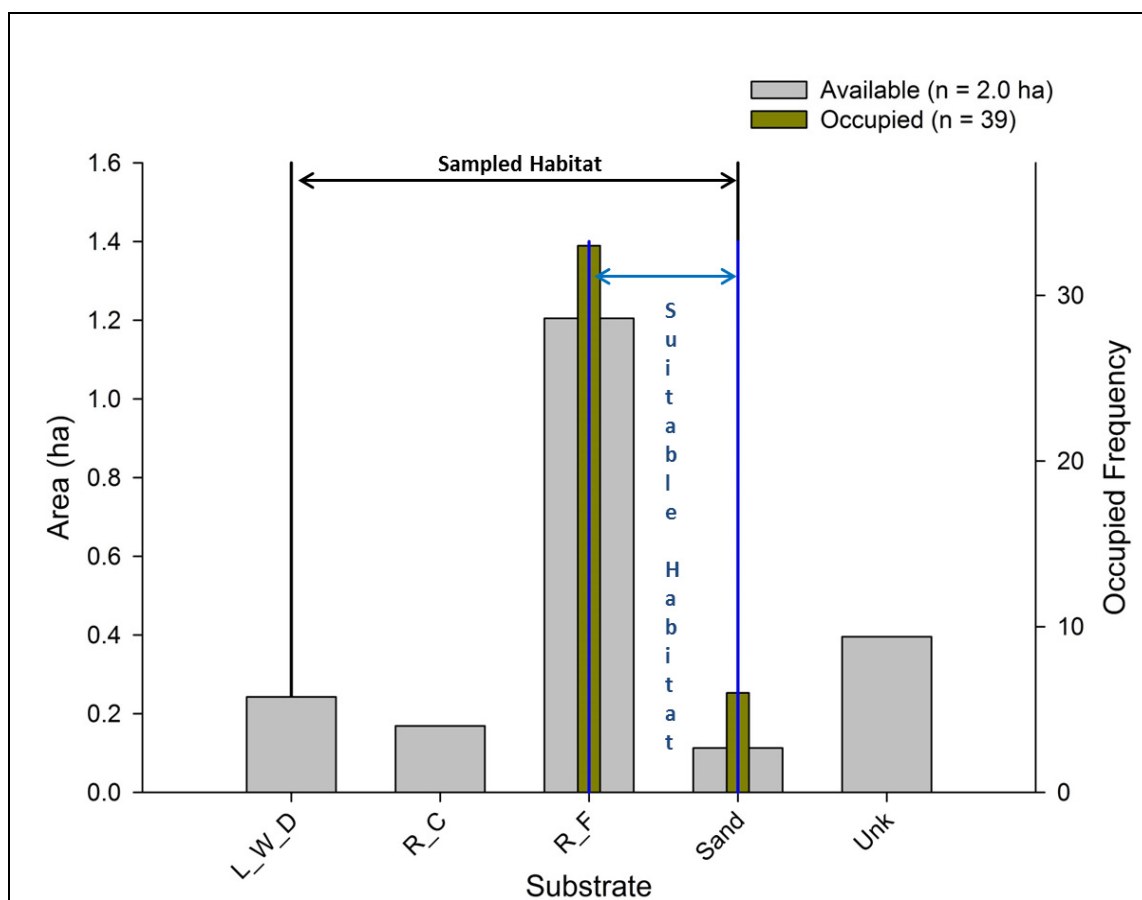


Figure 12. Frequency distribution of substrates at rkm 424.5. The grey bars represent the amount of available habitat and green bars represent the number of egg mats that collected Green Sturgeon eggs (e.g., occupied samples). Black and blue vertical lines represent the range of substrate sampled and where Green Sturgeon eggs were collected. Substrate classes include: Large woody debris (L_W_D), Rock Coarse (R_C), Rock Fine (R_F), Sand, and Unknown.

TABLE 5. SUBSTRATE COMPOSITION AND NUMBER OF OCCUPIED SAMPLES BY SUBSTRATE TYPE AT THE SIX SPAWNING LOCATIONS

Location	Date	Flow (m ³ /s)	Length (m)	Area (ha)	Available habitat					Number of occupied samples				
					Rock Fine	Rock Coarse	Sand	L W D	UNK	Rock Fine	Rock Coarse	Sand	LWD	UNK
rkm 426	6/12/2014	269.6	183	1.5	70%	9%	6%	4%	11%	7	0	0	0	0
rkm 424.5	6/12/2014	269.6	212	2.1	57%	8%	5%	11%	19%	33	0	6	0	0
rkm 407.5	6/12/2014	269.6	189	1.0	41%	54%	1%	0%	5%	1	2	0	0	0
rkm 377	4/18/2014	137.1	186	2.3	71%	3%	7%	0%	19%	33	0	1	0	0
rkm 366.5	6/5/2014	244.9	213	2.5	66%	25%	5%	1%	3%	0	1	0	0	0
rkm 332.5	6/13/2014	256.5	393	4.0	70%	5%	20%	5%	0%	2	0	1	0	0
Total				13.5	65%	13%	10%	4%	8%	76	3	8	0	0

Note: Substrate types were classified as rock fine, rock coarse, sand, large woody debris (LWD) and unknown (UNK; Table 3).

TABLE 6. CHI-SQUARE ANALYSIS OF THE
TRANSFERABILITY OF THE SUITABLE
SPAWNING HABITAT CRITERIA

	Suitable	Unsuitable	Total
Occupied	40	8	48
Unoccupied	837	382	1219
Total	877	390	1267
T = 2.1598		P = 0.0154*	

Note: * indicates significances at the 0.05 level.

TABLE 7. AVAILABLE, SUITABLE AND
PERCENT SUITABLE SPAWNING
HABITAT QUANTIFIED USING
THE SUITABLE SPAWNING
HABITAT CRITERIA

Location	Available (h)	Suitable (h)	% Suitable
rkm 426	1.50	0.71	47.1%
rkm 424.5	2.12	0.82	38.7%
rkm 407.5	1.03	0.19	18.2%
rkm 377	2.33	0.82	35.1%
rkm 366.5	2.47	1.33	53.8%
rkm 332.5	4.00	3.05	76.4%
Total	13.45	6.92	51.4%

Note: Habitat is quantified in hectares

CHAPTER V

DISCUSSION

Suitable Spawning Habitat Criteria

Egg mats were used to document six spawning location within the Sacramento River from rkm 426 to 332.5. Sampling at rkm 424.5 identify Green Sturgeon were spawning at depths from 2.8 to 11.3 m, velocities ranging from 0.12 to 1.11 m/s, over rock fine and sand substrates (Figures 10-12). The chi-squared test identified that the occupied samples were found at a higher proportion within areas that were defined as suitable habitat ($T=2.1598$; $P=0.0154$; Table 6). These results indicate that our suitable spawning habitat criteria are transferable outside of our study area. However, our sample size was rather small with only 48 occupied egg mats at the spawning sites located at rkm 426, 407.5, 377, 366.5, and 332.5. Studies indicate that tests with fewer than 55 occupied samples have an increased likelihood of committing a type 1 or 2 error (Thomas and Bovee, 1993). Rather than conducting additional egg sampling on the Sacramento River to increase the number of occupied samples one could collect the depth, velocity, and substrate data at the Thermalito Afterbay Outlet on the Feather River. Adding the 8 occupied and numerous unoccupied samples (Seesholtz et al., 2015) would increase the number of occupied samples to 56, bolstering the results of the test, as well as providing insight into the transferability of the suitable spawning habitat criteria to the Feather River.

Recovery Plan Implications

The assessment and monitoring of freshwater habitats is essential to the successful management of imperiled fishes (Minns et al., 1996; Maddock, 1999; Dudgeon et al., 2006). Using SSS, GIS mapping techniques, and the information collected during the RBFWO egg sampling studies (Poytress et al., 2015) I was able to define the suitable spawning habitat criteria for SDPS Green Sturgeon in terms of depth, velocity, and substrate type and quantify the 6.9 hectares of suitable spawning habitat contained within the six spawning locations. Yet this doesn't represent the total amount of suitable spawning habitat contained within the Sacramento River for SDPS Green Sturgeon. Currently the putative spawning grounds for adult Green Sturgeon is describe as a ~125 rkm stretch of the Sacramento River between rkm 323-451 (Hublein et al., 2009; Thomas et al., 2014). RBFWO egg sampling studies (Poytress et al., 2015) and DIDSON surveys (E. Mora, University of California, Davis, personal communication) indicate that spawning is likely occurring in relatively few deep holes, spread throughout a smaller section of the river (e.g., 75 miles) (NMFS, 2015). Additional habitat mapping studies need to be conducted within the deep water habitats (e.g., >5 meters) between rkm 323-451 to establish an effective recovery plan with respect to spawning habitat and spawner population metrics. Expanded use of these techniques could quantify the total amount and expected locations of spawning habitat throughout the Sacramento River. Between river comparison should also be conducted on the Feather and Yuba Rivers as these areas show a high probability areas for habitat restoration and establishing a secondary spawning population outside of the Sacramento River due to the presence of periodic spawning (Cramer Fish Sciences, 2011; NMFS, 2013; Seesholtz et al., 2015).

Comparisons of Suitable Spawning Habitat Criteria

Sturgeon spawning habitat is often described as deep, high velocity areas. Swimming performance studies indicate that *Acipenser spp.* can sustain swimming at velocities of 1.2 to 4.5 body lengths per second (Malinin et al., 1971). The RBFWO collected Green Sturgeon eggs in six deep hydraulically active pools during their five year egg sampling study in depths up to 11.3 m deep and velocities up to 1.28 m/s (Poytress et al., 2015). Likewise, SDPS eggs were collected within a high velocity area on the Feather River where depths ranged from 1.6 to 5.5 m (Seesholtz et al., 2015). HSC developed for White Sturgeon on the Columbia, Frazier, and Snake Rivers define suitable spawning habitat as areas up to 30 m deep with water velocities exceeding 4 m/s (EA Engineering, 1991; Parsley and Beckman, 1994; Gard, 1996; Olson, personal communication). These values greatly exceed the criteria identified by this study (Figure 13).

Though Green Sturgeon spawning wasn't documented at depths greater than 11.3 m or velocities greater than 1.28 m/s, these conditions do exist within the six spawning areas. Reviewing the distribution of egg mat sampling effort shows the deep, highest velocities areas were often times avoided (Figures 4-9). These areas were found to be unsampleable because the high water velocity typically caused the float to sink or the mat would be drug from its original sampling location (Poytress et al., 2013). Possible spawning areas were excluded from egg sampling on the Snake River due to the excessive water velocities, large standing waves, and other conditions that made areas unsafe for the sampling crews (Parsley and Kappenman, 2000).

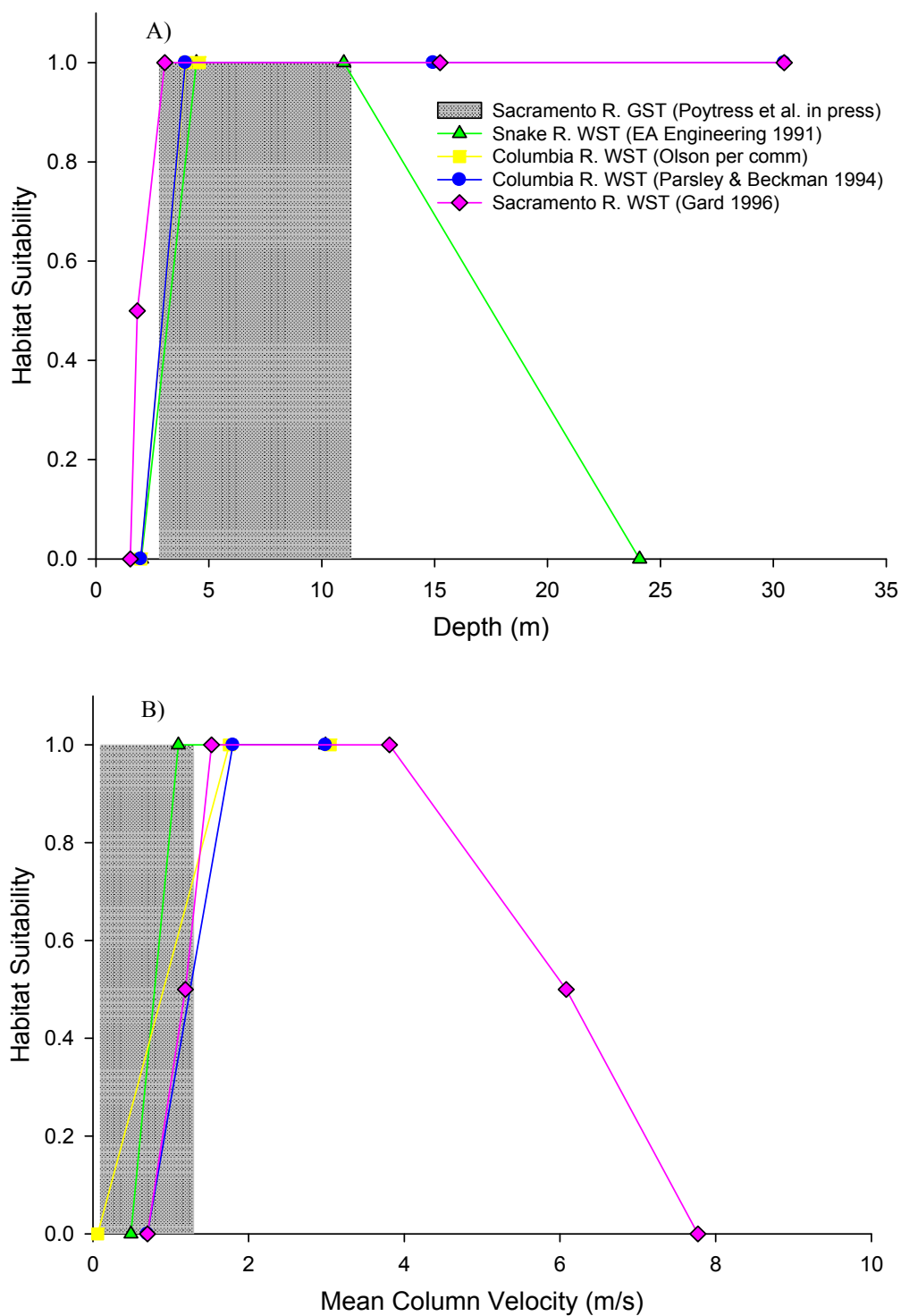


Figure 13. Depth and velocity habitat suitability criteria for White Sturgeon. Shaded areas represent the range of depths and velocities used to define suitable spawning habitat for this project.

Although there may be an upper limit to SDPS Green Sturgeon spawning depths and velocities, it is likely above our ability to detect. Future attempts to quantify the available spawning habitat should consider removing the upper criteria for depth and velocity so areas that are likely utilized as spawning habitat are not excluded due to limitations in our ability to sample and detect eggs in those types of environmental conditions.

Additional Suitable Habitat Criteria

A primary concern for the SDPS Green Sturgeon is spawning habitat suitability in terms of water flow and temperature in the Sacramento River (NMFS, 2015). Water management, specifically temperature, on the Sacramento River is heavily regulated through the Central Valley Project for the direct benefit of the winter run Chinook salmon, federally listed as Endangered (NMFS, 2009a, 2011). Federal mandates require river temperatures to be maintained below 13.3° C at various compliance points ranging from rkm 391 to 465.5 between April 1 to September 30 to allow successful reproduction of naturally spawning winter Chinook. RBFWO spawning studies identified Green Sturgeon spawning was occurring from rkm 332.5 to 426 between April and early July when water temperatures ranged from 11.8 to 14.8° C ($13.5^{\circ} \pm 1.0$; Poytress et al., 2015). When river temperatures are maintained at 13°C to benefit winter run Chinook, water temperatures may be restricting adult Green Sturgeon from using any potential suitable habitat above rkm 450, as temperatures are likely below 11°C. A CALFED Science Review Panel (2009) suggested that these water operations might be reducing the growth rate of larvae and post larval fish. Temperatures below 11° C have been shown to

decrease hatching rates and size at hatch (Mayfield and Cech, 2004; Van Eenennaam et al., 2005). By incorporating temperature into this habitat model one could better evaluate how water operations to benefit winter run Chinook spawning could be impacting the availability and distribution of suitable spawning habitat for Green Sturgeon. One might theorize that moving the temperature compliance point upstream would increase the amount of available habitat. However, this might simply shift the distribution of spawning upstream without an increase in available habitat.

The quality of spawning habitat can have a large impact on a species' ability to recover because better quality habitat generally increases survival at early life stages (Sutton et al., 2003; Velez-Espino and Koops, 2008; Caroffino et al., 2010). The lack of suitable spawning substrate is attributed to the recruitment failure of white sturgeon in the Kootenai River (Paragamian et al., 2002). Interstitial spaces within gravel substrate have been identified as important habitat characteristics for many sturgeon species (Kempinger, 1988; Auer, 1996). These spaces provide refuge for eggs and recently hatched larvae from predators. Areas composed of sand and other fine sediment have reduced egg survival as eggs can suffocate or lose their ability to attach to the substrate as sand coats their adhesive membrane. Egg embedded in as little as 2 mm below the sediment surface has been found to increase egg mortality, delay hatch timing, and result in smaller size at emergence (Kock et al., 2006). Laboratory experiments evaluating the suitability of various substrates for White Sturgeon embryo development found that sand was not a suitable attachment and incubation substrate as all eggs on the sand become buoyant and mobilized (Parsley and Kofoot, 2013).

Spawning locations above rkm 366.5 are dominated by clean small to medium gravel substrate compared to the lower most spawning area (rkm 332.5) which contained higher levels of fines likely due to tributary inputs, reduced gradient, and overall water velocity (Buer, 1985). If temperature management operations for winter Chinook are causing Green Sturgeon to spawn where temperatures are closer to the optimal thermal range for survival, this may result in these fish spawning in lesser quality habitat located in the lower section of the currently known spawning areas. Therefore incorporating water temperature into future suitable spawning habitat criteria or models has obvious benefits to evaluating effects of winter run Chinook temperature management operations on Green Sturgeon spawning habitat and developing population metrics within the SDPS Recovery Plan.

Conclusion and Recommendations

SSS has been shown to be highly accurate and efficient at identify substrate within navigable waterway (Kaesler and Litts 2010; Hook 2011). Workbooks and instructor lead workshops have been developed to help expand the usage of this technique. During this study I relied heavily on the step by step instructions contained within these documents to generate sonar mosaics of the spawning locations. Extensive underwater video increased my familiarity with the spawning locations helping me recognize the visual textures produced by the individual feature classes within our sample area. Researchers attempting to utilize this technology should at a minimum review the online resources provided by the Panama City Fish and Wildlife Service at <http://www.fws.gov/panamacity/sonarhabitatmapping.html>. Instructor lead training has

been offered infrequently but when available the opportunity should be taken advantage of as the creators of this methodology have extensive knowledge on the topic that would be beneficial to anyone at any skill level. These tools and trainings along with experimentation within specific study areas will help end user produce highly accurate substrate data layers of their study area.

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