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Observed and Estimated Bycatch of Green Sturgeon in 2002–2013 US West Coast Groundfish Fisheries

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Acknowledgements

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Executive Summary

In accordance with the National Marine Fisheries Service (NMFS) Biological Opinion on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS 2012, p. 126-127), this document provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act-listed green sturgeon (*Acipenser medirostris*) encountered in the U.S. west coast groundfish fisheries. Three federal groundfish fisheries and one state-managed fishery encountered green sturgeon between 2002 and 2013: limited entry (LE) bottom trawl fishery (2002-2010), Individual Fishing Quota (IFQ) bottom trawl fishery (2011-2013), at-sea hake fishery (A-SHOP) (2002-2013), and the state-managed California (CA) halibut bottom trawl fishery (2002-2013). It should be noted that "bycatch" in this report is defined as the discard of green sturgeon made at sea. Since being listed in 2006, landing and sales of green sturgeon is prohibited.

The Biological Opinion (NMFS 2012, aka BiOp) states that take of Southern distinct population segment (DPS) green sturgeon population in the combined federally managed fisheries (e.g., LE groundfish bottom trawl, IFQ groundfish bottom trawl, and at-sea hake fisheries) should not exceed more than 28 fish per year. A summary of annual total bycatch of green sturgeon in LE bottom trawl, IFQ bottom trawl, and A-SHOP sectors is given in Table 1. While the BiOp only concerns Southern DPS as a listed species, currently there is no direct method to differentiate between Southern DPS and Northern DPS fish at the time of observation at sea. Based on data from the NWFSC Observer Programs, the take of all green sturgeon (regardless of DPS) in recent three years, in all federally-managed sectors combined (i.e., IFQ bottom trawl and A-SHOP), was 38 in 2011, but declined to 22 in 2012 and 10 in 2013. Preliminary results from genetic stock identification of Northern and Southern DPS indicate that 55% of green sturgeon caught off the Oregon (OR) and Washington (WA) coasts are mostly likely Southern DPS individuals, whereas 90% of individuals caught off the CA coast are most likely Southern DPS fish (Carlos Garza, pers. comm., SWFSC, NMFS). If we apply a 55% genetic identification to our estimates, then the estimated number of Southern DPS green sturgeon bycatch is 20.9 in 2011, 12.1 in 2012, and 5.5 in 2013, below the authorized take level of 28 per year. However, the genetic stock identification results are preliminary and the genetic baseline consists of relatively few samples. In addition, only the point estimates of the DPS proportions were applied to proportionate bycatch estimates without error bounds as those statistics were not available at the time of this bycatch analysis, so these DPS assignment proportions should be interpreted with caution.

Even though identical in most cases, there are slight differences for some strata between the bycatch estimates provided in this report and in the previous report (Al-Humaidhi et al. 2012). These differences are due to the application of a slightly different bootstrapping scheme, as well as the use of updated observer and fish ticket data that were processed further with data quality assurance and quality control checks.

The BiOp only concerns federally-managed fisheries. However, the NWFSC West Coast Groundfish Observer Program (WCGOP) observes the state-managed California (CA) halibut fishery as well, which also encountered green sturgeon. We provide bycatch estimation of green sturgeon in this state-managed fishery as an appendix in this report to provide a more thorough understanding of the impacts of observed fisheries on this species.

Introduction

In accordance with the NMFS Biological Opinion on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS 2012, p. 126-127), this document provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act-listed green sturgeon (*Acipenser medirostris*) encountered in the U.S. west coast (WA-Canada border to California-Mexico border) groundfish fishery sectors, observed from 2002-2013. The North American green sturgeon (hereafter referred to as "green sturgeon") is an anadromous fish. Within the sturgeon family Acipenseridae, green sturgeon is the most widely distributed and one of the most marine-oriented members, spending much of its life in the ocean (Moyle 2002). Green sturgeon occurs along the coastal waters of North America, ranging from northern Baja California to the Bering Sea (Mecklenberg et al. 2002). Depending on spawning locations and genetic distinctions, populations are classified into the Northern Distinct Population Segment (DPS) and the Southern DPS. The Southern DPS of green sturgeon was listed as threatened under the ESA in 2006 (71 Fed. Reg. 17757), and critical habitat was designated in 2009 (74 Fed. Reg. 52300). In this report, we present observed green sturgeon bycatch (as number of individual fish) and bycatch ratio (as number of individual fish per metric ton of total target fish caught) per stratum. This bycatch ratio is then used to estimate fleet-wide total green sturgeon bycatch in each stratum, where only a portion of the total hauls were observed. This report includes green sturgeon bycatch estimates for all groundfish fisheries observed by the WCGOP and At-Sea Hake Observer Program (A-SHOP) from 2002 – 2013. This report does not include bycatch of green sturgeon in Tribal fisheries (except at-sea hake tribal) unobserved fisheries, recreational fisheries, research fisheries, or vessels fishing on an exempted fishing permit (EFP).

Life History and Biology of Green Sturgeon

The green sturgeon is a long-lived, slow-growing, anadromous fish species. Green sturgeon spend 1 to 4 years in fresh and estuarine waters before making their first migration into ocean waters as subadults (Nakamoto et al. 1995). The green sturgeon spends most of the rest of its life in marine and estuarine environments, and migrates into rivers for spawning. The green sturgeon likely live up to 60 – 70 years (Moyle 2002). The size of adult green sturgeon ranges from 1.4 – 2 m in fork length (FL) for males and 1.6 – 2.2 m FL for females. Green sturgeon have long reproductive cycles with late maturity. Males reach maturity at about 14 – 16 years and females at 16 – 20 years, at which time they make their first spawning migration into freshwater (Van Eenennaam et al. 2006). Females return to freshwater to spawn every 2 – 4 years, and males potentially return to spawn every 1 – 3 years (Erickson and Webb 2007). Between spawning runs, green sturgeon migrate along the U.S. west coast and can be found from Mexico to Alaska. Green sturgeon are known to aggregate in coastal estuaries in Oregon and Washington (e.g., Columbia River estuary, Grays Harbor, Willapa Bay, and Winchester Bay) in the spring and summer months (Israel et al. 2004, Moser and Lindley 2007, Lindley et al. 2008, 2011). Due to the species' life history characteristics, wide distribution along the coast, and dependence on freshwater systems for spawning, green sturgeon are particularly susceptible to human-induced environmental changes, including impassible dams and barriers in spawning rivers, insufficient freshwater flows, chemical contaminants, and entrainment by water projects.

Based on genetic analyses and spawning site fidelity (Adams et al. 2002, Israel et al. 2004), at least two distinct population segments (DPS) have been identified for North American green sturgeon: a Northern DPS and a Southern DPS. The Northern DPS consists of populations originating from coastal watersheds northward of the Eel River, CA. The Northern DPS has been confirmed to spawn in two different spawning river systems, the Rogue and Klamath-Trinity Rivers. The Southern DPS consists of populations originating from coastal watersheds southward of the Eel River, CA. The only known spawning population for the Southern DPS is in the Sacramento River system, making this population more vulnerable to catastrophic events. Northern DPS fish do not appear to occur in natal waters of the Southern DPS and vice versa. Outside of natal waters, however, their distributions generally overlap with one another. Because of this, green sturgeon observed in coastal bays, estuaries, and marine waters outside of natal waters could belong to either DPS. This is important because the Southern DPS is listed as threatened under the Endangered Species Act (ESA), whereas the Northern DPS is not (71 Fed. Reg. 17757; April 7, 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.

Population abundance, status, and trends for the Northern and Southern DPS are not well known due to limited data. Preliminary data from Mora (2013) suggest that the adult spawning run size in the Klamath-Trinity and Rogue Rivers (Northern DPS) would be in the range of several hundreds and the spawning run size in the Sacramento River system would be less.

In marine waters, adults and subadults primarily occur at depths of 40-110 m (Erickson and Hightower 2007). Once green sturgeon enter coastal habitats after their freshwater life stages, they tend to migrate northward from their natal habitats (Erickson and Hightower 2007, Lindley et al. 2008). Although green sturgeon are known to occur from Baja California to the Bering Sea (Mecklenberg et al. 2002), coastal marine waters from Monterey Bay to Vancouver Island are recognized as migratory habitat (NMFS 2009). Green sturgeon are often found in aggregations in coastal bays and estuaries. In October of 2009, NMFS designated coastal marine waters within 60 fathoms (approximately 110 m) from Monterey Bay, CA to the Washington-Canada border as critical habitat for the Southern DPS population (74 Fed. Reg. 52300). 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 (Lindley et al. 2011).

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 medium to high (41-81%), although they varied between years, between estuaries, and between the estimation methods (Israel et al. 2009). Preliminary genetic analyses on green sturgeon bycatch samples for the years 2007-2013 indicated that the proportions of Southern DPS fish varied between fishing areas: 55% of the green sturgeon encountered and sampled off Oregon and Washington and 90% of the green sturgeon encountered and sampled off the California coast likely belonged to the Southern DPS (Dr. Carlos Garza, pers. comm., SWFSC, NMFS, NOAA).

West Coast Groundfish Fishery

The west coast groundfish fishery (WCGF) is a multi-species fishery that utilizes a variety of gear types off the U.S. west coast between the Canada-WA border and the CA-Mexico border. 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 2011). Over 90 species are listed in the groundfish FMP, including a variety of rockfish, flatfish, roundfish, skates, and sharks. These species are found in both federal (> 5.6 km off-shore) and state waters (0 - 5.6 km). For a complete list of groundfish species defined in the Pacific Coast Groundfish Fishery Management Plan, see PFMC (2011). Groundfish are both targeted and caught incidentally by trawl nets, hook-&-line gear, and fish pots. Under the FMP, the groundfish fishery consists of four management components:

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.

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.

The Recreational component includes recreational anglers who target or incidentally catch groundfish species. Recreational fisheries are not covered by this report.

The Tribal component includes native tribal commercial fishers in Washington State that have treaty rights to fish groundfish. Tribal fisheries are not included in this report, with the exception of the observed tribal at-sea Pacific hake (*Merluccius productus*) (also known as whiting) sector.

These four components can be further subdivided into sectors based on gear type, target species, permits and other regulatory factors. This report includes data from the following sectors:

<u>Limited Entry (LE) sectors</u>

Beginning in 2011, an Individual Fishing Quota (IFQ) program for the LE bottom trawl fleet and the at-sea Pacific hake fleet was implemented, under the West Coast Groundfish Trawl Catch Share Program.

- IFQ fishery (formerly LE bottom trawl and at-sea Pacific hake). The IFQ non-hake sectors consist primarily of bottom trawl with some midwater trawl and allow for gear-switching (fishing the IFQ permit using fixed gear). This sector is subdivided into the following components due to differences in gear type and target strategy:
    - Bottom trawl: Bottom trawl nets are used to catch a variety of non-hake groundfish species. Catch is delivered to shore-based processors.
    - Midwater non-hake trawl: Midwater trawl nets are used to target midwater non-hake species. Catch is delivered to shore-based processors.

- Pot: Pot gear is used to target groundfish species, primarily sablefish (*Anoplopoma fimbria*). Catch is delivered to shore-based processors.
- Hook-and-line: Longlines are primarily used to target groundfish species, mainly sablefish. Catch is delivered to shore-based processors.
- LE California halibut (*Paralichthys californicus*) trawl: Bottom trawl nets are used to target California halibut by fishers holding both a state California halibut permit and an LE federal trawl groundfish permit. Catch is delivered to shore-based processors.
- Shoreside Pacific hake trawl: Midwater trawl nets are used to catch Pacific hake. Catch is delivered to shore-based processors.
- At-sea motherships and catcher-processors: Midwater trawl nets are used to catch Pacific hake. Catcher vessels deliver unsorted catch to a mothership. The catch is sorted and processed aboard the mothership. Catcher-processors catch and process at-sea. This component also includes the at-sea processing component of the tribal sector. The tribal sector must operate within defined boundaries in waters off northwest Washington. Tribal catch can be delivered to a contracted mothership by catcher vessels for processing or be caught and processed by a contracted catcher-processor.

- LE fixed gear (non-nearshore): This sector is subdivided into two components due to differences in permitting and management:
  - LE sablefish endorsed season: Longlines and pots are used to target sablefish. Catch is generally delivered to shore-based processors.
  - LE sablefish non-endorsed: Longlines and pots are used to target groundfish, primarily sablefish and thornyheads. Catch is delivered to shore-based processors or sold live at the dock.

<u>Open Access (OA) Federal sectors</u>

- OA fixed gear (non-nearshore): Fixed gear, including longlines, pots, fishing poles, stick gear, etc. is used to target non-nearshore groundfish. Catch is delivered to shore-based processors.

<u>Open Access (OA) state sectors</u>

- OA ocean shrimp[2] (*Pandalus jordani*) trawl: Trawl nets are used to target ocean shrimp. Catch is delivered to shore-based processors.
- OA California halibut trawl: Trawl nets are used to target California halibut by fishers holding a state California halibut permit. Catch is delivered to shore-based processors..
- Nearshore fixed gear: A variety of fixed gear, including longlines, pots, fishing poles, stick gear, etc. are used to target nearshore rockfish and other nearshore species managed by state permits in Oregon and California. Catch is delivered to shore-based processors or sold live.

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[2] *Pandalus jordani* is known as the ocean pink shrimp or smooth pink shrimp in Washington, pink shrimp in Oregon, and Pacific ocean shrimp in California. Herein we use the common name "ocean shrimp" in reference to *P. jordani* as suggested by the American Fisheries Society (McLaughlin et al. 2005).

Northwest Fisheries Science Center Groundfish Observer Programs

The NWFSC Groundfish Observer Program's goal is to improve estimates of total catch and discard by observing commercial sectors of groundfish fisheries along the U.S. west coast that target or incidentally take groundfish as bycatch. The observer program has two units: the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP). The WCGOP Program was established in May 2001 by NMFS, in accordance with the Pacific Coast Groundfish Fishery Management Plan (50 CFR Part 660) (50 FR 20609). 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 federal groundfish sectors: IFQ shore-based delivery of groundfish and Pacific hake, LE and OA non-nearshore fixed gear; and the state-managed nearshore fixed gear sectors in OR and CA. The WCGOP also observes several state-managed fisheries that incidentally catch groundfish, including the California halibut trawl and ocean shrimp trawl fisheries. The A-SHOP observes the IFQ fishery that delivers Pacific hake at sea including: catcher-processor, mothership, and tribal vessels. Details on how fisheries observers operate in both the IFQ (aka Catch Shares) and Non-IFQ (aka Non-Catch Shares) sectors can be found online at: http://www.nwfsc.noaa.gov/research/divisions/fram/observation/index.cfm.

Groundfish Fishery Sectors with Green Sturgeon Bycatch

A summary of the permits, gear(s) used, target groups, vessel length range, fishing depth range, and management of fishery sectors and sub-sectors in U.S. west coast groundfish fisheries that have had documented green sturgeon bycatch is presented in Table 2. The following commercial groundfish fishery sectors had observed green sturgeon bycatch from 2002–2013:

Federally-managed sectors

- LE and IFQ bottom trawl fishery
- IFQ at-sea Pacific hake mothership fishery
- IFQ at-sea Pacific hake catcher-processor fishery
- IFQ at-sea Pacific hake tribal mothership

State-managed sectors

- LE & OA California halibut bottom trawl fisheries (see Appendix A)

Commercial groundfish fisheries observed by the WCGOP that did not have any observed bycatch of green sturgeon from 2002–2013 include:

- LE fixed gear primary sablefish
- LE fixed gear non-primary sablefish
- OA fixed gear

- Nearshore fixed gear state-permitted (Oregon and California)
- IFQ non-hake midwater trawl fishery
- IFQ shoreside Pacific hake trawl
- OA ocean shrimp trawl

Green sturgeon bycatch off the U.S. west coast occurs in state operated commercial California (CA) halibut fishery sectors (LE and OA) in California, and the WCGOP observes these fisheries sectors. These CA halibut trawl fisheries are permitted by the state of California and are not regulated under the Pacific Coast Groundfish FMP, and therefore do not fall under the 2012 Biological Opinion for green sturgeon. Green sturgeon bycatch in these CA halibut trawl fisheries is important to understand from the perspective of species conservation. However, to clearly define the scope of the reporting required under the 2012 Biological Opinion, green sturgeon bycatch in CA halibut fisheries is reported in Appendix A and will not be further covered in the body of the current document. Recommendations to the PFMC regarding green sturgeon under the Biological Opinion should not include the CA halibut fisheries.

Amount and Extent of Take

The Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS 2012, p. 121-122) stated 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."

The current document presents WCGOP and A-SHOP observer data on bycatch of green sturgeon (in number of individuals) in the U.S. west coast groundfish fisheries covered by the Pacific Coast Groundfish FMP. While ESA-listing and BiOp statements are only relevant to Southern DPS green sturgeon, the bycatch information in this report include both Northern and Southern DPS green sturgeon, as combined without distinction between the segments, because the current observer data do not have information on the DPS origin of individual bycatches. In addition, we estimate the proportion of Southern DPS bycatch based on the estimate of Southern DPS individuals identified by genetic stock identification (see Life History section above). However, the genetic stock identification is preliminary and based on relatively small samples sizes, so these estimates should be interpreted with caution.

At the present time, we have no 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 in U.S. west coast groundfish fisheries. Green sturgeon tagging studies are currently beginning, thus more information on post-release mortalities and recapture rates will be available in the near future (see Discussion for more detail).

Materials and Methods

Data Sources

Data sources for this analysis include onboard observer data from the WCGOP and A-SHOP and landing receipt data (a.k.a. fish tickets), obtained from the Pacific Fisheries Information Network (PacFIN).

<u>Observer data</u>

To date, observer data is the sole source for discard estimation in U.S. west coast groundfish fisheries. A list of fisheries, coverage priorities and data collection methods employed by WCGOP in each observed fishery can be found in the Catch Shares (aka IFQ) and Non-Catch Shares (aka Non-IFQ) WCGOP manuals (NWFSC 2015a, b). A-SHOP program information and documentation on data collection methods can be found in the A-SHOP observer manual (NWFSC 2014).

The sampling protocol employed by the WCGOP is primarily focused on the discarded portion of catch. To ensure that the recorded weights for the retained portion of the observed catch are accurate, haul-level retained catch weights recorded by observers are adjusted based on trip-level fish ticket records. This process is described in further detail on the WCGOP Data Processing webpage (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_processing.cfm). Data processing was applied prior to the analyses presented in this report

<u>Fish ticket data</u>

The retained landing information from fish tickets (sales receipts) provides an effort metric of the landed amount of a particular fish species or group, and is necessary to estimate fleet-wide total bycatch for sectors of the west coast groundfish fishery with less than 100% observer coverage. Fish tickets are completed by fish-buyers in each port for each delivery of fish by a vessel. Fish tickets are trip-aggregated sales receipts for market categories that may represent single or multiple species. Fish tickets are issued to fish-buyers by a state agency and must be returned to the agency for processing. Fish tickets are designed by the individual states (Washington, Oregon, and California) with slightly different format in each state. In addition, each state conducts species-composition sampling at the ports for numerous market categories that are reported on fish tickets. Fish ticket and species-composition data are submitted by state agencies to the PacFIN regional database. PacFIN data for fish ticket landings was queried in March 2014 (for 2011-2013) and November 2012 (for 2002-2010), and subsequently divided into various sectors of the groundfish fishery. Observer and fish ticket data processing steps are described in detail on the WCGOP website under Data Processing Appendix (http://www.nwfsc.noaa.gov/research/divisions/fram/observer/data_processing.cfm/). All data processing steps specific to this report are described in the bycatch estimation methods section below.

Biological data

Beginning in 2007, when green sturgeon are encountered on vessels observed by the WCGOP, observers document fish length (in fork length, FL), 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. West Coast groundfish observers follow protocols detailed in the WCGOP manual and additional materials provided by the WCGOP program related to sturgeon sampling (NWFSC 2015a, NWFSC 2015b). Length frequency data were analyzed with descriptive statistics and linear regressions to examine the size structure of encountered green sturgeon, proportions of subadults/adults, and the relationship between green sturgeon size and fishing depth.

Beginning in 2007, when green sturgeon are encountered in a species composition sample on an observed vessel by the A-SHOP, observers document length and weight, determine sex if possible, take photographs, visually scan for tags, and take a pectoral fin ray sample. At-sea hake observers follow protocols detailed in the A-SHOP manual and additional materials provided by the A-SHOP program related to sturgeon sampling (NWFSC 2014).

Bycatch Estimation Methods

The landed amount of a target species (or species groups) was used as a proxy for fishing effort. The choice of target species and therefore, the effort metric, depends on fishery sector. Thus, green sturgeon bycatch was estimated for each individual fishery sector. Target species of those sectors that encountered green sturgeon during 2002–2013 were: all FMP-managed groundfish species except Pacific hake for LE bottom trawl and IFQ trawl sectors, and Pacific hake for at-sea hake fisheries.

LE bottom trawl fishery

The LE bottom trawl fishery was a multi-species fishery (2002–2010) that targeted various groundfish species. Since 2011, this fishery has been managed under an Individual Fishing Quota (IFQ) system. The data were stratified by year, state of landing, and season for bycatch estimation, as done in the previous report (Al-Humaidhi et al. 2012). Months of January-April and November-December are defined as winter, and May-October as summer. LE bottom trawl vessels can hold a California halibut bottom trawl permit and participate in the state-permitted California halibut fishery. California halibut tows can occur on the same trip as tows targeting groundfish and were identified based on the following criteria: 1) the reported 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 and south of 40°10’ N. latitude. All tows in the observer data that met at least one of these two requirements were removed from the LE bottom trawl data and included in the California halibut trawl data (see Appendix A).

A ratio estimator was used to estimate the fleet-wide total number of green sturgeon catch per stratum for the LE sector, in which only a portion of fishing vessels were observed out of all fishing vessels participated in the sector. A bycatch ratio (aka, bycatch rate) per stratum was computed from observer data as the observed catch of green sturgeon (number of individuals) divided by the observed retained weight of target species (or species groups). Total green sturgeon bycatch at the fleet-wide level was then estimated based on the simple expansion of the bycatch ratio by the total targeted fish landings, as the expansion factor, for a given strata. The estimation of bycatch ratio and fleet-wide expansion were done according to the following equation:

$$\hat{D}_s = \frac{\sum_t d_{st}}{\sum_t r_{st}} \times F_s$$

where:

s = individual stratum (a combination of sector, year, season, state)
t = individual tows
d = observed bycatch of green sturgeon (number of individuals)
r = observed retained weight of target species or species group
F = total weight of landed target species recorded on fish tickets
$\hat{D}$ = fleet-wide total bycatch estimate of green sturgeon

Catch Shares: IFQ bottom trawl fishery

Since 2011, the U.S. west coast LE groundfish trawl fishery has been managed under the Catch Shares Program, which led to the establishment of Individual Fishing Quotas (IFQs). Under this program, all participating vessels are required to carry a WCGOP observer on all fishing trips, resulting in 100% observer coverage. In addition, permit holders with IFQ and a trawl endorsement can fish multiple gear types (although not within the same trip), including bottom or midwater trawl, hook and line, or pot gear. Green sturgeon were encountered only in the IFQ bottom trawl gear sector. Fleet-wide green sturgeon bycatch for this sector is almost completely known because all vessels carry an observer, resulting in a complete census. Bycatch for this fishery was summarized by year and state of landing.

All Catch Shares fishing trips are observed, 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. Overall the unsampled catch was very small, comprising less than 0.5% of the total landed weight of IFQ species during 2011–2013. 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 do not belong to the IFQ species list. Estimates of green sturgeon bycatch for unsampled portion are derived per each unsampled category type separately. Estimated bycatch from the unsampled portion of the catch is then added to the observed bycatch amount to obtain the total bycatch estimate. Expansion for the unsampled portion was only needed if green sturgeon were encountered within a stratum. If no green sturgeon were encountered in a stratum, then it was assumed that no green sturgeon was encountered in the unsampled catch. The following equation was used to estimate bycatch in the unsampled portions of the catch in IFQ fisheries:

$$\hat{U}_{sc} = \frac{\sum_t d_{st}}{\sum_t w_{sct}} \times Z_{sc}$$

where:

s = stratum (a combination of sector, year, season, state)
c = category of unsampled catch (unsorted, discards, non-IFQ)
t = individual tows
d = observed bycatch of green sturgeon (number of individuals)
w = weight of sampled catch
Z = weight of unsampled catch (i.e., the expansion factor)
$\hat{U}$ = bycatch estimate of green sturgeon in unsampled catch

Green sturgeon bycatch was estimated within unsorted catch by multiplying the bycatch ratio (i.e., the number of green sturgeon in a given stratum divided by the sum of the sampled weight for all species (discarded and retained) by the sum of the weight of unsorted catch of all species within the stratum (i.e., expansion factor). Estimations for other unsampled categories were done in a similar manner, but with different denominators for the bycatch ratio and different expansion factors. For the unsampled discard category, the denominator was the sum of the sampled weight of all discarded species (IFQ and non-IFQ species) and the expansion factor was the unsampled weight of all discarded species. For the unsampled non-IFQ category, the denominator was the sum of the sampled weight of all discarded non-IFQ species and the expansion factor was the sum of the unsampled weight of discarded non-IFQ species.

<u>At-sea Pacific hake fishery</u>

Observed and expanded bycatch data were provided directly from the A-SHOP and incorporated into this report. The green sturgeon bycatch is reported by year and by 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 day (i.e., 100% coverage).

Even though very rare, entire hauls may not be sampled due to unforeseen circumstances (e.g., sickness of observers). These unsampled hauls need to be expanded at the strata level. Typically greater than 99% of hauls are sampled each year, thus unsampled portion that needs an 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. The total number of green sturgeon caught by the at-sea hake fleet per given stratum was calculated using the following formula:

$$B_s = \sum Y_{st} + \sum Y_{st} \cdot \left(\frac{U_s}{T_s}\right)$$

where:

B = the total estimated green sturgeon bycatch
s = individual stratum
t = individual tow
Y = observed number of green sturgeon bycatch
U = number of unsampled hauls
T = total number of hauls

Measures of Uncertainty

As a measure of uncertainty for the estimated bycatch ratio, upper and lower limits of the 95% confidence interval were estimated with a non-parametric bootstrap procedure for each stratum if the fishery was not 100% observed (i.e., non-IFQ fisheries). The bootstrap procedure randomly selects vessels that were observed within a stratum, with replacement. The number of vessels randomly selected is the same as the total number of observed vessels in the stratum. Random selection of vessels is intended to approximate the WCGOP vessel selection process. The bycatch ratio was estimated for each of 10,000 bootstrapped data sets to obtain a bootstrapped distribution of bycatch ratio estimates. The lower (2.5% percentile) and upper (97.5% percentile) confidence limits of the bycatch ratio were calculated from the bootstrapped distribution. The 95% confidence interval was also estimated for the fleet-wide bycatch estimate per 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 was truncated at the observed bycatch amount if the estimated lower bound was less than the observed bycatch amount.

Data confidentiality required that we pooled the strata over a three year time window to estimate and report bycatch for certain strata (i.e., < 3 observed vessels per strata). If there were fewer than three observed vessels in a given stratum, data confidentiality prohibits revealing catch and other associated fishing trip information in that stratum. To overcome these issues, we pooled strata from the year before, the year of, and the year after the confidential stratum. We then applied a bootstrapping procedure, as mentioned above, to the three-year pooled strata to estimate the bycatch ratio and its confidence limits in the confidential stratum. The average of bootstrapped ratios was calculated as the estimated bycatch ratio in the confidential stratum. This bycatch ratio can be viewed as a three-year running average. Among the federally managed sectors that encountered green sturgeon during 2002–2013, only one confidential stratum occurred, the winter season of 2008 in the Washington LE bottom trawl fishery sector.

Binomial Model for Encounter Probability

To understand the relationship between green sturgeon bycatch and environmental-habitat variables (average latitudes, average depths, and sea surface temperatures at fishing locations), we employed a generalized linear model with a binomial logit link to model bycatch (presence / absence) as a function of covariates. For modeling purposes, we focused on a small spatial area off the coast of the Columbia River, where most green sturgeon occurred as bycatch in the LE and IFQ trawl fisheries. A subset of observed individual haul data was selected based on geographical location of hauls, so that the model focused on the locations where green sturgeon bycatch occurred in a confined area off the Columbia River. Observed hauls within the latitudes between 45^0 N - 47^0 N and with average trawl depths less than 60 fathoms were selected for the model. The subset included 5,471 observed hauls, of which 69 hauls encountered green sturgeon. To model the green sturgeon encounter probability, the green sturgeon catch data was coded as either presence (positive catch) or absence (zero catch) per given tow. Mathematically, this green sturgeon encounter response can be linked to predictors in a linear fashion with the following equations:

$$Y_i \sim \text{Bernoulli}(p_i)$$

$$\text{logit}(p_i) = \text{X}_i b_i + e_i$$

where Y_i is a binary response indicating green sturgeon presence in tow i, p_i is the probability of encounter in tow i, X is a matrix of predictors, b_i are estimated coefficients, and e_i is an offset term for variable effort between tows. We used retained weight of all FMP groundfish species (not including Pacific hake) as a measure of effort and included it as an offset term in the model to account for varying fishing efforts between the hauls.

As described above, we fit a binomial generalized linear model (GLM) to the green sturgeon observer data in LE and IFQ trawl fisheries, using the ‘glm’ function in R (ver. 3.0.0) with a logit link (R Core Team 2015). Predictors included the average depth of the fishing gear (bottom depth at setting + bottom depth at retrieval divided by 2), average latitude (latitude at setting + latitude at retrieval divided by 2), and sea surface temperature anomaly (SST) of each tow location. Longitude was not considered because it is significantly correlated with depth in this region. Because bottom temperature at each tow location is not available, we use the SST as a proxy for temperature at fishing. For each tow, we obtained daily SST anomalies on a 0.25º grid, and used bilinear interpolation to create SST values corresponding to each haul location in the dataset (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.highres.html).

All predictors were treated as continuous variables in the model. Year effect was not considered in the model due to overall scarcity of green sturgeon encounters and the absence of encounters in several years over the modeled period. To select the key variables among the considered predictors and to identify the most parsimonious model, we first created a model using all linear predictors, then performed a stepwise variable selection (forward and backward), guided by the stepAIC function in R’s ‘MASS’ library. After key linear predictors were selected, we added the 2^{nd} order polynomials of those key predictors to allow for any non-linear relationships, and re-ran the stepwise variable selection with only the key predictors and polynomials to find the final best-fit model. Hosmer-Lemeshow test was used to test the overall predictability of the best-fit model (Simonoff 2003). To examine the effects of selected predictors on green sturgeon bycatch, the predicted probabilities and 95% confidence intervals of the best-fit model were estimated and plotted for each variable, while fixing other variables on their averages (i.e. marginal effects).

Observer Coverage

Reasonable and prudent non-discretionary measures for the ESA Section7(a)(2) 2012 Biological Opinion includes "…identify[ing] goals for minimum [observer] coverage levels to achieve fleet-wide take estimates for green sturgeon…and a plan for implementation." (p. 124, see also § Green Sturgeon p. 128). Unfortunately, the Biological Opinion provides no guidance on the metrics needed to identify minimum goals for appropriate observer coverage. Observer coverage is directly proportional to sampling effort and thus impacts both the accuracy and precision of bycatch estimates. Therefore, to address the goals for minimum observer coverage, the NWFSC Observer program embarked on a preliminary study of the effect of observer coverage on the accuracy and precision of take estimates (Jannot et al. 2015 preliminary study). The accuracy of an estimate is the difference between the mean of the sample and the true population value and any difference between those values represents bias. All bycatch estimates are subject to some level of bias that has numerous potential sources (NMFS 2004). In this preliminary work we only investigate one source of potential bias – the use of a ratio estimator. To the best of our knowledge, NMFS has not tried to identify an acceptable level of bias in bycatch estimates. Observer coverage not only influences the magnitude of bycatch estimates, but also, the precision of those estimates. Unlike bias, NMFS has a precision goal for bycatch estimates of 20-30% for the coefficient of variation (CV, ratio of the standard error to the estimate itself; NMFS 2004). Lower CVs indicate a more precise estimate.

Non-parametric bootstrap resampling and a ratio estimator were used to estimate the fleet-wide catch weight of green sturgeon in the IFQ bottom trawl fishery at varying levels of observer coverage. Because there is 100% observer coverage required in the IFQ fishery since 2011, a complete census of the population (vessels) occurs each year. Therefore we know very precisely and accurately the actual fleet-wide green sturgeon catch. In this study, we use catch weight rather than count of individuals because this work is part of a larger study examining the influence of observer coverage on fishing mortality in fish, by weight. Work is underway to incorporate a similar study on the counts of individuals. The goal of the bootstrapping is to resample vessels (with replacement) within the IFQ fishery at rates less than 100% (i.e., 5% to 90% at 5% intervals) to examine the effect on the accuracy and precision of bycatch estimation. Resampling vessels simulates the historical vessel selection process used to randomly select vessels for observation and the target observer coverage rate was based on the number of vessels selected for each bootstrap sample. Observed coverage (i.e., realized coverage rate) is calculated from the amount of landed groundfish in each bootstrap sample (wt. of 'observed' [i.e., sampled] landed groundfish /total weight of landed groundfish in stratum) and therefore is analogous to the WCGOP observer coverage rates which are based on landings at the end of the year, after observation.

For each level of target coverage, we estimated bycatch using the ratio estimator described above. Vessels were randomly drawn 2000 times within each of the year (2011-13), season (summer = Apr-Oct; winter = Nov-Mar) and depth (fathoms: 0-125, 125-250, 250<)

strata for each specific level of target coverage. The year-season-depth strata match the stratification used in the annual groundfish mortality report to estimate bycatch when observer coverage is less than 100% in the LE bottom trawl sector (Bellman et al. 2011). Therefore, strata in this study of observer coverage do not match strata used to estimate bycatch in this report. For each level of coverage, bycatch ratios were constructed from the sampled data (i.e., 'observed' sampled green sturgeon weight divided by 'observed' landed weight of all groundfish, except P. hake) and then multiplied by the total landed catch (all groundfish in the stratum, except P. hake) to obtain estimated bycatch within each stratum for each level of coverage. This simulates the use of ratio estimators to estimate bycatch by the WCGOP. Bycatch weights were then summed across strata to obtain coast-wide estimates of bycatch for each level of target coverage for each year (2011-13). The coast-wide standard deviation of bycatch for each year-stratum-target coverage level was estimated using the bootstrap samples. Bias (|actual - boot|/actual), error statistics, and coverage statistics were calculated for each year-stratum-target coverage level.

Results

Green Sturgeon Bycatch

Observer data indicated that fishing operations of the LE and IFQ bottom trawl sectors were geographically very extensive (Fig. 1). Fishing extended broadly north to south from the U.S.–Canada to the U.S.–Mexican boundaries. The map also shows that green sturgeon bycatch mostly occurred in confined shallow coastal waters off Astoria, OR, around the Columbia River outflow.

Summaries of green sturgeon encounters in the U.S. West Coast groundfish fishery sectors that were observed by WCGOP and A-SHOP between 2002 and 2013 are provided for the LE bottom trawl sector (2002-2010; Table 3), the IFQ bottom trawl sector (2011-2013; Table 4), and the at-sea hake fisheries sectors (2002-2013; Table 5). Considering the extent of fishing operations over broad latitudinal areas and depth zones (Fig. 1), green sturgeon bycatch in the LE bottom trawl sector were very few and sporadic, with mostly zero encounters within strata (Table 3). The highest observed bycatch was 6 green sturgeon in the summer of 2009, which resulted in a fleet-wide expanded bycatch estimate of 25 green sturgeon in that stratum. In the IFQ bottom trawl sector, the estimated fleet-wide total bycatch ranged between 38 and 10 green sturgeon during 2011-2013 (Table 4). There was a decreasing trend in fleet-wide green sturgeon bycatch numbers from 2011-13 in the IFQ sector, although the total fishing effort, estimated based on the total landed weight of all FMP groundfish (except Pacific hake), was relatively constant over this period and within the range of previous years. The at-sea hake trawl fishery rarely encountered green sturgeon, with 1 fish in 2005 and 2 fish in 2006, during 2002-2013 (Table 5).

We note that the observed catch data and fleet-wide total bycatch estimates for some strata in LE sector provided in this report are not identical to those in the previous report by Al-Humaidhi et al. (2012), though the differences are minor (Table 3). These differences are due to the application of a slightly different bootstrapping scheme. Al-Humaidhi et al. (2012) performed bootstrap estimations for confidential strata based on pooling of all years of available data, instead of a three-year time block. The use of updated observer and fish ticket data was another reason for these differences. For this report, we used most recently updated data that were further processed with data quality assurance and quality control check.

The extent of observer sampling rates differed by fishery sectors. Observer sampling rate is defined as the percent of observed effort (i.e., observed landed weight of target species) over total effort (i.e. fleet-wide landed weight of target species). Sampling rates for the LE bottom trawl sector at the state level ranged between 7.2% - 38.3%, with an average of 19.7%, during 2002-2010. Sampling rates for the IFQ bottom trawl and at-sea hake trawl sectors were close to 100%, based on a complete coverage of all fishing trips (i.e., all fishing vessels carry at least one observer during all fishing trips).

Fishing depths for both sectors ranged from 5 to 900 fathoms, and 100 and 300 fathom depths zones were most heavily fished, constituting over 60% percent of all observed hauls (Fig. 2). Depth distributions of observed fishing activities in other fishery sectors are available in Somer and Jannot (2014b). Examination of hauls within 100 fathoms indicated slightly more fishing was done in deeper waters, with a peak in the 60 fathom zone (51-60 fathoms) in both sectors. Depths from 0 to 60 fathoms were designated as critical habitat for green sturgeon in 2009. The proportions of fishing hauls made within 60 fathoms out of all fishing depths were 21% for the LE sector and 12% for the IFQ sector. Green sturgeon tended to be encountered in the shallower water depth zones in the IFQ bottom trawl fishery than in the LE bottom trawl sector (Fig. 4). The maximum depth of green sturgeon encounters was 47 fathoms for the LE sector and 56 fathoms for the IFQ sector. Out of all tows that encountered green sturgeon, green sturgeon was most frequently encountered in fishing hauls made within less than 40 fathoms (83% of hauls with green sturgeon in the LE sector and 96% of hauls in the IFQ sector).

The number of green sturgeon encountered per haul ranged from 1 to 3 (Fig 5). Most hauls encounter green sturgeon caught only one green sturgeon: 94% of hauls that encountered any green sturgeon in the LE sector and 78% in the IFQ bottom trawl sector. There were no hauls in the LE sector that caught more than 2 green sturgeon per haul. Only about 2% of hauls that encountered green sturgeon in the IFQ bottom trawl sector caught 3 green sturgeon per haul.

Length Frequency

Green sturgeon length data, collected since 2007, were analyzed to compare between sectors and to examine possible patterns. The average length of green sturgeon in the LE trawl sector (138.7 cm) was larger than the average length in the IFQ trawl sector (113.4 cm) (Fig. 6). This difference in average lengths between the sectors was statistically significant (two-sample t-test, t-stat = 2.72, p-value = 0.016). Once green sturgeon enter marine waters, they are considered to be in the subadult stage. Thus, green sturgeon in two life stages would be encountered in groundfish sectors in the ocean: adults (≥ 140 cm FL) and subadults (< 140 cm FL) (NMFS 2012, p. 88). The proportions of subadults were 54% in LE trawl sector and 87% in IFQ trawl sector. IFQ trawl sector caught higher proportion of green sturgeon subadults than the LE trawl sector. We note that the IFQ bottom trawl sector is a continued form of the LE bottom trawl sector with a different fisheries management framework. It is not clear whether encountering more subadults in recent years (i.e., in the IFQ bottom trawl sector) was due to changes in green sturgeon population structure or changes in fishing operations.

It is inconclusive that green sturgeon length at capture is related with the depth at capture (Fig. 4). The plot indicates that the variability of length data over depths is very large. When the length data was regressed with depth at capture for the combined LE and IFQ trawl data, the regression slope was significant ($F_{1, 72}$ = 4.725, p-value = 0.033) but with a very low goodness-of-fit (R^2 = 6.2%). However, when the regression was fitted separately by each sector, the slopes were not statistically significant for either sector. The results indicate that the size of green sturgeon encountered in the LE and IFQ trawl is not a function of fishing depth. Thus, size-selective green sturgeon bycatch avoidance cannot be achieved by avoiding certain fishing depths.

Binomial Model for Encounter Probability

The best-fit GLM contained all three original linear predictors (depth, latitude, SST anomaly). In addition, quadratic terms of depth and SST anomaly variables were selected as significant to the model (Table 6). Depth and SST anomaly had significant distinctive unimodal concave relationships with encounter probability of green sturgeon (Fig. 8). An increasing trend was found in the encounter probability with latitude from south to north. Concave relationships indicated that the encounter probability peaked around 15 fathoms of depth and around the SST anomaly. While the predicted encounter probabilities for these variables were statistically significant, the magnitudes of probability differences were very minimal (e.g., the difference between maximum and minimum predicted probability is less than 1.2% for the depth variable). Thus, the magnitude of biological importance was small even though depth variable was statistically important. Although it appeared that the model was able to effectively capture the relationships between encounter probability and predictor variables, the overall model predictability was low (Hosmer-Lemeshow test, p-value < 0.001).

Observer Coverage

Currently 100% of landings are observed in the IFQ bottom trawl fleet which also includes LE California halibut tows. At this point in time, the WCGOP plans to maintain 100% coverage in the IFQ bottom trawl fleet for the foreseeable future. In many fisheries, it is not physically or economically feasible to observe all fishing effort and bycatch. For example, prior to 2011 in the LE bottom trawl fleet, target observer coverage was 20-30% and realized observer coverage rates varied between 14-24% of total landings from 2002-10 (Somers and Jannot 2014a). In the unlikely event that observer coverage in the IFQ bottom trawl fleet was reduced, the WCGOP would strive to maintain historic levels of coverage, with a target of 20-30% of the landings observed.

Currently there are no national recommendations regarding acceptable levels of bias in bycatch estimation (NMFS 2004). Preliminary results from work conducted by NWFSC scientists indicates that observing 20-30% of the total landings in the Limited Entry bottom trawl fleet might lead to estimates of green sturgeon bycatch that are larger than the true value (Table 7, Figure 9, Jannot et al. unpublished work in progress). This preliminary work supports the well-known observation that ratio estimators consistently over-estimate the true value (Pearson 1897) particularly when data are stratified and sample sizes within a stratum are small to moderate (Hutchinson 1971, Rao & Beegle 1967, Williams 1961). Because ratio estimators appear to over-estimate green sturgeon bycatch, these estimates should be considered to be conservative. Other sources of bias have not been evaluated (NMFS 2004).

Preliminary results suggest that the WCGOP could achieve the NMFS national precision goal for green sturgeon, a CV of 20-30%, in the Limited Entry bottom trawl fishery with 15-30% observer coverage (Figure 10). These coverage levels (15-30%) are similar to historical coverage rates in this sector.

The preliminary work on observer coverage presented here is based on the IFQ bottom trawl fleet only. Caution should be used when trying to apply these results to other fishery sectors. The WCGOP is still working to understand how these results might apply to the OA California halibut fishery and other fishery sectors observed at less than 100%.

Discussion

The Biological Opinion (NMFS 2012, p. 122, aka BiOp) states that take of Southern DPS in the combined LE groundfish bottom trawl, IFQ groundfish bottom trawl, and at-sea hake fisheries should not exceed more than 28 fish per year. While the BiOp only concerns Southern DPS as a listed species, currently there is no direct method to differentiate between Southern DPS and Northern DPS fish at the time of observation at sea. A genetic study by Dr. Carlos Garza (NMFS, SWFSC), based on green sturgeon tissue samples from the years of 2007-2013, indicate that 55% of green sturgeon caught off Oregon and Washington waters belong to the Southern DPS and 45% of them belong to the Northern DPS. The DPS proportions change dramatically for green sturgeon caught off California: 90% belong to the Southern DPS and 10% to the Northern DPS.

Out of 91 total green sturgeon encountered and observed by the WCGOP and A-SHOP in these sectors across 12 years (2002-2013), 89 of them (97.8%) occurred off the Oregon and Washington coasts. Applying the proportion of Southern DPS fish (55%) from the genetic study to the combined fleet-wide expanded bycatch numbers, there would be no single year that exceeded the BiOp's annual take-limit of 28 fish between 2002 and 2013. However, the genetic stock identification results are preliminary and the genetic baseline consists of relatively few samples. In addition, only the point estimates of the DPS proportions were applied to proportionate bycatch estimates without error bounds, as those statistics were not available at the time of this bycatch analysis, so these estimates should be interpreted with caution.

With the implementation of the catch shares program since 2011, the IFQ bottom trawl fishery sector is observed at sea with 100% coverage. The at-sea hake trawl sector has been observed at 100%. Thus, the observed green sturgeon bycatch should be a complete census of all green sturgeon bycatch across all fishing vessels in these federally-managed fishery sectors. With more genetic samples in future years, the individual green sturgeon bycatch from these sectors will be more accurately assigned to the Northern or Southern DPS. Hence, the estimated number of Southern DPS green sturgeon bycatch in these fisheries will become more accurate.

The binomial model was successfully applied to green sturgeon data at the individual haul level to relate some habitat and environmental variables to encounter probability. The relationship with SST anomaly suggests that the chance of encountering green sturgeon drops if the fishing location is warmer or colder than average. A study on coast-wide green sturgeon distribution and migration patterns, based on the coastal tracking array records of acoustic tags, indicated that green sturgeon would respond differently to temperature changes by season (Huff et al. 2012). Our model did not include any temporal variable due to the limited number of green sturgeon encounters, so the current model assumed that the predicted responses over the modeled variables were constant across the time span of data. This assumption may not be very applicable to annually or seasonally dynamic variables such as SST. Our model was not built to depict such temporal patterns of green sturgeon encounters even if there were any. Thus it should be noted that the shape of the response curve over SST may not be constant from season to season or from year to year.

The shape of the latitudinal effect shown from the binomial model may be mainly driven by the range of input data, because the model only included a selected range of latitudes over which the fishery sectors occur. If the selected range of latitudes was widened, the predicted probability curve over latitude could show a different shape, as the latitude range would include more zero green sturgeon encounter data at both ends of the range. Overall predictability of the model was low due to too many zero green sturgeon encounters relative to non-zero encounters in the data. One of the general problems with binomial GLMs is in modeling rare event data (Firth 1993, King and Zeng 2001). Because of the low predictability, the current model and its results should be used for exploratory purposes of green sturgeon bycatch patterns in relation to habitat/environmental variables, rather than prediction purposes. Regardless of these shortcomings, it is encouraging that the fitted binomial logit model is able to illustrate a pattern of green sturgeon bycatch in relation to some external variables. More study is needed to understand the changes in green sturgeon behaviors and distribution patterns responding to environmental changes in the context of conservation and bycatch minimization.

Currently, we have no information on recapture and post-release survival rates of green sturgeon bycatch in these fisheries, but studies to address these data needs are underway. In January 2014, observers began applying passive integrated transponder (PIT) tags to green sturgeon observed in the IFQ bottom trawl and California halibut fisheries to assess recapture rates. A study is also being conducted to evaluate the post-release survival of green sturgeon encountered in the California halibut fishery. This study is a collaboration between the NMFS West Coast Region Protected Resources Division (WCR PRD), Southwest Fisheries Science Center (SWFSC), WCGOP, California Department of Fish and Wildlife (CDFW), and California halibut fishermen. Observers and fishermen will apply satellite tags to green sturgeon that are incidentally caught in this fishery in order to track the fish's survival and movements for a 30 to 60 day period after release. Tagging activities will be conducted in the spring through fall of 2015, with plans to continue the study into the future if funds are available. Both tagging studies are supported by funds from the SWFSC Cooperative Research Program and NMFS WCR PRD.

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Table 1. 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), that were observed by the WCGOP, and three sectors of the at-sea hake fishery that were observed by the A-SHOP (CP = Catcher Processor, MS = Non-Tribal Mothership, TM = Tribal Mothership). Estimates of Southern DPS (SDPS) bycatch are calculated based on genetic stock proportions by catch locations (55% for WA and OR, 90% for CA). NDPS indicates Northern DPS populations. Green sturgeon have never been encountered in federal open access (OA) fisheries and therefore those sectors are omitted from the table for clarity.

WCGOP

		NDPS + SDPS			SDPS (55%)		SDPS (90%)	Totals	
Sector	Year	WA	OR	CA	WA	OR	CA	All	SDPS
LE	2002	0	13	7	0.0	7.2	6.30	20	13.5
	2003	0	0	0	0.0	0.0	0.00	0	0.0
	2004	5	5	0	2.8	2.8	0.00	10	5.5
	2005	0	5	0	0.0	2.8	0.00	5	2.8
	2006	0	0	0	0.0	0.0	0.00	0	0.0
	2007	0	6	0	0.0	3.3	0.00	6	3.3
	2008	0	0	0	0.0	0.0	0.00	0	0.0
	2009	6	37	0	3.3	20.4	0.00	43	23.7
	2010	0	8	0	0.0	4.4	0.00	8	4.4
IFQ	2011	0	38	0	0.0	20.9	0.00	38	20.9
	2012	0	22	0	0.0	12.1	0.00	22	12.1
	2013	0	10	0	0.0	5.5	0.00	10	5.5

A-SHOP

	NDPS + SDPS			SDPS (55%)			Totals	
Year	CP	MS	TM	CP	MS	TM	All	SDPS
2002	0	0	0	0	0	0.0	0	0.0
2003	0	0	0	0	0	0.0	0	0.0
2004	0	0	0	0	0	0.0	0	0.0
2005	0	0	1	0	0	0.6	1	0.6
2006	0	2	0	0	1.1	0.0	2	1.1
2007	0	0	0	0	0	0.0	0	0.0
2008	0	0	0	0	0	0.0	0	0.0
2009	0	0	0	0	0	0.0	0	0.0
2010	0	0	0	0	0	0.0	0	0.0
2011	0	0	0	0	0	0.0	0	0.0
2012	0	0	0	0	0	0.0	0	0.0
2013	0	0	na	0	0	na	0	0.0

Table 2. Generalized descriptions of U.S. west coast groundfish fisheries that have had observed bycatch of green sturgeon.

							Management	
Sector	**Sub-Sector**	**Permits**	**Gear(s)**	**Target(s)**	**Vessel length (m)**	**Depths (m)**	**2002-2010**	**2011-2013**
Limited Entry (LE) Trawl		Federal LE permit with trawl endorsement	Bottom trawl	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
At-Sea Hake	Mothership-Catcher Vessel (MSCV)	LE permit with MSCV endorsement	Midwater trawl	Pacific hake	26–45	53–460	Seasonal quotas for target and bycatch species of concern; 100% observer coverage	IFQ; seasonal; 100% observer
	Catcher-processors (CP)	LE permit with CP endorsement	Midwater trawl	Pacific hake	82–115	60–570	Same as At-Sea Hake MSCV	IFQ; seasonal; 100% observer
	Tribal	(none)	Midwater trawl	Pacific hake		53–460	Tribal; 100% observer coverage	Tribal; 100% observer coverage

Table 3. Observed bycatch numbers, bycatch ratios, and fleet-wide total bycatch estimates of green sturgeon from limited entry bottom trawl fishery (2002-2010). Bootstrapped confidence intervals (95% CI) are provided for the estimates. Groundfish landings are in metric tons (MT). Winter season is January-April and November-December; summer is May-October. Asterisks (*) signify confidential strata with fewer than three observed vessels. Because of limited decimal points in the table, bycatch ratios for some strata are shown as zeros (0.00) although they are positive numbers (> 0.00). These positive but small bycatch ratios have numeric confidence intervals, rather than "na".

Washington

Year	Season	Observed bycatch	Observed groundfish landings (MT)	Fleet-total groundfish landings (MT)	Groundfish landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet-total bycatch	Lower CI of bycatch	Upper CI of bycatch
2002	winter	0	318.2	1332.4	23.9	0.00	na	na	0	na	na
	summer	1	155.9	1089.6	14.3	0.01	0.00	0.02	7	1	25
2003	winter	0	132.7	1371.0	9.7	0.00	na	na	0	na	na
	summer	0	59.1	674.2	8.8	0.00	na	na	0	na	na
2004	winter	0	343.3	895.7	38.3	0.00	na	na	0	na	na
	summer	0	188.5	958.3	19.7	0.00	na	na	0	na	na
2005	winter	0	174.2	1004.3	17.3	0.00	na	na	0	na	na
	summer	0	426.5	2026.3	21.1	0.00	na	na	0	na	na
2006	winter	0	92.2	528.0	17.5	0.00	na	na	0	na	na
	summer	0	304.9	1317.6	23.1	0.00	na	na	0	na	na
2007	winter	0	170.9	723.1	23.6	0.00	na	na	0	na	na
	summer	0	63.6	879.7	7.2	0.00	na	na	0	na	na
2008	winter	*	*	794.0	*	0.00	0.00	0.00	0	0	0
	summer	0	324.4	931.2	34.8	0.00	na	na	0	na	na
2009	winter	0	366.6	1415.3	25.9	0.00	na	na	0	na	na
	summer	0	397.0	1274.0	31.2	0.00	na	na	0	na	na
2010	winter	0	282.5	1237.3	22.8	0.00	na	na	0	na	na
	summer	0	221.9	891.6	24.9	0.00	na	na	0	na	na

Table 3. Continued.

Oregon

Year	Season	Observed bycatch	Observed groundfish landings (MT)	Fleet-total groundfish landings (MT)	Groundfish landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet-total bycatch	Lower CI of bycatch	Upper CI of bycatch
2002	winter	1	654.1	4288.8	15.3	0.00	0.00	0.01	7	1	23
	summer	1	538.0	3645.4	14.8	0.00	0.00	0.01	7	1	19
2003	winter	0	898.2	4667.3	19.2	0.00	na	na	0	na	na
	summer	0	576.1	4625.5	12.5	0.00	na	na	0	na	na
2004	winter	0	1230.3	4555.0	27.0	0.00	na	na	0	na	na
	summer	1	1032.7	5449.7	18.9	0.00	0.00	0.00	5	1	17
2005	winter	0	1268.8	4850.8	26.2	0.00	na	na	0	na	na
	summer	1	1271.9	5826.4	21.8	0.00	0.00	0.00	5	1	14
2006	winter	0	855.4	4347.9	19.7	0.00	na	na	0	na	na
	summer	0	1215.7	6644.1	18.3	0.00	na	na	0	na	na
2007	winter	0	877.4	6158.9	14.2	0.00	na	na	0	na	na
	summer	1	1199.4	6598.0	18.2	0.00	0.00	0.00	6	1	18
2008	winter	0	1401.0	7999.9	17.5	0.00	na	na	0	na	na
	summer	0	1922.9	7868.0	24.4	0.00	na	na	0	na	na
2009	winter	3	2204.7	9030.6	24.4	0.00	0.00	0.00	12	3	42
	summer	6	1901.7	7984.5	23.8	0.00	0.00	0.01	25	6	65
2010	winter	0	902.7	7488.3	12.1	0.00	na	na	0	na	na
	summer	2	1843.7	7512.0	24.5	0.00	0.00	0.00	8	2	20

California

Year	Season	Observed bycatch	Observed groundfish landings (MT)	Fleet-total groundfish landings (MT)	Groundfish landings sampled (%)	Bycatch ratio	Lower CI of ratio	Upper CI of ratio	Fleet-total bycatch	Lower CI of bycatch	Upper CI of bycatch
2002	winter	0	480.3	3758.7	12.8	0.00	na	na	0	na	na
	summer	0	533.5	3890.4	13.7	0.00	na	na	0	na	na
2003	winter	0	342.1	2925.5	11.7	0.00	na	na	0	na	na
	summer	0	582.1	4125.3	14.1	0.00	na	na	0	na	na
2004	winter	0	742.8	2193.5	33.9	0.00	na	na	0	na	na
	summer	1	772.1	3621.8	21.3	0.00	0.00	0.00	5	1	14
2005	winter	0	503.4	2492.0	20.2	0.00	na	na	0	na	na
	summer	0	596.6	3086.3	19.3	0.00	na	na	0	na	na
2006	winter	0	367.9	1926.7	19.1	0.00	na	na	0	na	na
	summer	0	607.3	3030.6	20.0	0.00	na	na	0	na	na
2007	winter	0	427.8	2377.5	18.0	0.00	na	na	0	na	na
	summer	0	703.1	3705.3	19.0	0.00	na	na	0	na	na
2008	winter	0	575.6	3179.3	18.1	0.00	na	na	0	na	na
	summer	0	663.2	3415.8	19.4	0.00	na	na	0	na	na
2009	winter	0	546.4	2832.3	19.3	0.00	na	na	0	na	na
	summer	1	637.0	3518.8	18.1	0.00	0.00	0.00	6	1	18
2010	winter	0	203.8	2133.8	9.5	0.00	na	na	0	na	na
	summer	0	565.0	3057.8	18.5	0.00	na	na	0	na	na

Table 4. Observed and fleet-wide total expanded numbers of green sturgeon bycatch from the IFQ bottom trawl fishery (2011-2013) (WA = Washington, OR = Oregon, and CA = California). Groundfish landings are in metric tons. Note that the IFQ fisheries are sampled at close to 100%. Due to confidentiality mandates, landings information for CA in 2013 is asterisked (*).

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	1849.3	1859.6	99.4	0.0	0
	2012	0	2035.1	2066.4	98.5	0.0	0
	2013	0	1486.9	1488.7	99.9	0.0	0
OR	2011	37	10793.0	10876.7	99.2	1.4	38
	2012	21	10625.4	10692.1	99.4	0.5	22
	2013	10	12098.2	12133.5	99.7	0.3	10
CA	2011	0	4596.5	4601.8	99.9	0.0	0
	2012	0	4442.9	4451.4	99.8	0.0	0
	2013	0	*	*	99.7	0.0	0

Table 5. Observed and expanded bycatch numbers of green sturgeon from the At-Sea hake fishery (2002-2013). Hake landings are shown in metric tons. Note that this fishery is sampled at close to 100%. The tribal mothership sector did not participate in this fishery in 2013. Asterisks (*) signify confidential strata with fewer than three observed vessels.

Sector	Year	Observed bycatch	Fleetwide Expanded bycatch	Sampled tow numbers	Sampled hake landings (MT)	% tows sampled
Catcher Processor	2002	0	0	556	36332.9	99.5
	2003	0	0	766	41468.6	99.7
	2004	0	0	1492	72858.7	99.4
	2005	0	0	1332	78497.5	99.6
	2006	0	0	1488	78246.3	99.4
	2007	0	0	1566	72898.1	99.3
	2008	0	0	1864	107754.4	98.8
	2009	0	0	863	34590.8	99.4
	2010	0	0	1063	54217.3	99.5
	2011	0	0	1530	71336.7	98.8
	2012	0	0	1100	55522.6	99.4
	2013	0	0	1439	78004.8	98.6
Non-tribal mothership	2002	0	0	573	26502.9	99.8
	2003	0	0	522	25332.9	97.4
	2004	0	0	569	24010.1	99.6
	2005	0	0	1038	48600.6	99.8
	2006	2	2	1243	54138.8	96.9
	2007	0	0	1135	47276.3	99.0
	2008	0	0	1346	57687.4	99.8
	2009	0	0	597	24066.4	99.5
	2010	0	0	908	35726.9	100.0
	2011	0	0	1246	49970.6	99.8
	2012	0	0	931	38042.1	98.1
	2013	0	0	1249	52348.3	99.4
Tribal Mothership	2002	0	0	625	21629.0	98.7
	2003	0	0	537	19430.8	99.4
	2004	0	0	632	23511.4	100.0
	2005	1	1	632	23561.6	99.8
	2006	0	0	154	5405.4	96.3
	2007	0	0	156	5129.4	100.0
	2008	0	0	380	14977.3	99.5
	2009	0	0	403	13469.4	99.8
	2010	0	0	516	16206.2	100.0
	2011	0	0	228	6146.9	100.0
	2012	*	0	*	*	*
	2013	na	na	na	na	na

Table 6. Parameter estimates and deviances for the best-fit binomial GLM, fit to green sturgeon presence-absence catch data in LE bottom trawl and IFQ bottom trawl fisheries.

	DF	Deviance	Residual DF	Residual Deviance	AIC
Null	NA	NA	5470	969.4	971.4
Model	5	192.7	5465	776.7	788.7

Variable	DF	Coefficient	SE	Z-stat	P-value
Intercept	1	-37.820	25.300	-1.50	0.135
Latitude	1	0.712	0.550	1.29	0.196
Depth	1	0.147	0.052	2.86	0.004
SST	1	0.087	0.163	0.53	0.594
$Depth^2$	1	-0.005	0.001	-5.13	0.000
SST^2	1	-0.237	0.109	-2.18	0.029

Table 7. Bias and error statistics from a simulation study examining the effect of variation in observer coverage on estimates of green sturgeon takes (discard weight, mt; Jannot, unpublished work in progress). RMSE = root mean squared error; MAE = mean absolute error; RRSE = relative root squared error; RAE = relative absolute error.

Strata			Bootstrapped Discard Statistics							Bootstrapped Coverage Statistics		
Year	Season	Target Coverage	discard (mt ± 1 SD)	bias	RMSE	MAE	RRSE	RAE	Actual Discard (mt, census)	No. vess. per draw	No. vess. in stratum	Observed Coverage (bootstrap ± 1 SD)
2011	summer	15%	0.68 ±0.37	0.22	0.32	0.16	1.16	1.00	0.47	3	22	13 ±7%
2012	summer	15%	0.55 ±0.49	0.29	0.45	0.23	1.16	1.06	0.27	4	24	16 ±8%
2013	summer	15%	0.27 ±0.21	0.20	0.15	0.06	1.35	1.10	0.08	3	20	14 ±5%
2011	winter	15%	0.49 ±0.15	0.28	0.18	0.09	2.08	1.82	0.22	1	6	16 ±13%
2012	winter	15%	0.02 ±0	0.01	0.00	0.00	6.05	7.03	0.02	2	10	21 ±32%
2013	winter	15%	0.3 ±0.19	0.25	0.16	0.07	1.65	1.45	0.05	2	14	14 ±23%
2011	summer	20%	0.61 ±0.32	0.15	0.29	0.16	1.10	0.97	0.47	4	22	18 ±8%
2012	summer	20%	0.46 ±0.4	0.20	0.37	0.21	1.11	0.98	0.27	5	24	20 ±9%
2013	summer	20%	0.22 ±0.16	0.14	0.13	0.05	1.32	1.13	0.08	4	20	19 ±6%
2011	winter	20%	0.49 ±0.15	0.28	0.18	0.09	2.07	1.82	0.22	1	6	16 ±13%
2012	winter	20%	0.02 ±0	0.01	0.00	0.00	5.73	6.54	0.02	2	10	20 ±31%
2013	winter	20%	0.23 ±0.16	0.19	0.15	0.07	1.54	1.35	0.05	3	14	23 ±29%
2011	summer	25%	0.53 ±0.27	0.07	0.25	0.17	1.03	0.99	0.47	6	22	26 ±10%
2012	summer	25%	0.4 ±0.33	0.14	0.32	0.18	1.08	0.98	0.27	6	24	24 ±10%
2013	summer	25%	0.18 ±0.15	0.11	0.12	0.06	1.22	1.05	0.08	5	20	24 ±7%
2011	winter	25%	0.38 ±0.17	0.17	0.18	0.11	1.37	1.27	0.22	2	6	33 ±19%
2012	winter	25%	0.02 ±0	0.01	0.00	0.00	5.48	6.39	0.02	2	10	19 ±31%
2013	winter	25%	0.19 ±0.13	0.14	0.14	0.07	1.44	1.25	0.05	4	14	28 ±32%
2011	summer	30%	0.52 ±0.27	0.06	0.25	0.18	1.02	0.98	0.47	7	22	31 ±11%
2012	summer	30%	0.36 ±0.27	0.09	0.26	0.17	1.05	0.98	0.27	7	24	29 ±11%
2013	summer	30%	0.16 ±0.12	0.09	0.10	0.05	1.21	1.10	0.08	6	20	29 ±8%
2011	winter	30%	0.38 ±0.17	0.17	0.19	0.11	1.39	1.30	0.22	2	6	33 ±19%
2012	winter	30%	0.02 ±0	0.00	0.00	0.00	3.83	4.33	0.02	3	10	30 ±38%
2013	winter	30%	0.19 ±0.14	0.15	0.14	0.07	1.46	1.26	0.05	4	14	27 ±31%
2011	summer	35%	0.49 ±0.25	0.03	0.24	0.18	1.01	0.99	0.47	8	22	35 ±11%
2012	summer	35%	0.35 ±0.27	0.09	0.26	0.17	1.05	0.97	0.27	8	24	33 ±12%
2013	summer	35%	0.15 ±0.11	0.07	0.10	0.06	1.18	1.10	0.08	7	20	34 ±9%
2011	winter	35%	0.38 ±0.17	0.17	0.18	0.11	1.39	1.28	0.22	2	6	32 ±19%
2012	winter	35%	0.02 ±0	0.00	0.00	0.00	3.16	3.58	0.02	4	10	40 ±42%
2013	winter	35%	0.16 ±0.12	0.11	0.12	0.07	1.38	1.18	0.05	5	14	36 ±37%

Figure 1. Map of green sturgeon bycatch in LE and IFQ bottom trawl sectors: fishing locations and landed amount of FMP listed all groundfish species, except hake (left panel), and locations of green sturgeon bycatch and its density (right panel). Observer data are aggregated to one-square-kilometer cells. Cells containing less than 3 vessels are not shown, to maintain confidentiality.

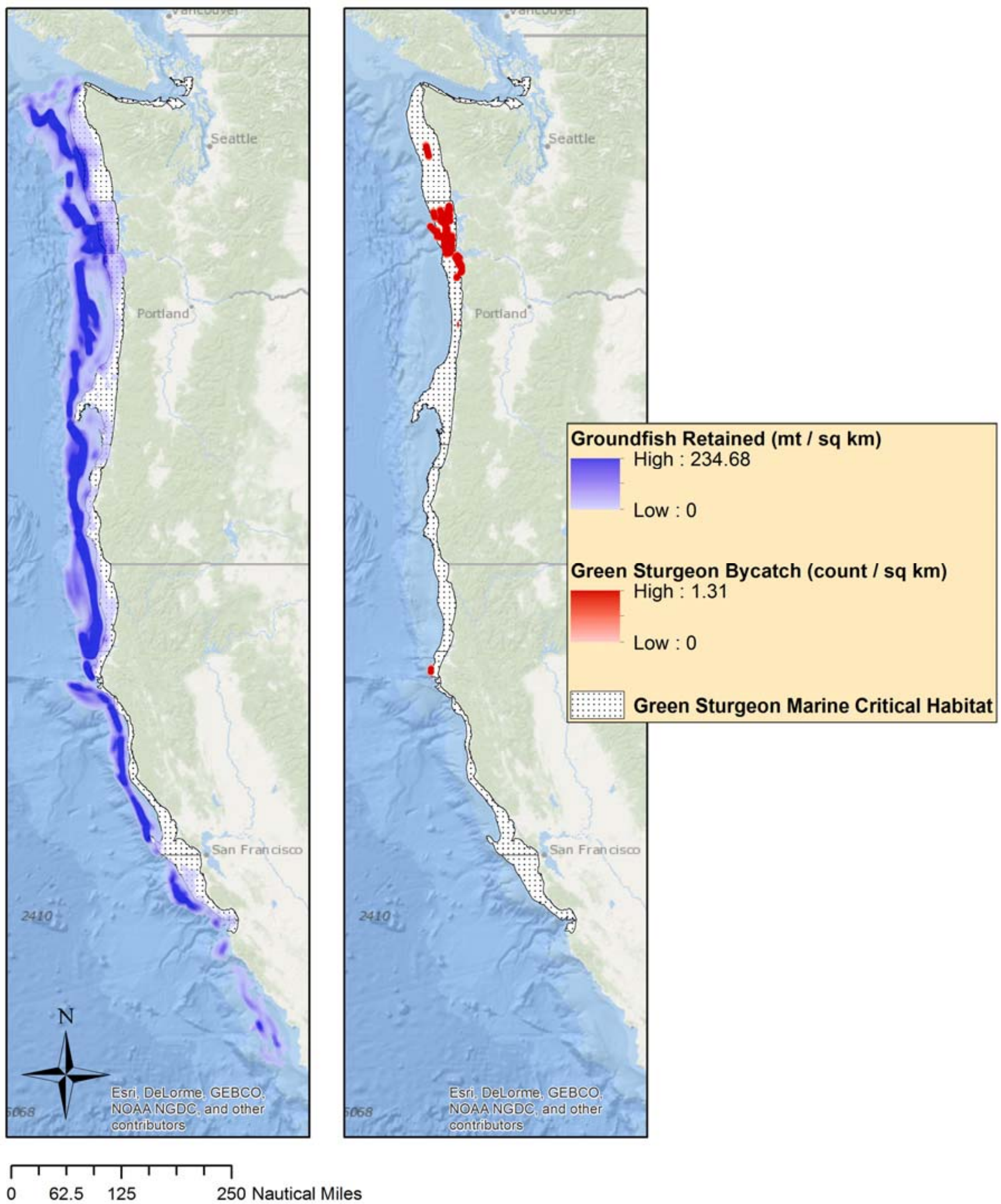


Figure 2. Frequency distribution of hauls over all fishing depths in LE bottom trawl sector for 2002-2010, and IFQ bottom trawl sector for 2011-2013. N is the total number of observed hauls.

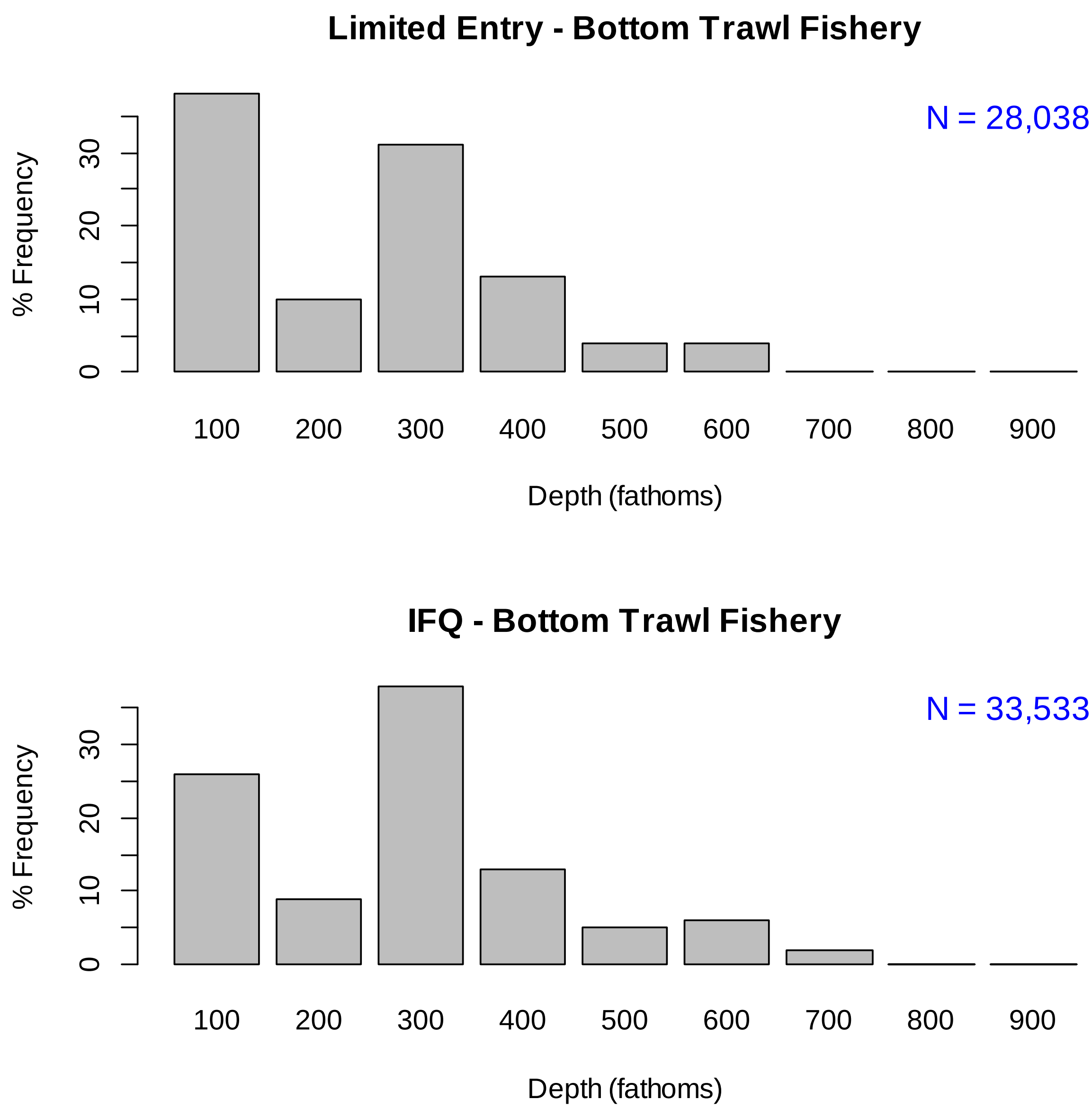
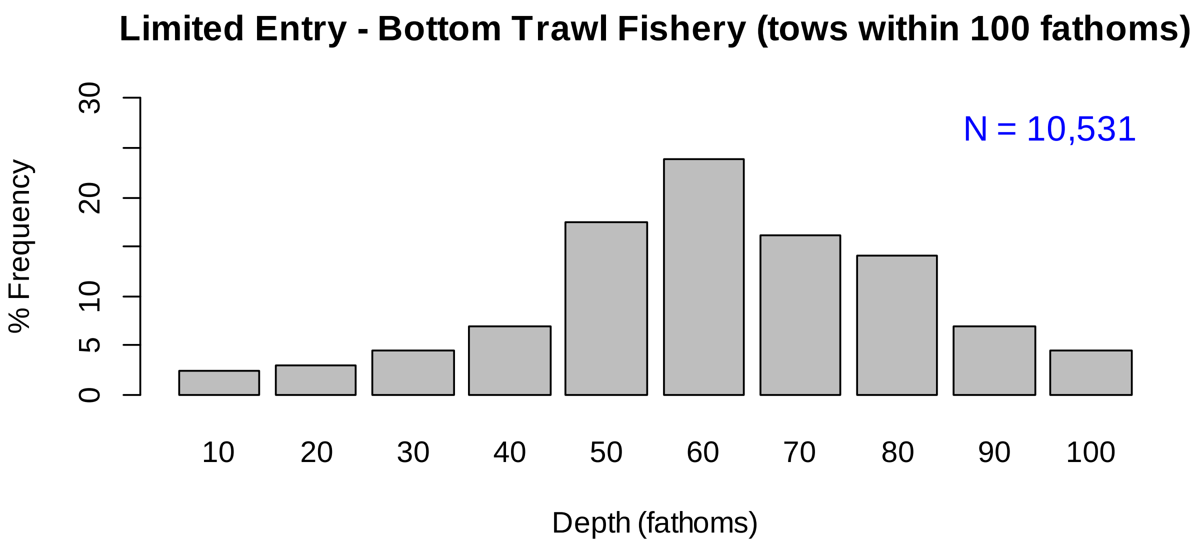


Figure 3. Frequency distribution of hauls within the depth of 100 fathoms in the LE bottom trawl sector for 2002-2010, and IFQ bottom trawl sector for 2011-2013. N is the total number of observed hauls.



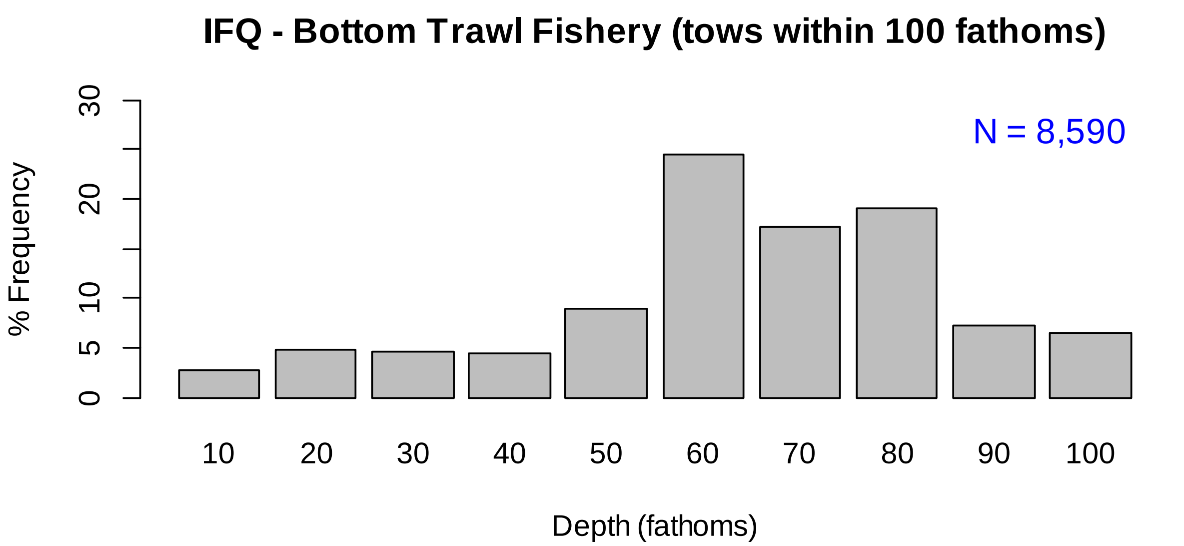
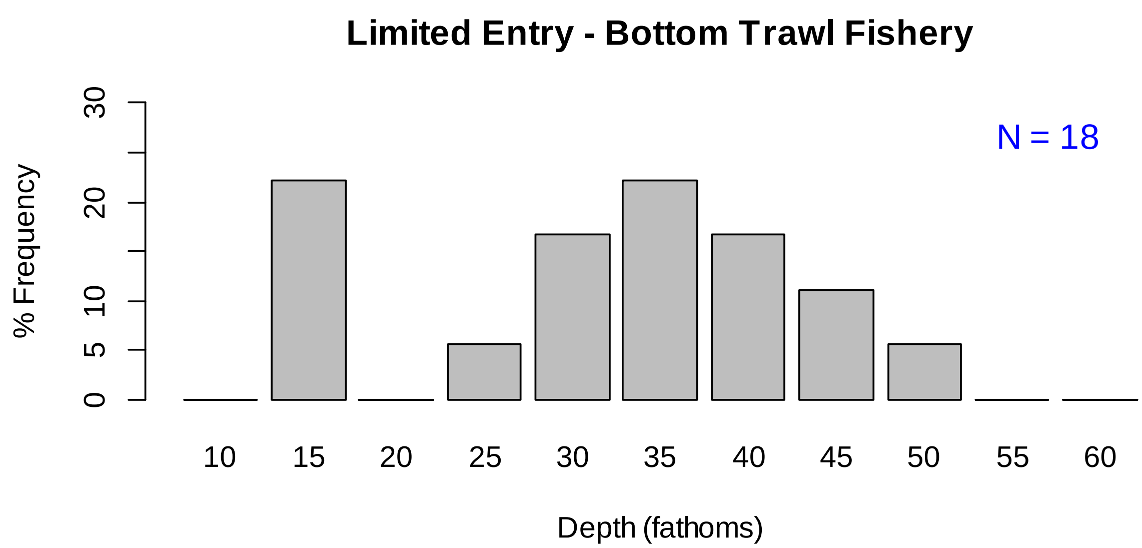


Figure 4. Frequency distribution of hauls by depth that encountered green sturgeon in the LE bottom trawl sector for 2002-2010, and the IFQ bottom trawl sector for 2011-2013. N is the total number of observed hauls that encountered green sturgeon.



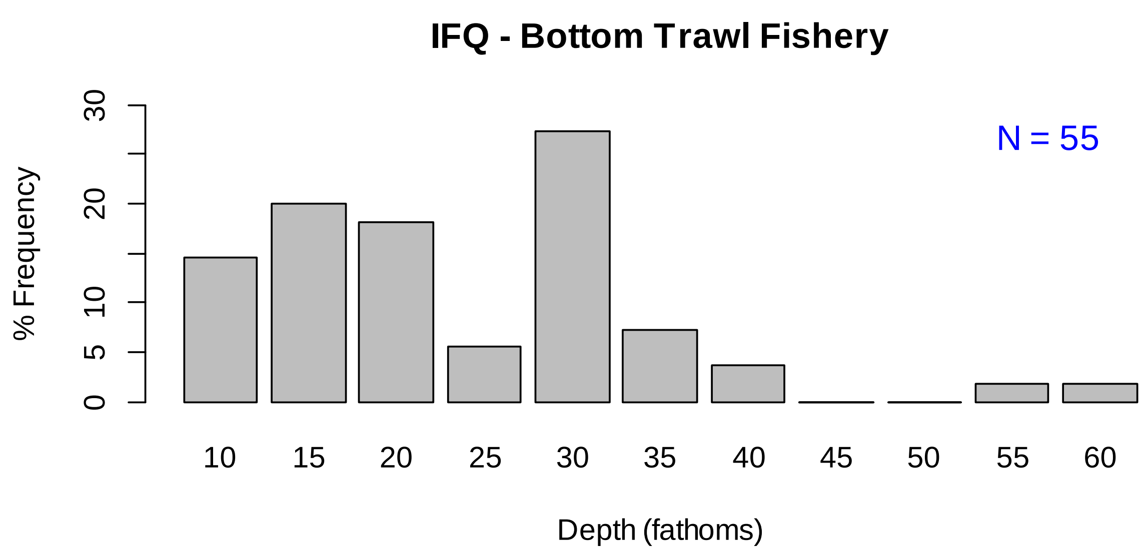
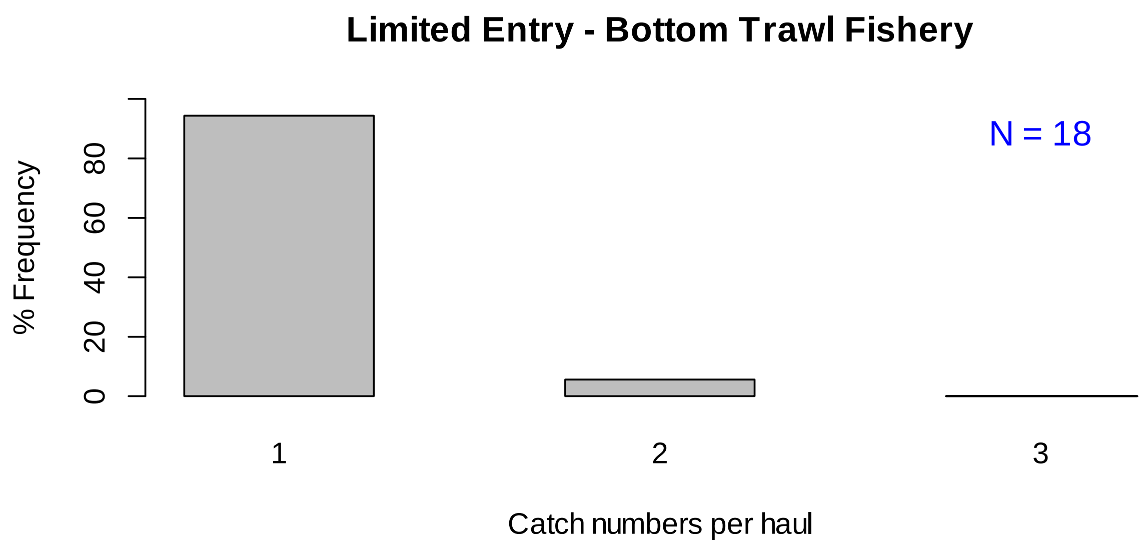


Figure 5. Frequency distribution of green sturgeon catch size per haul. N is the total number of observed hauls that encountered green sturgeon.



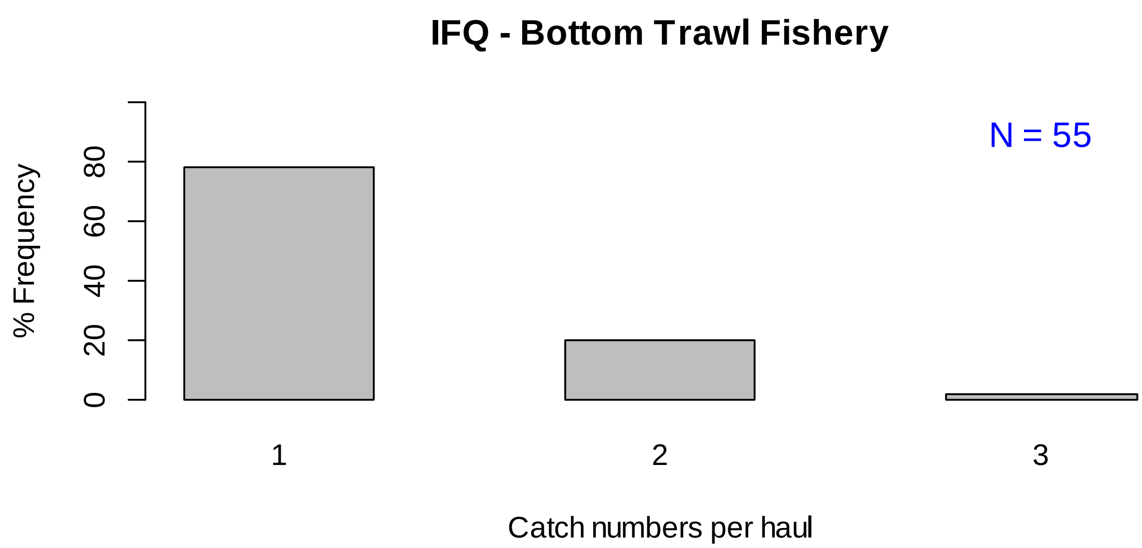


Figure 6. Box plot of green sturgeon length data by fishery sector: LE for limited entry trawl sector and IFQ for IFQ trawl sector. The cross bar is the median and the solid red circle inside the box is the mean. The horizontal dashed line indicates the fish length criteria (140 cm) that differentiates between the adult and subadult life stages.

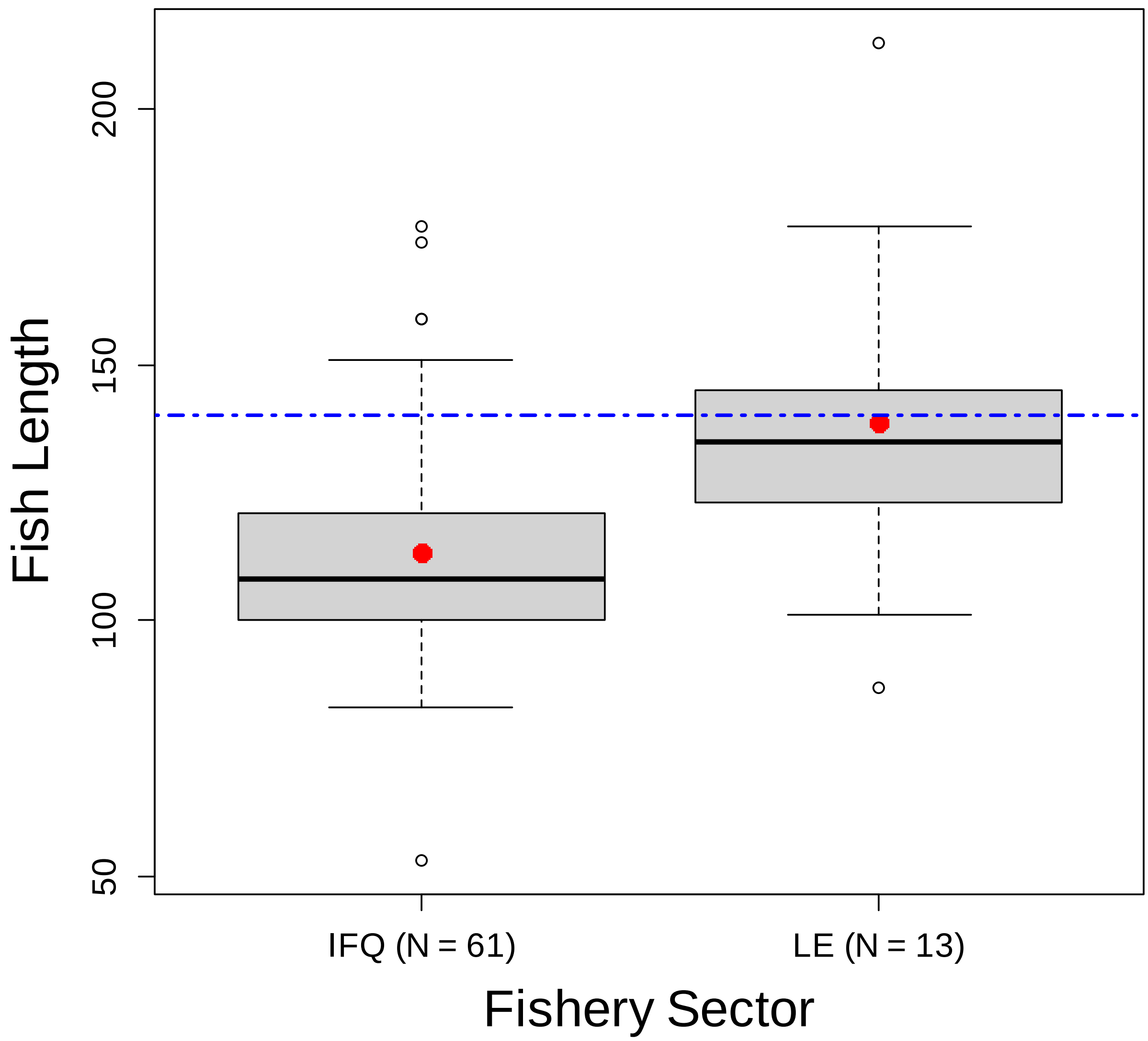


Figure 7. Scatter plot of green sturgeon lengths over fishing depths at capture in the limited entry (LE) trawl sector and IFQ trawl sector. The horizontal dashed line indicates the fish length criteria (140 cm) that differentiates between the adult and subadult life stages.

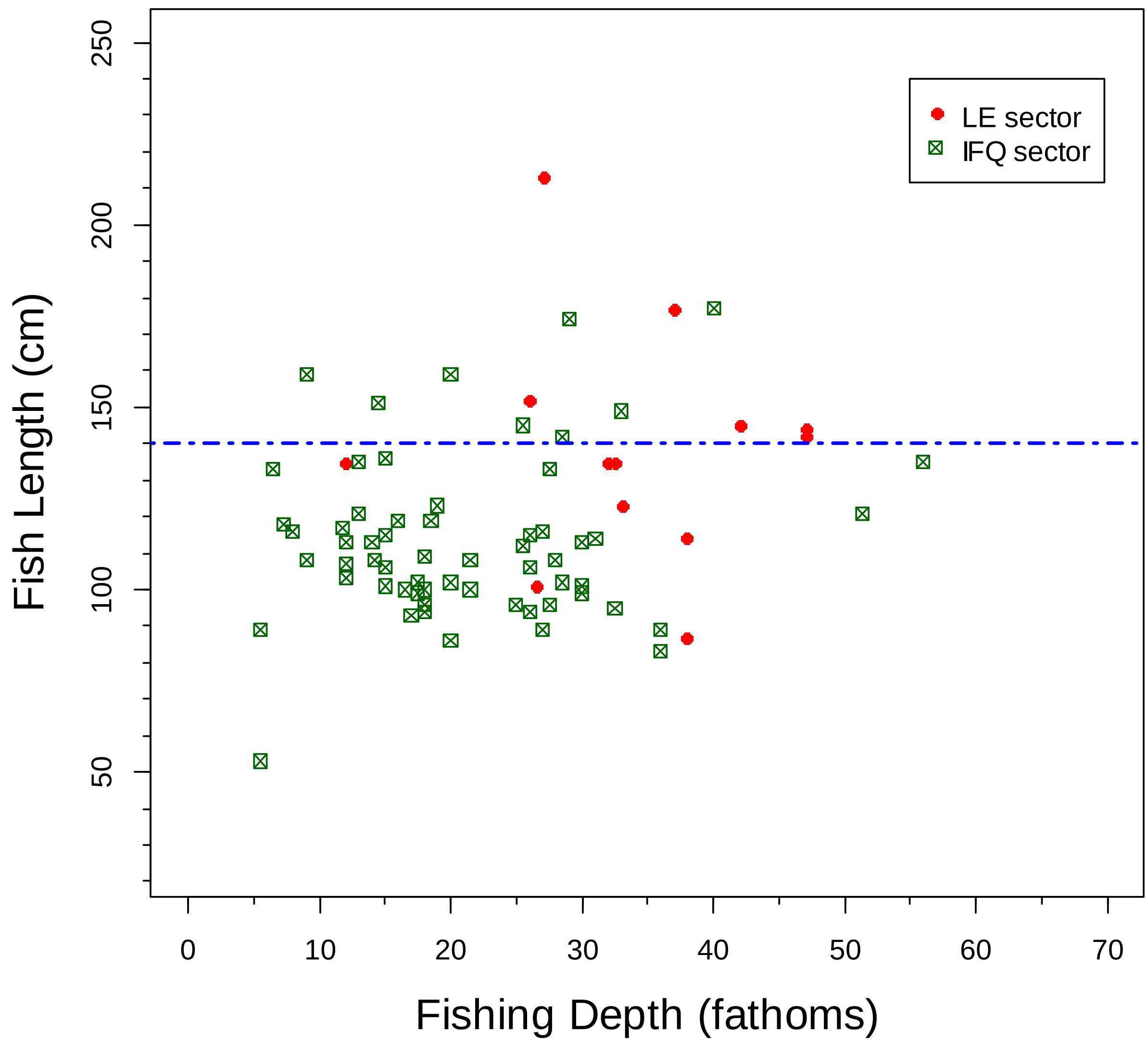


Figure 8. Marginal relationships between predictors and the predicted probabilities of green sturgeon encounters (solid blue line), with all other predictors held constant at their mean. The shaded area in grey represents the 95% confidence intervals.

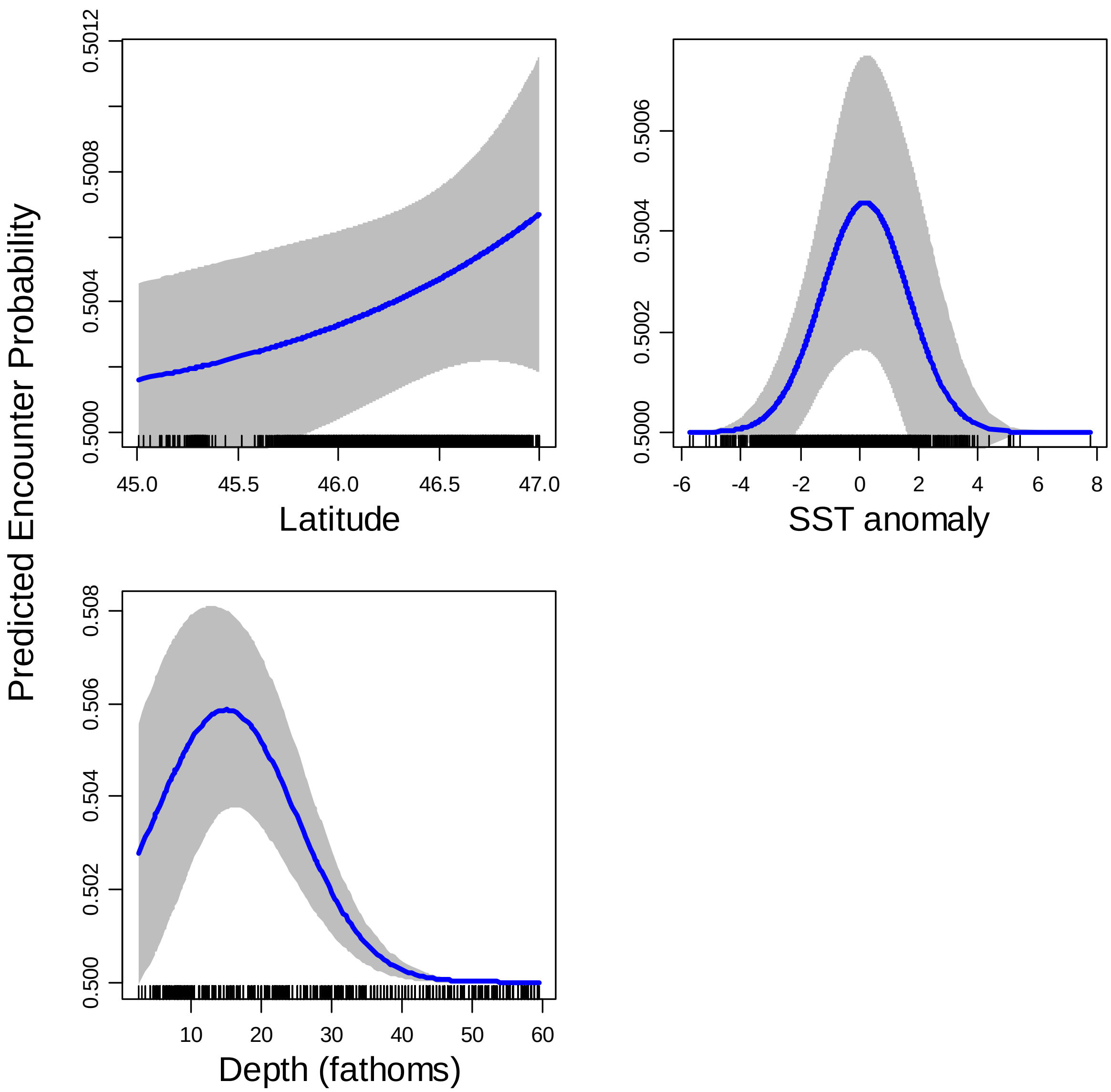


Figure 9. Plot of bootstrapped estimates of green sturgeon bycatch (mt) against true actual green sturgeon bycatch (mt) for each year of the IFQ bottom trawl fishery (2011-13). The line represents equivalency (slope=1) where the value of the bootstrap estimate is equal to the actual value. Each of the three sets of points per given actual green sturgeon bycatch represents a single year (2011-13) with both seasons combined (summer + winter). Variation among points within a year represents variation in the number of vessels sampled per bootstrapping run (i.e., observer coverage). For clarity we only show the simulation results for observer coverage between 15-35% which covers the historical (2002-10) range for this fishing sector. Each point is the coastwide mean (± 1 SE) of the bootstrapped bycatch estimate based on 2000 samples for each vessel sampling rate (15-35%).

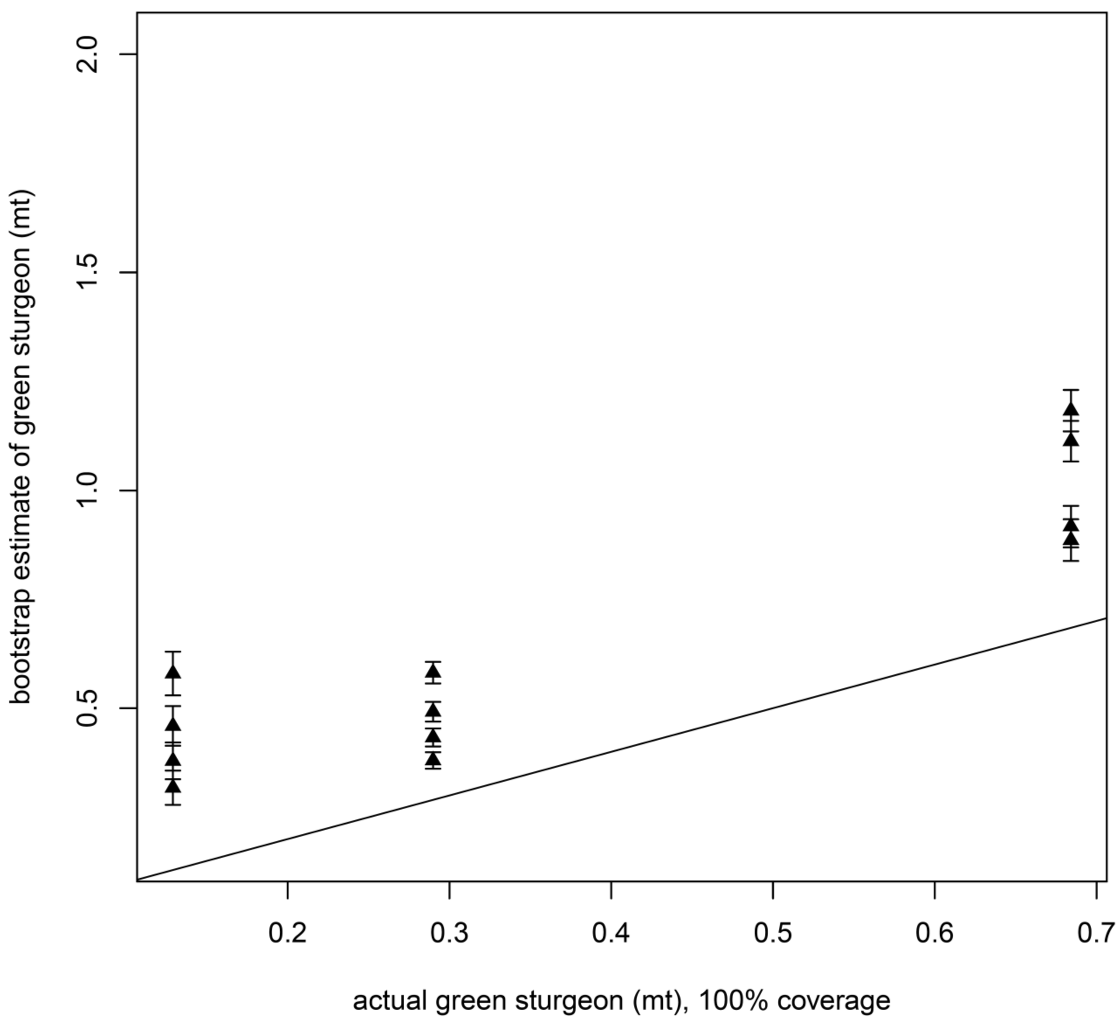
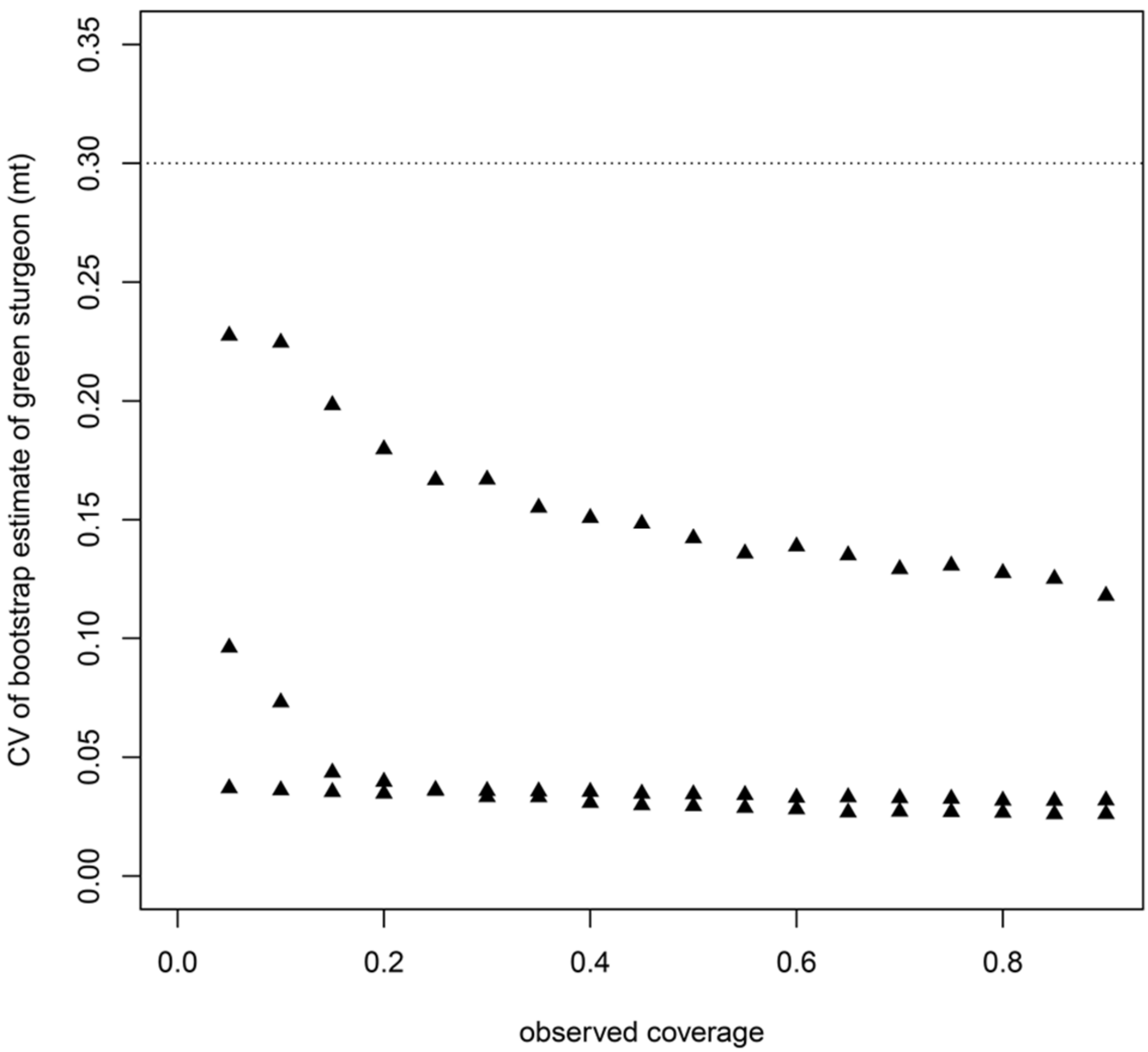


Figure 10. Coefficient of variation of the bootstrapped estimates of green sturgeon weight (mt, SD from bootstrap / true estimate of the discard), for each year (2011-13) of the IFQ bottom trawl fishery as a function of the observer coverage rate. The dotted line represents a CV of 30% which is the maximum of the national recommended precision goal (NMFS, 2004).



Appendix A

Observed and Estimated Bycatch of Green Sturgeon in US West Coast California Halibut Bottom Trawl Fishery From 2002 – 2013

Executive Summary

Fleet-wide green sturgeon bycatch estimates in the state-managed California (CA) halibut (*Paralichthys californicus*) bottom trawl fishery were derived from WCGOP observer data and fish ticket landings data (2002-2013), as described in the main section of this report. The estimated fleet-wide total bycatch of green sturgeon in this fishery is summarized in Table A1. "Bycatch" in this report is defined as the discard of green sturgeon made at sea. Since being ESA-listed in 2006, landings and sales of green sturgeon are prohibited.

Although the Biological Opinion is directed at federally-managed groundfish fisheries and does not apply to state-managed fisheries, we provide the bycatch estimates for the state-managed CA halibut fishery in this report to provide full understanding of the overall impact of NMFS-observed fisheries on green sturgeon.

It should be noted that estimates for some strata were derived from a bootstrap procedure due to confidentiality mandates. If a stratum had fewer than three observed vessels, observer data in those strata are considered confidential and cannot be reported. To effectively estimate and report the green sturgeon bycatch in those confidential strata, we applied a bootstrap procedure after pooling the strata. The pooled strata consist of the confidential stratum itself and neighboring strata over a three-year time block (see the Methods section for further details). The estimates in those strata should be considered as derived from a three-year running average of bycatch rates, rather than stratum-specific estimates. Thus, bycatch estimates in those confidential strata should be interpreted with caution.

Even though identical in most cases, there are slight differences for some strata between the bycatch estimates provided in this report and in the previous report (Al-Humaidhi et al. 2012). These differences are due to the application of a slightly different bootstrapping scheme. In the previous report, bootstrap estimations for confidential strata were based on pooling of all years of available data, instead of a three-year time block. The differences are also caused by the use of most recently updated observer and fish ticket data that were processed further with data quality assurance and quality control checks.

During the 12-year time period, green sturgeon in the CA halibut fishery were exclusively encountered off San Francisco Bay, although the CA halibut fishery operated in other coastal waters off CA (Fig. A1). A genetic study on green sturgeon bycatch samples from 2007-2013 showed that 90% of green sturgeon bycatch off California likely belong to Southern DPS (Dr. Carlos Garza, pers. comm., SWFSC, NMFS, NOAA). Applying this proportion of 90%, the fleet-wide bycatch estimates for Southern DPS fish in the CA halibut fishery ranged from 27 to 707.4 fish per year (see Table A1). We note that the genetic stock identification results are preliminary and the genetic baseline consists of relatively few samples. Only the point estimates of DPS proportions were applied to estimate bycatch by DPS without error bounds, as these statistics were not available. Thus, these estimates should be interpreted with caution.

Introduction

All California halibut (*Paralichthys californicus*) fishing vessels are permitted and managed by the state of California, and thus outside of the federal fisheries covered by the most recent Biological Opinion (NMFS 2012). The state of California requested the WCGOP to observe the CA halibut fishery and report discarded catch, much of which is incidentally caught groundfish and thus of interest to federal groundfish fisheries. The WCGOP classifies the CA halibut fishery into two components: limited entry (LE) and open access (OA). Vessels in the LE component possess both a federal LE groundfish permit and a state-issued CA halibut fishing permit. Vessels in the OA component only possess state-issued CA halibut fishing permits. Table A2 presents a summary of the permits, gear used, target groups, vessel length range, fishing depth range, and management of CA halibut fishery sectors.

The WCGOP provides observer coverage for both of these components. The LE component exists as a portion of the LE groundfish bottom trawl sectors, so the WCGOP isolates 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 took place in less than 30 fathoms, south of 40°10′ N latitude. All tows in the observer data set 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. It should be noted that since 2011 the LE California halibut sector has operated under the IFQ fishery rules and has nearly 100% observer coverage.

Methods

Bycatch Estimation

The same bycatch estimation methods and procedures, described in the main section of this report, were applied to WCGOP data collected from the CA halibut fishery sectors. Bycatch ratios were computed for this fishery using the observed retained weight of California halibut as the effort metric (i.e., the denominator). The fleet-wide landed weight of California halibut was then used as a multiplier (i.e., expansion factor) to expand the estimated green sturgeon bycatch to the fleet level.

To isolate fish tickets from trips on which California halibut was targeted, landings were only compiled from fish tickets that had greater than 150 lbs of California halibut during the period of 2002-2006. Starting in 2007, the state of California required that vessels participating in the LE and OA trawl fisheries landing more than 150 lbs of California halibut possess a California halibut bottom trawl permit. While all OA vessels that landed more than 150 lbs of CA halibut in 2007 possessed a permit, not all LE vessels did. To account for all California halibut fishing in 2007, the permit list was used to identify California halibut vessels in the OA fishery, while the ‘more than 150 lbs’ guide was used to isolate California halibut trips in the LE fishery. By 2008, California halibut bottom trawl permits for both the LE and OA trawl sectors effectively represented all vessels targeting California halibut. Thus, landed CA halibut weights for both the LE and OA sectors were compiled from “non-midwater” trawl fish tickets from those vessels that had a state-issued CA halibut bottom trawl permit and landed more than 150 lbs of CA halibut for the years of 2008-2013.

The LE and OA components of the CA halibut trawl fishery remain separate as independent sectors in this report. Thus, bycatch ratios and fleet-wide total bycatch numbers were estimated independently by each sector (Table A3). However, for the years 2011-2013, fleet-wide total bycatch is reported as a combined sum of both sectors even though estimations were done independently by sector (Table A4). Low fishing activity (< 3 observed vessels per stratum) resulted in confidentiality issues in the LE component and prevents us from reporting the bycatch by sector. Similarly, we were unable to report bycatch by seasonal strata for 2011-2013 because of confidentiality issues in the LE sector. The unsampled portion of the LE sector during 2011-2013 was estimated by the same method as described in the main section of this report for the IFQ bottom trawl sector.

Confidence intervals of bycatch ratios and fleet-wide total bycatch estimates for each stratum were estimated using the same bootstrap procedure as described in the main section of this report. There were several confidential strata in both the LE and OA components which prevent us from reporting observed bycatch numbers and associated trip information directly. Therefore, we pooled these data across a three-year time window around the confidential stratum as described in the main section of this report. If an adjacent stratum was unobserved, then the available data from the next closest year-season stratum was included in the pool so that at least 3 years were used (Table A5). The bycatch ratio and its 95% confidence limits for the confidential stratum were estimated from the bootstrapped distribution with average, 2.5% and 97.5% percentiles, respectively. Bycatch ratios in these confidential strata can be regarded as a three-year running average. The fleet-wide landed weight of CA halibut of a given confidential stratum (not pooled) was then used as the multiplier (i.e., expansion factor) to estimate the fleet-wide total bycatch for that confidential stratum.

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 (NMFS 2015a, NMFS 2015b). Length frequency data were analyzed with descriptive statistics and regression analyses to examine the size structure of encountered green sturgeon, proportions of subadults/adults, and the relationship between green sturgeon size and fishing depth.

Binomial Model for Encounter Probability

To understand the relationship between green sturgeon bycatch and environmental and habitat variables (average latitudes, average depths, and sea surface temperatures at fishing locations), we employed a generalized linear model with a binomial logit link to model bycatch (presence / absence) as a function of covariates. For modeling purposes, we focused on a small spatial area off San Francisco Bay, CA, where all green sturgeon were encountered as bycatch in the LE and OA CA halibut trawl fisheries. This subsetting was necessary for the model, because green sturgeon bycatch only occurred in one confined area off San Francisco Bay, although the CA halibut fishery operated in other areas off the CA coast. If all of the observer data for the CA halibut fishery were used as model input data, it would include too many zeros (i.e., hauls with no green sturgeon encountered) for an effective model fit. Observed hauls that occurred north of 37.15^0 N and in depths less than 40 fathoms were selected for a binomial logistic model. The subset included 1935 observed hauls, 274 of which encountered green sturgeon. The subset included all the hauls that encountered green sturgeon over the period of 2002-2013. To model the green sturgeon encounter probability, the green sturgeon catch data was analyzed as either presence (positive catch) or absence (zero catch) per given tow. Mathematically, this green sturgeon encounter response can be linked to predictors in a linear fashion shown by the following equations:

$$Y_i \sim \text{Bernoulli}(p_i)$$
$$\text{logit}(p_i) = \text{X}_i b_i + e_i$$

where Y_i is a binary response indicating green sturgeon presence in tow i, p_i is the probability of encounter in tow i, X is a matrix of predictors, b_i are estimated coefficients, and e_i is an offset term for variable effort between tows. We used retained weight of CA halibut catch (target species) as a measure of effort and included it as an offset term in the model to account for varying fishing effort (CA halibut landings) between hauls.

As described above, we fit a binomial generalized linear model (GLM) to the green sturgeon presence-absence data in LE and OA CA halibut trawl fisheries, using the ‘glm’ function in R with a logit link. Predictors included the average depth of the fishing gear (bottom depth at setting + bottom depth at retrieval divided by 2), average latitude (latitude at setting + latitude at retrieval divided by 2), and sea surface temperature anomaly (SST) of each tow location. Longitude was not considered because it is highly correlated with depth in this region. Because bottom temperature at each tow location is not available, we use the SST as a proxy for temperature at fishing. For each tow, we obtained daily SST anomalies on a 0.25º grid, and used bilinear interpolation to create SST values corresponding to each haul location in the dataset (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.highres.html).

All predictors were treated as continuous variables in the model. Year effect was not considered in the model due to overall scarcity of green sturgeon encounters and the absence of encounters in several years over the modeled period. To select the key variables among the considered predictors and to identify the most parsimonious model, we first created a model using all linear predictors, then performed a stepwise variable selection (forward and backward), guided by the stepAIC function in R’s ‘MASS’ library. After key linear predictors were selected, we added the 2nd order polynomials of those key predictors to allow for any non-linear relationships, and re-ran the stepwise variable selection with only the key predictors and polynomials to find the final best-fit model. Hosmer-Lemeshow test was used to test the overall predictability of the best-fit model (Simonoff 2003). To examine the effects of selected predictors on green sturgeon bycatch, the predicted probabilities and 95% confidence intervals of the best-fit model were estimated and plotted for each variable, while fixing other variables on their averages (i.e. marginal effects).

Results

Bycatch Estimation

WCGOP data shows the extent to which the CA halibut fishery operated in CA coastal waters between 2002-2013 (Fig. A1). However, green sturgeon were exclusively encountered in an area off San Francisco Bay, CA.

Summaries of green sturgeon bycatch and associated statistics in the CA halibut fishery sectors, estimated based on the WCGOP data, are provided in Table A3 for 2002-2010 and in Table A4 for 2011-2013. Annual fleet-wide bycatch estimates fluctuated between 0 and several hundred in the LE and OA sectors. The highest observed bycatch was 108 green sturgeon in winter of 2006 in the LE sector, which resulted in a fleet-wide total bycatch estimate of 786 green sturgeon (Table A3). Between 2002 and 2010, the LE sector was estimated to encounter more green sturgeon than the OA sector. When analyzing cumulative annual bycatch across sectors and seasons, there was an increasing trend in the annual fleet-wide total bycatch estimates from 2002-2006. After 2006, the annual fleet-wide total bycatch estimates declined due to fewer observed encounters in the OA sector from 2007 to 2012. However, observed bycatch in 2013 sharply increased, and resulted in the third highest annual fleet-wide total bycatch estimate (526) for 2002-2013 (Table A4).

We note that the observed catch data and fleet-wide bycatch estimates for some strata provided in this report are not identical to those in the previous report by Al-Humaidhi et al. (2012), though the differences are minor (Table A3). These differences are due to the application of a slightly different bootstrapping scheme. Al-Humaidhi et al. (2012) performed bootstrap estimations for confidential strata based on pooling of all years of available data, instead of a three-year time block. The use of updated observer and fish ticket data was another reason for these differences. The data were updated with data quality assurance and quality control check processes. There were only two strata that had updated observed bycatch numbers between 2002 and 2010: summer of 2003 (changed from 48 to 50) and winter of 2004 (changed from 0 to 1) in LE sector. The observed bycatch numbers for the other strata remained the same. Landings data from fish tickets were the same between the reports except in 2010.

The extent of observer sampling rates differed by fishery sectors and changed from year to year. Observer sampling rate is defined as the percent of observed effort (i.e., observed landed weight of CA halibut catch) compared to total effort (i.e., fleet-wide landed weight of CA halibut). Sampling rates for the LE sector during 2002-2010 ranged between 5.2% and 39.8%, with an average of 18.4%, not including unobserved and confidential strata. Since 2011, sampling rates for the LE sector are near 100%, due to the IFQ requirement of observer coverage on all fishing trips. Sampling rates of the OA sector were relatively low during 2002-2013 (range: 2.5% to 25.5%), with an average of 8.6%, not accounting for unobserved and confidential strata.

Beginning in 2011, the LE sector became part of the IFQ bottom trawl fishery and has received 100% observer coverage (i.e., all fishing trips had an observer). 100% coverage does not mean that 100% of catches are sampled by observers. Part or the entire catch of some hauls may not be sampled due to unforeseen circumstances (e.g., sickness of observer). For the period from 2011-2013, all catches were sampled, except in 2011 (99.99%). The unsampled portion in 2011 was expanded based on the method described in the main section of this report. Because the unsampled catch portion in 2011 was very small, the expansion did not affect the total green sturgeon bycatch estimate in that stratum. Observer coverage for the OA sector was fairly low from 2011 to 2013: 15.6% for 2011, 6.4% for 2012, and 6.3% for 2013. Thus, the uncertainty measure (i.e., 95% confidence limits) around the fleet-wide total bycatch estimates for 2011-2013, presented as combined estimates across the two sectors, was affected only by the OA portion.

According to the WCGOP data, fishing depths in the CA halibut fishery were fairly shallow, mostly within 40 fathoms (99% for LE and 100% for OA sector), and fishing was most concentrated in the 5-10 (LE) and 10-15 (OA) fathom depth zones (Fig. A2). Depths from 0 to 60 fathoms were designated as critical habitat for green sturgeon in 2009 (74 Fed. Reg. 52300), and almost 100% of the CA halibut fishery occurred within critical habitat.

Green sturgeon was most frequently encountered in the depth zone of 5-10 fathoms in both sectors: more than 50% of the encounters in the LE and 80% in the OA sectors (Fig. A3). The maximum depth that encountered green sturgeon was 70 fathoms for the LE sector and 28 fathoms for the OA sector.

The number of green sturgeon encountered per haul ranged from 1 to 7 in the LE and 1 to 4 in the OA sector (Fig A4). The proportion of hauls that caught one green sturgeon, out of those that encountered green sturgeon, were 42% in the LE sector and 75% in the OA sector.

Length Frequency

The average length of green sturgeon encountered and observed in the LE sector (100.02 cm) was larger than the average length in the OA sector (95.05 cm) (Fig. A5), but this difference was not statistically significant (two-sample t-test, t-stat = 1.33, p-value = 0.189).

Once green sturgeon enter marine waters, they are considered to be in the subadult stage. Thus, green sturgeon in two life stages would be encountered in groundfish sectors in the ocean: adults (≥ 140 cm FL) and subadults (< 140 cm FL) (NMFS 2012, p. 88). The proportions of subadults encountered in the CA halibut fishery sectors were 97.34% in the LE sector and 97.36% in the OA sector. The results show that the green sturgeon encountered in both sectors of the CA halibut fishery were mostly comprised of subadults.

We did not find a relationship between green sturgeon length and depth at capture and instead found a large amount of variability in fish length over a range of depths (Fig. 4). When the length data was regressed against depth at capture for the combined data of the LE and OA trawl sectors, the regression slope was significant ($F_{1, 114}$ = 4.725, p-value = 0.0298) but with a very low goodness-of-fit (R^2 = 4.1%). However, when the regression was fit separately for each sector, the slopes were not statistically significant for either sector. The results indicate that the size of green sturgeon encountered in the CA halibut fishery is not a function of fishing depth. Thus, size-selective green sturgeon bycatch avoidance cannot be achieved by avoiding certain fishing depths.

Binomial Model for Encounter Probability

The best-fit GLM contained all three original linear predictors (latitude, depth, SST anomaly). In addition, the quadratic term of the latitude variable was selected as significant to the model (Table A6). A distinctive unimodal concave relationship with latitude showed that the probability of encounter peaked at one latitudinal zone, around 37.6^0 N (Figure A7). Depth and

SST anomaly have decreasing relationships with encounter probability of green sturgeon over the range of input data. The decreasing trend of encounter probability over depth indicated that the encounter probability became higher at shallower fishing depths and became lower at deeper fishing depths. The probability trend over SST indicated that encounter probability decreased as water temperature became warmer. The relationships of predicted encounter probability with these variables were statistically significant. The magnitudes of predicted probability differences were not very large, but were significant (e.g., the difference between maximum and minimum predicted probability is about 18% for the depth variable). Hosmer-Lemeshow test indicated that overall predictability of the model was statistically valid (p-value < 0.073, chi-squared statistic = 14.3), suggesting that the model could be further developed for prediction purposes.

Discussion

Green sturgeon were exclusively encountered by the CA halibut fishery in a confined coastal area off San Francisco Bay. The annual fleet-wide bycatch estimates for green sturgeon ranged from 45 to 786 fish from 2002-2010 and from 30 to 526 fish from 2011-2013 (Table A1). Even though the CA halibut fishery is not covered by the Biological Opinion for the federal groundfish fisheries, the CA halibut fishery bycatch estimates are included in this report as an appendix to provide information on green sturgeon bycatch in all of the fisheries observed by the WCGOP.

Length frequency analyses showed that the green sturgeon encountered in the CA halibut fishery are mostly subadults. Assuming that the CA halibut fishery would not be size selective, the results indicate that the green sturgeon populations off San Francisco Bay, within the depths, seasons, and areas represented by the observer data, are mostly composed of immature subadults. Because reproduction success is a key factor for the sustainability of populations (i.e., allow them to reproduce at least once during their life span), protecting these immature green sturgeon in this area would be critical for the conservation of green sturgeon populations. These results suggest that more efforts should be geared toward understanding the effects of bycatch on the green sturgeon population structure (e.g., recapture rates and post-release survival rates by size classes) to inform management decisions for the protection of these immature individuals and the well-being of green sturgeon over generations.

The binomial model was successfully applied to green sturgeon data at the individual haul level to relate some habitat/environmental variables to the encounter probability. The relationship with SST anomalies suggests that the chance of encountering green sturgeon decreases if fishing occurs in warmer water for a given location at a given time. A study on the coast-wide green sturgeon distribution and migration patterns, based on coastal tracking records using acoustic tags, indicated that green sturgeon would respond differently to temperature changes by season (Huff et al 2012). Our model did not include any temporal variable due to the limited number of green sturgeon encounters, thus the model assumed that the predicted responses over the modeled variables were constant across the time span of data. This assumption may not be very applicable to annually and seasonally dynamic variables such as SST. Our model was not built to depict such temporal patterns of green sturgeon even if there were any. Thus the shape of the logit response curve over SST may shift from season to season or from year to year. More study is needed to understand the changes in green sturgeon behaviors and distribution patterns in response to environmental changes in the context of conservation and bycatch minimization.

Currently, we have no information on recapture and post-release survival rates of green sturgeon bycatch in these fisheries, but studies to address these data needs are underway. In January 2014, observers began applying passive integrated transponder (PIT) tags to green sturgeon observed in the IFQ bottom trawl and California halibut fisheries to assess recapture rates. A study is also being conducted to evaluate the post-release survival of green sturgeon encountered in the California halibut fishery. This study is a collaboration between the NMFS West Coast Region Protected Resources Division (WCR PRD), Southwest Fisheries Science Center (SWFSC), WCGOP, California Department of Fish and Wildlife (CDFW), and California halibut fishermen. Observers and fishermen will apply satellite tags to green sturgeon that are incidentally caught in this fishery in order to track the fish's survival and movements for a 30 to 60 day period after release. Tagging activities will be conducted in the spring through fall of 2015, with plans to continue the study into the future if funds are available. Both tagging studies are supported by funds from the SWFSC Cooperative Research Program and NMFS WCR PRD.The LE sector has been observed at 100 % since 2011. However, the observer sampling rate in the OA sector has been quite variable and mostly under 10% since 2007. Thus, the uncertainty in the bycatch estimation since 2011 is mainly driven by the data in the OA sector. As indicated in the results from analysis of observer coverage, green sturgeon bycatch estimates in the CA halibut fishery, based on the ratio estimator approach, could be positively biased. In addition, estimates in some strata were derived from a bootstrap procedure due to confidentiality requirements (< 3 observed vessels). Thus, the fleet-wide bycatch estimates for the CA halibut trawl sectors should be considered conservative.

Table A1. Summary of expanded fleet-wide bycatch estimates of green sturgeon in the LE and OA CA halibut fisheries that were observed by the WCGOP. For 2011-2013, bycatch numbers are reported as combined (RAC) between the sectors due to confidentiality mandates. Double dashes (--) signify strata with no observer coverage. Estimates of Southern DPS (SDPS) bycatch are calculated based on genetic stock proportion (90%) of green sturgeon in CA. Shaded cells indicate the strata containing estimates derived from a bootstrap procedure.

	NDPS + SDPS		SDPS (90%)		Totals	
Year	LE	OA	LE	OA	All	SDPS
2002	185	--	166.5	--	185	166.5
2003	360	74	324.0	66.6	434	390.6
2004	200	178	180.0	160.2	379	341.1
2005	505	147	454.5	132.3	652	586.8
2006	786	--	707.4	--	786	707.4
2007	103	0	92.7	0.0	103	92.7
2008	175	0	157.5	0.0	175	157.5
2009	45	0	40.5	0.0	45	40.5
2010	155	0	139.5	0.0	155	139.5
2011	RAC		RAC		30	27.0
2012	RAC		RAC		80	72.0
2013	RAC		RAC		526	473.4

Table A2. Generalized descriptions of CA halibut fisheries that have had observed bycatch of green sturgeon.

							Management	
Sector	**Sub-Sector**	**Permits**	**Gear(s)**	**Target(s)**	**Vessel length (m)**	**Depths (m)**	**2002-2010**	**2011-2013**
Limited Entry (LE) California Halibut Trawl	None	CA Halibut permit and LE permit with trawl endorsement	Bottom trawl	California Halibut	9–22	< 55	Cumulative two month trip limits; depth-based closures; 3-23% observer coverage	Individual Fishing Quotas (IFQ); 100% observer coverage
Open Access (OA) California Halibut Trawl	None	LE permit with MSCV endorsement	Bottom trawl	California Halibut	3–30	< 55	Most fishing occurs within CA waters in the California Halibut Trawl Grounds where minimum mesh sizes, seven month season, and minimum size requirements hold; 0-16% observer coverage	

Table A3. Observed bycatch numbers, bycatch ratios, and fleet-wide total bycatch numbers of green sturgeon from California halibut bottom trawl fishery (2002-2010), separated by limited entry (LE) and open access (OA) sectors. Bootstrapped confidence intervals (95% CI) are provided for the estimates. CA halibut landings are in metric tons (MT). Winter season is January-April and November-December; summer is May-October. Bycatch ratios in the shaded strata were derived from a bootstrap procedure, as explained in the Methods. 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	2002	winter	1	3.6	68.8	5.2	0.28	0.00	0.36	19	1	25
		summer	*	*	36.4	*	4.54	1.51	6.64	166	56	241
	2003	winter	2	12.9	61.9	20.8	0.16	0.00	0.23	10	2	14
		summer	50	6.2	43.6	14.3	8.03	1.54	12.13	350	68	530
	2004	winter	1	14.7	79.9	18.4	0.07	0.00	0.23	5	1	19
		summer	58	16.8	56.5	29.8	3.45	0.00	6.51	195	58	369
	2005	winter	18	10.7	131.4	8.2	1.68	0.00	14.33	220	18	1884
		summer	98	19.8	57.4	34.4	4.95	1.77	6.04	285	98	347
	2006	winter	108	11.1	80.6	13.7	9.75	2.18	14.75	786	178	1194
		summer	0	3.2	38.9	8.3	0.00	na	na	0	na	na
	2007	winter	6	3.0	27.4	11.0	2.00	0.00	3.51	55	6	96
		summer	10	2.4	11.8	20.8	4.09	0.00	5.36	48	10	63
	2008	winter	44	9.5	34.0	27.9	4.58	3.24	9.12	158	110	311
		summer	1	0.1	2.4	5.6	7.60	0.00	7.93	18	1	19
	2009	winter	--	--	39.9	--	--	--	--	--	--	--
		summer	18	2.9	7.3	39.8	6.21	5.88	6.87	45	43	50
	2010	winter	*	*	32.8	*	3.52	0.83	7.15	114	27	235
		summer	*	*	21.2	*	0.98	0.33	3.62	41	10	105
OA	2002	winter	--	--	21.6	--	--	--	--	--	--	--
		summer	--	--	14.2	--	--	--	--	--	--	--
	2003	winter	*	*	18.5	*	3.14	0.21	9.61	58	4	172
		summer	4	1.8	7.3	25.5	2.16	0.00	6.48	16	4	47
	2004	winter	2	0.9	29.6	3.1	2.20	0.00	4.28	65	2	127
		summer	*	*	41.3	10.2	2.73	0.00	6.38	113	0	263
	2005	winter	6	2.0	24.1	8.5	2.94	0.00	16.85	71	6	406
		summer	*	*	40.4	13.5	1.92	0.00	3.94	76	27	159
	2006	winter	--	--	18.4	--	--	--	--	--	--	--
		summer	--	--	36.4	--	--	--	--	--	--	--
	2007	winter	0	0.8	8.2	9.5	0.00	na	na	0	na	na
		summer	0	1.9	30.9	6.2	0.00	na	na	0	na	na
	2008	winter	0	0.8	21.2	4.0	0.00	na	na	0	na	na
		summer	0	1.8	30.3	5.8	0.00	na	na	0	na	na
	2009	winter	*	*	37.4	*	0.00	na	na	0	na	na
		summer	*	*	44.9	*	0.00	na	na	0	na	na
	2010	winter	0	0.7	28.0	2.5	0.00	na	na	0	na	na
		summer	0	1.7	41.5	4.0	0.00	na	na	0	na	na

Table A4. Observed bycatch numbers and fleet-wide total expanded numbers of green sturgeon bycatch from California halibut bottom trawl fishery (2011-2013), as combined from limited entry (LE) and open access (OA) sectors. 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. Landings for the OA sector are given in metric tons.

Year	LE + OA combined observed bycatch	LE + OA combined fleet-total bycatch	Lower CI of fleet-total bycatch	Upper CI of fleet-total bycatch	Coverage			
					Limited Entry	Open Access		
					CA halibut landings sampled (%)	Observed CA halibut landings (MT)	Fleet-total CA halibut landings (MT)	CA halibut landings sampled (%)
2011	13	30	16	35	99.99	12.4	79.9	15.6
2012	6	80	11	138	100.00	3.5	55.7	6.4
2013	46	526	228	976	100.00	4.3	68.8	6.3

Table A5. Confidential strata (asterisks) and neighboring strata (shaded) that were pooled for bootstrapping. Bycatch rates in the confidential strata were estimated based on a bootstrap procedure, which was applied to the pooled strata.

			Confidential Strata							
Sector	Year	Season	LE 2002 summer	LE 2010 winter	LE 2010 summer	OA 2003 winter	OA 2004 summer	OA 2005 summer	OA 2009 winter	OA 2009 summer
LE	2002	winter								
		summer	*							
	2003	winter								
		summer								
	2004	winter								
		summer								
	2005	winter								
		summer								
	2006	winter								
		summer								
	2007	winter								
		summer								
	2008	winter								
		summer								
	2009	winter	--	--	--	--	--	--	--	--
		summer								
	2010	winter		*						
		summer			*					
	2011	winter								
		summer								
OA	2002	winter	--	--	--	--	--	--	--	--
		summer	--	--	--	--	--	--	--	--
	2003	winter				*				
		summer								
	2004	winter								
		summer					*			
	2005	winter								
		summer						*		
	2006	winter	--	--	--	--	--	--	--	--
		summer	--	--	--	--	--	--	--	--
	2007	winter								
		summer								
	2008	winter								
		summer								
	2009	winter							*	
		summer								*
	2010	winter								
		summer								

Table A6. Parameter estimates and deviances for the best-fit binomial GLM fit to green sturgeon presence-absence catch data from the CA halibut fishery.

	DF	Deviance	Residual DF	Residual Deviance	AIC
Null	NA	NA	1934	1576.0	1578.0
Model	5	139.9	1930	1436.1	1448.1

Variable	DF	Coefficient	SE	Z-stat	P-value
Intercept	1	-4.69×10^4	9667.0	-4.85	0.000
Latitude	1	2.50×10^3	514.0	4.85	0.000
Depth	1	-0.083	0.015	-5.50	0.000
SST	1	-0.247	0.069	-3.58	0.000
$Latitude^2$	1	-0.005	0.001	-5.13	0.000

Figure A1. Map of green sturgeon bycatch in the LE and OA California (CA) halibut trawl sectors: fishing locations and landed amount of CA halibut (top panel), and locations of green sturgeon bycatch and its density (bottom panel). Observer data are aggregated to one-square-kilometer cells. Cells containing less than 3 vessels are not shown, to maintain confidentiality.

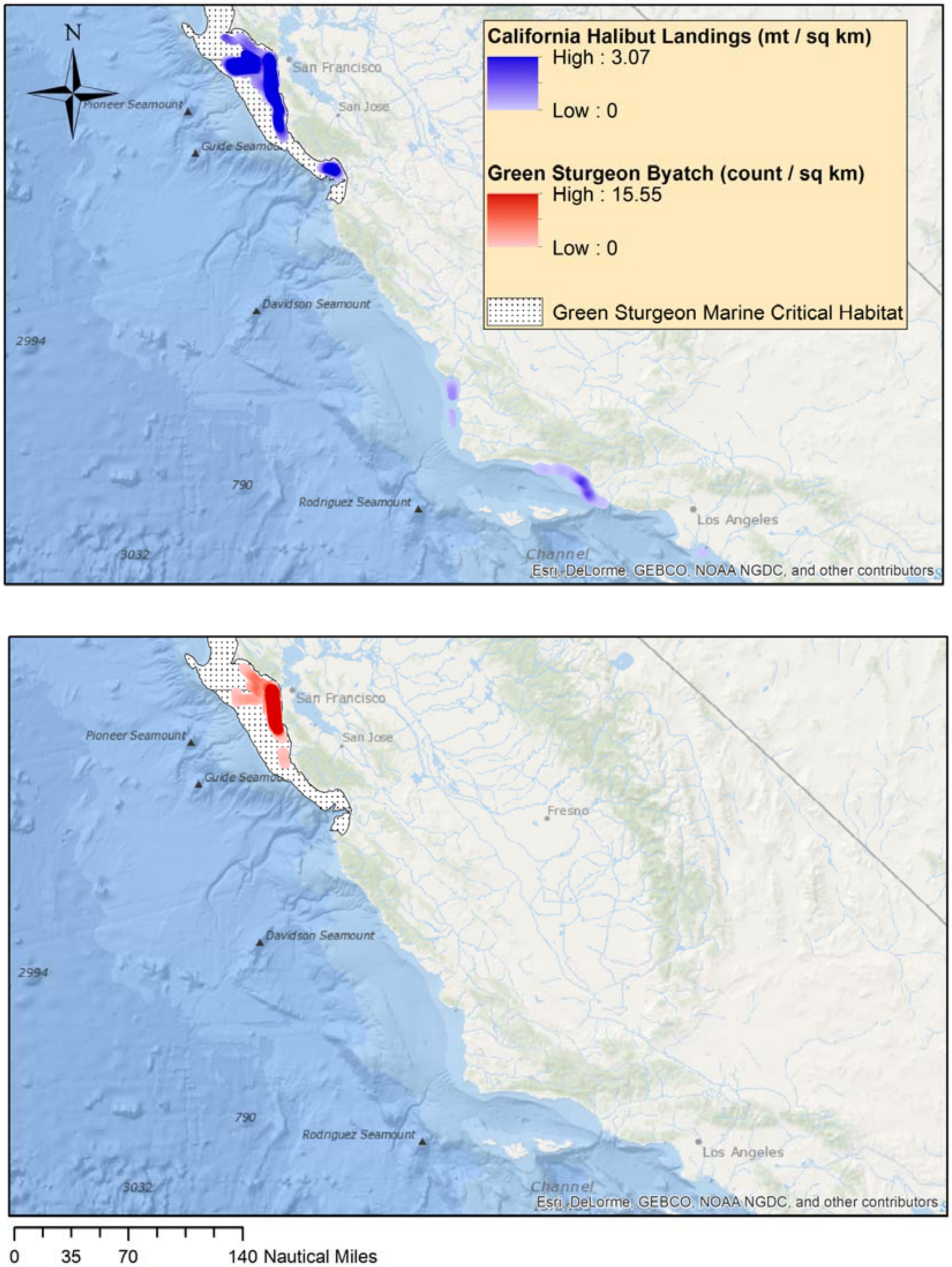
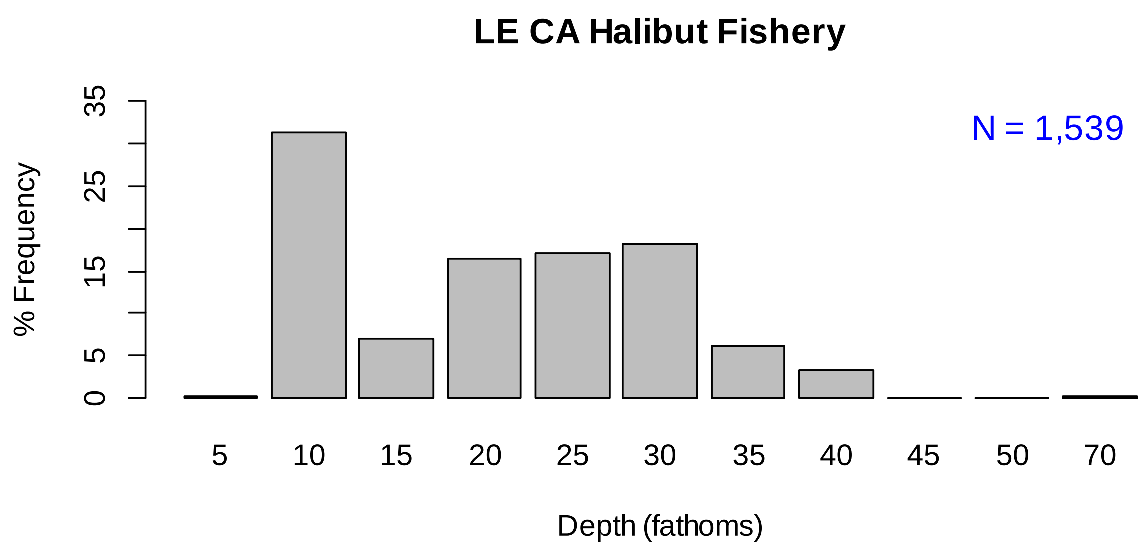


Figure A2. Frequency distribution of hauls by all fishing depths in LE and OA sectors of CA halibut bottom trawl fishery for 2002-2013. N is the total number of observed hauls.



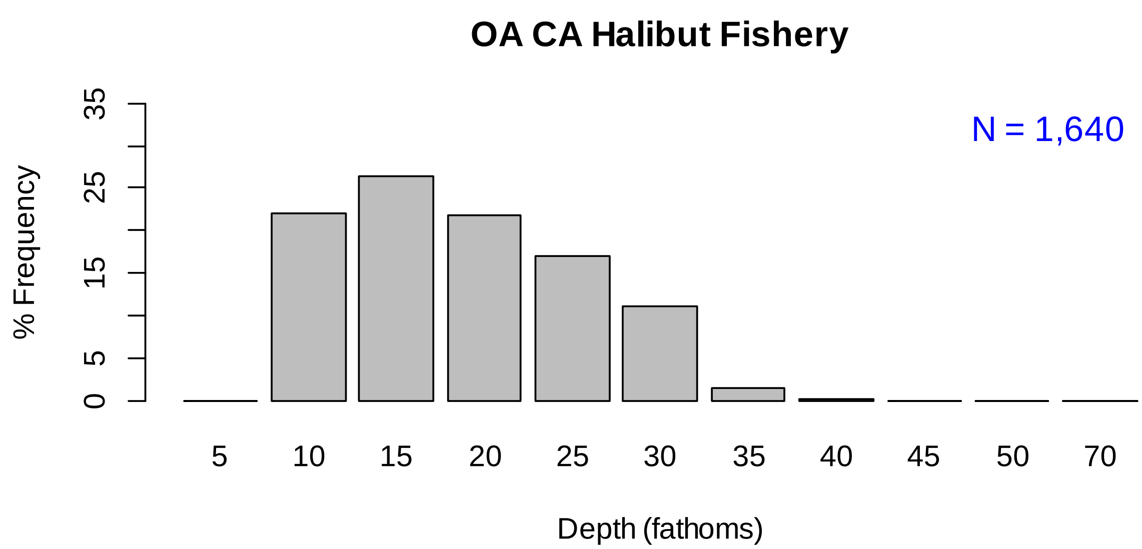


Figure A3. Frequency distribution of hauls by depth that encountered green sturgeon in LE and OA sectors of CA halibut bottom trawl fishery for 2002-2013. N is the total number of observed hauls that encountered green sturgeon.

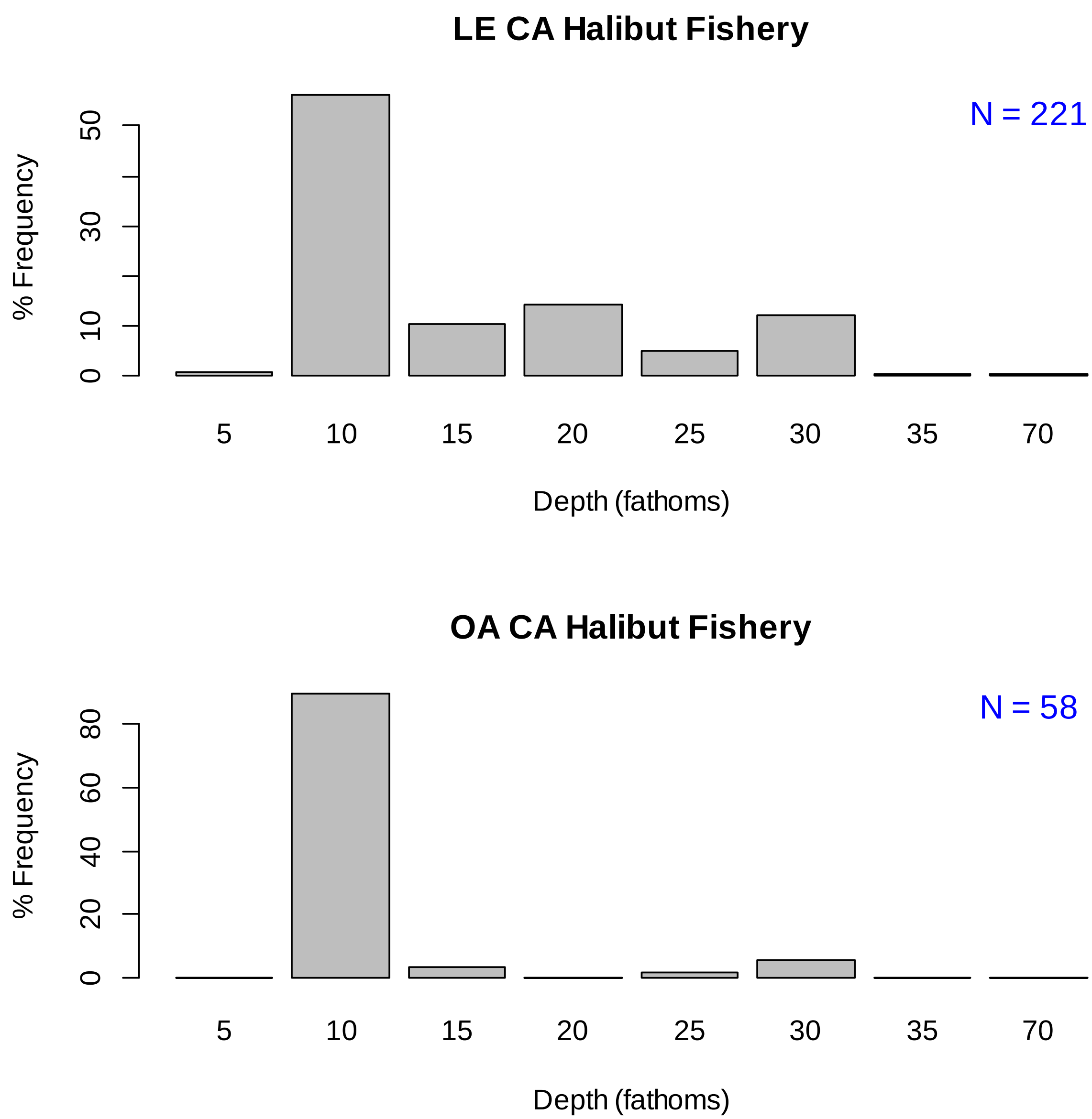


Figure A4. Frequency distribution of green sturgeon catch numbers per haul. N is the total number of observed hauls that encountered green sturgeon.

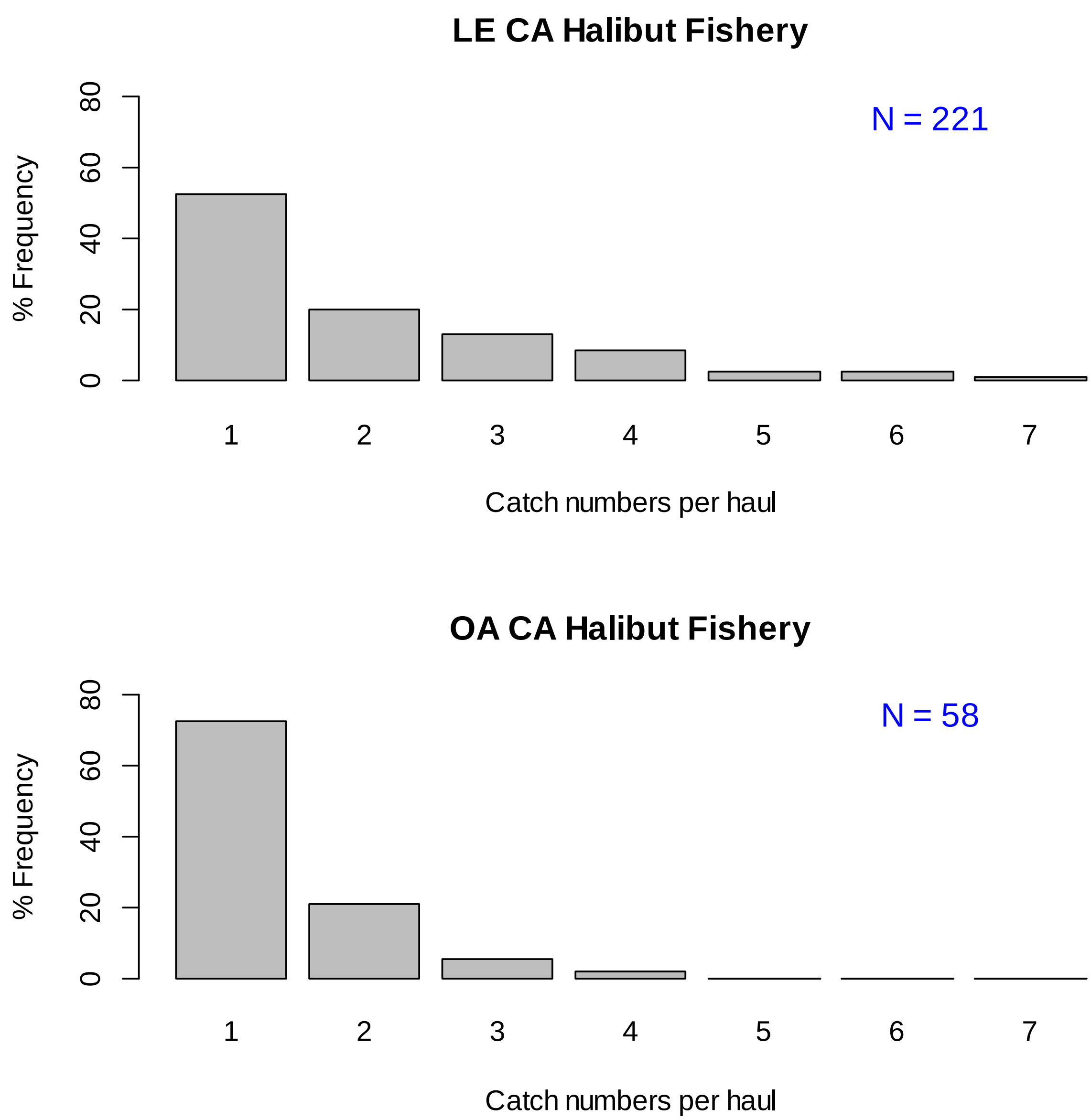


Figure A5. Box plot of length data for green sturgeon encountered in the LE and OA CA halibut fishery sectors. The cross bar is the median and the solid red circle inside the box is the mean. The horizontal dashed line indicates the fish length criterion (140 cm) that is used to differentiate between the adult and subadult life stages.

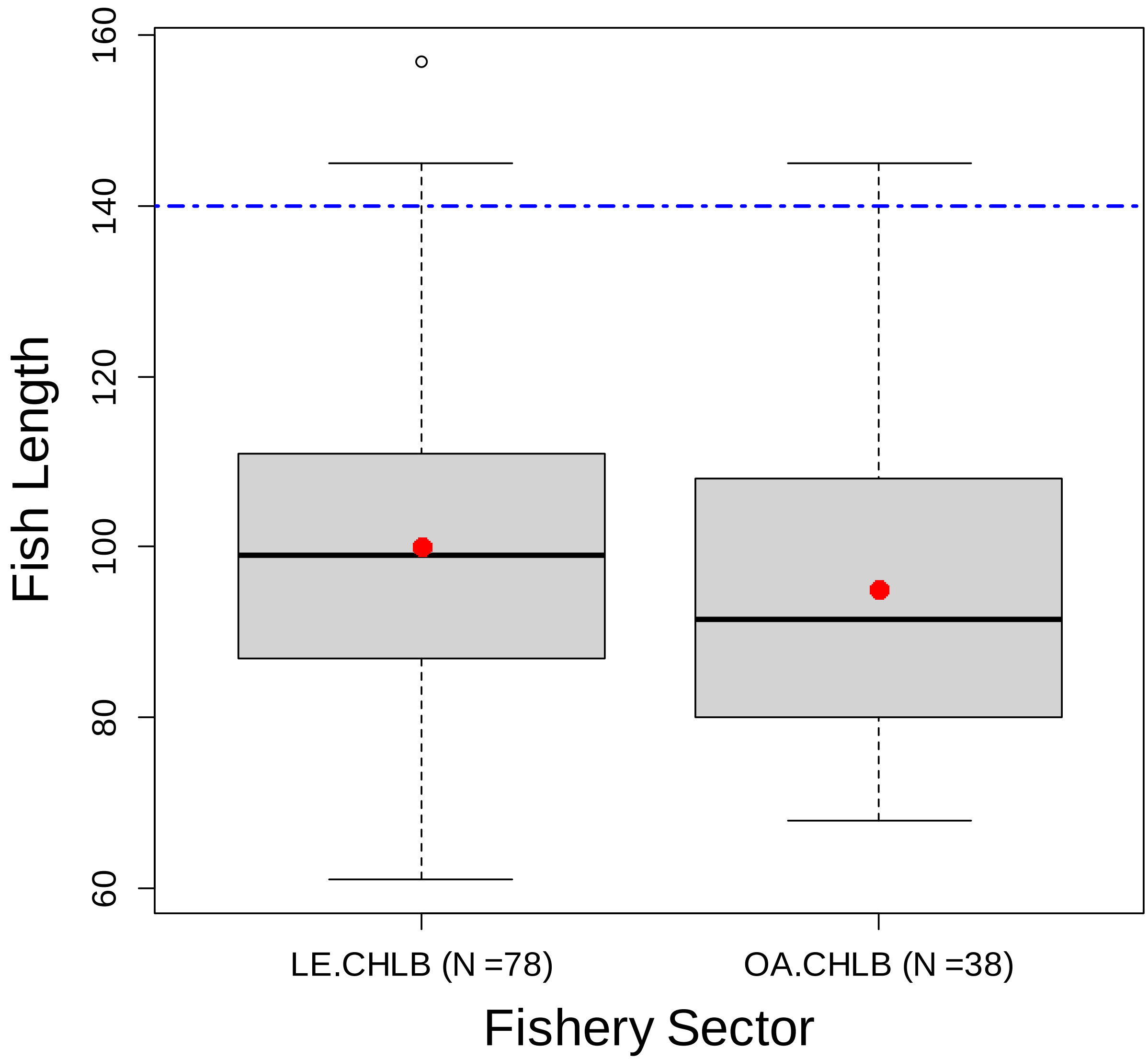


Figure A6. Scatter plot of green sturgeon lengths over fishing depths at capture in the LE and OA California halibut trawl sectors. The horizontal dashed line indicates the fish length criterion (140 cm) that differentiates between the adult and subadult life stages.

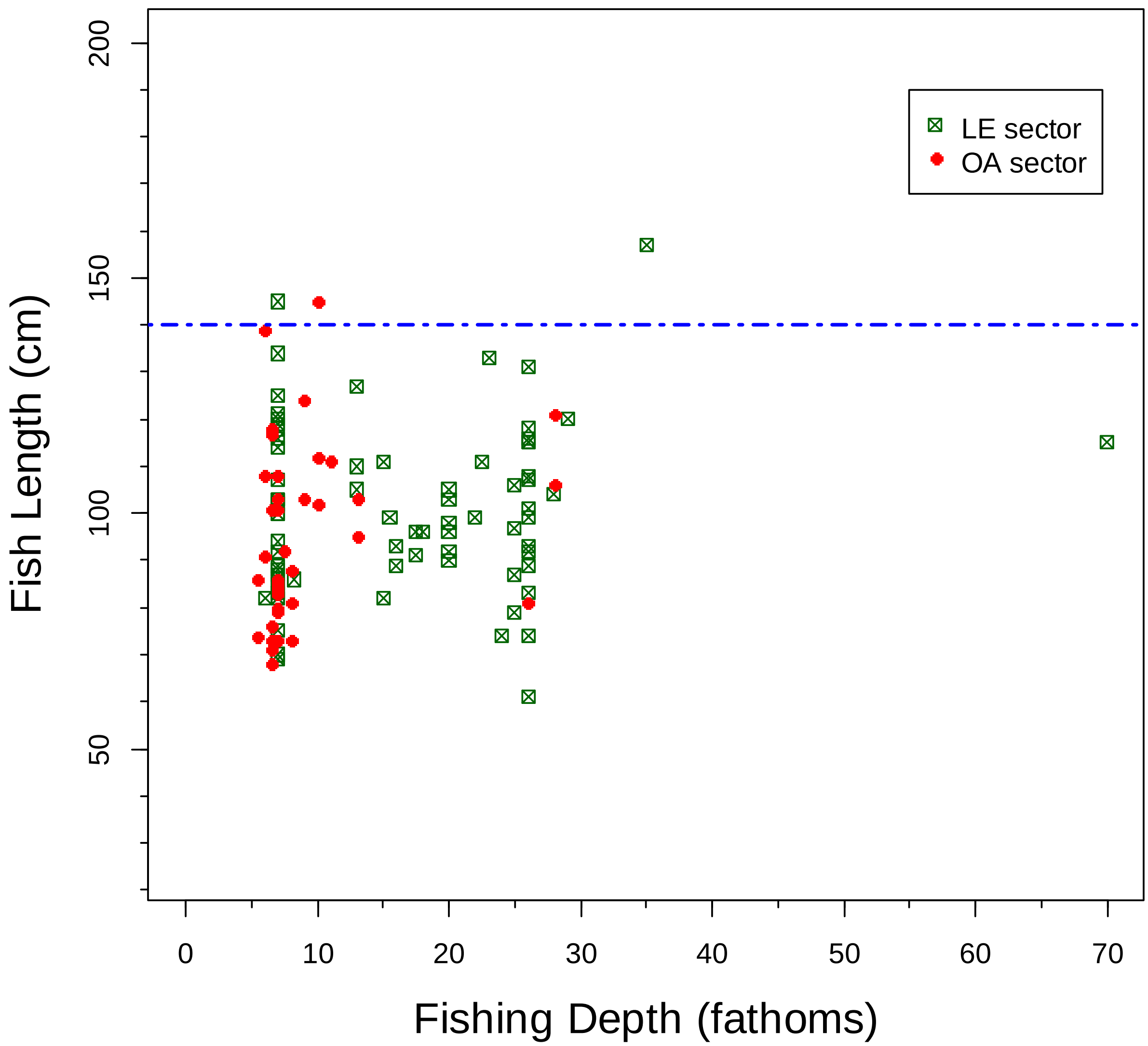


Figure A7. Marginal relationships between predictors and the predicted probabilities of green sturgeon encounters (solid blue line), with all other predictors held constant at their mean. The shaded area in grey represents the 95% confidence intervals.