Using VMS data to characterize fishing activity In the US yellowtail flounder [Limanda ferruginea (Storer 1839)] fishery

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Abstract

The traditional source of fishing effort data used to assign catches to statistical areas has been shown to be inaccurate, except for low resolution stock areas (Nies and Applegate, in press). Alternative sources of information include observed tow locations from sea sampling and vessel monitoring systems (VMS).

This analysis proves a reasonable and statistically valid association between VMS positions tagged as fishing activity and observed tows for 29 randomly selected trips from the groundfish trawl fishery. Unlike sea sampling which observes a small fraction of trips, the much more comprehensive VMS data can be used to more precisely determine where fishing occurs, allowing more accurate analyses of fishing effort and catch assignment at much higher resolution than is now possible.

Introduction

Vessel monitoring systems (VMS) that frequently detect and report a fishing vessel's location were deployed in selected US fisheries, beginning with the sea scallop [Placopecten magellanicus (Gmelin, 1791)] fishery in 1997. Initially, the US program was meant to count fishing effort against a vessel's annual effort allocation. This program however has expanded to address other uses and benefits, including monitoring compliance with closed areas. Internationally VMS programs have been deployed as well. The FAO Fishing Technology Service (2006) lists 14 countries and 5 regions of the US where VMS has been deployed, primarily to monitor compliance with fishery regulations.

Identifying where vessels fish and what they catch is also important information for both management and stock assessment. For the former, knowing where various fisheries and types of vessels operate enables estimation of how proposed fishery regulations will affect mortality, bycatch, and profits (NEFMC 2003; NEFMC 2006). For the latter, the location of catch may be important to assign catch to the appropriate stock area. The location of catch can be determined either through direct observation (such as through on-board observers) or through self-reporting by fishermen. Because of the costs of on-board observers, catch location in many fisheries is determined through vessel interviews or trip reports, or a combination of both.

In the NE region of the US, the primary source for catch location information is the vessel trip report. Landings are assigned to stock area based on rectangular three-digit statistical areas which are self-reported by captains on vessel trip reports (Wigley et al 1998). In some cases, the reported latitude and longitude for the general area fished is inconsistent with the reported statistical area, which is 'corrected' by an algorithm. To estimate total fishing mortality, discards are also often estimated and added to the landings, based on estimated discard to kept ratios in each statistical area (e.g. NMFS 2005). As a result, if the self-reported vessel trip reports are inaccurate, it can lead to substantial inaccuracies in the estimated catches and therefore in the assessments. Many groundfish stocks are assessed using virtual population analysis (VPA), a model which assumes that the catch is known without error (Hilborn and Walters 1992). Thus improper allocation to catch by stock area can lead to inaccurate estimates of stock size and mortality.

The most comprehensive source of fishing location data are vessel trip reports (VTR), which the US National Marine Fisheries Service (NMFS) requires of nearly all vessels fishing in the US Exclusive Economic Zone of the Northeast Region (ME to VA). These data are self-reported, but there is only data-level auditing and no external verification for this program. Wigley et al. (1998) used these data to prorate the dealer-reported commercial landings of cod (Gadus morhua), haddock (Melanogrammus aeglefinus), and yellowtail flounder by stock (Georges Bank, Gulf of Maine, Southern New England/Mid-Atlantic). Although the reported landings on VTRs was thought to be suspect, Wigley et al. (1998) prorated the dealer landings based on the proportion of VTR landings by stock area because the two data sources could not be reliably matched by trip. Both data sets were stratified by quarter, port group, and gear group.

Wigley et al. (1998) assumed that the VTR location data were accurate and did not examine how frequently VTR reports were made for more than one statistical area. Many (particularly large offshore) vessels fish in more than one statistical area on a trip and there was no examination of the newly available VMS data to validate the VTR area information.

Our analysis of the 2004 and 2005 yellowtail flounder fishery (Nies and Applegate, manuscript) showed that many vessels fished in more than one statistical area, but reported fishing in only one. Furthermore, a substantial proportion of reports were for the wrong area and often the catch was assigned to the wrong stock.

A second source of effort distribution data can be derived from the positions and characteristics of the vessel monitoring system (VMS) program. Many vessels are required to participate in this program to enter certain fisheries, participate in special access programs, or to count individual DAS use. Vessels are randomly monitored or polled every hour or less for its position while the vessel is seaward of a VMS demarcation line[1]. The vessel's activity can be deduced from the distance between successive pollings and the vessel's location, which allows the calculation of an average speed between pollings. These data can also be matched on a trip by trip basis with vessel trip reports or other data to assign additional characteristics of the vessel or its landings to the VMS data.

A sub-sample of trips are also observed by the NMFS Sea Sampling Observer Program (http://www.nefsc.noaa.gov/femad/fsb/). Observers are place on vessels for the duration of a trip to observe catch, bycatch, and interactions with marine mammals and sea turtles. Most vessels fish around the clock, but even though not all tows are observed, the total catch and location of all tows are recorded (theoretically). For some stocks, these data have been analyzed to estimate total discards (e.g. Mayo and Tercerio 2005), but the sampling intensity has been too low to characterize the entire catch of target species and assign it to statistical area. Not only is the location of each tow recorded in the sea sampling data, but the composition of the kept and discarded catch is also measured and recorded. A relatively small fraction of trips are observed, however, but more importantly thee is no statistical basis for expanding the distribution of observed effort to estimate total effort by area. Observed trips tend to over-sample large vessels that tend to operate offshore on extended trips.

VMS data for the scallop fishery had been used to characterize fishing activity (Rago and McSherry 2001) based on the implied vessel speed (1.9 to 7.4 km/h) between successive 30 minute VMS pollings. The vessel's position is recorded and the average speed between polling events is computed by the system from the Cartesian distance between successive positions, divided by time. Speed profiles by vessel demonstrated a distinct

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[1] The demarcation line runs in an irregular fashion, but approximately parallels the coastline for up to a few miles from shore.

bimodality which was presumed to correspond to fishing activity and transiting (aka ‘steaming’) from ports and among fishing locations. A similar analysis was performed to analyze the impact of closed areas on the distribution of fishing activity in the NE multispecies fishery (Murawski et al 2005). In this instance, observer data was used to determine likely speeds that indicated fishing activity and this speed was used to classify VMS positions as “fishing.” Murawski et al (2005) did not examine whether this classification was consistent with observed tow locations, however.

Between VMS pollings, a vessel may continue in the same direction, either towing fishing gear, steaming to its destination, or stopping to handle gear and process the catch. Many vessels generally follow depth contours to avoid changing the scope and performance of the fishing gear. While fishing in a general location, vessels often work back and forth over the same or nearby areas. Therefore a VMS poling may happen toward the end of one tow and then near the beginning of the next tow, giving the possibility that successive VMS pollings may occur near one another if the second tow reversed direction. Such an event would underestimate the true vessel speed, potentially indicating that the vessel is drifting to handle the gear or process the catch. Some vessels also increase speed when hauling the gear to deliver more power to the winches, if the hydraulics are driven off the main engine(s). This action would increase the computed vessel speed such that the action may not be classified as fishing.

Despite this possible pattern of fishing, a primary mode centered on known towing speeds based on survey protocols using dredges and observations aboard commercial vessels. In a preliminary analysis of the VMS data for vessels using trawls, slow speeds were included as being characteristic of fishing to account for the occurrence of reversals in the vessel’s heading while fishing on successive tows.

Similarly, our analysis of the yellowtail flounder trawl fishery VMS data (defined as those matching vessel trip reports having more than 226.3 kg (499 lbs) of yellowtail flounder landings) showed a similar pattern (Figure 1) of bimodality that Rago and McSherry (2001) observed for the scallop fishery. Vessels targeting yellowtail flounder are entirely different from those examined by Rago and McSherry (2001) because very few of them qualified for a scallop limited access permit. The yellowtail flounder vessels also use trawl nets which are often towed about 5.6 km/h (3 kn), instead of dredges which are customarily towed faster.

When attempting to characterize the fishing locations using VMS data, however, questions arose about the appropriateness of characterizing fishing activity based solely on this anecdotal information and the VMS speed profiles. Vessel speeds in fisheries other than the scallop fishery showed similar bi-modal patterns that indicated a vessel was fishing or steaming, but the absolute speed was different and there was no proof that these positions were where fishing actually occurred

Deng et al. (2005) examined VMS data for Australia’s northern prawn fishery to estimate how well the VMS data were able to accurately describe trawl tracks. They concluded that VMS data with polling intervals longer than 30 minutes could not accurately describe the trawl tracks, but VMS data could perform well to estimate fishery effects with acceptably short VMS polling intervals. This conclusion is probably not universal, because fisheries operate differently and tow duration varies.

In a similar analysis to ours, Salthaug (2006) analyzed VMS data for two Norwegian Sea factory trawlers which were automatically polled every 60 minutes. Detailed logbook data of self-reported haul locations were associated with the VMS data classified by speed, based on the position of and time between successive VMS pollings. Salthaug (2006) found that trawling activity (as indicated by the logbook) was highly probable around VMS positions with calculated speeds around 7.5 km/hr (4 kn). The VMS positions were not definitive, however, because the probability that the VMS position was near a trawling location peaked at 0.7-0.8. This probability fell below 0.5 when the VMS calculated speed was above 9.3 km/hr (5 kn) for one vessel and 11.1 km/hr (6 kn) for the other vessel. There was no evaluation of a lower threshold to be associated with non-fishing activity, possibly because factory trawlers fish more or less continuously unlike fishing activity on smaller vessels. Salthaug (2006) concluded that while the VMS data were indicative that trawling activity was occurring, “speed [data] alone could not be used to determine with high degree of accuracy whether the vessels were trawling or not.”

To test whether the VMS speed data for the US yellowtail flounder fishery could be used to determine where fishing occurred (for association with catch and fishing effects), we systematically compared observed tow locations in sea sampling data with VMS positions. Observed trips were matched to VMS trips using the hull number, date sailed, and date landed, and the VMS position time stamp was used to identify individual positions on a given trip.

The objective of this analysis was to show that VMS pollings tagged based on interpolated vessel speed as being representative of fishing activity were more closely associated to observed hauls than were VMS pollings that were characterized as not fishing. VMS data were also examined in more detail for a subset of trips to show that the general pattern of the VMS fishing activity accurately matched the locations of observed tows. We were not interested in whether a specific VMS polling represented fishing activity, but rather whether the VMS characteristics for a vessel could be used to reliably identify generally where the vessel fished during a trip and for how long it fished, rather than to identify specific trawl tracks as in Deng et al. (2005) or specific tow locations as in Salthaug (2006).

.Methods

This analysis focused on trawl trips landing significant amounts of yellowtail flounder to analyze VMS data for the groundfish trawl fishery. The observer database included 1,912 observed trips landing more than 226.3 kg (499 lbs.) of yellowtail flounder in 2005, but only observed trips that could be matched with vessel trip reports and VMS data were selected for further analysis (not all vessels landing yellowtail flounder on observed trips apparently had VMS equipment). Still, the 209 trips were too many to process manually using the ArcView® GIS program and statistically analyze the geographical relationship between the VMS data and the location of observed hauls. Instead, a subset containing 29 trips (15%) was randomly selected for direct comparison of the observed hauls with the ordered VMS polling data, categorized as fishing or non-fishing activity. In the aggregate, these trips displayed the same pattern of fishing and non-fishing activity (Figure 4) as the entire fleet (Figure 5).

The VMS and observer data were mapped and analyzed using ArcView® GIS software using a Universal Transverse Mercator projection (Zone 19N). Distances were measured in meters, between an observed haul and the nearest VMS position characterized as fishing (FVP), as well as the nearest VMS position characterized as not fishing (NFVP). There were 790 observed hauls for the 29 randomly selected trips. In addition, all distances between every FVP (N=2,985) and the nearest observed haul were measured. Distances between all NFVPs and the observed hauls were not measured, because many of the NFVPs were associated with transiting to port and were of no interest to the analysis.

These distance pairs were tested via a two-sample t-test and an ANOVA with the null hypothesis that the distances between the observed hauls and the FVPs were no different than the distances to the nearest NFVP. Rejection would mean that the FVPs had a better geographical association with observed fishing activity than other VMS polling, suggesting that our application of vessel speed to characterize fishing activity was reliable. The two-sample t-test was also used to test for differences in the mean distance between all FPVs and the nearest observed tow vs. the mean distance between the nearest NFPV and observed tow.

Results and discussion

The VMS data that matched VTR data for trips with more than 226.3 kg (499 lbs) of yellowtail flounder landings included 864 trips by 161 vessels in 2004 and 888 trips by 147 vessels in 2005 (Table 1). Between 134 and 138 thousand VMS pollings in each year were recorded between the trip's sailing and landing dates as recorded in the VTR. In comparison, the 2005 VTR data included 1,912 trips with more than 226.3 kg (499 lbs) of yellowtail flounder landings. Not all vessels landing yellowtail flounder however are required to operate VMS. Of these trips, 870 occurred in a management area where VMS were required while 919 occurred in an inshore management area where they were not required.

In both years, a strong primary mode in the aggregate speed profiles occurred at 5.5 km/h (3 kn) and speeds below 7.5 km/h (4 kn) were presumed to be associated with fishing activity. The mean speed was 4.31-4.32 km/h (2.3 kn), with a very small standard error (Table 1). These results are somewhat different than those in Murawski et al (2005), which analyzed the distribution of VMS polling data to compare with observer and VTR information. Murawski et al. (2005) assumed that VMS speed less than 3.5 knots constituted fishing activity, based on the towing speed recorded by sea samplers on observed trips.

The data for observed trips with landings more than 226.3 kg (499 lb) in 2005 (Figure 2) was likely similar to what Murawski et al. (2005) observed, but in addition exhibited secondary towing speed modes at 5.4, 5.6, 6.6 and 7.6 km/h (2.8, 3.0, 3.5, and 4.0 knots, respectively). Sea samplers are instructed to record the average towing speed over bottom for each haul, to the nearest tenth of a knot. These data do not appear to be actually measured in any way because nearly all tows on a trip have the same recorded tow speed.

More importantly, the observed tow speed probably reflects a maximum or intended tow speed, regardless of wind, current, and changes in tow direction. Here we are more interested in defining a range of calculated VMS speeds that are representative of fishing activity. The 60-minute interval between VMS pollings would smooth the tow speeds and have a negative bias relative to a straight line tow path speed. Thus while the tow speed recorded by observers is informative, it is too narrow to define the range of VMS characteristics that are representative of fishing activity.

A secondary, more-diffuse mode was evident at 15 km/h (8 kn) in both years, presumably associated with the vessel steaming from port and between distant fishing locations. The average speed was 13.8-14.0 km/h (7.5 kn), and corresponded with the usual cruising speed for many vessels in the groundfish fleet. VMS pollings above 7.5 km/h (4 kn) were therefore assumed to be not fishing.

Assuming that average speed less than 7.5 km/h (4 knots) was associated with fishing activity, about 75% of the VMS positions were categorized as fishing. The fishing positions averaged 113-115 per trip, while those classified as non-fishing averaged 40-43 per trip. Both values were quite consistent across years.

For all vessels submitting VTRs, the VMS positions classified as fishing were distributed as expected in areas where yellowtail flounder are known to occur (Figure 3). The pattern of fishing (Figure 5) was consistent between years and non-fishing VMS positions seemed consistent with transiting from port and among the major fishing grounds. Some fishing activity on trips landing yellowtail flounder were in deep water, for example off the shelf edge south of New England. This fishing activity is however consistent with vessels targeting other species on specific tows. The area south of New England, for example, is a well known goosefish (*Lophius americanus*) area and many vessels that target yellowtail flounder also target goosefish on the same trips.

All observed hauls on trips whose VTR had at least 500 lbs of yellowtail flounder were used in the analysis. Of the 888 trips that reported landing more than 226.3 kg (499 lb.) of yellowtail flounder during 2005, 209 of them were observed by the NMFS sea sampling program.

The randomly-selected subset in the analysis combined the VMS and observed haul data for 29 trips taken by 27 vessels, with 4,661 VMS pollings. All the diagnostic variables (Table 1) were very similar to those for the fleet as a whole. Overall, the subsampled trips averaged 114 VMS pollings classified as fishing and 46 classified as non-fishing. The average speed was 4.42 km/h (2.4 kn) while fishing and 14.1 km/h (7.6 kn) while not fishing. The VMS positions for these trips (Figure 4) appeared to also be representative of the general area of fishing, overall.

In general, the VMS positions characterized as fishing activity (FVP) were in good agreement with the observed haul locations (Figure 8). The haul locations represented the position where the gear was hauled and in many instances, the VMS positions leading up to an observed haul location could be identified (Trip O for example). There were in fact no areas on any trip with VMS fishing positions (FVPs) that did not have one or more observed tows in the general vicinity, although some tows caught few yellowtail flounder according to the observer data.

Most of the trips in the subset fished for groundfish in three primary locations, in good agreement with the observed hauls (Figure 8). These three locations were immediately NE of the Closed Area I boundary at 41°30'N latitude and 68°30'W longitude, along the northern edge of Georges Bank just west of the Closed Area II boundary at 41°30' to 42°00'N latitude and 67°30' to 68°00'W longitude, and SE of Closed Area II at 41°00'N latitude 67°30'W and longitude. The second general area of fishing was either inside of statistical areas 561 and 562 when the Eastern US/CAN management area was open to fishing or just to the west in statistical area 522 when the US/CAN management area was closed. Two of the selected trips (T and X) fished in Massachusetts Bay, north of Cape Cod, MA. This is an area were inshore groundfish vessels are known to target cod and yellowtail flounder. One trip (V) took a round trip around the Nantucket Lightship Area closed area, south of Cape Cod, MA, where it appears to have targeted monkfish in a traditional deep water area, cod along the western boundary of Closed Area I and then yellowtail flounder inshore before heading back to New Bedford, MA. All four locations on this trip where the VMS data suggested fishing activity had one or more observed hauls in the vicinity.

Vessels often fished in several local fishing areas during the same trip, possibly searching for better catches or targeting different species to maximize revenue and comply with various management limits. The VMS and observed haul data indicates that various trips in the subset fished in multiple locations, ranging from a single area up to seven distributed fishing areas (Trip B, Figure 8, for example). Eight of the 29 trips appeared to have fished in only one general geographic area. Others fished in several areas, including some that appeared to be testing the waters, so to speak, on the way to and from port.

Even with vessels fishing exploratory tows in different locations, the VMS pollings classified as fishing (FVP) appear to be associated with all of the observed fishing activity and there were few extraneous fishing sites indicated by the VMS data. Many fishing vessels in this trip subset appear to have fished some exploratory tows toward the beginning or end of the trip, based on the VMS data alone. In all but one case, these locations were very close to the location of observed tows.

For example according to the VMS data, trip G first began fishing NE of Closed Area I along the boundary (41°30'N, 68°30'W). The sea sampling data had one observed tow at this location, near the end of the vessel's travel while fishing. The core of the fishing activity for the trip happened SE of Closed Area I. But then on the way home, the VMS data suggests that the vessel fished in two general locations along the southern margin of Georges Bank, at 40°40'N, 67°00'W and 40°15'N, 68°40'W. The observer data had three tows located within the first general area and two tows within the second one.

In a different example, the majority of fishing for Trip J took place SE of Closed Area II, near 40°45'N and 67°15'W. On the way out, the VMS data indicates that the vessel traveled along the western boundary of Closed Area I, before fishing a bit along the southwestern edge of Georges Bank near 40°30'N and 68°40'W. On the way back to port, the VMS data indicates that the vessel fished for awhile along the northern edge of Georges Bank, near 41°45'N and 68°30'W. There were two observed tows at the former location and 4 observed tows at the latter location.

Trip P fished primarily just outside of Closed Area II, but the VMS data suggested that it also fished on the way from port along the NE boundary of Closed Area I at 41°30'N and 68°30'W. The observer data show two observed hauls within this general area (although they caught few yellowtail flounder), corroborating this VMS data treatment for the trip.

Trip ZC was similar to Trip J, except that there were no observed hauls in two locations where the VMS data indicated that 'fishing' had taken place. On the way out, the vessel appears to have traveled to the NE corner of Closed Area I, near 41°40'N and 69°30'W. Then the vessel steamed SE along the western boundary of Closed Area I and slowed to fishing speed due south of Closed Area I, near 40°40'N and 68°40'W. After that, the vessel traveled a little further south and both the VMS and observer data indicate that the vessel actually fished, with two tows catching a large amount of yellowtail flounder. The first two general areas where FVPs occurred had no observed tows, but the change in vessel direction may be indicative of a search for fish using sonar.

To test whether the FVPs were a better indicator of where fishing took place on the observed trips, the distance between an observed tow and the nearest FVP and NFVP was measured using the ArcView program using a Mercator projection. The minimum distances between the 790 matched pairs were much closer for the VMS data indicating fishing activity (FVP) than for non-fishing activity (NFVP) (Figure 6). Few of the nearest FVPs exceeded 1 km from an observed haul and many of the nearest NFVPs exceeded 4 km.

Over the 29 of the trips in the analysis subset, the average distance to the nearest FVP was 1,144 ± 96 m, while the nearest NFVP averaged 3,165 ± 379 m. The maximum distance between the nearest pairs were 4,631 ± 447 m for FVPs and 10,586 ± 1,154 m for NFVPs.

Examining the trips individually, the distribution of nearest neighbor distances was nearly always less for FVPs than for NFVPs (Figure 9), with the exception of Trips E and X.

For the 790 pairs taken as a whole, a two-sample T-test rejected the null hypothesis that the mean distance for the FVPs was not less than the mean distance for the NFVPs (Table 2). The mean distance to the nearest FVP was 1,059.9 ± 112.0 m, while to the nearest NFVP was 2,806.8 ± 132.6 m (Table 2). The two sample t-test was highly significant with a negligible p-value.

A two way ANOVA (Table 3) also showed that the classification of the VMS position based on vessel speed accounted for a substantial portion of the total variance, which gave a high F-ratio (91.1) and a negligible probability of rejecting the null hypothesis. Trips were also significant factor as was the interaction term, meaning that there was a difference in FVP and NFVP distances between trips. This may be related to differences in fishing behavior between vessels, such as tows repeated over the same area or increases in vessel speed to haul gear (see discussion below).

Lastly, it is also important to determine not only that the nearest FVP represented fishing activity, but that all VMS points classified as fishing (FVP) had a low probability of being associated with truly non-fishing activities. To examine this, we compared the 2,985 FVPs and the nearest observed haul with the nearest NFVPs (N=790). The nearest FVP should theoretically have smaller distances to observed hauls

The average distance between the 2,985 FVPs and the nearest observed haul was 3,136.2 ± 135.2 m, more than the 2,806.8 ± 132.6 m NFVP mean distance (Figure 7). While the average FVP distance is larger than the average NFVP distance, a two-sample T-test rejected the null hypothesis that the means were significantly different (alpha = 0.05) (Table 4).

This unexpected result prompted us to examine the progress of a representative trip in great detail to determine why the differences between all FVPs and observed hauls were not significantly less than the nearest NFVP, as we expected.

We examined the distance from the end of an observed haul to the nearest VMS position classified as fishing (FVP, vessel speed between 1 and 4 knots) and classified as not fishing (NFVP). We also compared the relative distance of the FVPs that were closest to the haul back location of observed tows, to the distance to the nearest NFVP for each observed tow. This second part helped reveal why the average distance between FVPs and hauls was not statistically different than the distance from the closest NFVP and observed haul pairs.

Trip A fished over 23 observed hauls in five distinct locations within statistical areas 522 and 525. During the trip defined by the date sailed and the date landed as listed on the vessel trip report, seventy-two (72) VMS positions were classified as fishing and (by chance) an equal number classified as non-fishing. There were no VMS pollings more than 7.81 km (4 nm) from the nearest observed haul that we classified as fishing based on imputed vessel speed.

Based on the VMS data, the vessel departed New Bedford, MA and accessed the ocean through Nantucket Sound, south of Cape Cod, MA. It steamed north of Closed Area I and began fishing 26 km (14 nm) northeast of Closed Area I, along the northern margin of Georges Bank, where it took three observed tows (see Figure 10). The first tow (#1) was hauled in at the eastern end of the range and the second tow appeared to double back on the first, hauled in by the vessel on the western part of the range. During the third tow, the vessel traveled NE again and hauled the net before steaming to a more remote fishing location. The observed catch was mainly cod with some winter flounder.

Within this range, there were three VMS positions (#17, 20, and 27) classified as not fishing (FVP). Position 20 may have been classified as not fishing if the vessel steamed a little before fishing the second tow. According to our statistical analysis, this VMS position was closest to the haul location for observed hauls 1 and 3. This non-fishing VMS position (NFVP) was furthermore no further away than the closest fishing VMS positions (#21 and 26, respectively).

For tow 2 (Figure 10), the closest NFVP appears as one when the vessel steamed to the general location to fish, but was associated with a tow that doubled back over the local fishing zone. There were 6 FVPs that were closest to the haul location for tow 2, all less than the distance to the nearest NFVP.

The vessel then steamed about 57 km (31 nm) to the NE to fish in about the same depth, a little to the west of Closed Area II. The vessel fished just outside the eastern Georges Bank US/CA management area, which was closed to fishing. The catch of cod was slightly higher than the first location, with a similar catch composition. Five tows were observed while the vessel fished in this local area (Figure 11) and the VMS positions suggest that the vessel towed back and forth in a NE/SW direction within a chosen depth zone.

VMS position 34 appears to have been registered as a NFVP after the vessel began is first tow, but before it had hauled in tow 4. Sometimes vessels increase speed during haul back to provide more power to the hydraulic winches, which may have increased the distance between position 33 and 34 above our 4 knot threshold. This NFVP was closest to tows 4, 6, and 8 within the eastern part of this local fishing area (Figure 11). This position was about the same distance as the FVPs that our analysis associated with tow 4, but was much further away than the seven FPVs associated with tow 8 and the two FVPs associated with tow 6. The closest FVP to tow 4 was actually VMS position 54 which appears to be more closely associated with tow 8.

The next NFVP was position 61, as the vessel began steaming away to the next fishing location to the SE. Our analysis associated this NFVP with tows 5 and 7. For both tows, the closest FVP was number 58 and was much closer than NFVP 61. Our analysis associated 13 FVPs with tow 5 (Figure 11), but the mean distance to these FVPs was greater than the distance from the haul back position of tow 5 to the nearest NFVP (#61).

The vessel on Trip A then steamed 98 km (53 nm) to the south to fish in the eastern part of statistical area 525, just to the west of Closed Area II. Along the way, the vessel fished one tow (#9) before tuning east to this new fishing location, where it took six more tows (#10 to 15). The vessel fished four tows (#11 to 14) by working in a N/S direction along the boundary of Closed Area II (Figure 12). It then fished observed tow 15 on its way west to the fourth fishing area during its trip. Unlike the previous fishing, the catches in these tows were dominated by yellowtail flounder and the catches of cod and winter flounder were much lower.

Within this area (Figure 12), VMS positions 79, 81, and 83 were classified as non-fishing (NFVP). All of them were close to tows 11 and 12 in the southeastern part of the fishing location. All also were very close to the previous VMS position either signifying that the vessel drifted or had doubled back on its path. In all three cases, it appears that this activity was associated with general fishing activity, but possibly not while the vessel had gear in the water.

In any case, our analysis associated these NFVPs with observed tows 11, 12, and 13, tows that were as close to these NFVPs as the nearest FVPs. The analysis associated no FVPs with tow 12, since all others were closer to adjacent tows 11 and 13 than they were to tow 12. NFVP #83 was also associated as the nearest non-fishing position to tow 14, much more distant than any of the four FVPs that were closest to the haul back location of tow 14 (Figure 12).

The analysis actually assigned the closest NFVPs for tows 10 and 15 that were in the next general fishing location on the trip, VMS positions 94 and 95 (Figure 12). Both were associated with other fishing activity, but were much more distant than the 3 FVPs associated with tow 10 and the two FVPs associated with tow 15.

After tow 15, the vessel moved about 5.5 km (3 nm) to the west, fishing eight more observed tows (#16 to 23, Figure 13). It appears that the vessel fished in an ENE/WSW direction, within which there were four NFVPs (#94, 95, 106, and 109), before steaming to the fifth and final fishing location via NFVP #110. Catches in this area were similar to the last, comprised mainly of yellowtail flounder according to the observer data.

NFVP 94 was associated with tow 17 and was closer than the nearest FVP 90, possibly due to the vessel speeding up to haul in tow 17. NFVP95 was classified as not fishing, possibly because the vessel might have steamed to a slightly different fishing location within the general area, but it was not the nearest NFVP to the haul back location of any adjacent tow. NFVP 106 was about the same distance from tow 22 as the nearest FVP 96, but closer than the average distance of the 4 FVPs that the analysis associated with tow 22. It was also much more distant than FVP 101 was to tow 19, but about the same as the average distance of the two FVPs associated with tow 19. The same sort of condition also occurred for tow 18, with respect to the six FVPs and the nearest NFVP 92.

The haul back locations of tow 18, 20, 21, and 23 were close to one another. All four were associated with NFVP 109 and FVP 104, which when taken together the two VMS positions were equidistant from the four tow locations.

After tow 23, the vessel then steamed 95 km (51.4 nm) to the northwest to make one final tow (#24) along the northern boundary of Closed Area I (Figure 14). The analysis classified one VMS position (#130) was classified as a NFVP, which appears again to have occurred toward the end of the tow when the vessel hauled its gear. In this case, the vessel may have slowed while the gear was brought aboard and therefore the analysis classified position 131 as a FVP. As a result of this set of events, our analysis associated six FPVs and one NFPV to tow 24, with the distance for the NFPV being less then the nearest FVP and also the average distance to all FPVs associated with that tow.

The results suggest that frequently there are VMS positions which can be classified as non-fishing events (NFVP) within the area being fished due to four potential causes.

- A vessel slows down to drift speed to handle gear
- A vessel speeds up to deliver more power to the hydraulically driven winch
- A vessel steams a short distance to get back to a preferred fishing location in the vicinity, and
- A non-fishing polling is associated with a haul simply because the vessel's path doubled back over an area that it had previously steamed passed.

Only 0.6% of the VMS positions classified as fishing on the 29 randomly selected trips were of sufficient distance from an observed haul that the characterization of fishing for that single position was incorrect. Furthermore, the result that the average distance of the nearest NFVP is no different than the average distance between all FVPs and the nearest observed haul does not invalidate the hypothesis and the method for using VMS positions to characterize fishing activity. Changing the thresholds that define fishing appears that it would include non-fishing activity (localized searching, gear processing, and haul back) and overestimate the total amount of time the gear is actually fishing.

Using speed profiles appear to be a valid method to determine the amount and location of fishing activity by unobserved vessels. The nearest FVP is statistically closer to the end of haul positions on observed trips than the nearest NFVP. Furthermore, examination of the position distributions of the 30 randomly selected trips reveals only a very small proportion of VMS positions that appear to be mis-classified as fishing activity.

The total haul duration on the 29 observed trips was 113.10 days. In comparison, the total duration between VMS pollings when the average vessel speed was less than 7.5 km/h (4 kn) was 127.89 days, an overestimate of 15.8% (range 3.7 – 55.2%). Although the VMS fishing time was in fairly good agreement with the observed fishing time, better agreement was achieved by establishing a minimum threshold on vessel speed defined to be 'fishing'. This minimum threshold may account for times when the trawl vessel was drifting to handle gear or process the catch.

The lowest sum of squared differences was achieved with a threshold of 1.85 km/h (1.0 kn) (Figure 15). Using this minimum VMS speed threshold to define fishing activity overestimated total fishing time by 5.1% (range -16 to +41%). Increasing the minimum VMS speed threshold to 2.4 km/h (1.3 kn) gave a best overall estimate of total observed fishing time (+0.6%, range: -26 to +41%), but agreement between the observed and VMS fishing time on individual trips was worse.

As such, the VMS data can be instrumental in assigning the proportion of fishing activity to statistical areas and performing more detailed analysis of fishing effort. In the vast majority of cases, vessel operators only make vessel trip reports for fishing activity in one statistical area, despite often fishing in more than one. Furthermore, a substantial amount of those are reported incorrectly, which may change the assignment of catch by stock area (Nies and Applegate, ms). VMS data has the potential to improve/correct the inaccuracies of the self-reporting system.

Conclusion

This analysis of the yellowtail flounder trawl fishery VMS data shows that characterizing vessel speed of 1.8 to 7.5 km/h (1 to 4 kn) as 'fishing' in the yellowtail flounder trawl fishery accurately characterizes the amount and spatial distribution fishing effort, because it corresponds very well with the observed haul locations and the distances from the observed hauls to the VMS positons were consistent with fishing activity. In addition, the total duration of fishing from the VMS data was consistent with the total duration of fishing on observed trips.

Like Salthaug (2006), this analysis showed that VMS positions classified as fishing are not always associated with fishing activity, and also VMS positions classified as not fishing appear in the general area where a vessel had been fishing. For other purposes (such as closed area enforcement), a different type of analysis would be needed to evaluate the probability of a VMS position classified as fishing being in an area where and when trawling actually occurred. Two or more such VMS positions (or more frequent polling) may be more definitive, so that speed alone can be used to determine whether fishing actually occurred at a specific location.

Although there is not a direct link between the VMS speed data and observed trawling activity, applying a filter to the computed average speed between VMS positions appears to be an accurate way to identify the location and amount of fishing activity on commercial trips using trawls (and possibly other mobile gear). The filter should be chosen based on speed profiles where modes distinguish fishing activity from transiting, considering information about how the gear is customarily fished.

Because the VMS data are more accurate and detailed than self-reported vessel trip reports and because they are a more complete representation of the fishery than are the observed trips, it may be possible to use VMS data to more accurately apportion catch by stock area and three digit statistical area, possibly by incorporating information on species distribution. The location and amount of fishing effort may also be used to determine the intensity and nature of habitat impacts as well as using the total effort to estimate bycatch from discard per hour fished data on observed trips. When coupled with gear size information from the vessel trip reports, the VMS data can also produce highly detailed maps of total area swept.

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Table 1. VMS summary statistics for VTR trips with reported landings of greater than or equal to 500 lbs. of yellowtail flounder.

	2004	2005	2005 subsample
Vessels	161	147	27
Trips	864	888	29
Average speed while fishing (km/h)	4.32 ± 0.04	4.31 ± 0.03	4.42 ± 0.08
Average speed while not fishing (km/h)	14.04 ± 0.09	13.77 ± 0.08	14.05 ± 0.19
Total VMS pollings	134,712	137,834	4,661
Average VMS pollings per trip while fishing	113	115	114
Average VMS pollings per trip while not fishing	43	40	46

Table 2. Two-sample t-test on minimum distance between the nearest VMS position to an observed haul, H0 = VMS fishing activity is not less than the distance to the nearest VMS non-fishing activity.

Group	N	Mean (m)	SE (m)
Fishing	790	1059.9	112.0
Not fishing	790	2806.8	132.6

```
Difference in means        =    -1746.8
95.00% confidence bound    =    -1461.2
t                          =      -10.1
df                         =     1534.8
p-value                    =      0.000
```

Table 3. ANOVA of minimum distance between an observed haul and the nearest VMS polling location, classified by activity (fishing vs. not fishing).

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
VMS activity	9.859E+08	1	9.859E+08	91.095	0.000
Trip	1.323E+09	28	4.726E+07	4.367	0.000
VMS activity * Trip	9.776E+08	28	3.491E+07	3.226	0.000
Error	1.647E+10	1522	1.082E+07		

Least squares means

VMS activity	LS Mean	SE	N
Fishing	1144.295	149.719	790
Not fishing	3165.174	149.719	790

Table 4. Two-sample t-test for equality in distances between VMS position and the nearest observed haul locations.

Group	N	Mean	SD
All fishing	2985	3136.207	7386.221
Not fishing	790	2806.756	3727.099

```
Separate variance:

Difference in means      =      329.451
95.00% CI                =      -41.882 to 700.784
t                        =        1.740
df                       =       2552.5
p-value                  =        0.082
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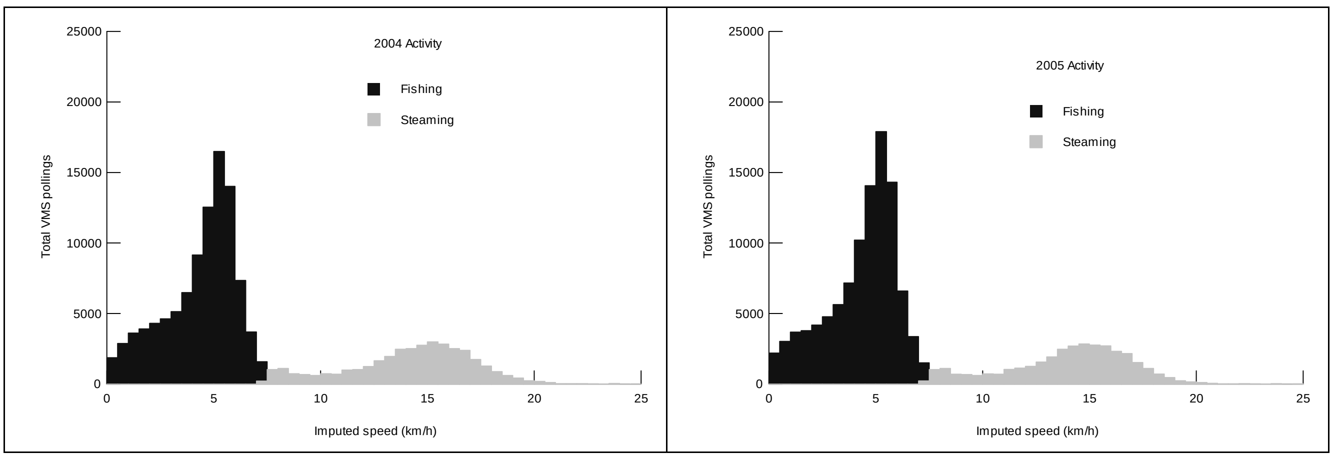


Figure 1. Frequency distribution of computed vessel speed between successive VMS pollings during 2004 and 2005. The vessels activity was categorized as 'fishing' if the average speed was less than 7.5 km/h (4 kn).

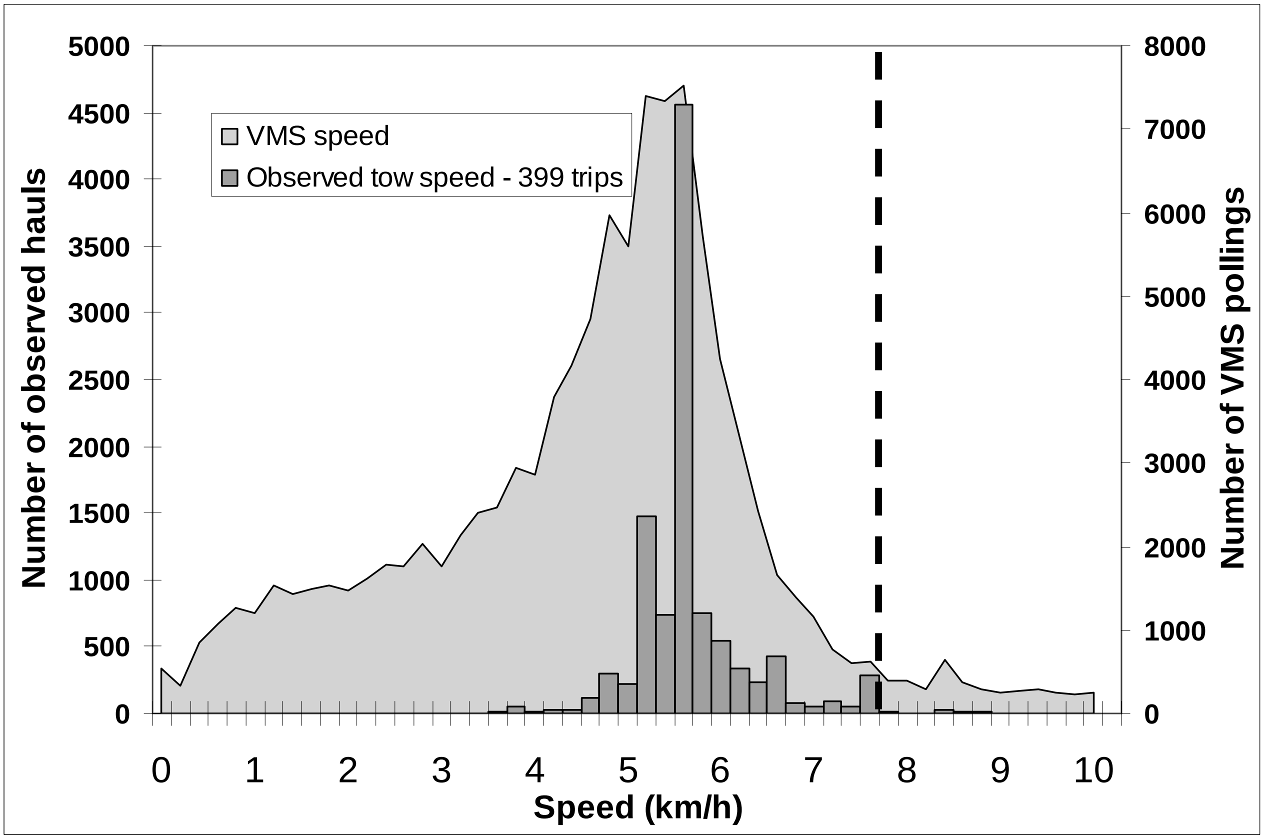


Figure 2. Frequency distribution of tow speed recorded by at sea observers and of vessel speed between successive VMS pollings on trips landing more than 226.3 kg (499 lb) of yellowtail flounder during 2005.

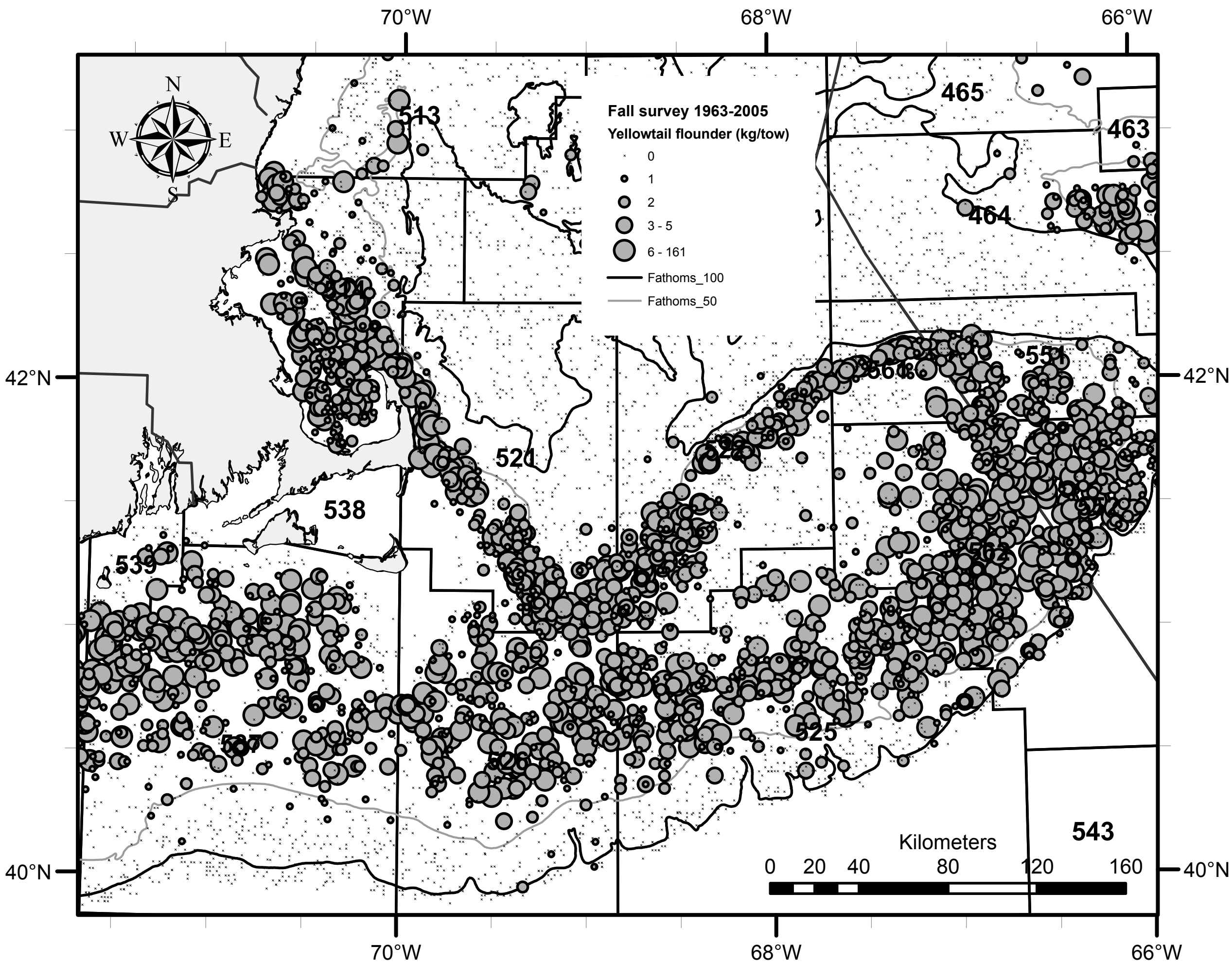


Figure 3. Georges Bank, southern Gulf of Maine, and Southern New England area abundance distribution for yellowtail flounder on the fall NMFS R/V Albatross survey, 1963-2005. The small x's represent tows with no yellowtail flounder. Statistical areas for commercial catch reporting and effort classification are shown.

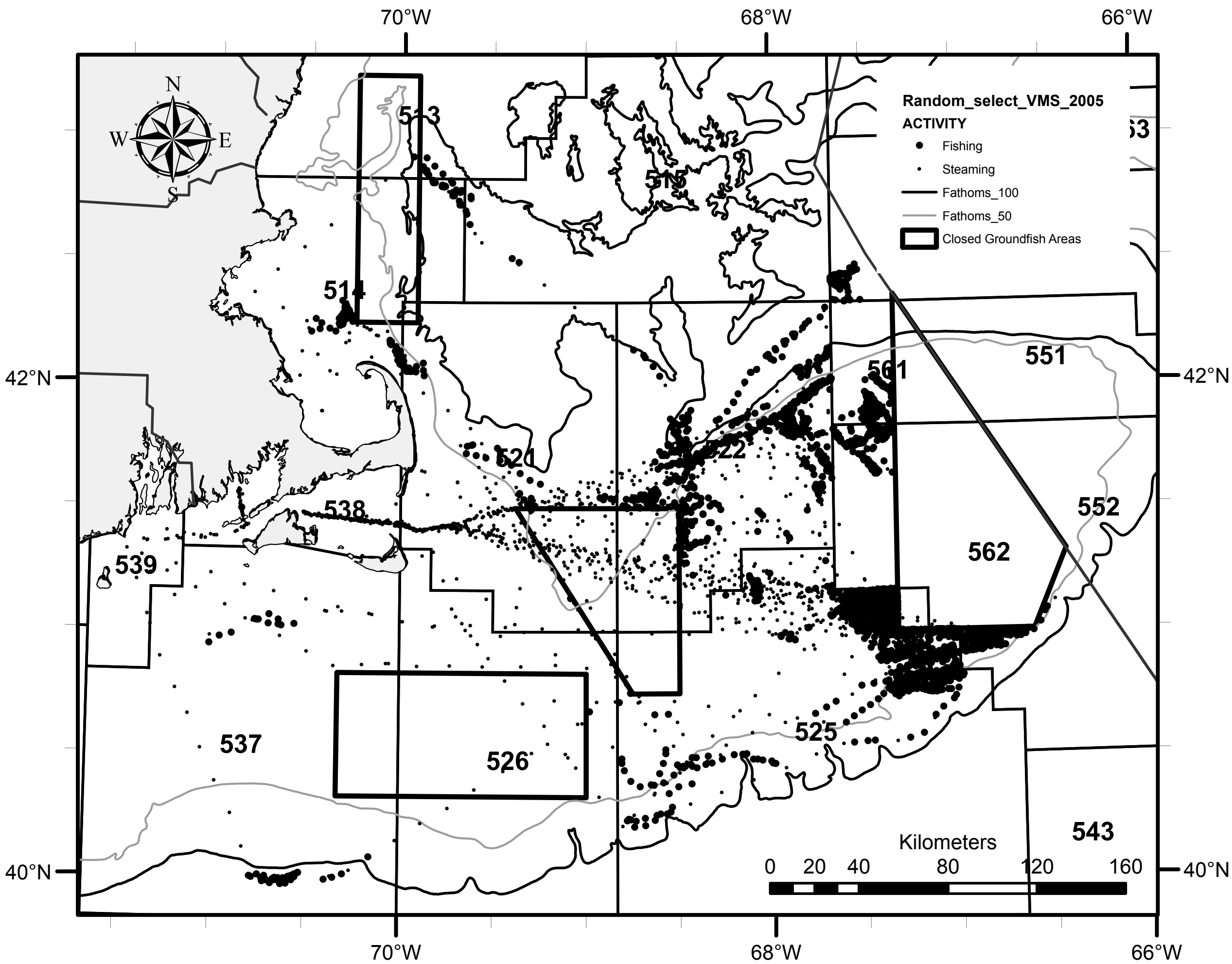


Figure 4. Distribution of VMS positions classified as fishing (dark) and not fishing (light) on 29 randomly selected trips having observed tows. Closed groundfish areas are shown for reference.

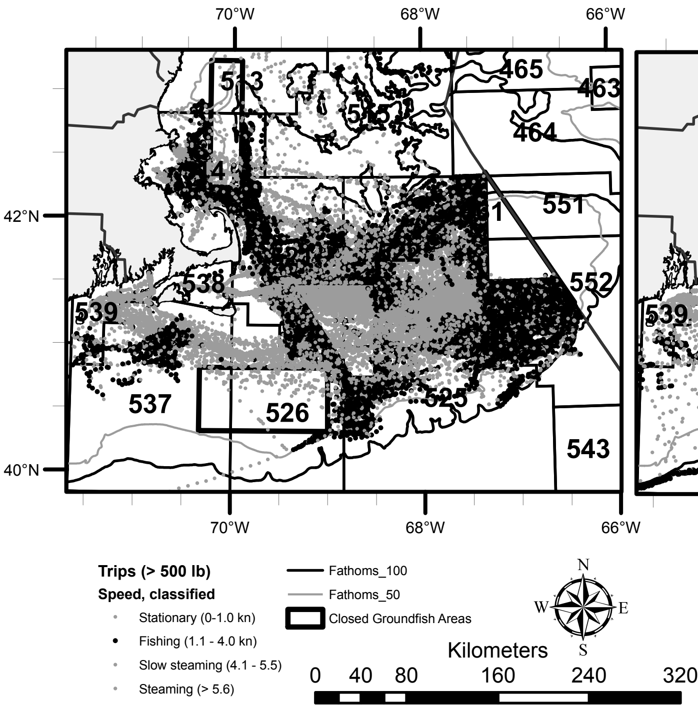


Figure 5. Distribution of VMS positions for vessels landing more than 226.3 kg (499 lb) of yellowtail flounder during 2004 (left) and 2005 (right). Dark VMS positions represent an average vessel speed between successive VMS pollings of more than 7.5 km/h (4 kn).

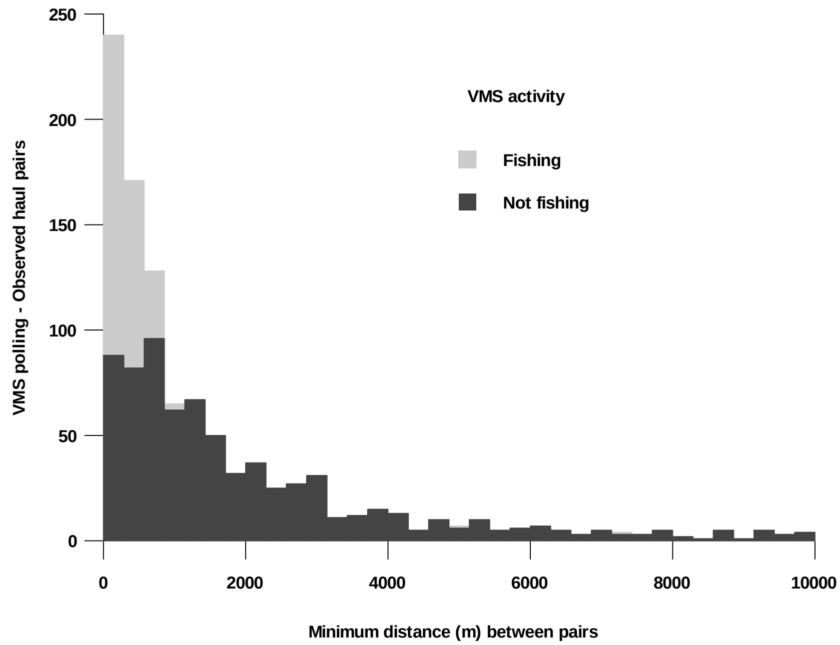


Figure 6. Frequency distribution of distance between an observed haul and the nearest fishing and non-fishing VMS position.

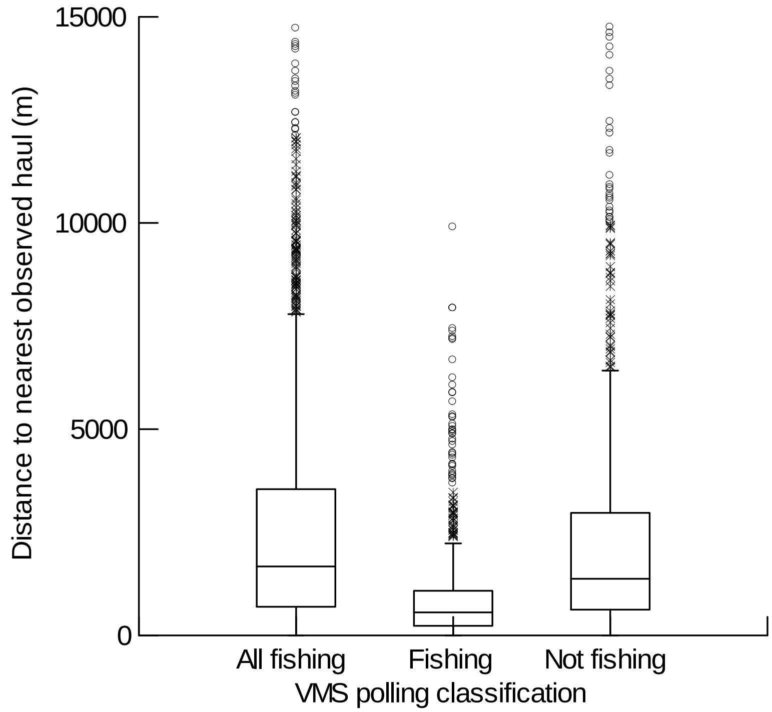
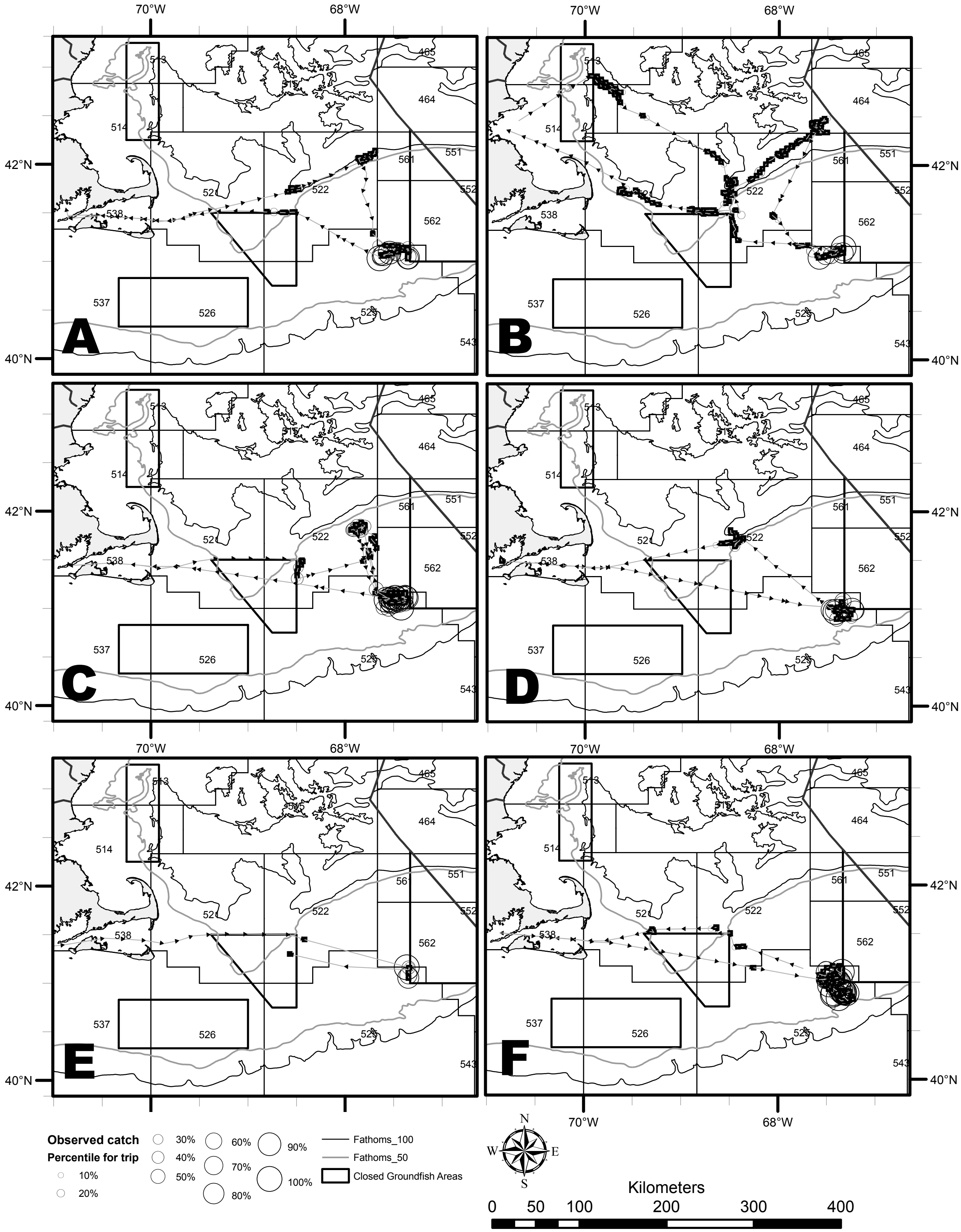
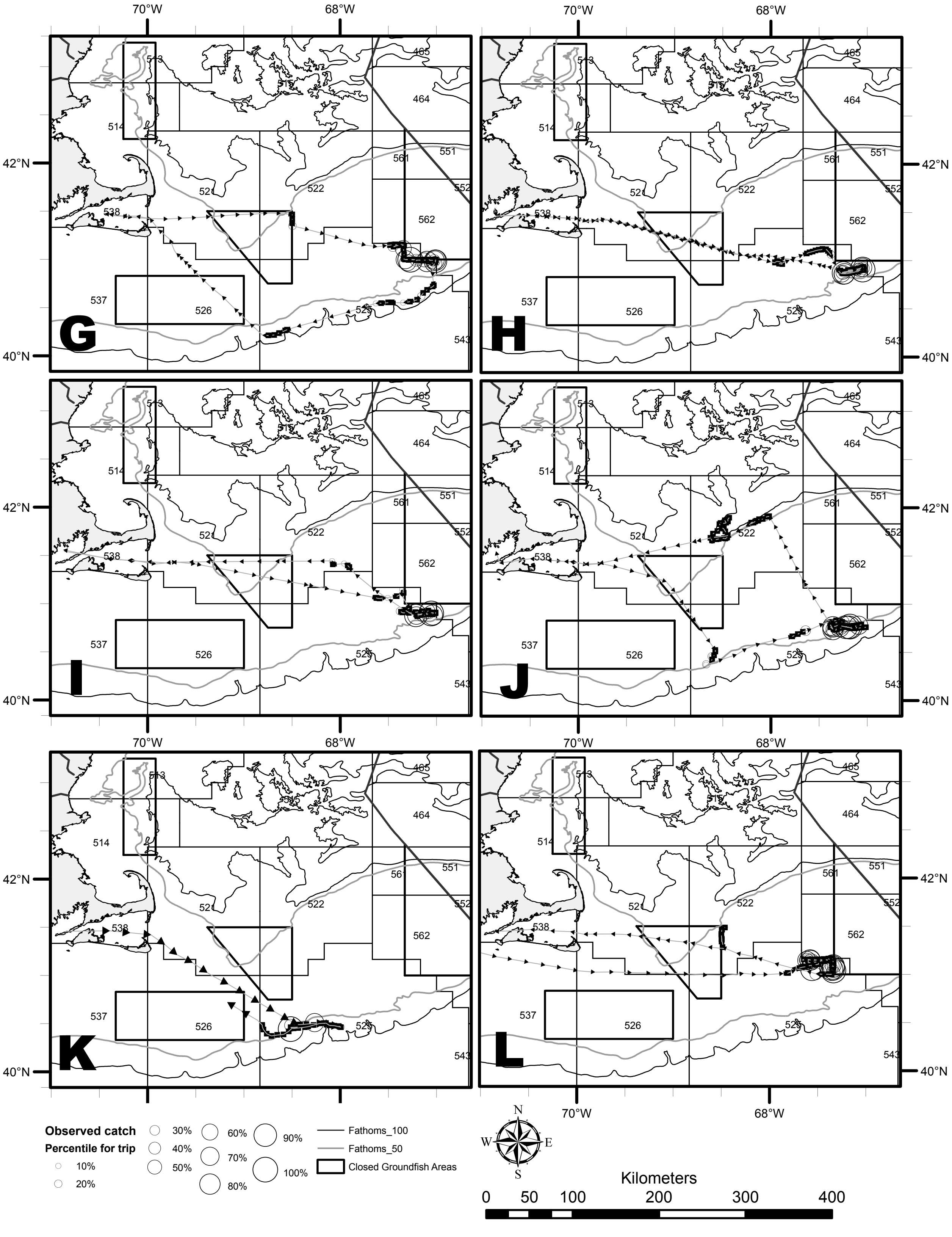


Figure 7. Box plot of distance from classified VMS polling positions to the nearest haul on a random sample of observed yellowtail flounder trips. “All fishing” is the distance from all VMS positions classified as “Fishing” to the nearest observed haul. “Fishing” is the distance from each observed haul to the nearest VMS position classified as “Fishing”, i.e. imputed speed between 1-4 knots (1.85-7.41 km/hr). “Not fishing” is the distance from each observed haul to the nearest VMS position not classified as “Fishing”.

Figure 8. Examples of VMS positions classified as 'fishing' (filled dots) with observed hauls (open circles, size represents amount of yellowtail flounder retained catch) along the track of 30 randomly selected observed fishing trips. All trips fished SE of Cape Cod, MA; outside of the Western Gulf of Maine Closed Area, the Nantucket Lightship Closed Area, Closed Area I, and Closed Area II.





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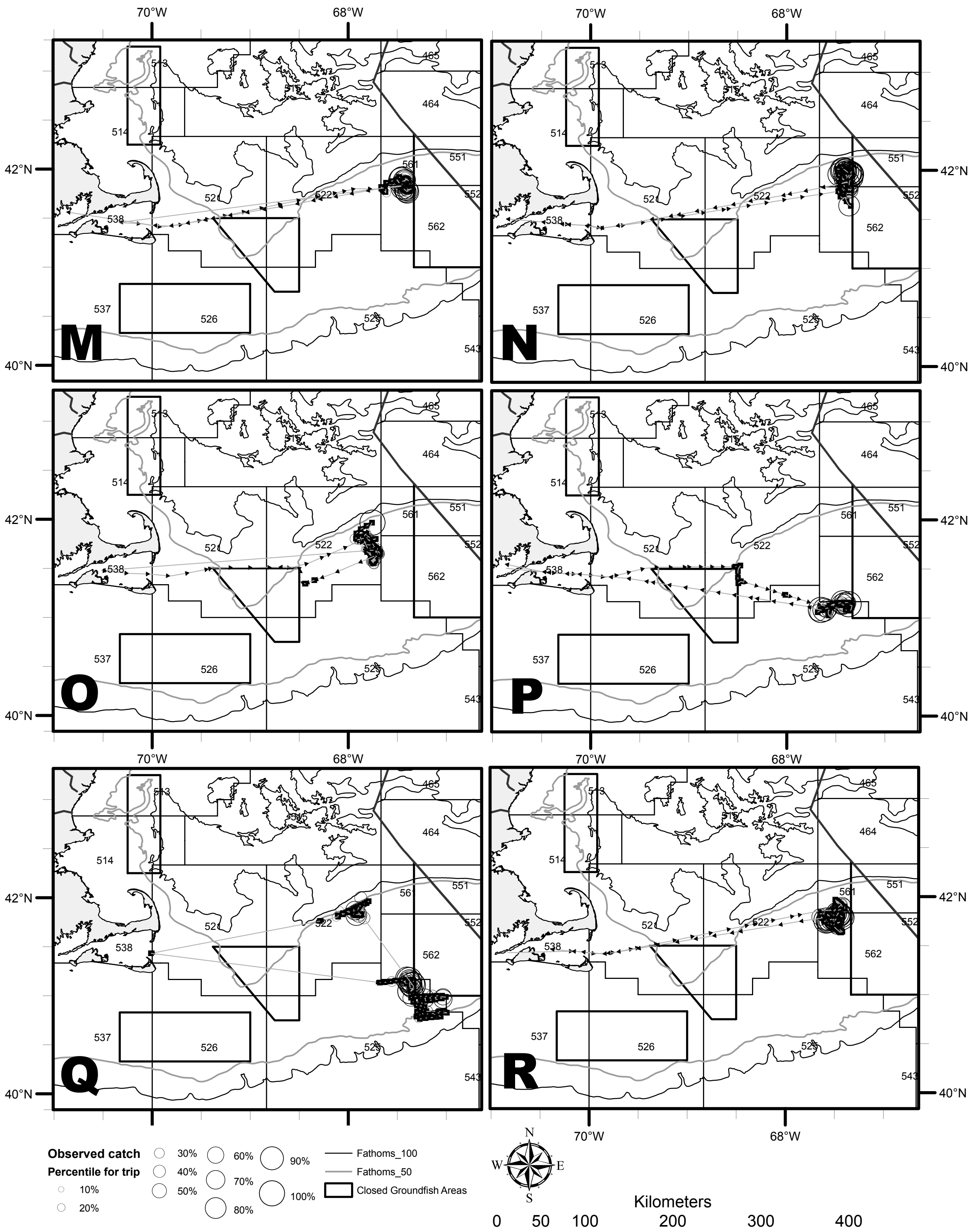
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Observed catch
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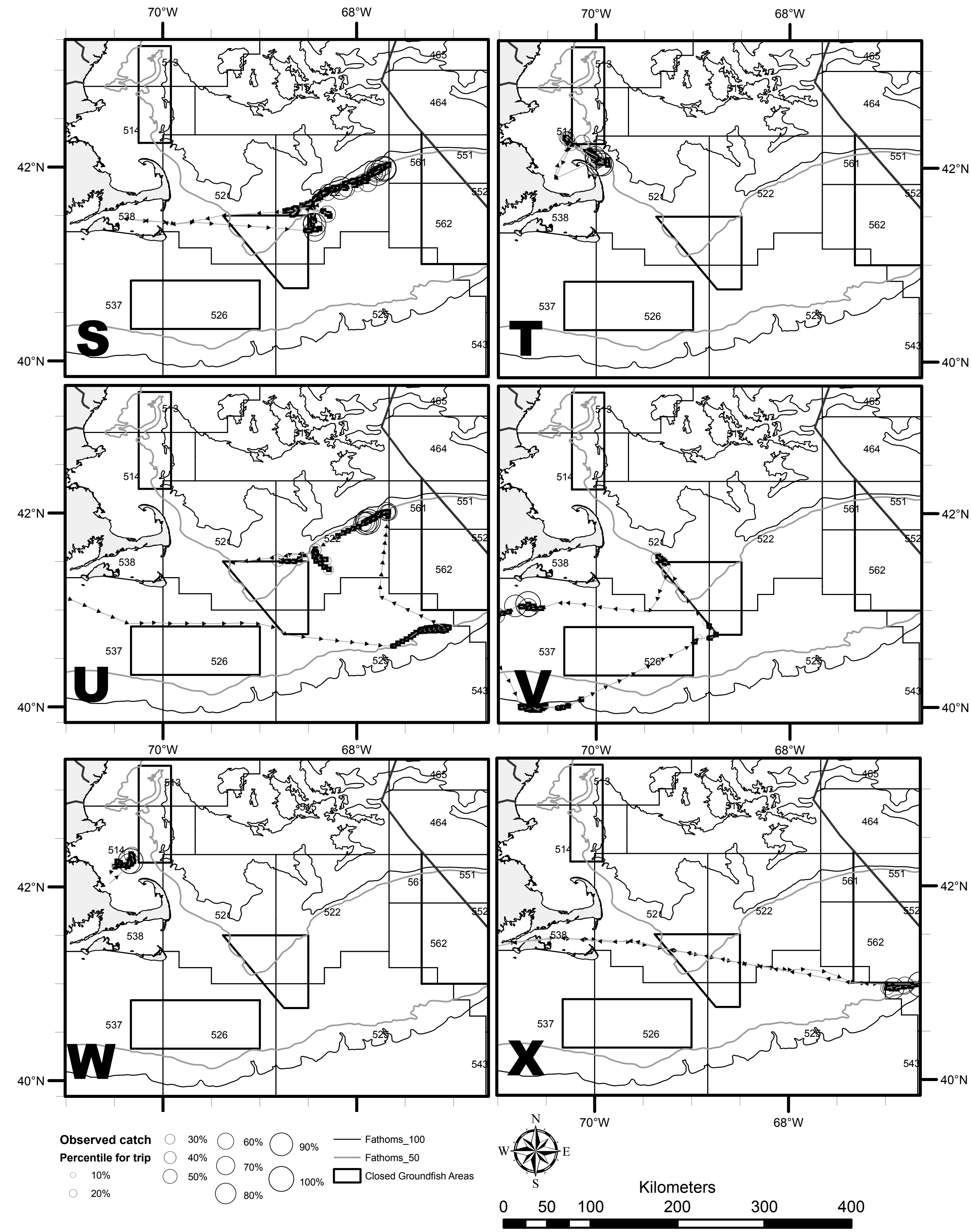
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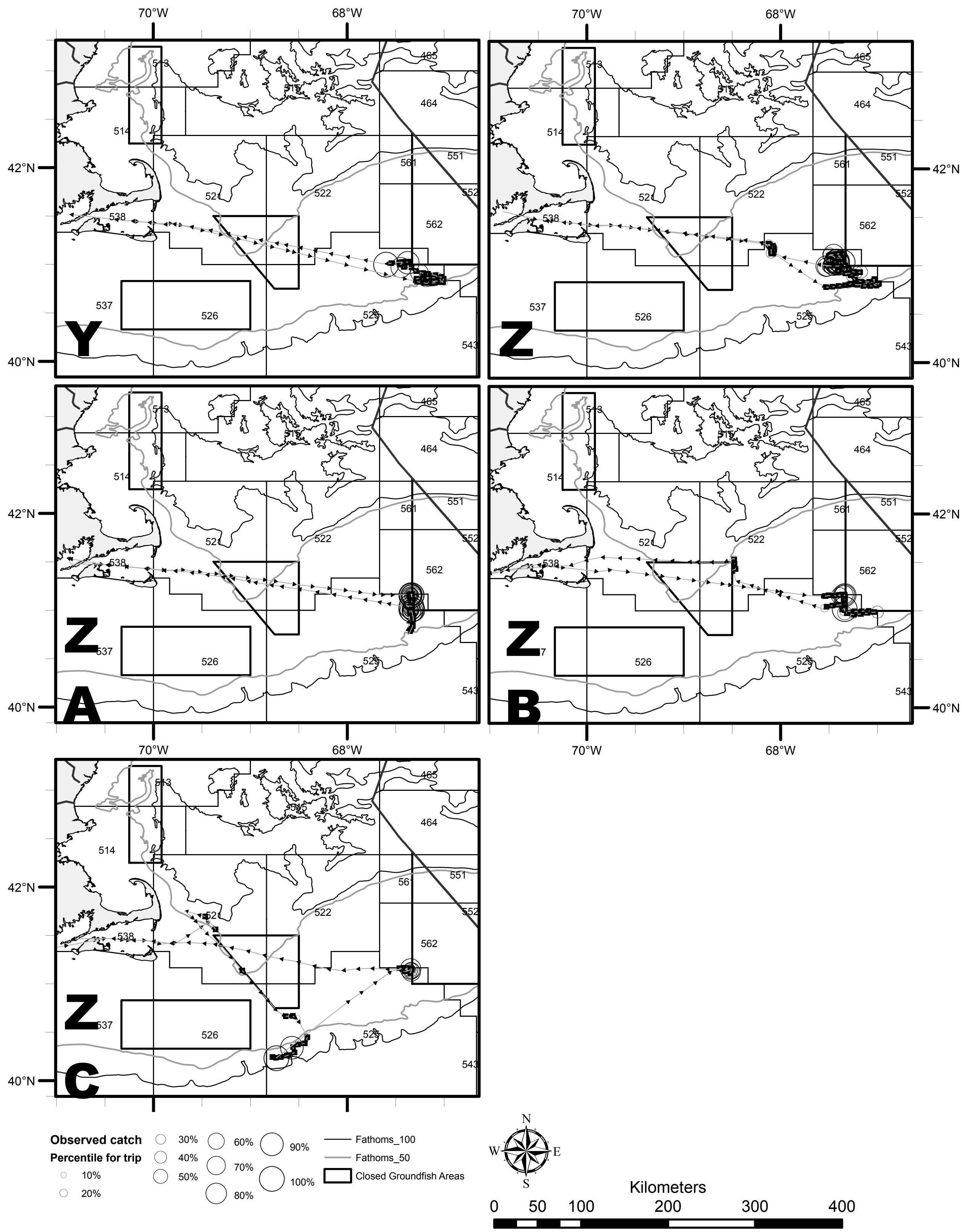
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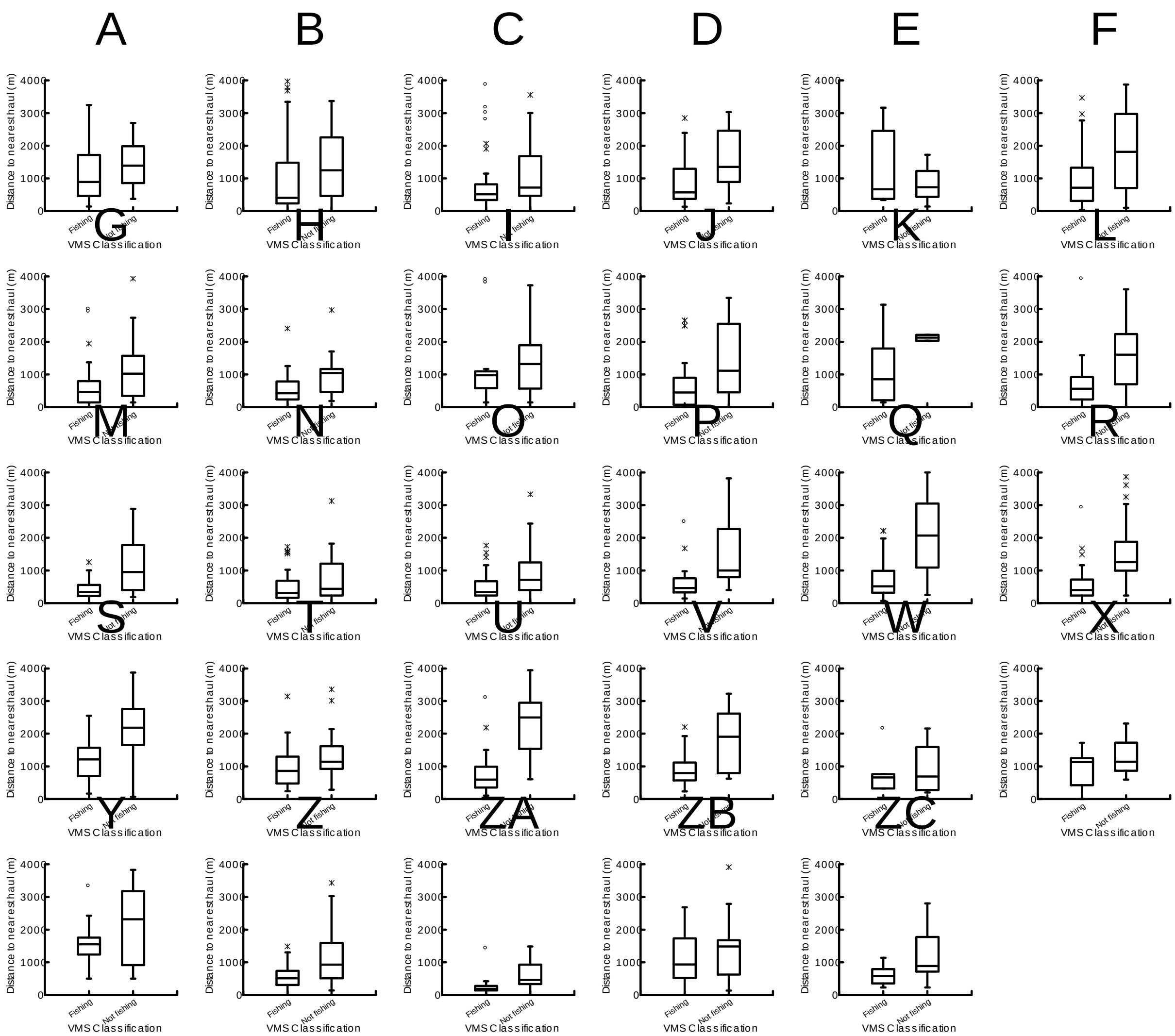

Figure 9. Comparison of nearest neighbor distances between FVPs (left). The graphs represent unique observed trips and the labels are above each one.

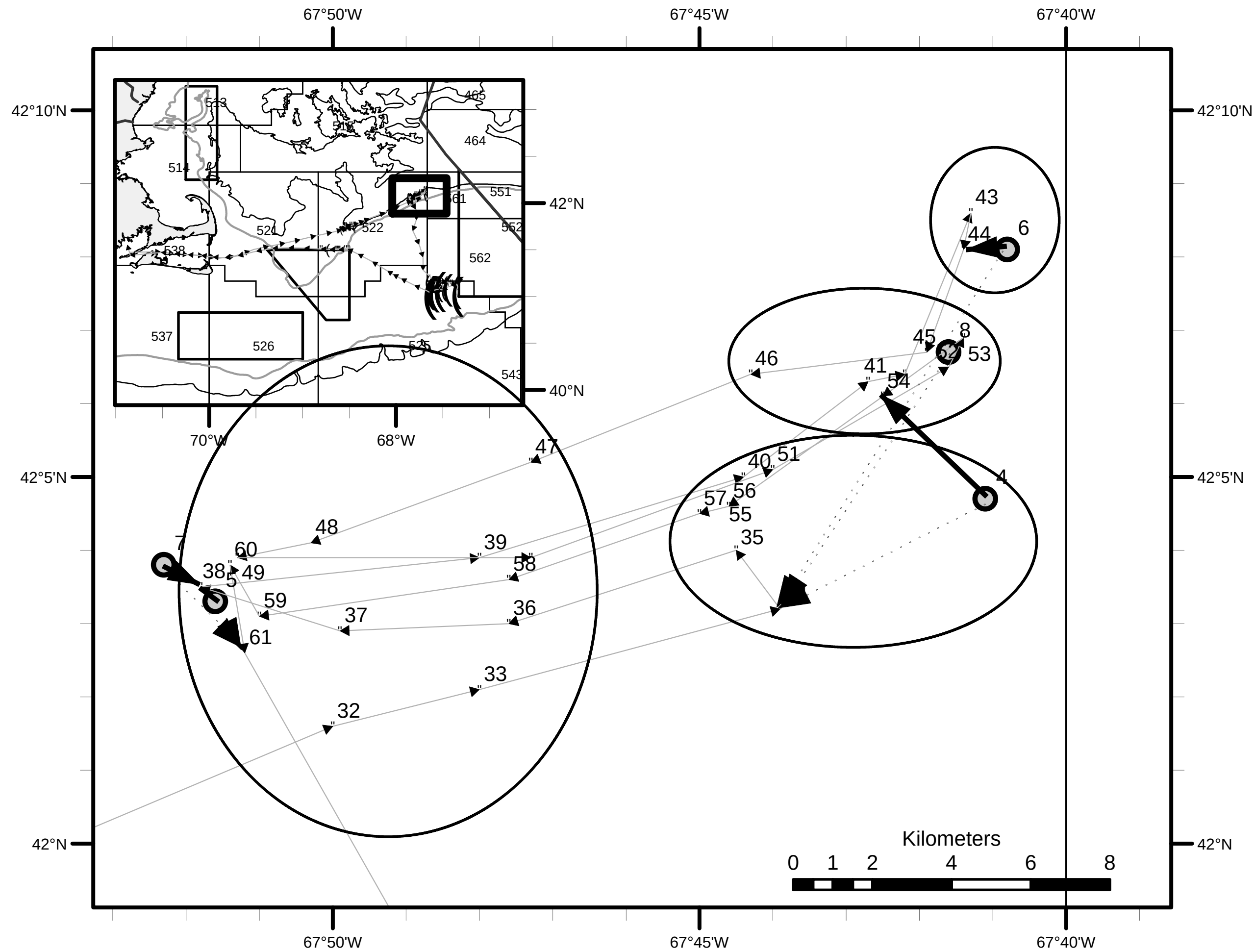

Figure 10. Association of fishing and non-fishing VMS pollings with three observed hauls (#1, 2, and 3) at fishing location A in an example trip. Solid arrows show association with closest VMS polling classified as fishing. Dashed arrows show association with closest VMS polling classified as not fishing. Circles show association of VMS pollings classifies as fishing with the nearest observed haul.

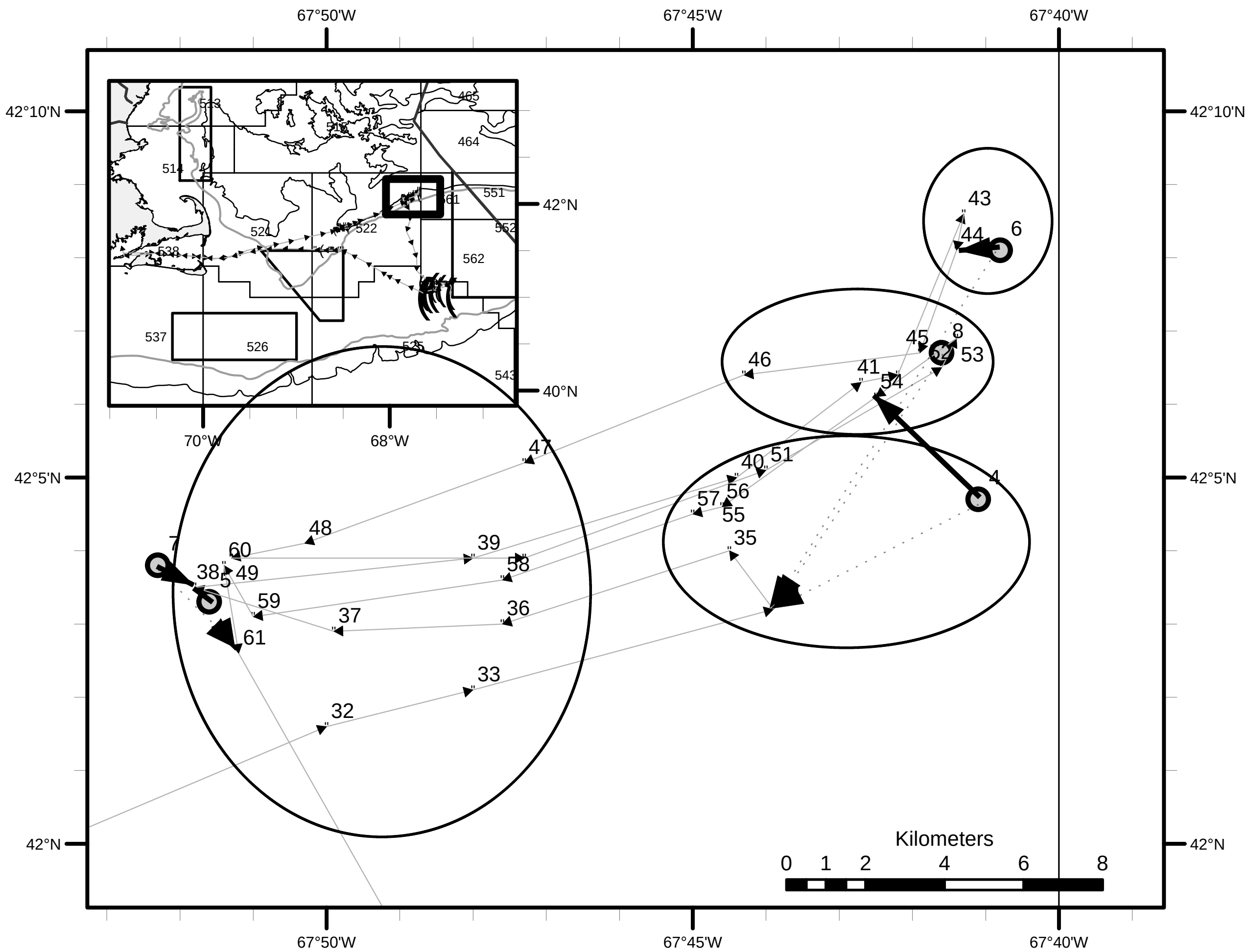

Figure 11. Association of fishing and non-fishing VMS pollings with five observed hauls (#4 to #8) at fishing location B in an example trip. Solid arrows show association with closest VMS polling classified as fishing. Dashed arrows show association with closest VMS polling classified as not fishing. Circles show association of VMS pollings classifies as fishing with the nearest observed haul.

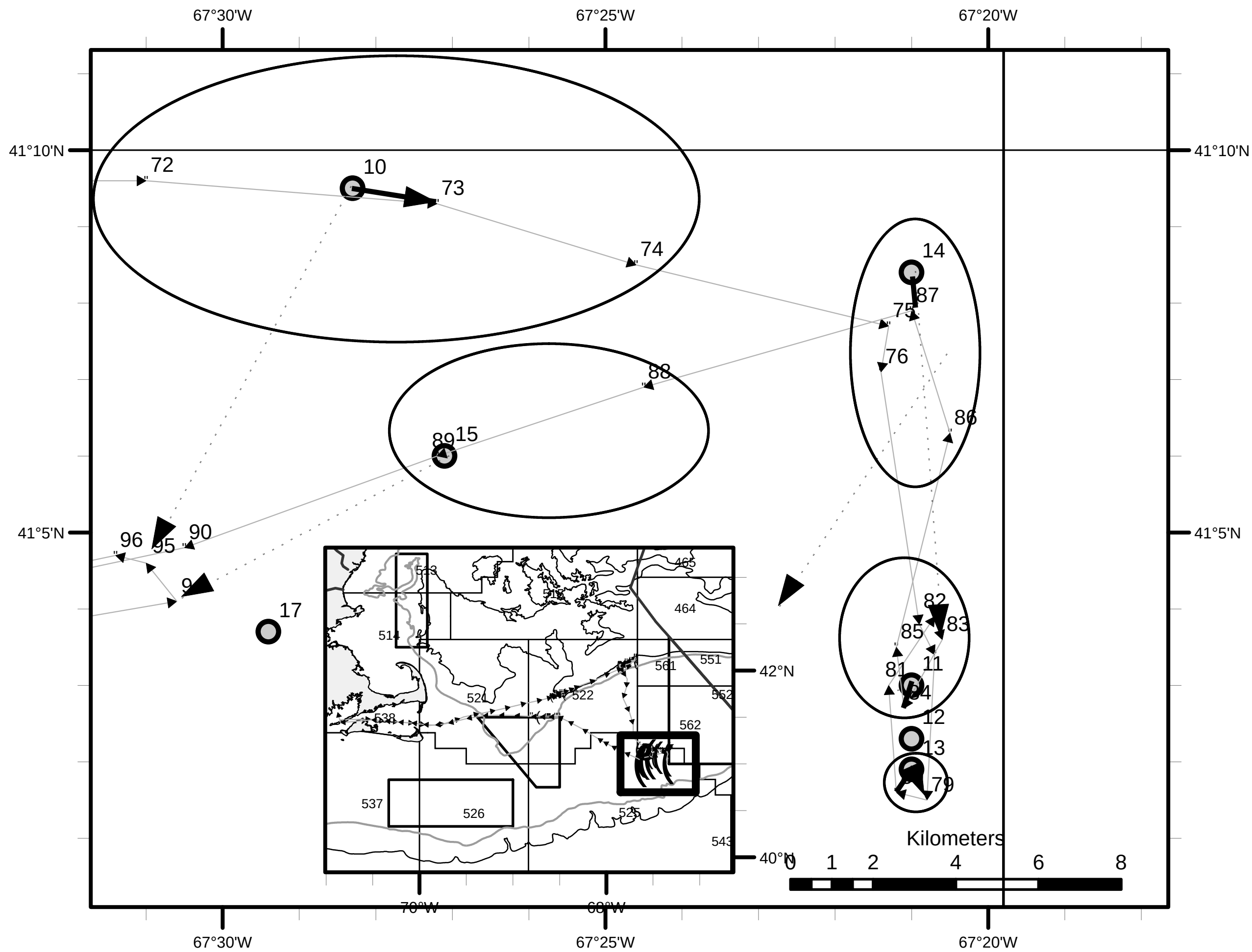

Figure 12. Association of fishing and non-fishing VMS pollings with six observed hauls (#10 to #15) at fishing location C in an example trip. Solid arrows show association with closest VMS polling classified as fishing. Dashed arrows show association with closest VMS polling classified as not fishing. Circles show association of VMS pollings classifies as fishing with the nearest observed haul.

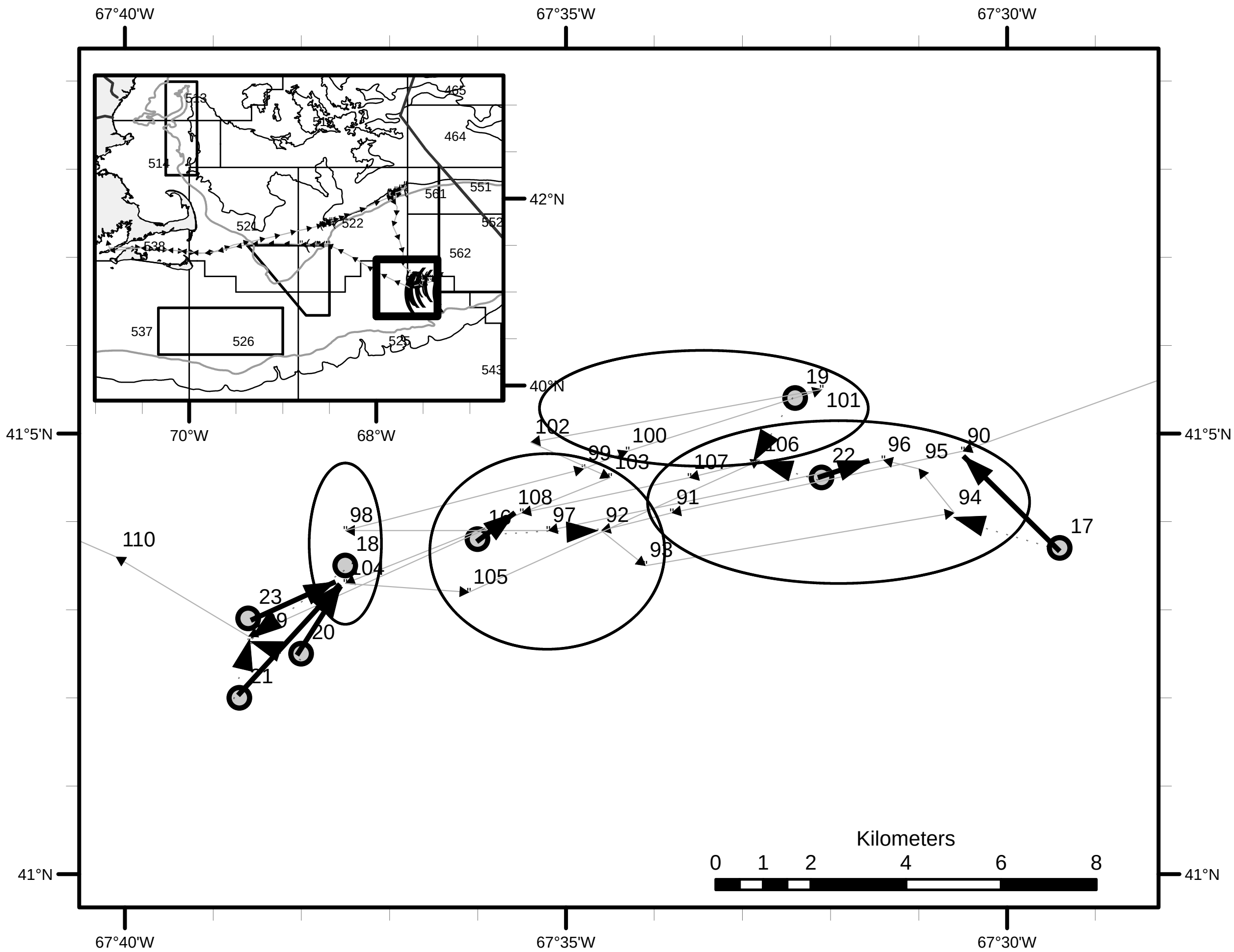

Figure 13. Association of fishing and non-fishing VMS pollings with eight observed hauls (#16 to #23) at fishing location D in an example trip. Solid arrows show association with closest VMS polling classified as fishing. Dashed arrows show association with closest VMS polling classified as not fishing. Circles show association of VMS pollings classifies as fishing with the nearest observed haul.

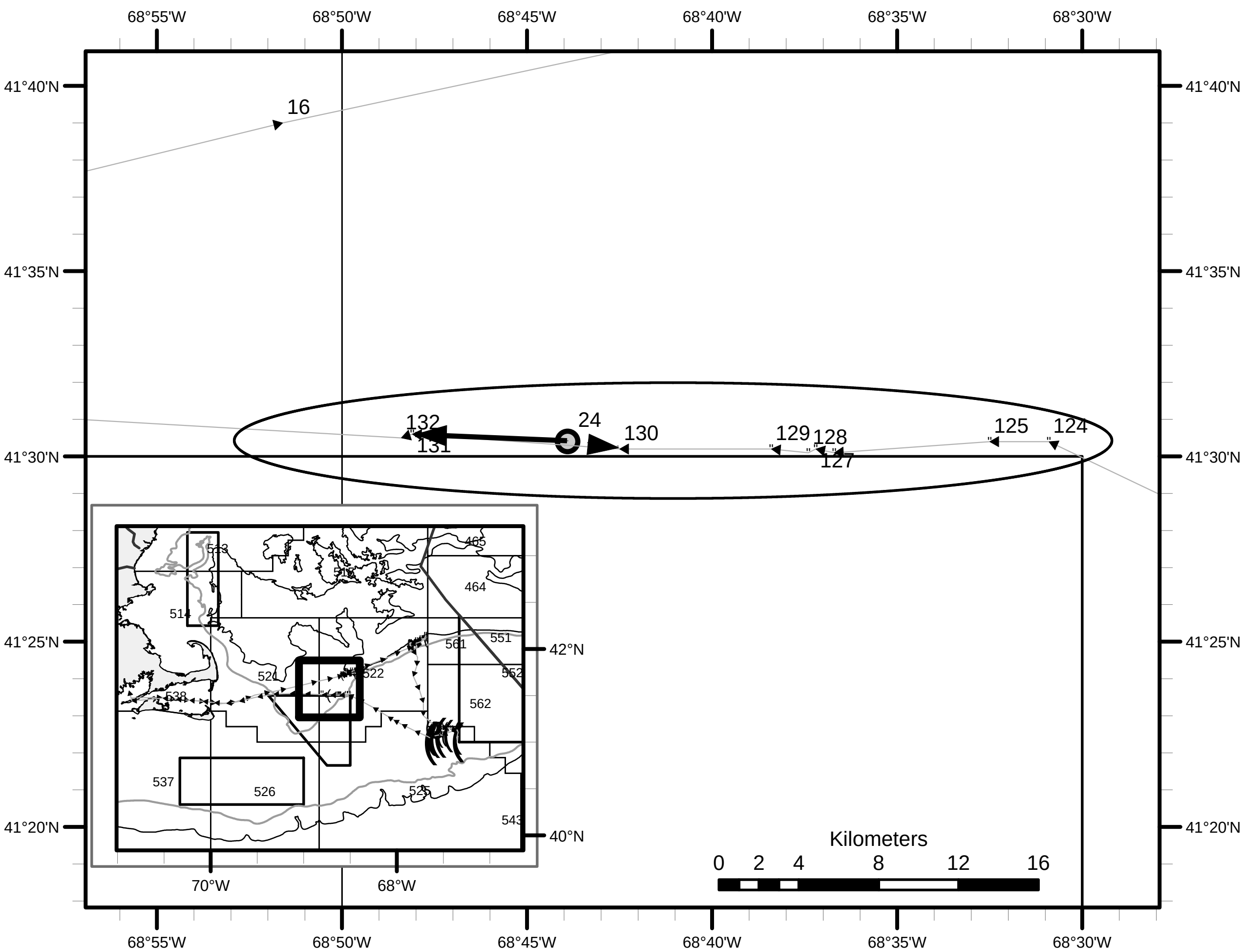

Figure 14. Association of fishing and non-fishing VMS pollings with one observed haul (#24) at fishing location E in an example trip. Solid arrows show association with closest VMS polling classified as fishing. Dashed arrows show association with closest VMS polling classified as not fishing. Circles show association of VMS pollings classifies as fishing with the nearest observed haul.

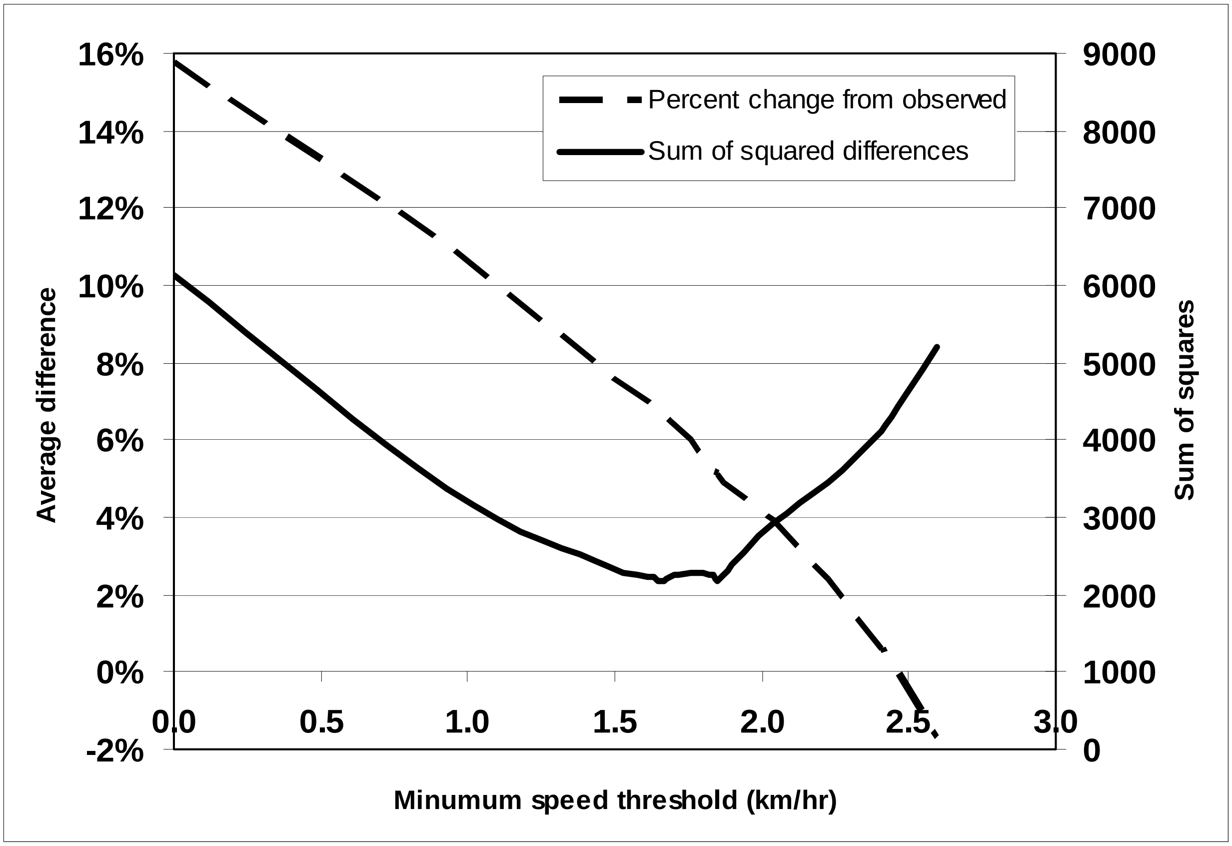

Figure 15. Agreement of VMS duration fished and observed haul time per trip for a subsample of 29 trips, with adjustment to a minimum vessel speed threshold for VMS pollings classified as 'fishing'.