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Migration and Habitat use of Green Sturgeon (Acipenser medirostris) near the Umpqua River Estuary

Prepared by
John Payne, Blue Dot Research
Daniel L. Erickson, Oregon Department of Fish and Wildlife
Michael Donnellan, Alaska Department of Fish and Game
Steven T. Lindley, NMSF Southwest Fisheries Science Center
On behalf of Oregon Wave Energy Trust

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Oregon Wave Energy Trust (OWET) is a nonprofit public-private partnership funded by the Oregon Innovation Council. Its mission is to support the responsible development of wave energy in Oregon. OWET emphasizes an inclusive, collaborative model to ensure that Oregon maintains its competitive advantage and maximizes the economic development and environmental potential of this emerging industry. Our work includes stakeholder outreach and education, policy development, environmental assessment, applied research and market development.

Project to Assess Potential Impacts of the Reedsport Ocean Power Technologies Wave Energy Generation Facility on Migration and Habitat use of Green Sturgeon (*Acipenser medirostris*)

FINAL REPORT

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Prepared for the
Oregon Wave Energy Trust
PO Box 8626
Portland, OR 97207-8626

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John Payne
Blue Dot Research
Box 95560
Seattle, WA 98145

Daniel L. Erickson
Oregon Department of Fish and Wildlife,
Marine Resources Program
2040 SE Marine Science Drive
Newport, OR 97365

Michael Donnellan
Alaska Department of Fish and Game
Commercial Fisheries Division, Southeast Alaska Region
P.O. Box 110024
Juneau, AK 99811-0024

Steven T. Lindley
NMFS Southwest Fisheries Science Center
110 Shaffer Rd
Santa Cruz, CA 95060

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1. ABSTRACT

Sites selected for ocean energy projects (e.g., wave energy) are typically near estuaries and bays. A wave energy project had been planned in the ocean at depths of 62–69 m near Reedsport, Oregon, northwest of the Umpqua River estuary. Green sturgeon (*Acipenser medirostris*) from the southern and northern distinct population segments (DPS) use this estuary during the spring–fall, presumably for feeding. The Southern DPS is listed as threatened under the U.S. Endangered Species Act. A "before-after" study was designed to identify potential interactions between the proposed wave energy project and green sturgeon, but the project was terminated before fieldwork ended. Nonetheless, understanding movements and habitat use of green sturgeon near estuaries and bays is important for site selection of future ocean energy projects. Using up to 43 automated acoustic receivers within and outside of the proposed project area, we monitored for the occurrence of 770 subadult and adult green sturgeon tagged with coded ultrasonic transmitters, which were affixed by other researchers on unrelated projects. We detected 248 green sturgeon within the receiver array from January 2013 through June 2014. Green sturgeon were detected on 492 of 515 monitoring days (95.5%) by the ocean array of receivers anchored at depths of 12–110 m. Peak detections occurred at 50–70 m. Some individuals migrated through the area quickly, whereas others used the area for extended periods of time (e.g., months). Although there was some migration of green sturgeon between receivers anchored in the Umqpua River estuary and the ocean receivers, most of the individuals detected on the ocean array were not detected inside of the estuary. These results suggest that the ocean immediately offshore and upcoast/downcoast of estuaries that support green sturgeon may be important green sturgeon habitats, and significant numbers of green sturgeon may interact with wave energy project projects in such areas.

2. INTRODUCTION

This study was originally designed as the first phase of a "before-after" study, with the long-term goal of evaluating the potential impacts of a proposed Ocean Power Technologies (OPT) wave energy project on migration patterns and habitat use of North American green sturgeon (*Acipenser medirostris*). The study team and the Oregon Wave Energy Trust (OWET) agreed that the goal of this study would be to collect phase one "before" data prior to the installation of the wave energy project, and that the collection of phase two "after" data would be the focus of a later study. This two-phased approach was understood to entail a calculated risk that funding could be acquired in the future to complete the study.

Licensed by the Federal Energy Regulatory Commission (FERC) in 2012, the OPT wave energy project (FERC Project No. 12713) was planned to initially consist of 10 power generation buoys that would occupy a project area of approximately 0.25 square miles (800 x 800 meters) at depths of 204 to 225 feet (62 to 69 meters) in the ocean off Reedsport, Oregon within state waters (OPT 2008; FERC 2012). The project would also consist of electric transmission cables spanning the 2.5 miles between the project area and the shore (FERC 2012). Eventually, a much larger build-out was planned. It was considered likely that this development would produce some level of electromagnetic field at the project site or along the cable route, which has been shown to affect elasmobranchs and sturgeons in (OPT 2008). It was also thought that the wave energy project might increase noise and other potential disturbances to aquatic organisms in this area (research reports on various potential impacts are available at http://oregonwave.org/research/owet-research/).

This OPT wave energy project was cancelled prior to the end of this study. Therefore, there is currently no source of support for the second phase of this before-after study. Nonetheless, results presented herein will be useful for understanding green sturgeon movements and habitat use in the ocean near bays and estuaries, and may prove useful for evaluating site-selection criteria for other ocean energy projects along the U.S. west coast.

2.1. Significance of green sturgeon

North American green sturgeon occur in coastal-marine and fresh waters along the west coast of the United States and Canada (Moyle 2002). This species is anadromous and spawns in freshwater in the Rogue, Klamath, and Sacramento river systems once every 2 – 4 years (Erickson et al. 2002; Van Eenennaam 2006; Benson et al., 2007; Erickson and Webb 2007). Green sturgeon larvae and subadults may rear in these freshwater systems during the initial 1-3 years of life (Nakamoto et al., 1995; Allen and Cech, 2007). These fish then move to estuaries and coastal-marine waters for the remainder of their life (maximum age ~ 60 to 70 years; Nakamoto et al., 1995), except during freshwater spawning migrations. Adults typically enter freshwater for spawning during the spring, and return to the ocean from their spawning rivers during late fall or early winter months (Erickson et al., 2002; Erickson and Webb 2007; Benson et al., 2007; Heublein et al., 2008). Some green sturgeon return to the ocean from their spawning rivers during spring or early summer after spawning (Benson et al., 2007). Adult and subadult green sturgeon also enter estuaries and bays during early spring – summer months, presumably for feeding

(Dumbauld et al., 2008), and return to the ocean from these estuaries and bays during summer and fall months (Moser and Lindley 2007; Lindley et al., 2011; Langness et al., 2014). Green sturgeon are typically absent from bays and estuaries during winter months (Lindley et al., 2011) when the inland water temperatures are lower than ocean water temperatures (Moser and Lindley 2007; D.L. Erickson unpublished data).

Genetic research has described two distinct population segments (DPS) for green sturgeon along the west coast of the U.S. and Canada: the Southern DPS, which spawns in the Sacramento River system, and the Northern DPS, which spawns in the Rogue and Klamath River systems (Israel, 2006). The Southern DPS of green sturgeon was listed as threatened under the U.S. Endangered Species Act on April 7, 2006, whereas the Northern DPS is listed as a species of concern (FR, 2006). This threatened status resulted in the release of a final rule to designate critical habitat for the threatened Southern DPS of green sturgeon (FR, 2009). The Southern DPS migrates throughout coastal waters of Oregon, mixing with individuals from the Northern DPS (Lindley et al., 2008). Oregon waters listed as critical habitat for the Southern DPS of green sturgeon include all coastal-marine areas inside of 60 fathoms (361 feet or 110 m) and the lower Columbia River estuary, Nehalem Bay, Yaquina Bay, Winchester Bay, and Coos Bay (FR, 2009). Erickson and Hightower (2007) demonstrated that coastal migrations for green sturgeon primarily occur between depths of 40 – 70 m, which coincided with the anticipated depth range of the OPT Wave Energy Project (62 – 69 m). Huff et al. (2011) showed similar depth patterns for green sturgeon, where five of seven individuals occupied average depths of 40 – 60 m. Green sturgeon may also occupy depths as great as 150 m (Erickson and Hightower, 2007).

Overlap of green sturgeon activities in the nearshore ocean with the proposed OPT licensed development of the wave energy project had the potential of impacting the migratory behavior of green sturgeon (Erickson et al., 2013a). In addition, the site licensed for construction may represent a concentration area used by green sturgeon for certain activities, such as feeding (see Erickson et al., 2013a). It has been demonstrated that Winchester Bay (= Umpqua river estuary), which is in close proximity to the proposed OPT wave energy project, is a concentration area for green sturgeon during the spring, summer, and fall (Lindley et al., 2011; Langness et al., 2014; D.L. Erickson, unpublished data). The OPT Wave Energy Project includes sandy and mud habitat (Henkel, 2011) that supports sturgeon prey (e.g., shrimp, mollusks, and small fish; Beamesderfer 2007; Dumbauld et al., 2008). Hence, ocean waters near Winchester Bay may support concentrations of green sturgeon, possibly for feeding or other behaviors. Lindley et al. (2008) identified a green sturgeon concentration site in the ocean north of Vancouver Island, Canada using acoustic telemetry. They hypothesized that this site was used for feeding.

2.2. Objective and Questions

The original objective of the study was to determine whether and how the proposed OPT wave energy project offshore of Reedsport, Oregon could affect green sturgeon migratory behavior and habitat use. We initially employed a "before-after" study design to compare the migratory path and habitat use of green sturgeon in the vicinity of the planned OPT wave energy project before versus after its construction. We asked three specific questions, prior to knowing that the OPT wave energy project would be cancelled:

1. Is the timing and depth distribution of migratory green sturgeon that has been described by others (e.g., Erickson and Hightower 2007; Lindley et al. 2008) consistent with the patterns observed off of Reedsport?

2. Are patterns of green sturgeon migration (e.g., speed, depth distribution, direction, distance traveled) or presence (e.g., extended or repeated presence in the study area) different after the introduction of a fully-operational wave energy development?

3. What other tagged species (e.g., sharks, salmonids, marine mammals) are present in the study area and what are the characteristics of these observations (e.g., depth distribution, seasonal timing, residence time, migration speed and direction)?

3. METHODS

The strategy employed for this study was to deploy an acoustic receiver array in the vicinity of the planned OPT wave energy project to track green sturgeon tagged with Vemco acoustic transmitters (http://vemco.com/products/v7-to-v16-69khz/) by other researchers. No fish were tagged with transmitters using funds for this study. Instead, resources were used to deploy and maintain the acoustic array. To identify the sturgeon that were detected, the study opportunistically relied on 975 green sturgeon previously tagged with transmitters by other research groups on the west coast over the past 10 years (Table 3.1). The study team coordinated with those research groups for permission to use some of their data (see Acknowledgments for a list of collaborators). Collaboration with these research teams was facilitated by the Ocean Tracking Network (OTN), which was used to join existing tag metadata with detections from the receivers in this study.

Table 3.1. Tag metadata for green sturgeon that were implanted with acoustic transmitters and were at large during this study.

Research collection	**Tagging location**	**Number of tags**	**Tagging years**
DION	Columbia River	96	2011-12
DION	Grays Harbor	95	2010-12
DION	Umpqua River	20	2011
DION	Willapa Bay	99	2010-12
KLIM	Sacramento River	465	2004-12
LIND	Grays Harbor	38	2005
LIND	Sacramento River	69	2004-8
LIND	Umpqua River	1	2005
RCS	Sacramento River	8	2009-2012
ROMINE	Columbia River	1	2010
ROMINE	Grays Harbor	24	2010-11
ROMINE	Klamath River	15	2010
ROMINE	Willapa Bay	18	2010
SEES	Sacramento & Feather Rivers	26	2008-13
TOTAL		975	2004-2014

The tag metadata included release dates and locations and sometimes information about the tag (such as tag model, serial number, battery type or ping rate), or the fish to which it was attached (such as fork length (FL), total length (TL), age, or sex). Estimated total lengths, when missing, were calculated as: TL = 1.10 x FL (Rien et al., 2002).

3.1. Pilot study

Prior to the main field study, a pilot study was completed in January, 2013, to inform the final design of the full-scale array of acoustic receivers. First, a permit for deployment of a pilot array of acoustic receivers was obtained from the Oregon Department of State Lands (Short Term Access, Waterway, 52289-AA). Ten Vemco VR2W acoustic receivers (http://vemco.com/products/vr2w-69khz/) were deployed in the study area to gather preliminary information about the depth distribution of green sturgeon, detection distances of the acoustic tags, and the suitability of the mooring design used for receivers (Figure 3.1).

In order to model detection probabilities in the area of the array where the background noise levels were unknown, three Vemco V16 "sentinel" tags that transmitted acoustic signals on a fixed schedule every 10 minutes were moored between receivers (Figure 3.2). The sentinel tag configuration was designed to create a time series of detections on receivers at a variety of distances from transmitters.

The time series data were examined for patterns in the probability of detection. Sentinel tags were essentially identical to the tags carried by sturgeon, except that the latter transmitted on a randomized schedule to avoid transmitted codes interfering with each other when many tagged fish are in close proximity. It has not been possible yet to obtain metadata on the transmission rates of individual tags, but typically Vemco acoustic tags are programmed to transmit on average between once per minute and once per 10 minutes.

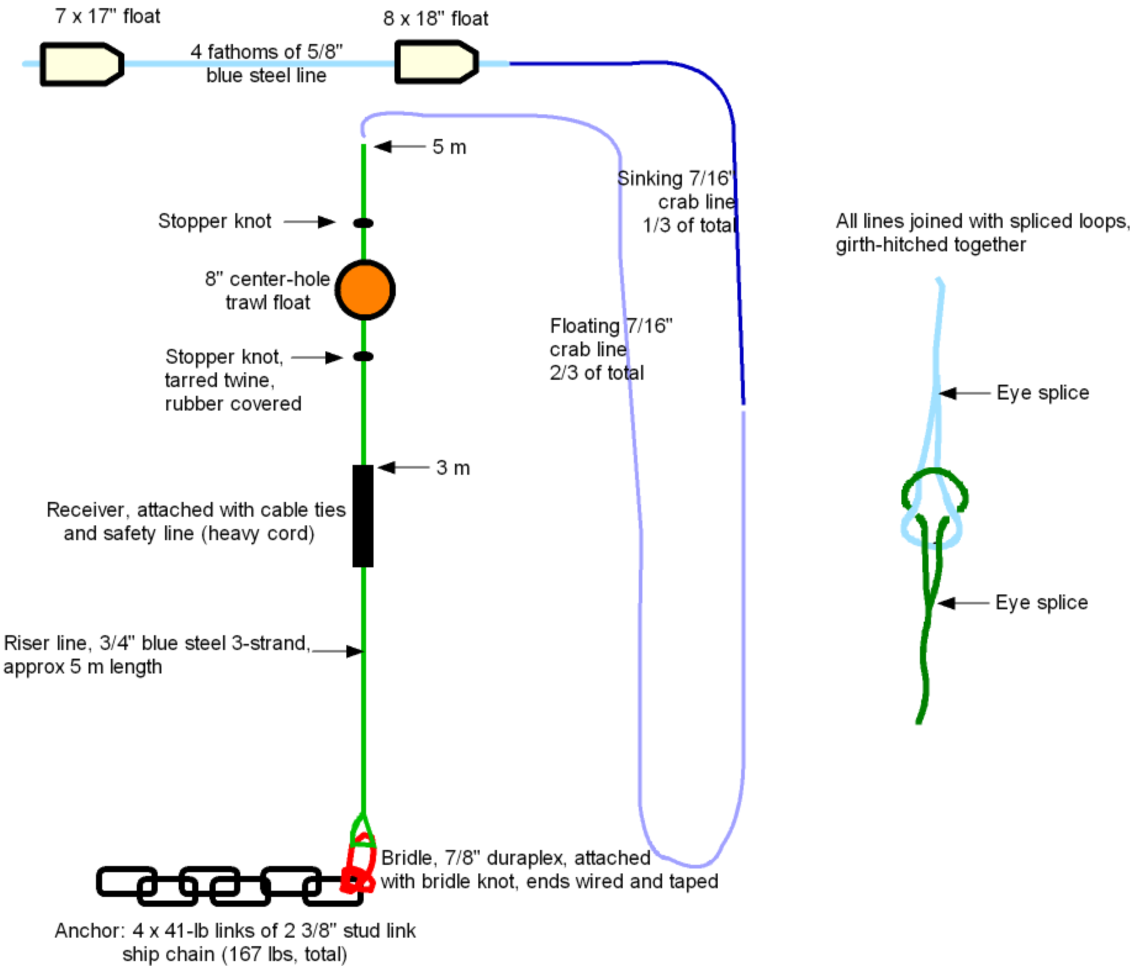


Figure 3.1. A schematic of the mooring design. A sentinel transmitter (not shown) was attached to the riser line immediately under the receiver for a subset of moorings in the main array. The mooring was designed by Captain Al Pazar, based on a mooring system designed by ODFW at-sea research staff, Matt Blume and Polly Rankin.

The pilot array of receivers was configured in a straight line perpendicular to the coastline (Figure 3.2). Receivers were clustered around the sentinel transmitters at a range of distances (200 m, 400 m, 600 m and 800 m). The 400 m transmitter-to-receiver spacing informed 800 m receiver-to-receiver spacing, since the farthest that a fish could be from either receiver while passing between them is half of the distance between receivers. One cluster was deployed in shallow water (where more wave noise was expected) and one cluster was deployed in deeper water (which was expected to be relatively quiet). In addition, two receivers were staged in the center of the depth range where green sturgeon were expected to occur most often.

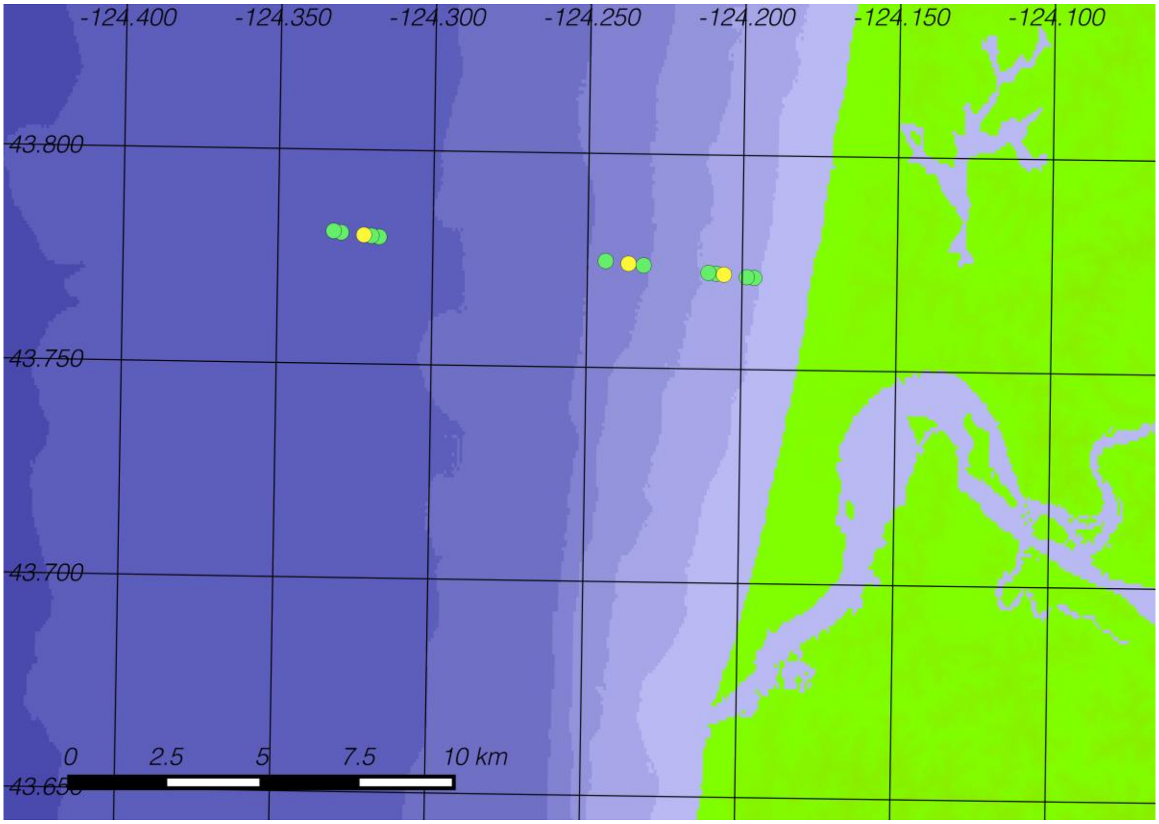


Figure 3.2. Configuration of the pilot array of VR2W acoustic receivers (green circles) and moored sentinel transmitters (yellow circles) north of the Umpqua River mouth, Oregon. The depth contours are at 20 m intervals. Sentinel transmitters were anchored independent of receivers for the pilot study.

3.2. Main study (Ocean Array of Acoustic Receivers)

The main ocean array of 43 VR2W acoustic receivers was deployed in mid-February, 2013 (Figure 3.3). The main array used the same mooring design as the pilot study (Figure 3.1). To monitor detection efficiency throughout the duration of the project, seven centrally located receiver moorings were equipped with fixed-rate "sentinel" transmitters (Figure 3.3).

The receiver array was designed to satisfy the following criteria:

- Cover the area and depth range of the planned OPT wave energy project;
- Have a large enough geographic scope that sturgeon behavior inside the array may be understood (i.e. so it could be determined whether the sturgeon were passing through or around the wave energy project, traversing a range of depths, or moving within the area for some extended period of time); and
- Have dense enough receiver coverage to provide 90% or better probability of detecting sturgeon.

Based on the results of the pilot study, receiver spacing of 800 m was chosen for the main array, which consisted of 3 lines extending from depths of 12 m to 110 m, centered on the planned wave energy project (Figure 3.3). The three lines of receivers were spaced about 2.5 km apart. Calculations showed that staggering the receivers in the main array line would make the array more likely to detect passing fish (the advantages of staggered lines were demonstrated by Kintama Research Services, who were the first to use them on a large scale; David Welsh pers. comm.). Two additional receivers were added to the south, and two to the north at central depths, to extend the latitudinal extent of the array. Two receivers were also placed near the mouth of the Umpqua River to help discriminate fish movements in and out of the river.

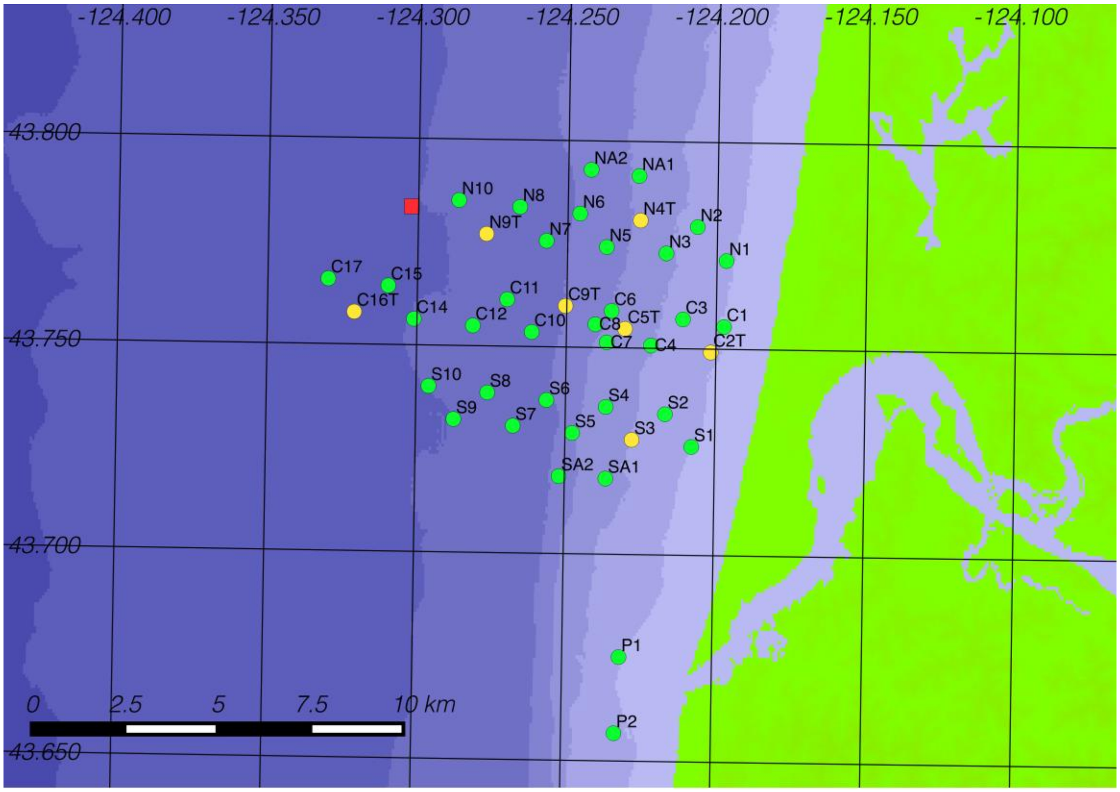


Figure 3.3. The main VR2W acoustic receiver array, located north of the Umpqua River. This configuration remained intact from February 2013 through September 2013, with only a few lost receivers. The station numbers are shown by each receiver location (green dot). Moorings equipped with both a receiver and a stationary sentinel transmitter are shown as yellow dots. The red square shows the location of average current data measurements recorded by high-frequency radar.

3.3. Acoustic Receivers in the Umpqua River Estuary (Langness et al., 2014)

Data collected by VR2W acoustic receivers anchored in the Umpqua River estuary were provided by a joint study between Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW) (Langness et al., 2014). These data, combined with data from the ocean array of acoustic receivers, were used evaluate movements of green sturgeon between the ocean array and the estuary.

3.4. Schedule of array maintenance and data downloads

The ocean array was visited at 1-2 month intervals for maintenance, and at longer intervals (every 2-4 months) for downloading data (Table 3.2). During both maintenance and download activities, moorings were pulled up and the line was bleached to control bio-fouling before being reset. Data were downloaded from each receiver using a Bluetooth connection before the unit was placed back in service and re-deployed at the same location. Receiver batteries were replaced after one year. When moorings were missing from stations, the boat would search the area as long as time allowed, and missing units were typically replaced on the same trip with a new receiver if they could not be found, or the station was left vacant if necessary. A few missing units were found and returned later by fishermen.

Table 3.2. Receiver maintenance and download schedule (actual). Data were downloaded on the dates shown below in bold font.

Activity	Date
	2013
Deploy pilot array	13-Jan
Recover pilot array	**9-Feb**
Deploy main array	17-18-Feb
Download	**27-Apr**
Maintenance	18-Jun
Maintenance	16-Jul
Maintenance	31-Jul
Maintenance	18-Aug
Maintenance	28-Aug
Download (part 1)	**21-Sep**
Download (part 2)	**27-Sep**
Maintenance	10-Oct
Maintenance	12-Oct
Maintenance	25-Oct
Download	**30-Nov**
Redeploy revised array	30-Nov
	2014
Maintenance	6-Jan
Maintenance	24-Feb
Download	**7-Apr**
Recovery	**16-Jun**

3.5. Notifying the ocean user community

The fishing industry had concerns about the moorings and surface floats used in this study interfering with their fishing operations, so we engaged the Southern Oregon Ocean Resource Coalition (SOORC) industry group and others about how to minimize conflicts. Daniel Erickson and Delia Kelly (ODFW) were invited to a SOORC meeting to present and discuss study details. A notice about at-sea equipment that included a detailed map and coordinates of the receiver positions was sent to numerous parties at the study's inception. Similar notices were distributed twice more during the study period. The recipients included the entire staff at the ODFW Marine Resources Program, the West Coast Seafood Processors Association, the Oregon Trawl Commission, the Oregon Dungeness Crab Commission, and the Oregon Salmon Commission. The commercial fishing organizations emailed the notice to their members. The notice was also mailed electronically to an Oregon state representative for fixed gear fisheries (pots, longlines, jigs, etc.). This notice also reached approximately 400 crab fishermen through a season opener notice distributed by ODFW. Laminated notices were posted for the public at fish processing plants and docks from Astoria to Brookings. Interviews were given to local media that resulted in an article in a local paper (Bartlett, 2013). Captain Al Pazar, whose boat was chartered for the array deployment and maintenance, discussed the project with fellow fishermen in person and over the radio, and gave a presentation at a local Kiwanis club. The local fisheries research and management community was informed about the study as well during the 9th Hecata Head Coastal Conference (Erickson et al., 2013b).

In addition, the receivers and buoys were clearly marked "RESEARCH", and radar reflectors and tall flags were added to nearly all of the moorings when weather permitted.

After a major loss of receivers, the array was reconfigured to lie on exact latitude lines near the end of the study to make it easier for fishermen to avoid the equipment (see Figure 4.6, below, for a monthly history of array configurations). This request was made by members of SOORC.

3.6. Environmental covariates

Detection probabilities of acoustic transmitters by receivers may vary depending on environmental conditions. Data on potential environmental covariates were compiled from colleagues and online sources for an analysis of the variation in detections of fixed-location sentinel tags. These data included weather data from National Oceanic and Atmospheric Administration (NOAA) stations, current data from coastal high frequency (HF) radar stations along the Oregon coast, and wave height and direction data from a National Data Buoy Center buoy 37 km offshore to the west of Newport, Oregon at 44.639 N 124.534 W. The buoy is about 101 km North by west of the array.

Ocean current data

High frequency radar stations on the Oregon coast produce estimates of ocean current strength and direction for most of the continental shelf on a 6 km grid. Ocean current data were accessed through the Oregon State University Ocean Currents Mapping Lab (OCML, 2015). These data were derived from station located on the seaward edge of our main VR2W acoustic array (Figure 3.3).

The variables used were:

- *ecurr* – Daily averaged eastward current vector (cm/s)
- *ncurr*- Daily averaged northward current vector (cm/s)
- *curr* - the magnitude of the resulting current vector, calculated as sqrt($ncurr^2$ + $ecurr^2$)

Wave and wind data from an offshore buoy

Data for wind and waves originated from the National Data Buoy Center's Stonewall Bank buoy located offshore of Newport (NDBC, 2015), approximately 101 km northwest of the center of the array (location not shown on map). The variables used were:

- *wvht* – daily maximum significant wave height (meters). Significant wave height is the average of the highest one-third of all of the wave heights during each 20-minute sampling period.
- *dwpd* – Daily median of the dominant wave period (seconds), which is the period with the maximum wave energy .
- *wvdir*- Daily median wave direction, which is the direction from which the waves at the dominant period (DPD) are coming (clockwise from north).
- *wspd* – Daily maximum wind speed. Wind speed (m/s) is averaged over an eight-minute period and reported hourly.
- *wdir* - Wind direction, which is the direction the wind is coming from in degrees clockwise from true north, measured during the same period used for wspd
- *wtmp* – Water temp at the surface (^{o}C).

Wind data from Coos Bay

Wind records were obtained for the Southwest Oregon Regional Airport in North Bend, OR, about 25 miles south of the array (GHCN ID: :USW00024284), which was used as a proxy for wind speed in the area of the main VR2W acoustic array (National Climatic Data Center, 2015). The variables used were:

- *awnd* – daily average windspeed

Precipitation data from Florence, OR

The National Climatic Data Center records for precipitation from a weather station in Florence, OR (GHCN ID: USC00352972) were used as a proxy for rain near the array location (National Climatic Data Center, 2015).

- *prcp_fl*—daily total precipitation

3.7. Selection of data for analysis

During the course of the study, some receivers were lost and some were later re-found, either in or out of position. In addition, some receivers were discovered to have been dragged out of position when they were checked.

The boat crew was able to deploy receivers very accurately, and it is likely that none of the receivers were out of position by more than a few meters when first deployed. However, once a receiver had been set in place on the bottom of the ocean, its position was never exactly known. The scope of the surface lines for most receivers varied from 2:1 to 4:1 depending on depth, and currents and wind usually pulled the surface floats to one side. For this reason, it was not possible to tell if a receiver was out of place unless the surface float was several hundred meters off station.

This analysis is based on a subset of receivers for which the position was known with relative certainty. Receivers that were recovered more than 400 meters from the station were excluded from the analysis.

3.8. Analysis of detection rates

Detections of acoustic tags have some unique properties that must be addressed during data analysis.

False detections

Vemco tag and receiver systems are designed with the specific goal of producing very low rates of false detections. Nonetheless, false detections occasionally occur. The data used in this study were vetted at two levels: by Vemco, who scanned the receiver files in detail when producing the list of "mystery" tags and eliminated some suspect detections, and by the Ocean Tracking Network, who applied an algorithm that flagged single detections which met certain criteria that made them likely to be false detections. The remaining data may contain a small number of single detections. Re-analysis with different criteria for excluding detections may change the results, but the change would likely to be subtle and unlikely to significantly change the study conclusions.

Simultaneous detections

Given the close spacing of the receivers in the study, it was possible for a tag to be detected simultaneously by adjacent receivers. There were 646 instances (1292 detections, or 0.25 percent of the total of 249,528 detections) in which a tag was detected at the same timestamp (accurate to the second) at two receivers simultaneously, and 2 instances (6 detections) that were simultaneous at 3 receivers. The simultaneous detections included 36 receivers and 82 tags.

The clocks on Vemco VR2W receivers are known to drift significantly, so the actual number of simultaneous detections is likely higher than the number of exact matches would suggest. In order to estimate the number of simultaneous detections, corrections have to be made for the clock drift on each receiver, based on synchronization at the beginning and end of each deployment with a computer that has an accurate clock. This potential solution may be ineffective, however, if the clocks drift randomly.

The exact timing of tag transmissions cannot be known because the Vemco tags used on sturgeon are programmed to transmit at random times within a fixed-length interval. In addition, the mean transmission intervals for each tag are not known, because that information was not included in the tag metadata that has been obtained for this study. For the purposes of this report, simultaneous detections were not excluded from the analysis, and dealing with them properly remains a task for more detailed analysis of sturgeon tracks.

Detections by depth zone

It should be emphasized that the actual depth at which sturgeon were swimming was unknown in all but a handful of cases where fish carried tags that included depth sensors. The analysis of depth zones in this report is based on the bottom depth at the location of receivers, not the swimming depth of the sturgeon that were detected. The analysis presented is not a study of sturgeon depth preference *per se*, rather a study of the ocean depths at which sturgeon may be found (which is arguably more relevant to the wave energy project). In the study area the ocean bottom is a relatively flat, gentle slope, and the distance at which fish tags can be detected rarely exceeds half a kilometer. Therefore, the bottom depth at the location of a receiver is a good proxy for the bottom depth at the location of a fish that is detected by that receiver.

Correcting for monitoring effort

Given that monitoring effort varied considerably by date and depth zone, it is necessary to either correct for variation in effort, or to model effort explicitly when reporting on statistics that span dates or depths. Several approaches might be appropriate, such as adjusting the number of detections by the cumulative planar area surrounding each receiver with detection probabilities greater than 80%, without double-counting areas of overlapping detection. Instead, we used the following approach, which implicitly assumes a linear relationship between the number of receiver-days and the number of detections expected:

A matrix, $\boldsymbol{E}$, of effort by day and 10m depth zone was created as:

$$\boldsymbol{E}_{day,depth} = Number\ of\ functioning\ receivers_{day,depth}$$

The elements of $\boldsymbol{E}$ were summed to obtain the total effort, TE (depth zone-receiver-days):

$$TE = \sum_{day,depth} \boldsymbol{E}$$

and weights ($\boldsymbol{w}$) were calculated as:

$$\boldsymbol{w} = \boldsymbol{E}/TE$$

The number of fish detected in each day and depth zone ($\boldsymbol{FDD}$) was calculated in another array:

$$\boldsymbol{FDD} = Unique\ fish\ detected_{day,depth}$$

The elements of **FDD** were summed to obtain the total number of fish-depth zone-days:

$$TFDD = \sum_{day,depth} \boldsymbol{FDD}$$

Each element of FDD was then multiplied by the inverse of the corresponding weight to obtain a weighted value:

$$\boldsymbol{wFDD} = \frac{1}{\boldsymbol{w}} * \boldsymbol{FDD}$$

The weighted value was normalized

$$\boldsymbol{nwFDD} = \frac{\boldsymbol{wFDD}}{\sum \boldsymbol{FDD}}$$

and then rescaled by dividing by the total number of fish-depthzone-days:

$$\boldsymbol{reFDD} = \frac{\boldsymbol{nwFDD}}{TFDD}$$

This general procedure was used for calculations on the number of fish that were detected across dates or depth zones. However, for statistics that grouped date or depth ranges (such as *fish per month* or *fish per depth zone*), the marginal sum of unique individual fish was re-calculated, to avoid double-counting fish that were detected in more than one day or depth zone.

4. RESULTS

4.1. Pilot study

The pilot study, which took place from January 13, 2013 to February 9, 2013, showed that the moorings were durable and did not move or settle into the sand. Ten receivers maintained their position over a 27-day time frame, when wave heights of 6 meters and wind speeds of 60 km per hour were experienced (NDBC, 2015). Results of the pilot study also indicated that monthly maintenance would be required to remove bio-fouling, especially on shallower units in summer.

Range tests demonstrated transmitter-detection probabilities relative to a) distance between the transmitter and receiver and b) distance from shore (Figure 4.1). Detection probabilities were greater than 90% when the distance between transmitters and receivers was 400 m or less, regardless of proximity to shore. Detection probabilities declined rapidly as distance increased beyond 400 m between the two instruments. Based on this information, the assumption was made that with 800 m spacing, receivers could detect over 90% of the tag transmissions of any fish that swam between receivers.

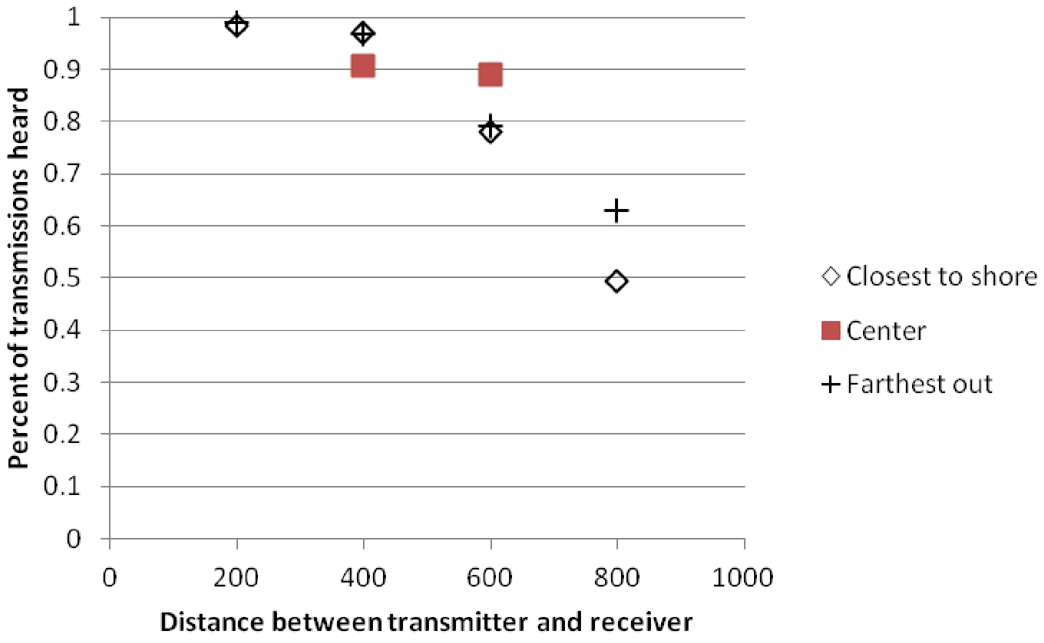


Figure 4.1. Range test results, showing the percentage of sentinel tag transmissions heard at various separation distances between transmitter and receiver. Receivers were clustered in three groups stratified by depth ("Closest to shore" were near 25 m, "Center" were around 50 m, "Farthest out" near 100 m; see Figure 3.2).

4.2. Variation in the rate of detection of sentinel transmitters

Fixed sentinel tags were used to investigate the variation in detection rates due to variables such as environmental noise. Every day, each sentinel tag transmitted 140 times. The rates of detection by receivers of those transmissions were extremely variable, even for receivers that were very close to the tag (Figure 4.2). Receiver A, which was ~1 m from the sentinel tag at a depth of 50.6 m over a bottom depth of 54.1m (see C5T in Figure 3.3), detected 29 – 140 transmissions per day (median = 133, or 95%). Variation in detection rates was higher for Receiver B (instrument depth = 38.7, bottom depth = 42.2 m), where the distance between instruments was approximately 825 m (see C4 in Figure 3.3). At this distance, the number of detections recorded per day ranged from 2 to 137, with a median of 86, or 61% of the daily transmissions. There were 23 days on which Receiver A, which was nearly adjacent to the transmitter, detected fewer transmissions than Receiver B.

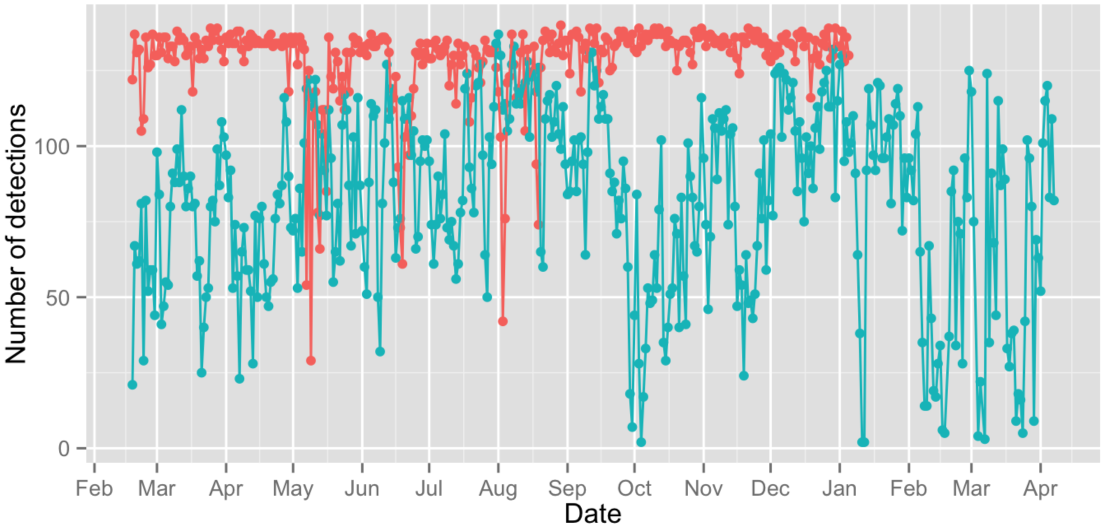


Figure 4.2. Detections per day of a sentinel tag by two receivers, from mid-February 2013 to April 2014. Receiver A (red) was located on the same mooring as the sentinel transmitter (approximately 1 m between the tag and the receiver), and Receiver B (blue) was approximately 825 m from the transmitter on another mooring. Each sentinel tag transmitted 140 times each day.

Detection probabilities relative to ocean conditions

The impact of ocean conditions on detection probabilities were modeled using detections recorded by Receiver B located at station C4 of the sentinel transmitter that was positioned 895 meters away at station C5T (Figure 4.2). A generalized linear model of *proportion of transmissions heard* regressed against a number of covariates *(curr + wvht + wvdir + dwpd + wspd + awnd + wdir ecurr + ncurr + curr + wtmp)* was fit to the data (see Methods). Hierarchical variance partitioning showed that the strongest independent effects on detection counts were caused by current strength, wave height, and two variables for wind speed. Precipitation was marginally significant. Wind speed was measured in two locations: 95 km to the NNW of the array on the NDBC buoy, and at Florence, OR. The correlation between the two measurements was low (0.2), so both variables were included (Figure 4.3).

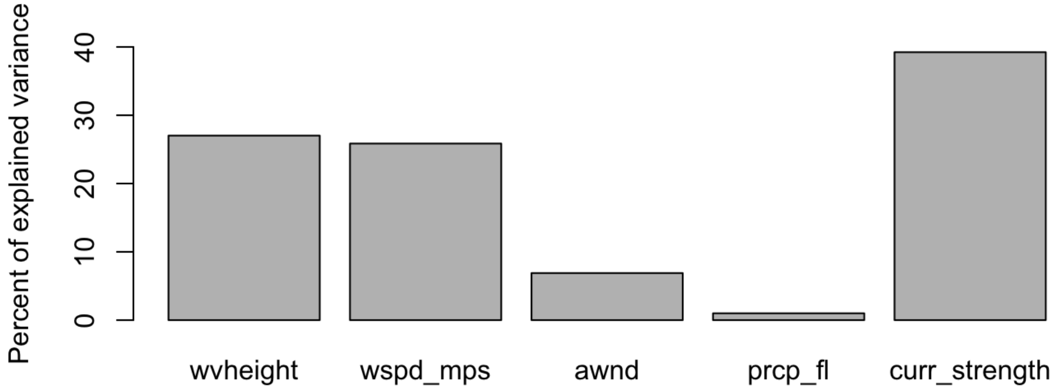


Figure 4.3. Independent effect sizes for a model of detection rates of a fixed-rate V16 sentinel transmitter by a stationary VR2W receiver. The receiver and transmitter were anchored 895 meters apart at depths of 42.2 m and 54.1 m, respectively. The dependent variable was the proportion detected by the receiver of 140 daily transmissions made by the transmitter. The explanatory variables are *wvht*=wave height, *wspd* = wind speed at the offshore NDBC buoy 95 km NNW of the array, *awnd* = wind speed in Coos Bay, *prcp_fl* precipitation in Florence*, curr* = current strength (see Environmental Covariates, in Methods, for more details).

4.3. Array configuration and monitoring effort

Monitoring effort by date

The number of receivers deployed at any one time varied throughout the study (Figure 4.4). Ten receivers were deployed during the pilot study in January, 2013. The main array of 43 receivers was deployed the following month. About half of the receivers were lost sometime between maintenance trips made in late September, 2013 (when they were present) and late October 2013 (when they were discovered to be missing). The array was reconfigured in November, 2013 to retain as much as possible the original breadth and depth of the array, but with a lower density of receivers. More than half of the receivers deployed in November, 2013 were lost between the 7th of April, 2014 (when they were present) and the 6th of June, 2014 (when they were discovered missing).

The cause of the losses is unknown, but a range of possibilities includes failure of the gear (broken lines, slipped knots, etc.), floats sinking because of high currents and bioaccumulation, receivers that were dragged to deeper depths by kelp or other floating debris, interactions with other ocean users. The gear was inspected carefully approximately once per month throughout the study during every trip to service the array, and no evidence was ever found of gear failure, despite major storms passing through the array. A few troll fishermen reported snagging surface floats with their gear and dragging a mooring short distances, and indeed the recovery positions of receivers suggested that receivers had been moved at least a short distance in 15 of 396 cases (4.1%) where a receiver was checked and was not missing.

Throughout the study, when the two large loss events are excluded, losses of 1-2 receivers per month were sustained. The large losses therefore stand out, and the timing of these losses was not consistent with weather events or other obvious physical factors being monitored as environmental covariates. On the last occasion when many receivers were lost, the only receivers spared were those that lacked flags and radar reflectors. The flags may increase the receivers' susceptible to loss.

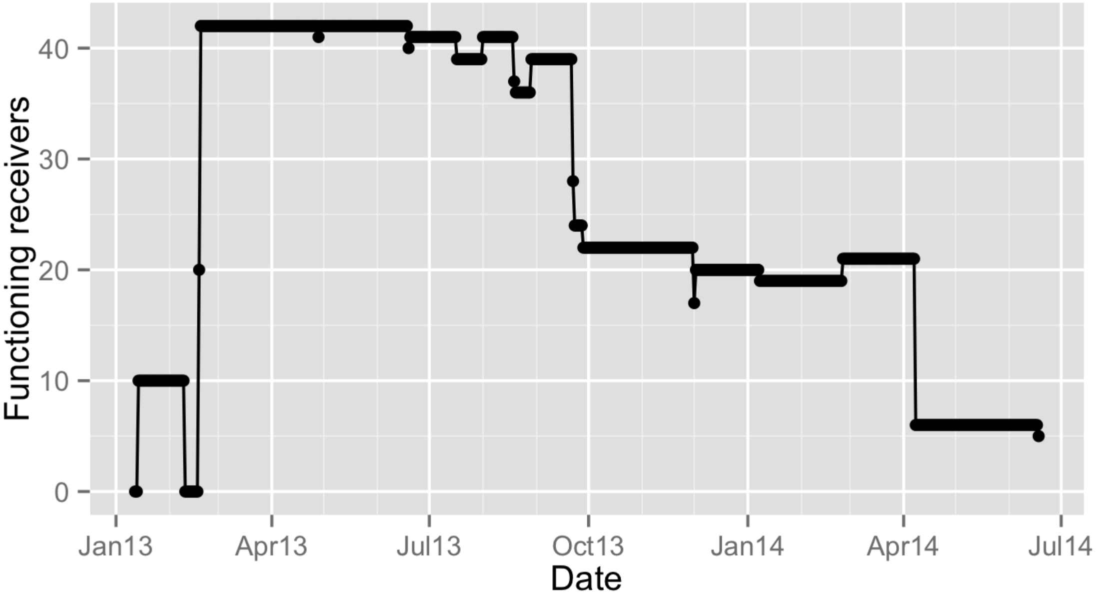


Figure 4.4. The number of functioning receivers (i.e., receivers from which data were successfully retrieved), per day. Vertical lines are at the first day of each month. A few of the receivers shown were dragged short distances out of position (most less than 300 m) between maintenance trips. The figure does not include receivers that were recovered more than 800 m out of position.

Monitoring effort by depth zone

Monitoring effort by 10 m depth zones was uneven due to equipment loss (Figure 4.5). There was no coverage at depths greater than 40m during the last 2.5 months of the study (April to June, 2014).

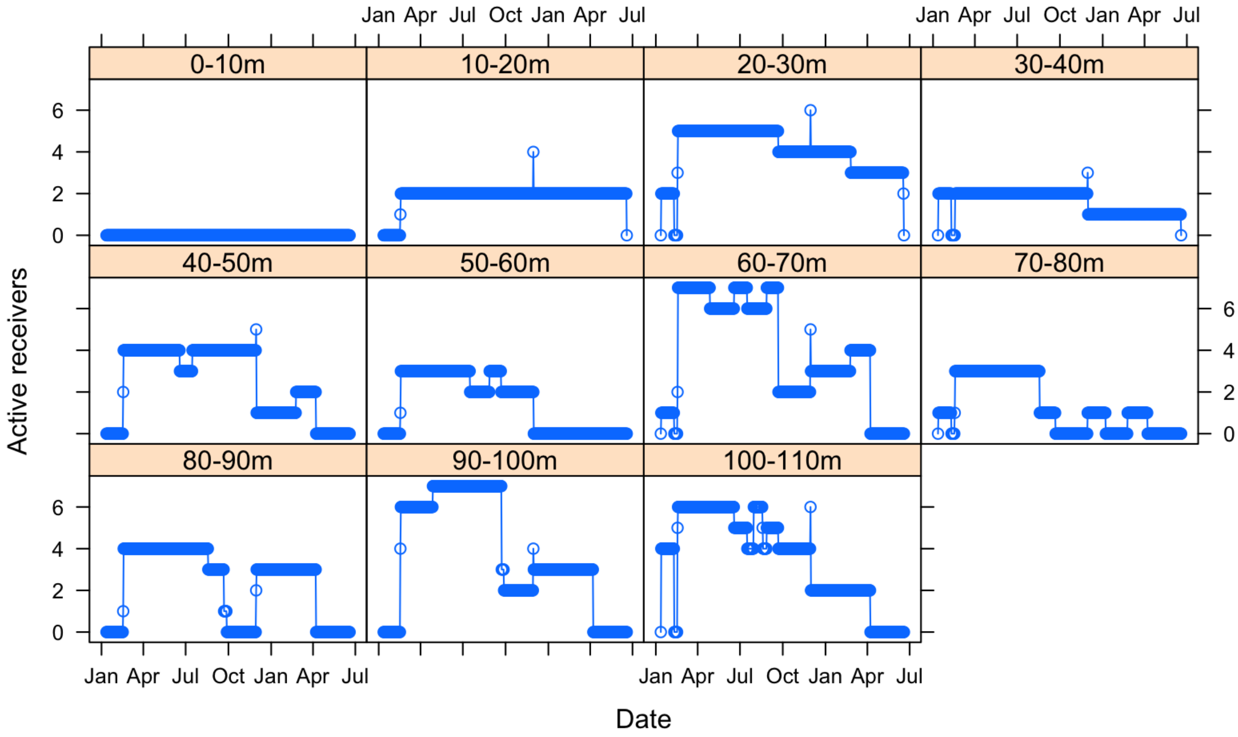


Figure 4.5. Monitoring effort (receivers from which data were recovered) by 10-meter depth zone and date from January 2013 to June 2014. The number of receivers deployed on each day is shown as a circle symbol and the days are connected with lines. The occasional small anomaly reflects receivers that were replaced or removed between consecutive maintenance trips that were one day apart (for example, a replacement receiver that was deployed one day before the in-service receiver was removed).

Monitoring effort by geographic scope

The geographic extent of the array varied little during the first year of the study. However, the density of receivers declined and gaps developed in the array as receivers were lost (Figure 4.6). On November 30, 2013, the array was reconfigured so that the latitudinal extent of the new array was slightly smaller than the original array, but the array retained most of its coverage of depth zones.

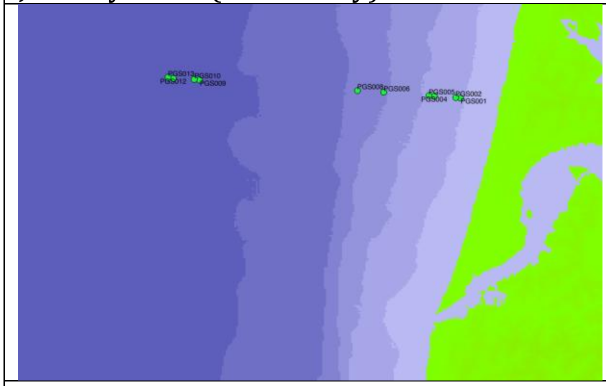
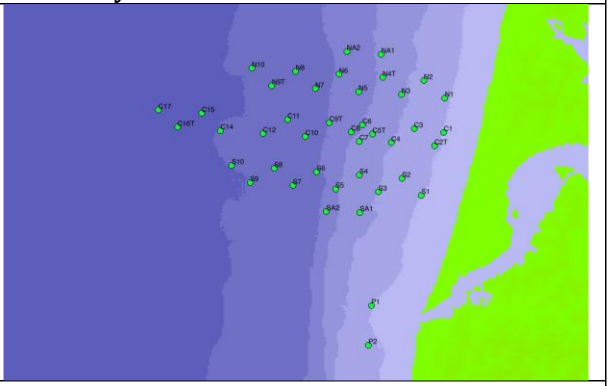
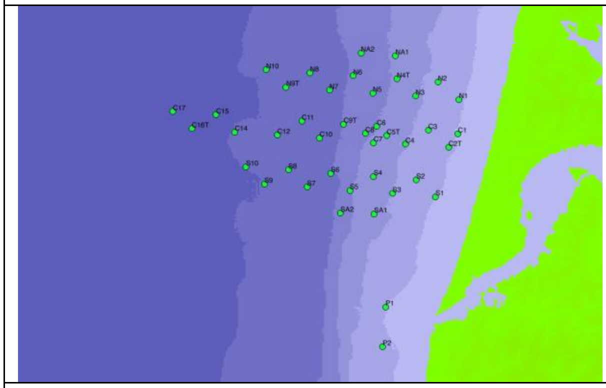
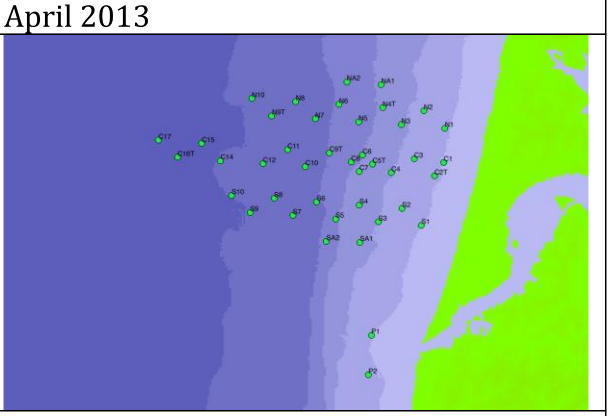
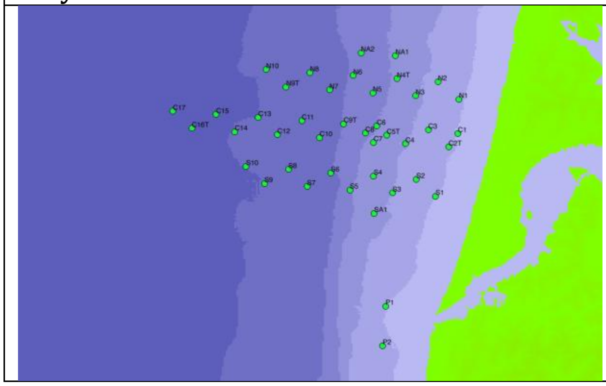
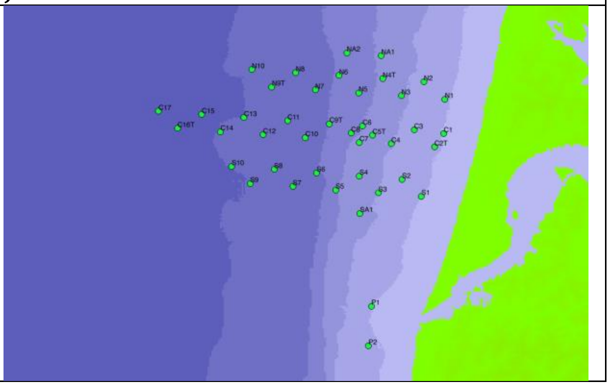
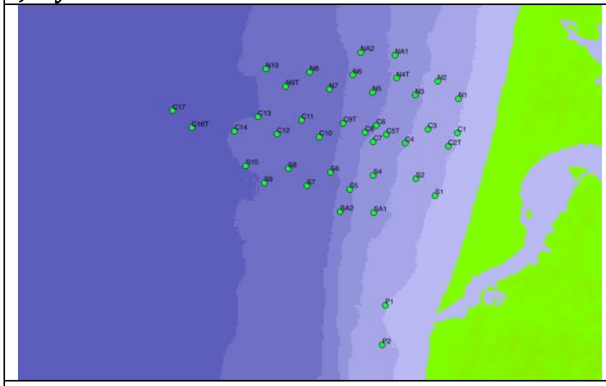
January 2013 (Pilot study)	February 2013
	
March 2013	April 2013
	
May 2013	June 2013
	

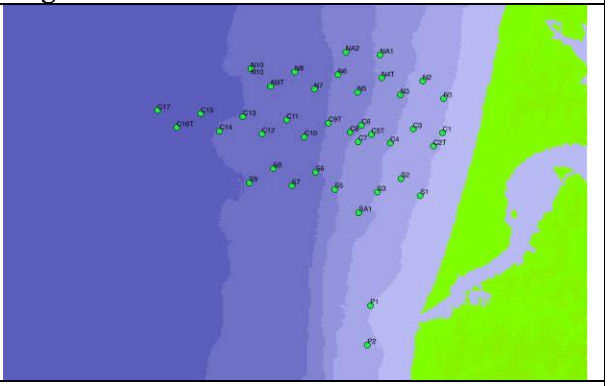
Figure 4.6. Array configuration on the 15th day of each month. Only receivers from which data were successfully recovered are shown.

Figure 4.6. Continued.

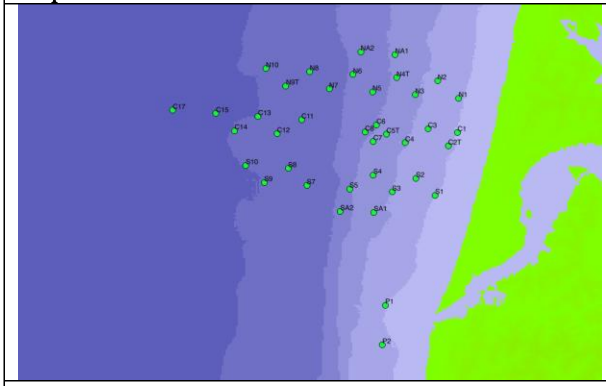
July 2013



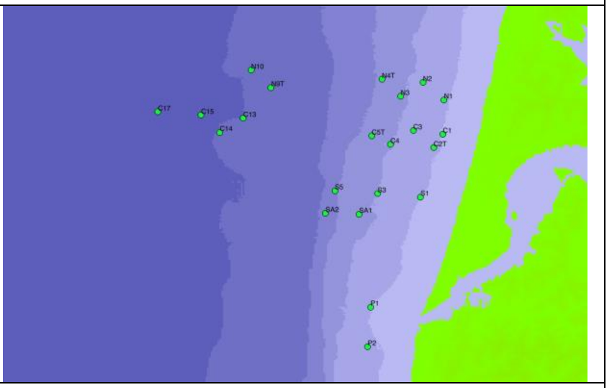
August 2013



September 2013



October 2013



November 2013

December 2013

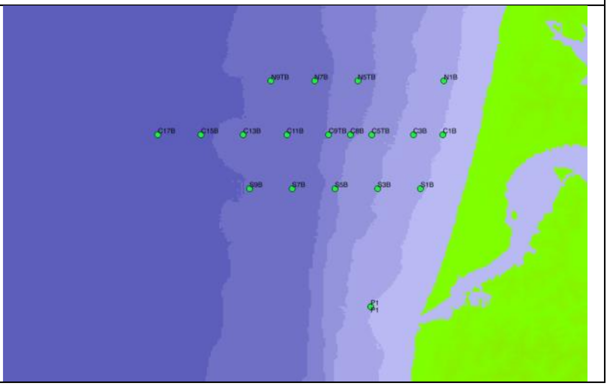
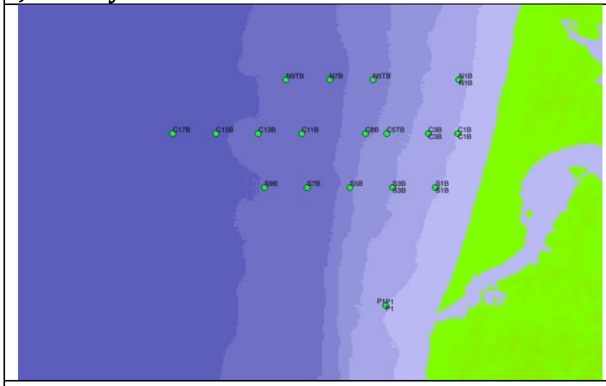
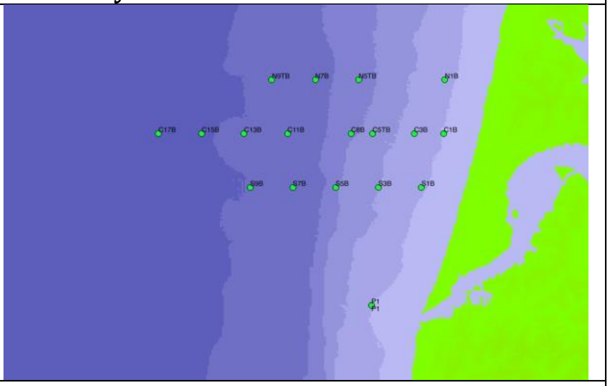
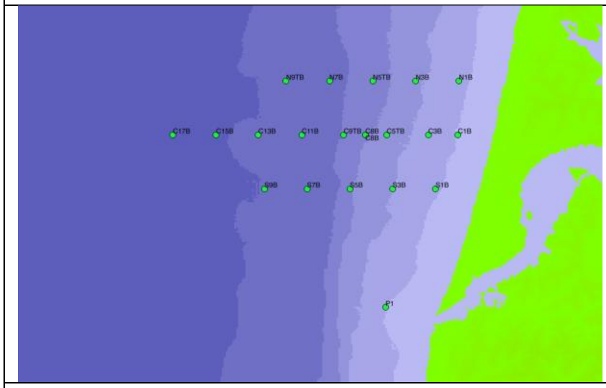
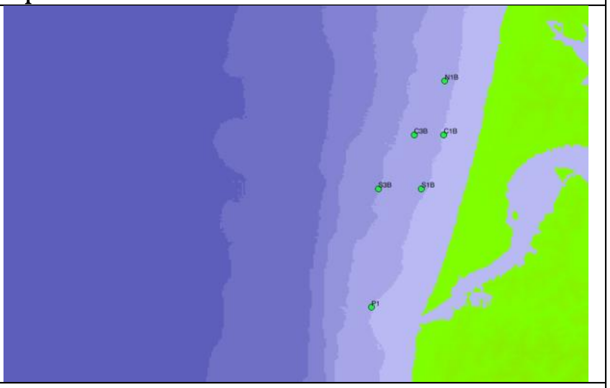
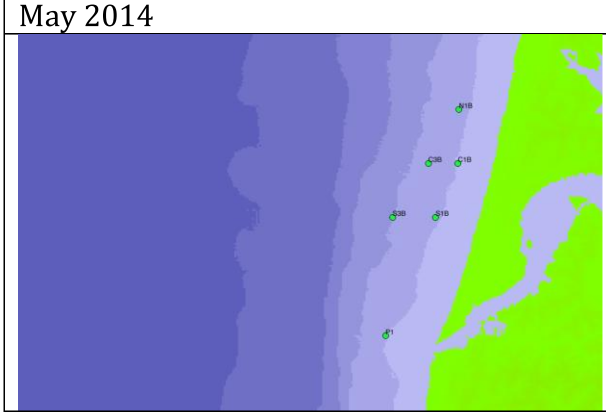
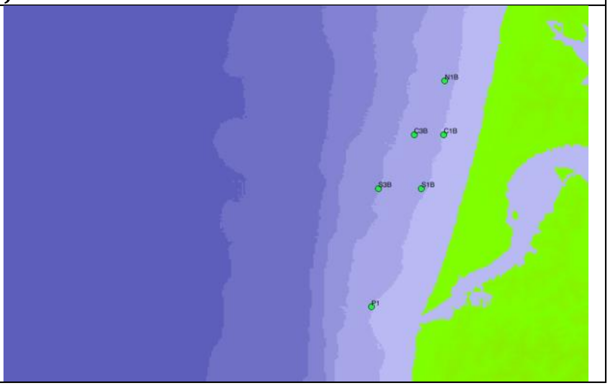


Figure 4.6. Continued.

January 2014	February 2014
	
March 2014	April 2014
	
May 2014	June 2014
	

4.4. Substrate

The substrate within the footprint of the main ocean array of receivers consisted of sand and mud (Figure 4.7). Sand was typically found shoreward of the 60 m depth contour, whereas mud was present beyond 60 m. High relief and rocky habitat was not present within the area of the array. With the exception of one small rock outcrop (11 Ha) approximately 500 m shoreward of the receivers, the nearest mapped rock outcrop (37 Ha) is 11 km from the center of the array, and 4.6 km from the nearest (northwest) corner. Large areas of sand were also present at deeper depths seaward of the receivers.

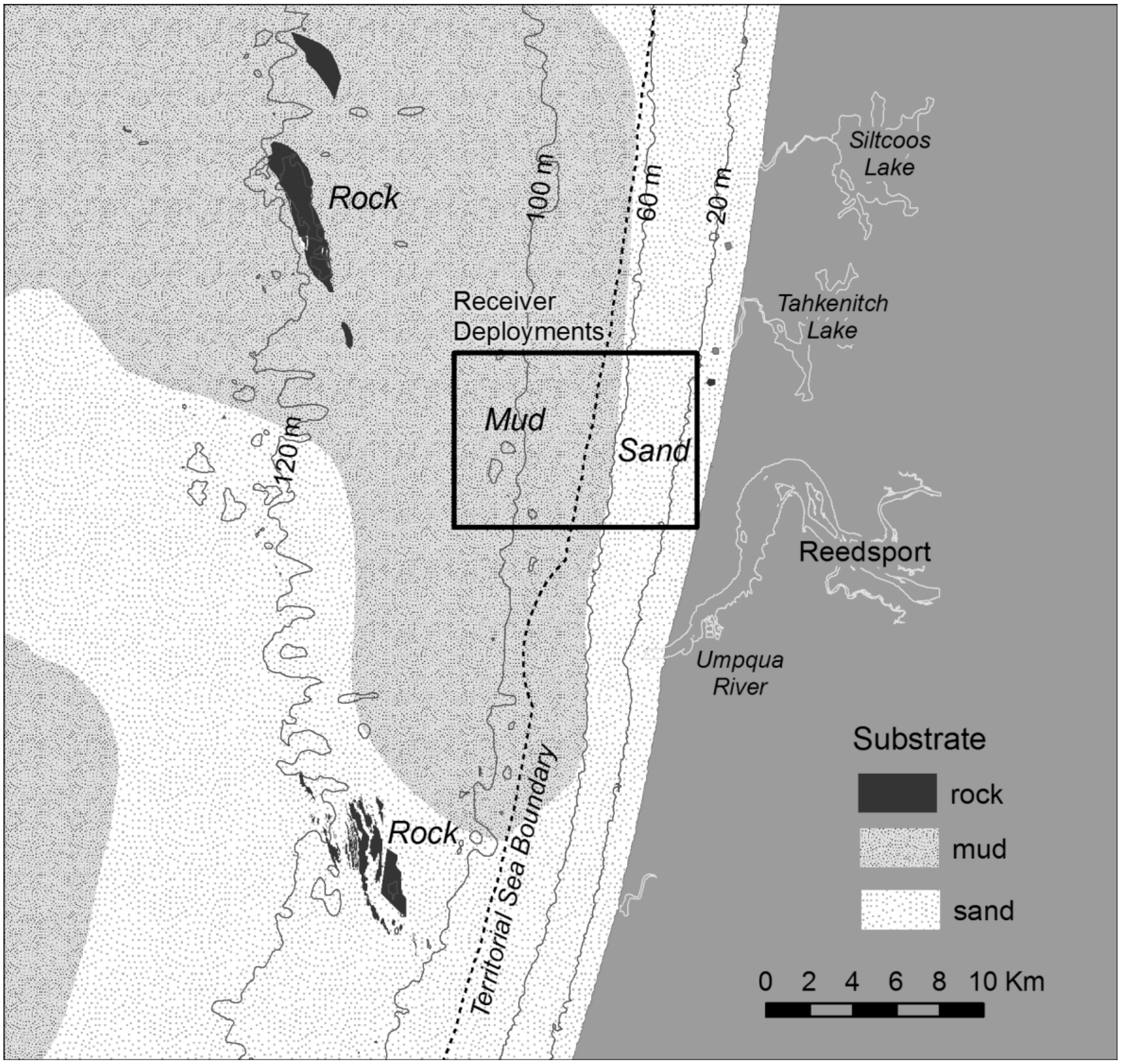


Figure 4.7. Substrate in the area of deployed VR2W receivers near Reedsport, Oregon. The open rectangle represents the bounds of the main ocean array, excluding the two receivers stationed outside of the mouth of the Umpqua River. Data source: Oregon State University Tectonics & Seafloor Mapping Lab (data layer = Benthic Habitat v. 3.6.1).

4.5. Number and species of fish detected

Tagging metadata for 989 individual fish were supplied to us by seven different research groups, who gave us permission to view their data on the Ocean Tracking Network data repository (OTN; at www.oceantrackingnetwork.org) or sent us data directly (Table 4.1). These included 736 green sturgeon tags for which the listed battery life extended beyond the beginning of our study (January 2013), and an additional 48 green sturgeon tags that had unknown battery lifespans.

The ocean array detected a total of 248 individual green sturgeon, including 228 of 736 (31%) of the sturgeon tags with a rated battery life that included the start date of our study, and 20 of 34 (59%) of the sturgeon tags with unknown tag battery life (Table 4.1). The sturgeon detected by the ocean array were a mixture of southern DPS and northern DPS. Acoustic receivers anchored inside of the Umpqua River estuary (Langness et al., 2014) detected 57 green sturgeon during this study. Twenty one of these fish were not recorded by the ocean array of receivers.

Table 4.1. Tags detected by the ocean array of acoustic receivers, in relation to known tags and tags presumed to be functioning.

Condition of tag batteries	Green sturgeon		Other species		Total
	Total tags	Detected	Total tags	Detected	
Expiration date beyond the start date of the study	736	228			736
Expiration date prior to the start date of the study	205	0			205
Unknown expiration date	34	20	14	11	48
Total	975	248	14	11	989

Detections of known and unknown tag codes

The ocean array recorded a total of 362 tag codes, of which 259 were in the tagging metadata that we obtained from other researchers, including 248 green sturgeon, 2 white sturgeon (*Acipenser transmontanus*) and 9 great white shark (*Carcharodon carcharias*) (Table 4.2). The array recorded a total of 260,850 detections. The 259 fish with metadata provided 249,920 detections (95.8% of the total detections). An additional 10,325 detections of as many as 103 unknown tag codes were recorded (Table 4.2). However, 59 of the unknown tags were only detected once, and most of those were probably false detections, according to the manufacturer. The remaining 44 tag codes may be real, and belong to unknown researchers. All unknown tag detections were excluded from further analysis.

Table 4.2. Species and number of individual fish detected by the ocean array of VR2W receivers. The number of transmissions detected per species is also shown. The unknown tag codes include some that could be false detections. The actual number of unknown tags may be smaller than the number of codes detected.

Species	Number of detections	Number of individual fish
Green sturgeon	249,850	248
White sturgeon	2	2
Great white shark	68	9
Unknown tag codes	10,325	≤103
Total	**260,245**	**≤362**

4.6. Number of fish detected by date and depth zone

Green sturgeon detected per day

The highest numbers of individual green sturgeon detected per day occurred in spring of both years, but in 2013 there was a broad peak from mid-January to mid-May (max = 24 fish/day), whereas in 2014 there was a narrower peak in mid-March (max = 12 fish/day; Figure 4.8). A peak was also observed October, 2013 (max = 15 fish/day). The raw and corrected estimates diverge at the beginning and end of the study when there was low effort (i.e., number of receivers in the water).

Green sturgeon were detected on 492 out of 515 days (95.5%) by VR2W receivers during this project. Outside of the peak periods (67 days on which 10 or more individual sturgeon were detected), the median number of green sturgeon detected per day was 3.0 (range: 0-9, standard error 0.11). No green sturgeon were detected in the area of the acoustic array on only 23 of 515 days (4.5%) of the study.

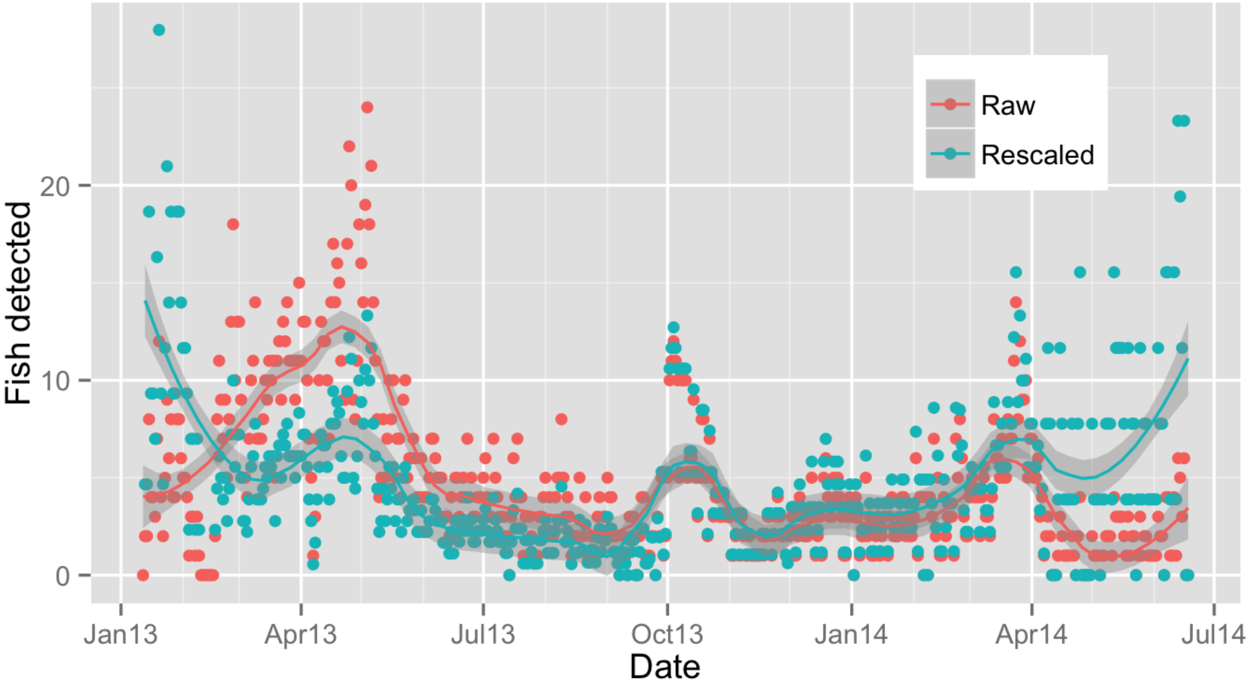


Figure 4.8. Number of green sturgeon detected per day by VR2W acoustic receivers off Reedsport, Oregon. The vertical lines are at the first day of each month and the date range is January 2013 to July 2014. The rescaled data are adjusted for effort (functioning receivers per day). The trend lines are LOESS smoothers with a span of 0.2. The 95% confidence intervals are shown in dark gray. The number of VR2W receivers included in the array was lowest during January 2013 and April – June 2014.

Green sturgeon detected per month

Raw and rescaled data are presented in Figure 4.9 to illustrate monthly patterns of green sturgeon detections. The re-scaled data are sensitive to low effort at the beginning and end of the study when the fewest functioning receivers were present; the array was largely incomplete during January 2013 and April – June 2014 (Figure 4.6). Therefore, only patterns from February 2013 – March 2014 are described here. The overall pattern of fish detected per month was similar between data sets.

Green sturgeon were detected by the ocean array of VR2W receivers in every month of the study (Figure 4.9). The raw data show highest detections of green sturgeon per month in February and March in both years (N = 69-71 fish/month in February- March 2013, and 54-64 fish/month in February-March 2014). A third distinct peak was also observed in October, 2013 (62 fish/month). The lowest numbers of green sturgeon detections (24 to 29 fish/month) occurred in summer and fall (July – September), as well as early winter (November, 15 fish detected).

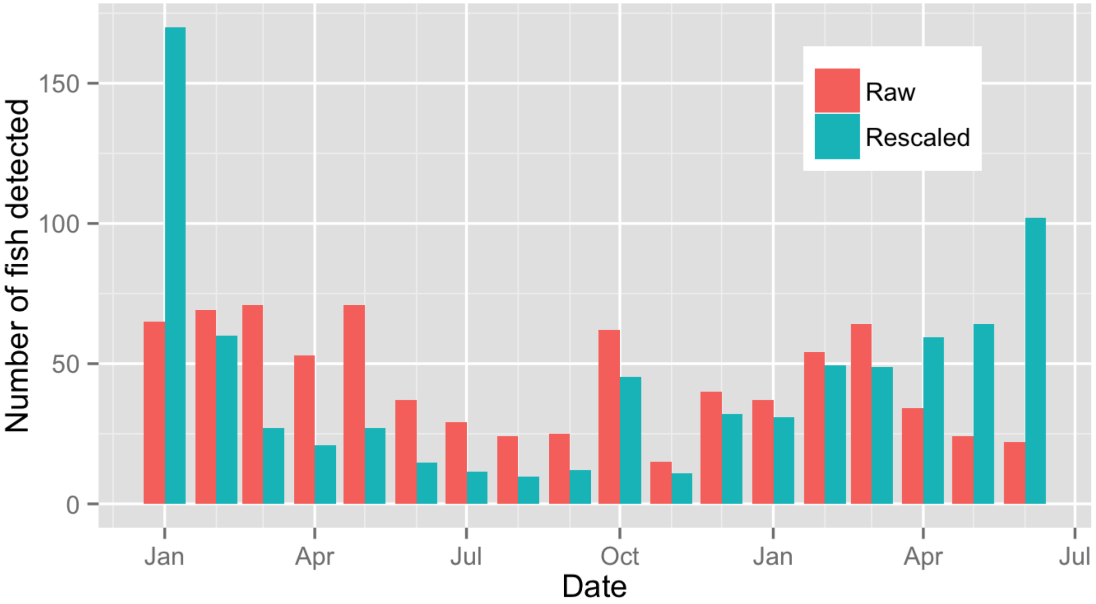


Figure 4.9. The number of individual green sturgeon detected per month by VR2W receivers. The rescaled data are adjusted for effort, measured in receiver-days per month. The horizontal axis is categorical and the date range is from January 2013 to July 2014. The number of VR2W receivers included in the array was lowest during January 2013 and April – June 2014.

Number of green sturgeon detected by depth zone

Detections of individual green sturgeon by depth (Figure 4.10) show that individual green sturgeon from all capture sites were found across a wide range of depths (15 – 110 m), which span shallower and deeper depths than the depth of the proposed OPT wave energy project. The center of the depth zones used most commonly by green sturgeon overlaps the proposed depth of the OPT wave project at 50-70m. The median depth at which green sturgeon were detected was 66.6 m (median of all detected transmissions; Figure 4.10), and there were relatively few detections by receivers stationed at depths greater than 90 m (Figure 4.11). There is some tendency for green sturgeon tagged in the Sacramento River system (southern DPS) to be shallower than fish tagged in the northern bays and estuaries (mixture of southern and northern DPS). An effort-corrected summary by 10 m depth zone shows similar results as the raw data (Figure 4.11).

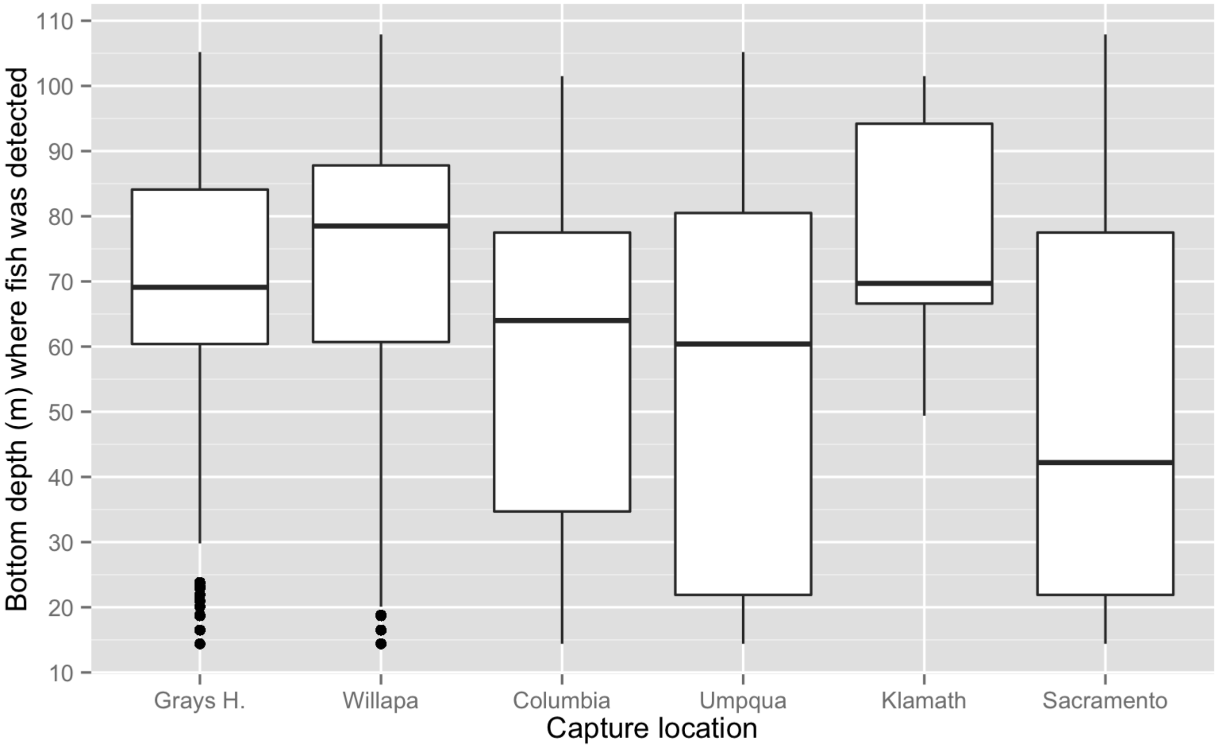


Figure 4.10. Boxplot of the depth ranges of detections of 248 individual green sturgeon, grouped by the river where they were captured (ranked from north to south, left to right). Each box shows the median value as a bar, and the box spans the first to third quartile of the data. The whiskers extend out to 2 standard deviations from the mean, and the dots are outliers.

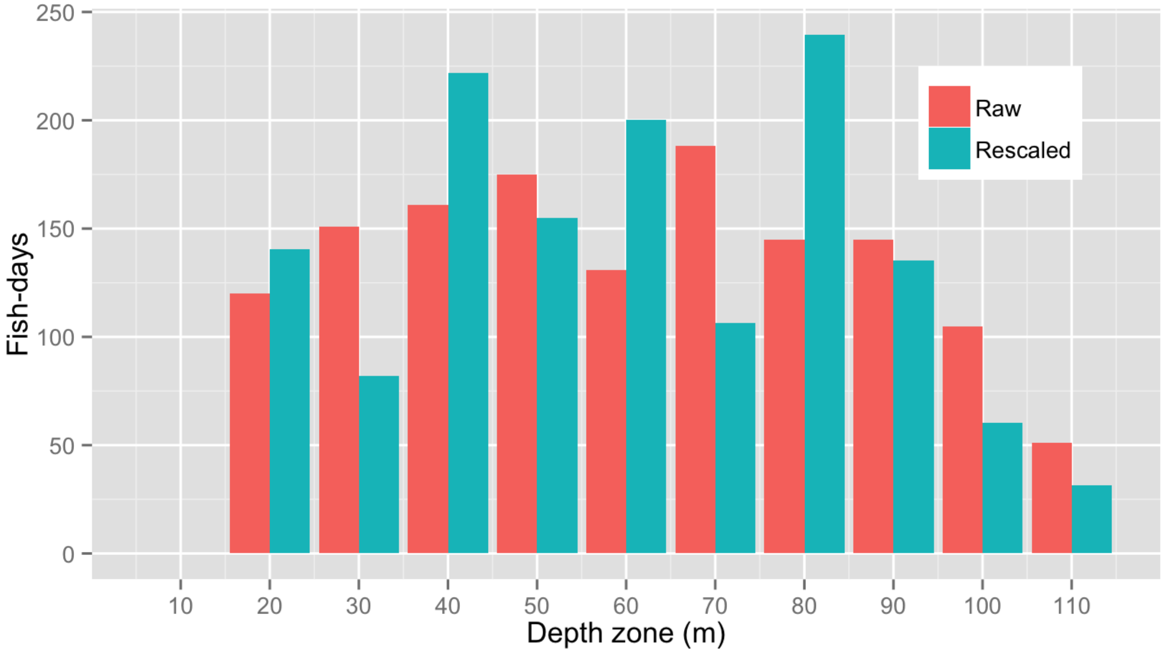


Figure 4.11. Distribution of green sturgeon by depth zone. The x-axis is categorical and each 10 m zone is defined by its deepest extent (e.g., the paired bars at the 50 m marker represent the depth zone that extends from 40 m to 50 m). The y-axis shows the sum over all days of the *count of unique green sturgeon per day*. The blue bars have been rescaled for monitoring effort in each 10 m depth zone, measured in receiver-days, as explained in Methods.

Depth ranges by month

Green sturgeon were at shallowest depths in March 2013, September 2013, November 2013, and March 2014 (Figure 4.12), when most detections (medians and 75th percentiles) were by receivers stationed at less than 30 m depth. These months correspond roughly with peaks in the number of fish detected per day (Figure 4.8). The median depth for these shallow months was approximately 15 – 20 m. The median depth of detections for the remaining months was 60 – 80 m, with the exception of October 2013, when the median depth was approximately 50 m.

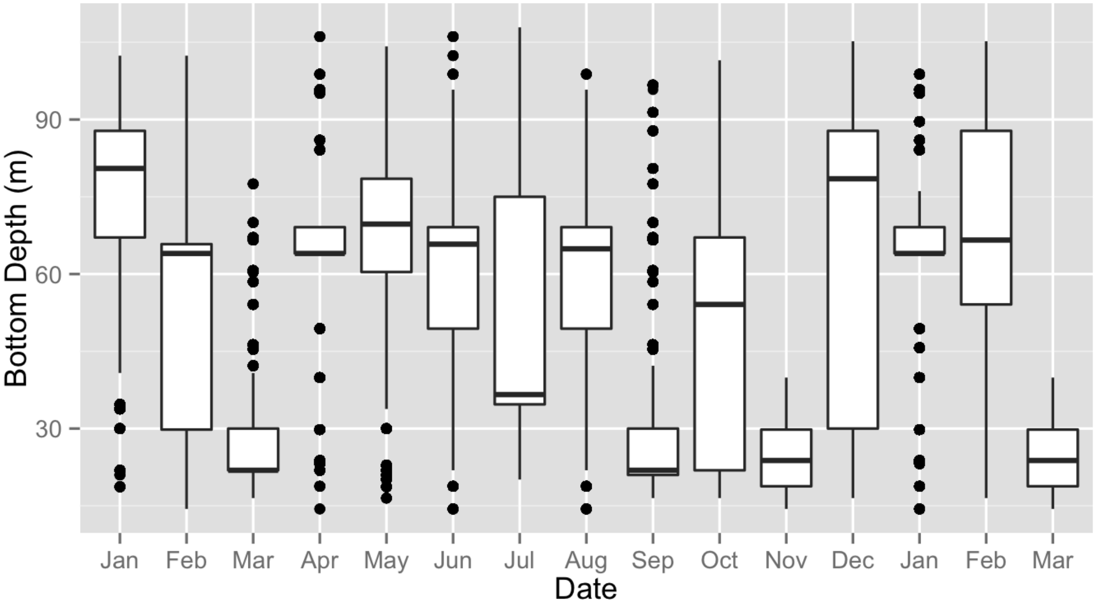


Figure 4.12. Standard boxplots showing depth ranges of green sturgeon detections by month, from January 2013 to March 2014. The last three months of the study (April – June 2014) were excluded because there was no receiver coverage at depths greater than 40 m. From October to December, 2013, the array was missing receivers in the 70-90 m range. Each box shows the median value as a bar, and the box spans the first to third quartile of the data. The whiskers extend out to 2 standard deviations from the mean, and the dots are outliers.

Green sturgeon per day, by depth zone

Green sturgeon were detected by shallow receivers (< 50 m) throughout all months of the year (Figure 4.13). Detections of green sturgeon were rare at deep receivers (> 70 m) between July and December. Note, however, that receivers were missing in the 70-90 m depth range from October to December, 2013. Detections at receivers over 70 m depth were common in the spring (Figure 4.13), even though Figure 4.12 suggests the lowest median depth of green sturgeon detecions. The springtime peak in fish per day seems to occur more strongly at depths from 60 to 100m than at shallower depths (Figure 4.13).

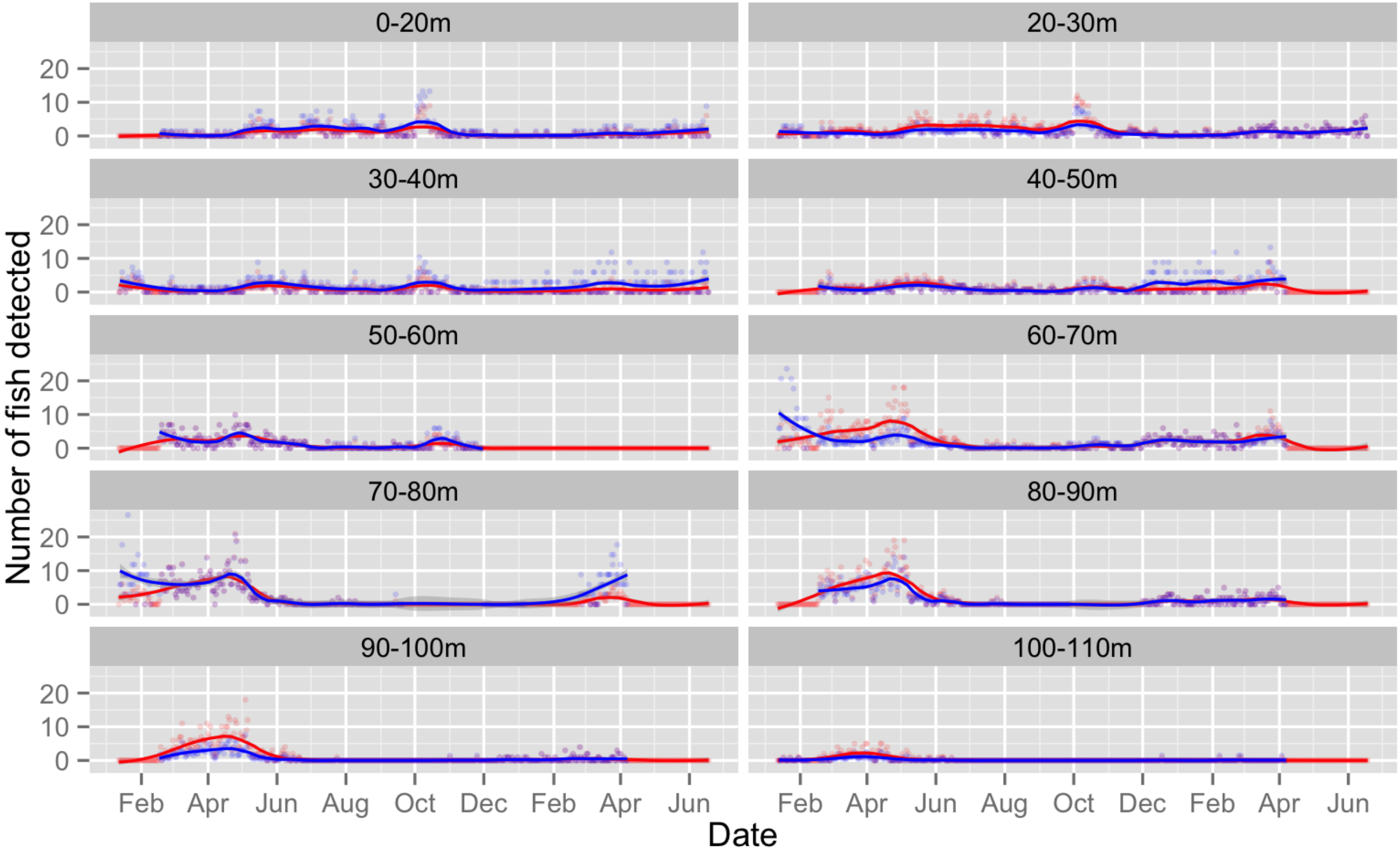


Figure 4.13. The number of unique green sturgeon detected per day, for each 10-m depth zone. Raw data are red dots, and rescaled are blue. The lines are LOWESS smoothers with a span of 0.5. The date range is from January 2013 to June 2014.

4.7. Detections of each species by depth and station

Green sturgeon were detected at every depth and every station. The nine great white shark were detected at a variety of depths, and the two white sturgeon were detected at 60 – 80 m (Figure 4.14).

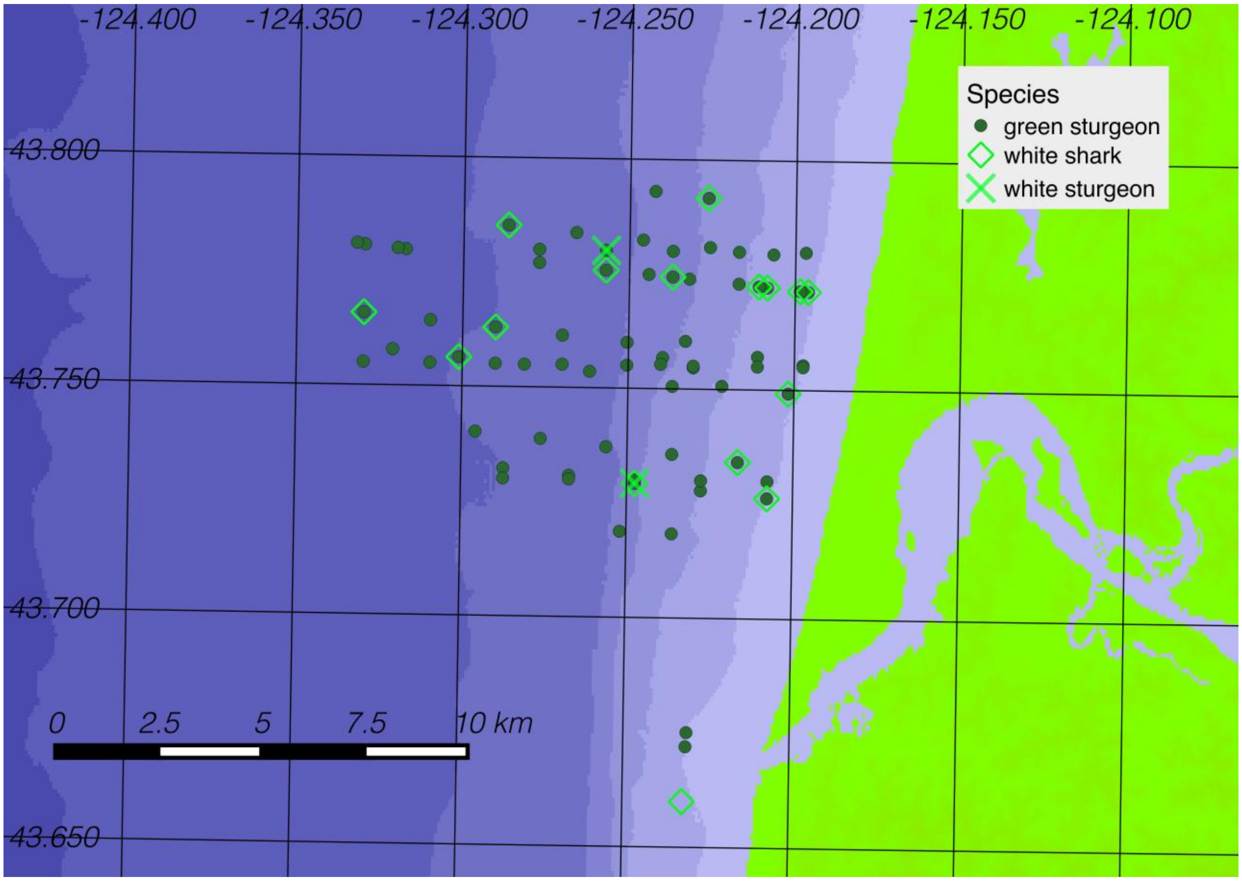


Figure 4.14. Receiver locations where detections were made of each species. The exact locations of the animals themselves were unknown, but were assumed to be within a few hundred meters of the receivers, because of the limited range of the acoustic tags (for example, 63% of sentinel tag transmissions were detected at a distance of 825 m). The depth contours are at 20 meter intervals.

Plotting the data geographically show that the pattern of depth preference extended throughout the study area. Detections were not isolated to a small area or a few receivers (Figure 4.15). The highest numbers of individual green sturgeon were detected near middle depths (30 – 70 m), with most detections (125 – 150 green sturgeon) recorded on a receiver near the 60 m contour. Numerous green sturgeon were also detected immediately in front of the mouth of the Umpqua River (100 – 125 green sturgeon). Although some green sturgeon were detected outside of the 100 m contour, the number of sturgeon recorded by these stations were lowest (1 – 25 green sturgeon per station). Most green sturgeon detections were shallower than 100 m.

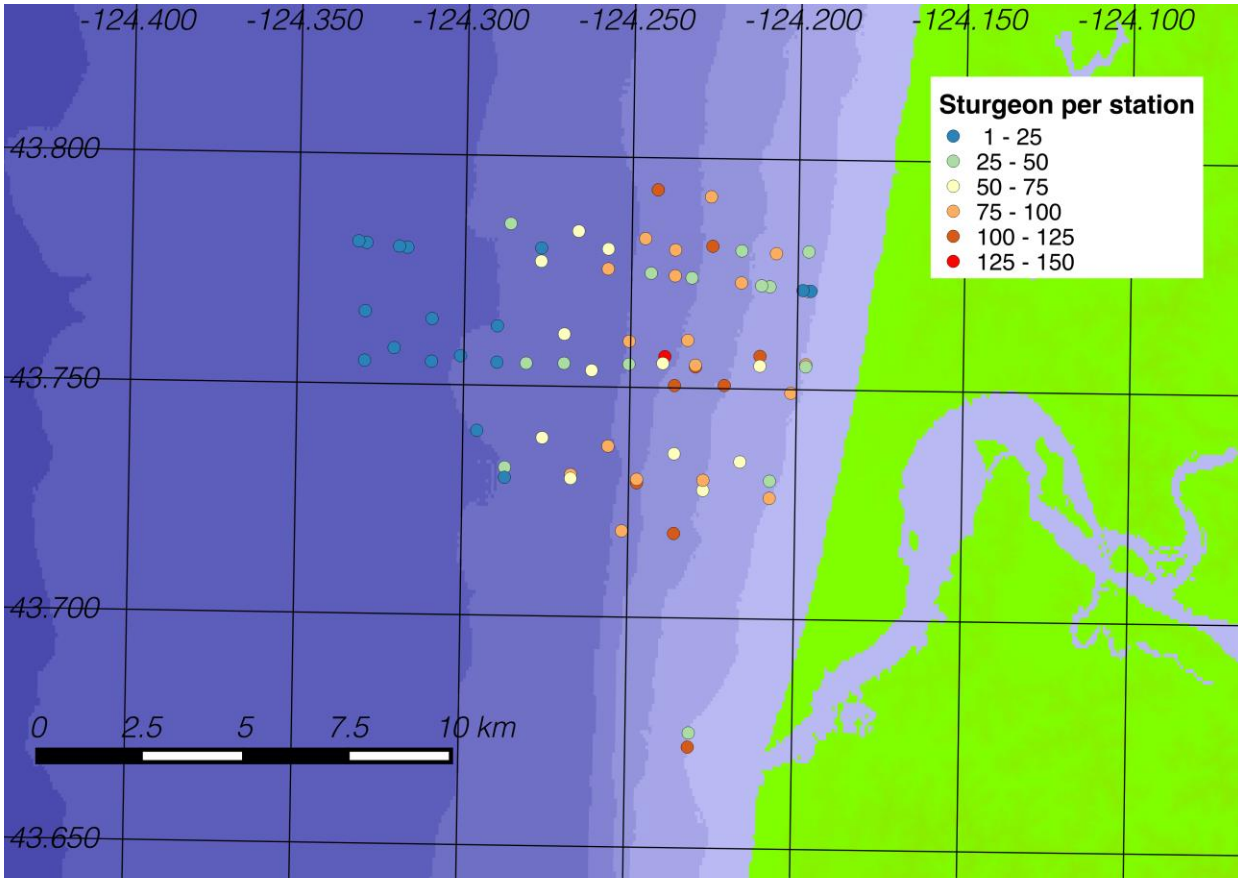


Figure 4.15. Number of unique green sturgeon detected at each VR2W receiver station. Some of the variance in the colors is accounted for by changes in the array configuration. Depth contours represent 20 meter intervals.

4.8. Occupancy Patterns

A plot of detection times by date (Figure 4.16) shows that many individual green sturgeon were detected repeatedly by the ocean array throughout the study. It also shows that many fish were absent from the array for long periods. Finally, Figure 4.16 shows several instances where green sturgeon were detected for very brief periods of time. These individuals were likely migrating through the area. Clearly, several different behavior patterns may be present. Certain patterns become apparent when the data are plotted in a way that emphasizes occupancy periods (Figure 4.17).

Many individual adult and subadult green sturgeon were detected repeatedly in the vicinity of the study area for approximately six weeks, from mid-March 2013 to early May 2013 (Figure 4.17). The pattern was repeated (by fewer fish) in 2014, but occurred approximately two weeks earlier in the season. Subadult green sturgeon were detected in the ocean study area (N = 71) throughout the year, although the concentration of subadults detected by the ocean array was less during summer and early fall months (July – October) than during late-fall and winter months (Figure 4.18). Most of these subadults did not enter the estuary throughout the study period (N = 67).

Adults were most concentrated in the Umpqua River estuary from May – October, and were mostly absent from the estuary during the remaining months (Figure 4.17).

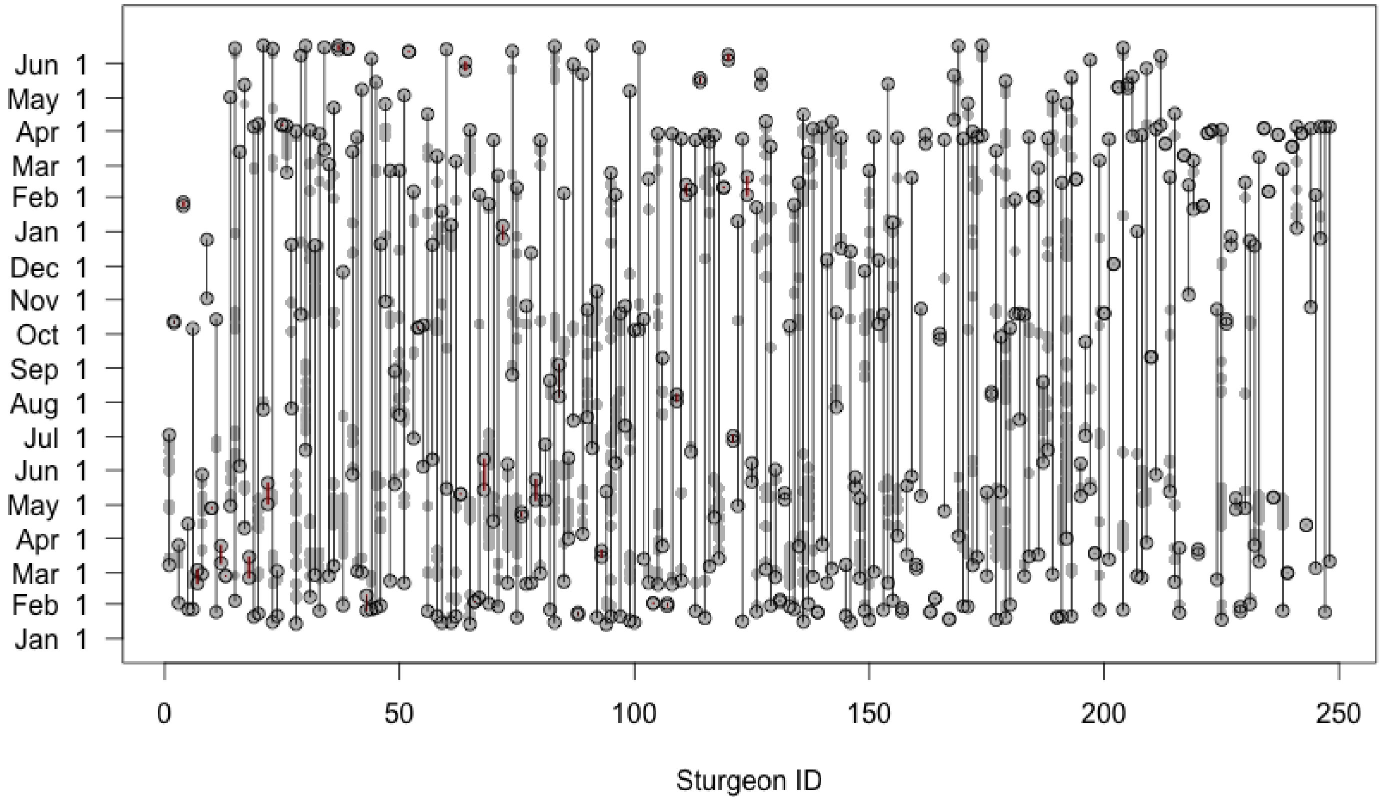


Figure 4.16. Date ranges on which each of 248 green sturgeon was detected by the ocean array of VR2W receivers from January 1, 2013 to June 30, 2014. First and last detections of each fish are shown as dots with darker outlines, and are joined with vertical lines. Where residence time is less than 30 days, the lines are red. Light gray dots are days on which additional detections occurred.

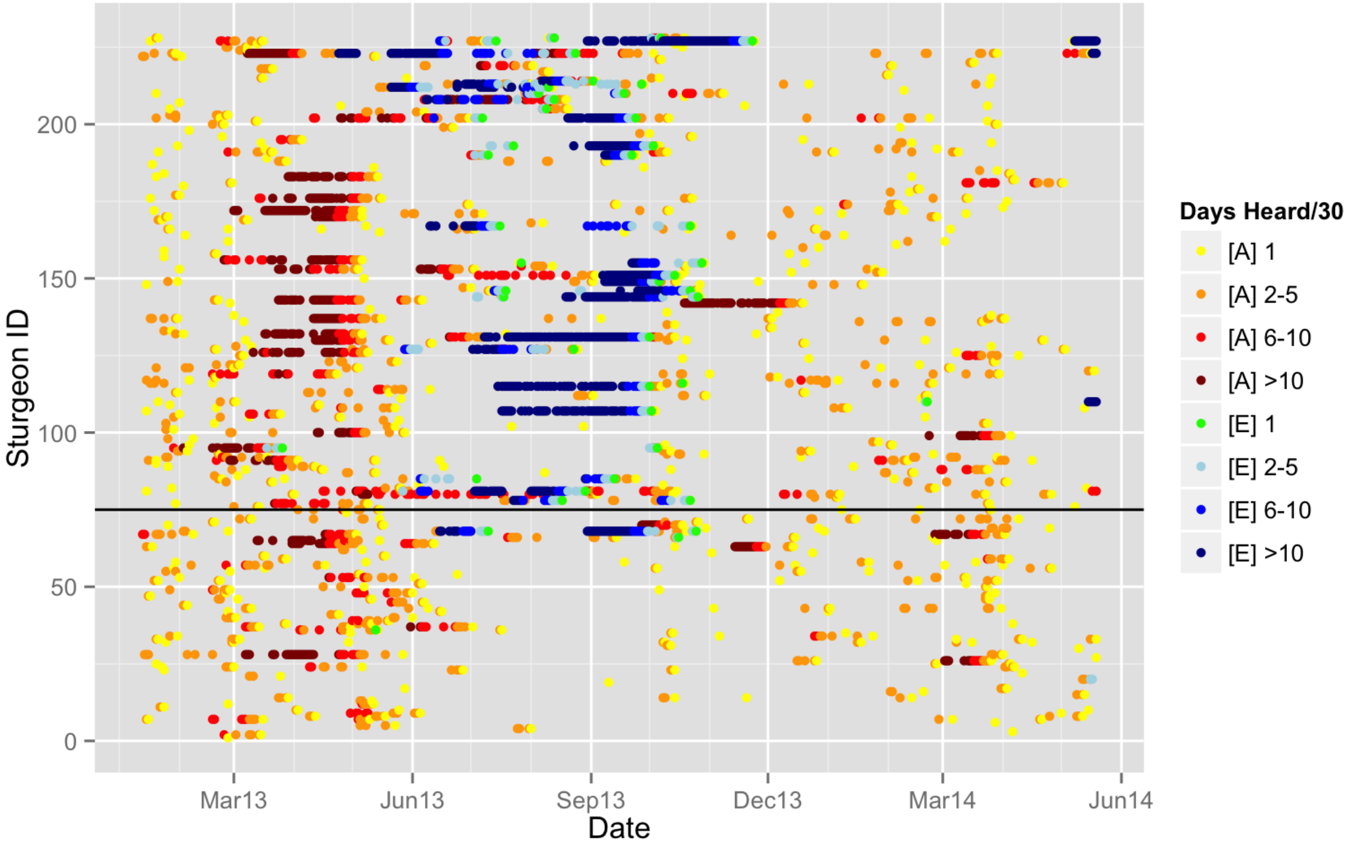


Figure 4.17. Daily detections of green sturgeon by receivers located in the Umpqua River estuary (N = 57; Langness et al., 2014) and in the ocean off Reedsport, Oregon (N = 248). Each row represents a different individual, and they are sorted by rank of fish length (range 99 cm – 223 cm total length (TL)). The horizontal black line is the assumed break-point between subadults (< 140 cm TL) below the line and adults (≥ 140 cm TL) above it. Color gradients indicate the number of days in a moving 30-day window following the detection, on which each fish was heard. The red/yellow gradient indicates occurrence in the array, and the blue/green gradient indicates occurrence in the nearby Umpqua River estuary. In the legend, items preceded by [A] are counts in the array, and items preceded by [E] are counts in the estuary.

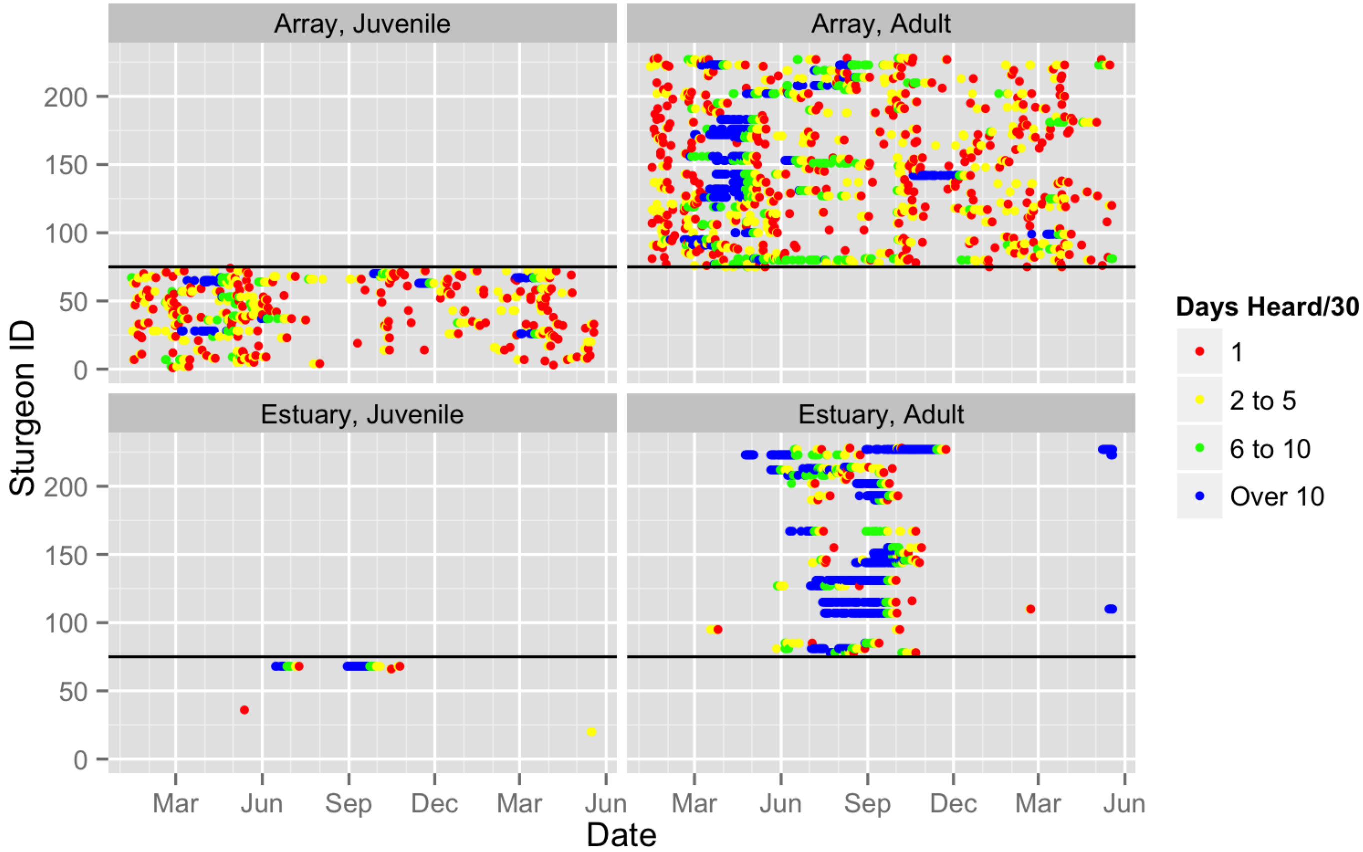


Figure 4.18. Daily detections of green sturgeon by receivers located in the Umpqua River estuary (N = 57; Langness et al., 2014) and in the ocean off Reedsport, Oregon (N = 248). Data are sorted by adult/subadult and estuary/array. Each row represents a different individual, and they are sorted by rank of fish length (range 99 cm – 223 cm TL). The horizontal black line is the assumed break-point between subadults (< 140 cm TL) below the line and adults (≥ 140 cm TL) above it. Color gradients indicate the number of days in a moving 30-day window following the detection, on which each fish was heard.

Migratory patterns and ocean-estuary movements

The geographic area covered by the array was too small to enable us to document long-distance migratory movements. However, data on the location where fish were tagged show that sturgeon from northern and southern rivers, bays, and estuaries are mixing in the area of the ocean array (Table 4.3). Monthly detections of sturgeons by the ocean array were typically lowest during June – September, and highest during winter months (Table 4.3). This trend was least apparent for fish that were caught and tagged in the Umpqua River estuary (N = 20 fish). The pattern difference may be due to sample size rather than tagging location.

There is also green sturgeon movement between the Umpqua River estuary (Langness et al., 2014) and the ocean array (Figure 4.17), with many of these individuals moving back and forth between the two sites. In total, 57 tag codes were detected in the estuary by the receivers that ODFW operated (Langness et al., 2014), and 36 of those were green sturgeon that were also detected on the ocean array (Figure 4.17). The timing of entry into the estuary is similar among green sturgeon originally tagged in the Sacramento, Umpqua and Columbia rivers, with some suggestion that Grays Harbor and Willapa Bay fish may enter later (Table 4.4). Monthly detections of green sturgeon by the estuary array were highest during the summer, and virtually absent during the winter (Langness et al., 2014; Table 4.4). This trend is opposite of what was seen for most of the green sturgeon detected on the ocean array (Table 4.3).

Of the 248 green sturgeon that were detected on the ocean array, only 36 were detected in the Umpqua River estuary, leaving 212 individuals that never entered the estuary (Figure 4.17). Twenty one green sturgeon were detected by the estuary array but not detected by the ocean array. Most of the green sturgeon detected in the Umpqua River estuary were adults (i.e., 52 of 57 individuals detected). Of the 71 subadults that were detected in the ocean array, only 4 entered the estuary. Furthermore, only one of 16 subadults that were detected for periods of 1 week or more on the ocean array was detected in estuary.

Table 4.3. Number of unique green sturgeon detected per month on the ocean array, by location where they were tagged (arranged from north to south, left to right). The numbers in the shaded cells show the total number of unique fish from each location. Individual fish may be counted more than once if they are detected in different months.

		Grays Harbor	Willapa Bay	Columbia River	Umpqua River	Klamath River	Sacramento River
	Month	n=56	n=49	n=46	n=20	n=2	n=75
2013	1	17	14	10	9	0	15
	2	24	13	17	4	1	10
	3	22	14	9	4	0	22
	4	10	15	12	4	0	12
	5	12	18	18	6	0	17
	6	5	4	11	7	0	10
	7	4	5	5	8	0	7
	8	4	4	4	6	0	6
	9	3	4	4	6	0	8
	10	14	7	14	10	1	16
	11	4	3	3	2	0	3
	12	11	9	12	1	0	7
2014	1	4	7	13	1	0	12
	2	13	12	12	3	0	14
	3	16	9	12	0	0	27
	4	10	5	4	0	1	14
	5	1	4	5	4	0	10
	6	4	6	4	3	0	5

Table 4.4 Number of unique green sturgeon detected in the Umpqua River estuary per month, by location where they were tagged (arranged from north to south, left to right). The numbers in the shaded cells show the total number of unique fish from each location. Individual fish may be counted more than once if they are detected in different months.

		Grays Harbor	Willapa Bay	Columbia River	Umpqua River	Klamath River	Sacramento River
	Month	n=56	n=49	n=46	n=20	n=2	n=75
2013	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	1	0	0	0	0	0
	4	0	0	0	0	0	1
	5	0	0	1	2	0	2
	6	0	0	2	4	0	5
	7	1	0	2	11	0	7
	8	0	0	2	14	0	6
	9	2	1	1	10	0	4
	10	4	1	2	8	0	2
	11	0	0	0	1	0	0
	12	0	0	0	0	0	0
2014	1	0	0	0	0	0	0
	2	1	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	1	0	2	2	0	2
	6	1	2	2	3	0	3

Most individual fish were only detected in a few months (i.e., < 5 months) of the 18 months during which the array was deployed (Figure 4.19). An examination of the dates of first detection shows an initial pulse of new sturgeon in January 2013, followed by a steep drop in new fish over 3 months, with pulses of new fish in May 2013, October 2013, and March 2014 (Figure 4.20).

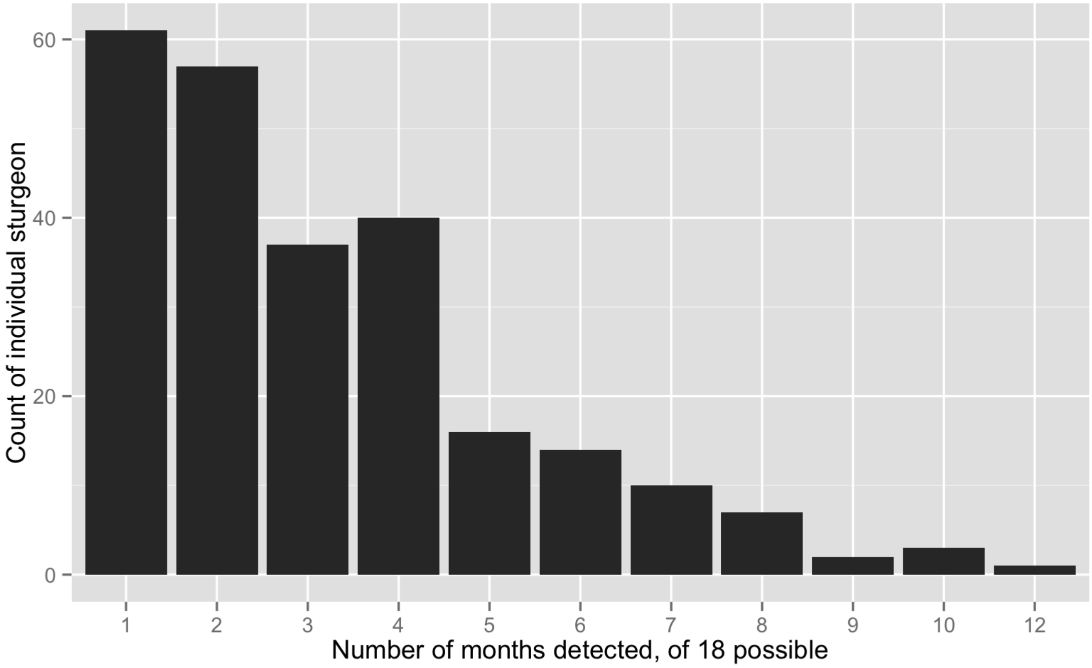


Figure 4.19. The distribution of the number of months on which each green sturgeon was detected, out of the total of 18 months during which the array was deployed. For example, 61 fish were seen in only 1 of the 18 months during which the array was deployed, and no fish was detected in more than 12 different months.

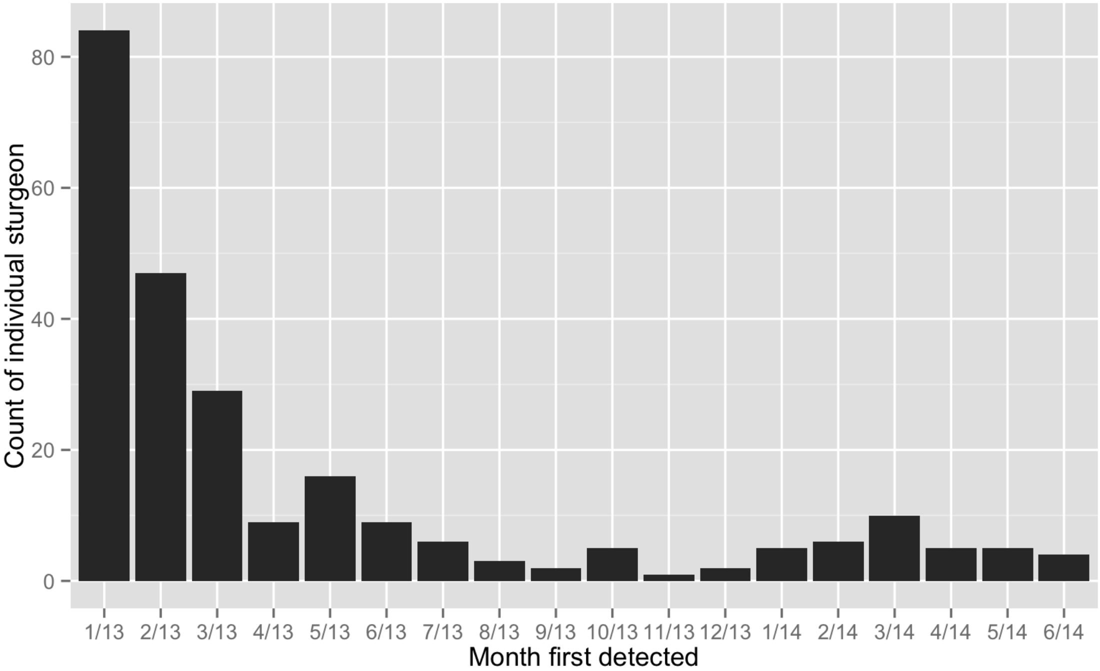


Figure 4.20. Distribution of dates on which individual green sturgeon were first detected, grouped by month.

North-south movements

Calculating the net north-south direction of movement for each fish per day (as the latitude of the last detection on a given day minus the latitude of the first detection on that same day) revealed that sturgeon movements were not mono-directional while within the array of receivers. North-south movements were plotted to emphasize large-scale migration patterns, but the results show a relative lack of coherence in direction of movement on daily and weekly scales, as individual sturgeon shuttled back and forth (Figure 4.21). Further analyses will be conducted to evaluate seasonal migratory patterns.

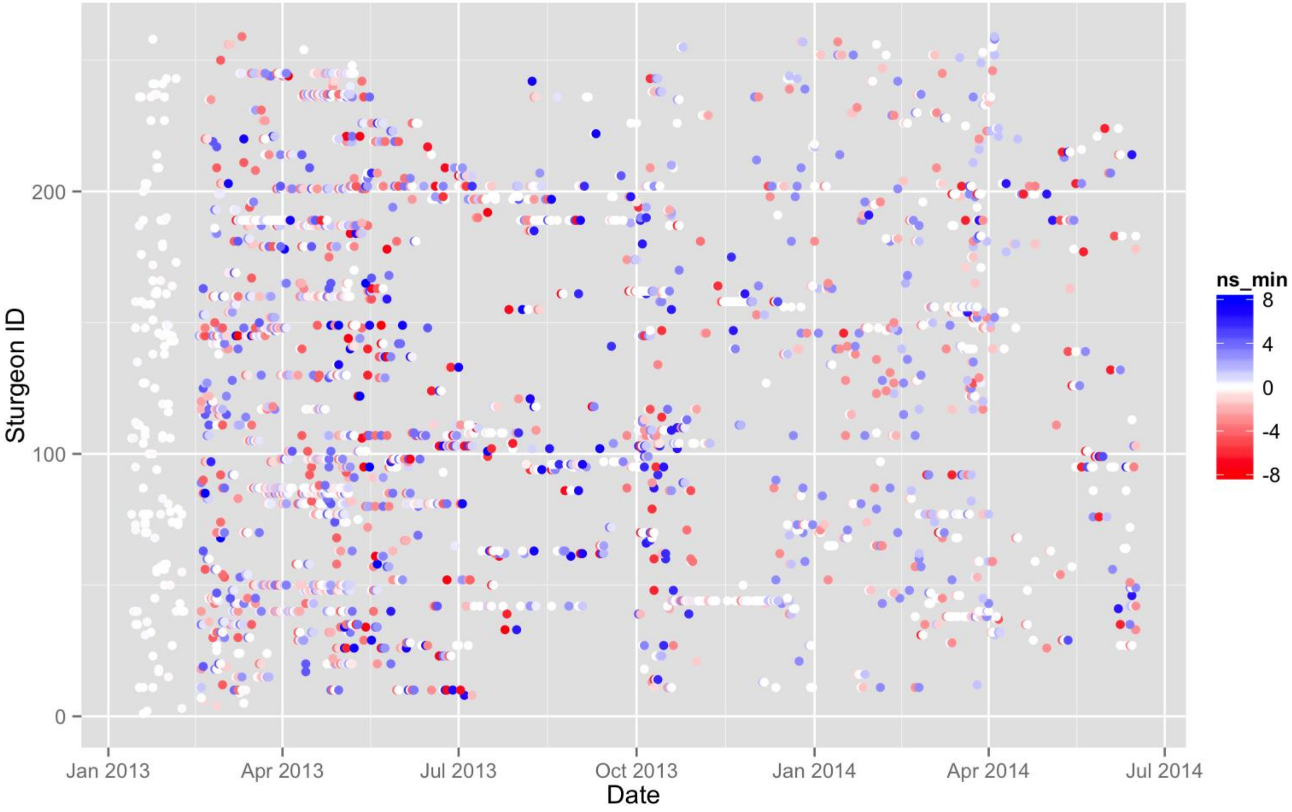


Figure 4.21. Direction of daily green sturgeon movements on the array. Each row represents a different fish. A dot is a day on which a fish was detected, and the color indicates the direction that it went (blue = north, red = south), between the first location of the fish on the given day, and the last detection on the same day. Distances are measured in minutes (i.e., 1/60th of a degree of latitude, or about 1.3 km at this latitude).

5. DISCUSSION

Despite significant losses of acoustic receivers, this project succeeded in collecting baseline data and new information on green sturgeon in the area of the licensed OPT wave energy project. Although this energy project is no longer moving forward, results of this study provided new information that better describe oceanic habitat use and movements by green sturgeon from the northern and southern DPS.

Erickson et al. (2013) hypothesized that this area just north of the Umpqua River may be important for green sturgeon for two reasons. First, the area of the proposed wave energy project was centered within the migratory corridor for green sturgeon, which are known to undertake northern and southern migrations annually (Lindley et al. 2008) at depths less than 110 m (and typically between 40 – 70 m; Erickson and Hightower, 2007). Second, because the Umpqua River estuary is used extensively by green sturgeon during the late spring to early autumn months (Lindley et al. 2011; Langness et al., 2014), Erickson et al. (2013) hypothesized that the area near the river mouth may also be an important concentration site for the species. They suggested that this area may be influenced by the river plume, and may therefore provide some of the special characteristics that are found within the estuary that attract green sturgeon (e.g., food). Results provided herein demonstrate that this nearshore-marine area is important for both green sturgeon migration and green sturgeon occupancy (i.e., this area can be considered a green sturgeon concentration site). Other concentration sites have been shown for green sturgeon in the ocean. Lindley et al. (2008) and Erickson and Hightower (2007) demonstrated a concentration site for green sturgeon on the northwest side of Vancouver Island, and suggested that the site might represent a feeding area. Erickson and Hightower (2007) also showed non-random concentrations of green sturgeon near bays and estuaries (e,g, Willapa Bay, Columbia River, and Yaquina Bay) using trawl bycatch data. Those areas are also near fishing ports, however, which may have confounded this interpretation.

Estuaries are well known to be high-value habitats, but the ocean immediately offshore and upcoast/downcoast of estuary mouths is sometimes considered as equivalent to any open coast habitat. That is clearly not the case for the open coast in the vicinity of the Umpqua River as it relates to green sturgeon, and possibly not for other river mouths (and bays) where green sturgeon occur. We showed that this area attracts green sturgeon during all months of the year, and hypothesize that this concentration site may be used for feeding. Some may argue that with only 18 months of data, it is uncertain whether the patterns observed will repeat annually. Other research suggests that they may. Lindley et al. (2011) found that individual green sturgeon tend to visit the same sites each year.

Marine concentration sites have been identified near estuaries and bays for other sturgeon species, and researchers have speculated that these sites are important for feeding. Stein et al. (2004) and Laney et al. (2007) described non-random encounter patterns for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) by commercial and research-fishing operations off the U.S. East coast, and Erickson et al. (2011) showed nearshore-marine concentration areas for Atlantic sturgeon near Delaware Bay, Chesapeake Bay, and the Hudson River using satellite tags. Fox et al. (2002) and Edwards et al. (2003, 2007) showed that Gulf sturgeon (*Acipenser oxyrinchus desotoi*) may select specific habitats off the Florida coast. Stein et al. (2004) noted that Atlantic sturgeon bycatch was often associated with coastal formations that may enhance prey concentration and therefore feeding opportunities for sturgeons. Likewise, Fox et al. (2002) and Edwards et al. (2003) suggested that Gulf sturgeon marine-concentration sites most likely represent important feeding habitats.

Lindley et al. (2011) and Langness et al. (2014) demonstrated that green sturgeon are present in the Umpqua River estuary during spring, summer, and early fall months, but are absent from the estuary by late fall/early winter through late winter/early spring (i.e., all had returned to the ocean). Moser and Lindley (2007) demonstrated this species occurs in Willapa Bay in the summer when estuarine water temperatures exceeded coastal waters by at least 2^{o}C. Erickson et al. (2002) also showed that green sturgeon departed the Rogue River during late fall/early winter when river temperatures fell below 10^{o}C. Erickson et al. (2013) suggested that as temperatures fall in the estuary, green sturgeon may shift to the warmer ocean waters to continue feeding in habitat that is influenced by the Umpqua River. Results of this study support this hypothesis, as adult green sturgeon were observed to migrate between the ocean array and the Umpqua river estuary seasonally.

Huff et al. (2011) showed that green sturgeon were associated with high relief habitat. Although this may be true in areas of high relief, this study demonstrated that green sturgeon are also associated with flat, soft bottom habitat that lacks high relief habitat. Our results are supported by Henkel (2011), who showed that substrate in the area of this study is comprised of sand (i.e., < 2% silt/clay) shallower than 62 m and a mixture of silt/clay at deeper depths (i.e., 2-53% silt/clay). The area in the immediate proximity of acoustic receivers did not show any high relief or rock.

Although this area of the planned OPT wave energy project was shown to be important for green sturgeon, results demonstrated seasonal depth patterns that may have been useful for constructing and operating the project while minimizing potential impacts to green sturgeon, had the project moved forward. For example, green sturgeon in this area tended to be present in deeper waters (> 70 m) only during spring months. These depths were largely unoccupied by green sturgeon during the remaining months. Seasonal depth distributions have been shown for other sturgeons. Erickson et al. (2011) showed that Atlantic sturgeon were typically found deeper than 20 m during winter, and shallower than 20 m during the summer and early fall.

The OPT wave energy project will not be completed at this location. Nonetheless, this study produced several outcomes that may be useful when planning other potential ocean-energy sites in the nearshore marine environment. These outcomes include (1) nearshore marine areas (< 110 m), near estuaries and bays used by green sturgeon, may represent important marine habitat for green sturgeon (e.g., for feeding and staging), (2) southern and northern DPS green sturgeon may mix at these potential marine concentration sites, and (3) abundance and depth-distributions of green sturgeon present at these potential concentration sites may display seasonal patterns.

Original Questions: Referring back to the original questions asked in the pre-proposal for this study, we find that *Question 1*, about timing, location and depth distribution of sturgeon movements, has been thoroughly answered. We do not yet understand the fine details of sturgeon behavior, but this study makes a significant contribution to the research to date. *Question 2*, about the impacts of a wave energy site, can only be answered after a wave energy project is built. This study produced baseline data that can be used as a "before" dataset if another wave energy site is proposed and built at this location. *Question 3*, about other species, cannot be answered in any detail simply because there were very few other individuals of other species tagged in the vicinity during the array, or we were unable to identify tags that belonged to other researchers without their cooperation.

Unanswered Questions: Numerous questions have yet to be answered with this database. Further analyses, some in collaboration with the research groups who tagged the sturgeon, may be necessary to fully understand differences in habitat use between adults and subadults, "residents" and "migratory fish", and northern DPS versus southern DPS groups. Some of these additional analyses will be reported in a scientific publication.

6. SUMMARY OF SOME RESULTS

- Green sturgeon were detected on 492 out of 515 days (95.5%) by the ocean array of VR2W receivers.

- The array detected 248 of 770 (32%) of the green sturgeon that presumably had functioning tags, all within a relatively short timeframe of a year and a half. The true proportion detected is likely higher because 1) some of the tag codes that we detected are still not identified, and may belong to green sturgeon, and 2) some of the tags that are counted in the total as functioning probably had failed or fallen off prior to this study, or some fish may have died prior to this study and were never detected. Lindley et al. (2008) estimated annual mortality of tagged green sturgeon (including tag loss, tagging-induced mortality, and emigration) at 17%. Langness et al. (2014) estimated annual mortality of 16% using mark-recapture methods.

- Green sturgeon were detected on all receivers, from approximately 12 m depth to 110 meters, which confirms the appropriateness of the ESA Critical Habitat designation (FR 2009). Peak detections occurred at middle depths of 50-70 meters, which is similar to results of previous research (Erickson and Hightower, 2007; Huff et al., 2011).

- This is the first study to demonstrate seasonal patterns of habitat use by green sturgeon in the ocean near the Umpqua River estuary. For example, green sturgeon in this area tended to be present in deeper waters (> 70 m) only during spring months (Figure 4.11). These depths were largely unoccupied by green sturgeon during the remaining months.

- Some detection patterns shown in Figure 4.16 and Figure 4.17 are suggestive of green sturgeon migrating rapidly through the area. Potential migration corridors for green sturgeon were first described by Erickson and Hightower (2007), and discussed in relation to the OPT wave energy site by Erickson et al. (2013). Lindley et al. (2008) provided more detail regarding annual oceanic migrations for green sturgeon. Our results confirm that the OPT wave energy project would have been constructed near the center of the green sturgeon migration corridor.

- Detection patterns show that numerous green sturgeon are not simply passing through the area during migration, but instead are utilizing this area over a long period of time (Figure 4.17). This supports the hypotheses by Erickson et al. (2013) that this area may represent an extension of the Umpqua River estuary habitat and is therefore utilized extensively by green sturgeon. Lindley et al. (2008) and Erickson and Hightower (2007) also hypothesized that certain nearshore oceanic habitat may be important green sturgeon concentration sites (e.g., for feeding).

- The lack of pattern for north/south migration shown in Figure 4.21 further supports the hypothesis of extended use of this concentration site for green sturgeon. Although some individuals clearly migrate through this area rapidly (Figure 4.16), the seasonal-directional migration of a few individuals is likely obscured by the numerous individuals that occupy the area for extended periods of time (see Figure 4.21). Data suggest that there could be both seasonal "residents" and "migratory" groups of green sturgeon that occupy this area off of the Umpqua River estuary (Figure 4.16, Figure 4.17, Figure 4.18). Additional analyses are needed with project collaborators to better understand habitat use by these different groups of fish.

- Lindley et al. (2011) and Langness et al. (2014) demonstrated that green sturgeon utilize the Umpqua River estuary during the late spring, summer, and early fall. This study, by combining data provided from Langness et al. (2014), confirmed this seasonal estuary use.

- Our review of data from the present study and other sources (e.g., Langness et al., 2014) is the first to demonstrate extensive use of specific oceanic and estuarine sites by individual green sturgeon.
    - Most tagged individuals that were detected by the ocean array (N = 248) never entered the estuary (N = 212). Some of these individuals remained in the area of the ocean receivers for a long period of time, whereas others traveled through the area quickly.
    - Some individuals (N = 36) migrated between the nearshore ocean array and the estuary array seasonally.
    - Twenty one green sturgeon were detected by the estuary array but not detected by the ocean array. The main array was well north of the river mouth. Even though we stationed two receivers near the river mouth during part of the study, only one of the two functioned properly throughout the study. The sturgeon detected in the estuary but not by the ocean array may have migrated from the south and entered the estuary before reaching the main ocean array of acoustic receivers. These individuals may have then traveled south immediately after leaving the estuary. Alternatively, these individuals may have passed through or near the array but were never detected (e.g., during stormy conditions or at shallow depths near the surf).
    - Most of the individuals that were detected in the estuary were > 140 cm TL (N = 52). Only five (10%) were considered subadults (i.e., < 140 cm TL). Langness et al. (2014) captured 34 green sturgeon in the Umpqua River estuary, of which 13 (38%) were < 140 cm TL (using a conversion of 1.09xFL as described by Rien et al., (2000)).

  - Only four of 71 subadults that were detected on the ocean array entered the estuary. Of the 16 subadults that were detected for periods of one week or more on the ocean array, only one entered the estuary.

- Nine great white shark were detected by the array at a variety of depths. Two white sturgeon were detected at 60 – 80 m (Figure 4.14).

7. LESSONS LEARNED

The study was carried out on an extremely tight budget and required strong collaborations with other researchers. Nearly half (30/64) of the receivers for the study were borrowed from other researchers, as were other equipment. All green sturgeon were tagged by other researchers for different research projects. The largest expense category for the project was vessel charter, which required about 66% of the budget. This project would not have been possible without the strong collaborations and cooperation from others (see Acknowledgements).

In order to minimize the number of days needed for vessel charter, the study used a mooring design with surface floats. Other long-term studies have relied on more advanced Vemco VR3 and VR4 receivers that can communicate via acoustic modem with a surface vessel, or VR2s on subsurface moorings with acoustic releases, and the loss rate on those receivers is typically low since there are no surface components. However, VR3 and VR4 receivers cost more than 5 times as much as the Vemco VR2W receivers used for this study ($8,000 each, vs. $1,500 each). The tradeoff is that it is very difficult to retrieve data from moorings that don't have surface floats, especially in deep water. Acoustic releases were also considered for this study as a way to retrieve data without requiring a surface float, but releases with long-lived batteries currently cost at least $2,500 each and were not affordable.

The use of moorings with surface floats was a calculated risk that was required by budgetary limits. The moorings had a nearly perfect record for 8 months. Unfortunately, despite substantial efforts to communicate with local ocean users and efforts to frequently check the array and clean buoy lines, numerous receivers were lost during at least two major episodes. The loss of receivers may be attributed to many causes that could include vessels inadvertently dragging the gear out of position and into deeper depths (e.g., on outrigger), barge traffic, floating kelp beds or other debris, and sabotage (e.g., someone upset about losing gear that may be snagged on the floats). Those episodes proved costly in funds needed to replace equipment, but the loss of data may be even more significant. Ironically, efforts to make the receivers more conspicuous and easier to locate backfired, because the only receivers that were spared in the final episode of a large loss were those that lacked radar reflectors and flags.

Finding missing receivers is a high-risk, high-cost endeavor, and budgeting appropriately for retrieval of missing receivers is difficult. In this study, detections of fixed transmitters by adjacent receivers suggest that at least some of the receivers were still in position when the study ended, and the data on those receivers would still be intact if that is the case.

The array design and the maintenance schedule both proved to be appropriate to the task at hand. The shallowest receivers (around 12 m) were almost in the surf line and had short riser lines and fewer, smaller floats. They had to be watched closely and tended to be more heavily fouled by algae and other growth.

The project would not have been nearly as successful without Captain Al Pazar, a local fisherman who was highly skilled at designing and maintaining gear, had detailed local knowledge and a genuine interest in the science, and did everything in his power to make the project a success. It also proved helpful to have discussed and negotiated the entire maintenance schedule in advance, despite the frequent need for flexibility in dealing with weather, tides, equipment failure, commercial fishing schedules, boat availability, and many other contingencies.

The pilot project was a useful step for testing the mooring design and calibrating expectations for detection rates and distances.

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