Observed and Estimated Bycatch of Green Sturgeon in 2002-2019 U.S. West Coast Groundfish Fisheries

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Executive summary

This report presents observed and estimated bycatch of green sturgeon (*Acipenser medirostris*) in fishery sectors observed by the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP) from 2002-2019. Three federal groundfish fisheries observed by the WCGOP and A-SHOP encountered green sturgeon over this time period, though none of these observations occurred during the most recent two years (2018 and 2019). These fisheries with observed green sturgeon bycatch include the limited entry (LE) bottom trawl fishery (active 2002-2010), the individual fishing quota (IFQ) bottom trawl fishery (active 2011-present), and the at-sea hake fishery (active 2002-present).

The southern distinct population segment (Southern DPS) of North American green sturgeon was listed as threatened under the Endangered Species Act in 2006, and landings and sales of green sturgeon has been prohibited since the effective date of the protective regulations (July 2, 2010). The Biological Opinion (BiOp; NMFS 2012) for the Pacific Coast Groundfish Fishery states that incidental take of Southern DPS green sturgeon in the combined federally managed fisheries should not exceed more than 28 fish per year, while allowing for up to 86 takes in no more than two years within a nine-year period. While the BiOp only concerns Southern DPS as a listed species, currently there is no direct method to distinguish between Southern and Northern DPS fish at sea. Based on data from the WCGOP and A-SHOP, the observed take of all green sturgeon (regardless of DPS) in all federally-managed sectors combined in the most recent five years (2015-2019) ranged from 0-26 per year. Some of these bycatch samples were analyzed with genetic stock identification (GSI) methods to differentiate between Northern and Southern DPS fish (pers. comm. Dr. Carlos Garza, SWFSC, NMFS). The GSI analyses indicated that the proportions between the DPSs differed spatially, with 48% of green sturgeon caught off the Oregon and Washington coasts and 96% of individuals caught off the California coast assigned to the Southern DPS. Based on the individual assignments and the estimated DPS proportions from each area, the estimated number of Southern DPS green sturgeon encountered in the federally-managed sectors for 2015-2019 ranged from 0-12 per year. Annual estimates from 2002-2019 are shown in Figure 0.1.

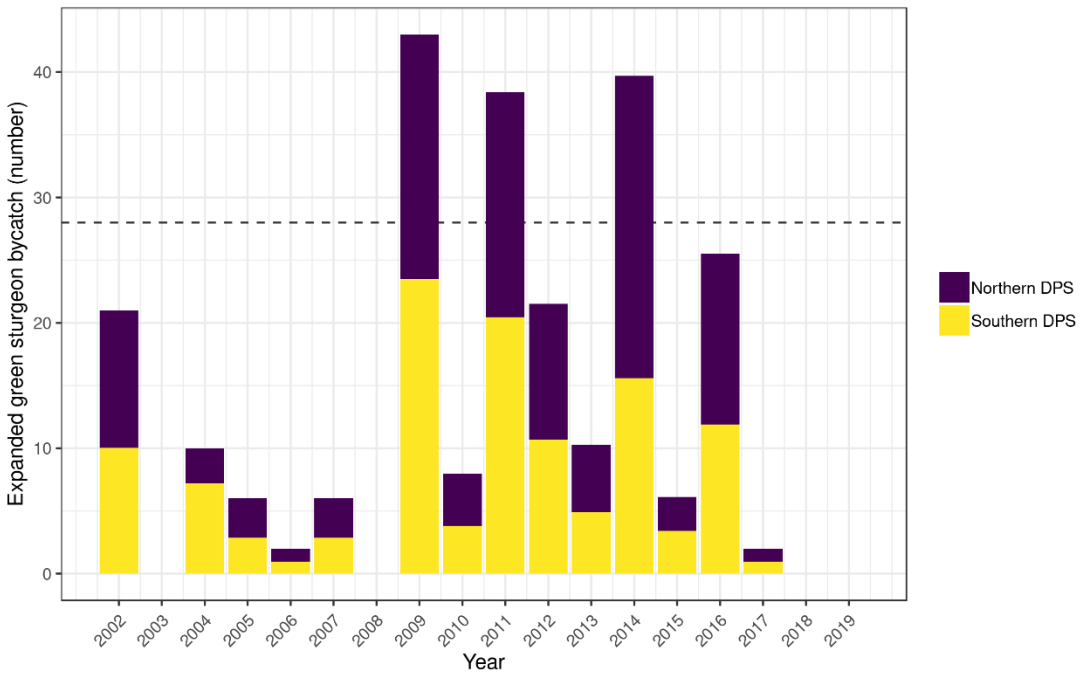

Figure 0.1. Green sturgeon bycatch estimates (number of individuals) in observed federally-managed groundfish fisheries by distinct population segment (DPS). Estimates of bycatch by DPS are calculated based

on individual assignments of genetic stock identification (GSI) and GSI proportions by catch areas (48% Southern DPS for Washington and Oregon, 96% Southern DPS for California). The horizontal dashed line shows the annual limit of 28 Southern DPS individuals that may be taken each year by combined federal groundfish fisheries according to the Biological Opinion for the Pacific Coast Groundfish Fishery.

The Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery only concerns federally-managed groundfish fisheries. However, the WCGOP also observes the state-managed California halibut fishery and California nearshore fixed-gear fishery, both of which also encountered green sturgeon between 2002 and 2019. We provide estimates of green sturgeon bycatch in these state-managed fisheries in a separate section of this report to provide a more thorough understanding of the impacts of observed fisheries on this species, but note that recommendations regarding green sturgeon under the BiOp should not include these fisheries.

In addition to federal and state fisheries, the WCGOP began observing the directed Pacific halibut fishery in 2017. Management of this fishery is coordinated jointly by the United States and Canada through the International Pacific Halibut Commission. This sector had one observed green sturgeon in 2019, and we present observed and estimated bycatch for 2017-2019 in a separate section.

Section 1. Federal Groundfish Fisheries

Introduction

In accordance with the National Marine Fisheries Service's (NMFS) Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS 2012, p. 126-127), this section provides observed bycatch and fleet-wide take estimates of green sturgeon (*Acipenser medirostris*) for all federal fisheries observed by the West Coast Groundfish Observer Program (WCGOP) and At-Sea Hake Observer Program (A-SHOP) from 2002-2019. Since the start of the individual fishing quota (IFQ) program in 2011, all trips and nearly 100% of catch in the IFQ fisheries have been monitored by onboard observers or electronic monitoring. From 2011 to 2019, the observed bycatch in the IFQ fisheries represents a near-complete census of fleet-wide total bycatch.

Green sturgeon background

Green sturgeon are a long-lived, slow-growing, anadromous fish species. They spend the majority of their adult life in marine and estuarine environments, but migrate into rivers for spawning every 1-4 years. Between spawning runs, green sturgeon migrate along the west coast of North America, and can be found from Baja California to the Bering Sea. Due to their life history, wide distribution, and dependence on freshwater systems, green sturgeon are particularly susceptible to human-induced environmental changes, including impassible dams and barriers in spawning rivers, insufficient freshwater flows, non-native species, poaching, chemical contaminants, and entrainment by water projects (Adams et al. 2007).

Green sturgeon are separated into two distinct population segments (DPSs), based on spawning site fidelity and genetic information. The Northern DPS includes individuals spawning in the Rogue and Klamath-Trinity river systems, while the Southern DPS includes individuals spawning in the Sacramento River and its tributaries. Northern DPS fish do not appear to occur in natal waters of the Southern DPS and vice versa; however, the two DPSs overlap in marine and estuarine habitats. This is important because the Southern DPS is listed as threatened under the Endangered Species Act (ESA), whereas the Northern DPS is not (NMFS 2006). Because green sturgeon from the Northern and Southern DPS are morphologically indistinguishable, physical tagging or genetic data are needed to determine to which DPS an individual belongs. The total population size of the Southern DPS is estimated at 12,614-22,482 individuals (1,246-2,966 adults, 6,540-15,571 sub-adults, and 2,595-6,179 juveniles; Mora et al. 2018), and the population of the Northern DPS is likely considerably larger (Adams et al. 2007).

In marine waters, adults and sub-adults primarily occur at depths of 40-110 m (Erickson and Hightower 2007). Once green sturgeon enter coastal habitats, they tend to migrate northward from their natal habitats (Erickson and Hightower 2007, Lindley et al. 2008). The coastal marine waters from Monterey Bay to Vancouver Island are recognized as the primary migratory habitat, and in 2009 NMFS designated coastal marine waters within 60 fathoms (approximately 110 m) from Monterey Bay to the U.S.A-Canada border as critical habitat for the Southern DPS (NMFS 2009). NMFS also designated the Sacramento River system and the adjacent estuaries as critical habitat, as well as several coastal estuaries in California, Oregon, and Washington (NMFS 2009). Genetic and acoustic telemetry studies suggest that Northern DPS and Southern DPS fish co-occur in large concentrations in the Columbia River estuary, Grays Harbor, and Willapa Bay. The proportions of Southern DPS fish in those estuaries were found to be moderate to high (41- 81%), although they varied between years, between estuaries, and between the estimation methods (Israel et al. 2009). Genetic analyses on green sturgeon bycatch samples collected by observers for the years 2007-2017 indicated that the proportions of Southern DPS fish varied between years and fishing areas (pers. comm. Dr. Carlos Garza, SWFSC, NMFS, NOAA). When data are aggregated across the years, about 48% of the green sturgeon sampled off Oregon and Washington and 96% of the green sturgeon sampled off the California coast likely belonged to the Southern DPS.

West Coast groundfish fishery

The West Coast groundfish fishery is a multi-species fishery that utilizes a variety of gear types off the U.S. West Coast (California, Oregon, and Washington). The fishery harvests species designated in the Pacific Coast Groundfish Fishery Management Plan (FMP) and is managed by the Pacific Fishery Management Council (PFMC; PFMC 2016). Under the FMP, the groundfish fishery consists of four management components:

1) The Limited Entry (LE) component encompasses all commercial fishers who hold a federal limited entry permit. The total number of limited entry permits available is restricted. Vessels with an LE permit are allocated a larger portion of the total allowable catch for commercially desirable species than vessels without an LE permit.

2) The Open Access (OA) component encompasses federal commercial fishers who do not hold a federal LE permit. Some states require fishers to carry a state-issued permit for certain OA sectors.

3) The Recreational component includes recreational anglers who target or incidentally catch groundfish species. Recreational fisheries are not included in this report.

4) The Tribal component includes native tribal commercial fishers in Washington that have treaty rights to harvest groundfish. Tribal fisheries other than the Tribal at-sea hake fishery are not included in this report.

The NWFSC Observer Program

A core goal of the NWFSC Observer Program is to improve estimates of total catch and discards by observing commercial fishery sectors along the U.S. West Coast that target or incidentally take groundfish. Table 1-1 shows generalized descriptions of these sectors covered by this program. The program has two operational units: the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP). The WCGOP was established in May 2001 by NMFS in accordance with the Pacific Coast Groundfish Fishery Management Plan (NMFS 2001, implemented as 50 CFR Part 660). This regulation requires all vessels that catch groundfish in the U.S. Exclusive Economic Zone (EEZ) from 3-200 miles offshore to carry an observer when notified to do so by NMFS or its designated agent. Subsequent state rule-making has extended NMFS's ability to require vessels fishing in the 0-3 mile state territorial zone to carry observers.

The WCGOP and A-SHOP observe distinct sectors of the groundfish fishery. The WCGOP observes the following groundfish sectors: IFQ (formerly LE) shore-based delivery of trawl-allocated groundfish and Pacific hake, LE and OA non-nearshore fixed gear; and state-permitted nearshore fixed gear sectors. The WCGOP also observes several state-managed fisheries that incidentally catch groundfish, including the California halibut trawl and ocean shrimp trawl fisheries, and the directed Pacific halibut fishery, which is permitted by the International Pacific Halibut Commission. The A-SHOP observes the IFQ fishery that processes Pacific hake at sea including catcher-processor, mothership, and tribal vessels. Details on how fishery observers operate in both the IFQ and non-IFQ sectors can be found online at the Fisheries Observation Program website.

Amount and extent of take

The BiOp (NMFS 2012, p. 121-122) states that

"… take of threatened Southern DPS green sturgeon will occur as a result of the continued operation of the Pacific Coast groundfish fishery. Incidental take of Southern DPS green sturgeon is expected to occur as a result of incidental capture and handling in the fishery, mortalities resulting from encounter with fishing gear

and/or removal of captured fish from the water, and handling by the NMFS observer program. Under the proposed action, incidental take of Southern DPS green sturgeon because of bycatch and handling in the fishery is not expected to exceed 28 fish per year; however, we recognize the potential for incidental take of greater numbers of Southern DPS green sturgeon in some years. Therefore, this take statement allows for incidental take of up to 86 Southern DPS green sturgeon per year in no more than 2 years within a period of 9 consecutive years."

While the ESA listing and BiOp only apply to Southern DPS green sturgeon, this report includes information on all green sturgeon bycatch due to our limited ability to assign bycatch observations to DPS. We currently have limited information on the recapture rate of the same individual green sturgeon or level of mortality of green sturgeon after being caught, landed on the deck, observed, handled, and released by observers. Most observed green sturgeon in the groundfish bottom trawl fisheries are released alive, and the BiOp assumes a 5.2% mortality rate for bycatch in the LE trawl sector. However, using data from green sturgeon tagged by WCGOP observers onboard vessels targeting California halibut, Doukakis et al. (2020) estimated that post-release mortality ranged from 2% (0.53 hours after release) to 26% (~28 days after release).

Federal sectors that encountered green sturgeon

This section contains information from the LE and IFQ groundfish bottom trawl fishery and the at-sea hake fishery. No other federal sector covered by WCGOP or A-SHOP had observed green sturgeon bycatch during 2002-2019. Starting in 2015, the Pacific State Marine Fisheries Commission (PSMFC) has administered an Electronic Monitoring (EM) program in the IFQ fishery. This program has partial WCGOP observer coverage at sea and full video coverage that has been reviewed for the presence of green sturgeon. No green sturgeon bycatch was observed on the EM video system (Pers. Comm. Courtney Paiva, PSMFC), and we consider this to be a complete accounting of bycatch in EM trips. For details on observer coverage and EM coverage, see Somers et al. (2020).

Methods

Data sources

The analyses in this report use observer data from the WCGOP/A-SHOP and fish ticket data (i.e. landing receipts) from the Pacific Fisheries Information Network (PacFIN). For information on observer sampling protocols see the WCGOP and A-SHOP manuals (NWFSC 2020, 2021). For information on how observer and fish ticket data are processed, see Somers et al. (2021). Daily mean sea-surface temperature data used in the bycatch models was obtained from the NOAA OI SST V2 High Resolution Dataset provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA. Bathymetry data was obtained from the NOAA NGDC Coastal Relief Model (available at https://www.ngdc.noaa.gov/mgg/coastal/crm.html).

Bycatch estimation

We use ratio estimators to estimate fleet-wide green sturgeon bycatch within each sector. This is a simple and widely-used method for expanding observed discarding rates to unobserved catches. The general method is to estimate the total amount of bycatch in a stratum as

$$Estimated\ bycatch = \frac{Observed\ bycatch}{Observed\ effort} * Total\ effort$$

The stratum typically represents some combination of fishery sector, year, state, and time of year (winter or summer, defined as November-April or May-October, respectively). The ratio of observed bycatch to observed effort is called the bycatch ratio, and the total effort is termed the expansion factor. In this report, bycatch is counted in units of individual fish and effort is measured as the total retained weight of the target species (California halibut, groundfish, or Pacific hake, depending on the sector).

In sectors with less than 100% observer coverage, we quantify uncertainty around our estimates using a nonparametric bootstrap procedure. This procedure randomly selects vessels that were observed within a stratum with replacement to create a sample with the same number of vessels as the observed data. Random selection of vessels is intended to approximate the WCGOP vessel selection process. We calculate the bycatch ratio for each of 10,000 bootstrapped data sets to obtain a bootstrapped distribution of bycatch ratio estimates, and then determine the 2.5th and 97.5th percentiles of the estimates. We then calculate the 95% confidence interval of fleet-wide bycatch in the stratum by multiplying the confidence limits of the bycatch ratio by total landed weight of the target species in a given stratum. The lower confidence bound of the total fleet-wide bycatch estimate is truncated at the observed bycatch amount if the estimated lower bound was less than the observed bycatch amount.

If fewer than three vessels were observed in a given stratum, we calculated the bycatch ratio and performed bootstrapping using data pooled across two adjacent strata to ensure confidentiality. The resulting ratio estimates can be viewed as a three-year running average (see Lee et al. 2017 for details). Further sector specific methods are described below.

Individual fishing quota bottom trawl

All IFQ fishing trips carry an observer or electronic monitoring, but a very small number of tows or a small portion of catch from a given tow may be unsampled due to observer illness or other circumstances. Less than 0.4% of all landings on average were unsampled over 2011-2019 (Somers et al. 2020). Three types of unsampled catch categories can occur during observed trips: completely unsorted catch (discards and retained), unsampled discards, and unsampled non-IFQ species. Both completely unsorted catch and unsampled discard could contain both IFQ and non-IFQ species, but unsampled non-IFQ species only contains species that are not managed as individual quota species. Estimates of green sturgeon bycatch for the unsampled portion are derived for each unsampled category type separately using the ratio approach described above. We use the weight of the sampled catch as the denominator of the ratio and the weight of the unsampled catch as the expansion factor. Estimated bycatch from the unsampled portion of the catch is then added to the observed bycatch amount to obtain the total bycatch estimate. If no green sturgeon were observed in a stratum we assume no green sturgeon was encountered in the unsampled catch.

At-sea hake trawl

We report observed and expanded bycatch data obtained directly from A-SHOP for each at-sea hake fishery sector (catcher-processors, motherships, and tribal catch delivered at-sea). All vessels fishing in the at-sea hake fishery carry two A-SHOP observers for every fishing trip. On rare occasions, entire hauls might not be sampled due to unforeseen circumstances. These unsampled hauls are expanded at the strata level. Typically greater than 99% of hauls are sampled each year (Somers et al. 2020), thus the unsampled portion needing expansion is a very small fraction. The green sturgeon catch in unsampled hauls is estimated by multiplying the green sturgeon catch from the sampled hauls by the proportion of unsampled hauls over the total number of hauls per given stratum. This estimated green sturgeon catch for unsampled hauls is then added to the sum of all green sturgeon catch in the sampled hauls to produce the total estimated green sturgeon bycatch per given strata.

Genetic stock identification

Tissue samples collected by observers were analyzed by Dr. Carlos Garza (SFWC, NMFS, NOAA), and the resulting GSI data from 2007-2017 were used to estimate the expanded bycatch numbers in each DPS. From the samples that have been analyzed, the overall proportion of Southern DPS was 48% for those bycatch samples (n = 92) collected off Columbia River/Willapa Bay/Grays Harbor areas in the LE and IFQ-bottom trawl fishery sectors, when calculated across the all available years. The proportion of Southern DPS was 96% for those green sturgeon bycatch samples (n = 306) caught off San Francisco Bay/Half Moon Bay from the California halibut fishery sectors. Thus, the bycatch estimates not analyzed with GSI are multiplied by 0.48

for Washington and Oregon bycatch and by 0.96 for California to estimate the Southern DPS numbers per stratum. We apply the point estimates of DPS proportions to point estimates of expanded bycatch, so our estimates do not include uncertainty in bycatch or in DPS assignment.

Length, season, and depth visualizations

When green sturgeon are encountered on vessels, observers document fish length (in fork length), weight, and general condition, take photographs, scan for scute markings and tags, and take a tissue sample. If the specimen is obviously dead, the observer will also take a fin ray sample and determine sex. For more information on sampling protocols, see the WCGOP and A-SHOP manuals (NWFSC 2020, 2021). We present visualizations of the length frequency to show the size structure of encountered green sturgeon, proportions of sub-adults/adults, and the relationship between green sturgeon size and fishing depth. Because green sturgeon undertake seasonal migrations (Lindley et al. 2008), we also visualized the seasonal patterns in bycatch in the trawl fisheries. We used the monthly average bycatch ratio (the ratio of the observed number of green sturgeon to observed weight of landed target species) as a measure of seasonal bycatch risk relative to effort. Both tow depth and Julian day were also used as predictors in bycatch probability models.

Environmental correlates of bycatch

We use generalized additive models (GAMs), which allow for flexible nonlinear relationships between the response variable and predictors, to explore the relationship between environmental covariates and green sturgeon bycatch. These are similar to the models presented by Lee et al. (2015) and Richerson et al. (2020), but we include new data and updated model structures. We include year and Julian day as predictors to account for potential interannual and seasonal influences on green sturgeon bycatch. We include tow depth, daily mean sea surface temperature (SST), and bottom roughness (derived from bathymetry) to characterize habitat. Roughness is used as a measure of bottom habitat complexity, and was included because Huff et al. (2011) found that green sturgeon presence was correlated with high seafloor structural complexity. Haul duration is included as an offset to account for effort. We used a thin plate regression spline for all terms except Julian day, where we used a cyclic cubic spline to avoid discontinuity between December and January.

We modeled green sturgeon encounter probability using a binomial GAM as well as bycatch counts using a negative binomial GAM. Specifically, we fit the encounter model

$$Y_i \sim Bernoulli(p_i)$$

$$logit(p_i) = s(year) + s(average\ tow\ depth) + s(SST) + s(day) + s(latitude) + s(roughness) + \log(haul\ duration)$$

Where Y_i is a binary variable representing green sturgeon presence or absence in tow i and s() represents smooth functions. Similarly, we modeled counts as

$$N_i \sim NB(\mu_i, k)$$

$$log(\mu_i) = s(year) + s(average\ tow\ depth) + s(SST) + s(day) + s(latitude) + \log(haul\ duration)$$

Where N_i represents the observed green sturgeon count in tow i and μ_i and k are the mean and dispersion parameters of the negative binomial distribution, respectively.

We used the R package *mgcv* to fit these models using restricted maximum likelihood, a basis size of 10, and an additional penalty on the null space of each smooth. This penalization allows for smooths to be removed from the model, effectively performing model selection. Daily mean SST data at a 1/4° resolution were obtained from the NOAA OI SST V2 High Resolution Dataset, and we used linear interpolation to estimate

SST at each tow location. Bathymetry data at the 3 arc-second resolution were obtained from the NOAA NCEI U.S. Coastal Relief Model. Following Lee et al. (2015), we fit the models to a subset of the LE/IFQ observer data that included tows between 45° and 47° N. latitude with tow depths <60 fathoms. We did this to exclude habitats where the fishery is very unlikely to encounter green sturgeon. We first fit models that also included bathymetry and a smoothed interaction between latitude and longitude, but found high concurvity with tow depth, and therefore did not include these predictors. We also fit a Poisson model to the bycatch counts and found very similar results to the negative binomial model (albeit with slightly poorer model diagnostics) so we do not report those results here.

Results and discussion

Bycatch overview

Between 2002 and 2019, green sturgeon were encountered in the following federal sectors and years:

- LE bottom trawl fishery (in 2002, 2004, 2005, 2007, 2009, and 2010). Note that this fishery transitioned into the IFQ bottom trawl fishery in 2011.
- IFQ bottom trawl fishery (in 2011-2017).
- At-sea hake fishery (in 2005 and 2006).

Estimated bycatch was higher in the LE/IFQ bottom trawl compared to the at-sea hake fishery. All other federal sectors covered by the WCGOP had no observed green sturgeon bycatch. Figure 1.1 shows expanded bycatch estimates for all federal sectors 2002-2019.

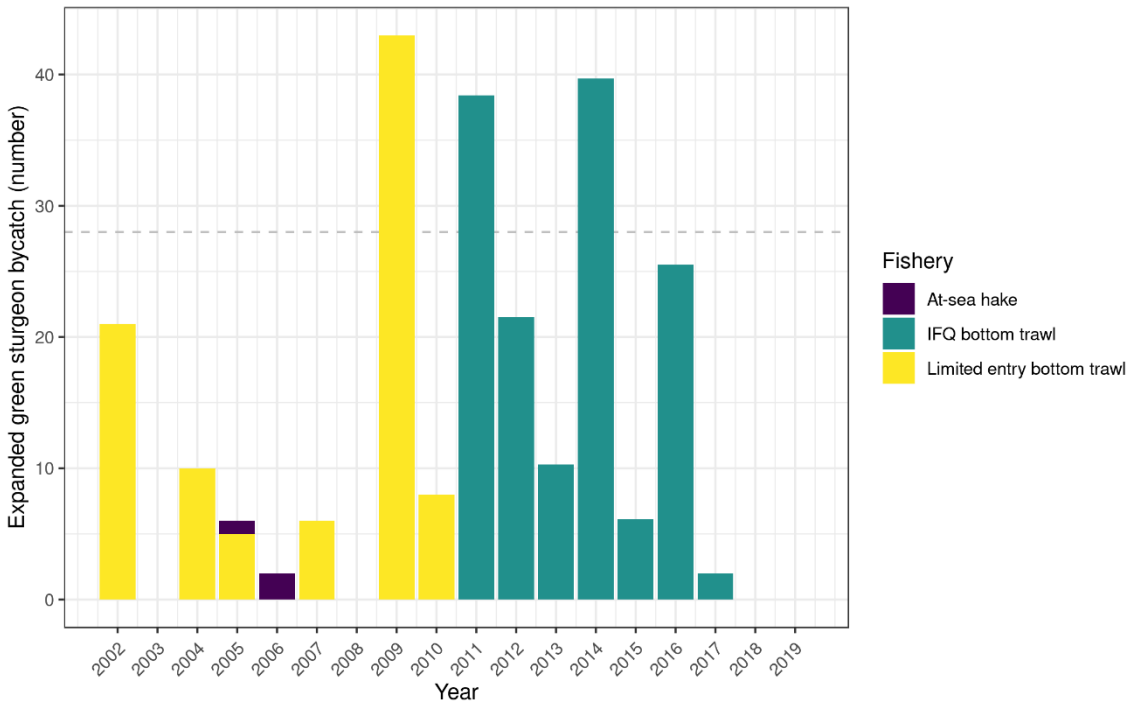

Figure 1.1. Combined Northern and Southern DPS green sturgeon bycatch estimates (number of individuals) for all federal sectors covered by the WCGOP and A-SHOP. The dashed line shows the annual limit of 28 Southern DPS individuals established by the BiOp.

Fishing effort in the LE/IFQ bottom trawl fishery was widely distributed from central California to northern Washington (Figure 1.2). Observed green sturgeon bycatch in this fishery was highest in southern Washington and northern Oregon, near the mouth of the Colombia River (Figure 1.2).

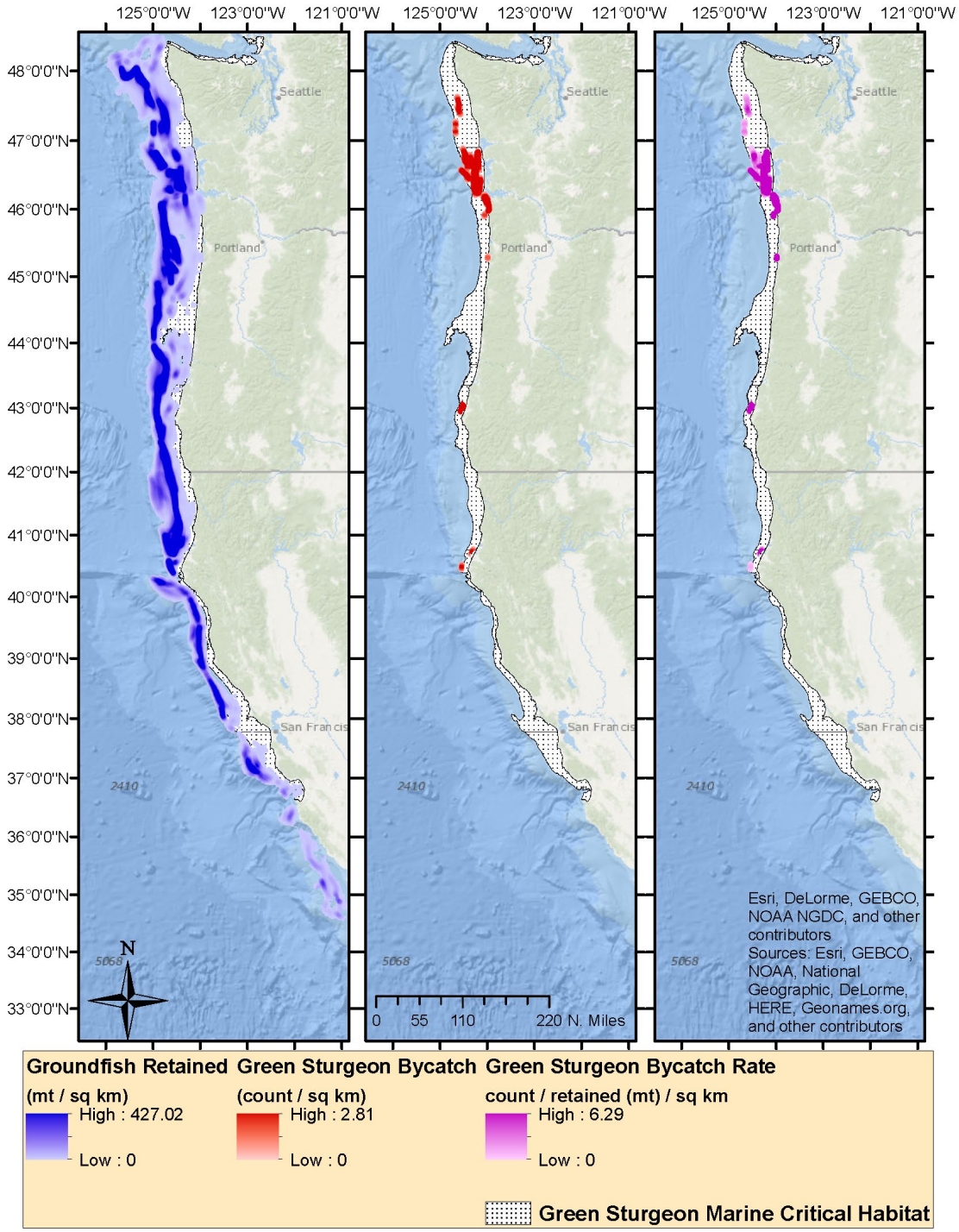

Figure 1.2. Map of observed fishing locations (left panel), observed green sturgeon bycatch locations (center panel), and observed bycatch per unit effort (right panel) in the limited entry and individual fishing quota bottom trawl sectors, based on observer data from 2002-2019. Observer data are aggregated to one-square-

kilometer cells. Fishing locations are weighted by fishing effort (landed weight of groundfish). Green sturgeon bycatch locations are weighted by number of green sturgeons in the defined spatial cells. Cells containing fewer than 3 vessels are not shown to maintain confidentiality.

Genetic stock identification

The estimated number of Northern and Southern DPS individuals encountered by federal groundfish fisheries from 2002-2019 are shown in Figure 0.1. The estimate for total green sturgeon bycatch in the IFQ fishery ranged from 0-12 per year over the most recent five-year period (2015-2019; Table 1-2). This is well below the limit of 28 Southern DPS takes established by the BiOp. The at-sea hake fishery did not have any green sturgeon bycatch in 2015-2019 (Table 1-3).

Limited entry bottom trawl

Expanded green sturgeon bycatch numbers in the LE bottom trawl fishery (2002-2010) are shown by state and time of year in Figure 1.3. Bycatch estimates, target landings, bycatch ratios, and coverage are presented in Table 1-4.

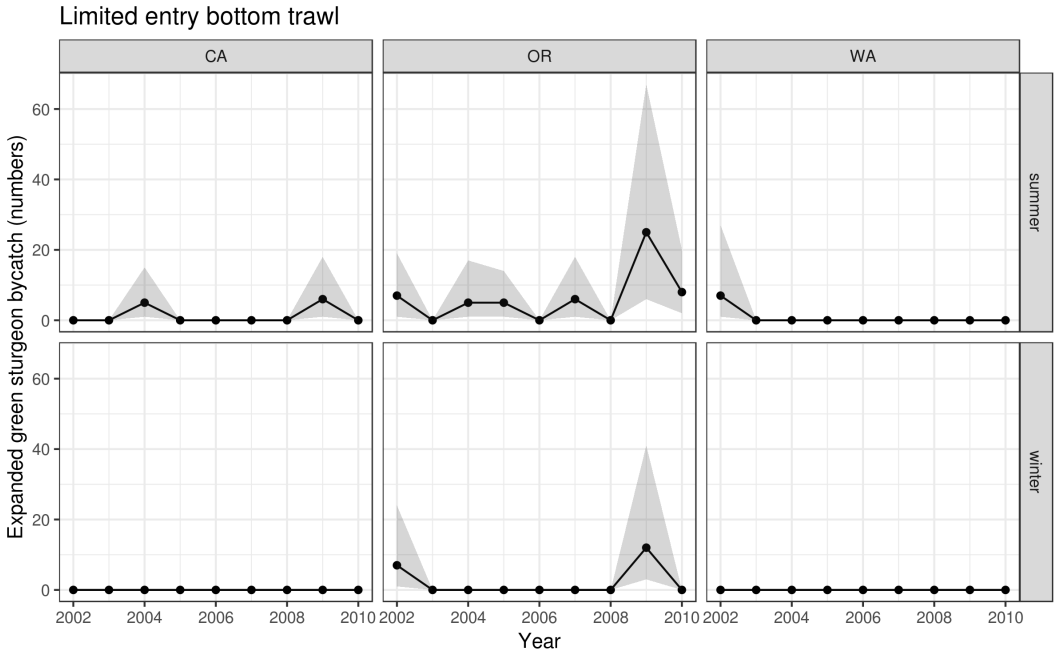

Figure 1.3. Green sturgeon bycatch estimates (numbers of individuals) in the limited entry bottom trawl fishery by state and time of year from 2002-2010. Winter is November-April and summer is May-October. Gray shading represents bootstrapped 95% confidence intervals.

Individual fishing quota bottom trawl

Expanded green sturgeon bycatch numbers in the IFQ bottom trawl fishery 2011-2019 are shown by state in Figure 1.4. Note that catch in this fishery is observed at close to 100%. Bycatch estimates, target landings, bycatch ratios, and coverage are presented in Table 1-5.

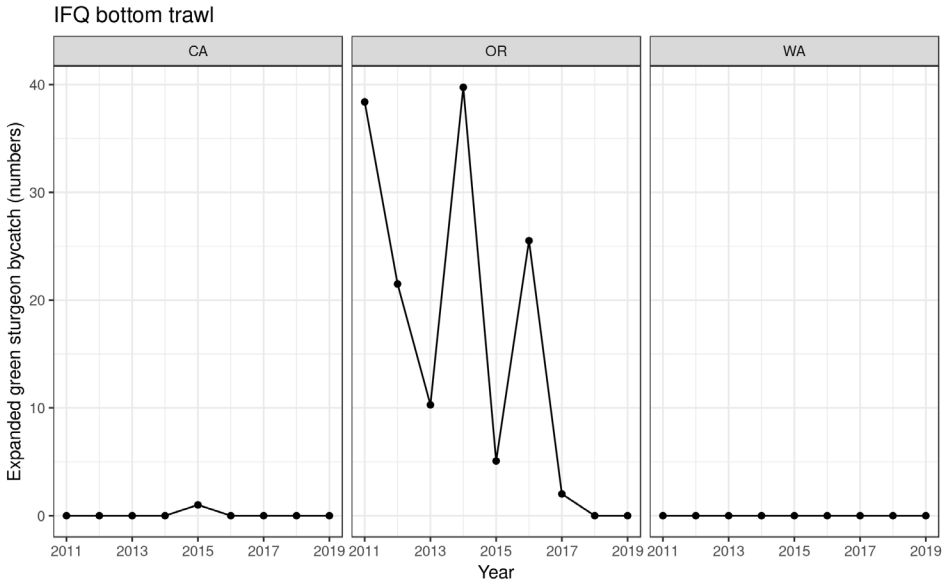

Figure 1.4. Green sturgeon bycatch estimates (numbers of individuals) in individual fishing quota (IFQ) bottom trawl fishery by state from 2011-2019. Note that catch in this fishery has nearly 100% observer coverage or electronic monitoring.

At-sea hake

Observed green sturgeon bycatch in the at-sea hake fishery is shown in Figure 1.5. Because of the high coverage rate, these values are equivalent to the expanded numbers. No bycatch of green sturgeon in this fishery has been observed since 2006. Bycatch estimates, target landings, bycatch ratios, and coverage are presented in Table 1-6.

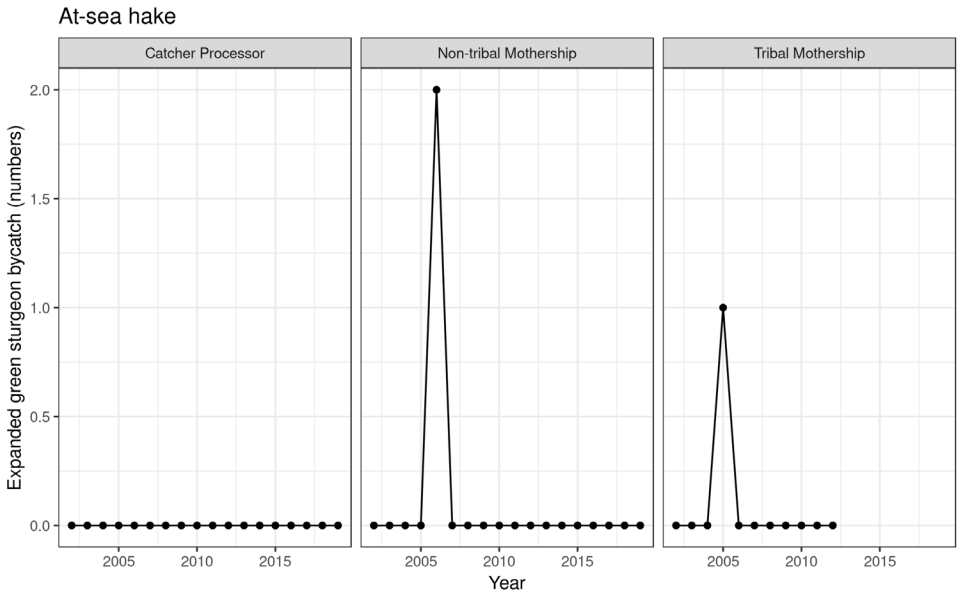

Figure 1.5. Green sturgeon bycatch estimates (number of individuals) in the at-sea hake fishery by sector from 2002-2019. Note that nearly 100% of hauls are sampled in this fishery.

Tow depth and green sturgeon bycatch

Green sturgeon bycatch generally occurred in trawl depths of <40 fathoms in the LE/IFQ trawl fishery (Figure 1.6). This fishery operated at a wide range of depths, with a mean tow depth of 208 ±132 fm, suggesting that most tows are unlikely to encounter green sturgeon.

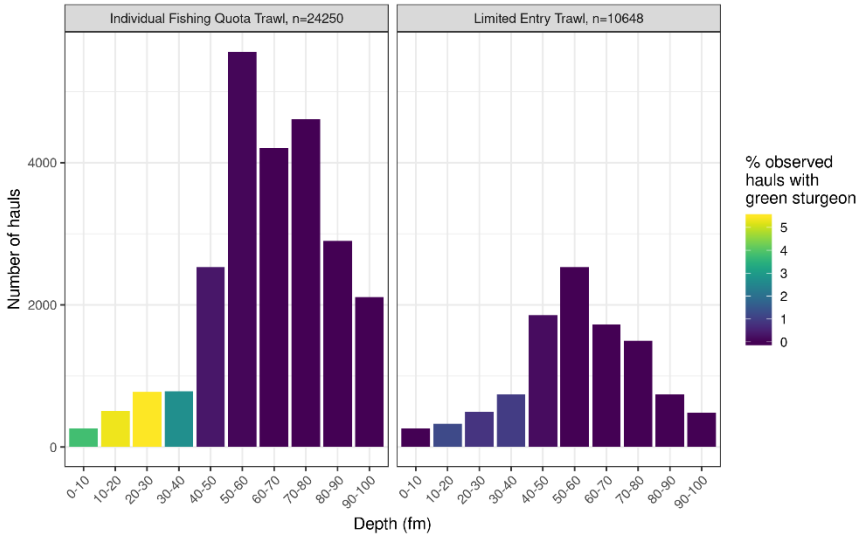

Figure 1.6. Distribution of observed haul depths and percent of hauls with green sturgeon in the individual fishing quota and limited entry bottom trawl fisheries 2002-2019. Hauls deeper than 100 fm are not shown because they did not encounter green sturgeon.

Length frequencies

Green sturgeon fork lengths from all observations over 2007-2019 ranged from 53-222 cm in the LE/IFQ trawl fishery (note that lengths were not recorded prior to 2007). The majority of individuals encountered by the IFQ trawl sector were <140 cm (the estimated length at maturity), indicating that bycatch is dominated by sub-adults. Observed bycatch in the LE trawl sector was comprised of approximately equal numbers of sub-adults and adults (Figure 1.7); however, only 14 individuals were measured in that sector.

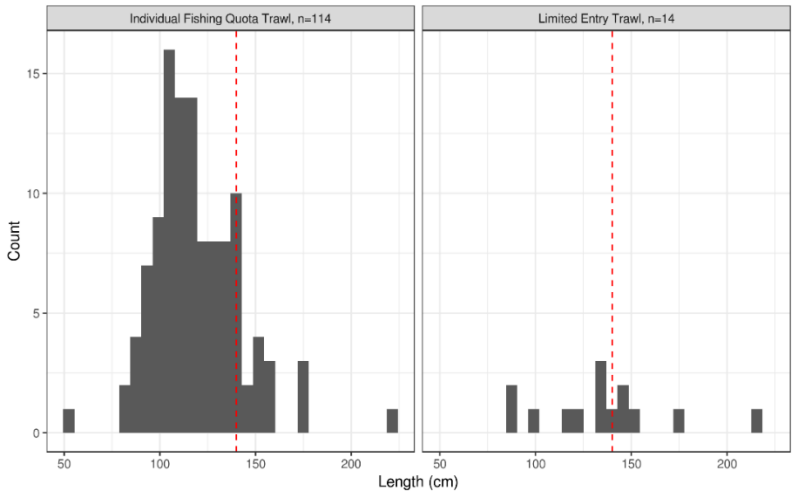

Figure 1.7. Distribution of observed green sturgeon lengths in the individual fishing quota and limited entry bottom trawl fisheries 2007-2019. The dashed red line indicates the boundary between sub-adult and adult size (140 cm).

Length and depth

There was no apparent relationship between observed green sturgeon length and tow depth in the LE/IFQ fishery (Figure 1.8).

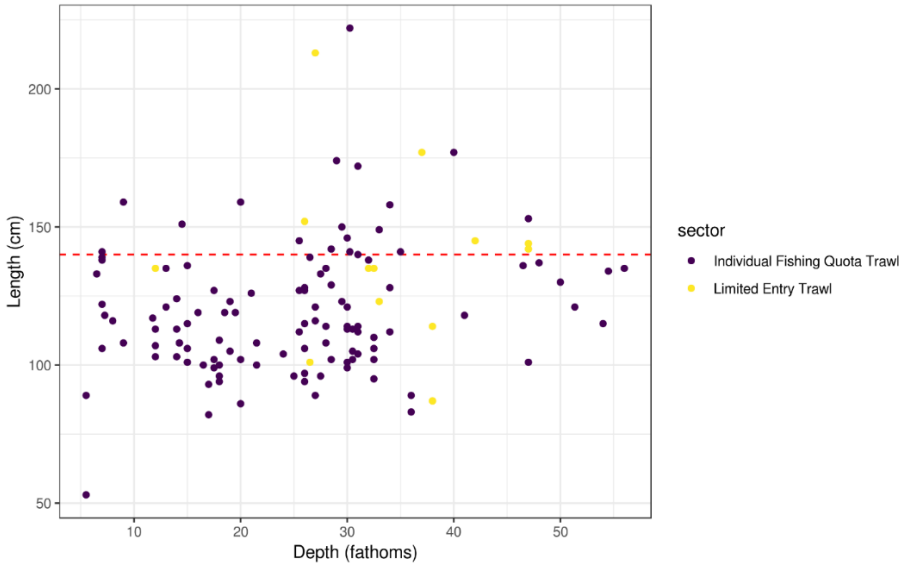

Figure 1.8. Scatter plot of green sturgeon lengths over average tow depths at capture in the limited entry and individual fishing quota bottom trawl sectors 2007-2019. The dashed red line indicates the boundary between sub-adult and adult size (140 cm).

Seasonal patterns

In the LE/IFQ bottom trawl fishery, average bycatch ratios were highest in the late winter/early spring (February and April) and late fall (November) (Figure 1.9). This may be related to the seasonal migration patterns noted in this species (Lindley et al. 2008).

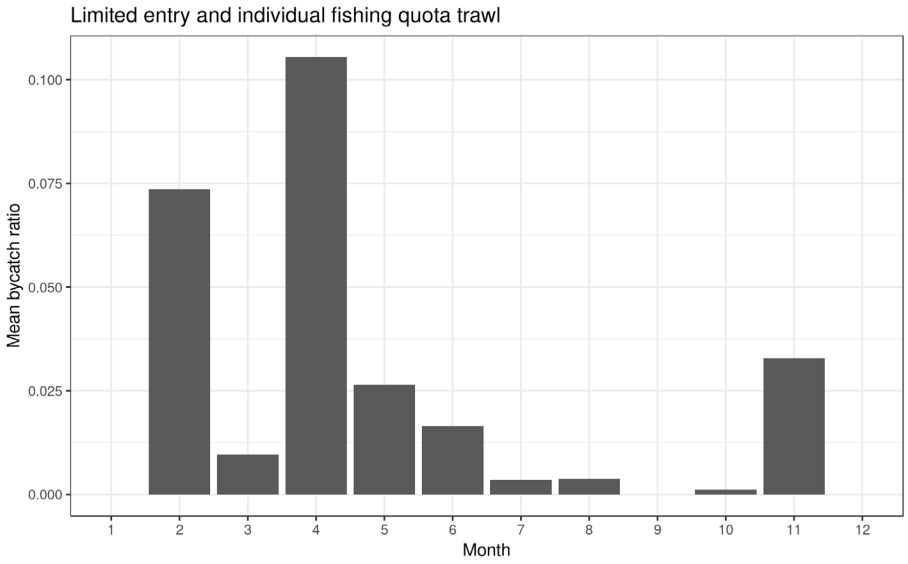

Figure 1.9. Mean bycatch ratio (number of green sturgeon observed divided by landed weight of observed groundfish) by month in the groundfish trawl fishery. Individual fishing quota and limited entry observations across all years are combined.

Environmental correlates of bycatch

In the LE/IFQ trawl fishery, Julian day, tow depth, and year had the largest impacts on bycatch in our models (Figure 1.10 and Figure 1.11). Latitude, SST, and rugosity had little to no effect in either model. Bycatch appeared to be highest in the spring at shallower tow depths. Deviance explained was 31.8% for the binomial encounter model and 47.6% for the negative binomial count model, indicating that these models do not fully capture the factors influencing bycatch. Further model results can be found in Table 1-7 and Table 1-8.

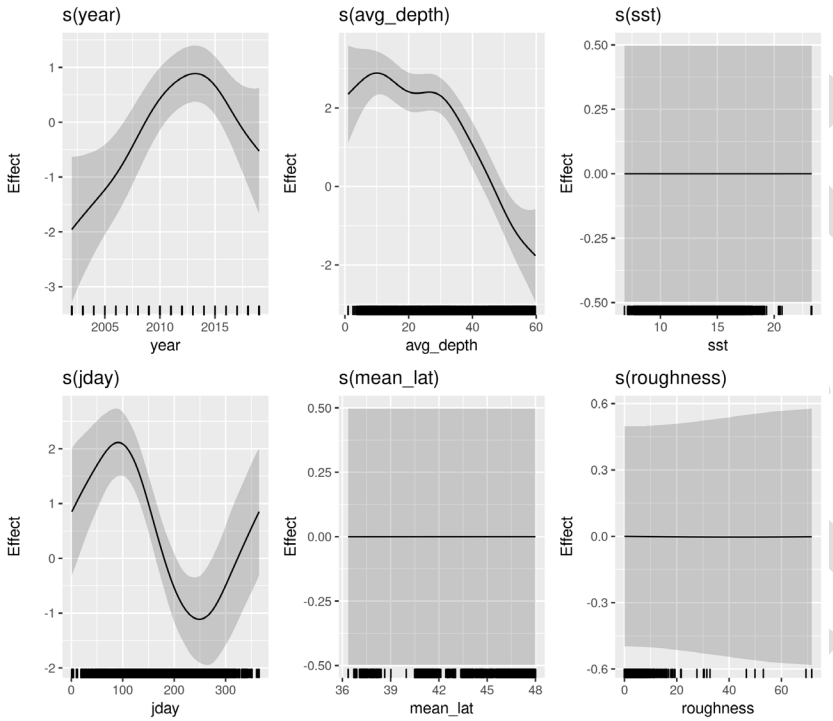

Figure 1.10. Estimated smooth functions for covariates in the binomial encounter probability model fit to limited entry and individual fishing quota bottom trawl data. Gray shading represents 95% confidence intervals.

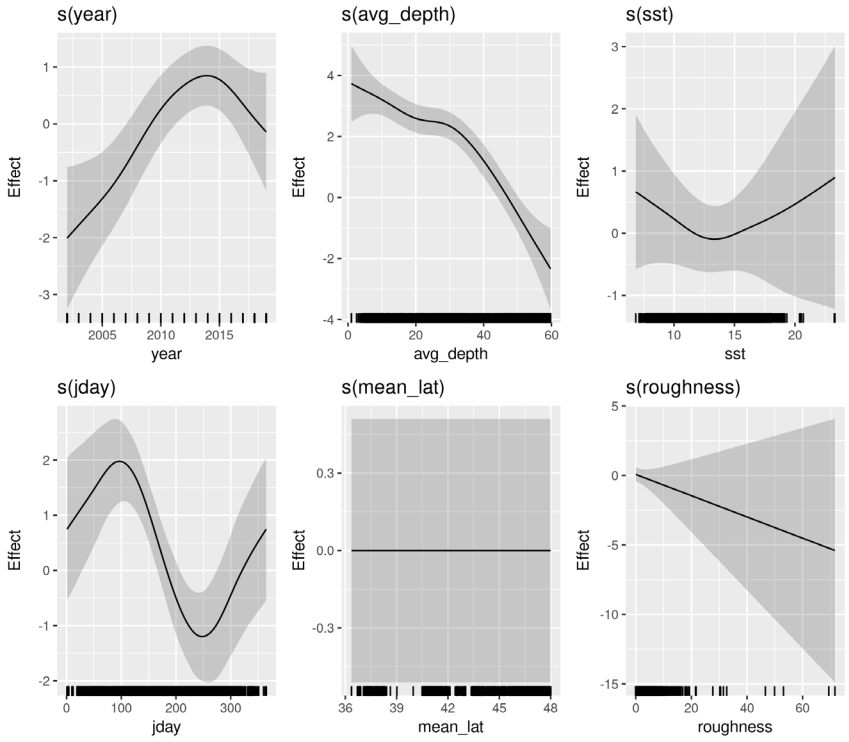

Figure 1.11. Estimated smooth functions for covariates in the negative binomial count model fit to limited entry and individual fishing quota bottom trawl data. Gray shading represents 95% confidence intervals.

Condition

When observers take biological samples from green sturgeon, they collect a fin ray sample only if the specimen is obviously dead. Thus, the number of individuals without fin ray samples taken can serve as a proxy for the maximum number of green sturgeon likely released alive after sampling. Few fin ray samples are collected in the LE/IFQ bottom trawl fishery; thus it appears that the large majority of green sturgeon encountered are likely alive at the time of release (Figure 1.12).

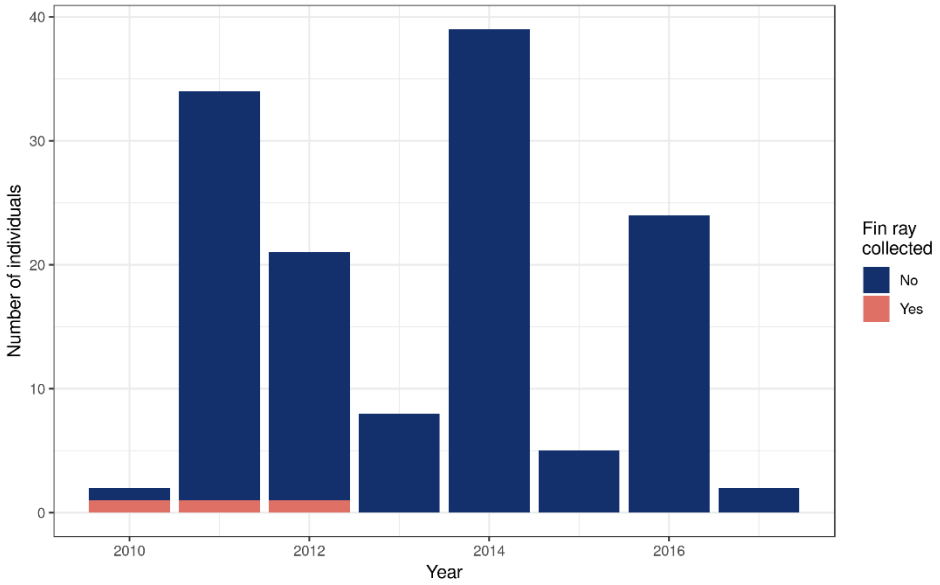

Figure 1.12. Number of green sturgeon sampled by observers with and without fin rays collected in the limited entry and individual fishing quota bottom trawl fishery from 2010 to 2019.

Tables

Sector descriptions

Table 1-1. Generalized descriptions of U.S. West coast fisheries observed by the West Coast Groundfish Observer Program and the At-Sea Hake Observer Program. Sectors that did not have observed green sturgeon bycatch at any time over 2002-2019 are in gray and sectors that did have observed green sturgeon bycatch are in black.

Federally managed Catch Shares fisheries								
Sector	**Sub-Sector**	**Permits**	**Gear(s)**	**Target(s)**	**Vessel Length (m)**	**Depths (m)**	**Management 2002-2010**	**Management 2011-present**
Federally managed Catch Shares fisheries								
Limited Entry (LE) Trawl	Limited Entry (LE) Trawl	Federal LE permit[1] with trawl endorsement	Bottom Trawl, after Jan 1, 2011 also Hook & Line and Pot gear	Groundfish assemblage	11-29	Wide range	Cumulative two-month trip limits; depth-based closures; 14-23% observer coverage	Individual Fishing Quotas (IFQ); 100% observer coverage
	LE California Halibut	CA Halibut permit[2] and LE permit with trawl endorsement[1]	Bottom Trawl	California halibut[5]	9-22	< 55	Cumulative two-month trip-limits; depth-based closures; 3-23% observer coverage	IFQ; 100% observer coverage
At-Sea Hake	Mothership-Catcher Vessel (MSCV)	LE permit with MSCV endorsement[1]	Midwater Trawl	Pacific hake[6]	26-45[4]	53-460[4]	Seasonal quotas for target and bycatch species of concern; 100% observer coverage	IFQ; Seasonal; 100% observer coverage
	Catcher-processors (CP)	LE permit with CP endorsement[1]	Midwater Trawl	Pacific hake	82-115	60-570	Seasonal quotas for target and bycatch species of concern; 100% observer coverage	IFQ; Seasonal; 100% observer coverage
	Tribal	(none)	Midwater Trawl	Pacific hake	< 38	53-460	Tribal	Seasonal; 100% observer coverage of at-sea deliveries

Shoreside Hake	n/a	LE permit with trawl endorsement[1]	Midwater Trawl	Pacific hake	17-29	Wide range	Seasonal quotas for target and bycatch species of concern; electronic monitoring	IFQ; Seasonal; 100% observer coverage

Other Federally managed fisheries							
Sector	Sub-Sector	Permits	Gear(s)	Target(s)	Length (m)	Depths (m)	Management 2002-present
Non-Nearshore Fixed Gear	Sablefish endorsed	LE permit with fixed gear endorsement[1] and sablefish quota	Longlines, Pots	Sablefish[7]	11-32	> 145	Sablefish tier quotas; seven month season; 9-27% observer coverage
	Sablefish non-endorsed (a.k.a. Zero Tier)	LE permit with fixed gear endorsement[1] w/o sablefish quota	Longlines, Pots	Sablefish, rockfish[8] and flatfish[9]	5-18	> 145	Trip limits; 1-12% observer coverage
	Open Access	(none)	Longlines, Pots	Sablefish and other groundfish	3-30	> 64	Trip limits; 1-6% observer coverage
	IPHC Pacific halibut directed	Pacific halibut permit from the International Pacific Halibut Commission	Longlines	Pacific halibut	3-32	40–400	Trip limits; 10-hr fishing periods south of Pt. Chehalis, WA Legal size: >82 cm
State managed fisheries							
Sector		Permits	Gear(s)	Target(s)	Length (m)	Depth (m)	Management
Open Access (OA) California Halibut		CA Halibut permit[2]	Bottom Trawl	California halibut	9-22	< 55	All fishing occurs within CA waters, most in the California Halibut Trawl Grounds where minimum mesh sizes, seven month season, and minimum size requirements hold; 1-

						16% observer coverage
Nearshore Fixed Gear[3]	CA or OR state nearshore permits and endorsements	Variety of hand lines, pot gear, stick gear, rod and reel	Rockfish, Cabezon[10], Greenlings[11]	3-15	< 110 (usu. < 55 in OR waters)	Federal and CA or OR state nearshore regulations; area closures; two-month trip limits; minimum size limits; 2-8% observer coverage
Pink Shrimp	WA, OR, or CA state pink shrimp permit	Shrimp trawl	Pink shrimp[12]	11.5-33	91-256	WA, OR, or CA state pink shrimp regulations; Bycatch Reduction Devices required; trip limits on groundfish landed; 4-14% observer coverage

[1]a.k.a., LE permit; all LE permits are issued by Federal agency (NOAA).
[2]Issued by the state of California.
[3]The state of WA does not conduct a nearshore fishery.
[4]Average values for catcher vessels delivering catch to motherships.
[5] *Paralichthys californicus*
[6]*Merluccius productus*
[7]*Anoplopoma fimbria*
[8]*Sebastes* spp.
[9] Pleuronectiformes
[10]*Scorpaenichthys marmoratus*
[11]Hexagrammidae
[12]*Pandalus jordani*

Limited entry and individual fishing quota bottom trawl GSI table

Table 1-2. Summary of expanded bycatch numbers of green sturgeon in limited entry bottom trawl (LE) and IFQ bottom trawl (IFQ) sectors by state (WA = Washington, OR = Oregon, and CA = California). Estimates of Southern DPS (SDPS) and Northern DPS (NDPS) bycatch are calculated based on individual assignments of genetic stock identification (GSI) and GSI proportions by catch areas (48% for WA and OR, 96% for CA). The LE sector was active 2002-2010 and the IFQ sector was active 2011-2019.

Year	CA SDPS	CA NDPS	CA total	OR SDPS	OR NDPS	OR total	WA SDPS	WA NDPS	WA total	SDPS total	NDPS + SDPS total
2002	0	0	0	6.6	7.3	13.9	3.5	3.8	7.2	10.1	21.2
2003	0	0	0	0	0	0	0	0	0	0	0
2004	4.5	0.2	4.7	2.5	2.7	5.3	0	0	0	7	9.9
2005	0	0	0	2.2	2.4	4.5	0	0	0	2.2	4.6
2006	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	3.7	1.8	5.5	0	0	0	3.7	5.5
2008	0	0	0	0	0	0	0	0	0	0	0
2009	5.4	0.1	5.5	17.3	20.3	37.6	0	0	0	22.7	43.1
2010	0	0	0	5.9	2.1	8	0	0	0	5.9	8
2011	0	0	0	19	19.4	38.4	0	0	0	19	38.4
2012	0	0	0	10.7	10.8	21.5	0	0	0	10.7	21.5
2013	0	0	0	4.9	5.4	10.3	0	0	0	4.9	10.3
2014	0	0	0	19.4	20.3	39.7	0	0	0	19.4	39.7
2015	1	0	1	2.4	2.6	5.1	0	0	0	3.4	6
2016	0	0	0	12.4	13.1	25.5	0	0	0	12.4	25.5
2017	0	0	0	1	1.1	2	0	0	0	1	2.1
2018	0	0	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0

At-sea hake GSI table

Table 1-3. Summary of expanded bycatch numbers of green sturgeon in the at-sea hake fishery. Estimates of Southern DPS (SDPS) and Northern DPS (NDPS) bycatch are calculated based on GSI proportions by catch area (48% for WA and OR, 96% for CA). For simplicity years and sectors without green sturgeon bycatch are not shown.

Year	Sector	SDPS total	NDPS + SDPS total
2005	Mothership	**0.48**	**1**
2006	Mothership	**0.96**	**2**

Limited entry trawl bycatch table

Table 1-4. Observed and fleet-wide total expanded numbers of green sturgeon bycatch from the limited entry bottom trawl fishery from 2002-2010. Asterisks (*) signify confidential strata with fewer than three observed vessels. Confidence intervals (CIs) in years with no bycatch are denoted as NA.

State	Year	Season	Observed bycatch	Observed target landings (MT)	Fleet-total target landings (MT)	Target landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet total bycatch	Lower CI of bycatch	Upper CI of bycatch
WA	**2002**	winter	0	297	1276.5	23.3	0	-	-	0	-	-
WA	**2002**	summer	1	142.4	1032.7	13.8	0.01	0	0.03	7	1	27
WA	**2003**	winter	0	124.3	1265.9	9.8	0	-	-	0	-	-
WA	**2003**	summer	0	56.4	647.9	8.7	0	-	-	0	-	-
WA	**2004**	winter	0	335.7	878.8	38.2	0	-	-	0	-	-
WA	**2004**	summer	0	179	902.5	19.8	0	-	-	0	-	-
WA	**2005**	winter	0	167.9	977.1	17.2	0	-	-	0	-	-
WA	**2005**	summer	0	408.6	1932.8	21.1	0	-	-	0	-	-
WA	**2006**	winter	0	89.1	511.3	17.4	0	-	-	0	-	-
WA	**2006**	summer	0	276.4	1194.6	23.1	0	-	-	0	-	-
WA	**2007**	winter	0	166	701	23.7	0	-	-	0	-	-
WA	**2007**	summer	0	60.7	813.1	7.5	0	-	-	0	-	-
WA	**2008**	winter	*	*	767	*	0	-	-	0	-	-

WA	**2008**	summer	0	292.1	832.7	35.1	0	-	-	0	-	-
WA	**2009**	winter	0	352	1355.8	26	0	-	-	0	-	-
WA	**2009**	summer	0	384	1200.4	32	0	-	-	0	-	-
WA	**2010**	winter	0	280.9	1230.6	22.8	0	-	-	0	-	-
WA	**2010**	summer	0	221.7	882.4	25.1	0	-	-	0	-	-
OR	**2002**	winter	1	579.8	4070.7	14.2	0	0	0.01	7	1	25
OR	**2002**	summer	1	490.8	3376.9	14.5	0	0	0.01	7	1	20
OR	**2003**	winter	0	801.5	4177.5	19.2	0	-	-	0	-	-
OR	**2003**	summer	0	551.2	4369.5	12.6	0	-	-	0	-	-
OR	**2004**	winter	0	1181.1	4372.8	27	0	-	-	0	-	-
OR	**2004**	summer	1	989.3	5201.2	19	0	0	0	5	1	17
OR	**2005**	winter	0	1204.2	4669.5	25.8	0	-	-	0	-	-
OR	**2005**	summer	1	1179.6	5348.4	22.1	0	0	0	5	1	14
OR	**2006**	winter	0	801.9	4070.1	19.7	0	-	-	0	-	-
OR	**2006**	summer	0	1123.5	6151.2	18.3	0	-	-	0	-	-
OR	**2007**	winter	0	851.2	5864.9	14.5	0	-	-	0	-	-
OR	**2007**	summer	1	1114.2	6147.7	18.1	0	0	0	6	1	18
OR	**2008**	winter	0	1335.7	7522.1	17.8	0	-	-	0	-	-
OR	**2008**	summer	0	1820.7	7360.1	24.7	0	-	-	0	-	-
OR	**2009**	winter	3	2167.9	8834.2	24.5	0	0	0	12	3	42
OR	**2009**	summer	6	1858.5	7846.9	23.7	0	0	0.01	25	6	67
OR	**2010**	winter	0	903.9	7445.9	12.1	0	-	-	0	-	-
OR	**2010**	summer	2	1850.6	7392.4	25	0	0	0	8	2	20
CA	**2002**	winter	0	462.8	3727.6	12.4	0	-	-	0	-	-
CA	**2002**	summer	0	523.5	3909.3	13.4	0	-	-	0	-	-
CA	**2003**	winter	0	333.4	2875.6	11.6	0	-	-	0	-	-
CA	**2003**	summer	0	566.9	4068.8	13.9	0	-	-	0	-	-
CA	**2004**	winter	0	734.4	2194.1	33.5	0	-	-	0	-	-
CA	**2004**	summer	1	756.6	3547.4	21.3	0	0	0	5	1	15
CA	**2005**	winter	0	496.7	2473.1	20.1	0	-	-	0	-	-

CA	**2005**	summer	0	585.8	3019.9	19.4	0	-	-	0	-	-
CA	**2006**	winter	0	365.4	1911.2	19.1	0	-	-	0	-	-
CA	**2006**	summer	0	590.8	2935.1	20.1	0	-	-	0	-	-
CA	**2007**	winter	0	424.5	2374.3	17.9	0	-	-	0	-	-
CA	**2007**	summer	0	694.8	3674.6	18.9	0	-	-	0	-	-
CA	**2008**	winter	0	555.6	3091.9	18	0	-	-	0	-	-
CA	**2008**	summer	0	648.5	3355.9	19.3	0	-	-	0	-	-
CA	**2009**	winter	0	548.4	2825.4	19.4	0	-	-	0	-	-
CA	**2009**	summer	1	636.6	3513.6	18.1	0	0	0.01	6	1	18
CA	**2010**	winter	0	203.5	2131	9.6	0	-	-	0	-	-
CA	**2010**	summer	0	581.9	3051.5	19.1	0	-	-	0	-	-

Individual fishing quota trawl bycatch table

Table 1-5. Observed and fleet-wide total expanded numbers of green sturgeon bycatch from the IFQ bottom trawl fishery from 2011-2019. Note that the IFQ fisheries are sampled at close to 100%.

State	Year	Observed bycatch	Observed groundfish landings (MT)	Fleet-total groundfish landings (MT)	Groundfish landings sampled (%)	Estimated bycatch from unsampled catch	Fleet total bycatch
WA	**2011**	0	1833.9	1855	98.9	0	0
WA	**2012**	0	2083.2	2119.6	98.3	0	0
WA	**2013**	0	1462.2	1463.9	99.9	0	0
WA	**2014**	0	717.3	719.9	99.6	0	0
WA	**2015**	0	434.8	434.8	100	0	0
WA	**2016**	0	451	451	100	0	0
WA	**2017**	0	834	834	100	0	0
WA	**2018**	0	747.2	747.2	100	0	0
WA	**2019**	0	838.4	838.4	100	0	0
OR	**2011**	37	10557.3	10637.2	99.2	1.4	38.4
OR	**2012**	21	10403.4	10469	99.4	0.5	21.5
OR	**2013**	10	12000.3	12035.3	99.7	0.3	10.3
OR	**2014**	39	10126	10184	99.4	0.7	39.7
OR	**2015**	5	11031.1	11080.8	99.6	0.1	5.1
OR	**2016**	25	12058.8	12101.5	99.6	0.5	25.5
OR	**2017**	2	12120.4	12131.8	99.9	0	2
OR	**2018**	0	9787.1	9824.5	99.6	0	0
OR	**2019**	0	9676.3	9714.4	99.6	0	0
CA	**2011**	0	4571.6	4577	99.9	0	0
CA	**2012**	0	4453.2	4461.7	99.8	0	0
CA	**2013**	0	5059	5072.7	99.7	0	0
CA	**2014**	0	4910.2	4934.8	99.5	0	0

CA	**2015**	1	4139.9	4142.6	99.9	0	1
CA	**2016**	0	2353.2	2353.2	100	0	0
CA	**2017**	0	3106.9	3109	99.9	0	0
CA	**2018**	0	2208.4	2208.4	100	0	0
CA	**2019**	0	2164.3	2190.2	98.8	0	0

At-sea hake bycatch table

Table 1-6. Observed and expanded bycatch numbers of green sturgeon from the at-sea hake fishery from 2002-2019. Note nearly 100% of hauls are sampled in this fishery. The tribal mothership sector did not participate in this fishery after 2012. Asterisks (*) signify confidential strata.

Sector	Year	Observed bycatch	Fleetwide expanded bycatch	Number sampled tows	Sampled hake landings (MT)	% tows sampled
Catcher Processor	2002	0	0	556	36332.9	99.5
Catcher Processor	2003	0	0	766	41468.6	99.7
Catcher Processor	2004	0	0	1492	72858.7	99.4
Catcher Processor	2005	0	0	1332	78497.5	99.6
Catcher Processor	2006	0	0	1488	78246.3	99.4
Catcher Processor	2007	0	0	1566	72898.1	99.3
Catcher Processor	2008	0	0	1864	107754.4	98.8
Catcher Processor	2009	0	0	863	34590.8	99.4
Catcher Processor	2010	0	0	1063	54217.3	99.5
Catcher Processor	2011	0	0	1530	71336.7	98.8
Catcher Processor	2012	0	0	1100	55522.6	99.4
Catcher Processor	2013	0	0	1439	78004.8	98.6
Catcher Processor	2014	0	0	1683	103171.3	99.2
Catcher Processor	2015	0	0	1503	68435.2	98.9
Catcher Processor	2016	0	0	2188	108780.6	99.2
Catcher Processor	2017	0	0	2143	137104.5	99.3
Catcher Processor	2018	0	0	1954	116005.5	99.1

Catcher Processor	2019	0	0	1936	116352.4	99.4
Non-tribal Mothership	2002	0	0	573	26502.9	99.8
Non-tribal Mothership	2003	0	0	522	25332.9	97.4
Non-tribal Mothership	2004	0	0	569	24010.1	99.6
Non-tribal Mothership	2005	0	0	1038	48600.6	99.8
Non-tribal Mothership	2006	2	2	1243	54138.8	96.9
Non-tribal Mothership	2007	0	0	1135	47276.3	99
Non-tribal Mothership	2008	0	0	1346	57687.4	99.8
Non-tribal Mothership	2009	0	0	597	24066.4	99.5
Non-tribal Mothership	2010	0	0	908	35726.9	100
Non-tribal Mothership	2011	0	0	1246	49970.6	99.8
Non-tribal Mothership	2012	0	0	931	38042.1	98.1
Non-tribal Mothership	2013	0	0	1249	52348.3	99.4
Non-tribal Mothership	2014	0	0	1288	61793.7	98.5
Non-tribal Mothership	2015	0	0	625	27544.5	97.7
Non-tribal Mothership	2016	0	0	1550	64597.1	99
Non-tribal Mothership	2017	0	0	1287	65358.5	98.3
Non-tribal Mothership	2018	0	0	1509	65979.1	98.3
Non-tribal Mothership	2019	0	0	1220	51829.1	99
Tribal Mothership	2002	0	0	625	21629	98.7
Tribal Mothership	2003	0	0	537	19430.8	99.4
Tribal Mothership	2004	0	0	632	23511.4	100
Tribal Mothership	2005	1	1	632	23561.6	99.8
Tribal Mothership	2006	0	0	154	5405.4	96.2
Tribal Mothership	2007	0	0	156	5129.4	100
Tribal Mothership	2008	0	0	380	14977.3	99.5
Tribal Mothership	2009	0	0	403	13469.4	99.8
Tribal Mothership	2010	0	0	516	16206.2	100
Tribal Mothership	2011	0	0	228	6146.9	100
Tribal Mothership	2012	*	0	*	*	*

Generalized additive models results

Table 1-7. Results from the binomial generalized additive model of green sturgeon encounter probability in the limited entry/individual fishing quota trawl fishery.

Term	Est. DF	Ref. DF	Statistic	p value
s(year)	3.019	9	33.662	<0.001
s(avg_depth)	3.927	9	121.535	<0.001
s(sst)	0	9	0	0.691
s(jday)	3.96	9	92.569	<0.001
s(mean_lat)	0	9	0	0.391
s(roughness)	0.002	9	0.002	0.349

Table 1-8. Results from the negative binomial generalized additive model of green sturgeon bycatch counts in the limited entry/individual fishing quota trawl fishery.

Term	Est. DF	Ref. DF	Statistic	p value
s(year)	2.811	9	34.203	<0.001
s(avg_depth)	3.474	9	133.289	<0.001
s(sst)	1.254	9	2.224	0.138
s(jday)	4.275	9	55.298	<0.001
s(mean_lat)	0	9	0	0.452
s(roughness)	0.609	9	1.32	0.14

Section 2. State Fisheries

Introduction

State-managed fisheries do not fall under the 2012 Biological Opinion (BiOp) for green sturgeon. We provide information on them here because they are important from a conservation perspective, but note that recommendations to the PFMC regarding green sturgeon under the BiOp should not include these fisheries. For further background on green sturgeon, West Coast groundfish fisheries, the West Coast Groundfish Observer Program (WCGOP), and the BiOp, see Section 1.

State sectors that encountered green sturgeon

This section includes information on the limited entry (LE) and open access (OA) California halibut fishery and the California nearshore fixed-gear fishery. The nearshore fixed gear and OA California halibut sectors are state-permitted and are therefore not regulated under the Pacific Coast Groundfish FMP. The LE California halibut sector requires both a California halibut permit and an LE federal trawl groundfish permit, making it both federally- and state-permitted. However, it is not covered by the BiOp and is therefore included in this section. The state of California requested that the WCGOP observe the California halibut fishery and report discarded catch, much of which is incidentally caught groundfish and thus of interest to federal groundfish fisheries. No other state-managed fisheries covered by the WCGOP encountered green sturgeon over 2002-2019.

Methods

The WCGOP classifies vessels in the California halibut fishery as belonging to either the LE or OA sector and provides observer coverage for both sectors. Vessels in the LE sector possess both a federal LE groundfish permit and a state-issued California halibut fishing permit. This sector has not been active since 2013. Vessels in the OA sector only possess state-issued CA halibut fishing permits. The LE sector exists as a portion of the LE/IFQ groundfish bottom trawl sector, so the WCGOP defines LE California halibut data based on the following criteria: 1) the tow target was California halibut; or 2) the tow target was nearshore mix, sand sole or other flatfish, and the tow took place in less than 30 fathoms south of 40°10' N latitude. All tows in the observer data that met at least one of the above requirements were included in the LE California halibut bottom trawl dataset. The WCGOP randomly selects the fishing vessels in the OA California halibut sector separately for observer coverage. Since 2011 the LE California halibut sector has operated under the IFQ fishery rules with 100% observer coverage, though again note this sector has not been active since 2013.

Both California and Oregon have state-permitted nearshore fixed-gear fisheries. Green sturgeon has not been observed in the Oregon fishery, so we only report estimates for the California fishery, which had one instance of observed bycatch in 2017 and none in other years. We estimate total bycatch using the ratio approach described in Section 1; however, the low coverage rate (averaging 4.4% of target landings) and low green sturgeon encounter rate in this fishery may result in inaccurate estimates for this fishery (Babcock et al. 2003).

For further information on data sources, bycatch estimation, models relating green sturgeon bycatch to environmental predictors, and other methods, see Section 1. Note that for the purposes of modeling encounter probability and bycatch counts we restricted the data to tows north of 37.15° N. latitude with depths < 40 fathoms. We imposed these restrictions to exclude habitats where the fishery is very unlikely to encounter green sturgeon. Only one green sturgeon has been observed as bycatch in the fishery outside this area/fishing depth.

Results and discussion

Bycatch overview

Between 2002 and 2019, green sturgeon were encountered in the following state-managed sectors and years:

- California nearshore fixed-gear fishery (in 2017)
- LE and OA California halibut bottom trawl fishery (in 2002-2019)

Bycatch was highest in the California halibut bottom trawl fishery, which encountered an estimated 288-664 green sturgeon annually over the most recent five year period (2015-2019). Only one instance of bycatch was observed in the California nearshore fishery between 2002 and 2019. Estimates of expanded green sturgeon bycatch by sector are shown in Figure 2.1.

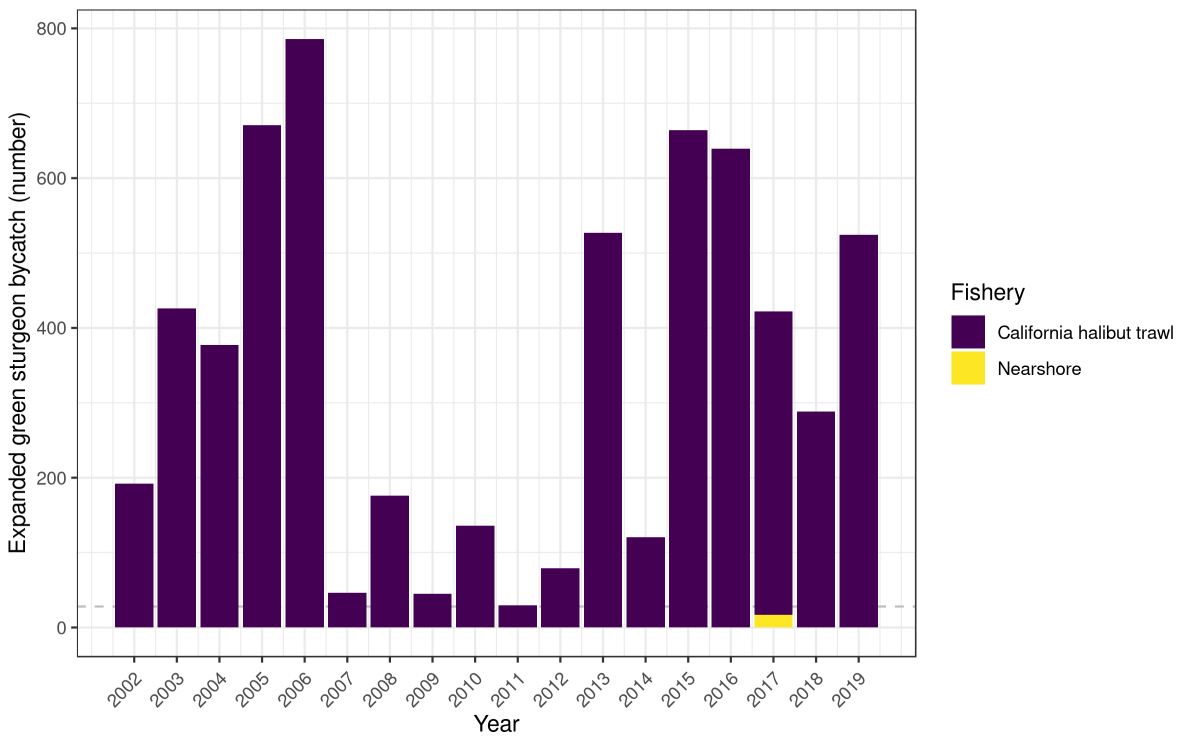

Figure 2.1. Green sturgeon bycatch estimates (number of individuals) for all state sectors covered by the WCGOP. Estimates for the limited entry and open-access California halibut sectors are shown combined.

Fishing effort in the LE/OA California halibut fishery was highest outside the San Francisco Bay, with some fishing occurring further south (Figure 2.2). Green sturgeon bycatch in this fishery primarily occurred close to shore outside the San Francisco Bay (Figure 2.2).

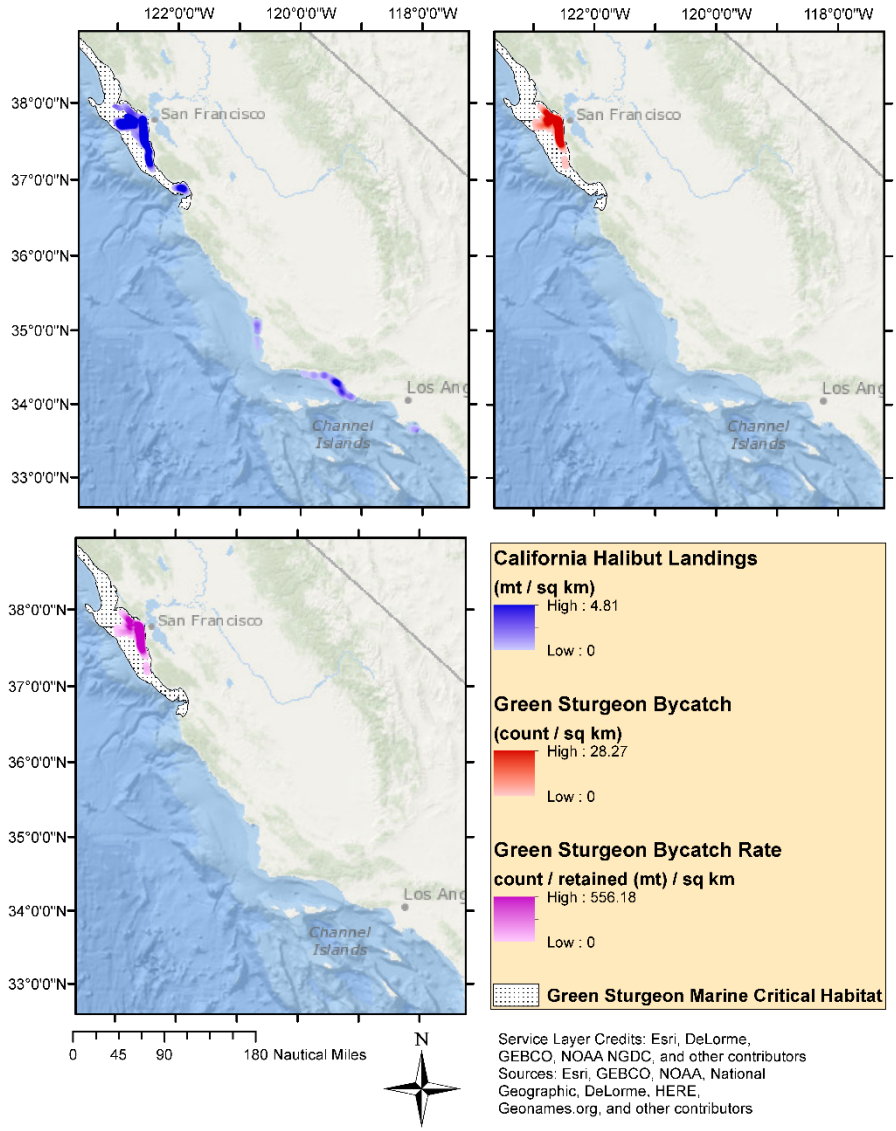

Figure 2.2. Map of observed fishing locations (upper left panel) and observed green sturgeon bycatch locations (upper right panel) in the limited entry and open access California halibut bottom trawl sectors, based on observer data from 2002-2019. Observer data are aggregated to one-square-kilometer cells. Fishing locations are weighted by fishing effort (landed weight of California halibut). Green sturgeon bycatch locations are weighted by number of green sturgeon in the defined spatial cells. Cells containing fewer than 3 vessels are not shown to maintain confidentiality.

Genetic stock identification

The estimated number of Northern and Southern DPS individuals are shown in Figure 2.3. The California halibut fishery had the highest estimated Southern DPS bycatch, ranging from 278-640 in the past five years (Table 2-1). The California nearshore sector caught an estimated 16 Southern DPS individuals in 2017 only (Table 2-2). However, as noted elsewhere, the estimates for the California nearshore sector may be inaccurate due to low coverage and encounter rates.

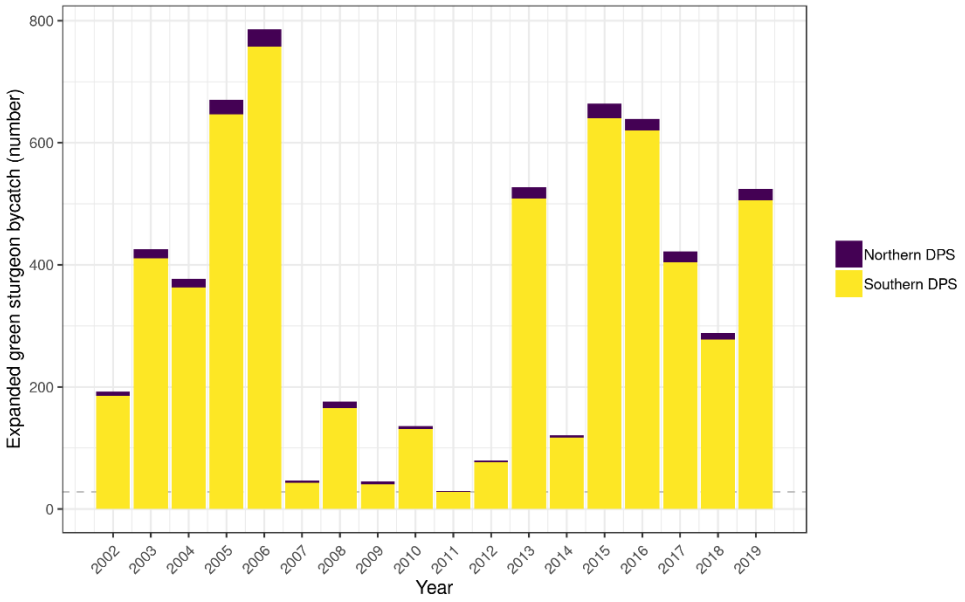

Figure 2.3. Green sturgeon bycatch estimates (number of individuals) in state-managed groundfish fisheries by distinct population segment (DPS). Estimates of bycatch by DPS are calculated based on individual assignments of genetic stock identification (GSI) and GSI proportions by catch areas (48% Southern DPS for Washington and Oregon, 96% Southern DPS for California).

California halibut

Green sturgeon bycatch estimates in the LE and OA California halibut fishery are shown in Figure 2.4 (2002-2010) and Figure 2.5 (2011-2019). To preserve confidentiality, the LE and OA sectors are combined across seasons from 2011-2019, though note the LE fishery was not active after 2013. Bycatch estimates, target landings, bycatch ratios, and coverage are presented in Table 2-3 and Table 2-4.

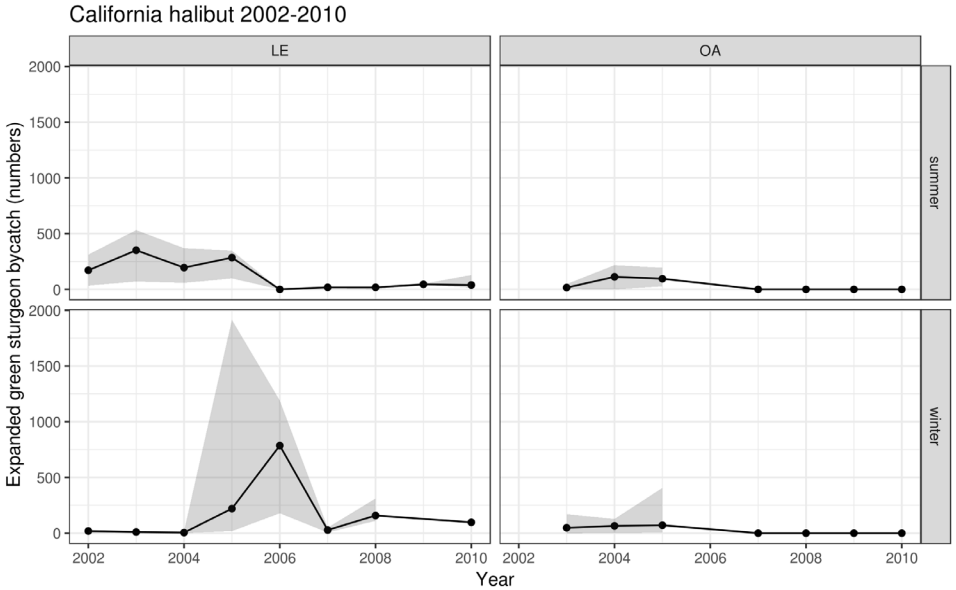

Figure 2.4. Green sturgeon bycatch estimates (numbers of individuals) in the limited entry (LE) and open access (OA) California halibut fisheries by time of year from 2002-2010. Winter is November-April and summer is May-October. Gray shading represents bootstrapped 95% confidence intervals.

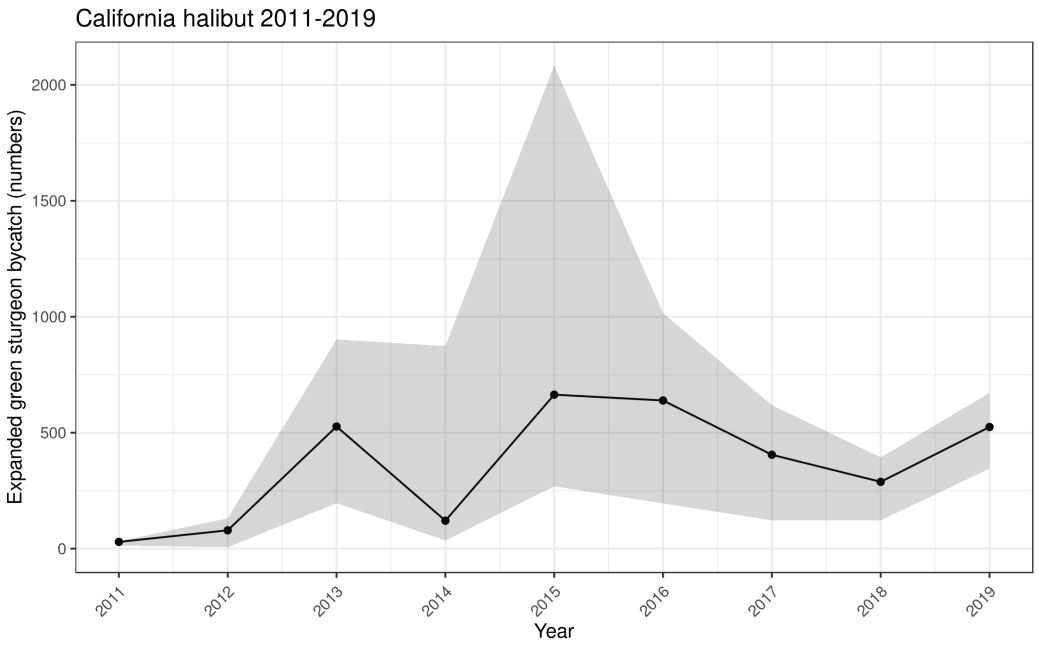

Figure 2.5. Green sturgeon bycatch estimates (numbers of individuals) in the combined limited entry and open access California halibut fisheries 2011-2019. Gray shading represents bootstrapped 95% confidence intervals.

California nearshore fixed gear

The first instance of observed green sturgeon bycatch in the California nearshore fixed-gear fishery occurred in 2017, consisting of a single individual caught with hook and line gear. The observation occurred near the mouth of the San Francisco Bay (between 37.2° and 38.2° N. latitude) in summer. The observer noted that the fish dropped off the line before being brought on board, so no biological data was taken. The expanded green sturgeon bycatch estimate for 2017 was 16 individuals (95% CI 1-58 individuals) and 0 for all other years. Table 2-5 contains further information about retained groundfish catch, observer coverage, and bycatch ratios. Note that the combination of low encounter rates and low observer coverage is likely to result in inaccurate bycatch estimates when ratio estimators are used (Babcock et al. 2003). Less than 10% of groundfish landings are typically covered by observers in this fishery (Table 2-5) and the historical lack of observed green sturgeon bycatch indicates low encounter rates. Thus, the expanded bycatch numbers estimated for this fishery should be interpreted with caution.

Tow depth and green sturgeon bycatch

Green sturgeon bycatch generally occurred in trawl depths of <40 fm in the California halibut trawl fishery and was most common at depths of <10 fm (Figure 2.6.). Tows in this fishery averaged 19±9 fm, indicating that most tows in this fishery occur in the depth range where green sturgeon may be encountered.

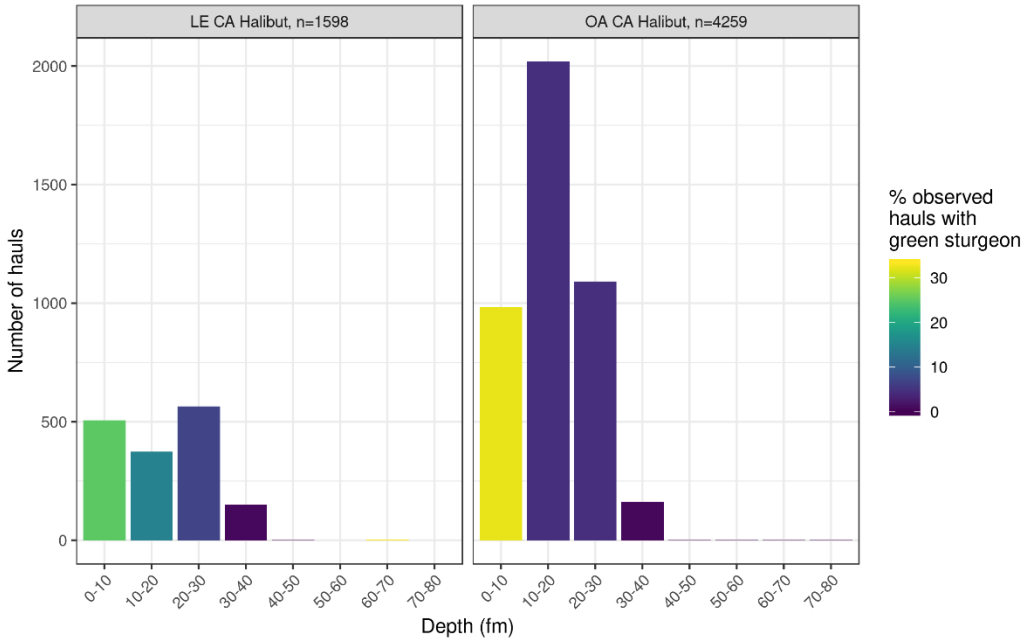

Figure 2.6. Distribution of hauls depths and percent of hauls with green sturgeon in the limited entry and open access California halibut bottom trawl fisheries 2002-2019.

Length frequencies

Observed green sturgeon fork lengths ranged from 59-213 cm in the California halibut sectors (Figure 2.7). The majority of individuals were <140 cm (the estimated length at maturity), indicating that bycatch is dominated by sub-adults.

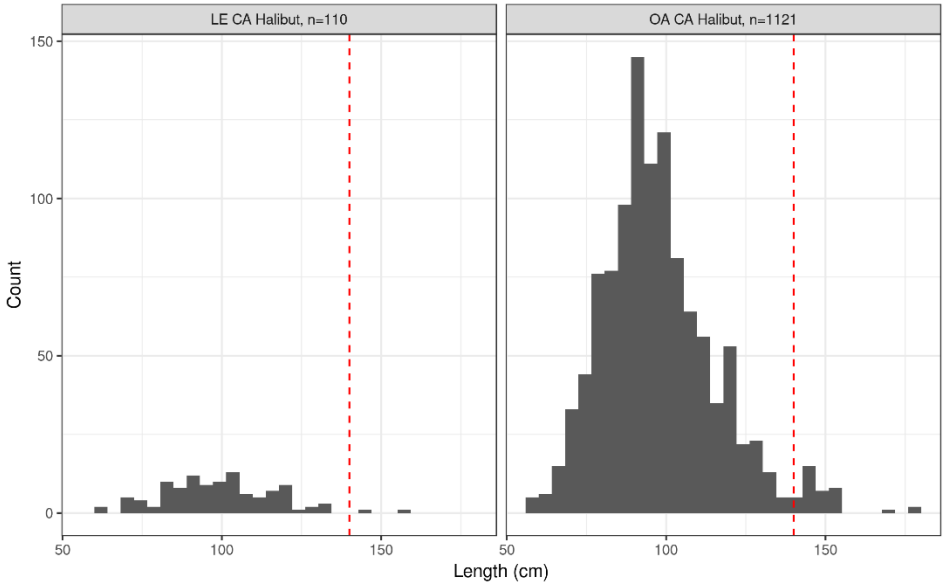

Figure 2.7. Distribution of green sturgeon lengths in the limited entry and open access California halibut bottom trawl fishery 2007-2019. The dashed red line indicates the boundary between sub-adult and adult size (140 cm).

Length and depth

There was no apparent relationship between green sturgeon length and tow depth in the California halibut trawl fishery (Figure 2.8).

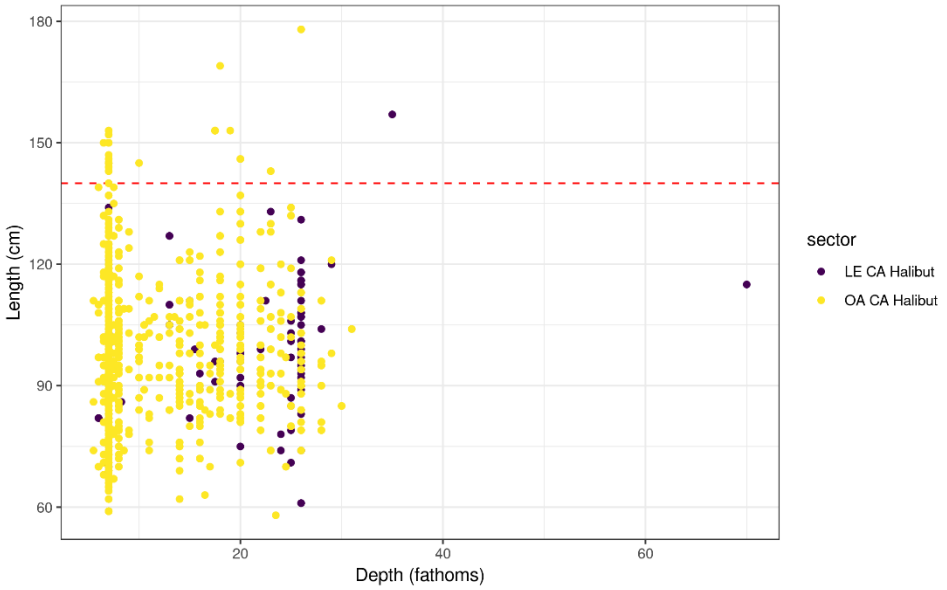

Figure 2.8. Scatter plot of green sturgeon lengths over fishing depths at capture in the limited entry and open access California halibut bottom trawl sectors 2007-2019. The dashed red line indicates the boundary between sub-adult and adult size (140 cm).

Seasonal patterns

In the California halibut trawl fishery, the average bycatch ratios were highest in the spring (April and May) and fall/winter (October-December) (Figure 2.9). They were lowest in late winter (January-March).

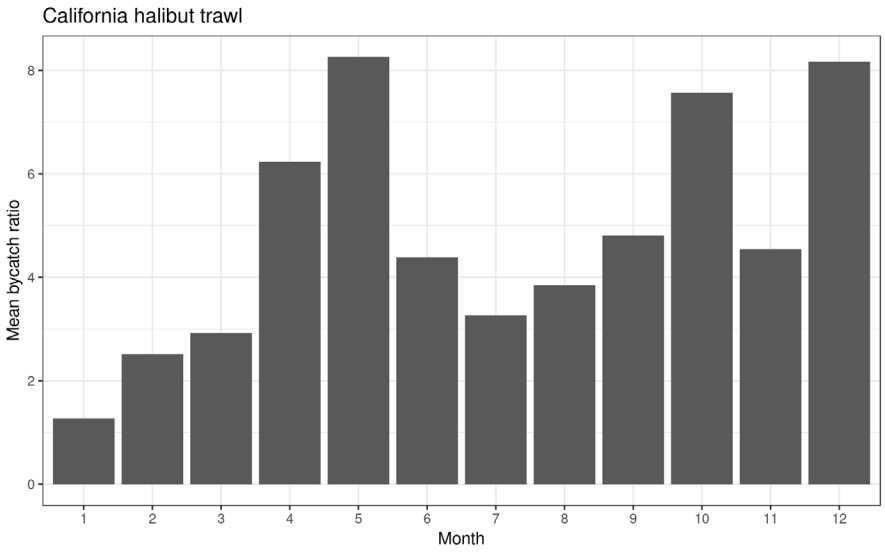

Figure 2.9. Mean bycatch ratio (number of green sturgeon caught divided by landed weight of California halibut) by month in the California halibut trawl fishery. Open access and limited entry observations are combined.

Environmental correlates of bycatch

In the California halibut fishery, tow depth, year, latitude, and Julian day had the largest impacts on green sturgeon bycatch in our models (Figure 2.10 and Figure 2.11). SST had a smaller effect, and was not statistically significant at the 0.05 level in the negative binomial model. Roughness did not have a significant effect in either model. The results indicate that bycatch is likely to be highest in spring and fall at shallow tow depths near the mouth of the San Francisco Bay. However, note that percent of deviance explained was only 25% for the binomial encounter model and 35.6% for the negative binomial count model, indicating fairly large amounts of unexplained variation in bycatch. For tables of model results, see Table 2-6 and Table 2-7.

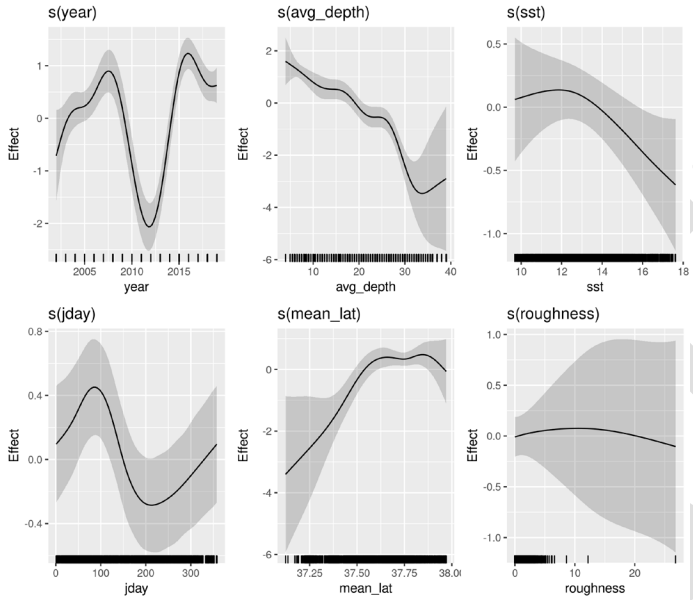

Figure 2.10. Estimated smooth functions for covariates in the binomial encounter probability model fit to California halibut trawl fishery data. Gray shading represents 95% confidence intervals.

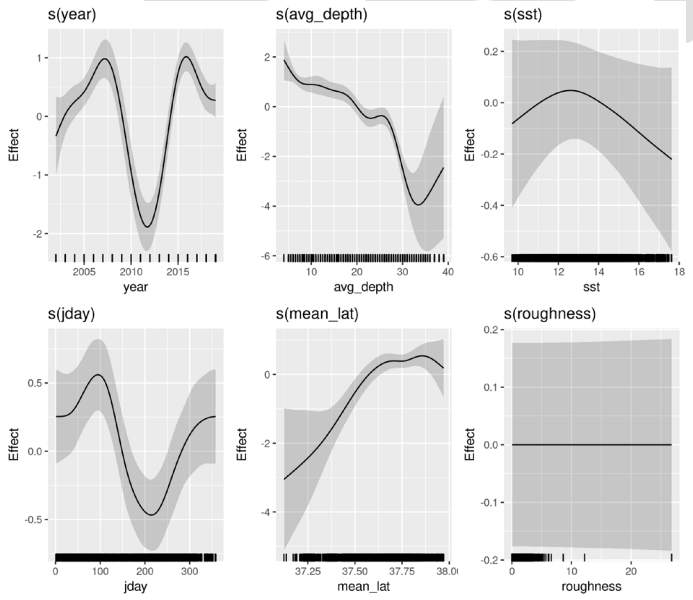

Figure 2.11. Estimated smooth functions for covariates in the negative binomial bycatch count model fit to California halibut trawl fishery data. Gray shading represents 95% confidence intervals.

Condition

When observers take biological samples from green sturgeon, they collect a fin ray sample only if the specimen is obviously dead. Thus, the number of individuals without fin ray samples taken can serve as a proxy for the maximum number of green sturgeon likely released alive after sampling. Few fin ray samples are collected in the California halibut bottom trawl fishery; thus it appears that the large majority of green sturgeon encountered are likely alive at the time of release (**Error! Reference source not found.**).

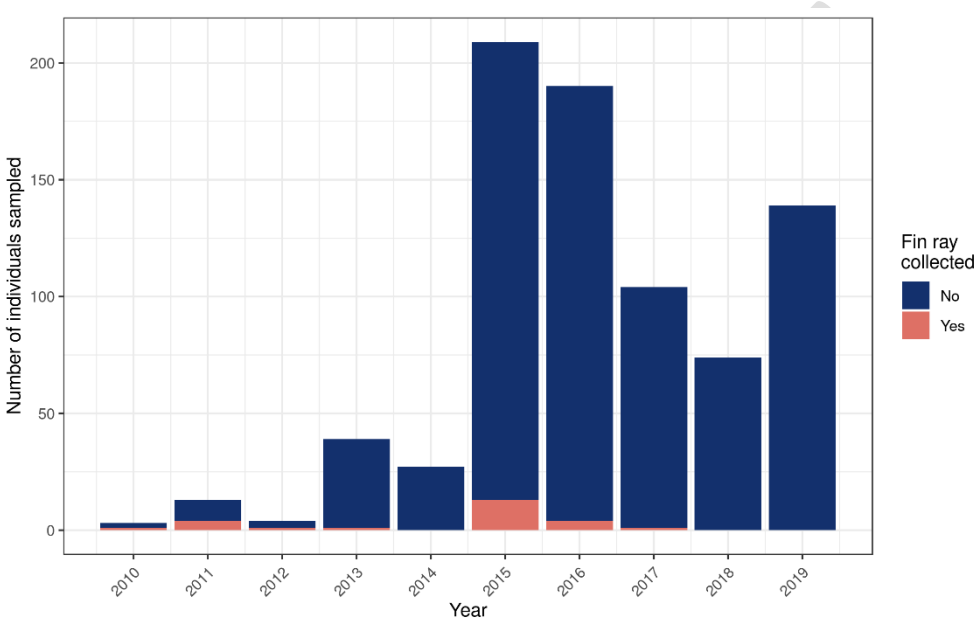

Figure 2.12. Number of green sturgeon sampled by observers with and without fin rays collected in the limited entry and open access California halibut bottom trawl fishery from 2010 to 2019.

Tables

California halibut GSI table

Table 2-1. Summary of expanded fleet-wide bycatch estimates of green sturgeon in the combined limited entry (LE) and open access (OA) California halibut sectors. Estimates of Southern DPS (SDPS) bycatch are calculated based on individual assignments and the genetic stock proportion (96%) of green sturgeon in CA.

Year	NDPS	SDPS	NDPS + SDPS total
2002	6.9	185.1	192
2003	15.3	410.7	426
2004	13.6	363.4	377
2005	24.1	646.9	671
2006	28.3	757.7	786
2007	3	43	46
2008	10.7	165.3	176
2009	4.4	40.6	45
2010	4.9	131.1	136
2011	1	28.3	29.3
2012	2.7	76.4	79.1
2013	17.8	509	526.8
2014	3.5	117	120.5
2015	23.8	640.2	664
2016	18.5	620.5	639
2017	17.4	387.4	404.8
2018	10.4	277.8	288.2
2019	18.9	505.7	524.6

California nearshore fixed-gear GSI table

Table 2-2. Summary of expanded bycatch numbers of green sturgeon in the California nearshore fixed-gear sector. Estimates of Southern DPS (SDPS) and Northern DPS (NDPS) bycatch are calculated based on GSI proportions by catch area (48% for WA and OR, 96% for CA). For simplicity years and sectors without green sturgeon bycatch are not shown.

Year	SDPS total	NDPS + SDPS total
2017	**15.6**	**16.2**

California halibut bycatch tables

Table 2-3. Observed bycatch numbers, bycatch ratios, and fleet-wide total bycatch numbers of green sturgeon from California halibut bottom trawl fishery (2002-2010). Limited entry (LE) and open access sectors (OA) are shown separately. Bootstrapped 95% confidence intervals (CI) are provided for the bycatch estimates. Winter is November-April; summer is May-October. Asterisks (*) signify strata with fewer than three observed vessels. Double dashes (--) signify unobserved strata.

Sector	Year	Season	Observed bycatch	Observed CA halibut landings (MT)	Fleet total CA halibut landings (MT)	CA halibut landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet-total bycatch	Lower CI of bycatch	Upper CI of bycatch
LE CA Halibut	**2002**	winter	1	3.6	71.9	5	0.28	0	0.37	20	1	26
LE CA Halibut	**2002**	summer	108	23	36.6	62.9	4.69	0.88	8.64	172	108	316
LE CA Halibut	**2003**	winter	2	12.9	62	20.8	0.16	0	0.23	10	2	14
LE CA Halibut	**2003**	summer	50	6.2	43.7	14.2	8.05	1.61	12.16	352	70	532
LE CA Halibut	**2004**	winter	1	14.7	80	18.4	0.07	0	0.23	5	1	19
LE CA Halibut	**2004**	summer	58	16.8	56.5	29.7	3.45	0	6.53	195	58	369
LE CA Halibut	**2005**	winter	18	10.7	131.4	8.2	1.68	0	14.34	220	18	1885
LE CA Halibut	**2005**	summer	98	19.8	57.4	34.4	4.95	1.58	6.1	285	98	351

LE CA Halibut	**2006**	winter	108	11.1	80.6	13.7	9.75	2.32	14.75	786	187	1189
LE CA Halibut	**2006**	summer	0	3.2	38.9	8.2	0	0	0	0	0	0
LE CA Halibut	**2007**	winter	6	3	14.1	21.3	2	0	3.51	28	6	49
LE CA Halibut	**2007**	summer	10	2.4	4.5	54.2	4.09	0	5.36	18	10	24
LE CA Halibut	**2008**	winter	44	9.5	34	27.9	4.63	3.24	9.12	158	110	311
LE CA Halibut	**2008**	summer	1	0.1	2.4	5.6	7.6	0	7.93	18	1	19
LE CA Halibut	**2009**	winter	--	--	39.9	NA	--	--	--	--	--	--
LE CA Halibut	**2009**	summer	18	2.9	7.3	39.8	6.21	5.88	6.87	45	43	50
LE CA Halibut	**2010**	winter	48	16.2	32.8	49.4	2.96	0.7	5.85	97	48	192
LE CA Halibut	**2010**	summer	27	14.5	21.2	68.4	1.86	0.72	6	39	27	127
OA CA Halibut	**2002**	winter	--	--	21.6	NA	--	--	--	--	--	--
OA CA Halibut	**2002**	summer	--	--	14.6	NA	--	--	--	--	--	--
OA CA Halibut	**2003**	winter	8	3.1	18.5	16.7	2.6	0	9.2	48	8	170
OA CA Halibut	**2003**	summer	4	1.8	7.3	25.4	2.17	0	6.48	16	4	47
OA CA Halibut	**2004**	winter	2	0.9	29.6	3.1	2.21	0	4.29	65	2	127
OA CA Halibut	**2004**	summer	31	11.4	41.2	27.8	2.71	0	5.37	112	31	221
OA CA Halibut	**2005**	winter	6	2	24.1	8.5	2.94	0	16.85	71	6	406
OA CA Halibut	**2005**	summer	27	11.5	40.4	28.4	2.35	0	4.85	95	27	196

OA CA Halibut	**2006**	winter	--	--	18.4	NA	--	--	--	--	--	--
OA CA Halibut	**2006**	summer	--	--	36.4	NA	--	--	--	--	--	--
OA CA Halibut	**2007**	winter	0	0.8	8.2	10.1	0	0	0	0	0	0
OA CA Halibut	**2007**	summer	0	1.9	31	6.2	0	0	0	0	0	0
OA CA Halibut	**2008**	winter	0	0.9	21.5	4.2	0	0	0	0	0	0
OA CA Halibut	**2008**	summer	0	1.8	30.3	5.8	0	0	0	0	0	0
OA CA Halibut	**2009**	winter	0	1.7	37.4	4.6	0	0	0	0	0	0
OA CA Halibut	**2009**	summer	0	4	44.9	8.9	0	0	0	0	0	0
OA CA Halibut	**2010**	winter	0	0.7	27.9	2.7	0	0	0	0	0	0
OA CA Halibut	**2010**	summer	0	1.7	41.5	4	0	0	0	0	0	0

Table 2-4. Observed bycatch numbers and fleet-wide total expanded numbers of green sturgeon bycatch from the combined limited entry (LE) and open access (OA) California halibut bottom trawl sectors from 2011-2019. Estimates for each sector were calculated separately and then summed to generate the fleet-wide total expanded bycatch estimates across both sectors. The low number of vessels that participated in the LE sector (< 3 vessels per year) resulted in the need to combine the LE and OA sectors bycatch estimates and not report LE landings to maintain confidentiality. Since 2011, the LE sector has been observed at 100% as a part of the IFQ program, but no LE trips were made after 2013. Landings for the OA sector are given in metric tons. In years when the LE fishery was not active the percent of landings sampled are denoted as NA.

Year	LE + OA combined observed bycatch	LE + OA combined fleet-total bycatch	Lower CI of fleet-total bycatch	Upper CI of fleet-total bycatch	LE CA halibut landings sampled (%)	OA observed CA halibut landings (MT)	OA fleet-total CA halibut landings (MT)	OA CA halibut landings sampled (%)
2011	13	29.3	13	31.7	100	12.4	79.9	15.6
2012	6	79.1	6	130.9	100	3.5	55.3	6.4
2013	46	526.8	196.3	902	100	4.3	69	6.2
2014*	27	120.5	35.3	873.6	--	18.1	81	22.4
2015*	221	664	269.1	2082.6	--	30.6	92	33.3
2016*	195	639	195	1015.6	--	27.3	89.5	30.5
2017*	106	404.8	122	618.7	--	24.3	92.8	26.2
2018*	74	288.2	122.2	393.9	--	18.6	72.4	25.7
2019*	140	524.6	345.4	671.1	--	32.2	120.7	26.7

*LE sector not active

California nearshore fixed gear bycatch table

Table 2-5. Observed and expanded bycatch numbers of green sturgeon from the California nearshore fixed-gear sector from 2002-2019.

Year	State	Season	Observed bycatch	Observed target landings (MT)	Fleet-total target landings (MT)	Target landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet total bycatch	Lower CI of bycatch	Upper CI of bycatch
2003	CA	winter	0	0.8	46.4	1.7	0	-	-	0	-	-
2003	CA	summer	0	7.3	209.1	3.5	0	-	-	0	-	-
2004	CA	winter	0	8	57.3	14	0	-	-	0	-	-
2004	CA	summer	0	15.3	234.9	6.5	0	-	-	0	-	-
2005	CA	winter	0	3.6	68.5	5.3	0	-	-	0	-	-
2005	CA	summer	0	9.4	213.3	4.4	0	-	-	0	-	-
2006	CA	winter	0	2.4	55.4	4.4	0	-	-	0	-	-
2006	CA	summer	0	6	205.3	2.9	0	-	-	0	-	-
2007	CA	winter	0	4.1	71.4	5.7	0	-	-	0	-	-
2007	CA	summer	0	7.9	205.8	3.8	0	-	-	0	-	-
2008	CA	winter	0	2.7	87.1	3.1	0	-	-	0	-	-
2008	CA	summer	0	4	209.6	1.9	0	-	-	0	-	-
2009	CA	winter	0	2.7	76.1	3.6	0	-	-	0	-	-
2009	CA	summer	0	4	184.7	2.2	0	-	-	0	-	-
2010	CA	winter	0	0.1	51.4	0.2	0	-	-	0	-	-
2010	CA	summer	0	7	168.2	4.2	0	-	-	0	-	-
2011	CA	winter	0	1.7	61.7	2.7	0	-	-	0	-	-
2011	CA	summer	0	6.9	155.1	4.4	0	-	-	0	-	-
2012	CA	winter	0	2	55.3	3.7	0	-	-	0	-	-
2012	CA	summer	0	10	145.8	6.8	0	-	-	0	-	-
2013	CA	winter	0	3.2	66.7	4.8	0	-	-	0	-	-
2013	CA	summer	0	8.7	154.8	5.6	0	-	-	0	-	-

2014	CA	winter	0	2.7	66.7	4.1	0	-	-	0	-	-
2014	CA	summer	0	8.8	180.7	4.9	0	-	-	0	-	-
2015	CA	winter	0	7.3	110.8	6.6	0	-	-	0	-	-
2015	CA	summer	0	15.6	222.6	7	0	-	-	0	-	-
2016	CA	winter	0	5.7	70.2	8.2	0	-	-	0	-	-
2016	CA	summer	0	7.5	179.2	4.2	0	-	-	0	-	-
2017	CA	winter	0	3.6	63.6	5.7	0	-	-	0	-	-
2017	CA	summer	1	10.7	177.6	6	0.09	0	0.35	17	1	62
2018	CA	winter	0	2.6	65	4	0	-	-	0	-	-
2018	CA	summer	0	8.3	161.4	5.2	0	-	-	0	-	-
2019	CA	winter	0	1.7	73.1	2.3	0	-	-	0	-	-
2019	CA	summer	0	11.2	184.6	6.1	0	-	-	0	-	-

Generalized additive models results

Table 2-6. Results from the binomial generalized additive model of green sturgeon encounter probability in the California halibut trawl fishery.

Term	Est. DF	Ref. DF	Statistic	p value
s(year)	7.703	9	227.137	<0.001
s(avg_depth)	5.186	9	129.799	<0.001
s(sst)	1.732	9	6.823	0.01
s(jday)	5.108	9	25.169	<0.001
s(mean_lat)	3.589	9	28.784	<0.001
s(roughness)	0.194	9	0.233	0.269

Table 2-7. Results from the negative binomial generalized additive model of green sturgeon bycatch counts in the California halibut trawl fishery.

Term	Est. DF	Ref. DF	Statistic	p value
s(year)	7.233	9	244.488	<0.001

s(avg_depth)	6.55	9	157.935	<0.001
s(sst)	1.125	9	1.939	0.154
s(jday)	5.558	9	50.923	<0.001
s(mean_lat)	3.466	9	43.811	<0.001
s(roughness)	0	9	0	0.931

Section 3. Directed Pacific Halibut Fishery

The WCGOP began observing the west coast directed Pacific halibut fishery in 2017. This fishery uses longlines to target Pacific halibut (*Hippoglossus stenolepis*) from northern California to Washington. Management is coordinated through the International Pacific Halibut Commission (IPHC), and the Pacific Fishery Management Council allocates the total allowable catch set by the IPHC among user groups.

One green sturgeon was observed in this fishery in 2019. The observation occurred in California, where effort is low compared to Oregon and Washington, and where nearly 80% of retained Pacific halibut were covered by observers in 2019 (Table 3-1). The expanded green sturgeon bycatch estimate for 2019 was 2 individuals and 0 for all other years. Table 3-1 contains further information about retained Pacific halibut catch, observer coverage, and bycatch ratios.

Table 3-1. Observed and expanded bycatch numbers of green sturgeon from the directed Pacific halibut sector from 2017-2019. Asterisks (*) signify strata with fewer than three observed vessels. Double dashes (--) signify unobserved strata.

Year	State	Observed bycatch	Observed target landings (MT)	Fleet-total target landings (MT)	Target landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet total bycatch	Lower CI of bycatch	Upper CI of bycatch
2017	WA	0	7.4	34	21.7	0	-	-	0	-	-
2018	WA	0	14.6	37	39.4	0	-	-	0	-	-
2019	WA	0	15.7	53	29.6	0	-	-	0	-	-
2017	OR	0	2.8	99.3	2.9	0	-	-	0	-	-
2018	OR	0	14.7	83.1	17.7	0	-	-	0	-	-
2019	OR	0	3.1	102	3	0	-	-	0	-	-
2017	CA	--	--	1.8	0	--	--	--	--	--	--
2018	CA	*	*	0.5	*	0	-	-	0	-	-
2019	CA	1	2.3	2.8	79.7	0.44	0	0.71	1	1	2

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