Partial Coverage Fishery Observer Programs in the United States: A Comparative Review and Alaskan Case Study

University of Washington School of Marine & Environmental Affairs Graduate Student Capstone Project

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I. Introduction

Fisheries observers are placed on vessels to monitor and collect data from commercial fishing and processing vessels. The data collected is used to monitor fisheries, assess fish populations, set fishing quotas, and support compliance with fishing laws and safety regulations (NOAA, 2019a). Observers also collect information on rates of bycatch of non-target fish species that may either be of commercial value to other fleets or are protected under federal laws. For example, bycatch of Pacific halibut in the Gulf of Alaska's non-pelagic trawl fleet is monitored by fisheries observers in the North Pacific Groundfish Observer Program (NPGOP) (DiCosimo et al, 2016).

While some observer programs have 100% coverage, meaning that all trips and all hauls are subject to observer inspection, many programs only cover a fraction of total trips or hauls are observed. The appropriate level of observer coverage necessary to precisely estimate total bycatch is the subject of ongoing debates in academia and fisheries management. Some argue that only 100% observer coverage provides accurate catch and bycatch data to make informed management decisions (Babcock & Pikitch, 2004). The costs associated with providing travel funds, salary, benefits, and training for observers make it financially impractical for most fisheries to maintain 100% coverage. When 100% observer coverage is not achievable, a partial coverage target level, coupled with a random sampling design, must be set by managers in order to obtain reliable estimates of bycatch. In a study on catch estimation in the Bering Sea Pollock trawl fishery, Dorn et al. (1997) found that there is a drastic reduction in the uncertainty of catch estimates for frequently encountered bycatch species, specifically Pacific halibut, with increasing levels of observer coverage until about a 25% trip coverage rate. However, they found more coverage was necessary to accurately estimate less frequently encountered species like herring and salmon. Fisheries managers must develop protocols and methodologies to determine the level of coverage needed to properly manage their fisheries on a case-by-case basis while operating under budget constraints (Babcock & Pikitch, 2004).

In fisheries where there is high concern regarding the incidental capture of non-target species, like in the Gulf of Alaska non-pelagic trawl fleet and Pacific halibut, caps or limits may be implemented to control the incidental capture of non-target species (O'Keefe, Cadrin &

Kevin, 2013; DiCosimo et al. 2016). Management measures such as time or area closures, target catch reductions, and gear restrictions may be put into effect when bycatch caps or limits set on the number of interactions allowed with marine mammals or protected species by incidental take statements (ITS) are reached. Such restrictions can have severe socio-economic impacts on fisheries resulting from increased travel time and fuel costs necessary to reach to areas not impacted from the closure, lost fishing opportunities, and reduced catch of target species (Armsworth, Block, Eagle & Rougharden, 2010; Murray, Reed, & Solow, 2000). The restrictions may also incentivize harvesters to take actions that reduce their bycatch when observed (Golden, 2019; Babcock & Pikitch, 2004; Vølstad and Fogarty 2006). Specifically, these incentives can result in harvesters avoiding area where bycatch is high or changing trip duration, length of tow, or other aspects of fishing operations to reduce bycatch when observers are on board. Any changes in fisher's behavior – known as the observer effect - may cause bycatch rates from observed trips to be inaccurate when applied to the whole fleet (Gillis et al. 1995; Liggins et al, 1997; Faunce, 2011).

While methods to account for the observer effect in fisheries observer program design are well studied, there is limited research on the existence and impacts of the observer effect in fisheries management (Benoit & Allard 2009). The literature shows mixed findings regarding whether partial coverage programs create an observer effect, with observed vessels shown to have higher target catch in Faunce & Barbeaux, (2011), higher bycatch in (Benoit & Allard) 2009, yet Jannot (2013) finds that observed and unobserved vessels have similar fishing characteristics in SOME/MANY? fisheries. For the NPGOP, managers examine the evidence for an observer effect using the difference in trip metrics, between observed and unobserved vessels, including: spatial patterns, trip duration, vessel length, amount of landed catch, number of species caught, and proportion of the total catch made up by the target catch (AFSC, 2019). For bottom-trawl vessels in Alaska, three trip metrics are consistently statistically significant different: (1) trips are shorter for observed vessels; (2) less species are caught on observed vessels; and (3) landed catch is lower on observed vessels (AFSC, 2019). In both the scientific literature and the work done by the NPGOP, the incentives and motivations for an observer effect are not discussed. However, understanding the incentives harvesters face and the program design is important first step in determining the reliability of current bycatch estimates

This capstone report builds on knowledge of the ability of partial coverage observer programs to produce unbiased estimates of bycatch in U.S. fisheries. The report is comprised of two sections. First, we conduct a literature review and comparative analysis of the design features of all partial coverage fishery observer programs in the United States that are relevant to the observer effect. Second, we present a case study of differences in fishing locations between observed and unobserved vessels in the partial coverage program for the groundfish bottom trawl fishery, in the Gulf of Alaska, where Pacific halibut is caught as bycatch.

II. Partial Coverage Observer Programs and the Observer Effect in the United States

A. Introduction

In the 1970's, NOAA established the National Observer Program (NOP) to provide support to different regions in developing their own observer program. Since that time, five regional programs have been established – (1) Alaska, (2) West Coast split between Northwest and Southwest, (3) Greater Atlantic, (4) Southeast, and (5) Pacific Island. These programs currently oversee 16 partial-coverage fisheries to monitor the bycatch of a total of 31 different species. Each program has a unique methodology for how they fund their program, set observer coverage rates, and select vessels to be observed. Through looking at the different characteristics of regional observer programs, we seek to understand the degree in which different design features can impact the reliability of bycatch estimates.

Depending on how the programs are structured, their methods for funding their program can impact the amount of resources available to increase observer coverage. When funds are limited and observer coverage is low, observer data may not be an accurate representation of fleet activity, resulting in imprecise bycatch estimates. In fisheries with low observer coverage and bycatch caps, bycatch estimates may be further biased as harvesters may be more likely to alter their behaviors when being observed to avoid reaching the cap. Although there are many manifestations of the observer effect, our focus is on the spatial dimension of this phenomenon because it represents a key issue in the quality of halibut bycatch estimates, in the Gulf of Alaska, the case study explored in section III of this report.

B. Methods

A set of three guiding questions was developed to compare partial-coverage observer programs: (1) *what is the cost per sea day for partial observer programs, and what amount are harvesters accountable for?* (2) *how do coverage rates compare between regions and fisheries and is there a spatial component incorporated in observer deployment protocols?* And (3) *are there caps on bycatch or protected species interactions in partially observed fisheries?*

16 partial observer coverage programs were identified by reviewing the FY 2017 National Observer Program Annual Report (National Marine Fisheries Service, 2019). After the universe of partial observer coverage programs was identified, a literature review of publications and reports from the NOAA Fisheries and regional program websites was conducted to obtain background information on observer programs, funding data, coverage rates, and regulatory changes made in fisheries with high bycatch interactions. To fill in data gaps and validate the data collected in our literature review, a list of contacts knowledgeable about the observer programs was created by identifying representatives from the National Observer Program Advisory Team (NOPAT). A schedule of interviews was established and took place over the course of the late fall and early winter of 2019.

Information to determine the cost comparison for partial-coverage observer programs was gathered from a report conducted by the Alaska Fisheries Science Center (Alaska Fisheries Science Center, 2017). The cost data was then verified by representatives from the respective regions, and the amount that harvesters are responsible for was identified. Initial coverage rate information was collected from the FY 2017 Annual Report. This information and whether observer deployment protocols, i.e. the random sampling design that assigns observers to a trip, include a spatial component, was further discussed with key representatives from each region. Caps and limits on bycatch and protected species were identified through reviewing fisheries management plans (FMPs), Biological Opinions, federal registrar notifications, and catch reporting data and were corroborated through informational interviews.

C. Cost Per Sea Day for Partial Coverage Observer Programs

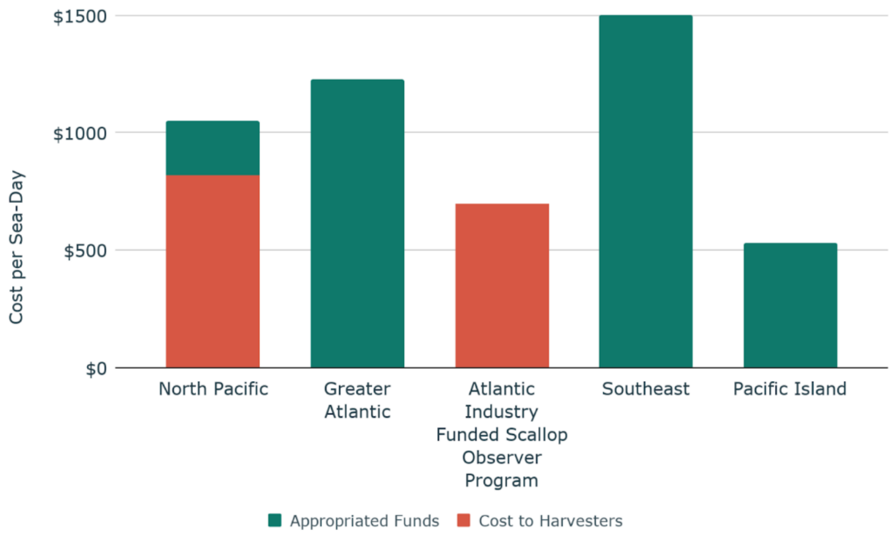
Observer programs are costly, and regional programs acquire federal appropriations through the National Observer Program (NOP) to fund observers in the different fisheries covered in their program. Eight fisheries as well as all fleets covered under the Greater Atlantic Regional Observer Program only use federal funds[1]. The Alaskan fisheries supplement their federal appropriations with industry funds and the Atlantic scallop fishery fully funds their own observer program (National Marine Fisheries Service, 2019). How and whether a program solicits industry fees can have a large impact on the level of observer coverage available. Industry fees add additional resources to observer programs, which enables a higher target level of coverage to be set and achieved as will be further discussed below.

The daily cost for observers includes both the daily rate of the observer, training, debriefing and traveling. Figure 1 displays the average daily cost per observer program in each region for FY 2016 (Alaska Fisheries Science Center, 2017) and, if applicable, how much harvesters are responsible for. Reimbursable fees such as travel costs contribute to the high level of variation of observer costs in each region, particularly in Alaska (Alaska Fisheries Science Center, 2017). For example, in the Pacific Islands where there is little on-the-ground travel between ports, sea-day costs average about $530 per sea-day. Meanwhile, in Alaska reimbursable travel costs are much higher due to the higher costs associated with transporting observers to ports that may be further away and in more remote locations. This results in an average sea-day cost of twice the amount in the Pacific Islands, around $1,049 per sea-day.

The Southeast region has the highest reported cost per sea-day, despite the region having relatively low reimbursable cost requirements. However, this can be explained by examining the coverage-rates and lengths of observed trips. The region has some of the lowest coverage-rate requirements for their fisheries and observed trips primarily range from only one to three days (DiCosimo & Nance, 2015). When coverage rate is low and trips are shorter, reimbursable fixed costs are distributed over less days and trips than in fisheries with higher coverage rates and longer trips (Alaska Fisheries Science Center, 2017) resulting in higher sea-day costs.

[1] Cost data for the West Coast region is not included, as their contract is administered by the Pacific States Marine Fisheries Commission and costs are not available to NMFS.

*Figure 1: Cost per Sea-Day**



* Data was collected by the North Pacific Fisheries Observer program (Alaska Fisheries Science Center, 2018). Sea-day costs are aggregated for all partially-observed fisheries in each region, apart from the Greater Atlantic. The Industry Funded Scallop Observer program is represented as its own, separate bar in the graph, as it is the only program in the region currently utilizing industry funds instead of being included within the Greater Atlantic region program. This is done as to not give the impression that the rest of the programs in this region use industry funds.

Fisheries in the Greater Atlantic (apart from the scallop fishery and groundfish at-sea monitoring program), Southeast, and Pacific Island Observer Programs all use only federally appropriated funds from the National Observer Program and taxpayer dollars to fund observer programs, with no burden falling on harvesters (Martins, 2019; Golden, 2019; National Marine Fisheries Service, 2019). Although this frees harvesters from the financial burden associated with hosting an observer, it limits the resources available to deploy observers and in some of these fisheries results in goal coverage rates not being achieved (see Table 7 and Table 8).

The fisheries that incorporate industry funds into their observer programs – the partial-coverage observer program in Alaska and the Industry Funded Scallop Observer Program and At-Sea Groundfish Monitoring programs in the Greater Atlantic region – have distinct methodologies for setting and collecting fees from harvesters. In Alaska, observer coverage is funded through a fee based on the ex-vessel value associated with the landings of IFQ or CDQ halibut and IFQ sablefish (Alaska Fisheries Science Center, 2017). The fee is currently set at 1.25 percent of the ex-vessel value of the landed fish, but this is under re-consideration. At the October 2019 Council meeting, the Council has recommended increasing the observer fee to 1.65 percent and to continue developing ways to increase cost efficiencies and achieve higher coverage given limited federal funding (North Pacific Fisheries Management Council, 2020).

Harvesters in the industry funded scallop observer program proposed to fully fund their own observer coverage to gain access to areas previously closed and strictly governed by the council through demonstrating harvest can occur with low levels of bycatch. To cover the costs of observers, the industry has created a one percent set-aside program where vessels with observers on board are allocated an extra one percent of scallop poundage when being observed (Martins, 2019). This methodology has proven effective at helping the industry not suffer an increased financial burden associated with funding observer coverage, as the sale of the additional allocation of quota is set to cover the cost of having an observer on board. If the quota does not make up for the cost of coverage, the crew has to pay out-of-pocket, but this rarely occurs. More often than not, the sale of the additional scallops supersedes the cost of the observers, so observed harvesters actually earn more than if they had not had an observer on board (Martins, 2019).

In the industry-funded At-Sea Groundfish Monitoring program, the industry is technically responsible for one hundred percent of sea-day costs, however these costs are currently being subsidized and federally allocated funds are being used to reimburse the sectors for one hundred percent of their monitoring costs (Martins, 2019). However, once federal reserves are used up, groundfish harvesters will be responsible for covering these fees. This, alongside recent proposals to increase coverage in the program to up to 100 percent, has resulted in strong industry push-back (Horgan, 2019).

The Alaskan, scallop, and groundfish fisheries are high-value and/or high-volume fisheries and industry-funded programs operate under the presumption that harvesters can afford the extra fees to increase observer coverage and therefore the quality of bycatch estimates. Due to the high financial strain being felt by fisheries in the Greater Atlantic and Southwest, requiring industry funds has not been recommended (Scott-Denton, 2019; A.I.S., Inc., 2013). As will be seen in the following sections, the Greater Atlantic faces difficulty in achieving program goals while the Southwest has some of the lowest observer coverage in the country. These factors may be the result of low funding availability, which could be ameliorated if industry funds were solicited.

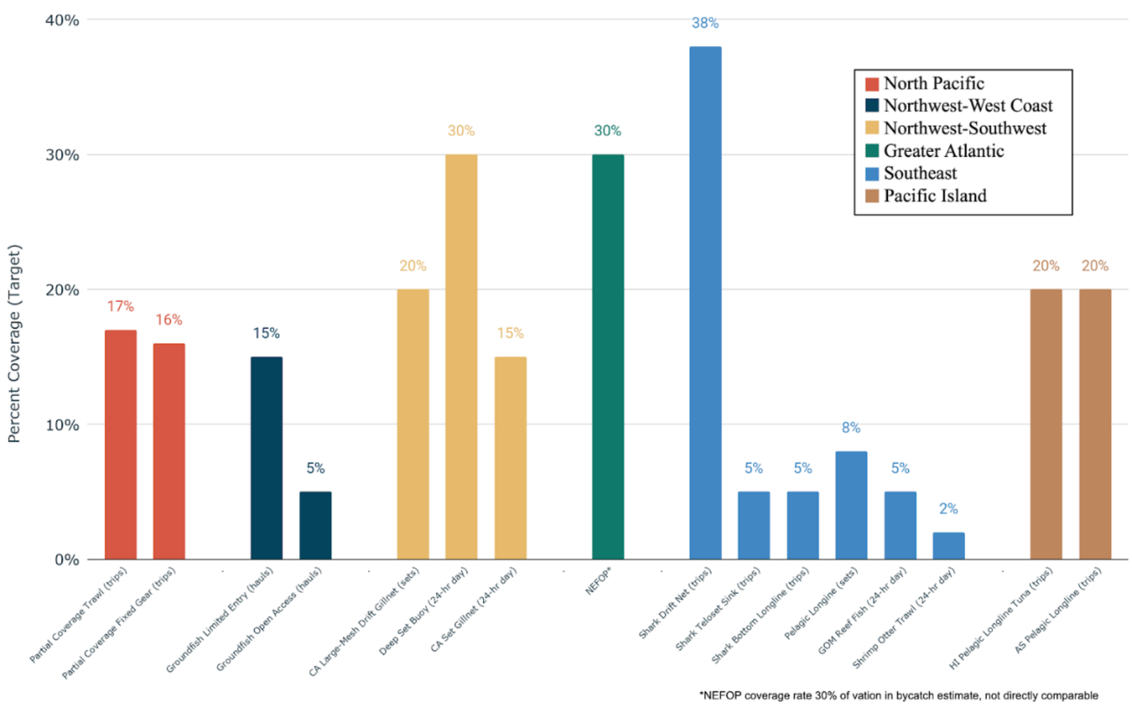
The set-aside program in the scallop fishery and the percent landing fee in Alaska have been developed to limit harvesters being observed to bear a higher-costs, reducing the potential of any bias impacting observer data. In the scallop fishery, the set-aside amount is meant to provide the extra resources needed to cover the observer’s costs. The landing fee on target catch in Alaska is meant to ensure that all harvesters are proportionally contributing to the program. Through these strategies, harvesters are not incentivized to avoid observer coverage for financial reasons, although there are other costs associated with having an observer onboard including reducing space on the vessel and altering the dynamic of the captain and crew. Thus, vessels that are observed may still not be representative of the entire fleet. Additionally, bias can occur through the observer effect which is not addressed by either the quota set-aside program or a landing fee. Here our focus is on how the coverage rate or bycatch limits may alter the spatial behaviors of observed vessels impacting accuracy of bycatch estimates, as will be discussed below.

C. Coverage Rate Comparison

C.1. Coverage Rate Targets

When not financially constrained, observer effort is set to meet a predetermined coverage goal (Babcock & Pikitch, 2004). Higher levels of coverage can result in larger amounts of observer data and more precise bycatch estimates, but resource availability limits the actual amount of coverage available and achieved in different regions. Additionally, as proven by Dorn et al., the increased reduction in uncertainty of bycatch estimates associated with increased observe coverage begins to level off after 25 percent of trips are observed. Given these constraints and the decreasing rates of benefits associated with increased coverage after a certain level, different regions have developed different methodologies of setting coverage rates in attempt to achieve a target goals that fit the unique attributes of the fishery (see *Figure 2. Coverage Rate Comparison*).

Figure 2: Coverage Rate Comparison



Directly comparing coverage rates across fisheries is difficult due to the variation in methodologies utilized. 47 percent of fisheries (or 7 out of 15 fisheries) and the Greater Atlantic North East Fisheries Observer Program (NEFOP) have observer coverage rates based on the number of trips, with the average observer coverage set at about 15 percent. There are also three fisheries that set coverage on hauls (the fisheries in the Westcoast-Northwest), three that set coverage on 24-hour day (CA deep set buoy and Southwest reef fish and shrimp), and three that set coverage on sets (CA drift and set gillnet and Southwest pelagic longline). The Greater Atlantic region does not have pre-determined coverage rate, but instead is focused on targeting the variability in discard estimations for 15 species.

The methodology in the Greater Atlantic is based on a strict statistical process that looks at the variability in bycatch of each fleet[2], and determines the number of sea days necessary for each fleet to reach a target precision level of discards (30% coefficient of variation of CV) for 15 species groups[3] based on the previous year's landings data for each fleet (Martins, 2019). These discard estimates are published in the annual Standardized Bycatch Reporting Methodology (SBRM) report. This information is then utilized to estimate total discards for each federally regulated species and the number of sea days required to meet the target precision level the following year (Martins, 2019). Once the total number of days for each species is determined, a prioritization ranking protocol is utilized to divide the days among fleets (NOAA, 2019c). This process includes a prioritization protocol if sufficient funding is not available to allocate days to the highest-priority fleets with the available number of sea days. For most fleets, this results in less than 10% of observer coverage for trips, sea days, or landings (Northeast Fisheries Science Center, 2018).

C.2. Actual Coverage Rates

There are various reasons why proposed observer coverage may not be realized, which can impede the success and effectiveness of the program in accurately quantifying bycatch. Table 1 displays a summary of which regions have been able to achieve their coverage rate goals observer coverage for partial observer programs for FY 2010-2013 and FY 2017[4]. Table 7 and Table 8, in Appendix I, provide more details for each region and fishery. (Northeast Fisheries Science Center, 2018).

Table 1: Summary of Success Rate in Achieving Goals for FY 2010-2013 and FY 2017

Region	Fishery	Success rate
Alaska	All partial-coverage fisheries	100%
West Coast – Northwest	All partial-coverage fisheries	100%
West Coast – Southwest	CA Drift Gillnet (sets)	0%
	Deep Set Buoy (24-hour day)	100%
	CA Set Gillnet (sets)	50%
Southeast	All partial-coverage fisheries	100%
Pacific Islands	All partial-coverage fisheries	100%
Greater Atlantic	Target discard estimate goal for 13 species	53%

[2] A fleet is defined by the geographic statistical area they fish in, gear type, mesh size category, and if it is a single- or multi-day trip (Martins, 2019).

[3] Atlantic salmon, bluefish, fluke/scup/black sea bass, Atlantic herring, monkfish, red deep sea crab, sea scallop, skate, small mesh groundfish, spin dogfish, squid/butterfish/mackerel, surfclam/ocean quahog, tilefish, loggerhead turtles (NOAA, 2019).

[4] Reports and data for FY 2014 – 2016 have not yet been completed (Benaka, 2020).

Observer coverage goals are met or exceeded in 93 percent of the partially observed fisheries in the North Pacific, West Coast, Pacific Islands, and South Atlantic. For fisheries not meeting their observer coverage goals, resource availability has been cited as the biggest hurdle in achieving these goals. The only region to have not met their percent goals for the years in our data is the Westcoast-Southwest, with a lack of funds being the primary reason (Villafana, 2019).

Additionally, the Greater Atlantic has not been able to achieve their goal precision level of discard estimates. The Greater Atlantic region has been struggling with harvester compliance ever since the Sea Day Schedule has been implemented, and from FY 2015-2017 goal discard estimates were only reached for 53 percent of our fishery/fishing year observations. After the implementation of the Sea Day Schedule in 2015, observer coverage has been better funded in some fleets than previously was the case as funds are allocated differently than they previously were. This has resulted in an increase in sea-days required to have an observer on vessels of fleets that previously received little coverage. This has been seen as an undue burden by some industry members, who refuse to take observers on board without formal documentation. (Northeast Fisheries Science Center, 2018). Low observer job satisfaction and a resulting lack of retention have also created an obstacle for achieving target sea-day coverage (Northeast Fisheries Science Center, 2018).

Despite the Greater Atlantic region having met their goal less often than other regions, it does not necessarily mean that it is a less effective program due to the highly distinct methodology and difficulty in comparing directly across programs. However, a lack of enforcement and resistance to comply with regulations has been a huge hurdle in successful implementation, underlying the potential need for harvester input in developing and re-structuring observer programs. For example, the restructuring of the Alaskan groundfish and halibut fisheries involved high amounts of stakeholder input from fishermen and processors and a robust public comment period to shape the final program (NOAA Fisheries, 2012), and the program has exceeded coverage rate goals since its implementation.

In Hawaii, due to variable costs and observer availability, the region experiences difficulty in maintaining the goal 20 percent coverage year-round. They have therefore adapted a flexible selection rate process, with coverage fluctuating from one quarter to the next. Some quarters have up to 50 percent of trips covered and others only having 5 percent of trips covered, with the goal that coverage will average out to 20 percent by the end of the year (Golden, 2019). This, along with their trip selection process, leaves a lot of room for harvesters to avoid being observed. Vessels are selected through a systematic sampling procedure, where at the start of the quarter, contractors are supplied with a sample of notification numbers drawn by the Pacific Island Fisheries Science Center (PIFSC). When a vessel declares a trip, they are assigned a number and if it matches one of the contractor notification numbers they are to be observed. However, complications arise if the vessel does not leave in a reasonable amount of time, at which point the observer is reassigned. When the selected vessel is then ready to depart, a different observer is placed onboard if there is one available (McCracken). This is not always the case, however, and therefore if a vessel simply delays departure there is a chance they will not have an observer onboard.

C.3. Spatial Dimension to Coverage Rates

In order to account for spatial bias that may occur when being observed, all fisheries except for the shark fisheries in the Southwest and two fisheries in Hawaii have incorporated a spatial component to their trip selection process (see Appendix I - Table 6). However, the approaches to addressing spatial issues varies across fisheries. In the Greater Atlantic, the Sea Day Schedule and prioritization protocol, the Sea Day Selection protocol in the Greater Atlantic nearly eliminates the opportunities for harvesters to exhibit spatial bias when being observed. Vessels are only assigned an observer once they have declared their location and unless there are unforeseen circumstances that arise, the fishing area cannot be changed after observer placement occurs. In the pelagic observer program (POP), effort per fishing area from the previous year is included in the observer deployment and trip selection process in attempt to have higher observer coverage rates in areas more heavily fished, but as can be seen in Appendix I fishing areas in this fishery are very large. This leaves room for spatial bias to still occur within the large regions (Scott-Denton, 2019; Keene, 2016). The spatial component of observer deployment is most effective for fisheries where spatial zones are small and where vessels are not able to evade being assigned an observer as is seen in the Hawaiian fisheries (described above).

Although understanding if target coverage rate or discard estimate goals are reached is one important factor in determining the effectiveness of program implementation, it does not account for the spatial bias in observed trips. In other words, just because the target level is reached does not mean that those observed trips are an accurate representation of the fleets' activity as a whole. As described below, any spatial bias due to the observer effect may be exacerbated in fisheries where there are caps on bycatch or limits on interactions with protected species.

D. Bycatch Caps in Observed Fisheries

Bycatch caps are set if the incidental harvest of a species by one fishery may have negative impacts on a target fishery, and Incidental Take Statement (ITS) limits are set based on the expected number of interactions with marine mammals and protected species. These limits and the authority to place observers come from two overarching laws that govern fisheries management– the Magnuson-Stevens Fisheries Conservation Act (MSFCMA or MSA) and the Marine Mammal Protection Act (MMPA). Both Acts require that the government collect data on activities that affect marine resources - including bycatch data – to sustainably manage stocks and protect marine mammals.

The MMPA was established as a national policy in 1972 out of increased concern that human activities were causing declines of certain species and stocks of marine mammals. Observers monitor incidental mortality and serious injury of marine mammals during the course of commercial fishing operations in order to fulfill monitoring requirements outlined in the Act. In some fisheries, an ITS limit may be established to cap the number of interactions a fishery can have with marine mammals. NMFS considers onboard observers to be the most reliable source for fishery-specific marine mammal interactions (NOAA, 2000).

The MSA was enacted in 1976 to protect and conserve domestic fishing practices by preventing overfishing, rebuilding overfished stocks, protecting the economic and social benefits derived from the fishing industry and maintaining a sustainable supply of seafood. Provisions within the Act require that regional councils gather sufficient information to develop reports on stock status and health, bycatch, habitat status, and more (16 U.S.C. § 1852). To do so, the MSA dictates that fisheries management plans "require that one or more observers be carried on board a vessel of the United States engaged in fishing for species that are subject to the plan, for the purpose of collecting data necessary for the conservation and management of the fishery" (16 U.S.C. § 1853).

Of the 32 fisheries evaluated, 14 have caps or limits set on non-target or protected species (see Appendix II and Table 9). For these fisheries, reaching bycatch caps or ITS limits will result in increased management measures such as catch reductions, time/area closures, or gear restrictions that can have severe socioeconomic implications on harvesters. ITS numbers set by the MMPA or ESA may not be exceeded, as doing so may jeopardize the existence of the protected species (Klemm, 2020). If reached, the fishery must be closed down. Given the severity of this management measure, harvesters in fisheries with MMPA or ESA set ITS limits have the strongest incentive to avoid bycatch or marine mammal interactions when being observed.

Bycatch caps and ITS limits incentivize harvesters to avoid areas with high abundance of these species or find ways to avoid observation altogether. To avoid financial loss or missed catch opportunities, unobserved harvesters may misreport interactions or bycatch rates, which has been found in studies that have compared bycatch data to predictions made by discard models developed from harvester logbook reports (Babcock & Pikitch, 2004). According to the Southeast Regional Observer Program NOP representative, increased observer coverage has helped to more effectively and accurately monitor for interactions with ESA listed species and determine if ITS limits are being reached. Before observer coverage was mandatory in the reef fish fishery, sea turtle interactions were self-reported by fishermen and there had been no historically recorded instances. After the first year of the program's implementation, there were 22 observed interactions (Scott-Denton, 2019). These numbers could still be an underestimate if an observer effect is occurring and harvesters are selectively avoiding areas of high turtle abundance when observed.

Of the 14 fisheries with bycatch caps or species interaction limits, 7 fisheries have exceeded their allowance 2005, triggering increased management measures (see Appendix I: Table 9). In three of these fisheries, the management measure triggered was a closure for the remainder of the season since the limit in these fisheries is set under MMPA authorization to protect the species from jeopardy. In the Hawaiian shallow set pelagic longline fishery, the ITS limit of 26 leatherback sea turtles and 17 loggerhead sea turtles has been reached and resulted in complete closure of the fishery three times since 2005 (NOAA Fisheries, 2020). In the remaining four, gear restrictions and target catch reductions were implemented.

There are six other fisheries where reaching caps or limits would trigger a closure, four of which are under MMPA authorization for observer coverage. Published reports for these fisheries indicate that these limits have not ever been reached. However, when looking at the achieved coverage rate of these fisheries and if they include a spatial component in observer deployment, three fisheries have coverage rates of less than 10 percent of trips/24-hour days. The other three have an MMPA dictated ITS limit for whitetip shark and giant manta ray interactions and a coverage rate of 20 percent of trips but do not include a spatial component when selecting vessels to be observed (NOAA, NMFS & HMS Division, 2020). (see Table 10). Given the severe impacts the MMPA-authorized closures can have on harvesters, these factors create room for reports based on observer data to underrepresent the actual number of interactions if the abundance of the bycatch species varies across space.

E. Discussion

Due to the high costs associated with onboard observers and limited resources available, regional programs have established different methodologies for funding their programs, setting observer coverage and placing observers on vessels to quantify bycatch. When observed, harvesters may be exhibit behaviors caused by the observer effect such as fishing in areas with low levels of bycatch. Behavioral changes are more likely to occur in fisheries that have management measures enacted when bycatch caps are reached (Vølstad & Fogarty, 2006). If harvesters are exhibiting the observer effect, then these regulations meant to protect stocks, marine mammals, or protected species may not be triggered when they should be.

Several elements of five regional observer programs investigated – the costs, coverage rate and vessel selection, and bycatch caps – impact the precision of bycatch estimates. Holding all else constant, it would be assumed that higher levels of coverage would result in more accurate bycatch estimates. However, as coverage rates are set differently (on sets, trips, hauls, or targeting a rate of discard estimates), methodologies for vessel selection vary across regions, and sea-day costs are highly varied it is difficult to conclude if this holds true (see Appendix I: Table 10).

Funding is the key reason that observer coverage is low or not realized. Unfortunately, the only region to consistently not meet percent observer coverage target goals is the West Coast-Southwest region, but funding data is not available for this region, so we are unable to draw a concrete conclusion between sea-day costs and realized coverage. However, the five fisheries with the lowest coverage are all in the Southeast, which has the highest sea-day costs. The Greater Atlantic is the second most-costly program has had only a 53 percent success rate in achieving discard estimates for species they monitor. These regions both suggest that high costs can impact the observer coverage rate and, thus, the quality of bycatch estimates.

With low funding and observer coverage, gathering accurate data on bycatch and marine mammal interactions is difficult, and data may be biased if harvesters are changing their behaviors when observed. As discussed above, fisheries with the most severe management measures implemented when caps are reached have some of the lowest occurrences of these measures being triggered. This may be a result of the observer effect and biased data. In the next section, we examine harvester behaviors in the Gulf of Alaska groundfish fishery as a case study to examine differences in fishing location choice between harvesters are that are observed and unobserved and the potential impacts on bycatch estimates.

III. Spatial Comparison of Observed and Unobserved Fishing Activity in the Gulf of Alaska and Pacific halibut Abundance

A. Introduction

This section of the capstone report analyzes evidence of spatial bias in the observer coverage and Prohibited Species Catch (PSC) estimates of the Gulf of Alaska groundfish bottom trawl fleet, and the implications of potential bias. Put another way, this section looks at whether there is a difference between the fishing locations of observed and unobserved bottom trawl vessels, and analyses whether that difference matters. This section will: (1) define the research questions and hypotheses; (2) briefly summarize relevant technical reports[6]; (3) describe the data and methods used to answer the research questions; and (4) discuss the results and implications of the analysis.

B. Research Questions & Hypotheses

1. Does Pacific halibut abundance vary within NMFS reporting areas? We expect that abundance will vary within NMFS Reporting Areas.

2. Are there areas of high unobserved fishing activity and areas of high observed fishing activity? We expect that there will be statistically significant clusters of observe and unobserved vessels in different places.

3. Are areas of observed and unobserved fishing activity related to halibut abundance? We expect that observed vessels will cluster in: (1) areas of relatively low Pacific halibut abundance, and (2) near shore and ports, indicating shorter observed fishing trips. Conversely, we expect to find unobserved vessel clusters in areas of high halibut abundance further from shore and ports.

C. Background

1. North Pacific Groundfish Observer Program

Vessels participating in the groundfish fishery in federal waters off the coast of Alaska are required to have full or partial observer coverage[7]. Catcher processors (CPs), motherships, community development quota (CDQ) vessels, and the Central Gulf of Alaska (GOA) Rockfish program are required to have at least one observer on board (100% coverage). Catcher vessels (CVs) and smaller CPs are required to have partial observer coverage (50 CFR § 672 (a)(2)).

Within the partial coverage category, target coverage rates are set by splitting fishing vessels into sampling strata based on fishing gear and whether vessels deliver to a tender. There are five partial coverage strata: hook-and-line (HAL), pot (POT – No Tender), tender pot (POT – Tender), trawl (TRW – No Tender), and tender trawl (TRW – Tender). Bottom trawl vessels are included in both the TRW – No Tender and Trawl – Tender strata, along with pelagic trawl

[6] This report will briefly review and update the work completed by Lou Forristall and Sunny Jardine for the Deep-Sea Fishermen's Union over the summer of 2019. That initial report contains a more detailed discussion of the relevant literature about the NPGOP and Catch Accounting System on pages 1-7

[7] Smaller vessels are not required to have observer coverage, but there are not trawl vessels in the GOA that fall into the no coverage category, so they will not be discussed in this report.

vessels. The focus of this analysis are all bottom trawl vessels that fall into the partial coverage category.

Target coverage rates are set for strata across all areas, meaning that the target rates are the same for the Gulf of Alaska, Bering Sea, and Aleutian Islands. Fishing trips are used to set expected coverage goals and are the main criteria for evaluating coverage in the Annual Reports published by the NPGOP (AFSC, 2019).

2. Catch Accounting System

Observers on board NPT vessels collect information on catch, including halibut bycatch. The rate of bycatch from observed trips is applied to unobserved fishing activity in the Catch Accounting System (CAS). The CAS matches unobserved fishing activity, reported in industry landings reports, to data collected by observers and provides an estimate of total, industry-wide catch (Cahalan et al., 2014). For partial coverage trawl fisheries, the methods for estimating directed fishery catch and discarded bycatch are different and described below. The methods used in the CAS to estimate bycatch may create the incentive for an observer effect where observed vessels avoid areas of high halibut abundance.

Total unobserved, retained groundfish catch is estimated through industry landing reports. Landings reports contain information on fishing trips, specifically: the date, length, gear used, state statistical area fished, weight of species delivered, and weight of species discarded. Unobserved retained catch is estimated by determining the target (or predominant) species from the landing report, then summing all landings reports across the target species for fishery-level catch estimates. This process, where sampling strata are further broken down to estimate retained catch, is called post-stratification (Cahalan et al, 2014). Target species for partial coverage bottom trawl vessels in the GOA are set on the following criteria: "(1) if 95% or more of the retained catch is pollock, then a target of pelagic pollock is assigned to the trip; (2) if the sum of all flatfish is greater than the amount of any other species, then a target of flatfish is assigned to the trip; (3) if neither pollock or flatfish is not determined as the target, then the groundfish species that has the highest proportion of the retained catch is assigned as the trip target" (Cahalan et al, 2014). The target species determined in the estimation of retained catch is used to estimate bycatch. The spatial resolution of individual landings reports is Alaska State Statistical Areas. In the CAS, data is summed across NMFS Reporting Areas, which are larger than state statistical area.

While the landings reports contain information on discarded species, that data is not used in the CAS to determine discards because it is not verified (Cahalan et al, 2014). Instead, a combination of observer data and landings reports are used to estimate the discards of unobserved fishing activity, including halibut PSC. To estimate discards, observed rates of bycatch on observed vessels are applied to the total groundfish reported on landings reports. Discard and bycatch rates are applied to landings reports based on the time of fishing activity, gear type used, NMFS reporting area, and target species (Cahalan et al, 2014). The target species, determines the rate of bycatch that will be used for a specific landings report. For instance, a landings report for a GOA bottom-trawl, partial-coverage vessel fishing for Pacific cod will have a bycatch rate applied using data from observed bottom-trawl vessels fishing for cod in the same reporting area in the 2.5 weeks before and after the date of fishing activity on the landings report. Because the rate of bycatch applied to unobserved vessels is determined by the NMFS reporting area, if Pacific halibut abundance varies within reporting areas there could be an incentive to avoid areas with high halibut abundance when observed. This observer effect could reduce rate of bycatch applied to unobserved vessels and the overall PSC estimate.

D. Data

Two data sources were used to address the research questions regarding Pacific halibut abundance and bottom trawl fishing activity. IPHC setline survey data was used to represent Pacific halibut abundance. Specifically, weight of catch per unit of effort (CPUE) served as a proxy for abundance and was calculated by dividing the total weight of Pacific halibut by the number of skates set at each survey station[8]. The CPUE measure should give an indication of the density of the Pacific halibut population. The data did not include information on sex, and the only information on size in the data is whether halibut were over or under 32 inches in length.

In the IPHC survey, latitude and longitude are recorded at the beginning, middle, and end locations where the fishing gear is deployed. The middle point was used as the survey station location in this analysis. Using these locations, the points were aggregated either to: (1) a 20km hexagonal grid, or (2) the 20km incomplete grid for annual bottom trawl fishing activity for analysis.

To address observed and unobserved fishing location, Steve Lewis, with the NMFS Alaska Regional Office, supplied an aggregated dataset that uses data from the Vessel Monitoring System Observer Enabled - Catch-In-Areas (VOE-CIA) database. The VOE-CIA uses a combination of observer data, fish ticket data, and satellite tracked vessel movements tracked through Vessel Monitoring Systems (VMS) to assign a finer spatial resolution to fisheries data than the CAS alone (Lewis, 2008). The VOE-CIA has different methods to match observer data to VMS records than it does for matching landings reports to VMS records.

For observed vessels, data in the VOE-CIA is match based on single hauls, since gear deployment and retrieval locations are recorded as exact coordinates by observers. These coordinates are then matched to VMS records based on exact date and time. A straight trackline is then drawn between the deployment and retrieval locations to fix the VMS data to the underlying fishing activity. The catch total from a given haul is distributed evenly along its trackline. Tracklines are then aggregated to polygons that are roughly seven square kilometers in area. For public release of data, to avoid confidentiality restrictions, these seven-kilometer areas may be aggregated up to twenty-kilometer areas (Lewis, 2008).

For unobserved vessels, the data is matched based on fishing trip, since landings reports only report location (State Statistical Area) throughout an entire trip. VMS locations are matched to landings reports based on: (1) vessel speed; (2) whether an area is known to be a fishing area; (3)

[8] For a more detailed discussion of the survey methods in the IPHC Setline Survey, see the previous report submitted to the DSFU by Lou Forristall and Sunny Jardine on page 11.

whether the VMS location matches at least one of the state statistical areas reported on a landings report; and (4) the date of the VMS point matching the date range on the landings report. Like observed vessels, once VMS records are matched to a landings report of unobserved fishing activity, the catch data from the landings report is distributed evenly across a vessel's trackline. Tracklines are then aggregated to the same rough seven-kilometer grid for analysis or twenty-kilometer grid for public release (Lewis, 2008).

Our analysis is based on the annual VOE-CIA spatial dataset, aggregated to a twenty-kilometer grid, measuring unique vessel counts for observed and unobserved vessels, as well as their total catch (retained + discards). Table 2 contains the variables and definitions of the variables from the VOE-CIA dataset.

Table 2: COE-CIA Variables and Definitions

Variable	Definition
Reporting Area	The NMFS reporting area for each grid cell. 610, 620, 630, and 640 correspond to the Gulf of Alaska.
SubArea	FMP area, either Bering Sea Aluetian Islands of Gulf of Alaska
CntDistinct	Number of distinct or unique vessels that fished in an area.
Hex_ID	Unique identification number assigned to each hexagon.
Tons	Estimated catch (retained plus discard) by all boats that fished in the hexagon in tons.
Obs_UnObs	Whether the row of data corresponds to observed or unobserved vessels.
Year	The year in which the fishing activity occurred. Ranges from 2003-2019. 2019 data is incomplete.
Shape_Length	Length of the long diagonal of each hexagonal grid cell.
Shape_Area	Area of each hexagon grid cell.
Shape	The coordinates of each grid cell.

This dataset includes data from all CVs, including the full coverage CVs from the Rockfish program[10]. The Rockfish vessels are not of interest to this analysis as these vessels have 100% observer coverage. To address the inclusion of Rockfish trips, grid cells where more than 50% of the catch was observed were removed from the data. Table 3 contains the actual retained, discarded, and total catch for observed partial coverage CVs and the entire fleet that were used as reference for manipulating the VOE-CIA data. This data is from the NPGOP's Annual Reports. The second and third columns contain the retained catch for all vessels and

[10] Data from the Rockfish could likely be filtered out by NOAA Alaska Fisheries (Steve Lewis) before the data is aggregated and released. Data without the Rockfish vessels would make the findings in this analysis more reliable.

observed vessels in the partial coverage CV fleet, respectively. The fourth and fifth columns show the discarded catch for those two categories of vessels. The sixth and seventh columns show the total catch (retained + discarded) for the entire fleet and observe vessels, respectively. The final column shows the percent of total catch that was observed. These last three columns calculated from the VOE-CIA data, and were used as reference points for filtering the data.

Table 3: Actual NPT Partial Coverage CV Catch in Metric Tons

Year	CV Retained Total	CV Retained Observed	CV Discard Total	CV Discard Observed	CV Total	CV Total Observed	CV Total Catch Coverage
2012	34331	9180	7170	1071	41501	10251	24.7%
2013	43968	5807	6168	666	50136	6473	12.9%
2014	45998	3404	7298	693	53296	4097	7.7%
2015	34832	4762	4462	517	39294	5279	13.4%
2016	34257	3970	5936	531	40193	4501	11.2%
2017	32003	5014	3327	424	35330	5438	15.4%
2018	26109	3771	5063	636	31172	4407	14.1%

Table 4 shows observed and unobserved catch totals from the VOE-CIA dataset, after areas with more than 50% catch observed were removed. The second, third, and fourth columns show catch for the observed, unobserved, and total from both coverage categories for all areas remaining in the data set. The fifth column contains the percent of total catch that was observed in the remaining areas. The last three columns show the percent of the original data that remained in the after areas with more than 50% of catch observed were removed.

The CV Total Observed and CV Total Catch Coverage columns from Table 3 should be compared to the Total Filtered and Coverage Filtered columns in Table 4. The final three columns in Table 4 show how much of the VOE-CIA data remained after areas with more than 50% catch observed were removed.

Table 4: Catch Data Filtered for Areas with Greater than 50% of Vessels Observed in Metric Tons[11]

Year	Observed Filtered	Unobserved Filtered	Total Filtered	Coverage Filtered	% Original Observed	% Original Unobserved	% Original Total
2013	6817	41501	48319	14.1%	45.3%	97.2%	83.6%
2014	5159	46106	51266	10.0%	36.5%	96.2%	82.6%
2015	4832	30853	35685	13.5%	33.4%	94.6%	75.8%
2016	4985	32931	37916	13.1%	28.7%	95.2%	73.0%

Removing areas with more than 50% of catch observed preserved at least 94% of the unobserved catch data in each year (Table 4, % Original Unobserved). It also brought the total catch from the VOE-CIA dataset (Table 4, Total Filtered) closer to the actual catch for partial coverage CVs in each year (Table 3, CV Total Observed). While this data manipulation moves the VOE-CIE data closer to the actual catch numbers of the partial coverage CV fleet, it is problematic. There is no guarantee that the vessels removed are Rockfish vessels, and not other partial coverage vessels.

To address the second research question, i.e. whether there are differing areas of with high and low observer coverage, and to work within the confidentiality constraints given on the data, the percent difference of the observed and unobserved distinct vessel count in each area was used as a proxy for fishing location selection. Thus the variable does not account for repeat fishing trips. The percent difference between distinct vessel counts of observed and unobserved vessels was calculated as: observed vessels minus unobserved vessels divided by total vessels.

The percent of catch observed in each area was also used to approximate observer coverage in the analysis. Observer coverage is determined as a percentage of fishing trips by the NPGOP, but trip information was not available to us. Because the percent of catch and trips observed are typically significantly different (AFSC, 2019), our estimate of observer coverage will be different than the definition used by the NPGOP. The percent of catch covered was calculated by taking the observed catch in each area and dividing by the observed plus unobserved catch. The observed and unobserved catch totals provided from the VOE-CIA database included both retained and discarded catch.

E. Methods

1. Abundance Mapping at Varying Spatial Scales with Survey CPUE

The first research question (does Pacific halibut vary at levels smaller than the NMFS Reporting Area) was addressed through mapping the CPUE from IPHC setline survey. The first step was to map survey CPUE at the NMFS Reporting Area level and compare the high and low

[11] For the rest of the analysis, only the years 2013-2016 will be referenced. This for three reasons: (1) major observer program changes implemented in 2013 (AFSC, 2012); (2) the beginning of Annual Observer Program Report publications and availability of NPT catch data; and (3) a lack of data in the second VOE-CIA dataset for years after 2016.

areas to the performance of the observer program against expectations reported in NPGOP Annual Reports.[12] At the NMFS Reporting Area level, there was no obvious relationship between fishing trip location and halibut abundance. The next step was to map the data at a finer scale to see if there is variation of the halibut population within NMFS Reporting Areas by aggregating the survey CPUE data to the same size hexagonal grid (20km) as the VOE-CIA data.

2. Detection of Observed and Unobserved Distinct Vessel Count Clusters

The second research question (whether there are differing areas of with high and low observer coverage) was addressed by analyzing the VOE-CIA data for spatial clustering and identifying locations of observed and unobserved vessels clusters. Spatial differences of observed and unobserved fishing activity is an indicator of an observer effect (AFSC, 2019; Jannot, 2015; Benoit, 2009). The method used to identify differences between observed and unobserved fishing activity in this analysis was the Getis-Ord Gi* Hotspot Analysis (Getis, 1992 & Ord, 1995). The Getis-Ord Hotspot Analysis allows for the identification of statistically significant clusters of high and low values in spatial data. If clustering is present in the data, it is an indication that observed and unobserved fishing activity are different and an observer effect may be present. Locating the clusters will provide an estimate of where vessels go as a result of the observer effect. In the Hotspot Analysis, the distinct vessel percent difference variable described above was used to test for differences in observed and unobserved trips. The areas with observer coverage may still have Rockfish vessels in the data. The potential presence of Rockfish data could skew the percent difference of observed and unobserved vessels and influence the identification of clusters of fishing activity. Essentially, if there are Rockfish vessels still present in the filtered data, the Hotspot Analysis could be an inaccurate depiction of spatial differences between observed and unobserved vessels in the partial coverage fleet.

The Getis-Ord Gi* Hotspot Analysis is widely applied in fisheries management (Moutopoulos et al, 2011; Maina et al, 2015; Jalali at al, 2016). In the North Pacific specifically, hotspot analysis was used to identify areas of bottom trawl intensity (Steves, 2017), reconstruct winter population distributions of Red King Crab from logbooks (Zacher, 2018), and identify persistent areas of high halibut bycatch (Keaton, 2016).

The first step of the Hotspot Analysis is to identify if there is any clustering in the data. For this specific application, this step checks that fishing activity is not randomly distributed throughout the Gulf of Alaska. This step requires the generation of a Moran's I statistic and the statistic in a Monte Carlo simulation (Moran, 1948). The Moran's statistic is a measure of spatial autocorrelation, or whether neighboring areas have similar values. For this analysis, neighbors were defined as areas that shared a border, given that the VOE-CIA dataset already aggregates fishing trips to larger areas. Defining neighbors as areas with shared borders should best approximate the underlying fishing activity, since trips that cross multiple areas would already be split among those areas.

Once neighbors are defined, the next step is generating the Moran's statistic. The Moran's I statistic compares areas to the mean for the whole dataset. If neighboring areas

[12] This analysis can be found in the previous report submitted to the DSFU by Lou Forristall and Sunny Jardine.

compare similarly to the mean, then the Moran's I statistic will be high. High Moran's statistics indicate clustering of similar values in space. The Moran's I statistic can be tested through a Monte Carlo simulation, to check that the result is statistically significant. The Monte Carlo simulation randomly redistributes values from the data across the areas defined in the data and generates a new Moran's I Statistic for each simulation. For the VOE-CIA data used to answer this question, the percent differences will be shuffled and reassigned to different grid cells at random, but the actual locations of the grid cells will stay the same throughout the simulations. The original Moran's I statistic is then compared to the randomly generated versions. If it is different from the randomly generated values, then there is an indication of clustering in the data and results from a hotspot analysis will be meaningful (Moran 1948; Steves, 2017).

The Getis-Ord Gi* analysis can be used to identify the location of specific clusters of high and low values in data where there is overall clustering. The Getis-Ord Gi* analysis works by determining the relationship of each area to its neighbors and comparing that relationship to the entire dataset. The sum of values for an area and its neighbors is compared proportionally to the mean of all other areas, generating a z-score. Z-scores allow for the identification of clusters of relatively high and low values, with high positive z-scores identifying clusters high values and high negative z-scores identifying clusters of low values. In this analysis, high z-scores correlate to statistically significant clusters of areas with more observed than unobserved vessels and low z-scores correlate to statistically significant clusters of areas with more unobserved vessels (Ord, 1995; Zacher, 2018).

An example of how the Getis-Ord analysis would work using this data is if one grid cell was touching three other grid cells, the percent differences in four areas would be added. That total value of those percent differences would then be compared to the average of all percent differences times four (the area plus its three neighbors). If the four actual values are higher than the four means, then the first area that was tested would be assigned a z-score above zero. The higher the value of grid cell and its neighbors, the higher the z-score. Z-scores that are above 1.96 would be statistically significant cluster of observed vessels. If the percent differences in the above example were negative (more unobserved vessels), then it could result in a negative z-score. Areas with a z-score below -1.96 would be clusters of unobserved vessels.

One issue with this analysis is that the overall percent of trips coverage level is low by design (28% of trips covered in 2019 - AFSC, 2019), so the Getis-Ord analysis may identify all areas of that may be unobserved clusters. If the low areas are compared to an overall low mean, they may not stand out even if there are groups of areas with little to no observer coverage. To account for this effect, areas with exclusively unobserved fishing activity were compared to observed clusters. That process is described in the next section.

3. Permutation Test for Survey CPUE in Observed Clusters, Unobserved Clusters, and Areas with No Observed Vessels

Clusters identified in the answer to the second research question can be used to answer the third research question (whether there is relationship between observed fishing activity, unobserved activity, and halibut abundance). If clusters are present and there is an indication of an observer effect, the locations where observer activity is significantly different can be used to test assumptions about what drives the observer effect. To determine if observer effects present in the GOA bottom trawl are due to halibut abundance, the mean CPUE from IPHC survey stations that fall within observed and unobserved clusters were tested for differences through a permutation test. In multiple years, few unobserved clusters were identified, so the survey CPUE in observed clusters were also compared to unobserved clusters and areas that had: (1) unobserved vessels; (2) no observed vessels; (3) but were not identified as unobserved clusters. This category of data was used as an attempt to compare observed clusters, not just to clusters of unobserved vessels, but areas that also had no observer coverage.

In this part of the analysis, a two-sample Monte Carlo permutation test was used to test whether the difference between survey CPUE means of observed and unobserved clusters was statistically significant. This test can be used to test whether the difference between groups of data is statistically significant when the is not normally distributed and has a small sample size These conditions apply to the groups of survey stations that fall within observe and unobserved clusters each year.

To run a permutation test, first a test statistic needs to be defined. Here, for each year, the test statistics were the difference in the means of survey CPUE stations that fell within: (1) observed and unobserved clusters, and (2) observed clusters and unobserved clusters plus areas that had unobserved vessels and no observed vessel.

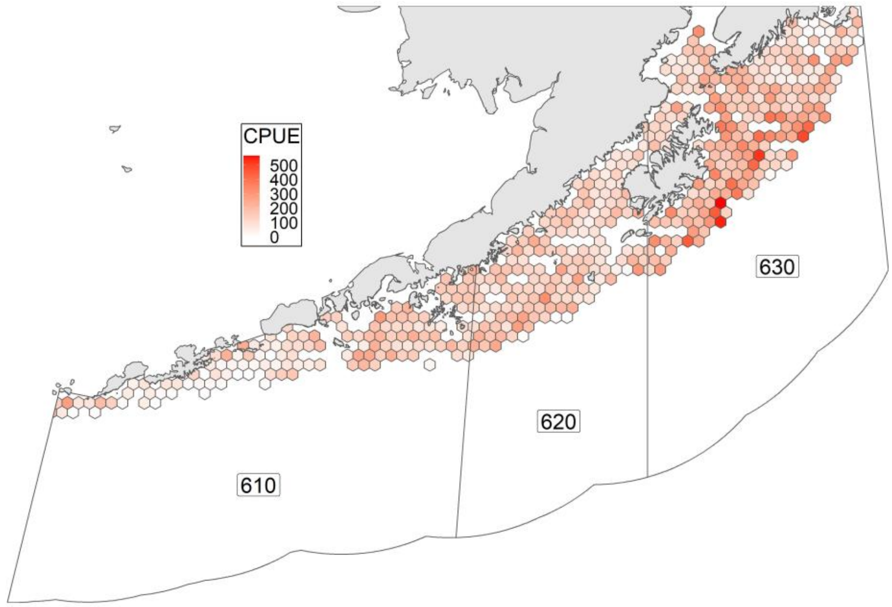
Once a test statistic is defined, the permutation will randomly resample the data to simulate new test statistics. The original test statistic is then compared to the randomly generated test statistics. A p-value can be calculated based on how many of the simulations the actual test statistic is greater than. The smaller the p-value, the more likely the difference is means is statistically significant. A p-value threshold of .05 was used to determine if the difference in means was statistically significant in this analysis.

F. Analysis

1. Abundance Mapping

Figure 3, shows the mean IPHC survey CPUE for survey stations in each grid cell from 2013-2016. NMFS reporting areas are on the map and labeled. Mapping the survey CPUE with the reporting areas clearly shows that the halibut population varies within NMFS regulatory areas. The areas of high CPUE are consistently in reporting area 630 offshore south of Kodiak Island.

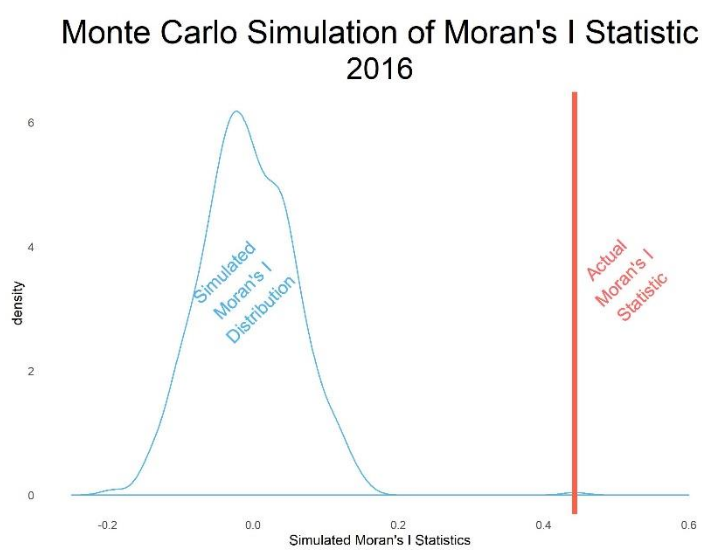
Figure 3: Mean CPUE from the IPHC Survey from 2013-16



2. Observed and Unobserved Clusters

Every year from 2013-2016 showed evidence of clustering based on the Moran's I Statistic. Figure 4 shows an example of the results from the Monte Carlo simulation (the blue curve in Figure 4) conducted to test the Moran's I Statistic (the red line in Figure 4) generated from the data. If the actual Moran's I Statistic falls outside the distribution of simulated Moran's I Statistics, that is an indication that there are clusters in the data. For 2016, this test resulted in a p-value of .001 for the actual Moran's I Statistic, supporting the conclusion that there is clustering in the data and there this an observer effect.

Figure 4: Example of Monte Carlo Simulation Result



Given that the data for each year showed evidence of clustering, the Getis-Ord Gi* Hotspot Analysis can be used to identify meaningful clusters of observed and unobserved fishing activity. The percent difference of the observed and unobserved distinct vessel counts in each grid cell was used to identify clusters. Figure 5 shows the raw percent difference for each grid cell that was used as an input for the Hot Spot analysis for 2016. Figure 6 shows the results of the Hot Spot Analysis for 2016. Appendix IV has the same maps for 2013-2016.

Figure 5: Percent Difference of Observed and Unobserved Vessels: (Observed – Unobserved)/Total Vessels

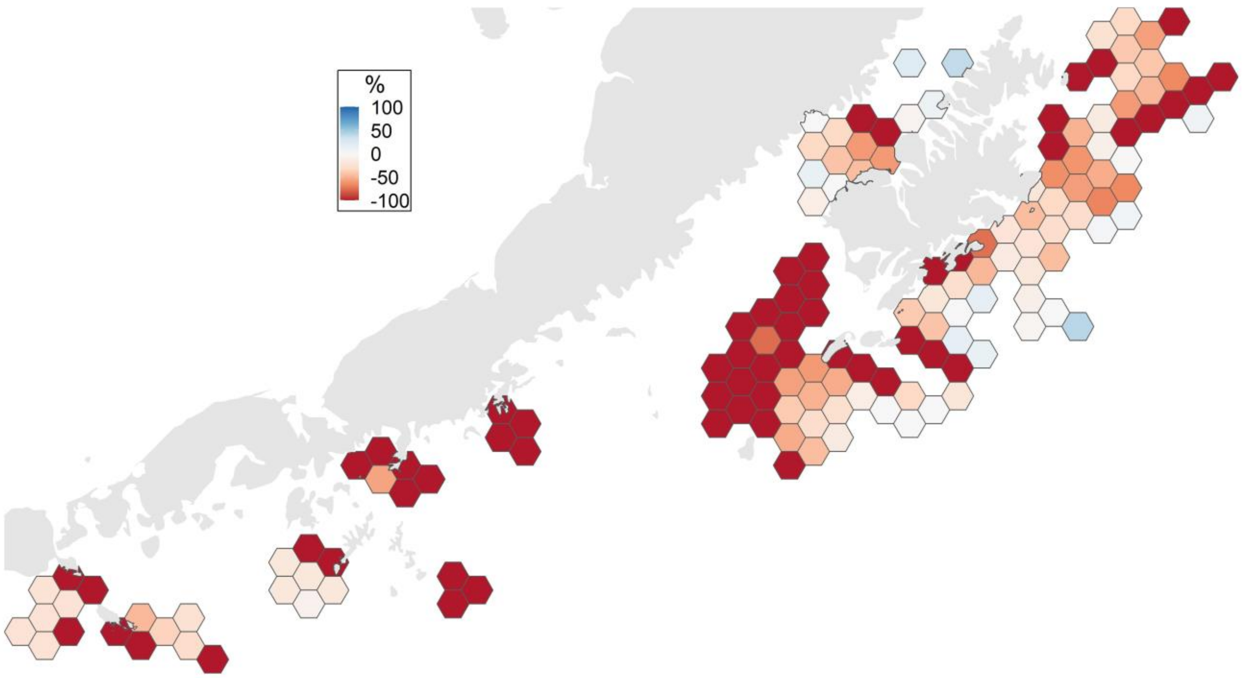
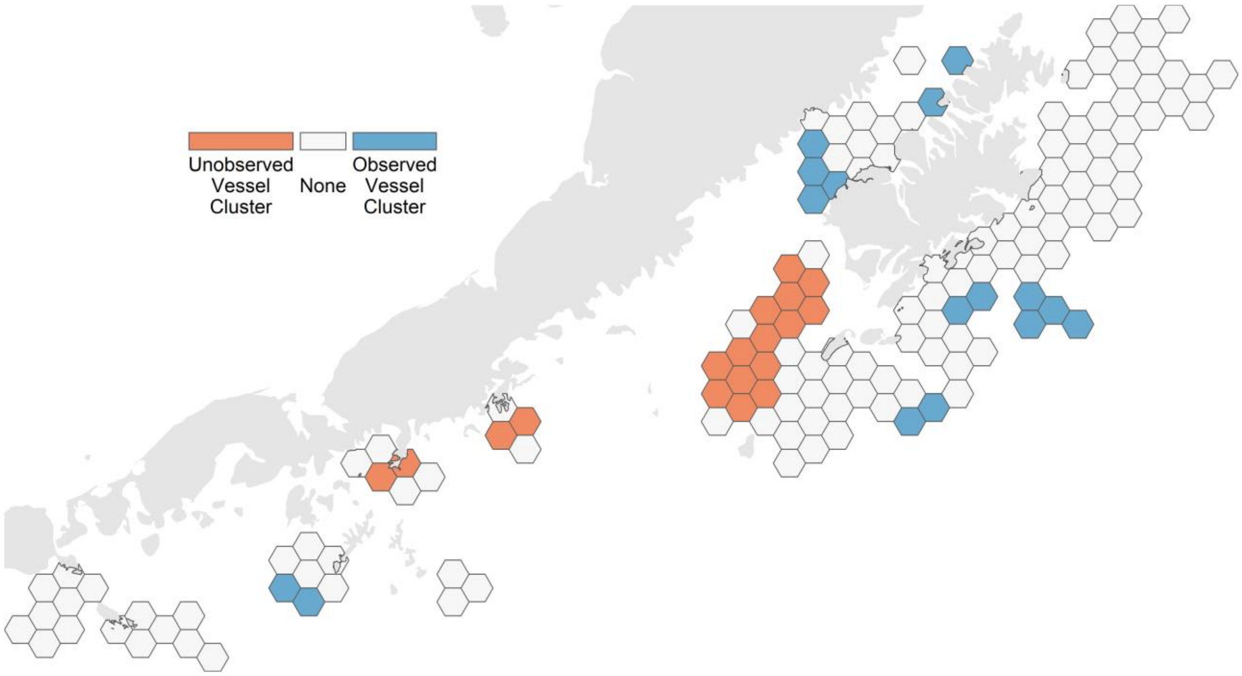


Figure 6: Unobserved and Observed Clusters



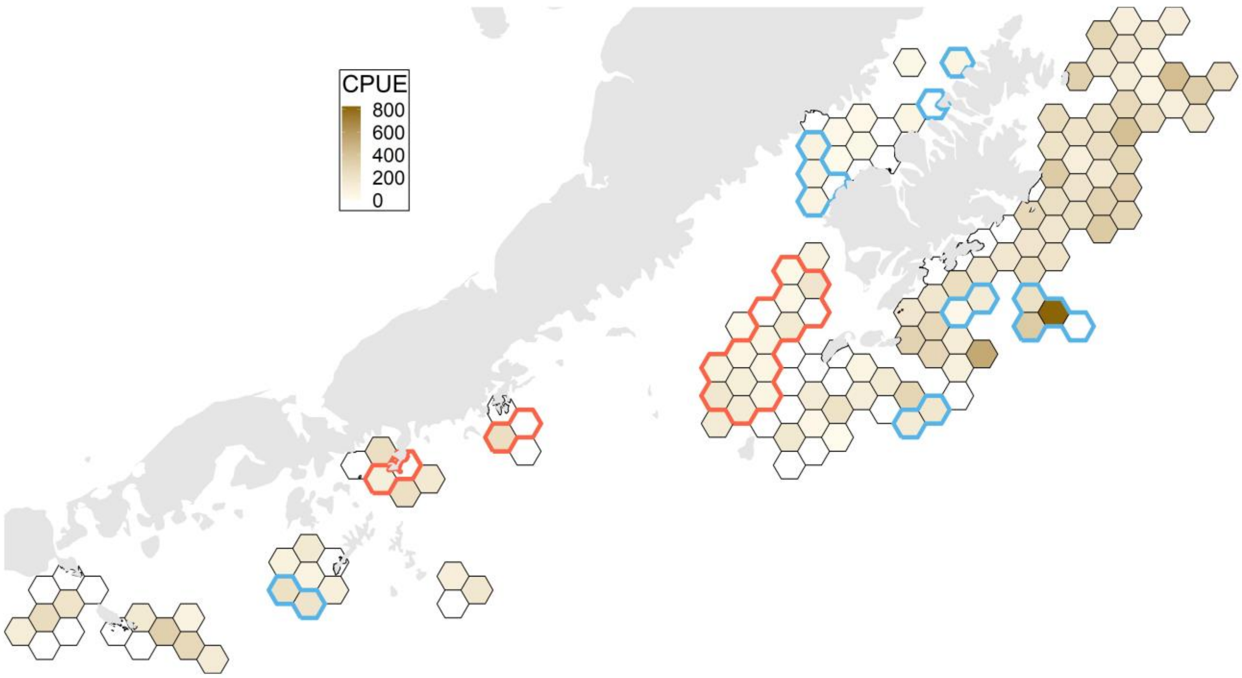
For 2016, the Hot Spot Analysis identified a large unobserved cluster to the southwest of Kodiak Island, with smaller clusters east of King Cove. Observed clusters were identified to the south of Kodiak Island, and relatively close to shore on the north side of Kodiak Island. 2016 was an outlier in terms of cluster identification for the years analyzed (see Appendix IV for the raw inputs and results of the hotspot analysis). Although the Getis-Ord analysis did a poor job of identifying areas with more unobserved vessels, it did identify the areas with relatively more observed vessels as clusters. In most years, the observed clusters occur to the south of Kodiak at varying distances from shore (see Appendix IV Figure 2 for cluster locations by year, and Figure 4 for a discussion of Rockfish catch). 2016 is an exception here as well, with the few observed clusters identified occurring to the north and south of Kodiak. The main reason that less observed clusters were identified in 2016 is that coverage appears to be more evenly distributed throughout the waters immediately south of Kodiak Island (see the lack of extreme reds and blues south of Kodiak Island in Figure 5).

Ultimately, the results of the Getis-Ord analysis showed that there are differences in the fishing locations of observed and unobserved vessels. What is not clear from the analysis, is a reason why. The hypothesized reason at the start of the project was that halibut abundance drives fishing location selection when a vessel is observed or unobserved. Under this hypothesis, observed vessels would choose to fish in areas with relatively lower halibut abundance and unobserved vessels would fish in areas with relatively higher halibut abundance. If this relationship occurs in reality, halibut PSC could be underestimated. The bycatch rate from observed vessels applied to an unobserved vessel's total landings could be lower than the actual rate of bycatch. Next, we explore evidence for this hypothesis using the IPHC setline survey CPUE data.

3. Survey CPUE in Observed and Unobserved Clusters

Once clusters of observed and unobserved areas were identified, the above assumption about fishing location selection could be tested using the IPHC Survey CPUE information. First, the survey stations that fell within observed and unobserved clusters needed to be identified. Figure 7 shows the IPHC Survey aggregated to the VOE-CIA grid and averaged when there were multiple stations in a grid cell. The unobserved clusters are outlined in red and the observed clusters are outlined in blue. To account for the lack of unobserved clusters identified in 2013-15, areas that had exclusively unobserved fishing activity were added to the identified unobserved clusters and included as a third group to compare with observed clusters.

Figure 7: IPHC Survey CPUE Data with Observed and Unobserved Clusters



After the survey stations were grouped into these three categories, a permutation test could be conducted to test the difference between mean CPUE in: (1) observed clusters and unobserved clusters; and (2) observed clusters and unobserved clusters plus areas with exclusively unobserved fishing activity. For reference, Figure 8 shows violins and boxplots for the three categories in 2016. The width of the violin plot correlates to the number of survey stations at different CPUEs within each category. The box plot shows the 25th percentile, median, and 75th percentile. The median is represented by the black line within the boxplot. The key take-away from this plot is the similarity of Survey CPUE percentiles and distributions in clusters of observed and unobserved areas (excluding one high CPUE outlier in the observed clusters).

Figure 8: 2016 Violin and Boxplot for Survey CPUE in Clusters

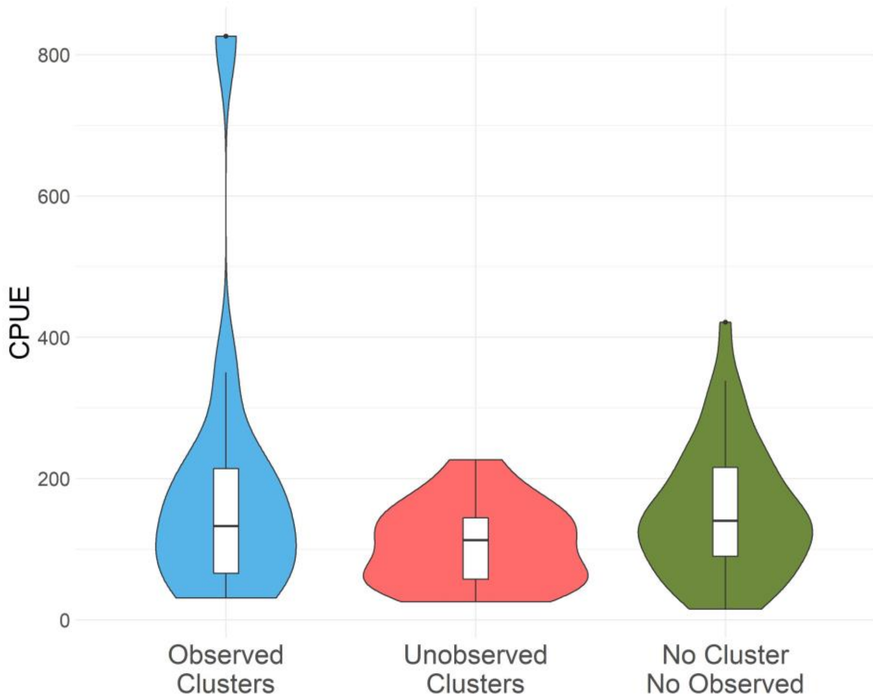


Table 5 contains the results of the permutation tests. P-value 1 is for the CPUE mean in observed clusters compare to the CPUE mean for unobserved clusters. P-value 2 is for the CPUE mean in observed clusters compared to the CPUE mean for unobserved clusters plus non-clusters that had unobserved fishing activity but no observed fishing activity. Regardless of comparison, the difference in means was not significant in three out of the four years tested. Only in 2015 was the difference in means statistically significant, and that result went against expectations. Instead of observed areas having a lower mean CPUE as expected, they have a higher mean than both unobserved clusters on their own and unobserved clusters combined with areas that only had unobserved fishing activity. The results of the permutation tests lead to the conclusion that the potential observer effect identified in the second research questions are not driven by halibut abundance.

Table 5: Distinct Vessel Clusters & Survey CPUE Permutation Test Results

Year	Observed Cluster Survey CPUE Mean	Unobserved Cluster Survey CPUE Mean	No Cluster, Zero Observed	p-value 1	p-value 2
2013	194	149	146	.34	.07
2014	196	176	169	.9	.32
2015	207	73	119	.01	.006
2016	193	107	151	.14	.36

G. Discussion & Issues

We find evidence that: (1) halibut abundance varies within NMFS reporting areas; (2) there may be an observer effect in the GOA bottom trawl partial coverage fleet based on fishing location; (3) that observer effect is not due to measures of Pacific halibut abundance taken during the IPHC surveys. However, there are several issues and complicating factors with this analysis that would need to be addressed before definitive conclusions about the observer effect and Pacific halibut in the GOA could be made.

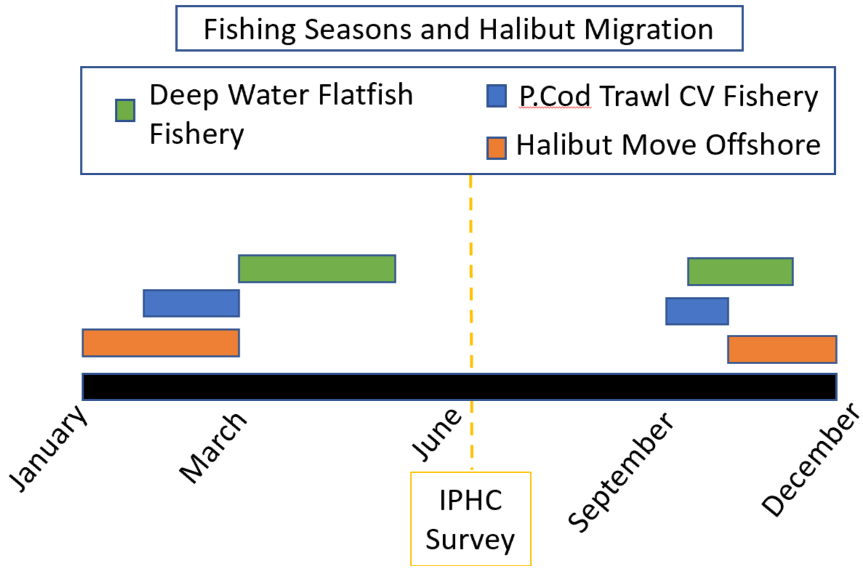
The first and biggest problem with the analysis, specifically with cluster identification, is the presence of Rockfish program vessels in the data. If these were filtered out before data is released, findings like the ones above would be more reliable. While removing areas with more than 50% of observed catch brought the VOE-CIA data closer to the actual totals for CVs in the partial coverage category, it is impossible to know whether the areas removed consisted solely of Rockfish vessels, and that there are not Rockfish vessels in the remaining data.

A second problem related to both cluster identification and connecting halibut abundance to trawling location is the lack of trip-level data. A similar analysis looking at trips instead of distinct vessels would be more indicative of vessel behavior. Several relevant factors are omitted when data is aggregated beyond the trip level. Repeat trips are lost when the distinct vessel count is used to compare observed and unobserved fishing activity, which could alter the results of the hotspot analysis. Temporal elements are also lost, with the year fishing activity occurred being the most specific in the aggregated data. Given that the CAS matches observed and unobserved trips within a five-week window, the timing of fishing trips could be important for a more thorough comparison of observed and unobserved fishing activity.

A third issue, again related to cluster identification, is that any information on primary target-species is unavailable due to data aggregation and confidentiality rules. This is an important consideration because the CAS matches unobserved and observed fishing activity based on target-species in addition to time. Examining individual fishing fleets would be preferable because the halibut PSC limit may be constraining to varying degrees across target fleets within the partial coverage CV category, resulting in varying incentives to avoid halibut when observed. In theory, the less constraining a limit is on a fleet, the lower the incentive will be to avoid areas of high halibut abundance when observed. Additionally, the different target species fleets may simply fish in different areas, meaning they should not be grouped together for an analysis like this to begin with.

A final issue in this analysis related to connecting halibut abundance to vessel clusters is that the abundance data is gathered at a different time than groundfish bottom trawling occurs. The Pacific halibut survey is conducted in the summer (IPHC, 2019), whereas all bottom trawl fishing is conducted in the winter (NOAA, 2019j). Figure 9 is a timeline showing when the annual survey occurs in comparison to bottom trawl fishing.

Figure 9: GOA Fishing Seasons and Halibut Migrations



Seasonality would not be an issue if Pacific halibut were believed to be relatively stationary. Unfortunately, the scientific literature is clear that halibut move throughout their lives and seasonally. Throughout their lives, there is believed to be an east to west migration of halibut along the continental shelf (Loher, 2008). More importantly for this analysis, the IPHC tracked Pacific halibut moving to deep waters (deeper than 200m) off the continental shelf to spawn in the fall (Loher, 2008 & Loher, 2011). Halibut then remain in these waters until the spring, when they migrate back to shallower waters (less than 200m), where they stay until the next fall. When abundance data is collected, halibut are believed to be in shallower waters for the summer. When bottom trawl fishing occurs, on the other hand, Pacific halibut are moving, or already moved, to deeper waters. The exact amount of Pacific halibut that migrate each year is unclear, so the effect of migration on bottom trawl bycatch encounters is unclear (Loher, 2008). More detailed spatial information on halibut abundance would be necessary before a definitive conclusion could be reached that halibut abundance does not drive the observer effect. Any potential halibut abundance-based incentives on fishing location choice would likely change throughout the trawling season as halibut migrate.

H. Conclusion

Based on this analysis, we find evidence of differences in fishing location choices for observed vessels. Each year from 2013-2016 had clusters of observed and unobserved fishing activity, meaning that fishing locations differ when vessels are observed and there is potential evidence of an observer effect. The observer effect does not appear to be related to Pacific halibut abundance measured in the IPHC summer survey. We expected that observed vessels would fish in areas of relatively low halibut abundance when observed, but the CPUE in areas with relatively more observed fishing activity had similar (or higher) CPUE as areas with relatively more unobserved fishing activities. The analysis can be refined with the exclusion of Rockfish trips from the aggregated VOE-CIA data or an analysis of the confidential trip-level data.

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Appendix I: Tables

Table 6: Spatial Component in Trip Selection

Region	**Fishery**	**Spatial Component to Observer Deployment?**
Alaska*	Partial Coverage Trawl	Yes
	Partial Coverage Fixed Gear	Yes
Northwest	Groundfish CS LE	Yes
	Groundfish CS OA	Yes
Southwest	CA Drift Gillnet	Yes
	Deep Set Buoy	Yes
	CA Set Gillnet	Yes
Greater Atlantic	All Fisheries (via sea-day schedule)	Yes
Southeast	Shark Drift Net	No
	Shark Teloset Sink	No
	Shark Bottom Longline	No
	Pelagic Longline	Yes
	Reef	Yes
	Shrimp Otter Trawl	Yes
Pacific Islands	HI Longline Tuna	No
	AS Longline	No

Table 7: Achieved Coverage Rates

Region	Fishery	FY 17*	FY 13**	FY 12	FY 11	FY 10
Alaska	Partial Coverage Trawl (trips)	19-21%	14% TS***	30% vessels 60-124 ft	30% vessels 60-124 ft	30% vessels 60-124 ft
	Partial Coverage Fixed Gear (trips)	5-12%	10% VS			
West Coast – Northwest[2]	Groundfish CS LE (hauls)	15-30%	15-20%	15-20%	15-25%	15-25%
	Groundfish CS OA (hauls)	1-8%	1-8%	1-8%	2-8%	3-8%
West Coast – Southwest[3]	CA Drift Gillnet (sets)	18.6%	19%	TBD	16%	14%
	Deep Set Buoy (24-hour day)	40%	NA	NA	NA	NA
	CA Set Gillnet (sets)	10-20%	3%	TBD	TBD	TBD
Southeast	Shark Drift Net (trips)[4]	38%	38%	38%	38%	38%
	Shark Teloset Sink (trips)[4]	5%	5%	5%	5%	5%
	Shark Bottom Longline (trips)[4]	4-6%	4-6%	4-6%	4-6%	4-6%
	Pelagic Longline (sets)[5]	~13%	~10%	~10%	~10%	~10%
	Reef (24-hr day)[6]	2-6%	2%	2%	~6%	3%
	Shrimp Otter Trawl (24-hr day)[6]	2%	2%	2%	2%	2%
Pacific Islands	HI Longline Tuna (trips)[7]	20%	20%	20%	20%	20%

	AS Longline (trips)[7]	20%	20%	20%	20%	20%

* Reports and data for FY 2014 – 2016 have not yet been completed (Benaka, 2020)

**Note that not all target rates denoted as achieved (as indicated in green) match with target coverage rates. This is because coverage rate goals/metrics for determining coverage rate have changed over this time in some fisheries. If the percentage is denoted in green, that indicates the target as it was in that year was met.

*** For FY 13, coverage goals were 15% catcher vessels > 57.5 ft (TS) and 11% catcher vessels 40-57.5 ft (VS). For FY 10-12, coverage goal was 30% vessels 60-124 ft

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Table 8: Achieved Coverage per Species for Greater Atlantic

Bycatch Species	SBRM 2017	SBRM 2016	SBRM 2015
Atlantic Salmon	Met	Met	Met
Bluefish	Met	Met	Met
Fluke, Scup, Black Sea Bass	Met	Met	Met
Atlantic Herring	Met	Met	Met
Large Mesh Groundfish	Met	Met	Not met
Monkfish	Not met	Met	Not met
Red deep sea crab	Not met	Not met	Not met
Sea scallop	Not met	Not met	Not met
Skate complex	Not met	Not met	Met
Small mesh groundfish	Not met	Not met	Met
Spiny dogfish	Not met	Not met	Not met
Squid, mackerel	Met	Not met	Not met
Surfclam, ocean quahog	Met	Met	Met
Tilefish	Met	Met	Met
*Turtles – loggerheads	Met	Met	Met
Turtles – Kemp's ridley, leatherback, loggerheads**	Not met	Not met	Not met

Number of species targets met	8 out of 15	8 out of 15	8 out of 15

*The precision standard estimate was met for loggerheads in the Mid-Atlantic sink gillnet fleets Mid-Atlantic bottom otter trawl and scallop trawl fleets. The precision standard estimate was not met loggerheads in scallop dredge gear, nor for Kemp's ridley or leatherback turtles in sink gillnet gear. Total overall met consideration lumps turtles all together as overall not met.

Table 9: Bycatch Caps and ITS Limits

Region	Fishery	Cap or limit	Consequence	Exceeded?
Alaska[1]	BSAI Groundfish	Cap on Chinook salmon, non-chinook salmon, halibut, herring, and snow (*opilio*), tanner (*bairdi*), and red king crab	Variable	Snow crab cap reached in 2010
	GOA Groundfish	Cap on Chinook salmon and halibut	Variable	No
Northwest[3,4,5]	Groundfish	Cap on eulachon, green sturgeon, humpback whales, leatherback turtles, short-tailed albatross, and salmon	Variable	Salmon in whiting (2005, 2014) and non-whiting (2002, 2003)
Greater Atlantic	Mackerel[6]	Cap on river herring and shad	Fisheries closure	2019
	Longfin Squid[7]	Cap on butterfish mortality	Catch reduction or closure	No
	Atlantic Herring[8,9]	Cap on haddock	Limit to 2,000 lbs of target catch	2013, 2014, 2016
	Atlantic Scallop[10]	Cap on yellowtail and windowpane flounder	Gear restrictions	2006, 2008, 2009
Southeast[4]	Shark Drift Net[11]	ITL on sea turtles, smalltooth sawfish, Atlantic sturgeon, scalloped hammerhead sharks, whitetip sharks, and giant manta rays	Fishery closure	No
	Shark Teloset Sink[11]			No
	Shark Bottom Longline[11]			No
	Pelagic Longline[12,13]			2002

	Reef[14]			No
	Shrimp Otter Trawl[14]			No
Pacific Islands[15]	HI Longline Tuna	ITL on sea turtles	Fishery closure	2006, 2011, 2019

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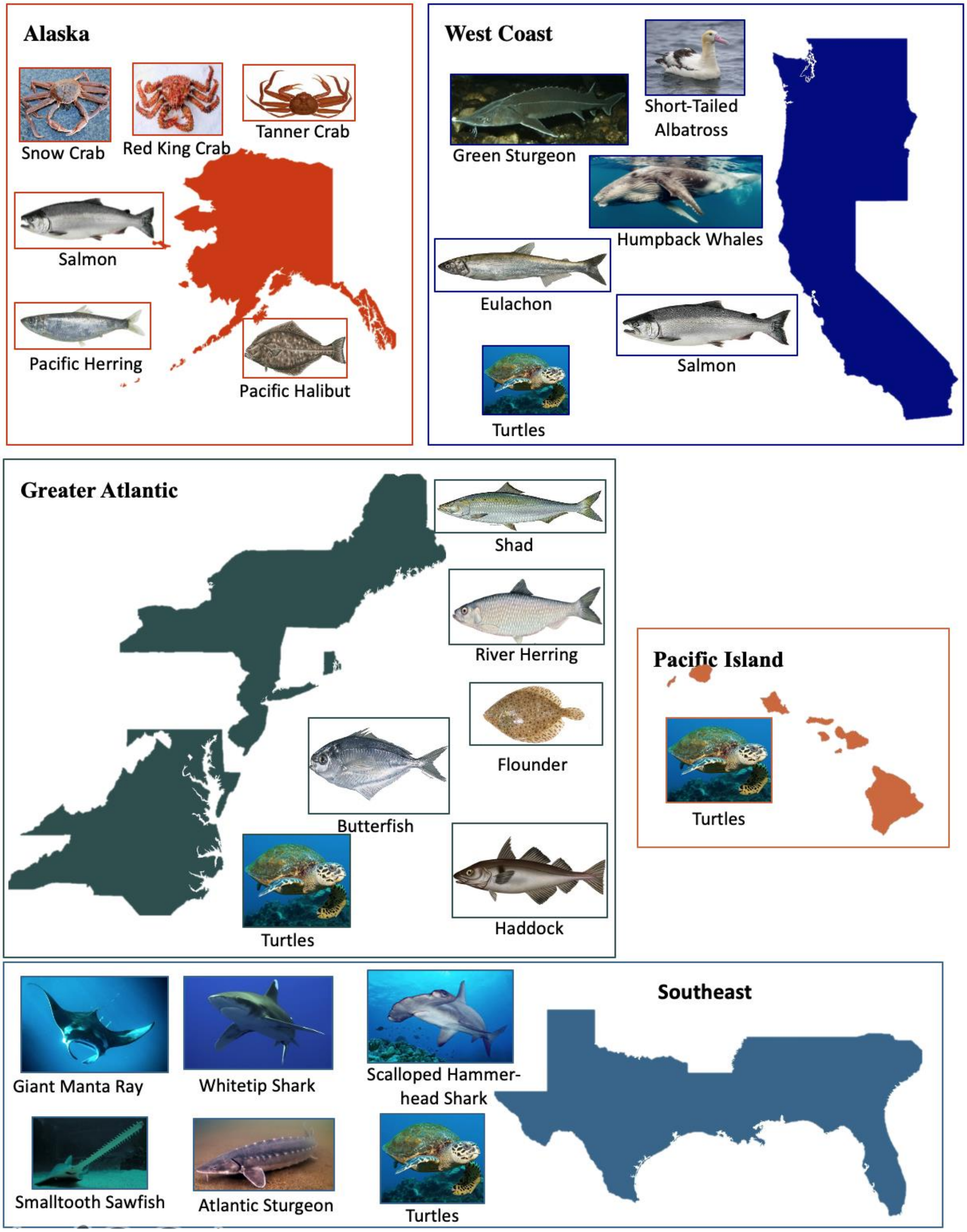
Table 10: Comparison of Observer Program Methodologies in Fisheries with Caps or Limits

Region	Fishery	Authority	Cap or limit reached?	Consequence	Coverage Rate	Spatial component?
Alaska	BSAI Groundfish	MSA	Yes, 1 time	Variable	19-21% (trips)	Yes
	GOA Groundfish	MSA	No	Variable	9-21% (trips)	Yes
Northwest	Groundfish	MSA	Yes, 4 times	Variable	15-30% (hauls)	Yes
Greater Atlantic	Mackerel	MSA/ MMPA	Yes, 1 time (but catch reduction, not closure, implemented)	Fisheries closure	Precision in discards, typically <10% trips	Yes
	Longfin Squid	MSA/ MMPA	No	Catch reduction or closure	Precision in discards, typically <10% trips	Yes
	Atlantic Herring	MSA/ MMPA	Yes, 3 times	Limit to 2,000 lbs of target catch	Precision in discards, typically <10% trips	Yes
	Atlantic Scallop	MSA/ MMPA	Yes, 3 times	Gear restrictions	Precision in discards, typically <10% trips, usually 10-20% trips	Yes

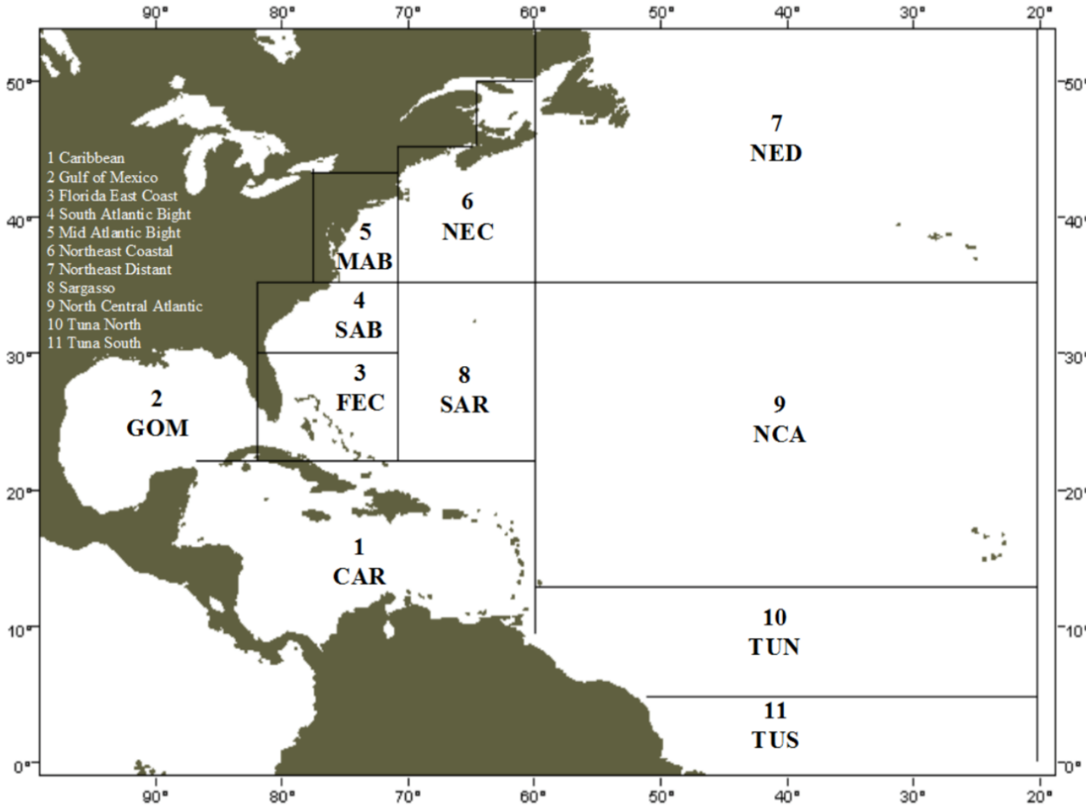
Southeast	Shark Drift Net	MMPA	No	Fishery closure	20% (trips)	No
	Shark Teloset Sink	MMPA	No	Fishery closure	20% (trips)	No
	Shark Bottom Longline	MMPA	No	Fishery closure	20% (trips)	No
	Pelagic Longline	MSA	Yes, 1 time	Fishery closure	~13% (sets)	Yes
	Reef	MSA	No	Fishery closure	2-6% (24-hour day)	Yes
	Shrimp Otter Trawl	MSA	No	Fishery closure	2% (24-hour day)	Yes
Pacific Islands	HI Longline Tuna	MSA	Yes, 3 times	Fishery closure	20% (trips)	No

Appendix II: Bycatch Species per Region

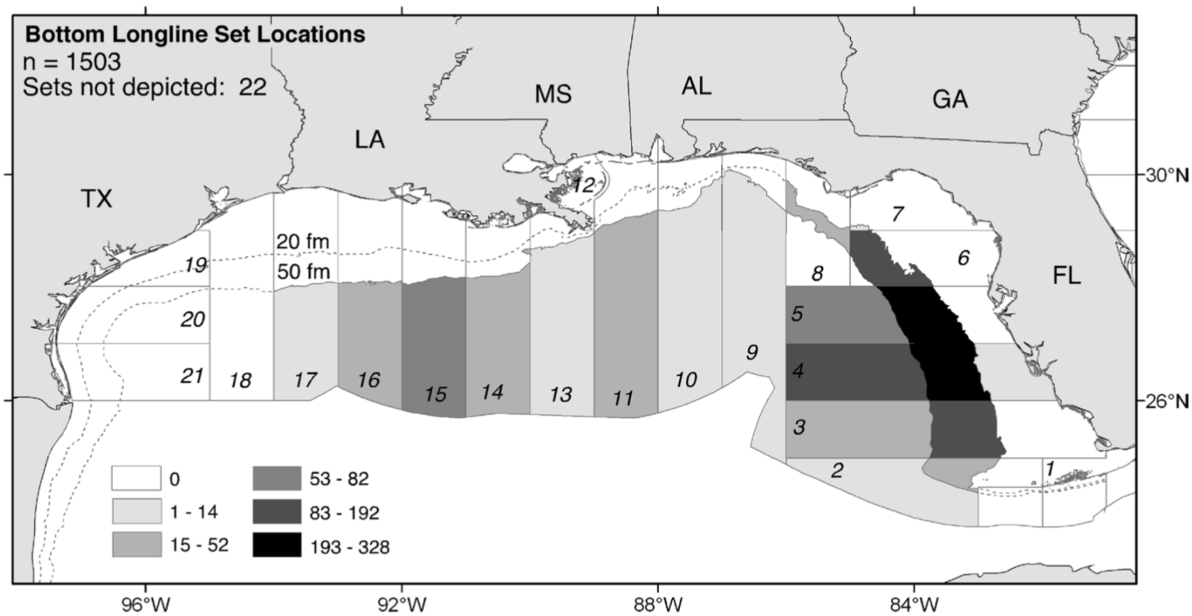


Appendix III: Spatial Scale for Observer Deployment

Southeast pelagic longline fishing areas *(Keene, 2016)*



Southeast reef fish fishery regions *(Scott-Denton & Williams, 2013)*



Southeast shrimp fishery regions *(Patella, 1975)*

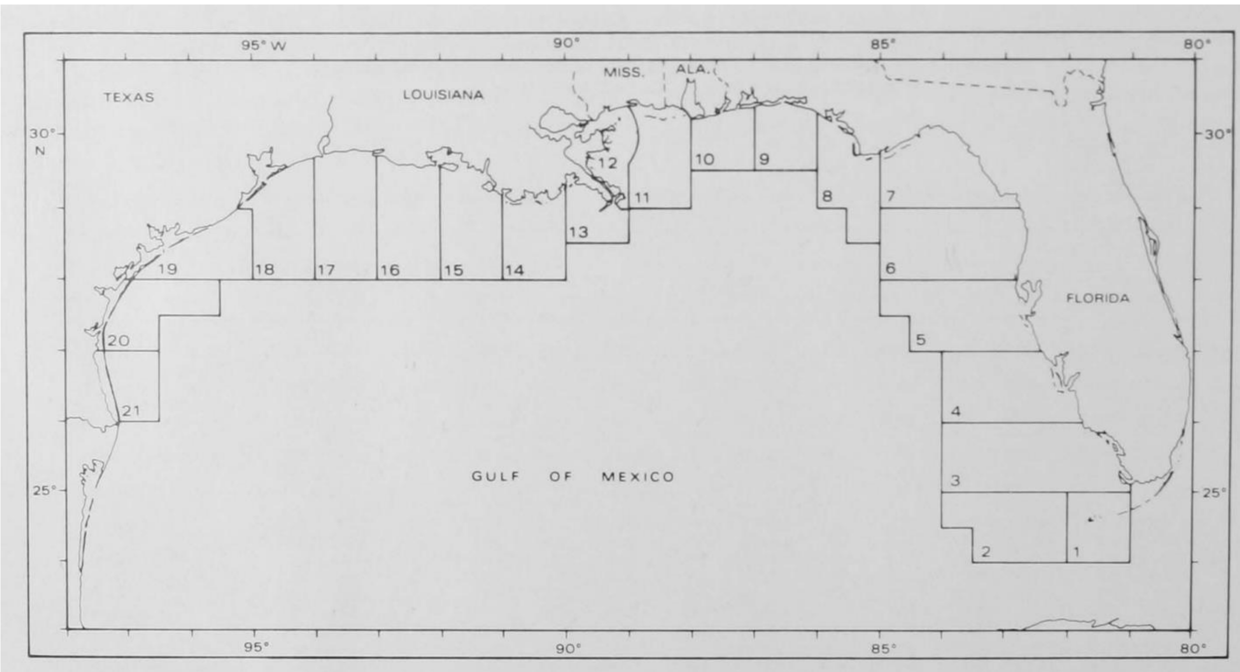


Figure 1.—Statistical subareas used in reporting Gulf Coast Shrimp Data (after Kutkuhn, 1962).

Appendix IV: Observed and Unobserved Fishing Location Plots 2013-2016

Figure 1

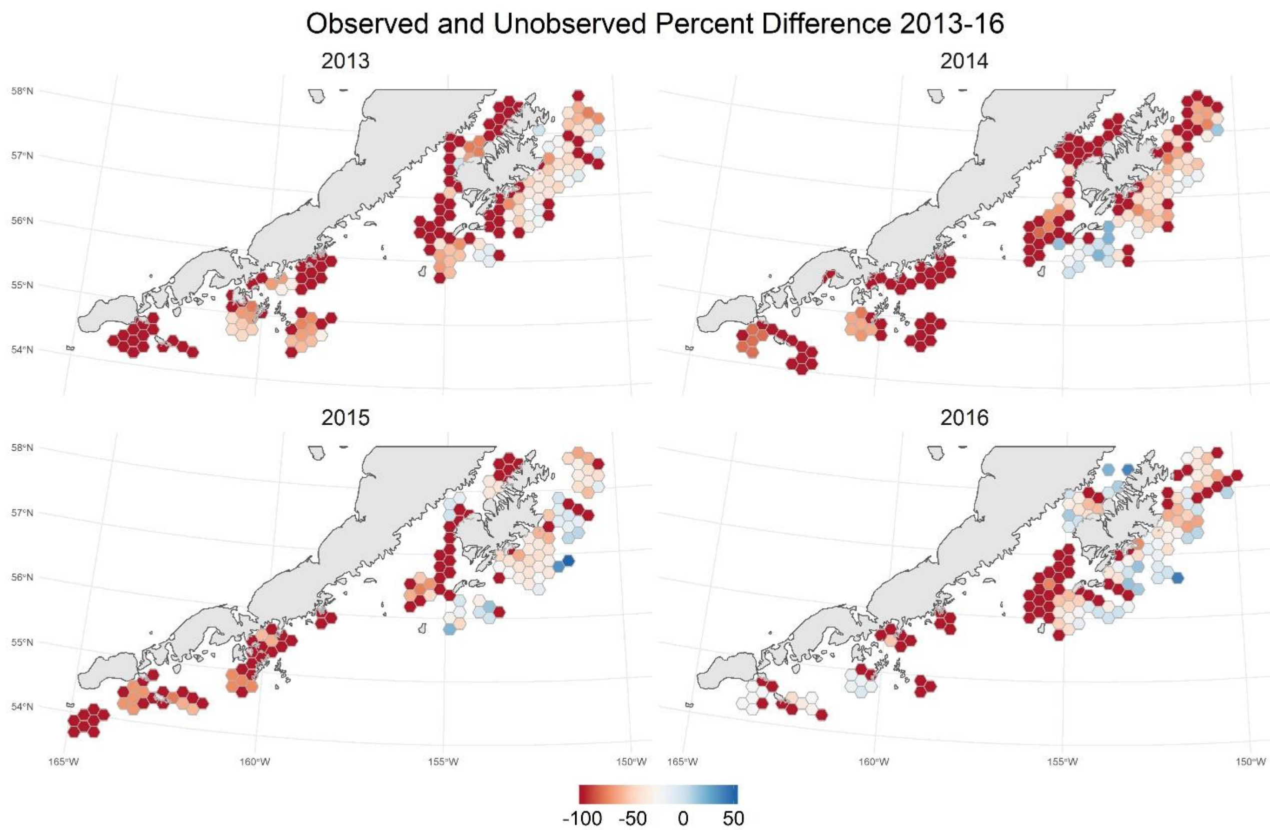
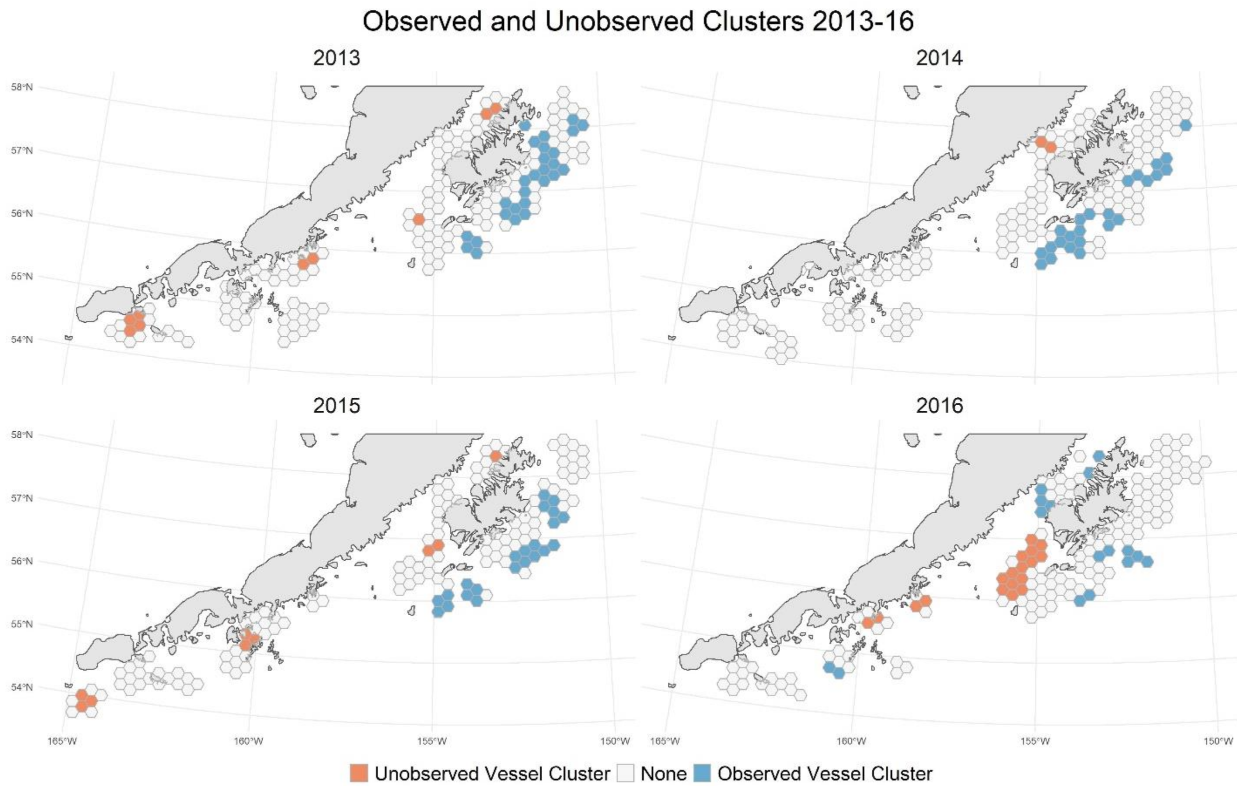
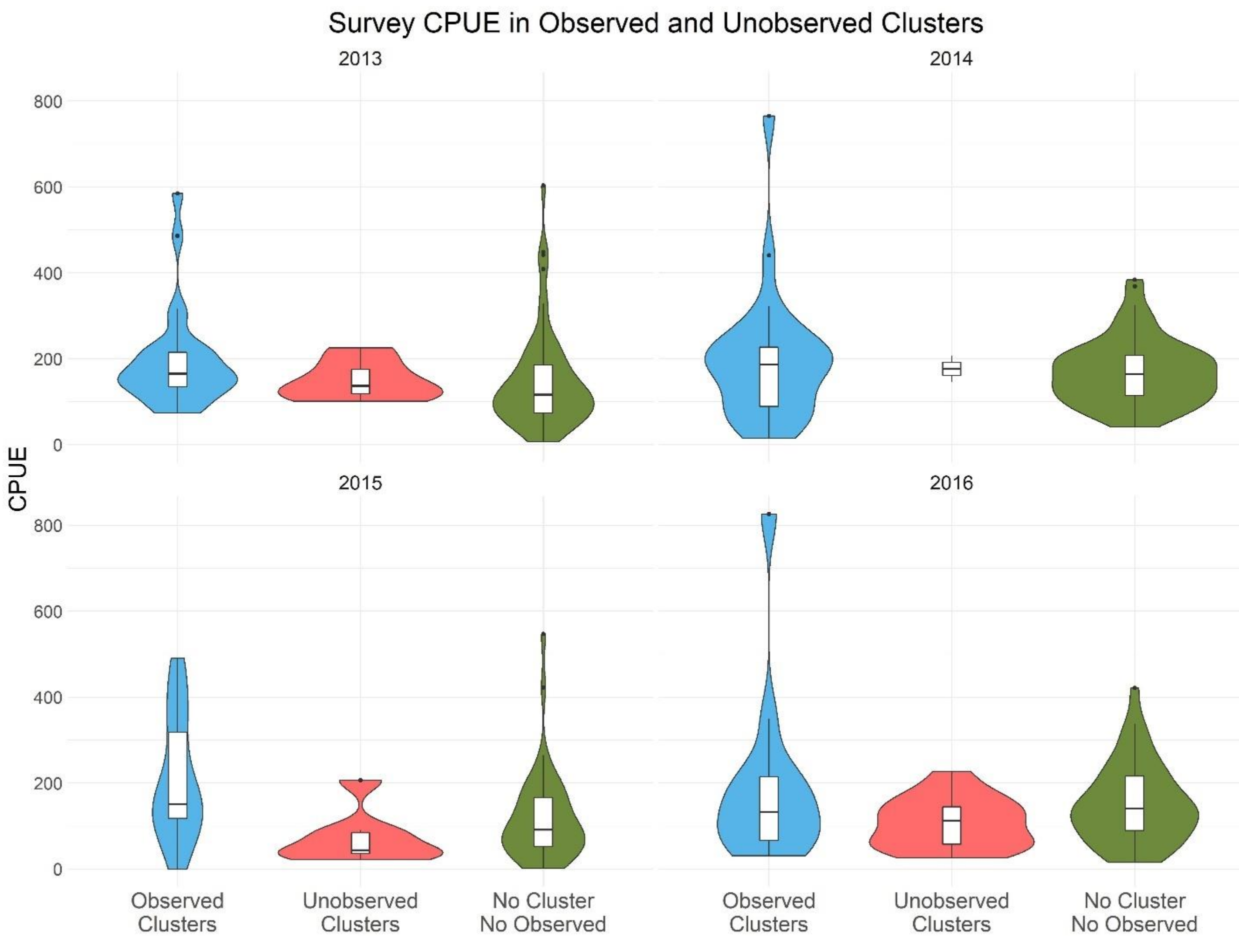


Figure 2



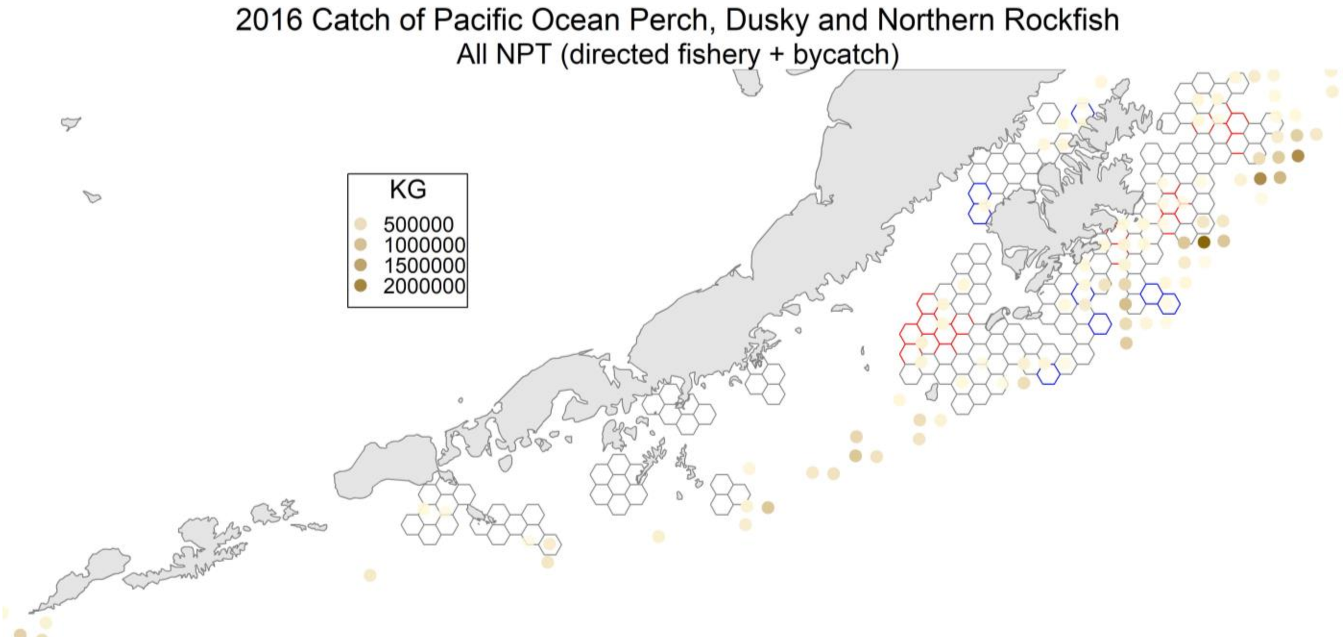
In 2013-2015, few unobserved clusters were identified. This is because there were many areas with only unobserved vessels, which translates to a -100% difference in vessel counts. If there are many areas with this extreme a percent difference, the overall mean of the data will be drawn down. Because the Getis-Ord Gi* Hot Spot Analysis compares neighbors to the mean, most of the areas with only unobserved areas will not show as clusters because they are not extreme compared to the mean. Only the areas most surrounded by other areas with 100% difference will be identified as clusters, despite the presence of many of these areas in the raw percent difference maps.

Figure 3



Survey CPUE in Observed and Unobserved Clusters
2013
2014
2015
2016
CPUE
800
600
400
200
0
Observed Clusters
Unobserved Clusters
No Cluster No Observed

Figure 4



This map shows observed rockfish catch for the directed fishery and bycatch sources, compared to the areas remaining after the data treatment removing all areas with greater than 50% of catch observed for 2016. One problem with this data is that it is not for the CGOA Rockfish program vessels, exclusively. This catch data includes partial coverage CVs, CPs, and Rockfish vessels. However, it appears that removing areas with greater than 50% of catch observed may have removed CPs and Rockfish CVs, assuming that areas of high rockfish catch are where rockfish vessels fish. Pacific Ocean Perch, Dusky and Northern Rockfish were chosen as the species to use in this map because they are the three most frequently caught species in the Rockfish program (NPFMC, 2019)[13]. There appears to be a relatively small amount of Rockfish catch in areas left in the data, making it possible that vessels left in the VOE-CIA data do not affect the analysis if this catch is bycatch from partial CVs and CPs, with the latter already removed from the data. Additionally, there is a possibility that Rockfish vessels may not affect the analysis, if Rockfish vessels and partial coverage vessels fish in the same areas. Most vessels participating in the Rockfish program also operate in the partial coverage CV fishery. If they do in fact fish in the same areas as Rockfish vessels, they would only be counted as distinct vessels once.

NPFMC (2019) Initial Review Draft: Environmental Assessment/Regulatory Impact Review for a Proposed Fishery Management Plan for the Gulf of Alaska: Central Gulf of Alaska Rockfish Program Reauthorization. North Pacific Fishery Management Council, 2019. Available at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=53c0e648-7182-4a82-960d-

[13] This data is from the publicly available observer data, available at: https://archive.fisheries.noaa.gov/afsc/maps/fma/datamap/obsmap.html

0a97777af701.pdf&fileName=C7%20Rockfish%20Reauthorization%20-%20Initial%20Review%20Analysis.pdf