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Occurrence of green sturgeon in Puget Sound and the Strait of Juan De Fuca: A review of acoustic detection data collected from 2002 to 2019

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14. ABSTRACT
Information on green sturgeon occurrence in Puget Sound and the Strait of Juan de Fuca is needed to ensure that potentially harmful human actions do not impact this species, particularly the southern distinct population segment (DPS), which is listed as threatened under the U.S. Endangered Species Act. We reviewed acoustic detection data from 2002 to 2019 for incidence of acoustically tagged green sturgeon in these areas. Acoustic receiver coverage expanded in Puget Sound from 2002 to 2008, at the same time that 350 acoustically tagged green sturgeon of known origin were at large (67% from the southern DPS). During this time, 17 green sturgeon were detected in Puget Sound: 4 from the southern DPS, 12 from the northern DPS and 1 of unknown origin. After 2008, no green sturgeon were detected on central or southern Puget Sound receiver lines, even though over 400 tagged sturgeon of known origin were at large (83% from the southern DPS). However, at Admiralty Inlet (northern Puget Sound), 6 green sturgeon were detected during 2013-2018: 4 from the northern DPS, 1 from the southern DPS and 1 of unknown origin.

A receiver line was operated at the Strait of Juan de Fuca starting in 2004, and by 2019, 210 green sturgeon had been detected at this line. Of these fish, 97 were identified as southern DPS, 39 as northern DPS, and the remaining fish were of unknown origin. That is, of the known-origin green sturgeon detected at the Strait of Juan de Fuca line, 71% were members of the southern DPS. These data indicated that green sturgeon use the Strait of Juan de Fuca as a corridor, residing at receiver sites for relatively short periods as they pass through the strait. Few of these fish were detected subsequently at Admiralty Inlet, suggesting that most of the acoustically tagged population move

northward into the Strait of Georgia after transiting the Strait of Juan de Fuca.
Acoustic detection data indicated that green sturgeon from both the northern and southern DPSs can occur in Puget Sound and at Admiralty Inlet, but at low rates relative to their presence in the Strait of Juan de Fuca. Our results support the decision by NOAA Fisheries to designate the Strait of Juan de Fuca as an area of high conservation value for southern DPS green sturgeon. These results also confirm earlier findings that Puget Sound is of lower conservation value to southern DPS green sturgeon, based on the lower rate of detections in this area. However, these data have implicit biases associated with receiver placement and origin of the tagged population. To address these concerns, tagging of green sturgeon captured in Puget Sound or the Strait of Juan de Fuca, along with genetic sampling for DPS determination, could increase sample sizes and help resolve patterns of spatial and temporal habitat use in these important areas.

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Executive Summary

Information on green sturgeon occurrence in Puget Sound and the Strait of Juan de Fuca is needed to ensure that potentially harmful human actions do not impact this species, particularly the southern distinct population segment (DPS), which is listed as threatened under the U.S. Endangered Species Act. We reviewed acoustic detection data from 2002 to 2019 for incidence of acoustically tagged green sturgeon in these areas.

Acoustic receiver coverage expanded in Puget Sound from 2002 to 2008, at the same time that 350 acoustically tagged green sturgeon of known origin were at large (67% from the southern DPS). During this time, 17 green sturgeon were detected in Puget Sound: 4 from the southern DPS, 12 from the northern DPS and 1 of unknown origin. After 2008, no green sturgeon were detected on central or southern Puget Sound receiver lines, even though over 400 tagged sturgeon of known origin were at large (83% from the southern DPS). However, at Admiralty Inlet (northern Puget Sound), 6 green sturgeon were detected during 2013-2018: 4 from the northern DPS, 1 from the southern DPS and 1 of unknown origin.

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Acoustic detection data indicated that green sturgeon from both the northern and southern DPSs can occur in Puget Sound and at Admiralty Inlet, but at low rates relative to their presence in the Strait of Juan de Fuca. Our results support the decision by NOAA Fisheries to designate the Strait of Juan de Fuca as an area of high conservation value for southern DPS green sturgeon. These results also confirm earlier findings that Puget Sound is of lower conservation value to southern DPS green sturgeon, based on the lower rate of detections in this area. However, these data have implicit biases associated with receiver placement and origin of the tagged population. To address these concerns, tagging of green sturgeon captured in Puget Sound or the Strait of Juan de Fuca, along with genetic sampling for DPS determination, could increase sample sizes and help resolve patterns of spatial and temporal habitat use in these important areas.

Contents

Introduction

The southern distinct population segment (sDPS) of green sturgeon *Acipenser medirostris* is listed as *threatened* under the U.S. Endangered Species Act (ESA; Adams et al. 2007). Efforts to designate and protect critical green sturgeon habitat highlight the lack of information regarding its use of Puget Sound and the Strait of Juan de Fuca. Green sturgeon from the sDPS spawn in the Sacramento River drainage and sub-adults and adults aggregate in Washington estuaries (e.g., Columbia River, Willapa Bay, Grays Harbor) in summer (Moser et al. 2016; Borin et al. 2019). However, the relative importance to green sturgeon of Puget Sound and its surrounding areas is unknown.

Sturgeon apparently use estuaries to "recharge" after coastal migrations, but may also simply hold in these relatively predator-free and physiologically benign zones (Moser and Lindley 2007). Unlike many Washington estuaries, Puget Sound is a very large (650,000 ha) fjord-like system with multiple river inputs and lengthy water retention times relative to the open ocean. Several dense human population centers in the Puget Sound area contribute to degraded water and sediment quality (Myers et al. 1998). Nevertheless, some areas of the sound are sparsely populated, experience regular flushing, and receive relatively little pollution. The duration of green sturgeon exposure to Puget Sound waters and sediments is unknown.

Green sturgeon is potentially affected by a host of human activities, such as dredging, blasting, sand mining, oyster and clam culture, and proliferation of invasive plants (Moser et al. 2016). To minimize the effects of these activities, managers need basic information on the occurrence and distribution of this species in Puget Sound and the surrounding area. Due to the apparent lack of spawning by green sturgeon in tributaries to Puget Sound, adult and subadult green sturgeon are the only life stages likely to be affected by these activities.

The U.S. National Marine Fisheries Service (NOAA Fisheries) is responsible for managing threatened and endangered fish species in Pacific Northwest waters and reviewing U.S. Navy permit applications under the ESA. The U.S. Navy conducts training and testing in Pacific Northwest range areas to prepare combat-ready military forces. Both agencies share the common goal of minimizing impacts to imperiled species without compromising training and testing efforts.

The objective of this study was to provide data on the occurrence and distribution of green sturgeon in Puget Sound and the Strait of Juan de Fuca. This information is needed by managers for assessment of human impacts to this threatened species. For example, these data serve as a foundation for the analysis of trade-offs between the need for U.S. Navy training and testing and conservation measures for green sturgeon populations. To avoid harmful impacts to green sturgeon during human activities, information on the spatial and temporal occurrence of this species in Puget Sound and the Strait of Juan de Fuca is essential.

Detections of acoustic transmitters (tags) implanted in adult and subadult green sturgeon have been used to map their migrations along the West Coast (e.g., Lindley et al. 2008). Acoustic tag detection data can provide the basis for estimates of the relative importance of a given area to these fish, based on the percentage of tagged fish detected in that area (e.g., Borin et al. 2017). This type of information was key to the designation of critical habitat for green sturgeon from the southern DPS (NMFS 2009). Hence, it is critical that a representative group of green sturgeon is tagged.

Over the last 18 years, hundreds of green sturgeon have been implanted with acoustic transmitters that could potentially be detected by receiver arrays in Puget Sound and the Strait of Juan de Fuca. Beginning in 2002, over 350 adult and sub-adult green sturgeon were tagged in their natal rivers (Sacramento and Klamath rivers in California and the Rogue river in Oregon) and in Washington estuaries with long-lived transmitters (~5 years; 69 kHz). Detections of these fish allowed documentation of movement and distribution (Lindley et al. 2008, 2011). In 2011, a second large group of longer-lived transmitters (~8 years) was used to tag green sturgeon occupying Oregon and Washington estuaries to document habitat use and population composition (Schreier et al. 2016). Meanwhile, green sturgeon from the southern DPS were regularly tagged in the Sacramento River Basin to document movement patterns and spawning periodicity (e.g., Kelly et al. 2007, Heublein et al. 2009, Seesholtz et al. 2015).

Acoustic receiver arrays in the Puget Sound area have primarily been used to evaluate movement and survival of salmonids. While not specifically designed to track sturgeon, these arrays have the capacity to detect green sturgeon in Puget Sound and the Strait of Juan de Fuca, providing occurrence and distribution data. Our principal objective was to mine these valuable datasets for opportunistic green sturgeon detections.

In its *Critical Habitat Designation for Southern Distinct Population Segment of North American Green Sturgeon* (NMFS 2009), NOAA Fisheries concluded that Puget Sound was of moderate importance to these fish, but that they occur regularly in the Strait of Juan de Fuca. Using opportunistic detections of green sturgeon in Puget Sound and the Strait of Juan de Fuca, we tested these conclusions. We hypothesized that the green sturgeon Southern DPS does not use Puget Sound to a large extent, but relies on the Strait of Juan de Fuca as an important migratory route to and from overwintering areas.

Methods

In 2002, NOAA Fisheries began tagging green sturgeon in collaboration with other agencies. All green sturgeon transmitter codes from this work were available to us, along with their associated metadata (e.g., length, sex, DPS). A number of other agencies have tagged additional green sturgeon that could occur in Puget Sound.

To ensure that all detections of acoustically tagged sturgeon were included in our collection, we searched two existing databases that collate acoustic detections in the region: the Ocean Tracking Network,[1] and the Hydra database.[2] We collaborated with other sturgeon researchers from Canada to California to ensure that the working list of unique green sturgeon tag codes was as complete as possible.

Hydra Database

We queried the Hydra database on 12 May 2020 for detections of 306 green sturgeon that had been acoustically tagged during 2002-2008.[3] The resulting 1,048,576 records were downloaded in csv format. Mapping of these detection data from Hydra indicated that all receiver sites in the study area were located within a bounding box of 47.17 to 47.95°N and -122.30 to -122.84°W. Hence, all detection data were filtered for detections falling within this area. The resulting 507,696 detection records were from 39 unique transmitter codes.

There were also a number of detection records lacking geocoordinates (latitude and longitude). We contacted the Hydra database manager to see if these records could be ascribed to a receiver site in some other way (Jennifer Scheuerell, Sound Data, personal communication). In addition, we reviewed historic email correspondence to the authors from receiver operators in Puget Sound to obtain detection data that were: 1) obtained prior to the start date for Hydra or Ocean Tracking Network (see below), 2) obtained from researchers that did not share data on either database, or 3) were mobile tracking records not included in the databases. This exercise yielded 131 additional detection records, but no new codes.

[1] Available from oceantrackingnetwork.org
[2] Available from hydra3.sound-data.com
[3] GreenSturgeon2002-2008PacificEstuary project

Of the unique codes used to tag green sturgeon, 14 were detected in Puget Sound only once. These were likely spurious detections and were omitted (Pincock 2012, Simpfendorfer et al. 2015). The next step was to confirm that the remaining codes were indeed green sturgeon tags. Duplicate codes, or detections of the same code used on two different fish in the same time period, were identified by Hydra. Most code duplicates were used by only one other project, and the manager of this project provided tagging data for his code duplicates (Kelly Andrews, NOAA Fisheries, personal communication).

Most duplicate transmitter codes were implanted in sedentary species that tend to remain near the areas where they were tagged (e.g., lingcod *Ophiodon elongatus* and copper rockfish *Sebastes caurinus*; Tolimieri et al. 2009). Indeed, three of the code duplicates were determined to be lingcod, and six were fixed "beacon" transmitters. These codes were censored from the database.

Of the remaining duplicate codes, three were used on bluntnose sixgill sharks *Hexanchus griseus* (Williams et al. 2010). Detection data for these codes required case-by-case examination to determine whether the species could be identified. Some duplicate code detections were confirmed as green sturgeon based on tagging date. For example, in one case a green sturgeon code was detected before the tag code was used on a shark in October 2007.

Three tag codes used on both green sturgeon and sharks were detected in 2008 while monitoring English sole *Parophrys vetulus* in Eagle Harbor (Moser et al. 2013). We decided that these were probably sixgill shark detections. This determination was based on the short time between shark tagging in Puget Sound and detections on the Eagle Harbor array, not far from the tagging site. These data were censored, although they could have been green sturgeon.

The remaining codes were sent to the tag manufacturer to confirm that they were unique to green sturgeon and had not been used on other species occurring in Puget Sound during this period (Matthew Holland, InnovaSea, formerly Vemco, personal communication). After reviewing our request, the tag manufacturer was able to confirm that all but three of the transmitter codes were unique to green sturgeon (Colleen Burliuk and Courtney MacSween, InnovSea, personal communication). We were unable to obtain any information from the researchers who had used the three unconfirmed codes. Detections of the remaining putative green sturgeon codes were included for analysis of spatial and temporal patterns of occurrence (see Tables 1 and 2).

On 8 September 2020, we obtained permission to access Hydra detection data for green sturgeon originally tagged by researchers at the University of California, Davis (A. Peter Klimley, UC Davis, retired, personal communication) and their collaborators at the Oregon Department of Fish and Wildlife (Ryan Battleson, ODFW, personal communication). These detection data were downloaded for the period ranging 1 January 2002-1 January 2011 and yielded 84,466 records for the 107 green sturgeon tagged in this study (records coded GS-UCDavis-Heublein in Hydra).

Table 1a. Acoustic-tagged green sturgeon detected repeatedly in Puget Sound. Release date (in chronological order) and location, distinct population segment (DPS northern, southern, or unknown) are shown with number of detections (hits) and first and last detection date by location (no last date indicates a fish was detected only on a single day).

	Release		DPS	Hits	Detection location		Detection date	
Code	Date	Location	(N/S/U)	(n)	Latitude (°N)	Longitude (°W)	First	Last
GUIL1041	12 Apr 2003	Klamath	N	4	48.4577	-122.702	14 Nov 2003	19 Nov 2003[a]
				14	48.4574	-122.699	25 Nov 2003	6 Jan 2004[a]
				413	47.6077	-122.344	15 Aug 2006	18 Aug 2006
GUIL1034	16 Apr 2003	Klamath	N	459	48.4699	-122.700	13 Dec 2003	19 Dec 2003
				3	48.4699	-122.700	6 Jan 2004	
				13	47.8769	-122.337	26 Sep 2005	
				18	47.7452	-122.385	26 Sep 2005	
				3	47.6945	-122.4097	27 Sep 2005	
				33	47.6633	-122.436	27 Sep 2005	
				76	47.7085	-122.518	27 Sep 2005	
				54	47.7095	-122.52215	27 Sep 2005	
				104	47.5296	-122.481	30 Sep 2005	1 Oct 2005
				9	47.5726	-122.422	4 Oct 2005	
				6	47.5978	-122.384	4 Oct 2005	
				26	47.6633	-122.436	5 Oct 2005	
				18	47.7452	-122.385	5 Oct 2005	
				24	47.8769	-122.337	6 Oct 2005	
MOSER1134	13 Jul 2004	Columbia	U	18	47.7488	-122.4663	14 Oct 2006	
				21	48.03082	-122.63593	15 Jun 2007	16 Jun 2007
				145	47.86393	-122.63163	17 Jun 2007[b]	
				349	47.85837	-122.62162	19 Jun 2007[b]	
				317	47.85626	-122.61788	20 Jun 2007[b]	
				239	47.85983	-122.62445	21 Jun 2007[b]	
				107	47.86393	-122.63163	17 Jun 2007	9 Jul 2007[b]
				307	47.90791	-122.62687	10 Jul 2007[b]	

Table 1a. Continued.

	Release		DPS	Hits	Detection location		Detection date	
Code	Date	Location	(N/S/U)	(n)	Latitude (°N)	Longitude (°W)	First	Last
MOSER1195	31 Aug 2005	Grays Harbor	N	54	47.6645	-122.4379	18 May 2006	21 May 2006[b]
				99	47.528	-122.4038	19 May 2006[b]	
				55	47.124	-122.348	20 May 2006[b]	
				161	47.6946	-122.4099	21 May 2006[a]	
				13	47.8968	-122.385	2 Nov 2006	
				9	47.74875	-122.4662	5 Nov 2006	
				24	47.6633	-122.4364	5 Nov 2006	
				24	47.66467	-122.49527	5 Nov 2006	
				9	47.5864	-122.4765	6 Nov 2006	
				39	47.5759	-122.451	7 Nov 2006	
				38	47.528	-122.4038	8 Nov 2006	
				11	47.59738	-122.38295	9 Nov 2006	
				36	47.66537	-122.44477	10 Nov 2006	
				41	47.6946	-122.4099	10 Nov 2006	
				107	47.8968	-122.385	18 Nov 2006	

[a] Detections at this site included single hits on days that were separated by more than 24 h during the specified period.
[b] Many detections were recorded on individual receivers in this array. Only continuous records for dominant receivers are given.

Table 1b. Discontinuous detections of acoustic-tagged green sturgeon in Puget Sound (Hydra). Release date (in chronological order) and location are shown with distinct population segment (DPS) as northern, southern or unknown; total detections (hits); and first and last date of detection at each location (no last date indicates a single day).

Code	Release Date	Release Location	DPS (N/S/U)	Hits (n)	Detection location Latitude (°N)	Detection location Longitude (°W)	Detection date First	Detection date Last
KLIM257	13 May 2002	Klamath	N	1	48.4577	-122.702	17 Nov 2003[b]	
					47.7004	-122.579	17 Aug 2005[c]	
					47.6619	-122.465	4 Jun 2006[b]	
					47.62560	-122.3752	19 Jun 2008[b]	
YUROK513	26 May 2002	Klamath	N	4	47.9082	-122.438	19 Dec 2005	15 Feb 2006[d]
GUIL1029	10 Apr 2003	Klamath	N	3	48.4577	-122.702	13 Nov 2003[a]	
GUIL1044	14 Apr 2003	Klamath	N	4	48.4577	-122.702	15 Nov 2003[b]	
				18	48.4574	-122.699	25 Nov 2003	15 Jan 2004[b]
GUIL1028	24 Apr 2003	Klamath	N	6	48.4577	-122.702	13 Nov 2003[a]	
GUIL1026	6 May 2003	Klamath	N	5	48.4577	-122.702	13 Nov 2003[a]	
GUIL1043	14 May 2003	Klamath	N	4	48.4577	-122.702	20 Nov 2003	23 Nov 2003[b]
				21	48.4574	-122.699	27 Nov 2003	14 Jan 2004[b]
MOSER1052	26 Aug 2003	Willapa Bay	S	5	47.9082	-122.438	6 Mar 2009	11 May 2009[b]
				7	47.90647	-122.43262	16 Mar 2009	26 May 2009[b]
ERKSN1057	6 Oct 2003	Rogue	N	2	47.90688	-122.43549	5 Apr 2009	3 May 2009[b]
				2	47.9082	-122.438	25 Apr 2009	15 May 2009[b]
				2	47.90647	-122.43262	26 Apr 2009	31 May 2009[b]
YUROK529	4 Jun 2004	Klamath	N	9	47.4372	-123.119	6 Sep 2008	3 Jan 2009[d]
KLIM984	8 Sep 2004	Sacramento	S	4	47.9082	-122.438	1 Jan 2006	22 Feb 2006
KLIM986	10 Aug 2004	Sacramento	S	2	47.9082	-122.438	5 Jan 2006	16 Jan 2006
KLIM230	14 Jul 2006	Sacramento	S	1	47.9082	-122.438	21 Feb 2009[b]	
				1	47.90647	-122.43262	13 Mar 2009[b]	
				1	47.90688	-122.43549	28 Mar 2009[b]	

a Consecutive detections for each tag code (hits) were of short duration.
b Less than two hits in 24 h on the same receiver and in the same time period.
c Less than two hits in 24 h on the same receiver but supported by mobile tracking detections in the same area.
d Duplicate tag codes were used in this time period, and receivers had less than two hits in one 24-h period.

Table 2. Acoustic transmitter codes from tagged green sturgeon detected near Admiralty Inlet (Ocean Tracking Network). Release date and location are shown with distinct population segment (DPS) as northern, southern, or unknown; number of detections (hits); detection location; and first and last detection date.

Acoustic tag	Release		DPS	Hits	Detection location		Detection date	
code	Date	Location	(N/S/U)	(n)	Latitude (°N)	Longitude (°W)	First	Last
Admiralty Inlet								
DION28689	7 Jul 2012	Columbia	N	65	48.0731	-122.633	29 Jul 2016	30 Jul 2016
DION28701	16 Jul 2012	Grays Harbor	N	9	48.59568	-122.73	13 Mar 2013	
DION28708	16 Jul 2012	Grays Harbor	N	60	48.073	-122.655	19 Aug 2015	
DION28714	17 Jul 2012	Grays Harbor	N	17	48.60028	-122.831	23 May 2013	25 May 2013
KLIM34010	19 Apr 2012	Sacramento	S	156	48.07318	-122.65	3 May 2013	5 May 2013
DION28744	11 Sep 2012	Columbia	U	47	48.0699	-122.645	21 Feb 2018	
Lime Kiln State Park								
DION47109	16 Jul 2011	Willapa Bay	U	89	48.51571	-123.153	1 Jul 2013	4 Jul 2013

When screened for receiver sites in the study area (as above), the dataset collapsed to only 11 records of six unique transmitters. Four of these transmitters had only one detection, but the remaining two were detected multiple times in the same space and time. These codes were sent to the tag manufacturer on 9 September 2002 to confirm that they were used only with green sturgeon (Colleen Burliuk, InnovaSea, personal communication).

This dataset also had a large number of detections (n = 5,766) at sites without location information (n = 23). Sites within the dataset were filtered for those with multiple detections and added to the list sent to the Hydra database manager for a total of 31 sites with green sturgeon detections of unknown latitude and longitude. We asked for help from Hydra in updating the list and determining location information for these sites. We received a list of receiver operators, all of whom operated outside of our study area (California; Jennifer Scheuerell, Sound Data, personal communication).

Ocean Tracking Network database

In order to access green sturgeon detection data from the Ocean Tracking Network (OTN) database, we obtained permission from the researchers who had uploaded tag data to their individual projects within the database. Projects were organized by collection code within the Ocean Tracking Network database. We began contacting these researchers on 13 May 2020.

In addition, we obtained assistance in retrieving a map of receiver deployments (Kolten Ollom, NOAA Fisheries Veteran's Conservation Corps, personal communication). This map was needed to determine whether Ocean Tracking Network detection data existed beyond what was available from detection data obtained from NOAA Fisheries researchers operating in our study area (Megan Moore, Kelly Andrews, and Anna Kagley, NOAA Fisheries, personal communication).

Sturgeon detection data for each of the collection codes from the Ocean Tracking Network were downloaded and sorted by station. Detections from station codes (e.g., JDF, MMS, and BOOONC) in the study area (47.00 to 49.00°N and -122.25 to -124.00°W) were placed in a separate file, and individual code detections were added to a master list provided by a researcher who had screened Puget Sound databases in November 2018 (Megan Moore, NOAA Fisheries, personal communication).

This initial screening in 2018 had detected 62 individual green sturgeon on receivers deployed in the Strait of Juan de Fuca during October 2012-2014 and two green sturgeon at Admiralty Inlet during August 2014-February 2019. However, the complete time series of detection data had not been accessible for this screening. Many more putative green sturgeon codes were identified in the process of screening individual collection code data.

We submitted a request to Ocean Tracking Network for help in summarizing all green sturgeon data in the entire study area (47.00 to 49.00°N and -122.25 to -124.00°W) on 6 August 2020. This was done to ensure that all detections for all receivers deployed in the study area were included in the final database and to allow cross-checking with the collection-code screening described above.

Data summaries from Ocean Tracking Network were received on 2 September 2020 and were compared to summary data identified from searching records by collection code. The Ocean Tracking Network data included three green sturgeon detected in the Strait of Juan de Fuca that had not been identified during collection code screening. Detection data from these transmitter codes were included in the master database.

A total of 113 transmitter codes were identified in both datasets, with 102 that were detected only during collection-code screening. These were not included in the summary from Ocean Tracking Network, likely due to buffers automatically set by OTN algorithms (Naomi Tress, Ocean Tracking Network, personal communication). Hence, each of these discrepancies was scrutinized before inclusion in the summary data.

Summary data in Tables 1-4 were compiled by grouping detection histories of an individual tag code in a specific area (e.g., Strait of Juan de Fuca receiver line, JDF). Separate blocks of data were defined by gaps in the detection record of at least 24 h (exceptions in Table 1b). For each transmitter code representing an individual green sturgeon, time and location of the first detection for each block were listed, along with the total number of detections (hits) of that transmitter code (Tables 1-4). These data provided information on the length of time a fish was within range of these receivers, whether it returned to this area, and if so, how frequently.

Information on the distinct population segment (DPS) of each sturgeon (if known) and the time and general location at release were also compiled (Table 5). Any green sturgeon tagged in a natal river was assumed to be from the DPS of that river. For example, the Northern DPS was assumed for fish tagged in the Rogue or Klamath River, while the Southern DPS was assumed for fish tagged in the Sacramento River. All fish captured in estuaries with unknown natal river were fin-clipped, and some were later identified to DPS using genetic methods (Schreier et al. 2016).

Table 3. Green sturgeon tagged with acoustic tags and detected in the Strait of Juan de Fuca (Ocean Tracking Network). For each tag code representing a green sturgeon, the distinct population segment (DPS) is shown (N, northern; S, southern; U, unknown), along with release date (in chronological order) and location, date and time of first detection, number of individual transmissions detected (hits), water depth at detection site, and detection location coordinates.

	DPS	Release		First detection		Hits	Bottom	Detection location	
Tag code	(N/S/U)	Date	Location	Date	Time	(n)	depth (m)	Latitude (°N)	Longitude (°W)
ERKSN100	N	28 May 2002	Rogue	30 Aug 2004	0942	61	208	48.30027	-124.01153
GUIL1034	S	16 Apr 2003	Sacramento	11 Jun 2004	0913	266	189	48.27874	-124.03619
MOSER1104	U	27 Aug 2003	Willapa Bay	12 May 2006	0640	26	150	48.33335	-123.97295
MOSER1121	S	28 Aug 2003	Willapa Bay	13 Aug 2005	2035	39	196	48.27183	-124.03697
ERKSN1075	N	8 Oct 2003	Rogue	14 Jul 2004	0219	145	190	48.29309	-124.01953
LIND891	S	19 Apr 2004	Sacramento	19 Dec 2004	2031	49	138	48.36395	-123.93322
LIND901	S	17 May 2004	Sacramento	18 Jun 2005	0120	51	134	48.34442	-123.96383
MOSER1113	U	9 Jun 2004	Willapa Bay	3 Nov 2007	1739	10	135.3	48.22933	-124.10517
MOSER1130	U	22 Jun 2004	Columbia	20 Oct 2007	2128	209	60.4	48.224	-124.11197
MOSER1141	U	29 Jun 2004	Willapa Bay	24 Oct 2004	2232	5	138	48.36395	-123.93322
MOSER1138	U	30 Jun 2004	Willapa Bay	23 Feb 2007	0630	614	135.3	48.22933	-124.10517
MOSER1148	U	30 Jun 2004	Willapa Bay	26 May 2005	0129	16	166	48.32478	-123.98114
MOSER1134	U	13 Jul 2004	Columbia	29 Sep 2006	2003	199	182.9	48.26507	-124.06977
MOSER1149	S	14 Jul 2004	Columbia	4 Jun 2005	1435	10	136	48.37535	-124.58175
LIND909	S	8 Aug 2004	Sacramento	24 May 2007	0612	39	150	48.23426	-124.09857
LIND913	S	8 Aug 2004	Sacramento	12 Jun 2007	0402	25	47.5	48.37334	-123.92152
LIND986	S	10 Aug 2004	Sacramento	12 Nov 2007	0047	63	150	48.23957	-124.09203
LIND992	S	15 Aug 2004	Sacramento	24 Jun 2005	2109	31	196	48.27183	-124.03697
LIND993	S	24 Aug 2004	Sacramento	8 Aug 2005	2350	44	177	48.24835	-124.06632
LIND1009	S	28 Aug 2004	Sacramento	4 Mar 2007	1256	55	181.1	48.27039	-124.0527
LIND996	S	29 Aug 2004	Sacramento	10 Apr 2008	0124	12	135.3	48.22933	-124.10517
LIND997	S	29 Aug 2004	Sacramento	9 Apr 2007	1114	103	188.4	48.29625	-124.0201
LIND998	S	1 Sep 2004	Sacramento	10 Apr 2007	0703	13	150	48.23957	-124.09203
YRK533	N	27 Apr 2005	Klamath	8 Jan 2008	2325	139	177.4	48.31483	-123.6565

Table 3. Continued.

Tag code	DPS (N/S/U)	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
LIND1006	S	1 May 2005	Sacramento	8 Aug 2007	0626	84	102.4	48.36832	-123.92743
LIND1169	U	21 Jul 2005	Grays Harbor	29 Feb 2008	0151	22	60.4	48.224	-124.11197
KLIM2218	S	11 Aug 2005	Sacramento	4 Nov 2006	1321	38	135.3	48.22933	-124.10517
KLIM2220	S	12 Aug 2005	Sacramento	17 Feb 2009	2209	62	60.4	48.224	-124.11197
LIND1181	U	17 Aug 2005	Grays Harbor	31 Dec 2007	1542	104	47.5	48.37334	-123.92152
LIND1200	U	25 Aug 2005	Grays Harbor	11 May 2007	0707	145	173.7	48.26001	-124.06572
KLIM2226	S	27 Aug 2005	Sacramento	9 Jun 2007	0519	66	164.6	48.25492	-124.07238
KLIM2227	S	27 Aug 2005	Sacramento	1 May 2006	0518	193	54.9	48.22032	-124.10104
LIND1195	U	31 Aug 2005	Grays Harbor	6 May 2006	1117	166	175.6	48.32296	-123.98677
KLIM2230	S	3 Sep 2005	Sacramento	11 Oct 2008	0508	24	182.9	48.30689	-124.00658
KLIM2238	S	3 Sep 2005	Sacramento	22 Jan 2010	1248	8	170.1	48.32226	-123.98656
LIND1193	U	6 Sep 2005	Grays Harbor	19 Jul 2008	0104	81	181.1	48.27039	-124.0527
KLIM2240	S	6 Sep 2005	Sacramento	26 Nov 2007	0519	29	60.4	48.224	-124.11197
VOGL228	S	13 Jul 2006	Sacramento	24 Oct 2007	2018	135	47.5	48.37334	-123.92152
VOGL231	S	16 Jul 2006	Sacramento	2 Feb 2008	0526	202	181.1	48.27039	-124.0527
ASGS4325	S	10 Oct 2009	Sacramento	22 Sep 2010	1454	157	60.4	48.224	-124.11197
KLIM48420	S	3 May 2010	Sacramento	15 Nov 2013	1253	9	229	48.50842	-124.75072
ASGS4337	S	11 Jul 2010	Sacramento	27 Jul 2013	0225	20	165	48.27411	-124.04274
DION47066	U	26 Aug 2010	Willapa Bay	22 Aug 2011	0206	215		48.26502	-124.05906
DION47067	S	26 Aug 2010	Willapa Bay	22 Jul 2011	2226	76	170	48.24991	-124.07858
DION47068	U	26 Aug 2010	Willapa Bay	3 Jul 2011	1742	20	135.3	48.22933	-124.10517
DION47071	S	26 Aug 2010	Willapa Bay	1 May 2012	2229	171	173.7	48.25366	-124.06885
DION47073	S	26 Aug 2010	Willapa Bay	7 Nov 2012	1524	55	129.8	48.22796	-124.10164
DION47075	S	26 Aug 2010	Willapa Bay	15 Nov 2012	0325	50	60.4	48.22279	-124.10785
DION47076	U	26 Aug 2010	Willapa Bay	5 Dec 2012	2038	117	129.8	48.22796	-124.10164
DION47079	U	26 Aug 2010	Willapa Bay	31 Mar 2011	1122	349	173.7	48.26001	-124.06572

Table 3. Continued.

Tag code	DPS (N/S/U)	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
DION47098	N	16 Sep 2010	Grays Harbor	21 Feb 2014	0201	24	181.1	48.264	-124.05578
DION47101	N	16 Sep 2010	Grays Harbor	9 May 2011	1430	186	135.3	48.22933	-124.10517
DION47097	S	14 Oct 2010	Grays Harbor	24 May 2012	2141	304	102.4	48.36865	-123.92755
KLIM6625	S	12 Apr 2011	Sacramento	8 Jul 2017	2113	280	182	48.27886	-124.04689
KLIM48421	S	6 May 2011	Sacramento	7 Nov 2013	1658	5	229	48.50842	-124.75072
DION47094	N	7 Jun 2011	Grays Harbor	17 Jun 2013	0107	592	182.9	48.30688	-124.00625
DION47095	N	7 Jun 2011	Grays Harbor	6 Jan 2012	0912	149	153.6	48.23299	-124.09512
DION31412	U	7 Jun 2011	Grays Harbor	8 Dec 2015	0114	98	60.4	48.22279	-124.10785
DION31416	N	7 Jun 2011	Grays Harbor	1 Jun 2013	1453	2	231	48.50813	-124.74912
DION47096	N	8 Jun 2011	Grays Harbor	19 Feb 2012	0948	197	129.8	48.22796	-124.10164
DION31413	N	8 Jun 2011	Grays Harbor	12 Jul 2013	0403	338	150	48.23813	-124.0884
DION31417	U	8 Jun 2011	Grays Harbor	2 Dec 2012	1435	41	171.9	48.25878	-124.06211
DION31421	U	8 Jun 2011	Grays Harbor	21 Oct 2014	0810	24	129.8	48.22796	-124.10164
DION31433	S	9 Jun 2011	Grays Harbor	31 Oct 2011	1726	14	102.4	48.36865	-123.92755
DION31435	U	9 Jun 2011	Grays Harbor	28 Jul 2013	1121	164	131.7	48.34808	-123.95387
DION47114	U	14 Jun 2011	Willapa Bay	11 Jan 2013	0724	106		48.22279	-124.10785
DION31437	S	14 Jun 2011	Willapa Bay	24 May 2012	1225	36	193.9	48.2899	-124.02301
DION31441	U	14 Jun 2011	Willapa Bay	23 Nov 2013	1200	2	229	48.50842	-124.75072
DION31444	S	14 Jun 2011	Willapa Bay	15 Oct 2013	1744	14	231	48.50813	-124.74912
DION47111	S	15 Jun 2011	Willapa Bay	5 Apr 2013	0730	597	173.7	48.26001	-124.06572
DION31449	S	15 Jun 2011	Willapa Bay	24 Apr 2014	1733	25	102.4	48.36865	-123.92755
DION47090	S	27 Jun 2011	Columbia	27 May 2012	0434	57	131.7	48.34808	-123.95387
DION31460	N	1 Jul 2011	Columbia	15 May 2013	0852	140	168.2	48.24871	-124.07527
DION47085	S	7 Jul 2011	Grays Harbor	15 Feb 2012	0213	68		48.26502	-124.05906
DION47086	U	7 Jul 2011	Grays Harbor	21 Dec 2012	1634	426	160.9	48.32747	-123.97988
DION31425	U	7 Jul 2011	Grays Harbor	28 Oct 2013	1640	6	229	48.50842	-124.75072

Table 3. Continued.

Tag code	DPS	Release		First detection		Hits	Bottom	Detection location	
	(N/S/U)	Date	Location	Date	Time	(n)	depth (m)	Latitude (°N)	Longitude (°W)
DION31426	S	13 Jul 2011	Grays Harbor	9 Jan 2014	1030	52	188	48.35637	-124.21577
DION31450	N	13 Jul 2011	Grays Harbor	24 Jun 2013	2202	4	231	48.50813	-124.74912
DION47108	N	14 Jul 2011	Willapa Bay	27 May 2012	0153	23	102.4	48.36865	-123.92755
DION47112	N	14 Jul 2011	Willapa Bay	18 Apr 2012	2027	79	190.2	48.295	-124.01631
DION31485	S	14 Jul 2011	Willapa Bay	30 Jun 2014	2025	11	230	48.50833	-124.75008
DION47109	U	16 Jul 2011	Willapa Bay	29 Dec 2011	1429	518	129.8	48.22796	-124.10164
DION31493	S	16 Jul 2011	Willapa Bay	18 Oct 2011	1433	18	42.1	48.37385	-123.92093
DION31461	N	18 Jul 2011	Columbia	22 Jul 2012	2207	53	117	48.35835	-123.94067
DION31462	U	19 Jul 2011	Columbia	15 Apr 2012	0642	8	102.4	48.36865	-123.92755
DION31465	U	21 Jul 2011	Columbia	22 May 2015	1329	177	190.2	48.28474	-124.02966
DION47103	N	25 Jul 2011	Willapa Bay	21 Dec 2013	1111	50	60.4	48.22279	-124.10785
DION47104	U	25 Jul 2011	Willapa Bay	9 Jun 2012	0148	58	182.9	48.30688	-124.00625
DION47105	S	25 Jul 2011	Willapa Bay	25 Mar 2012	0117	463	188.4	48.27947	-124.03596
DION47110	N	25 Jul 2011	Willapa Bay	10 Feb 2012	1445	423	150	48.23426	-124.09857
DION31495	U	26 Jul 2011	Willapa Bay	30 Apr 2013	0416	160	117	48.35835	-123.94067
DION31558	U	26 Jul 2011	Umpqua	19 Sep 2015	0024	110	153.6	48.23299	-124.09512
DION31559	U	26 Jul 2011	Umpqua	29 Nov 2014	1826	33	60.4	48.22279	-124.10785
DION31466	U	1 Aug 2011	Columbia	28 Jul 2014	0057	64	131.7	48.34808	-123.95387
KLIM47870	S	2 Aug 2011	Sacramento	17 Apr 2013	0615	223	60.4	48.22279	-124.10785
DION31467	U	2 Aug 2011	Columbia	1 Nov 2013	1259	22	229	48.50842	-124.75072
DION47091	S	4 Aug 2011	Columbia	18 Jun 2013	2140	90	102.4	48.36865	-123.92755
KLIM47880	S	9 Aug 2011	Sacramento	19 Jun 2012	1158	212	129.8	48.22796	-124.10164
DION31548	N	9 Aug 2011	Umpqua	26 May 2014	2312	56	60.4	48.22279	-124.10785
DION31428	U	10 Aug 2011	Grays Harbor	6 Aug 2014	1608	62	187	48.35652	-124.21602
DION31546	S	11 Aug 2011	Umpqua	10 Jan 2012	1242	281	131.7	48.34808	-123.95387
DION31562	N	11 Aug 2011	Umpqua	29 May 2014	1010	5	187	48.35652	-124.21602

Table 3. Continued.

Tag code	DPS (N/S/U)	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
DION31544	U	12 Aug 2011	Umpqua	6 Jun 2014	9120	526	179.2	48.31188	-123.99943
DION31567	U	12 Aug 2011	Grays Harbor	25 Jul 2013	1809	135	231	48.50813	-124.74912
DION31571	S	12 Aug 2011	Grays Harbor	9 Nov 2013	9430	14	229	48.50842	-124.75072
DION31471	S	17 Aug 2011	Columbia	17 Oct 2016	1027	28	153.6	48.23299	-124.09512
DION31469	S	18 Aug 2011	Columbia	14 Aug 2013	9751	18	231	48.50813	-124.74912
DION31473	S	18 Aug 2011	Columbia	20 Oct 2014	9804	85	153.6	48.23299	-124.09512
DION31474	U	18 Aug 2011	Columbia	16 May 2014	9247	4	230	48.50833	-124.75008
DION31475	U	19 Aug 2011	Columbia	19 Dec 2012	9242	191		48.22796	-124.10164
DION31476	U	19 Aug 2011	Columbia	15 May 2013	1559	66	173.7	48.25366	-124.06885
DION31478	U	19 Aug 2011	Columbia	26 Jul 2015	2100	190	190.2	48.295	-124.01631
KLIM56457	S	25 Aug 2011	Sacramento	28 May 2017	0013	32	117	48.35835	-123.94067
DION31496	S	30 Aug 2011	Columbia	22 Jul 2012	1229	94	190.2	48.28474	-124.02966
DION31497	S	31 Aug 2011	Columbia	24 Nov 2014	1304	87	188.4	48.30167	-124.01273
DION31499	S	31 Aug 2011	Columbia	27 Apr 2012	0123	449	60.4	48.22279	-124.10785
DION31500	S	31 Aug 2011	Columbia	24 Jul 2012	2330	158	102.4	48.36865	-123.92755
DION31527	U	31 Aug 2011	Willapa Bay	22 Jun 2012	0155	47	150	48.23813	-124.0884
DION31502	N	1 Sep 2011	Columbia	1 Jul 2012	0539	202	42.1	48.37385	-123.92093
DION31505	S	1 Sep 2011	Columbia	24 Nov 2011	1052	106	150	48.23813	-124.0884
DION31506	N	2 Sep 2011	Columbia	20 Jul 2016	0850	94	129.8	48.22796	-124.10164
DION31507	U	2 Sep 2011	Columbia	18 Jun 2015	2257	58	102.4	48.36865	-123.92755
DION31508	S	2 Sep 2011	Columbia	13 Sep 2013	0711	2	231	48.50813	-124.74912
DION31511	S	2 Sep 2011	Columbia	8 May 2014	0044	5	229	48.50842	-124.75072
DION31523	N	2 Sep 2011	Grays Harbor	25 May 2013	1038	154	150	48.33263	-123.97338
DION31543	U	6 Sep 2011	Umpqua	28 Sep 2015	1854	152	181.1	48.264	-124.05578
DION31515	S	12 Sep 2011	Columbia	21 Jun 2017	2118	24	70	48.22465	-124.11407
DION31517	S	13 Sep 2011	Columbia	27 Nov 2016	0517	71	168.2	48.24871	-124.07527

Table 3. Continued.

Tag code	DPS (N/S/U)1	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
DION31518	S	13 Sep 2011	Columbia R	14 Aug 2017	0332	32	190	48.28973	-124.03367
DION31519	S	13 Sep 2011	Columbia R	5 May 2014	1018	287	181.1	48.2691	-124.04905
DION31538	U	14 Sep 2011	Columbia River	9 Feb 2018	0520	32	175.6	48.31717	-123.993
DION31539	S	15 Sep 2011	Columbia River	30 Oct 2013	1103	14	229	48.50842	-124.75072
KLIM56472	S	13 Apr 2012	Sacramento	31 May 2013	0157	6	231	48.50813	-124.74912
KLIM56496	S	13 Apr 2012	Sacramento	16 Apr 2013	0406	329	60.4	48.22279	-124.10785
KLIM56497	S	16 Apr 2012	Sacramento	8 Dec 2013	1358	289	102.4	48.36865	-123.92755
KLIM56499	S	17 Apr 2012	Sacramento	5 May 2014	2216	193	60.4	48.22279	-124.10785
KLIM4008	S	19 Apr 2012	Sacramento	29 May 2017	1903	33	60.4	48.22279	-124.10785
KLIM4010	S	19 Apr 2012	Sacramento	29 Apr 2013	1800	116	102.4	48.36865	-123.92755
KLIM4017	S	25 Apr 2012	Sacramento	1 May 2014	1449	135	129.8	48.22796	-124.10164
KLIM4016	S	30 Apr 2012	Sacramento	19 Feb 2018	0424	223	70	48.22465	-124.11407
KLIM4019	S	30 Apr 2012	Sacramento	1 Jun 2018	0404	78	175.6	48.31717	-123.993
KLIM4022	S	3 May 2012	Sacramento	23 Mar 2016	0222	131	102.4	48.36865	-123.92755
KLIM4023	S	6 May 2012	Sacramento	12 Dec 2013	1737	162		48.26502	-124.05906
KLIM4024	S	6 May 2012	Sacramento	1 Jun 2017	1631	19	190	48.35597	-124.21578
DION31534	U	29 May 2012	Columbia River	6 Dec 2012	0139	31	60.4	48.22279	-124.10785
DION31529	U	21 Jun 2012	Columbia River	5 Jul 2013	0204	69	42.1	48.37385	-123.92093
DION31528	N	28 Jun 2012	Columbia River	26 Mar 2016	2345	138	129.8	48.22796	-124.10164
DION28655	U	1 Jul 2012	Willapa Bay	3 Sep 2014	1347	139	60.4	48.22279	-124.10785
DION28657	N	1 Jul 2012	Willapa Bay	12 Dec 2015	2119	178	102.4	48.36865	-123.92755
DION28658	N	1 Jul 2012	Willapa Bay	13 Dec 2014	1058	108	150	48.23813	-124.0884
DION28659	S	1 Jul 2012	Willapa Bay	22 Oct 2014	0443	131	60.4	48.22279	-124.10785
DION28660	S	1 Jul 2012	Willapa Bay	21 Jun 2013	2321	51	180	48.36067	-124.21282
DION28661	U	1 Jul 2012	Willapa Bay	21 May 2018	0349	19	190	48.28973	-124.03367
DION28663	U	1 Jul 2012	Willapa Bay	17 Jul 2013	0121	176	188.4	48.30167	-124.01273

Table 3. Continued.

Tag code	DPS (N/S/U)	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
DION28665	S	1 Jul 2012	Willapa Bay	22 Oct 2016	1256	37	129.8	48.22796	-124.10164
DION28668	N	1 Jul 2012	Willapa Bay	26 Dec 2013	0354	134	60.4	48.22279	-124.10785
DION28669	S	1 Jul 2012	Willapa Bay	9 Jun 2014	0638	25	188.4	48.27947	-124.03596
DION28670	S	1 Jul 2012	Willapa Bay	4 Sep 2014	2358	289	102.4	48.36865	-123.92755
DION28673	S	1 Jul 2012	Willapa Bay	30 Aug 2015	1057	192	129.8	48.22796	-124.10164
DION28674	U	1 Jul 2012	Willapa Bay	18 Nov 2015	1133	78	129.8	48.22796	-124.10164
DION28675	S	1 Jul 2012	Willapa Bay	24 Nov 2016	0807	6	190	48.35597	-124.21578
DION28730	U	7 Jul 2012	Grays Harbor	4 Aug 2013	2316	58	188.4	48.30167	-124.01273
DION28688	U	12 Jul 2012	Columbia	12 Mar 2016	1049	74	129.8	48.22796	-124.10164
DION28689	N	12 Jul 2012	Columbia	25 Jul 2016	2354	176	131.7	48.34808	-123.95387
DION28690	U	12 Jul 2012	Columbia	16 Nov 2017	2347	86	147	48.23552	-124.10051
DION28691	U	12 Jul 2012	Columbia	17 Jun 2013	1352	88	231	48.50813	-124.74912
DION28695	S	12 Jul 2012	Columbia	29 Apr 2013	0021	89	180	48.36067	-124.21282
DION28696	U	12 Jul 2012	Columbia	17 Oct 2014	1714	322	142.6	48.33775	-123.9669
DION28697	U	12 Jul 2012	Columbia	14 Apr 2015	0516	162	150	48.33263	-123.97338
DION28676	U	13 Jul 2012	Columbia	24 May 2014	0945	48	230	48.50833	-124.75008
DION28677	S	13 Jul 2012	Columbia	14 Jun 2019	0527	2	184	48.3059	-124.01351
DION28680	S	13 Jul 2012	Columbia	24 Apr 2015	0013	62	168.2	48.24871	-124.07527
DION28681	N	13 Jul 2012	Columbia	13 Feb 2018	2100	14	147	48.23552	-124.10051
DION28682	N	13 Jul 2012	Columbia	28 Jan 2015	0635	182	181.1	48.2691	-124.04905
DION28683	N	13 Jul 2012	Columbia	27 May 2013	2320	118	60.4	48.22279	-124.10785
DION28684	N	13 Jul 2012	Columbia	20 May 2016	1337	82	190.2	48.28474	-124.02966
DION28685	U	13 Jul 2012	Columbia	25 Jan 2013	0614	123		48.23813	-124.0884
DION28686	N	13 Jul 2012	Columbia	9 Feb 2013	1157	88		48.34808	-123.95387
DION28698	U	13 Jul 2012	Columbia	30 Jun 2013	1533	338	180	48.36067	-124.21282
DION28701	N	16 Jul 2012	Grays Harbor	22 Nov 2012	1909	213	129.8	48.22796	-124.10164

Table 3. Continued.

Tag code	DPS (N/S/U)	Release Date	Release Location	First detection Date	First detection Time	Hits (n)	Bottom depth (m)	Detection location Latitude (°N)	Detection location Longitude (°W)
DION28702	U	16 Jul 2012	Grays Harbor	4 Jul 2013	0540	60	102.4	48.36865	-123.92755
DION28703	U	16 Jul 2012	Grays Harbor	26 Dec 2013	0150	60	229	48.50842	-124.75072
DION28704	U	16 Jul 2012	Grays Harbor	24 May 2014	1325	49	230	48.50833	-124.75008
DION28706	U	16 Jul 2012	Grays Harbor	13 Jun 2013	1504	36	42.1	48.37385	-123.92093
DION28708	N	16 Jul 2012	Grays Harbor	24 Jan 2015	0110	250	129.8	48.22796	-124.10164
DION28710	U	17 Jul 2012	Grays Harbor	22 Jun 2015	0157	216	188.4	48.30167	-124.01273
DION28714	N	17 Jul 2012	Grays Harbor	7 Nov 2012	0253	336	168.2	48.24871	-124.07527
DION28718	S	17 Jul 2012	Grays Harbor	6 Feb 2017	1056	90	131.7	48.34808	-123.95387
DION28721	N	17 Jul 2012	Grays Harbor	21 Jul 2014	0626	47	173.7	48.25366	-124.06885
DION28723	U	17 Jul 2012	Grays Harbor	30 Oct 2012	1035	9	188.4	48.27947	-124.03596
DION28715	N	18 Jul 2012	Grays Harbor	26 Jun 2015	0139	176	188.4	48.27947	-124.03596
DION28719	S	18 Jul 2012	Grays Harbor	26 Jun 2013	1317	6	180	48.36067	-124.21282
DION28729	S	25 Jul 2012	Willapa Bay	10 Aug 2017	2228	114	147	48.23552	-124.10051
DION28726	S	31 Jul 2012	Columbia River	7 Jul 2014	1823	5	230	48.50833	-124.75008
DION28727	S	1 Aug 2012	Columbia River	22 Dec 2012	0811	84	137.2	48.3429	-123.96035
DION28728	U	1 Aug 2012	Columbia River	29 Dec 2015	1417	221	129.8	48.22796	-124.10164
DION28732	S	7 Aug 2012	Grays Harbor	26 Jun 2014	0658	4	230	48.50833	-124.75008
DION28748	S	7 Aug 2012	Grays Harbor	1 Jun 2014	2241	19	181.1	48.264	-124.05578
DION28751	U	9 Aug 2012	Grays Harbor	13 Mar 2014	1205	53	173.7	48.25366	-124.06885
DION28745	U	16 Aug 2012	Willapa Bay	18 Nov 2015	1140	198	129.8	48.22796	-124.10164
DION28744	U	11 Sep 2012	Columbia River	18 Apr 2015	1344	360	60.4	48.22279	-124.10785
DION28736	U	12 Sep 2012	Grays Harbor	17 Oct 2016	2302	44	129.8	48.22796	-124.10164
DION28738	U	17 Sep 2012	Grays Harbor	16 May 2015	2059	172	129.8	48.22796	-124.10164
ASGS4345	S	12 Nov 2013	Sacramento	4 Nov 2016	1020	39	60.4	48.22279	-124.10785
ASGS4323	S	18 Nov 2013	Sacramento	25 Aug 2018	0548	9	190	48.28973	-124.03367

Table 4. Green sturgeon data from archival acoustic tags (temperature and depth) detected in the Strait of Juan de Fuca (Ocean Tracking Network). For each fish, distinct population segment (DPS) is shown (northern, southern, or unknown) with release date and location, date and time of first detection, number of individual transmissions (hits), depth, temperature, and location. Each sensor transmits data on two codes; thus, each shaded block represents one fish.

		Release		First detection						Detection location	
Tag code	DPS (N/S/U)	Date	Location	Date	Time	Hits (n)	Bottom depth (m)	Sensor depth (m)	Sensor temp (°C)	Latitude (°N)	Longitude (°W)
ROMINE35	U	26 Aug 2010	Willapa Bay	8 Jul 2013	2210	50			10.1	48.27947	-124.03596
ROMINE35				11 Dec 2013	2041		229		7.9	48.50842	-124.75072
ROMINE36				8 Jul 2013	2207	52		13.0		48.27947	-124.03596
ROMINE36				11 Dec 2013	2044		229	76.1		48.50842	-124.75072
ROMINE43	U	16 Sep 2010	Grays Harbor	17 Jul 2013	0131	155			7.1	48.22796	-124.10164
ROMINE43				21 Jul 2013	0111						
ROMINE43				19 Jan 2015	2114				9.0	48.295	-124.01631
ROMINE43				14 Jun 2016	1922					48.22279	-124.10785
ROMINE44				17 Jul 2013	0127	157		76.1		48.22796	-124.10164
ROMINE44				21 Jul 2013	0112			47.6		48.37385	-123.92093
ROMINE44				19 Jan 2015	2113			10.9		48.295	-124.01631
ROMINE44				14 Jun 2016	1927					48.22279	-124.10785
ROMINE47	U	16 Sep 2010	Grays Harbor	24 Oct 2011	2100	607	113.4			48.36357	-123.9341
ROMINE47				7 Dec 2012	0601		60.4			48.22279	-124.10785
ROMINE47				9 Dec 2012	0304		102.4			48.36865	-123.92755
ROMINE47				28 Aug 2013	2358				8.3	48.24339	-124.08191
ROMINE47				1 Sep 2013	2322				8.3	48.22279	-124.10785
ROMINE47				8 Aug 2014	0110				8.8	48.33775	-123.9669
ROMINE47				24 May 2017	0929				7.9	48.264	-124.05578
ROMINE48				24 Oct 2011	2113	570	113.4			48.36357	-123.9341
ROMINE48				7 Dec 2012	0551		129.8			48.22796	-124.10164
ROMINE48				9 Dec 2012	0302		42.1			48.37385	-123.92093
ROMINE48				28 Aug 2013	2354			42.8		48.24871	-124.07527
ROMINE48				1 Sep 2013	2323			62.2		48.22279	-124.10785
ROMINE48				8 Aug 2014	0111			76.1		48.33775	-123.9669
ROMINE48				24 May 2017	0936			76.1		48.264	-124.05578
ROMINE57	U	16 Sep 2010	Grays Harbor	2 Oct 2013	1042	45			9.7	48.30167	-124.01273
ROMINE58				2 Oct 2013	1039	39		43.1		48.295	-124.01631
ROMINE63	N	8 Jun 2011	Grays Harbor	24 Apr 2012	1135	21	168.2			48.24871	-124.07527

Table 5. Distinct population segment (DPS) assignment for acoustically-tagged sturgeon in 2002-2013. Northern DPS fish were either tagged in the Klamath, Rogue or Mad rivers, or were genetically identified after capture in estuarine aggregation areas (WA estuaries or Umpqua river). Similarly, Southern DPS fish were either captured in the Sacramento River or genetically identified after capture in estuarine aggregation areas. Unknown DPS were fish captured in estuaries that did not have genetic identification.

Location tagged	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Northern DPS	**24**	**71**	**13**	**12**					**11**	**36**	**22**		**189**
Klamath	14	25	8	8									
Rogue	10	44	4										
Mad				1									
WA Estuary		2	1	3					11	33	22		
Umpqua										3			
Southern DPS		**13**	**58**	**103**	**56**		**11**	**31**	**46**	**120**	**90**	**37**	**565**
Sacramento			54	94	56		11	31	33	45	54	37	
WA Estuary		13	4	9					13	69	36		
Umpqua										6			
Unknown DPS		**15**	**24**	**27**					**39**	**81**	**50**		**236**
WA Estuary		15	24	27					39	70	50		
Umpqua										11			
Total	**24**	**99**	**95**	**142**	**56**	**0**	**11**	**31**	**96**	**237**	**162**	**37**	**990**

Results and Conclusions

Puget Sound

Receiver arrays in Puget Sound have varied considerably over the years, both in terms of temporal coverage and period of operation. These changes coincided with specific projects and their funding levels, which have varied with the completion of individual projects. From a modest start of only 20 receivers deployed in 2002, the number of receiver sites in Puget Sound increased to over 200 by 2008. For example, the array in summer 2006 included a line across Hood Canal and a wide distribution of sites in both shallow and deep water (Figure 1).

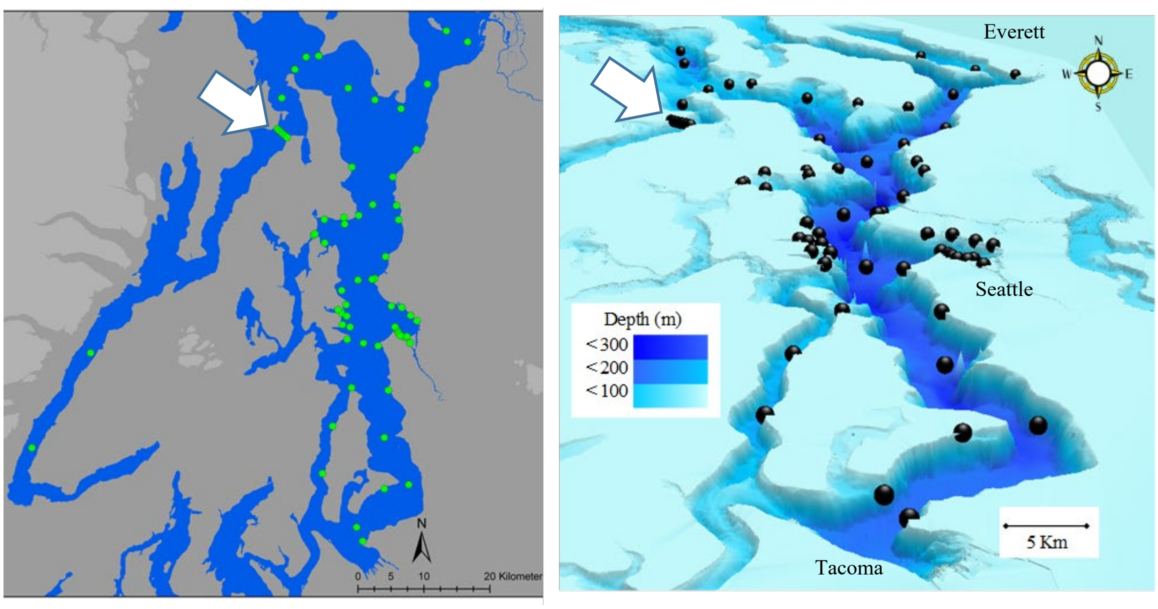

Figure 1. Acoustic receiver sites (left) and depth distribution in Puget Sound (right), 2006. During this period of rapid expansion, the Hydra database was developed to archive detection data not relevant to a particular study and to allow regional data sharing. By 2008, spatial receiver coverage was extensive, and several receiver "lines" (closely spaced receivers) were in place to detect fish as they crossed into specific areas such Hood Canal (block arrows) and Admiralty Inlet (coded ADM; Figures 2 and 3).

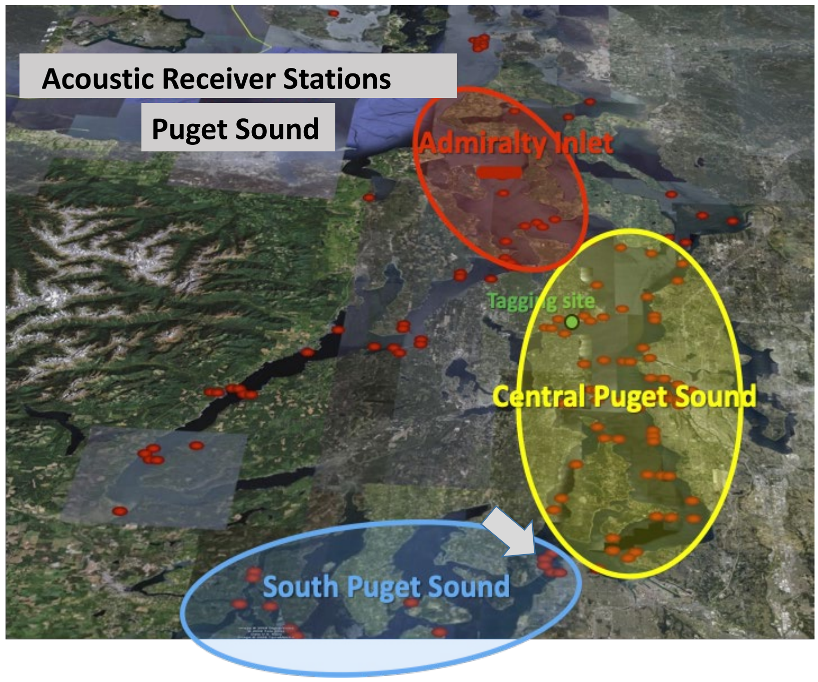

Figure 2. Acoustic receiver sites historically and currently maintained in Puget Sound. The line at Admiralty Inlet has been maintained from 2008 to present, a some of the receiver sites in Central Puget Sound (yellow circle) have been monitored continuously from 2005–2018, and a some of the receiver sites south of the Tacoma Narrows (white arrow) have been maintained continuously from 2014 to present.

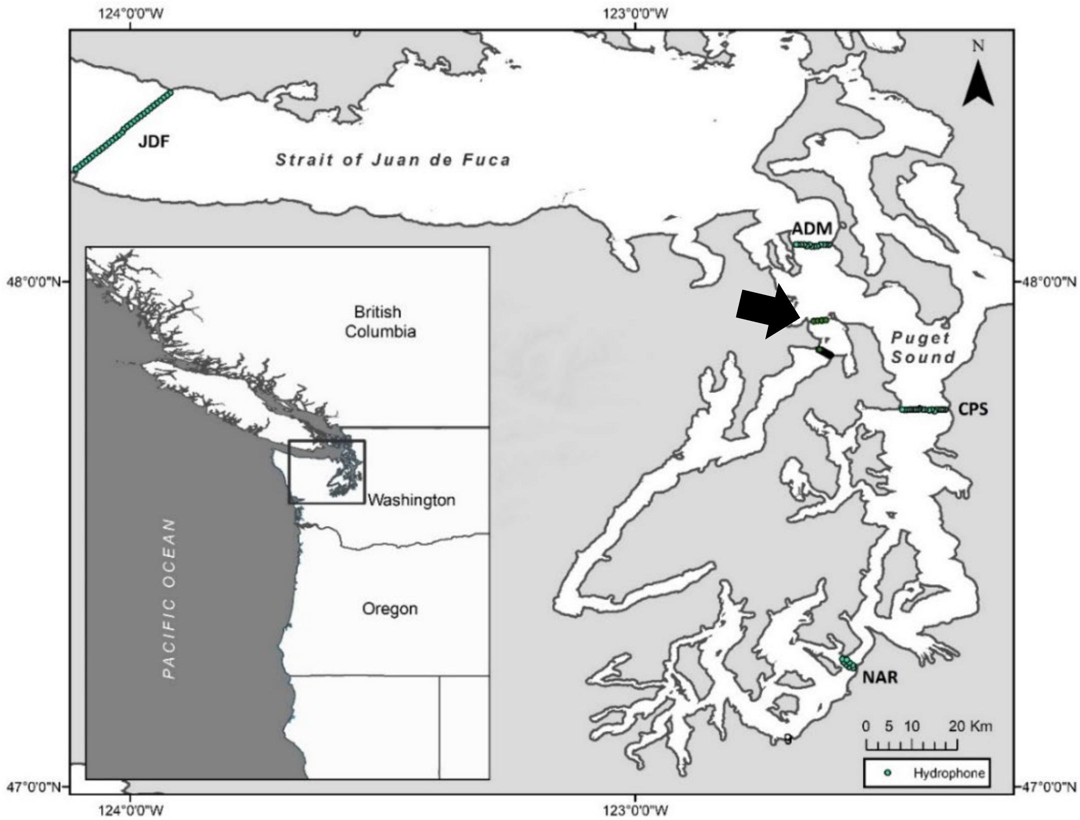

Figure 3. Major hydrophone lines (indicated by rows of blue circles) maintained in Puget Sound and the Strait of Juan de Fuca (JDF): Admiralty Inlet (ADM), Central Puget Sound (CPS) and Tacoma Narrows (NAR). Two lines were located in Hood Canal at the Hood Canal Bridge (black arrow) during March-August 2017 and March-September of 2018. A single receiver line was maintained at the Hood Canal Bridge from March-August from 2006-2010.

From 2002 to 2009, data from Hydra indicated that 17 individual green sturgeon had been detected in Puget Sound on more than one occasion (Table 1). Two additional tag codes were detected but not included in this list, as they were codes used to tag both green sturgeon and an unidentified species (see Methods). These confounded detections occurred together in the southernmost part of the study area, and in habitat unlikely to be used by green sturgeon. Consequently, these data were not included for mapping known green sturgeon locations (Figure 4).

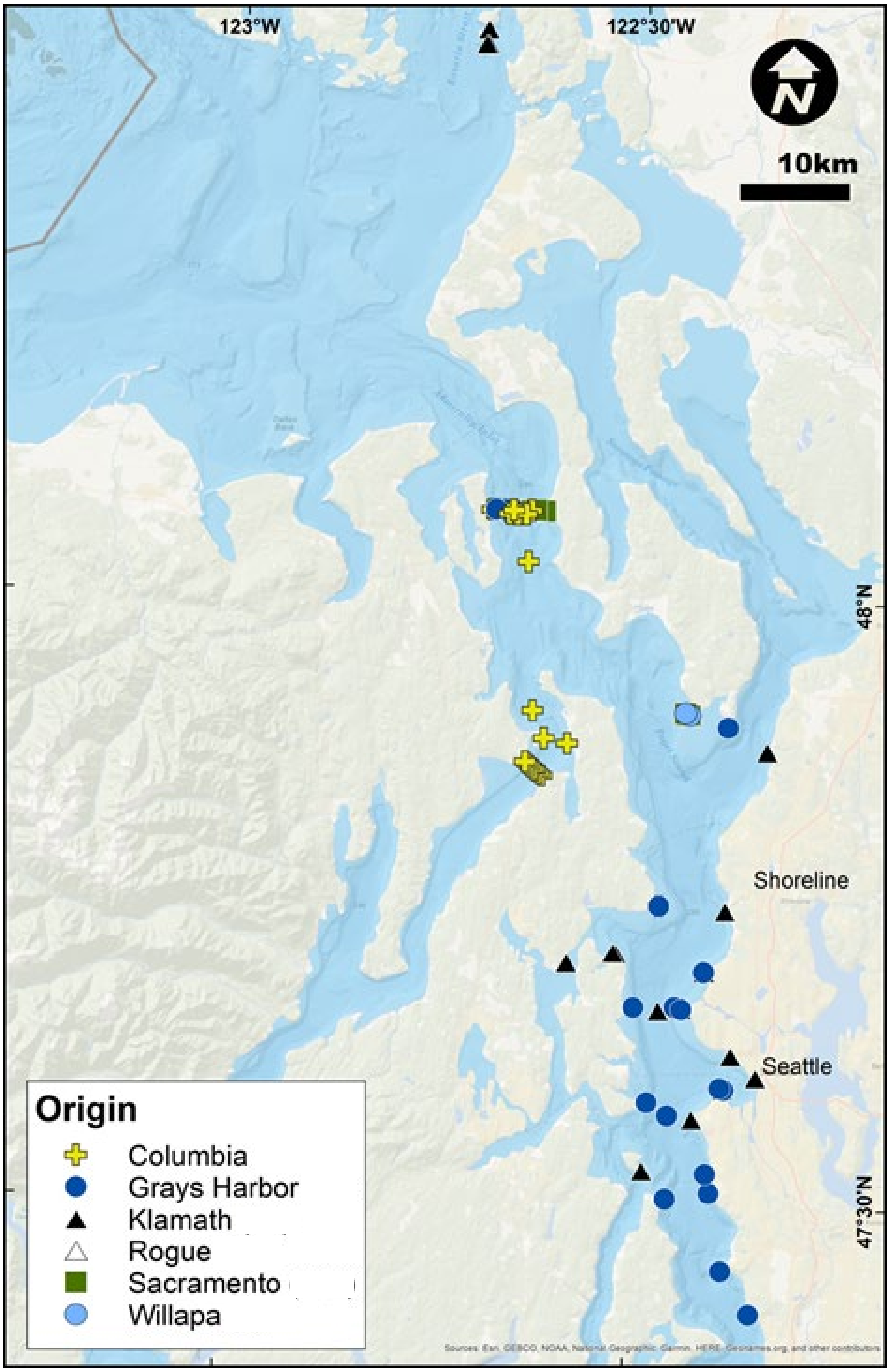

Figure 4. Green sturgeon detection sites in Puget Sound coded by release location. Sacramento (green square) and Willapa Bay (light blue circle) fish were from the southern DPS. The Columbia River fish (yellow cross) was from an unknown DPS. Remaining fish were all from the northern DPS.

Prior to 2009, many receiver sites were not maintained throughout the year or even for more than a few months at a time. Consequently, monitoring in years prior to 2009, although representing a large and expensive effort, resulted in a patchwork of detections from specific research projects. While a large number of receivers were operated during this period, their placement was not designed to detect green sturgeon. Nevertheless, green sturgeon were detected, and some individuals were documented moving about within Puget Sound and across multiple years.

Of the 17 green sturgeon detected within Puget Sound, 12 were northern DPS, 4 were southern DPS, and one was of unknown origin (Table 1). At least one green sturgeon was detected in Puget Sound each year from 2003 to 2009. In both 2006 and 2009, two southern DPS fish were detected there. Three northern DPS individuals were detected in multiple years (Table 1). There was no clear seasonal pattern of detection, with green sturgeon detection occurring across most months.

Several green sturgeon were detected at multiple sites throughout Puget Sound, and one individual of unknown origin was detected entering Hood Canal. Mapping of all Hydra receiver sites in Puget Sound during the study period (n = 514, Figure 5) revealed that receiver spatial coverage was 57 km^2 (assuming a 400-m radius of reception, Moser and Lindley 2007), or approximately 2.4% of the total water area of Puget Sound.

Interestingly, green sturgeon were detected only at the shallow ends of the Central Puget Sound receiver line, but were detected across the entire Hood Canal line (Figure 5). There are other instances of sturgeon detections in deep water, indicating that they can occur at all depths.

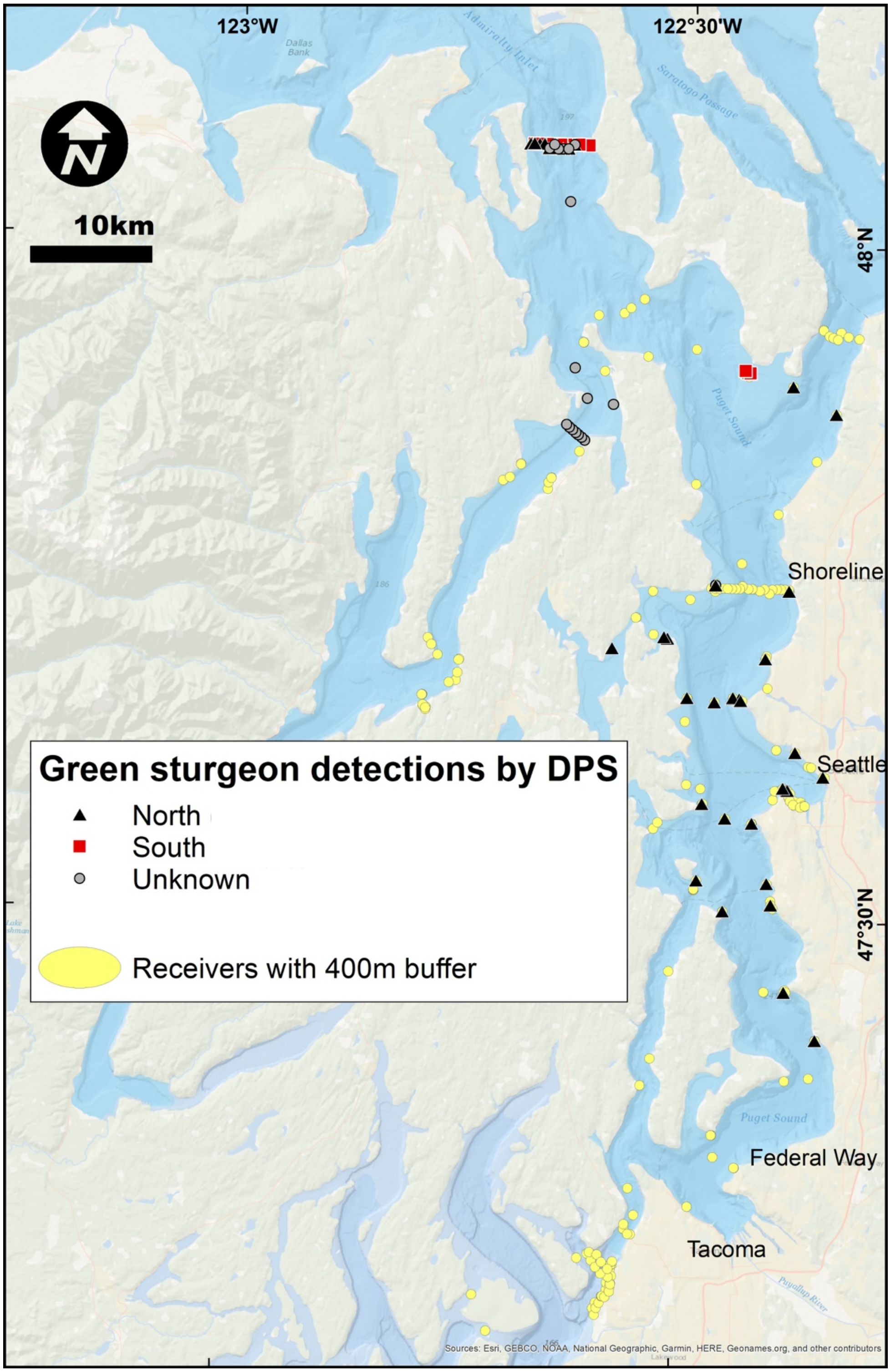

Figure 5. Hydra receiver sites that did not detect green sturgeon (yellow circles drawn to scale to indicate 400-m detection radius) and those that did detect green sturgeon: black triangles for northern DPS, red squares for southern DPS, and grey circles for unknown origin.

Most sturgeon detections (81%) occurred within a 400-m radius of the reported receiver sites (Figure 5). Detections outside this radius were from tracking with portable receivers (for salmonid and English sole studies) or from inaccurate receiver location data. Detections outside the receiver radii could also be due to exceptional acoustic conditions that increased transmitter range. In some cases, high-power transmitters, like those implanted in green sturgeon, can be detected at ranges of more than 1 km (Moser and Lindley 2007).

For the period 2009-2020, no green sturgeon were detected on any of the receiver lines at Hood Canal or in Central Puget Sound (shown in Figure 3); however, nine putative green sturgeon were detected at sites at or near Admiralty Inlet (ADM). Of these nine, three were detected only once and were censored, leaving five fish with multiple detections at the Admiralty Inlet receiver line. The remaining fish was detected for several days at a site to the north positioned off Lime Kiln State Park (Table 2) in the San Juan Islands. Our summary of Ocean Tracking Network data revealed one additional green sturgeon code detected at Admiralty Inlet.

Interestingly, half of the uncensored codes (n = 3) at Admiralty Inlet were detected in March-May 2013, less than a year after a transmitter was used to tag a green sturgeon. The remaining three were detected in 2015, 2016, and 2018 at 3, 4, and 6 years after tagging, respectively. Rapid rates of movement (up to 50 km/d) between estuaries and from northern overwintering sites to natal rivers have been noted in previous studies (Moser and Lindley 2007, Lindley et al. 2008). Detections at Admiralty Inlet were within the time frame that green sturgeon would require for seasonal migrations to and from northern wintering sites (Lindley et al. 2008).

Of the six fish detected at Admiralty Inlet, four were from the northern DPS, one from the southern DPS, and one had been tagged in the Columbia River estuary and had no genetic identification to indicate DPS. These results were similar to records obtained for Puget Sound after the initial coast-wide tagging of green sturgeon in 2002-2006. Though few in number, these detections supported the idea that Puget Sound is used primarily by the northern DPS, but that both populations can occur in this large, fjord-like estuary.

Differences in the tagged population over time may explain why so few fish tagged after 2010 were detected at Admiralty Inlet or within Puget Sound. The majority of fish detected in Puget Sound prior to 2009 were originally captured and tagged in the Klamath River, Oregon. After 2009, tagging effort focused on fish collected from Washington and Oregon estuaries (Table 5). The percentage of Klamath River fish from the northern DPS in these collections is unknown. Lindley et al. (2011) observed intra-population diversity in migratory behavior, with fish tagged from a specific population or area tending to migrate in similar patterns.

The potential lack of Klamath River fish in the tagged population after 2009 may have biased the tagged sample away from Puget Sound detections. This absence also highlights the concern that there may be other sub-populations of green sturgeon that use Puget Sound but have never been well represented in the tagged population.

Strait of Juan de Fuca

A receiver line in the Strait of Juan de Fuca (Figure 3) was originally operated by the Pacific Ocean Salmon Tracking (POST) project during 2004-2013, and is now maintained by the Ocean Tracking Network. All detection data for the life of this receiver line are archived with the Ocean Tracking Network and represent the longest time series of data in the same general location that we reviewed.

In contrast to the relatively small numbers of green sturgeon detected at Admiralty Inlet (n = 6) and in Puget Sound (n = 17) since 2002, 210 acoustically tagged green sturgeon were detected at the Strait of Juan de Fuca between June 2004 and June 2019 (Tables 3 and 4). These fish were first detected on Strait of Juan de Fuca receivers from 2.8 months to 6.9 years after they were tagged (mean 2.32 years, SD 1.47).

Of these 210 fish, 97 were identified as southern DPS based on either the tagging location (Sacramento River drainage) or genetic analysis. Of the remaining fish, 39 were northern DPS individuals, and the remaining fish were of unknown origin. Fish of unknown origin were those tagged in Oregon or Washington estuaries that had no record of subsequent genetic analysis. Therefore, while a large number of fish detected at the Strait of Juan de Fuca were of unknown origin, 71% of known-origin green sturgeon were identified as members of the southern DPS.

Continuous detections were obtained for most fish detected at the Strait of Juan de Fuca receiver array, and many individuals were detected on multiple receivers within the array (Table 3). On average, 116 transmissions from pinger transmitters (those without sensors) were received for each individual, with a range of 2-614 (SD 122) detections. The average bottom depth at sites where green sturgeon were detected was 129 m (range 15-231 m). In addition, 5 of the 210 individuals had transmitters with depth and temperature sensors (Table 4). Data from these transmissions indicated that sturgeon were traveling at an average depth of 52.4 m and that temperatures recorded by the sensors ranged 7.1-10.1°C (Table 4).

Green sturgeon were detected every year at the Strait of Juan de Fuca line, with peaks of 70-90 fish annually in 2012-2014 (Figure 6). These were the years immediately after the second major group of fish were tagged in Washington and Oregon estuaries (Table 5). Declines in detection since that peak could be attributed to transmitter battery failure or green sturgeon mortality. In previous coast-wide analyses, Lindley et al. (2008) estimated that annual survival of green sturgeon implanted with acoustic transmitters was 0.83.

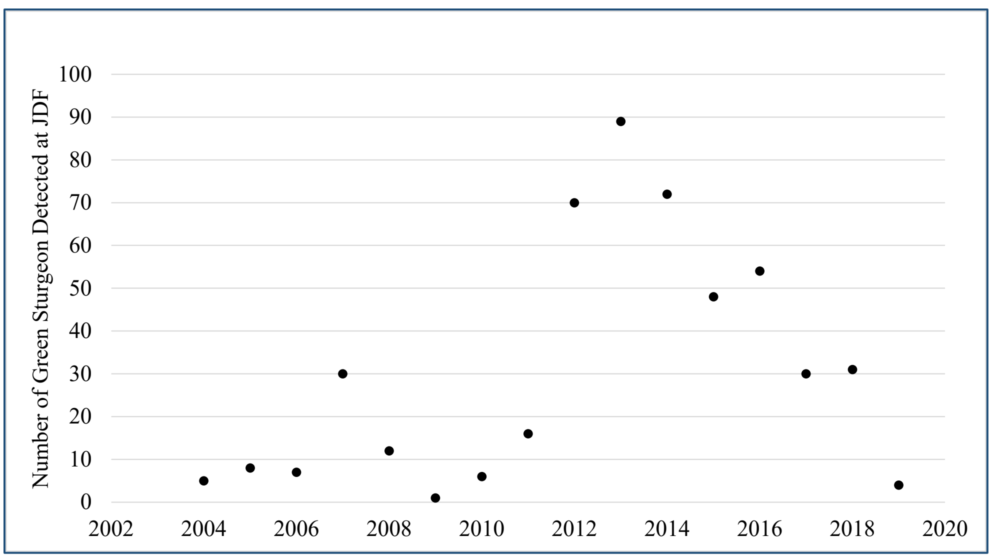

Figure 6. Number of green sturgeon detected at Strait of Juan de Fuca by year

It is also possible that the persistent marine heat wave in the Northeast Pacific Ocean altered ocean conditions along the west coast of Vancouver Island during 2014-2015. Anomalous high ocean temperatures may have modified the distribution and/or migratory pathways of green sturgeon, causing reduced incidence in the Strait of Juan de Fuca (Di Lorenzo & Mantua 2016).

Future modeling of green sturgeon ingress and egress from this area could be coupled with oceanographic data to predict the likelihood of green sturgeon occurrence in this area in a given period. A receiver line operated off Lippy Point (50.4393°N, -128.0388°W) on the northwest tip of Vancouver Island regularly detects green sturgeon, and this detection data could be used to test model predictions.

First detections of individual transmitter codes occurred more frequently at the Strait of Juan de Fuca in early summer (May-July) than during other times of the year. Prior to 2007, the Strait of Juan de Fuca array was not operated year-round, so observations of the number of sturgeon detected in early years may have been skewed towards summer, when the array was usually in place (Figure 7).

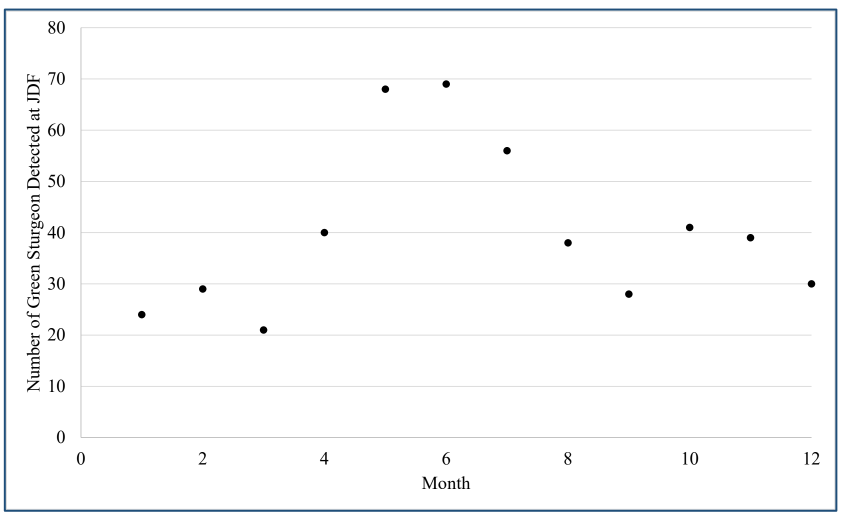

Figure 7. Number of green sturgeon detected at Strait of Juan de Fuca per month.

To address potential bias toward summer detection, we plotted seasonal green sturgeon occurrence at the Strait of Juan de Fuca during only the three highest detection years (2012-2014) when the receiver array was in place year-round (Figure 8). As in Figure 7, only first detections of green sturgeon in a given month were included.

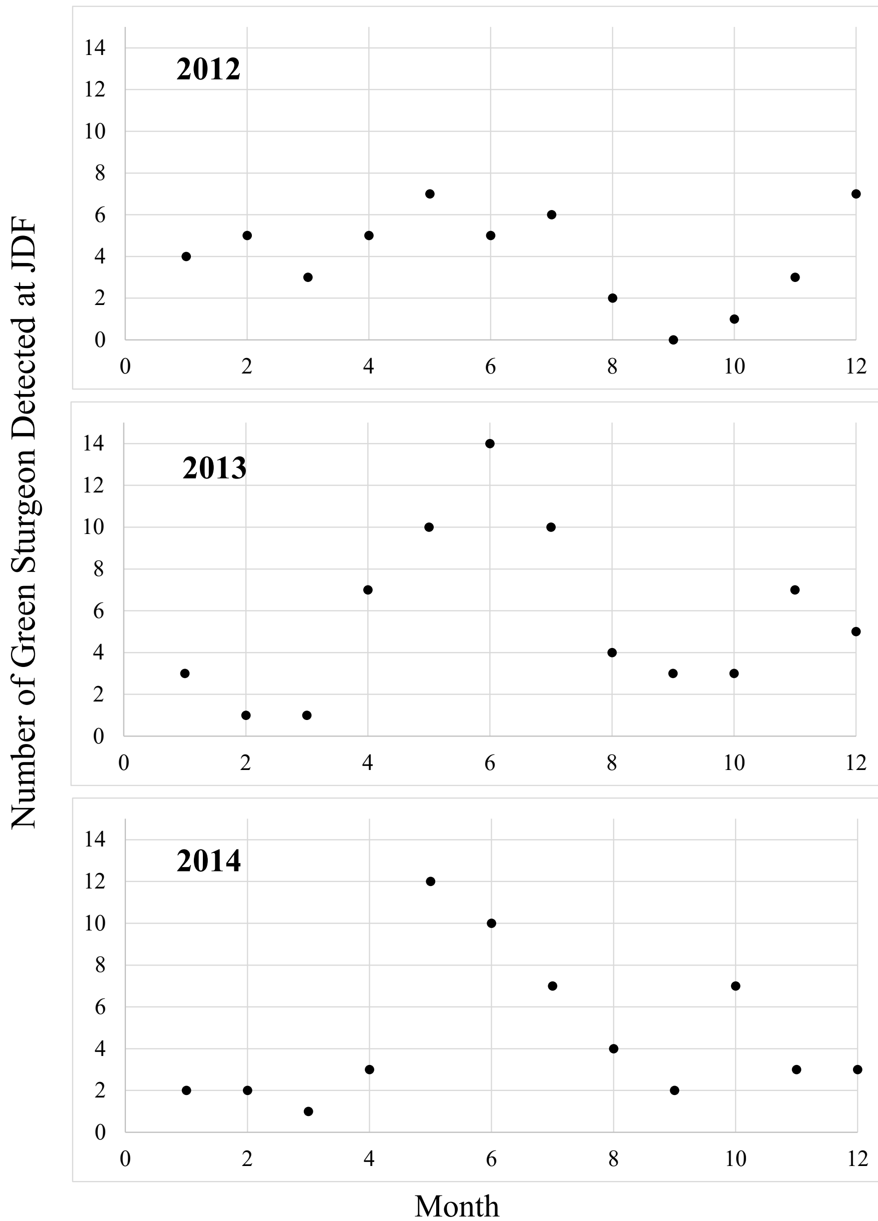

Figure 8. Monthly occurrence of individual green sturgeon at Strait of Juan de Fuca in 2012-2014.

These data still indicated a seasonal pattern of most frequent green sturgeon detections at the Strait of Juan de Fuca receiver line during April-July, with a smaller peak in October-December. These periods corresponded to the annual migrations from summer aggregation areas off Oregon and Washington to overwintering sites north of Vancouver Island, British Columbia (Lindley et al. 2008).

Detection data suggest that green sturgeon use the Strait of Juan de Fuca as a corridor, residing at receiver sites for relatively short periods as they pass through the strait. Few of these fish were detected subsequently at Admiralty Inlet, suggesting that they move northeast into northern inland U.S. waters and possibly the Strait of Georgia in British Columbia. This is consistent with trends reported by Lindley et al. (2008), who found that adult green sturgeon move northward from summering grounds in Oregon and Washington estuaries to overwintering areas between the north end of Vancouver Island, British Columbia and Cape Spencer, Alaska.

Summer estuarine habitat for green sturgeon is characterized by soft sandy or muddy substrate and relatively shallow water (< 20 m; Moser et al. 2017). However, coastal marine habitats, where green sturgeon are known to occur, can feature complex substrates, including high-relief, rocky habitats at depths greater than 20 m (Erickson and Hightower 2007, Huff et al. 2011). Whether green sturgeon use these areas to feed, shelter from predation, or simply pass through is unknown. Clearly, additional information is needed to characterize coastal habitats and the role they play in green sturgeon ecology (Moser et al. 2016).

Discussion

Information on green sturgeon occurrence in Puget Sound and the Strait of Juan de Fuca is needed to ensure that potentially harmful human actions do not impact this species, particularly the ESA-listed southern DPS. Our review of acoustic detection data indicated that both the northern and southern DPSs of green sturgeon commonly occupy waters in the Strait of Juan de Fuca and do occur in Puget Sound and at Admiralty Inlet, but at low rates relative to the Strait of Juan de Fuca.

Known members of the southern DPS were detected at Admiralty Inlet and at one site near the southern tip of Whidbey Island, WA. Among green sturgeon of known origin detected in these areas, the southern DPS was represented by 20% of the population at Admiralty Inlet (1 of 5) and 25% of those in Puget Sound (4 of 16). These southern DPS sturgeon were all detected during January-May.

In contrast, green sturgeon from the southern DPS dominated the population of tagged green sturgeon detected at the Strait of Juan de Fuca. During the peak of green sturgeon observations at the Strait of Juan de Fuca line, 70-90 individuals were detected each year, with 71% of known-origin fish identified as members of the southern DPS. Moreover, green sturgeon occurred in this area at all times of the year.

As with all telemetry studies, the absence of transmitter detections cannot be used to infer that a tagged animal does not occur in a given area. For example, a green sturgeon of unknown origin was detected regularly on the receiver line in the northern part of Hood Canal (Figures 4 and 5), but not further south in Hood Canal. This fish may have used the rest of Hood Canal regularly and simply traveled outside the range of operating acoustic receivers.

The fact that green sturgeon from the southern DPS were detected in this study demonstrates conclusively that these fish occur in Puget Sound, Admiralty Inlet, and to a greater degree, at the Strait of Juan de Fuca. Firstly, for every tagged green sturgeon there are many untagged fish. Hence, the tagged population at any moment in time represents only a small fraction of the total green sturgeon population.

Secondly, the odds that a green sturgeon will swim within range of an acoustic receiver during optimum acoustic conditions for detection are remote. As noted in this study, even if all receivers were operating for the entire study period (which was not the case) the areal coverage within Puget Sound was only 2.4%. Moreover, wind waves, ferry or other boat traffic, and physical obstructions can substantially reduce transmitter detection range.

Finally, this study used opportunistic detections of tagged sturgeon from receiver arrays that were explicitly designed to detect other species. Receiver operation in Puget Sound has traditionally focused on commercially and recreationally important species (e.g., rockfish, lingcod, salmonids, English sole). A directed study to better elucidate green sturgeon use of this area would employ a vast grid of bottom-mounted receivers, starting in areas where green sturgeon were detected in this study.

Our results support the decision by NOAA Fisheries to designate the Strait of Juan de Fuca as an area of high conservation value for the southern DPS of North American green sturgeon (Figure 9). Our results also confirm the earlier finding that Puget Sound is of lower conservation value to green sturgeon, based on the lower rate of detections in this area. However, these data have implicit biases associated with origin of the tagged populations and receiver placement.

Among the challenges we encountered for this analysis were the uneven distribution of tagging over time for the two DPSs, the large number of fish tagged without genetic identification, and the high variability in tagging and receiver deployment effort over time. Other challenges included the unknown percentage of each population bearing active transmitters, and the necessarily biased source populations used for tagging (i.e., only from known aggregation areas where sub-adults and adults could be reliably captured). Fortunately, the large body size of green sturgeon allowed use of long-lived transmitters, allowing us to track individuals over multiple years and great distances (Lindley et al. 2011).

Present efforts funded by the Navy to tag green sturgeon for coastal monitoring programs focus on tagging and genetic sampling of fish collected from Washington estuaries (L. Heironimus, Washington Department of Fish and Wildlife, personal communication). These aggregation areas provide ready access to large numbers of sturgeon from a mix of populations. However, they are unlikely to provide a tagged population that is truly representative of subadult and adult green sturgeon populations occurring in coastal areas throughout their range. This is due in part to strong intra-population patterns of habitat use and migration (Lindley et al. 2011).

Lindley et al. (2011) tagged green sturgeon from both DPSs on the spawning grounds in natal rivers (Klamath, Rogue, and Sacramento) and in estuaries where the species aggregates in mixed population groups. Their large, coast-wide effort helped elucidate migration behavior over a large spatial scale. More recently, spawning of green sturgeon in the Columbia River was confirmed by genetic methods (Schreier et al. 2016).

The identification of this heretofore unknown subpopulation highlights the need to tag green sturgeon across its range in the United States and Canada. In the period from 2002 to 2013, 565 green sturgeon from the southern DPS were tagged with acoustic transmitters. Continued funding of such tagging efforts, both in the Sacramento River Basin and in estuarine aggregation areas are needed to ensure adequate representation of the listed southern DPS in the tagged sample.

Another limitation to our study was the fact that receiver placement and maintenance was not directed towards green sturgeon detection. Many receivers were not operated year-round and not placed in areas where sturgeon were likely to reside or feed. This is exemplified by receiver operation during the past decade that has increasingly relied on receiver lines at key locations as opposed to a broader distribution of sites. This deployment structure has likely contributed to low Puget Sound detection rates and uncertainty regarding the conservation value of this area.

To address these concerns, efforts to capture green sturgeon in Puget Sound for genetic analyses and acoustic tagging could increase sample sizes and resolve concerns about population representation. Such efforts, coupled with an array of acoustic receivers specifically designed to detect green sturgeon in Puget Sound, could provide more definitive evidence of spatial and temporal patterns of habitat use in this area of concern.

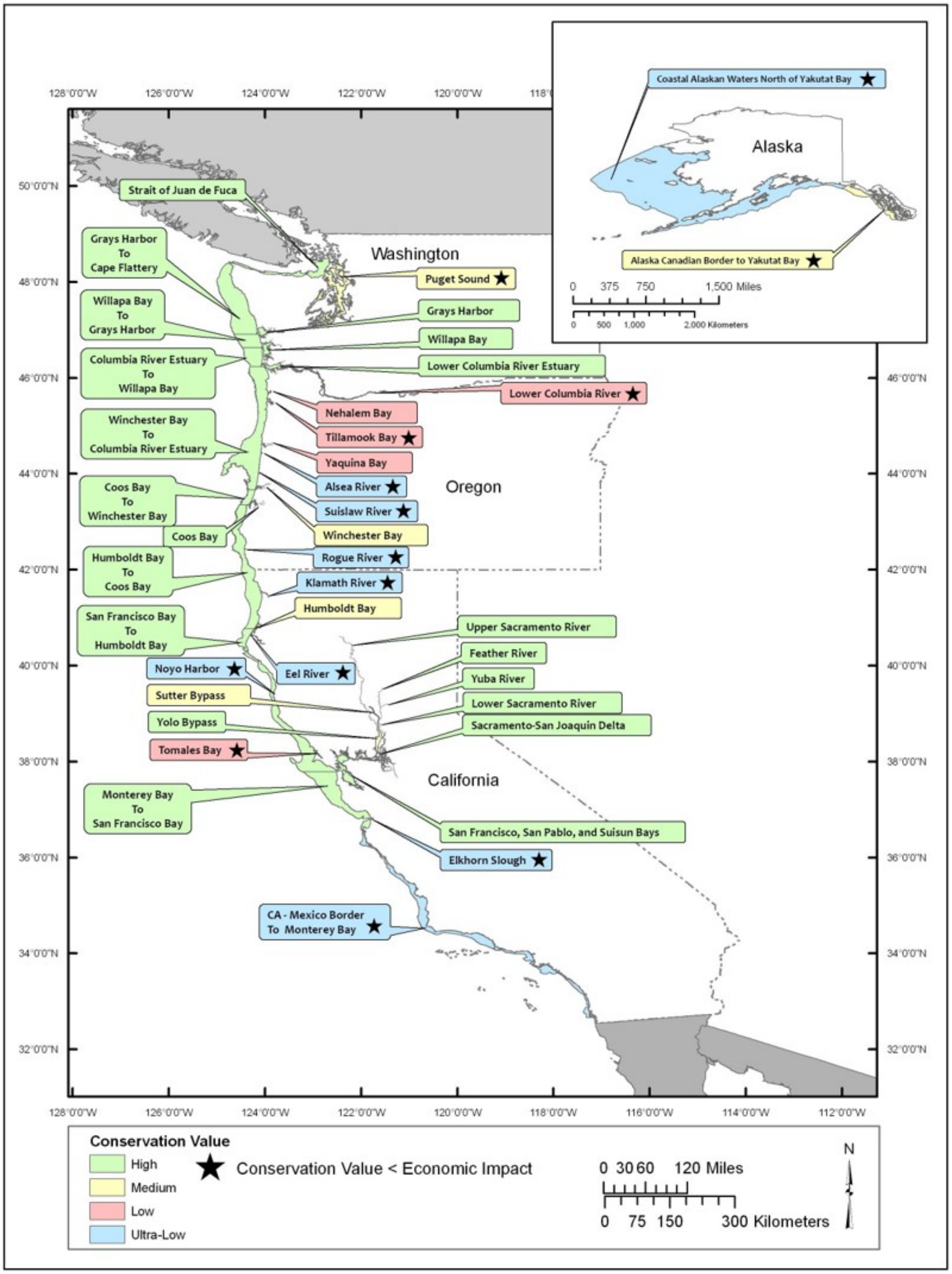

Figure 9. Results from the *Critical Habitat Designation for Southern Distinct Population Segment of North American Green Sturgeon* (NMFS 2009). Green areas are of high conservation value, yellow are medium, pink are low, and blue are ultra-low.

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