

GEOSPATIAL ANALYSIS OF FISHERIES TO IMPROVE FEDERAL ENFORCEMENT

by

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Abstract

Fisheries are an important economic engine for the United States. Laws, regulations, and international agreements keep this engine running sustainably. Compliance with these laws is vital to their success and the sustainability of the country's living marine resources. The U.S. Coast Guard is the nation's primary at-sea enforcement authority for living marine resources laws and regulations. The Coast Guard is challenged with effectively and efficiently employing its limited resources to achieve the highest possible level of compliance with U.S. and international fisheries laws. Geospatial analysis provides the Coast Guard with a low cost way of analyzing fisheries and current enforcement strategies to correct shortfalls, recognize enforcement gaps, and effectively plan future operations. Through the use of spatial analysis, the Coast Guard can match enforcement with temporal, spatial, and sector-based patterns in fishing effort to achieve more comprehensive and effective compliance with federal fisheries regulations. This study demonstrates possible methods of improving enforcement in two fisheries: Atlantic Highly Migratory Species and Gulf of Alaska Sablefish. I compare historical enforcement strategies with fishing effort information to evaluate spatial and temporal alignment. I also make recommendations for improving enforcement in these fisheries. I then discuss the development of a spatial analysis tool for the Alaskan multi-species groundfish fishery to show some possible solutions to improving enforcement in these fisheries. Finally, I make overall recommendations for improving the effectiveness and efficiency of the Coast Guard's enforcement of federally permitted fisheries.

Introduction

The value of U.S. Fisheries

The U.S. has the largest Exclusive Economic Zone (EEZ) in the world, encompassing approximately 3.36 million square miles of ocean surface (USCG 2004). This resource provides the U.S. with a rich, long-term potential source of revenue from sustainable fisheries. In 2011, U.S. commercial landings at domestic ports were valued at over \$5.6 billion (NMFS 2012). The U.S. Department of Labor estimates that there were 32,000 fishers and related fishing worker jobs in the United States in 2010 (BLS 2012). Related industries such as boat building, fisheries scientists and managers, and tourism workers are also dependent upon healthy and sustainable fisheries to provide an economically viable source of income. Fisheries are also a major source of healthy, low fat protein for worldwide consumption and are a major factor in both domestic and international food security. In 2011, Americans consumed 15.0 pounds of commercial fish and shellfish per capita (NMFS 2012). Maintaining healthy and sustainable fisheries is in the best interest of the United States.

Regulations and Compliance

Domestic and international fisheries are subject to regulations and agreements that control factors such as fishing effort, total allowable catch, bycatch reduction measures, and time and location of fishing. Managers employ these regulations to encourage long-term sustainability within the fishery. Domestically, these regulations are prescribed by the Regional Fishery Management Councils (RFMCs) under the National Marine Fisheries Service (NMFS). These organizations have been authorized to manage fisheries in accordance with the ten national standards in the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) (MSFCMA 2007).

Compliance with established regulations is necessary to sustain federally regulated fisheries for long-term use. Without high levels of compliance, any management plan may fail (Randall 2004). Fishery Management Councils rely on the assumption that federally permitted fishers comply with regulations when designing and implementing regulations (Randall 2004). The effectiveness of enforcement on achieving compliance directly impacts the success of fishery

management plans. Driven by individual profits, however, not all fishers will comply with regulations. The incentive to gain an advantage over competitors is tempting in the fishing business, where profits margin are sometimes very low. Therefore, gaining a high level of compliance with these regulations is a key to the success of the fishery. “Enforcement of domestic regulations and international agreements is necessary to achieve U.S. goals and objectives for living marine resource conservation” (USCG 2004).

There are three main factors to gaining compliance for any rule or regulation. They include the reducing the incentive to cheat, increasing the perceived likelihood of getting caught, and increasing the penalty for getting caught (Randall 2004). Nøstbakken (2008) states that “The probability of conviction, or rather, the combined probability of an offence being discovered and the offender being apprehended and convicted, is determined by the level of enforcement (the expenditure on police, courts, etc.). The number of offences is assumed to decrease as both the level of punishment and the probability of prosecution and conviction increases.” Enforcement of fisheries has been cited as the number one challenge to managing any fishery (Sutinen 1988). Enforcement costs for many highly migratory species fisheries have been estimated as being up to 50% of the total economic rents likely to be produced by the fishery (Sutinen 1988). This cost is staggering and vastly decreases the economic efficiency of the use of these resources (Sutinen and Andersen 1985). The U.S. Coast Guard’s role in this paradigm is to encourage compliance through enforcement in the manner of increasing the perceived likelihood of violators being caught.

Agency Responsibilities

The U.S government agency “responsible for the management, conservation and protection of living marine resources within the United States' Exclusive Economic Zone” is the NMFS, part of the National Oceanic and Atmospheric Administration (NOAA) (NOAA Fisheries 2012). NMFS works to promote sustainable fisheries and to prevent lost economic potential associated with overfishing, declining species, and degraded habitats (NOAA Fisheries 2012). Both NOAA’s Office of Law Enforcement (NOAA OLE) and the U.S. Coast Guard (USCG) are mandated with enforcing fisheries regulations pertaining to U.S. federal waters and the high seas.

The statutory basis for Coast Guard law enforcement authority is contained in 14 USC 2 which states "The Coast Guard shall enforce or assist in the enforcement of all applicable federal laws on, under, and over the high seas and waters subject to the jurisdiction of the United States" (USCG 2004). "14 USC 89 provides active duty Coast Guard petty officers, warrant officers and commissioned officers authority to board, search, detain, arrest, and/or seize in appropriate circumstances" (USCG 2004).

The primary statutory basis for Coast Guard fisheries enforcement is contained in Section 311 of the MSFCMA and its subsequent amendments and re-authorizations (MSFCMA 2007). The MSFCMA tasks "the Secretary (of Commerce) and the Secretary of the department in which the Coast Guard is operating" with enforcement responsibility for federal living marine resource laws (MSFCMA 2007). It also states that the Secretaries "...by agreement, on a reimbursable basis or otherwise, utilize the personnel, services, equipment (including aircraft and vessels), and facilities of any other Federal agency, including all elements of the Department of Defense, and of any State agency, in the performance of such duties" (MSFCMA 2007).

The Coast Guard is the primary at-sea enforcement authority because it is the "only (federal) agency with the infrastructure and authority to project a law enforcement presence throughout" U.S. waters "and in key areas of the high seas" (Randall 2004, USCG 2004). Within the Coast Guard, the Office of Living Marine Resources (LMR) Enforcement is the office tasked with enforcing fishery regulations. On an average day in 2010, the Coast Guard conducted over 100 law enforcement boardings and conducted 20 commercial fishery vessel inspections (USCG 2011). In 2010 Coast Guard had approximately 195 aircraft, 247 cutters, 1784 boats, and 42,000 active duty personnel (USCG 2011). Nationwide, NOAA OLE consists of 149 special agents, 15 uniformed enforcement officers, and 71 support staff (USCG/NOAA 2008). The four primary missions of NOAA OLE are to conduct investigations and patrols, constituent outreach, support technology and vessel management systems partnerships, and strengthen partnerships with other federal, state, local, and tribal law enforcement agencies along with industry partners and NGOs (USCG/NOAA 2008).

The U.S. Department of State is the chief party negotiating international agreements related to international fisheries on behalf of the United States (USCG 2004). There are many fisheries that straddle the boundaries of the U.S. EEZ, and more that U.S. fishers target in international waters. The U.S. Coast Guard, NOAA, and NMFS work with the Department of State in order to advise on the formation of agreements and are also tasked with enforcing those agreements (USCG 2004).

Coast Guard Living Marine Resources Enforcement

The mission of the Coast Guard's Living Marine Resources enforcement program is to "provide effective and professional at-sea enforcement to advance national goals for the conservation and management of living marine resources and their environment (USCG 2004)." The three main goals of the Coast Guard fisheries enforcement program are 1) "Prevent illegal encroachment of the U.S. Exclusive Economic Zone by foreign fishing vessels", 2) "Effectively enforce federal regulations that provide stewardship of living marine resources and their environments", and 3) "Ensure compliance with international agreements for the management of living marine resources". (USCG 2004) To achieve the mission through these goals, the Coast Guard has adopted four key concepts that will serve as the framework for implementing this strategic plan. These are "sound regulations, effective presence, application of technology, and productive partnerships" (USCG 2004).

In order to achieve effective presence, which is a major deterrent to fisheries violations, the Coast Guard needs to know where fishers are fishing and conduct boarding inspections as well as show presence to deter violations and EEZ incursions. The aim is to conduct fisheries enforcement boardings while fishers are in the act of fishing, hauling in catch, and transiting with both catch and gear onboard (Brosnan 2012). In these situations the Coast Guard can ensure compliance with the full spectrum of fisheries regulations including gear specifications, time-area closures, bycatch handling procedures, and catch limits. Additionally, patrol activity provides "a highly visible deterrent to illegal activity" (Randall 2004). Historically, the Coast Guard has had difficulties locating fishers in the act of fishing (Brosnan 2012). Through the use of geospatial analysis, the Coast Guard can more effectively and efficiently reach this goal by determining when and where fishers actively target their catch.

As the nation's law enforcement arm at sea, the Coast Guard conducts boarding inspections of fishing vessels to examine compliance with federal regulations. This is the act of getting onboard the vessel to inspect the catch, fishing gear, and bycatch reduction practices and determine where the vessel is fishing in relation to protected areas and closed areas. Boarding inspections are how Coast Guard Living LMR Boarding Officers are able to inspect compliance with all applicable federal laws and regulations, including fishery regulations. In the event of finding a violation, the boarding team documents the violation and consults their operational command to determine further actions such as terminating the voyage, issuing summary settlements, and seizing the catch. Upon the finding of a major violation, the Coast Guard will work with NOAA's Office of Law Enforcement to comprehensively document the findings and help build a body of evidence to be used if the case is prosecuted. In such cases, the operator's fishing permit may be revoked and fines may be levied.

Recently, the Coast Guard has measured compliance with fishing regulations by calculating Observed Compliance Rates (OCR) based on the number of violations per number of boardings (USCG LMR 2012). The overall domestic at-sea target for all fisheries is 97 percent compliance (USCG 2004). The Coast Guard communicates these statistics to NOAA OLE in order to advise them on which fisheries or regulations present problems for enforcement or have a low level of compliance. For most domestic fisheries, the Coast Guard observes compliance rates between 95 and 98 percent (USCG 2004). Any fishery with OCR less than 97 percent is considered in need of improvement. However, the OCR statistic is problematic in that it does not accurately show where and how USCG assets are being effective or ineffective with fisheries enforcement (USCG LMR 2012).

In order to address this shortfall and improve compliance across all federally regulated fisheries, the Coast Guard developed a metric for assessing the overall effectiveness of Coast Guard living marine resources boarding inspection efforts at encouraging compliance. This metric is called the Level of Effective Enforcement, or LEE (USCG LMR 2012). LEE sets a target number of boardings based on the number of active federally permitted vessels in a fishery and the economic, social, and at-sea safety impacts of the fishery (USCG LMR 2012). In each of the nine Coast Guard districts, the senior Living Marine Resources Officer establishes the LEE for

all federal fisheries within their area of responsibility. In general, low priority fisheries have a target of 10 percent of the active fishing vessels to be boarded annually (USCG 2004). High priority fisheries have a target of 20 percent (USCG 2004). Performance is evaluated by reaching the target number of boarding inspections and assessing the number of boardings where significant violations were found (USCG LMR 2012). This applies to all domestic federally regulated fisheries and includes different goals for each sector; commercial, recreational, and charter/headboat. In some fisheries it is not clear how many permit holders are active in the charter and recreational sectors of the fishery. This makes it difficult to estimate the number of boarding inspections that need to be conducted for each fishery sector in order to achieve the LEE.

Problem Definition

When the Office of Living Marine Resources Enforcement started measuring performance under the LEE metric, they saw a lack of comprehensive enforcement across all sectors and found it difficult to achieve the target number of boardings for some fisheries. These tended to be fisheries where the fishing fleet is scattered over a large area and highly mobile. In addition, the current budgetary climate within the U.S. government requires achieving the same level of effectiveness with fewer resources. Other missions have also taken priority over fisheries enforcement over the past decade. There was an especially large decline (nearly 50 percent) in the amount of Coast Guard resources dedicated to this mission after the terrorist attacks of September 11, 2001 as mission priorities changed (Randall 2004). Therefore, the Coast Guard is challenged with achieving a high compliance rate through enforcement actions, using limited personnel and financial resources.

Fisheries enforcement is an expensive responsibility. In 2012, the Coast Guard requested \$628.5 million dollars for the Living Marine Resources Enforcement mission in their congressional justification (USCG 2011). Each of the Coast Guard's enforcement platforms, from a 23-foot small boat to a 418-foot National Security Cutter, costs time and money to operate and maintain. Operation costs tend to increase with increasing capability of the platform. Typically, the further offshore a platform is rated to operate, the more expensive it is to use in patrolling the ocean. To

enforce fisheries at the edge of the U.S. EEZ or in international waters, the costs are increasingly high. In addition, planning and providing logistical support for long duration at-sea patrols requires additional manpower and resources. The cost of enforcement is typically not considered in designing regulations, and enforcement agencies rarely receive additional resources as their enforcement requirements increase (Randall 2004).

To prioritize enforcement objectives, District Living Marine Resources Officers inform enforcement personnel on significant changes in the status of fishery regulations, probable locations of high fishing effort and fishing vessel safety issues, and problematic violation patterns. However, the Coast Guard continues to struggle with achieving their enforcement targets because of a lack of information on where fishing effort actually occurs. Finding and boarding vessels in the act of fishing or hauling catch onboard continues to be problematic for enforcement staff since little to no spatial analysis has been conducted for most fisheries. The Coast Guard is considering applying geospatial analysis to these problem fisheries because it is a low cost method to analyze spatial trends in fishing effort, can predict the location of vessels at various temporal and spatial scales, and does not directly intrude on the fishers in any way. The expectation is that finding these spatial trends in fishing vessel locations will help the Coast Guard allocate enforcement assets in a manner appropriate to the circumstances in order to maximize efficiency and effectiveness in achieving compliance. The two fisheries addressed in this study, Atlantic Highly Migratory Species and Gulf of Alaska Sablefish fisheries, have been identified by the Coast Guard as difficult fisheries in which to achieve their set enforcement targets.

Potential Applications of Geospatial Analysis

The U.S. Coast Guard considers geospatial analysis a viable method to improve the efficiency of fisheries enforcement due to its comparatively low cost, high potential for effectiveness, and low level of intrusion on fishers. Fishers have opposed VMS tracking and logbook recording because they assume the data will be used by fishery managers to close off productive areas or that the information will become public and their fishing grounds will be overfished by other fishers (HMSD 2006). The cost of geospatial analysis only requires the Coast Guard to utilize a

Geographical Information System (GIS) software package and train analysts to examine fishery and enforcement data and to provide recommendations to operational commanders for asset tasking. Geospatial modeling has already proven an effective means of analyzing and predicting fish locations and is employed extensively by various fishing industries. Using spatial analysis to locate fishers and identify enforcement gaps will likely have a dramatic improving the spatial and temporal match of enforcement with fishing effort.

There are many options for helping fishery enforcement agencies predict fishing vessel locations or identify popular fishing grounds where enforcement actions can be conducted efficiently. Whatever method is used, appropriate time and spatial scales need to be considered. The LMR officer needs to decide, based on operational planning and asset availability, whether the prediction needs to be made for the next few hours or the next month, for example. He also needs to decide how far in advance the prediction needs to be made, and over what geographical scale. For example, planning a daily patrol of HMS recreational and charter fishing activity by a boarding team on a 25' Coast Guard small boat is far different from tasking a 378' Coast Guard cutter to patrol the U.S.-Russia Maritime Boundary Line for EEZ incursions over a three month period. The latter also requires a much greater lead time in order to plan logistics, port calls, and operational control. By considering the appropriate time and space scales, and lead time needed to plan an operation, managers can solicit the right type of analysis from their analyst (Figure 1).

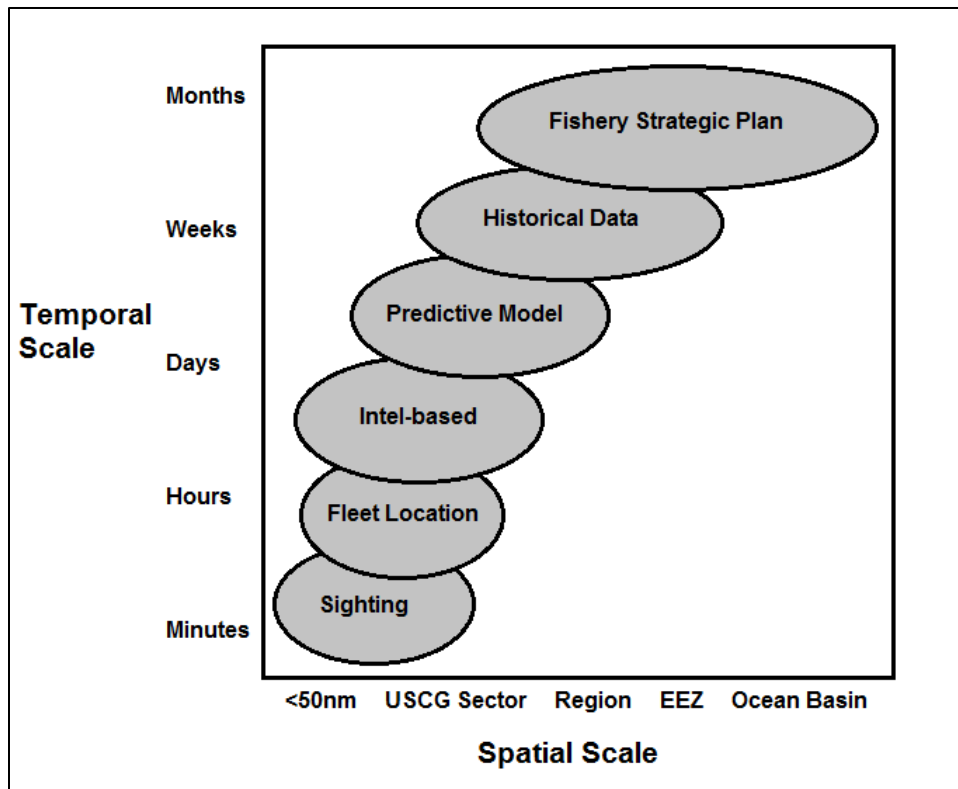


Figure 1: Space-Time model for applying the appropriate enforcement strategy. This study focuses on the larger space and time scales using historical data and recommends future efforts to focus on increasingly smaller scales.

Data Available for Analysis

The Coast Guard records information from boarding inspections in a computer database system called MISLE, which stands for Marine Information for Safety and Law Enforcement (USCG 2004). Each MISLE entry includes a latitude and longitude where the boarding took place. It also has an entry for the federal fishery in which the vessel was involved and its observed activity at the time of the boarding. This MISLE entry information is how the Coast Guard tracks its boarding inspections and compliance, and is able to recognize trends in violations or safety issues. The Coast Guard also uses MISLE entries as official log data which is included as evidence in cases that go to prosecution. Only recently has the Coast Guard begun to utilize the spatial information contained within these entries to recognize trends and mismatches in enforcement.

While MISLE is a powerful source of data, there are many potential sources of error and systemic problems within MISLE that the Coast Guard has identified. A MISLE entry is heavily scrutinized and corrected only in cases where violations are prosecuted (Caldwell 2012). For cases of no violation, many of these errors go unrecognized and are not reviewed for correction. Therefore, a great deal of potentially useful spatial and operational data is lost in MISLE entries whose spatial information is incorrect or absent. Collecting accurate spatial information on where boardings are conducted could help the Coast Guard recognize where their enforcement efforts are concentrated and determine areas where violations are more or less likely to occur. Correcting these entry errors could help the Coast Guard allocate assets to areas of more importance. In addition, some minor and hard to recognize errors in spatial location are prevalent in the database. These errors, if corrected in the future, could help refine the accuracy of much of the spatial analysis. This would improve enforcement efficiency and help locate true gaps in enforcement coverage. Recommendations for correcting some of the more common errors are found in Appendix A.

Data sources that have the potential to help predict fishing vessel locations are numerous. NOAA's Fishery Science Center data is commonly fishery, sector, and region specific and is usually publicly available. Commercially available fish prediction models may also be used as a proxy method for locating fishing vessels. Government meteorological, oceanographic, and bathymetric data can be used to model fish locations based on their ecology and predict the location of vessels targeting them. Each specific fishery requires different types of data to be analyzed. Bottom fisheries may depend more on bathymetry, substrate, bottom rugosity, and seasonality to predict fish, and therefore fisher, locations. Pelagic fisheries that are highly dependent on sea surface temperature, location of fronts oceanic and eddies, distance to the continental shelf break, and chlorophyll concentrations are much more mobile and require more precise and timely prediction methods. For some fisheries, identifying historical fishing grounds on a seasonal time scale, based on past fishing effort and catch data, may be enough to accurately predict future fishing vessel locations. In the absence of explicit information on fishing vessel presence, a proxy for fishing vessel presence may have to be assumed based on catch or effort data.

Previous data on vessel tracks, such as Vessel Monitoring System (VMS) or Automatic Identification System (AIS) data, may also be used to identify areas of high predicted vessel presence. VMS is required for certain fisheries and the vessel's location is broadcast any time it is underway. VMS is available anywhere in the ocean, no matter the distance from land, because it is a satellite-based system. AIS is a ship collision avoidance system with a limited range. The Coast Guard could use AIS to locate specific vessels within a fishing fleet when an enforcement asset has located the fleet. AIS data is also recorded near land by land-based stations. These vessel tracks are stored for planning future vessel traffic patterns. Both VMS and AIS would be good options for making long-term predictions to aid in planning operations around historical vessel densities. Real-time VMS and AIS data could be used to directly pinpoint fishing vessel locations and direct enforcement efforts to the individual fishing vessel.

VMS is currently mandated in two South Atlantic fisheries; the Atlantic Highly Migratory Species (HMS) fishery and the Rock Shrimp fishery (HMSD 2006 and SAFMC 2004). Vessels operating in these fisheries are required to operate and transmit their VMS system any time they are underway. Vessels in these two fisheries are displayed in real-time on the Coast Guard's situational awareness displays and within NOAA's Office of Law Enforcement. For these fisheries, the Coast Guard is able to locate vessels in real time and direct enforcement assets to their locations. The Coast Guard is advocating the use of VMS in additional fisheries where enforcement is difficult due to the inability to find vessels while they are at sea (USCG 2004).

Fisher recorded fishery logbook data is also a potential source of fisher presence data. Logbook data is typically required in fisheries where bycatch is high, and the data is used to design management plans to reduce bycatch. Logbook data has its limitations because it is recorded by fishers rather than scientists or paid observers. Fishers may not be motivated to record accurate observations, and may not capture significant information such as discarded bycatch or correct location. Positional accuracy may also be in question for some data, especially if the fisher does not want to disclose his fishing grounds to other fishers or management agencies.

There is very little spatial fishing effort and catch data for recreational and charter sectors of federal fisheries. Much of the information that is available is voluntarily submitted by

conservation minded fishers. Therefore, analysts must find correlations between available data and the locations of recreational and charter fishers, or they must find a proxy to use in the place of these fishers. For some fisheries, the locations where recreational and charter fishers fish may be the same locations as a sector of the commercial fishery. Parsing out these spatial differences is essential to achieving comprehensive enforcement across all sectors.

Permit holder information may also help narrow the search for fishers. Permit holder data is publicly available and the address of the permit holder is displayed in the data. This information may be used to locate areas along the coast of higher permit holder density. A correlation can then be made with the locations that these fishers frequent to predict fishing vessel density at any given place and time. On a larger scale, the Coast Guard can identify states and fisheries where significantly higher numbers of permit holders are located and base large scale enforcement strategies on this information.

Strategies for Improvement

To improve enforcement in problem fisheries, the Coast Guard should begin by evaluating its enforcement strategies on large space and time scales. Evaluation of existing strategies may provide significant keys to improving enforcement (Randall 2004). Gathering historical fishing effort and catch data and comparing it to the locations where boardings or enforcement patrols are being conducted is the first step to ensuring that enforcement is directed to the correct locations. Evaluating the same information temporally will also indicate whether there is a match between when fishing is occurring and when patrols are being conducted. These actions will reduce search times so that enforcement resources can be allocated more efficiently. Working at these larger space and time scales will likely result in the greatest benefit in enforcement for the least amount of effort. The Coast Guard will quickly see what enforcement strategies are mismatched with fishing effort and be able to redesign their strategies accordingly.

At smaller space and time scales, predictive models based on fish ecology, migration patterns, suitable habitat, and seasonality may be a good way of predicting fish locations, and therefore the location of fishers. Fisheries with clearly identifiable environmental predictors are good candidates for this type of analysis. For example, groundfish that strictly adhere to specific

substrates, depths, or other bottom features may be simple to model. Pelagic species that adhere to easily predicted oceanic features such as sea surface temperature may also be good candidates. Using historical records of fishing effort or species presence in relation to natural features may strengthen the reliability of these predictions. Predictions of large scale patterns may help focus enforcement operations in the general area where fishers are located. On scene, the use of aircraft overflights, radar, radio calls, and sightings will help enforcers find the individual fishing vessels.

Whatever prediction method is used, the number of federally permitted vessels actively engaged in the fishery will also be a determining factor in predicted vessel density. Even with an accurate prediction, if there are few federally permitted vessels predicted to be within a large geographic area, the Coast Guard will have trouble locating and boarding those vessels. Other factors such as weather patterns, fishery seasonality, regulations, locations of MPAs, and combined species fisheries may impact the location of fishing vessels within the geographic area of the prediction. LMR officers will have to use these factors, outside of any geospatial model, to help determine where to logically allocate enforcement assets.

One of the main values of geospatial analysis may be to show the mismatch between historical enforcement activities and fishing vessel presence. Using MISLE records of Coast Guard fishery boardings and historical fishing effort data, plotted on the same map, it is easy to see whether there is a spatial match or mismatch in enforcement. Further analyzing the data for temporal and fishing sector mismatches will add to the value of these comparisons. Once LMR officers see the mismatch on a map, they can identify potential reasons for the mismatch, such as employing the wrong enforcement platform or misconceptions about the location of the fishery, and quickly adjust their enforcement strategy to be more effective. Simply identifying that most of the fishing happens at the continental shelf break, for instance, versus over the continental shelf where vessels transit but don't fish, could greatly improve the effectiveness and number of fishery boarding inspections.

How and where the Coast Guard can most effectively and efficiently enforce a fishery depends on factors that are specific to the fishery such as gear type, fishing method, number of vessels,

geographical extent of fishing area, vessel size, and seasonality. For each fishery, every sector (commercial, charter, recreational) has different capabilities and regulations that further determine which enforcement strategy will be most effective. For commercial fisherman in most fisheries, there are numerous gear, time-area, and bycatch regulations that need to be inspected and enforced at sea while the vessel is actively engaged in fishing.

To enforce regulations that are not required to be inspected while vessels are in the act of fishing, the Coast Guard could identify “choke points” where vessels transit in high density, return to port, or offload catch. These locations are likely closer to shore and can be patrolled more frequently and with less expenditure of fuel and patrol time costs. These locations are good candidates for enforcement of recreational and charter fisheries, since most of these vessels return to port after a day or two of fishing, rather than spending weeks at sea, and their transit locations are predictable. Additionally, most recreational and charter fishing regulations involve catch size and bag limits rather than gear or closed area prohibitions. Therefore, the Coast Guard may have more success enforcing recreational and charter fisheries near ports where the vessels make predictable transits when returning with their catch. Table 1 contains a list of potential strategies for improving enforcement.

Table 1:

Potential strategies for improving enforcement:
Identify large scale spatial and temporal patterns in historical fishing effort and catch data
Identify seasonal patterns in fishing effort and build them into strategic enforcement plans
Identify enforcement mismatches
Identify priority enforcement areas
Identify choke points where vessels must transit to land their catch
Identify easy to enforce areas with high vessel densities
Identify violation-prone areas and violation hotspots
Use VMS to locate vessels in real-time
Use historical vessel tracks to design enforcement strategies
Analyze spatial patterns in permit holder locations
Identify patrol areas where boarding numbers are low
Identify successful patrol areas and times

Improving Enforcement in the Atlantic HMS Fishery

The Coast Guard identified the Atlantic Highly Migratory Species (HMS) fishery as a fishery in which they have struggled to achieve their target level of effective enforcement. This fishery consists of pelagic tunas, swordfish, and sharks within the U.S. Atlantic, Caribbean, and Gulf of Mexico EEZs (HMSD 2006). Within this vast geographic area in the western North Atlantic, these highly migratory species migrate on an annual basis, driven by biological needs and following large scale oceanographic features. These species often travel outside of the U.S. EEZ and are targeted in international waters as well as the waters of other countries. The Coast Guard is tasked with enforcing domestic HMS fishery regulations within the EEZ, stopping incursions of foreign vessels into the U.S. EEZ, and enforcing the international laws and regulations on vessels in international waters. The Coast Guard identified the Atlantic HMS fishery as a high priority fishery for enforcement due to its high economic value, importance to food security, and recreational/charter importance.

Beginning in 1999 with the consolidation of Atlantic HMS under one fishery management plan, NMFS began implementing time-area closures in the Atlantic HMS fishery in order to reduce bycatch of marine mammals, marine turtles, and sharks, and non-targeted fish species (HMSD 2006). There are currently six active closures with others under consideration. Five of these closures are located in the U.S. EEZ (DeSoto Canyon, Florida East Coast, Charleston Bump, Mid-Atlantic, and Northeastern U.S. Closed Areas), and one is located in international waters (Northeast Distant Restricted Fishing Area) (Figure 2) (HMSD 2006). These closures are for pelagic or bottom longline gear and their effective dates coincide with historical knowledge on the abundance of bycatch species within each closed area. In September 2003, NMFS implemented mandatory fleet-wide VMS requirements in the Atlantic pelagic longline fishery in order to ensure compliance with these closures (HMSD 2006). Remote tracking of vessel positions allows NOAA's Office of Law Enforcement to monitor for incursions by longliners into these closed areas.

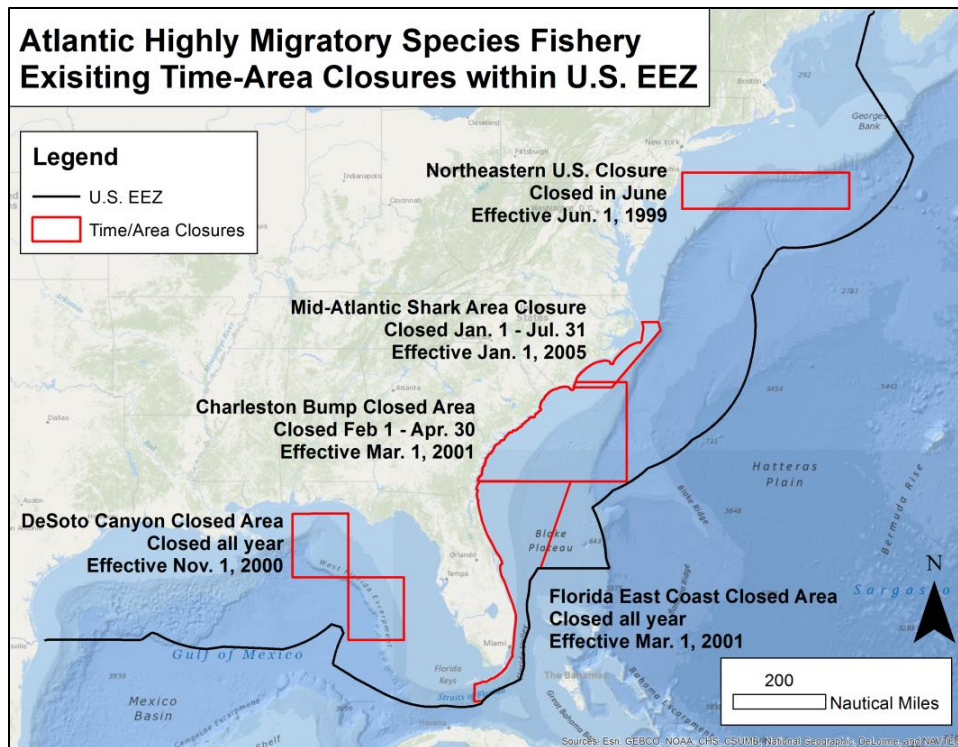


Figure 2: The five existing time-area closures for the Atlantic HMS fishery in the U.S. EEZ. There is one additional closed area in the international waters of the North Atlantic called the Northeast Distant Restricted Fishing Area. These areas are closed to pelagic or bottom longline fishing in order to reduce bycatch.

VMS is helpful to the Coast Guard in locating commercial pelagic longline vessels in real time to conduct boardings, but VMS is only implemented in the pelagic longline fishery which consists of only 4.2 percent of the commercial HMS permit holders (HMSD 2006). Other sectors of the fishery including commercial (non-longline), recreational, and charter fishers have no VMS requirements. In some areas, especially the northeast U.S., a large portion of the commercial fishery consists of non-VMS mandated vessels. Enforcement targets on these vessels have been difficult to achieve due to the lack of spatial fishing effort data and real-time VMS information.

The Coast Guard's target for all sectors of the Atlantic HMS fishery is to board 20 percent of federally permitted vessels annually. The total number of permitted vessels that are active in the fishery is difficult to determine, but In 2006 NMFS issued 4,173 Charter/Headboat HMS Permits, 25,238 HMS Angling Permits, and 1,131 Commercial HMS Permits (604 commercial permit holders) (HMSD 2006). Some permit holders are allowed to have multiple types of permits, but no vessel with an HMS Angling Permit may also have a Charter/Headboat or

Atlantic Tunas permit issued at the same time (HMSD 2006). The Tuna Longline Permit is only valid if the permit holder also holds a Directed or Incidental Swordfish Permit and a Shark Permit, for instance (HMSD 2006).

Pelagic longline fishers in the Atlantic HMS fishery typically fish near the continental shelf break and further offshore on trips that can last up to a few weeks. Recreational fishers typically go on trips that last one to two days, stay closer to shore, and use either trolling or live baiting fishing techniques with rod and reel. Charter fishermen typically behave like recreational fishers, but can go further offshore and stay out for up to a few days. Both recreational and charter fishers have regulations that govern their catch and size limits, rather than fishing methods. There are no federal time-area closures for recreational or charter fishers since bycatch is not a major issue in these sectors of the fishery.

35.4 percent (214 of 604) of commercial longline HMS permit holders hold a Tuna Longline Permit and are required to report their fishing effort and bycatch in accordance with NMFS Pelagic Logbook requirements (HMSD 2006). This logbook requirement was instituted in order to collect effort, catch, and bycatch data for future management decisions. Non-longline commercial, Charter/Headboat, and HMS Angling Permit holders are not required to record or report spatial fishing effort information. For the purposes of this study, I used commercial Pelagic Longline Logbook data from 2005 to 2008 compiled by NOAA's Southeast Fisheries Science Center as a proxy for fishing HMS effort (<http://www.sefsc.noaa.gov/data/pelagiclogbook.htm>) (Figure 3). Although this data does not contain spatial catch or effort information for recreational, charter, or non-longline commercial fishers, I assumed that these fishers could be found in the same locations as longline fishers since they are targeting the same catch. It is highly likely that recreational and charter fishers fish in spatially different locations than longline fishers, but due to the lack of spatial information for those sectors, I am attempting to use pelagic longline data as a reasonable comparison. I will note findings that contradict this assumption in my analyses below. Although this data only represents a small section of the commercial HMS fishery, it does provide an indication of where Atlantic HMS fishers may be targeting their catch. The major value is that this data represents the large scale spatial and temporal patterns of Atlantic HMS fishing effort.

Data in NOAA’s Pelagic Longline Logbook dataset is available from 1986 to 2008. I chose a subset of the data from 2005 to 2008 (35,652 recorded sets) in order to analyze fishing effort in relation to recent Coast Guard enforcement strategies from the same years. Although NOAA has made every effort to control the accuracy of the data, there are still spatial errors such as set positions that are located on land (Figure 3). Still, this is the most reliable and abundant spatial data for HMS commercial fishing effort.

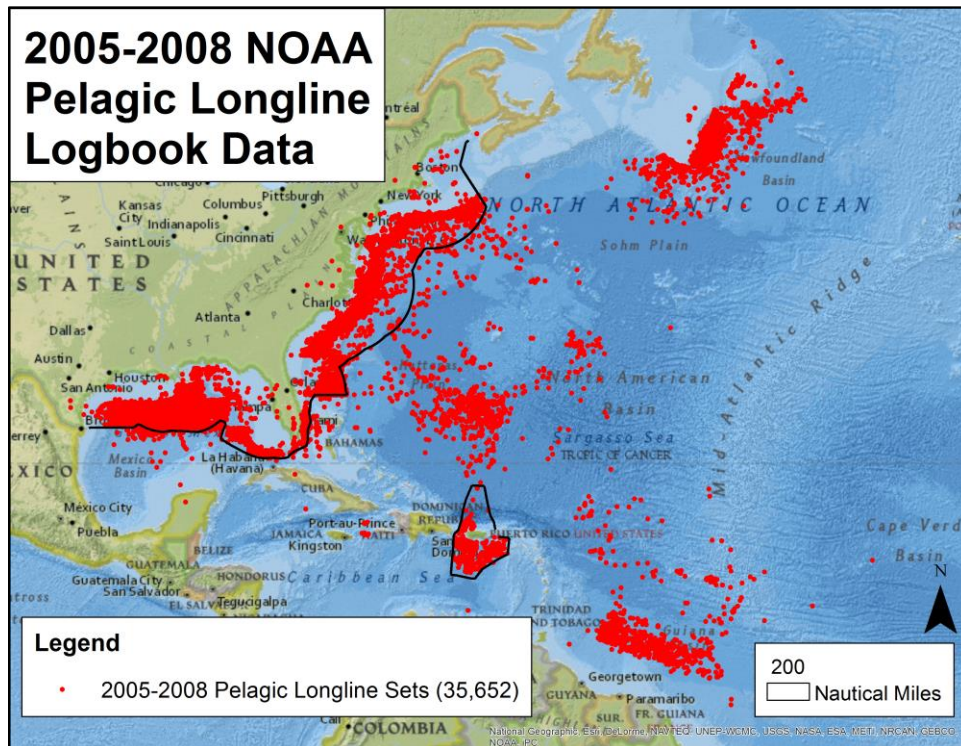


Figure 3: Pelagic Longline sets in the Atlantic HMS fishery from 2005-2008. The Atlantic, U.S. Caribbean, and Gulf of Mexico EEZs contain a large portion of the fishery. There are also locations in international waters where U.S. longline fishermen target Atlantic HMS.

For the purposes of this study, I extracted Atlantic HMS boarding records of all vessels (commercial, charter, and recreational) from the Coast Guard’s MISLE database. I chose the following ‘Fishery_Type’s available in MISLE as Atlantic HMS fishery related:

'Fishery_Type' for Atlantic HMS Boardings
(Caribbean) Highly Migratory Species
(East Coast) Highly Migratory Species
(Gulf of Mexico) Highly Migratory Species
Atlantic Billfishes
Atlantic Tuna, Swordfish and Sharks

After deleting records with incorrect or no spatial information (approximately 2 percent) and correcting some records with incorrect hemisphere assignments, I was able to accumulate 568 Coast Guard Atlantic HMS boarding records with quality spatial information from 2005-2008. Mapping the locations of the Coast Guard's boardings of HMS fishing vessels and the location of the commercial fishing effort reveals that there is a possible spatial mismatch between these two (Figure 4). Figure 4 shows the Coast Guard's boardings of HMS fishing vessels from all sectors of the fishery during the years 2005 to 2008 and the pelagic longline (PLL) fishing effort during the same time period. There are clearly identifiable areas where longliners concentrate their efforts. From Cape Hatters, North Carolina to George's Bank, the highest effort tends to be located along the continental shelf break of the Mid-Atlantic Bight, for example. Over the Blake Plateau in the South Atlantic Bight, most of the fishing effort is concentrated directly north or east of the Florida East Coast Closed Area and the area directly north of the Bahamian EEZ. Some HMS fishery law enforcement boardings occurred in the locations of high commercial fishing effort, but the majority (53.9 percent) did not occur in these areas (within 20 nautical miles of a PLL set). In addition, 86.9 percent of the boardings occurred outside of areas with a set density greater or equal to 0.0155 sets per square kilometer (the area with a red color ramp in Figure 4).

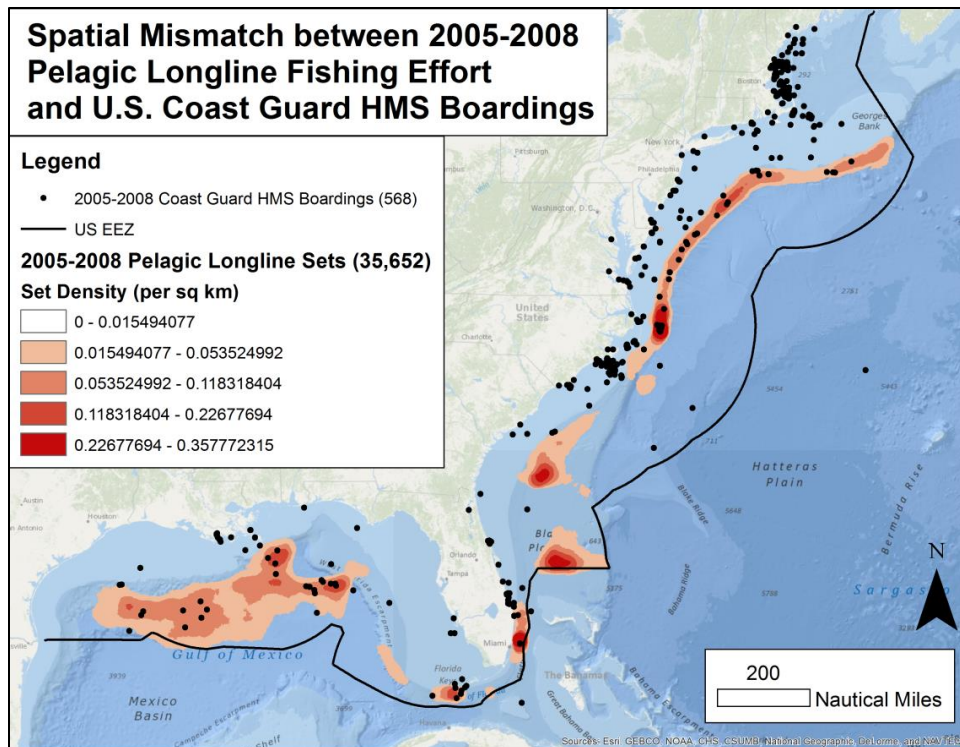


Figure 4: Spatial mismatch between HMS commercial fishing effort and enforcement. Most (53.9%) of the 2005-2008 Coast Guard Atlantic HMS fishery boardings occurred greater than 20 nautical miles from a known pelagic longline set during the same time period.

There is also a temporal mismatch between commercial fishing effort and enforcement. As seen in Figure 5, the proportion of boardings conducted each month does not align with the temporal pattern in fishing effort. Although the month of August did see the most fishing and enforcement effort, overall the number of boardings conducted in each month are not consistent with effort.

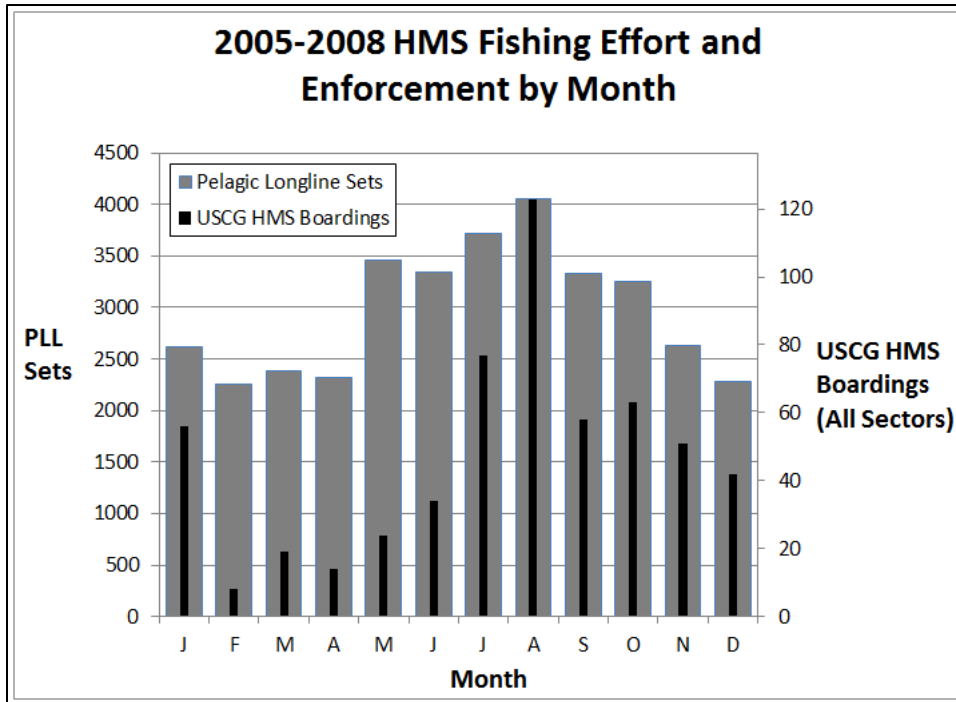


Figure 5: Temporal patterns in Atlantic HMS commercial fishing and enforcement effort. Although high and low months of effort coincide, the Coast Guard is not effectively matching enforcement effort to fishing effort during each month.

To correct for the spatial and temporal mismatches in fishing effort and enforcement, the Coast Guard could base their enforcement strategies on these apparent large scale historical patterns. One of the most recognizable patterns is the seasonal change in the location of the fishing grounds with respect to large scale oceanographic features, notably the Gulf Stream’s location, temperature, and intensity. Figure 6 contrasts the location of the highest fishing effort for the months of February and August during the same time period (2005-2008). In February, almost all of the fishing effort is located south of Cape Hatteras, with the highest density off Florida’s East Coast and Cape Hatteras. In August, a large portion (approximately 37 percent) of the overall fishing effort is located from Cape Hatteras and to the north. Additionally, the number and maximum density of PLL sets in the month of August was nearly twice that in February. Recognizing this, the Coast Guard can plan long-term enforcement strategies to take advantage of this historical pattern in seasonality.

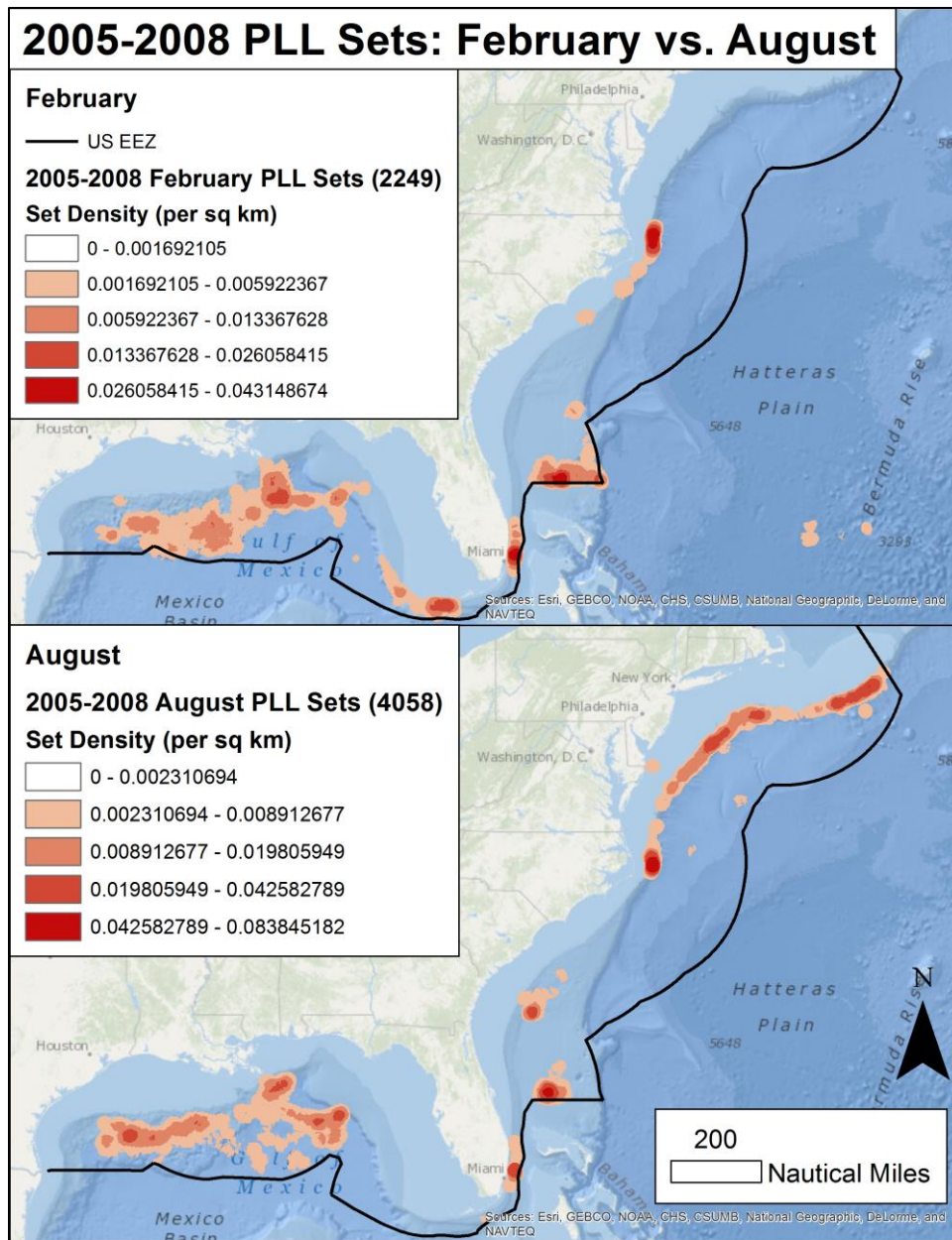


Figure 6: Seasonal patterns in Atlantic HMS commercial pelagic longline fishing effort for February and August (2005-2008). The number and highest density of sets is nearly twice as high in August as that in February.

Analysis of the HMS Fishery off North Carolina

Approximately ten percent of the overall Atlantic HMS pelagic longline fishing effort is concentrated along a 100 nautical mile length of continental shelf break off of Cape Hatteras, North Carolina from latitude 35°9'N to 36°18'N (Figure 7). Nationally, 11.1 (465) percent of the Charter/Headboat Permits and 7.4 percent (1,863) of the HMS Angling Permits are held in North

Carolina (HMSD 2006). Off Cape Hatteras, the continental shelf only extends 30 km offshore and the warm Gulf Stream Current mixes with the cold Labrador Current, causing very high productivity. This area is known to local recreational anglers as the “Offshore Fishing Capital of the World” due to its high concentration of tunas and billfishes.

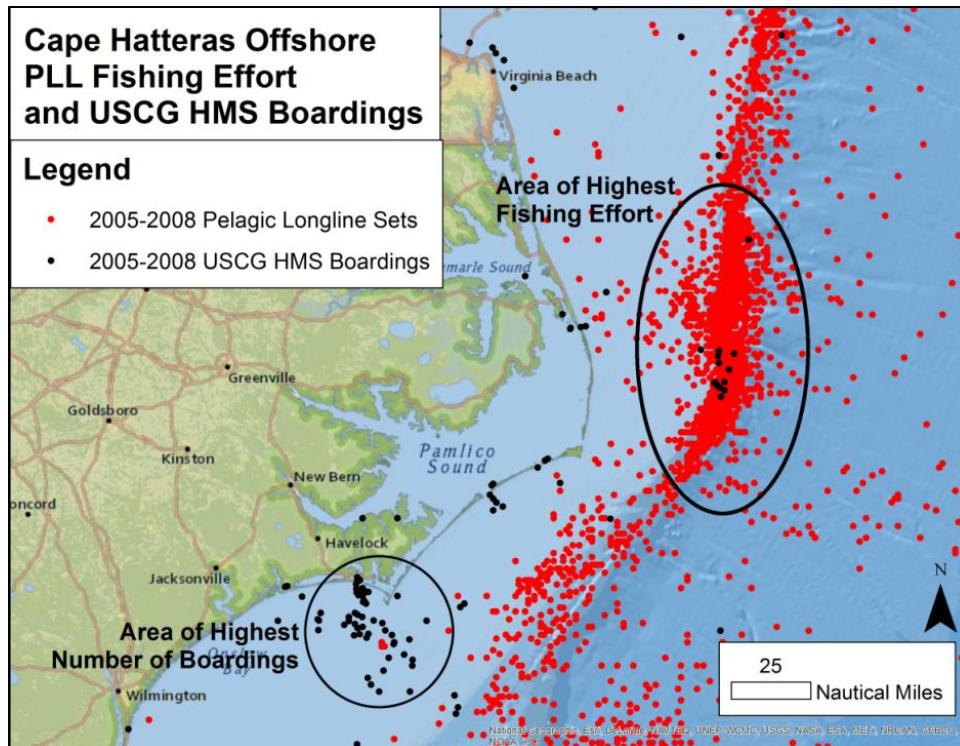


Figure 7: Commercial pelagic longline Atlantic HMS fishing effort and enforcement effort off the North Carolina coast. Fishing effort is concentrated within a 100 nautical mile length of the continental shelf break off Cape Hatteras, yet only 2% of the boardings were conducted in this area. Enforcement effort is concentrated south of Beaufort/Morehead City, where there is a large charter/headboat and recreational angling fleet.

Between January 15 and March 22, 1997, one study recorded 1,020 charter and 370 private recreational boat trips targeting Bluefin Tuna from Hatteras, NC alone (Bohnsack et al. 2002). North Carolina residents only accounted for 15.6 percent of these fishers studied (Bohnsack et al. 2002). Thus, many of the recreational fishers targeting Atlantic HMS off Hatteras are out of state tourists, meaning the fishing pressure is likely high for trophy sized tuna and billfishes. Recreational, charter, and commercial HMS fishing occurs in this location year round with the heaviest pelagic longline effort occurring from May to December (Figure 8). However, only two percent of the Coast Guard’s HMS fishery boardings occurred in this location of such high

fishing effort. With this high number and density of HMS fishing vessels from all sectors, this area is a key enforcement priority for both HMS fishery and fishing vessel safety regulations that the Coast Guard can address.

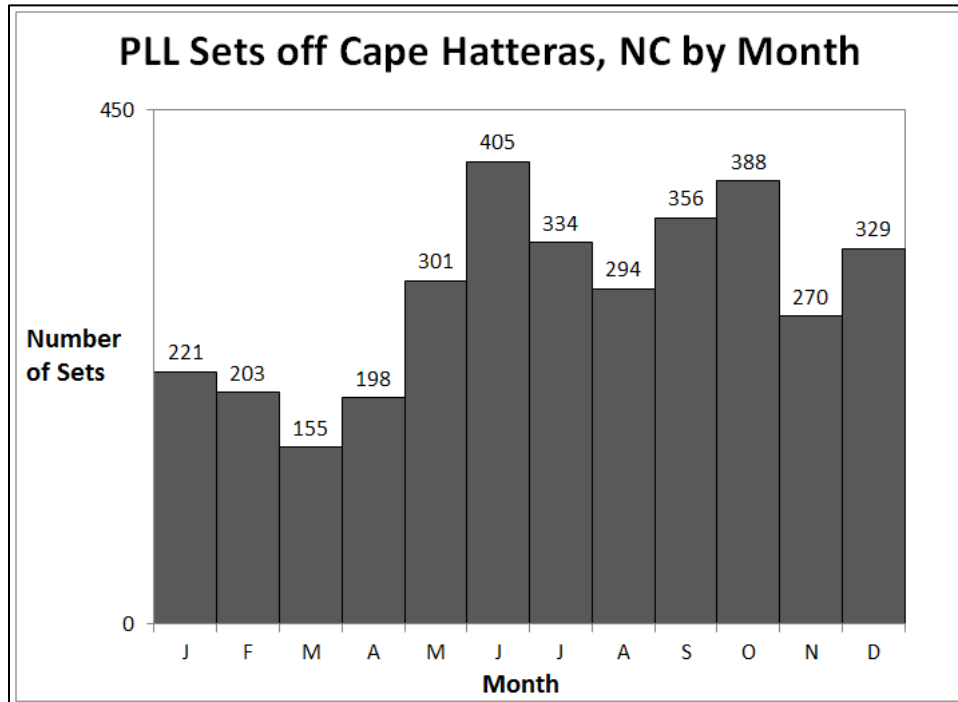


Figure 8: Temporal pattern in Atlantic HMS commercial fishing effort offshore of Cape Hatteras, NC by month (2005-2008). HMS fishing here is year-round, but that higher fishing effort occurs from May through December.

Most of the HMS boardings conducted in North Carolina occurred in an area directly offshore of Beaufort and Morehead City, NC, which are home to a large recreational and charter fleet. A popular fishing location named “Big Rock” is located offshore of Cape Lookout and is easily accessed via this port area. This area of high enforcement presence comprised 13.3 percent (76/568) of the overall Atlantic HMS boardings for 2005-2008. Boardings in this area were composed of 63.2 percent commercial, 22.3 percent recreational, and 14.5 percent charter vessels. Despite the lack of fishing effort data for this location, it appears that fishing vessel density is high and the Coast Guard may choose to continue to concentrate their efforts here. Additionally tasking enforcement efforts to target recreational and charter vessels as they return to port via the four main inlets of the Outer Banks will allow the Coast Guard to save time and money searching for these smaller vessels offshore.

Analysis of the HMS Fishery in Coast Guard District One

The Coast Guard's District One is located in New England and contains both George's Bank and the Gulf of Maine, two highly productive HMS fishing grounds (Figure 9). As seen in Figure 10, the HMS fishing in District One is very seasonal, with 85 percent of the total effort occurring in the months of July through October. Almost half, about 45 percent, of the Coast Guard's total Atlantic HMS boardings in 2005-2008 occurred in the Coast Guard's First District despite this area containing only 8.4 percent of the total Atlantic HMS pelagic longline fishing effort. This is due to the large commercial importance of Bluefin Tuna and swordfish caught in this area (HMSD 2006). 85 percent of the boardings in District One, or about 32 percent of all Atlantic HMS boardings, occurred in the western Gulf of Maine on the fishing grounds near Gloucester, Massachusetts. This area is well known for large catches of Bluefin Tuna by the recreational, charter, and commercial (non-longline) fishers (HMSD 2006).

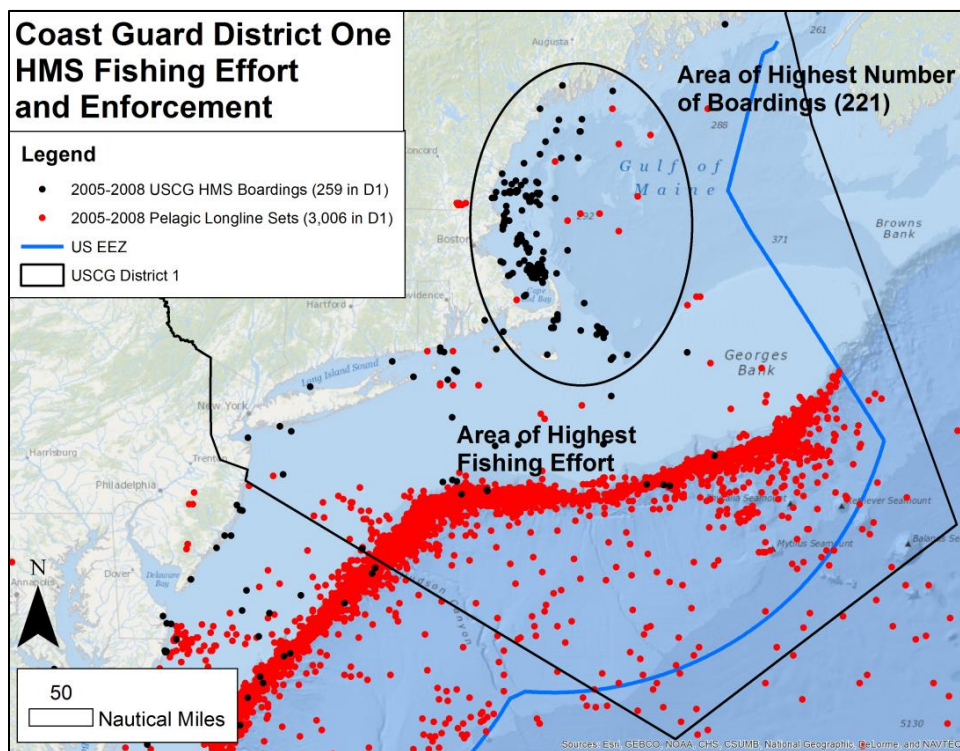


Figure 9: Atlantic HMS fishing and enforcement efforts in Coast Guard's District One (2005-2008). Most of the fishing effort is concentrated along the continental shelf break, while most of the enforcement efforts are taking place in the western Gulf of Maine near Gloucester, MA. Recreational and non-longline commercial fishers are known to target Bluefin Tuna in this area.

The Coast Guard has identified the area near Gloucester as one in need increased enforcement patrols due to the high numbers of HMS fish caught here and issues with fishing vessel safety, as many of the vessels are small and not as seaworthy as larger commercial vessels. Many part-time fishers operating smaller vessels during the General category Bluefin Tuna season fail to meet safety equipment requirements prescribed by the Coast Guard (HMSD 2006). Some have even capsized while trying to load commercial-sized Bluefin Tuna onboard smaller vessels. Of the boardings conducted in this area from 2005 to 2008, 67.3 percent were commercial vessels, while 25.5 percent were recreational and 2.6 percent were charter vessels.

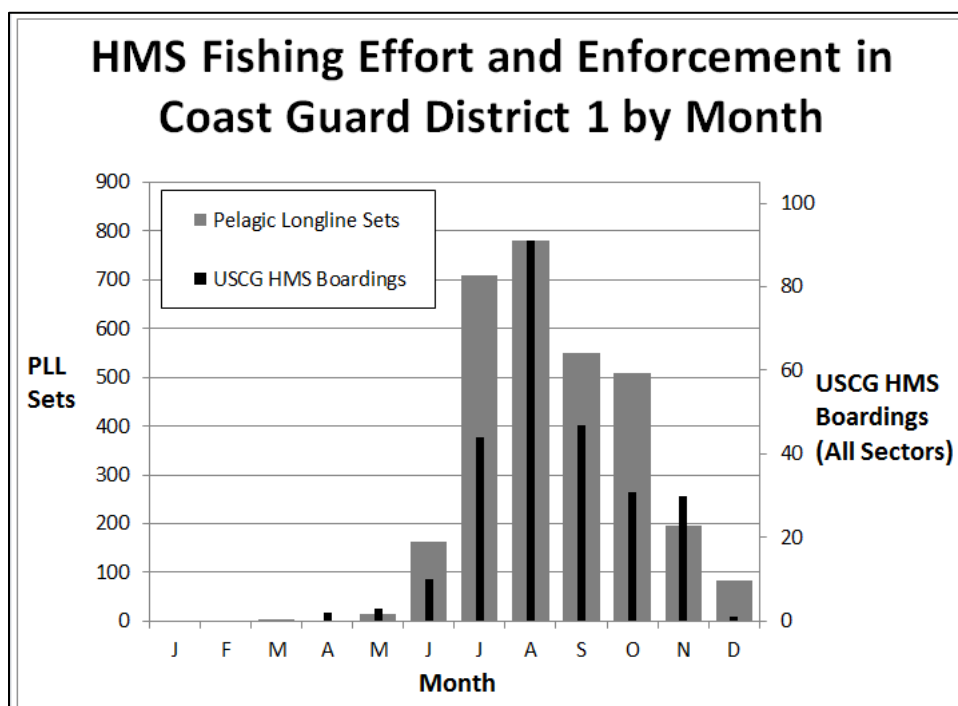


Figure 10: Atlantic HMS fishing and enforcement effort in Coast Guard District One by month. The fishing in District One occurs from June through December. The number of boardings was highest in August, which coincided with the peak fishing month.

The majority of the pelagic longline fishing effort in District One occurs along the continental shelf break from June through December. This is a good indication that other commercial, charter, and recreational fishers may be fishing in the same area during this time period. This is a seasonal area of high HMS fishing vessel density along a relatively small, well-defined area. For ease of enforcement, the Coast Guard could patrol the region of the continental shelf break, with monthly patrol effort coinciding with the historical level of fishing effort in the area.

Recognizing these spatial and temporal patterns in Atlantic HMS fishing in District One, the Coast Guard can plan enforcement strategies to take advantage of these large scale patterns. During the enforcement operation, as vessels move in relation to the fish and oceanographic features, the Coast Guard can adapt to these location changes accordingly. Overflights of these areas could quickly confirm the presence and relative density of fishing vessels, and surface enforcement assets could be directed accordingly (Randall 2004).

In order to board the vessels further offshore, the Coast Guard must employ larger, more capable patrol assets such as 210', 270', and 378' cutters. Utilizing these assets involves months of operational planning that require patrol areas, logistical port calls, and operational control to be established well ahead of time. Therefore, the Coast Guard is looking to achieve accurate predictions of fishing fleet location, for a 1-2 month period, approximately three months in advance of conducting a patrol. Once in the patrol area, the Coast Guard cutter can be directed to the fishing vessels in the area using other methods of detection. Recognizing these large spatial-temporal patterns in HMS fishing effort, the Coast Guard may be able to plan patrols accordingly, well in advance of the operation.

Recreational and Charter HMS Fisheries

For recreational and charter HMS fishers, the Coast Guard must use slightly different methods than in the commercial sector to locate areas of high fishing vessel density and evaluate enforcement strategies. Since no comprehensive spatial dataset for recreational and charter HMS fishing effort exists, analyzing past boarding records and the location of permit holders may be a valuable method for determining enforcement priorities. Three states stand out as having the most charter/headboat and recreational Atlantic HMS permit holders; Florida, New Jersey, and Massachusetts (Figure 11) (HMSD 2006). New York and North Carolina also have a larger number of permit holders (HMSD 2006). The waters adjacent to these states should be considered primary enforcement targets for recreational and charter Atlantic HMS fisheries since these fishers tend to stay closer inshore and have shorter trip durations. Identifying popular fishing grounds in these offshore areas will also help decrease search times.

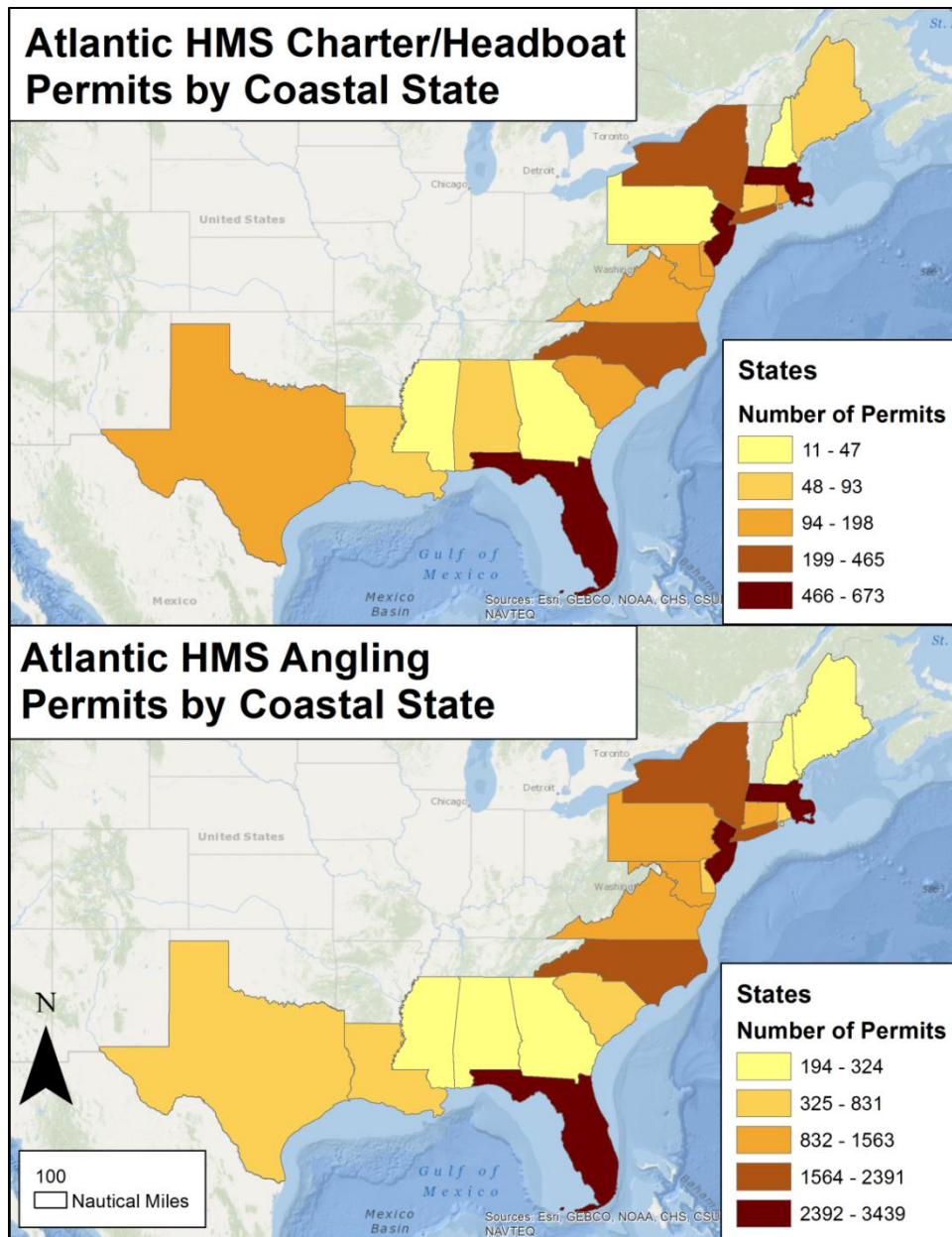


Figure 11: Atlantic HMS Charter/Headboat and Recreational (HMS Angling) permits by state. Florida, North Carolina, New Jersey, New York, and Massachusetts stand out as states where recreational and charter HMS fishing may be a higher enforcement priority than other states.

Boardings of recreational and charter HMS fishers by the Coast Guard in 2005-2008 tended to be closer to shore than commercial boardings, especially in the Gulf of Mexico and mid-Atlantic Bight, where the continental shelf is further offshore (not shown). For 2004, NMFS estimated the number of recreational and charter trips originating from Virginia to Maine and targeting Atlantic HMS to be 57,545 and 13,939, respectively (HMSD 2006). Since the Atlantic HMS

fishery is highly seasonal north of Cape Hatteras, these trips likely occurred in June through December, greatly condensing the enforcement effort needed to effectively enforce these sectors of the fishery.

One of the main methods of determining where recreational and charter fisheries occur, especially if spatially different than commercial fisheries, may be to conduct intelligence gathering by monitoring fishing blogs and fishing reports. Recreational and charter fishers typically often display their catch and fishing success in public forums. Fishing reports often publicize specific locations where fish are biting, and many fishers frequent these popular fishing sites. By reading and analyzing these resources, Living Marine Resources Officers may be able to identify popular non-commercial fishing grounds and increase patrols in those areas.

Monitoring popular VHF radio frequencies used by fishers will also give the Coast Guard real-time knowledge of fleet location and, vessel density, and fishing activity. Additionally, most recreational and charter fishing regulations involve mainly catch limits rather than time-area closures or gear restrictions. Therefore, it may be advantageous to concentrate enforcement efforts around harbor entrances, charter boat docks, or marinas where recreational and charter fishers return to port with their catch. These areas are usually easily determined using local knowledge or by “walking the docks”. The Coast Guard has the ability to conduct “dockside boardings” when the fishers have returned to land their catch. These times and places are easy to predict based on fishing season and local conditions. Taking special care not to encroach on charter vessel customer relations, the Coast Guard could potentially use this strategy to cooperate with charter fishers to educate fishers, encourage compliance, and increase perceived presence of enforcement personnel (Randall 2004).

Summary of Recommendations for improvement of Atlantic HMS fishery enforcement:

- 1) Plan enforcement strategies to match historical large-scale spatial and temporal patterns in fishing effort.
- 2) Time enforcement in each District to match seasonal patterns in fishing effort.

- 3) Conduct overflights or presence verifications to locate the fishing fleet. Once the fleet is located, conduct high intensity enforcement operations to maximize efficiency of enforcement efforts.
- 4) Locate areas of highest density of fishing effort. These are areas with small geographical areas and high vessel density, which will be easier to patrol and enforce.
- 5) Analyze and identify areas where patrol and boarding efforts have been effective in the past. Use information on time of year and sector breakdown to predict the effectiveness of future enforcement operations.
- 6) Conduct local intelligence gathering to determine when and where recreational and charter fishers go. Fishing blogs, fishing reports, and commercially available fishery prediction products are good sources of local and time sensitive information.
- 7) Identify harbor entrances and transit areas where large numbers of HMS vessels return to port to land their catch. These are areas where the vessels can be boarded when returning to port with fish onboard and catch regulations can be enforced.
- 8) Conduct “dockside boardings” to educate fishers, encourage compliance, and increased the perceived presence of enforcement personnel.

Improving Enforcement in the Gulf of Alaska Sablefish Fishery

Many Alaskan commercial fisheries occur far from land and are spread over large geographic areas. The U.S. Alaskan EEZ is approximately one million square miles (NPFMC 2011) and the weather and sea state are often dangerous, making enforcement of many Alaskan fisheries difficult. Geographically large seasonal migrations of fishes also make it problematic to know where the fleet is fishing at any given time. The Coast Guard identified the Gulf of Alaska (GOA) Sablefish (Black Cod) fishery as a fishery in which they have struggled to achieve their target level of enforcement. The Coast Guard’s target is to board 20 percent of the active federally permitted vessels within the GOA Sablefish fishery annually, which is primarily a commercial fishery. In 2012 NMFS issued approximately 1,180 federal permits to fishers who could legally target Sablefish in the Gulf of Alaska (NOAA Fisheries 2013). In 2010, this number was approximately 1,300 (NOAA Fisheries 2013). If the yearly average number of permit holders is assumed to be around 1200, the Coast Guard’s target is to board approximately 240 of these vessels annually. In 2010, 27 Coast Guard boardings were recorded as GOA

Sablefish or Southeast Alaska Sablefish boardings. The failure to achieve the targeted number of boardings is likely due to the inability to locate the fishing vessels while actively engaged in fishing.

The GOA Sablefish fishery occurs annually from March to November and is managed by total allowable catch (TAC) limits (NPFMC 2012). The Gulf of Alaska groundfish fishery management plan stipulates that only hook-and-line and trawl gear are legal methods of commercially taking Sablefish (NPFMC 2012). In the Eastern Regulatory Area, hook and line fishers are allowed to take up to 95 percent of the TAC, while vessels using trawl gear are allowed to take up to 5 percent of the TAC, typically as bycatch (NPFMC 2012). In the Western and Central Regulatory Areas, hook and line fishers are allowed to take up to 80 percent of the TAC, while trawl fishers are allowed to take up to 20 percent of the TAC (Figure 12) (NPFMC 2012). Therefore the majority of the GOA fishing effort targeting Sablefish is done using bottom longline gear (NPFMC 2012). Since Sablefish are demersal, they are usually targeted by either bottom longline or non-pelagic trawl.

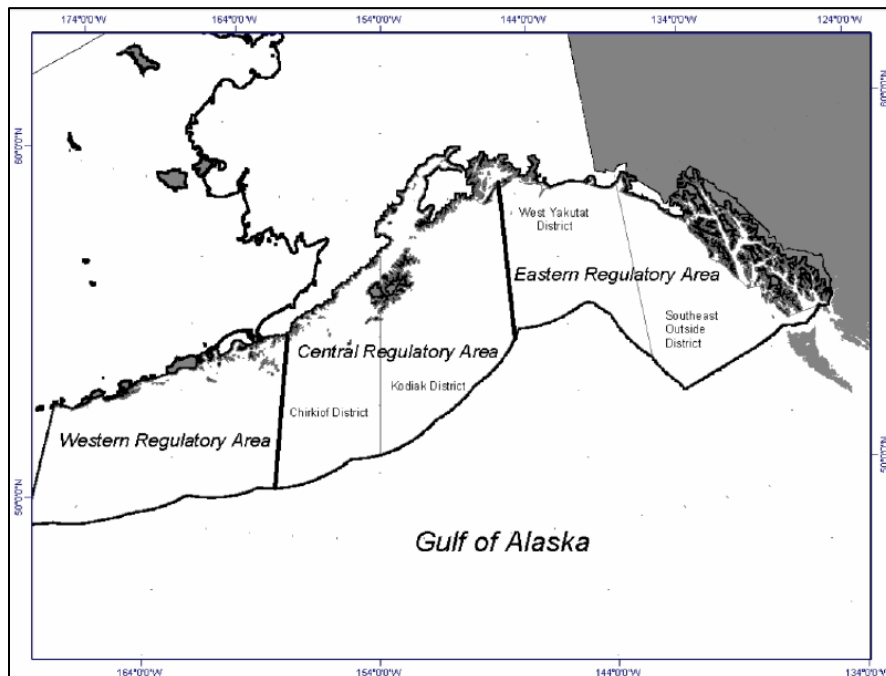


Figure 12: Regulatory Areas of the Gulf of Alaska. 95% of the TAC is allocated to hook and line fishers in the Eastern Regulatory Area, while 80% of the TAC is allocated to hook and line fishers in the Western and Central Regulatory Areas. The remainder of the TAC is allocated to trawl fishers. (Source: North Pacific Fishery Management Council, 2012)

This study spatially analyzes the fishing effort in the Gulf of Alaska Sablefish fishery using catch statistics compiled by the NMFS Alaska Fisheries Science Center (AFSC). The data is available on their website: (http://www.afsc.noaa.gov/FMA/spatial_data.htm). The “Most Fish Data” dataset represents the NOAA observer catch data for numerous species including mid-water species and groundfish from 1993 to 2011. I used this entire dataset assuming that fishing locations did not change significantly over time. The primary value of this dataset is that it specifies the fish species associated with haul information. Each feature point is located at the center of a 20 km x 20 km grid cell (discussed in the following paragraph), and each feature represents a unique combination of species, gear type, and year. The four gear types are Longline (LGL), Pot (POT), Non-Pelagic Trawl (NPT), and Pelagic Trawl (PTR) (AFSC 2012).

The attributes for catch include “KG”, or catch weight in KG extrapolated to the observed haul, and “RATE” or the species catch as a percent within the sampled hauls for that year and gear combination (AFSC 2012). The data does not include statistics for any grid cell that had less than three observations for that year’s observation period (AFSC 2012). This filters out the low observed effort fishing grid cells. The “Effort Data” dataset also available from the AFSC is only categorized by gear type, not species. Therefore, I used the “Most Fish Data” dataset to analyze the GOA Sablefish fishery specifically, as opposed to all groundfish caught by a certain gear type. The “Map Grid Shapefile” is the 20km x 20km grid cells that the AFSC uses to analyze fisheries statistics. Catch data is compiled for each grid cell and assigned a location at the center of the grid cell (AFSC NOAA Fisheries 2012). For this study, I assigned data from the “Most Fish Data” to the grid cells for ease of representing catch information.

Each point feature is specific to that species, gear, and year combination with attributes for “KG” and “RATE”. I computed the mean summary statistics of “KG” and “RATE” for each grid cell by species, resulting in a mean “KG” and mean “RATE” covering all gear types for the entire time period of the dataset (1993-2011). The minimum and maximum values for “MEAN RATE” are 10^{-6} percent to 78.8 percent. I assumed that grid cells containing a “MEAN RATE” for Sablefish of 20 percent or greater are grid cells where fishers were targeting Sablefish (hereafter referred to as “Targeted Sablefish Grid Cells”). 16.9 percent of the grid cells where Sablefish

were recorded are Targeted Sablefish Grid Cells. Of these 148 grid cells within the dataset, 143 are located within the GOA Regulatory Areas.

To evaluate the Coast Guard’s enforcement strategy for the GOA Sablefish fishery, I used MISLE boarding records from 2005-2010 with the following “Fishery Types” to evaluate recent enforcement strategies:

‘Fishery_Type’ for GOA Sablefish Boardings
(Alaska) Gulf of Alaska Jig Boat
(Alaska) Gulf of Alaska Longliner
(Alaska) Gulf of Alaska Sablefish
(Alaska) Gulf of Alaska Trawl
(Alaska) Southeast AK Sablefish

These are all of the fishery and gear types that are legally allowed to catch Sablefish in the Gulf of Alaska. This query returned 330 boarding records. 235 of these were trawl fisher boardings, which highly skewed the data towards trawl fishers. Since fishers targeting Sablefish in the Gulf of Alaska are primarily hook and line fishers, I excluded the “(Alaska)” Gulf of Alaska Trawl” boarding records, and was left with 95 boardings where Sablefish were targeted. For the purposes of this study, I used these 95 boarding records, assuming that the trawl fishery boardings were not of vessels directly targeting Sablefish.

Figure 13 shows the mean rate of Sablefish catch for each grid cell. It is apparent that the majority of the fishing effort targeting Sablefish was located within a narrow strip along the continental shelf break with the mean rate higher in the eastern portion of the GOA. There is also a spatial separation between Sablefish caught with trawl (pelagic and non-pelagic) gear versus longline gear (not shown). Longline Sablefish catches were strongly concentrated near the shelf break, while trawl Sablefish catches were spread over the shelf in areas where other groundfish species are typically targeted by trawl gear.

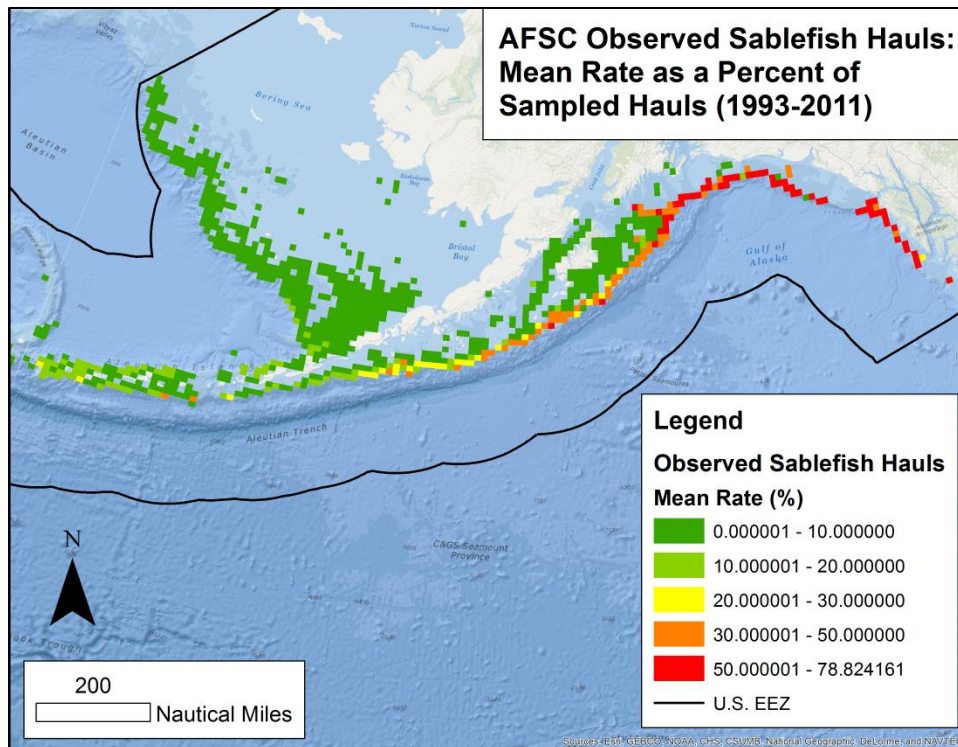


Figure 13: Grid cells where Sablefish were observed in the hauls. Grid cells are colored on a green to red color ramp based on the value of the “Mean Rate” attribute. Sablefish are caught as a higher percentage of the catch along the continental shelf break in the Gulf of Alaska.

Figures 14 and 15 show the spatial mismatch between GOA Targeted Sablefish Grid Cell locations and Coast Guard GOA Sablefish fishery boardings. 54.7 percent of the boardings were conducted within 50 nautical miles of a Coast Guard unit or Dutch Harbor, showing a strong bias towards boardings being conducted close to homeport. Although no USCG enforcement assets are permanently stationed in Dutch Harbor, I included this location in this analysis because there is typically a strong Coast Guard enforcement presence found near Dutch Harbor. This is due to the high concentration of fishing vessels found here as they land their catch, as this is the number one fishing port in the United States (NPFMC 2012). No GOA Sablefish boardings were conducted within 50 nautical miles of Dutch Harbor despite this being a popular location to land Sablefish for processing.

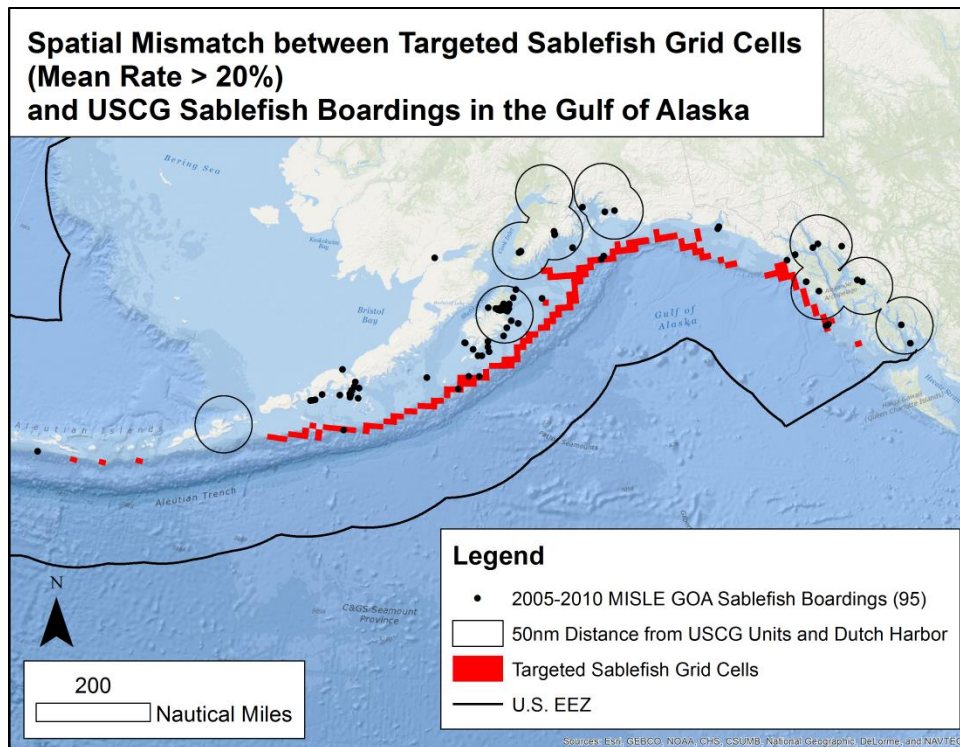


Figure 14: Spatial mismatch between Coast Guard Gulf of Alaska Sablefish enforcement and grid cells where fishers targeted Gulf of Alaska Sablefish (mean rate > 20%). No Sablefish boardings were conducted within 50 nm of Dutch Harbor, although many fishers land their catch in that location. The fishing effort is concentrated along the continental shelf break, whereas most enforcement is concentrated near Coast Guard units.

84.2 percent of the boardings occurred greater than 20 nautical miles from grid cells with a mean rate of 20 percent or higher (Targeted Sablefish Grid Cells). There are 143 Targeted Sablefish Grid Cells in the Gulf of Alaska Fishery Regulation Area. Only 8.4 percent of these grid cells were within 50 nautical miles of a Coast Guard unit and Dutch Harbor. 80.4 percent of these grid cells were located between 50 and 250 nautical miles from the nearest Coast Guard unit or Dutch Harbor. This shows a spatial mismatch between where the GOA Sablefish fishing is occurring and where the Coast Guard is conducting its enforcement operations for the fishery.

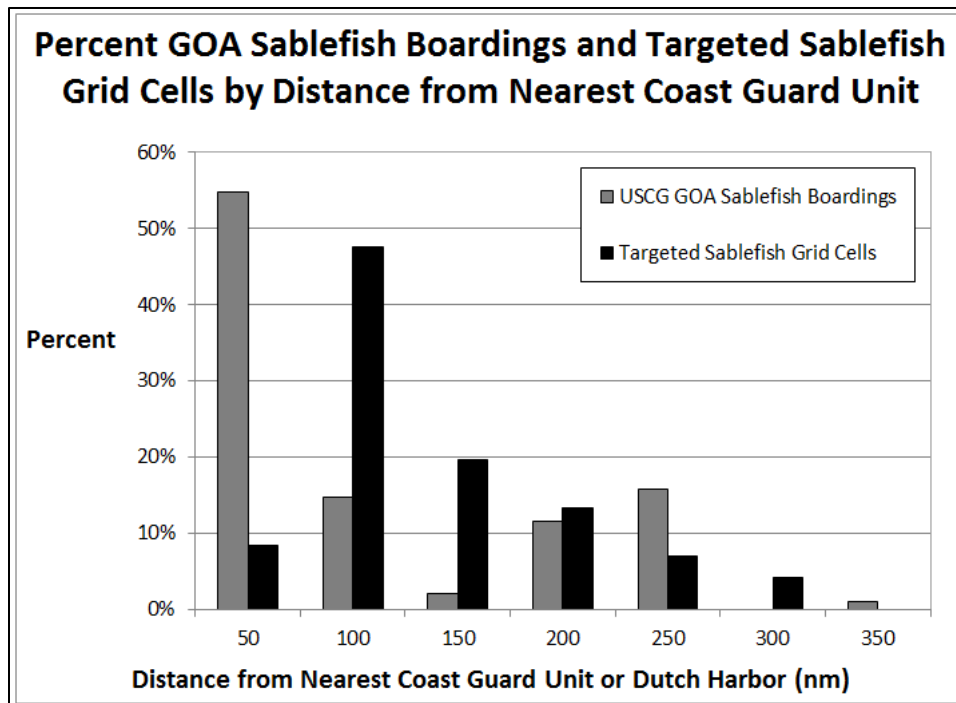


Figure 15: Percent of Coast Guard Gulf of Alaska Sablefish boardings (2005-2010) and Targeted Sablefish Grid Cells by distance from nearest Coast Guard unit (including Dutch Harbor). Approximately 55% of all boardings were conducted within 50 nm from the nearest Coast Guard unit homeport, while approximately 80% of the Targeted Sablefish Grid Cells occurred between 50 and 250 nm from the nearest Coast Guard unit homeport.

There is also a temporal mismatch between USCG GOA Sablefish boardings and the fishing season (March through November). January was the month with the highest number of boardings despite the fishing season being closed during January. 24.2 percent, of the 2005-2010 GOA Sablefish boardings occurred in January (Figure 16). 26.3 percent of the boardings occurred during the closed season (December through February). In addition, all of the boardings conducted in January were on Longline fishing vessels. The Coast Guard may have been conducting these boardings to ensure compliance with the closed season, but it appears that the boardings are mismatched in time with the fishing season. The Coast Guard may want to reappportion these enforcement resources to the active fishing season to be more effective at achieving their goal of boarding fishers engaged in fishing.

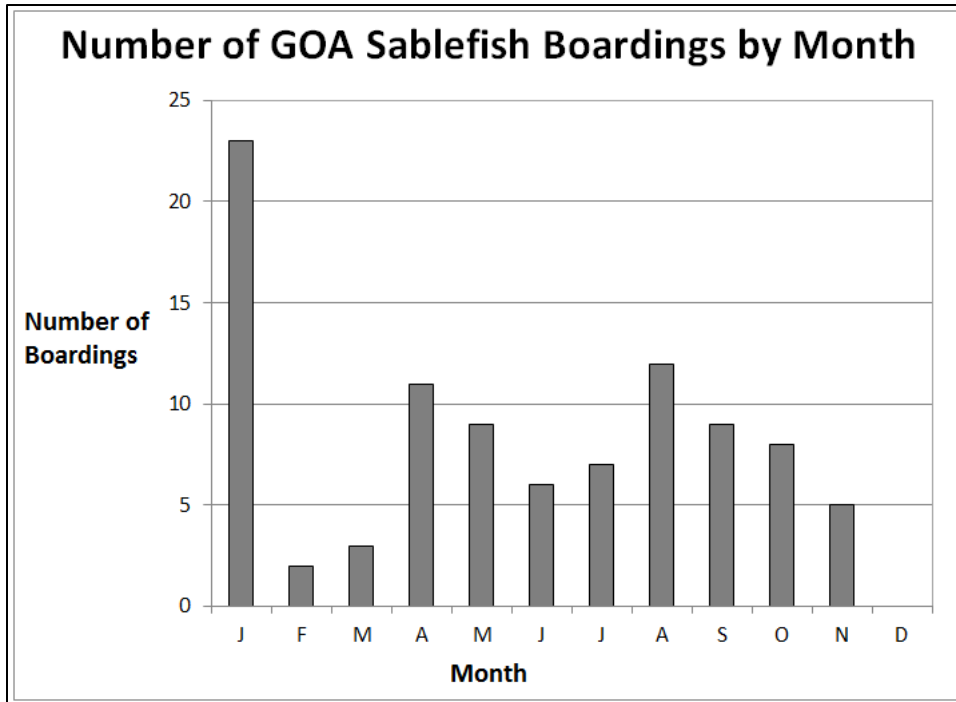


Figure 16: Coast Guard Gulf of Alaska Sablefish boardings by month (2005-2010). The fishing season extends from March to November. The month with the highest number of boardings is January, which is during the closed season. The Coast Guard may be enforcing the fishery closure during this month, but these enforcement resources may be more effectively allocated during the active fishing season.

Alaska Groundfish Fishery Analysis Tool

For future improvement of Alaskan Groundfish fisheries enforcement, including GOA Sablefish, I developed a tool to design and evaluate potential patrol areas. The tool allows the user to analyze a specific fishery(s) and gear type(s) and design an enforcement strategy around the analysis. First, the user can select one or two fisheries and specify desired gear types, if applicable. This allows enforcement officers to examine the spatial location of fishing effort for a specific fishery or a specific gear-based sector of the fishery. The tool involves two steps. Step One outputs the locations where the fishery occurs based on catch composition. Step Two allows the user to plan and evaluate an enforcement strategy for the desired fishery. Step Two uses the output from Step One as an input.

In Step One, the user selects one or two fisheries and is allowed to specify a gear type(s) for the fishery(s). Then, the user is given the option of what summary statistics to compute for each grid

cell. The recommended values are “MEAN KG” and “MEAN RATE”, so that the analysis can be conducted similarly to the GOA Sablefish analysis above. Figure 17 shows a sample output of Step One, which is Sablefish (no gear type specified) in this case.

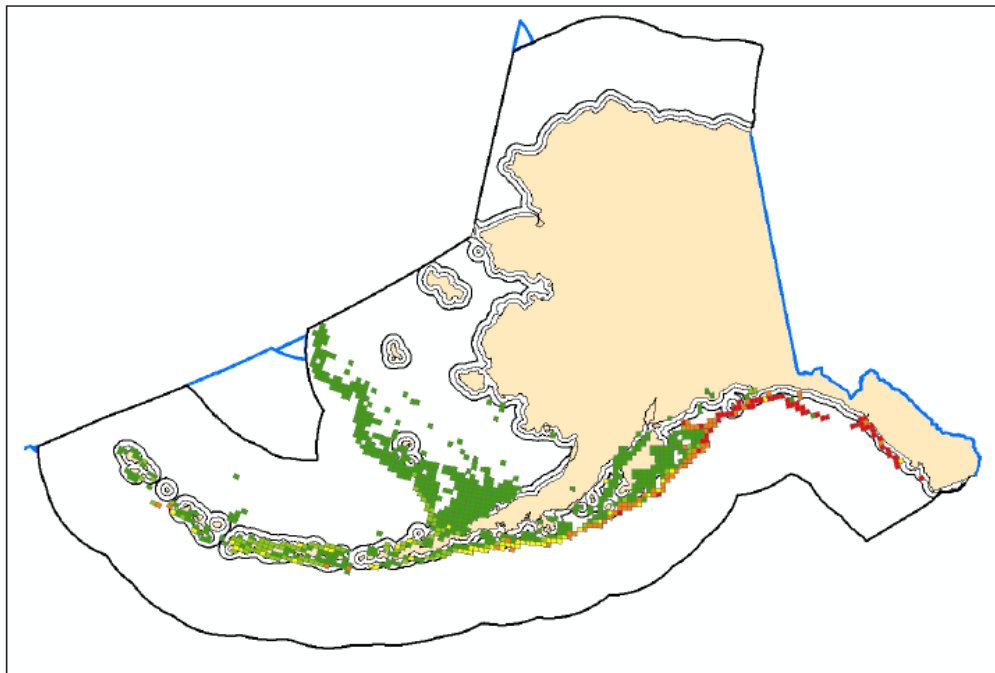


Figure 17: Sample output from Step One of the tool. In this example, Sablefish is the target species with no gear type specified. Cells are displayed with a green to red color ramp based on the value of the “Mean Rate” attribute. This output allows users to identify priority areas around which to design a potential patrol area.

After Step One runs, the user is able to display and examine the location of the fishing effort on the map. This step involves visually evaluating the map and seeing where the fishers are targeting the chosen species (based on mean rate). The enforcement officer will then consider factors such as size of the fishery (spatial scale), time within fishery season, weather conditions, location of enforcement assets to be tasked, and the operational limits of enforcement assets to determine a reasonable size and location of the potential search area. These grid cells are each 20km x 20km, and the user should consider the spatial scale while designing a reasonable potential search area.

Then, the user is ready to begin Step Two. Step Two takes the output from Step One as an input. The user is asked to draw a polygon around the grid cells where they think they will want to

potentially conduct a search. After manually drawing the polygon on the map, the user will continue with the tool for Step Two. The user can specify the statistics to extract for the final output and the geometry type for the search area polygon. The user can also specify if they want to extract the MPAs that are within the search area polygon or within a user specified distance of the search area polygon. Then, the user can specify if they want to output the geographic positions for the vertices of the search area polygon. This is useful for tasking enforcement assets to search within specified GPS positions that they can input in their navigation systems to create a search pattern based on local conditions, size of search area, and the type of vessel being searched for. Figure 18 shows sample output search areas from Step Two.

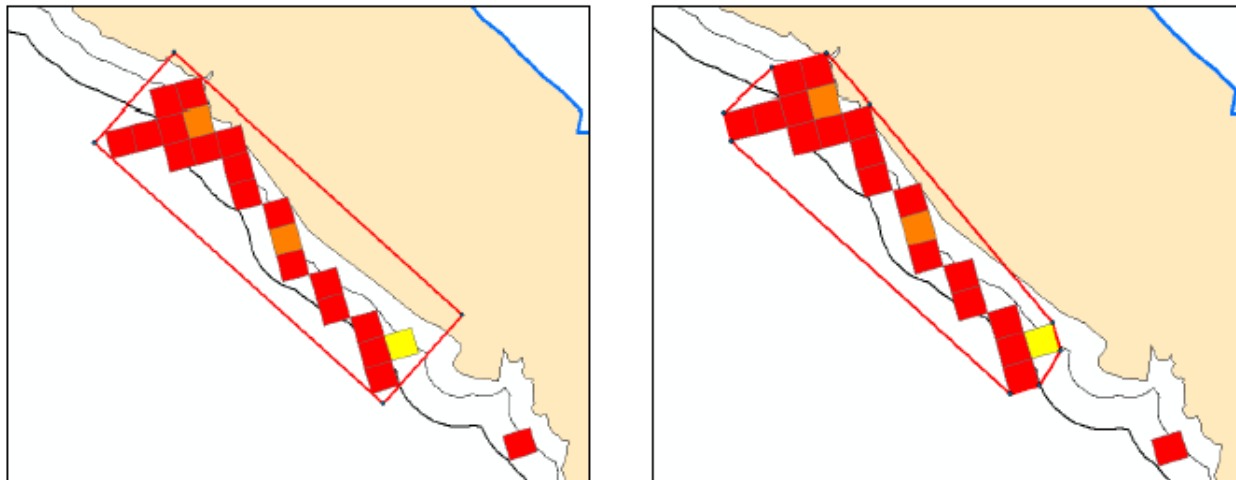


Figure 18: Sample options for patrol area design. Options for search area design include convex hull, rectangle by area, rectangle by width, circle, and envelope. On the left is a rectangular (rectangle by width) search area with only four vertices. On the right is a convex hull with more vertices, but smaller total area.

Outside of this tool, the user can make a reasonable estimate of the amount of vessels that should be within the search area for a given period of time using factors such as the number of active federally permitted fishing vessels in the fishery, the homeport locations of the permit holders, the length and current time within the fishing season, and the status of the fishery quota for the year. Using this information, the enforcement officer can then move forward with tasking enforcement assets or redesign their potential search area until they get a manageable amount of search area with a reasonable likelihood of finding the type and number of fishing vessels they

are seeking. Figure 19 shows a sample of the final output search area with the MPAs intersecting the search area and a sample of the output search area vertices locations.

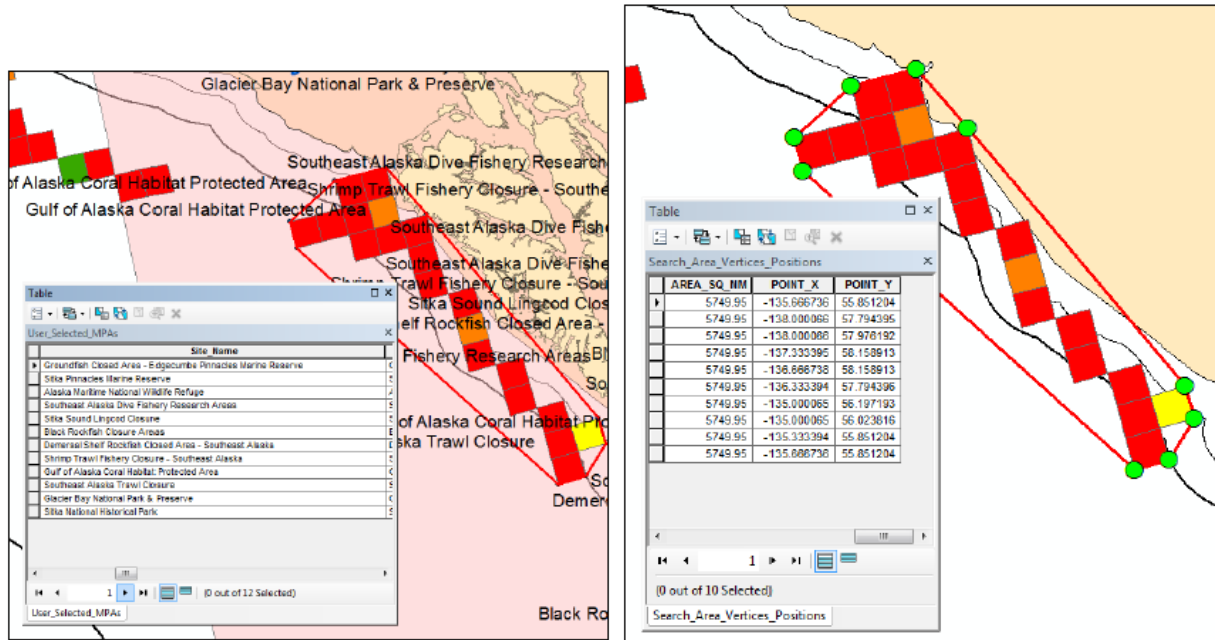


Figure 19: Sample outputs of MPAs intersecting the search area and the search area vertices' locations. These products will allow operational planners to design an enforcement strategy to enforce all closed or managed areas related to the fishery and easily distribute the search locations to operational units.

The significance of this tool is that Alaska's groundfish fisheries are very complex and comprises a vast area of the ocean. Enforcing these fisheries is tough due to the large spatial area and hazardous environmental conditions. Searching for vessels in the open ocean is the toughest part of achieving the Coast Guard's enforcement targets in Alaskan fisheries. By narrowing the searches to areas where the vessels are likely to be found fishing for a specific species, the Coast Guard can reduce search times to improve enforcement efforts and increase the efficiency of employing these resources.

Recommendations to Improve Enforcement in the GOA Sablefish Fishery

Given the spatial mismatch between USCG GOA Sablefish enforcement boardings and the areas of fishing effort targeting Sablefish, my first recommendation is for the Coast Guard to spatially match their patrol areas to the known fishing grounds. This involves conducting patrols along the

continental shelf break in the Gulf of Alaska in the locations of these Targeted Sablefish Grid Cells. Many of the GOA Sablefish boardings were conducted near Coast Guard units and in areas of high vessel densities such as port entrances or inlets. These locations may be areas where the Coast Guard can continue to achieve boardings, but in order to board vessels actively fishing at sea, the Coast Guard should focus on boarding vessels on known fishing grounds for the target fishery. The Coast Guard may wish to evaluate whether the operational capabilities of the enforcement assets used to enforce the GOA Sablefish fishery are well matched to the locations and environmental conditions of the fishing grounds.

On smaller time and space scales while conducting patrols, the Coast Guard could use alternative means to locate fishing vessels such as listening to radio traffic on VHF frequencies popularly used by fishers, conducting boardings where the fishers offload their catch, or using AIS data to locate areas with high vessel traffic density. In Alaskan commercial fisheries, where the spatial scale can be thousands of nautical miles, the Coast Guard needs to allocate enforcement assets efficiently to achieve the target level of effective enforcement for these high value fisheries. Additionally, the Coast Guard should consider increasing Sablefish fishery boardings around Dutch Harbor and other known landing locations to minimize search times.

Violation Hotspots

According to Ocean Guardian, the Coast Guard LMR Program's first goal is to "Prevent illegal encroachment of the U.S. Exclusive Economic Zone by foreign fishing vessels" (USCG 2004). Through examining MISLE data, the Coast Guard can identify hot spots along the EEZ border where incursions and violations tend to occur. The three primary high threat areas for U.S. EEZ incursions are the Maritime Boundary Line with Russia in the Central Bering Sea, the Central and Western Pacific, and the U.S.-Mexico boundary line in the Gulf of Mexico (USCG 2004). Along these boundaries, there may be certain hotspots where incursions tend to occur. Factors such as distance from land, time of day, moonlight intensity at night, and weather conditions may be predictors for incursions. Using past data on violations, spatial and temporal correlations can be made between these factors and the locations of EEZ incursions. Then, enforcement assets can be positioned to effectively deter and detect violations.

Spatial analysis of MISLE boardings records may also show that some areas tend to have higher numbers of violations and more significant violations. Knowing when and where violations are likely to occur would allow the Coast Guard to predict these occurrences and target violators (Randall 2004). Eventually these repeat violators may be removed from the fishery, which has a direct on compliance as well as an indirect effect of increasing compliance behaviors of other fishers (Randall 2004). Although I did not find any clear patterns in my analysis of all fisheries, specific fisheries may have areas where significant or numerous violations tend to occur. Further analysis for each specific fishery will have to be conducted at varying time and space scales in order to find any patterns that provide the Coast Guard with usable information.

Future Work

This study primarily focused on analyzing historical fishing effort and enforcement effort data to define large scale patterns and modify enforcement strategies to take advantage of these patterns. As the Coast Guard works towards improving enforcement through geospatial analysis, they should continue refining enforcement strategies at smaller spatial and temporal scales and take advantage of local patterns to comprehensively improve compliance across all fishing sectors at each geographic level. The National Marine Fisheries Service has been collecting spatial historical fishing effort and catch data for many fisheries. This data may be useful for identifying ways to improve enforcement. The Coast Guard should begin analyzing additional fisheries where enforcement targets have been difficult to meet. Finding where the fishers conduct fishing activities is the first step to improving at-sea enforcement.

For some fisheries, focusing enforcement on historical fishing grounds may not be a viable way to design an enforcement strategy. Fisheries with highly mobile and sparsely populated fleets may not concentrate their fishing effort in predictable ways that are easy to detect by patrolling enforcement assets. For these fisheries, I recommend creating a predictive model based on oceanographic features that forecast where the fish, and therefore the fishers, are located. For the Atlantic HMS fishery, this may be the next step to refining enforcement strategies beyond the large spatial and temporal scales addressed in this study. This will require fisher presence data in relation to predictable oceanographic features to accurately predict future fisher locations. The limit to how far in advance, and to what spatial accuracy, these fisheries can be predicted is

limited on the temporal and spatial limits of the predictive inputs to the model. There are sea surface temperature (SST) predictive models that may be useful in predicting future Atlantic HMS fishing effort, but these models will only be able to predict out so far in the future and spatial resolution will be limited. These are future steps to improving enforcement efficiency that should be considered when the effectiveness of using past fishing effort data has been maximized.

The Coast Guard could also begin to analyze not only their boarding records, but patrol effort data to see where patrols are effective at finding the targeted fishers. There may be areas where the Coast Guard has historically concentrated patrol efforts, but few or no fishers were found and boarded. These areas could be identified and those patrolling efforts could be reduced and directed towards areas of higher fishing vessel and violation densities.

To further analyze current enforcement strategies, the Coast Guard should begin recording spatial data on where patrols are conducted and determining the number of fishing vessels sighted or boarded at those locations in relation to the amount of patrolling effort being expended. By conducting systematic flight surveys to determine the locations and activities of fishing vessels, the Coast Guard could determine areas of high fishing vessel densities and dispatch enforcement assets accordingly. Keeping “presence” information on sightings of vessels that are not boarded, and their activity at the time of the sighting, may also help to increase awareness of fishing vessel spatial patterns. This option is one potential additional use of the MISLE database. These sighting records could further add to the spatial awareness of fishing vessel location patterns and help with predictions.

Analyzing MISLE for fisheries and areas with exceptionally high numbers or degrees of violations could also help the Coast Guard identify times and locations in fisheries where violations are more likely to occur. Planning operations around intelligence to better target high threat areas during which fisheries regulations are likely to be violated may be effective at deterring or apprehending violators. For these situations, the Coast Guard could increase presence of enforcement assets by steaming with the fishing fleet, using aircraft to conduct fly overs, or increasing boardings on the fleet. The increased presence of federal law enforcement

could be a deterrent to fishers violating regulations without having to board every fishing vessel in the fleet (Randall 2004). Concentrating enforcement activities in a focused “pulse operation” to achieve more boardings in a smaller period of time will also minimize the total amount of resources it takes to achieve enforcement targets.

As stated in the Coast Guard’s strategic plan for living marine resources enforcement, Ocean Guardian, the Coast Guard will continue advocating incorporation of VMS into the management plans for fisheries that require monitoring of protected areas (USCG 2004). This will decrease the amount of patrol effort spent ensuring that fishers do not fish, or in some cases transit, inside of closed areas. For foreign fishing vessels legally fishing near U.S. waters or in international fisheries that the U.S. enforces, the Coast Guard should advocate the use of U.S. compliant VMS systems in international fisheries to detect suspected EEZ incursions (USCG 2004). Continuing to train District Living Marine Resources Officers and Fisheries Intelligence Analysts in geospatial analysis techniques will help the Coast Guard evaluate and design better enforcement strategies. Turning raw fisheries and enforcement data into meaningful intelligence is a key to future success. Combining intelligence with real-time observations will allow operational commanders to plan effective patrols and accurately dispatch response assets in a timely manner.

Employing geospatial analysis as a method of improving enforcement is a low cost and effective method of achieving these strategic goals. For every fishery that presents a problem for enforcement, the Coast Guard can conduct simple analyses and begin to see trends in fishing patterns, gaps in enforcement, and potential hotspots of violations. As these techniques are used, it is important to evaluate their effectiveness and adapt them accordingly. By examining and learning from past efforts and refining these strategies, the Coast Guard will ultimately use fewer resources to achieve a higher level of compliance in federal fisheries.

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Appendix A

Recommendations for improving the accuracy of boarding locations in MISLE:

- 1) Make every effort to enter a geographic position where the vessel was first spotted so that the activity at the time of sighting corresponds with this location. If the boarding is conducted at a different location or when the vessel changes activity, note that location and the vessel's change in activity in the comments section.
- 2) Pay special attention to the difference between decimal degrees and degrees-minutes-seconds format for latitude and longitude. Ensure that the correct format is entered into MISLE.
- 3) Enter the vessel's observed activity at the time of sighting. This should correspond to the geographic location at the time of sighting. Pay special attention to whether the vessel is in the act of fishing (ENGAGED IN FISHING), as this designation has a special importance to future analyses.
- 4) Ensure the hemisphere assignment to the location is accurate. Latitudes in the northern hemisphere have a positive sign. Latitudes in the southern hemisphere have a negative sign. Longitudes west of the Prime Meridian have a negative sign. Longitudes east of the Prime Meridian have a positive sign.
- 5) Pay special attention to the sign of the longitude in the Pacific Ocean near the International Dateline. Entries could appear to be correct, even with an incorrect sign, if the location lies near the International Dateline.
- 6) Pay special attention to the sign of the latitude near the Equator. Entries could appear to be correct, even with an incorrect sign, if the location lies near the Equator.
- 7) If there is no spatial location for the boarding when the MISLE entry is being completed, review track logs and any other available information to get the most accurate location possible for the boarding.
- 8) After the MISLE entry is completed and submitted for approval and review, each reviewer should ensure that the geographic location of the boarding is correct and coincides with the vessel's observed activity at that location.
- 9) Make an effort to submit MISLE entries for sightings of vessels, even if they are not boarded. This will help identify areas where vessels transit or conduct fishing activities.
- 10) Revised MISLE so that multiple fisheries ("FISHERY_TYPE") are allowed to be recorded for vessels that are actively fishing for numerous species. Species such as Atlantic Monkfish are typically not the main target species for fishing vessels. Since only one fishery is able to be entered in MISLE, there is a false sense that boarding targets in some fisheries are not being achieved. Allowing multiple fishery types to be entered for

each boarding will ensure that every federally permitted fishery that the vessel is engaged in will be recorded and count towards enforcement targets.

- 11) Avoid entering the same geographic location for every boarding that the unit conducts or every boarding that is conducted during a patrol or enforcement period. This appears to be a common occurrence when high intensity enforcement operations are conducted during a short time period.
- 12) If in doubt about the location entered into MISLE, verify that the location makes logical sense by plotting it on a chart or computer-based mapping service. If the geographical position is on land, in the wrong hemisphere, or in the wrong body of water, correct the MISLE entry before submission.