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ABSTRACT

Amendment 16 to the Northeast Multispecies Fishery Management Plan was implemented in May 2010 and brought about many changes in the management of the Northeast United States groundfish fishery. Among the changes was a shift from an input control system (days-at-sea, trip limits, etc.) to a quota based catch-share system with each vessel and harvest cooperative accountable for its total catch (landings and discards). This quota-based system could have created incentives to intentionally misreport catch along these lines, particularly for stocks where quota was limited. This possibility of incentives would be particularly true for allocated groundfish species managed as multiple stocks (Atlantic cod [*Gadus morhua*], haddock [*Melanogrammus aeglefinus*], yellowtail flounder [*Limanda ferruginea*], and winter flounder [*Pseudopleuronectes americanus*]).For these four stocks, catches of lower quota stocks of the same species could be reported in another stock area where quota was less limiting by either inaccurately reporting the fishing area or catch location on the vessel trip report (VTR). Accurate reporting is critical to ensuring that fishery removals are managed appropriately and that fish stocks are not overharvested.

Vessel monitoring system (VMS) positional data were used to validate the statistical area fished and stock apportionment of allocated groundfish landings derived from mandatory VTRs for the period January 1, 2007 to April 30, 2016 (covers fishing years 2008 to 2015) to examine whether changes in reporting patterns occurred after the transition to the catch-share system. Additionally, the relative amount of stock-level catch reporting errors was estimated from the differences between the VMS-based method and reported VTR landings. While the VMS methods can be imprecise, they are useful for detecting shifts in reporting patterns over time and estimating the general scale of the errors. Results show the difference in VMS estimated catch and VTR reported catch changing markedly beginning in fishing year 2010 for several of the quota-limited stocks. These discrepancies occurred despite marginal improvements in compliance with VTR area fished reporting requirements over the same time period. For the majority of the stocks examined, the overall error is estimated to be small and may not substantially impact resource monitoring and stock assessment efforts; however for some stocks the estimated errors are large in one or more years (Eastern Georges Bank and Gulf of Maine cod, Gulf of Maine haddock, Southern New England/Mid-Atlantic winter flounder). While the impacts on some stocks may be large, the magnitude in terms of number of vessels contributing to the overall error is small. Much of the error could be mitigated through improvements in catch monitoring and/or management measures designed to improve catch accounting.

INTRODUCTION

Errors in catch accounting can be caused by many factors including both intentional reporting practices and unintentional errors. Intentional errors could include deliberately changing fishing practices when carrying a fisheries observer (observer effects; Benoît and Allard 2009), unreported catch (Ainsworth and Pitcher 2005), false species identification (Faunce 2011), and reporting the catch of one stock of the same species in another stock area (Palmer and Wigley 2007, 2009). Unintentional catch accounting errors could include unintentional reporting mistakes or recall bias resulting from filling out catch reports after the conclusion of the fishing trip rather than during the trip. The distribution of unintentional errors is more likely to be random, and while these errors may contribute to the imprecision of the catch estimates, they are less likely to affect the accuracy of those estimates compared to more deliberate practices. Catch accounting errors can have far reaching impacts on both in-season catch monitoring and stock assessment efforts. Errors in the fishery landings impact not only the landings component of the catch, but because landings estimates are also used to expand the observed discard ratio to the population level (Wigley et al. 2007), these errors will also impact fishery discard estimates. Biased estimates of fishery removals (high or low) negatively impact the ability of fishery managers to constrain catch below Annual Catch Limits (ACLs; USOFR 2009) for some stocks while at the same time maximizing the fishery yield of other stocks. Catch errors can also lead to biased stock assessment model results (e.g., Hammond and Trenkel 2005; Dickey-Collas et al. 2007; Legault 2009) which then will adversely affect future fisheries management advice.

Large-scale changes in the management of the Northeast United States (U.S.) groundfish fishery were introduced in May 2010 with the implementation of Amendment 16 to the Northeast Multispecies y Fishery Management Plan (FMP; NEFMC 2009). Among those changes introduced by Amendment 16 was a shift from an input control system (days-at-sea, trip limits, etc.) to a quota based catch-share system managed at the level of fishing sector (i.e., harvest cooperatives, Clay et al. 2014). Each sector is composed of a collective of self-organized fishing permits, each having its own allocation history for all groundfish stock (these allocations are referred to as Potential Sector Contributions or PSCs). For each allocated groundfish stock, the collective sum of the permit PSCs within a sector constitutes a sector's annual stock quota, or Annual Catch Entitlement (ACEs). In principal, individual vessel permits do not receive a quota allocation, only the collective sector. In practice however, the sector system operates more as a collective of individual vessels each with its own quota (equal to the PSC contribution) rather than a cooperative using the pooled quota to maximize sector profits. With each vessel effectively operating under an individual quota, a vessel must either limit total catch (landings and discards) below their allocated amounts or lease additional quota through ACE trading (Murphy et al. 2015), potentially at a cost higher than the ex-vessel value of the leased catch. Overall, groundfish catch, and therefore profitability, is often constrained by the stock with the most limiting quota. At the same time, the stocks with the most limiting quota are typically those most at risk of overharvesting if fishery removals are not monitored or managed appropriately. Accurate reporting of catch by stock area is particularly important under this system from both resource management and profitability perspectives. Accurate reporting ensures that fishing removals are managed appropriately and that stocks are not overharvested; conversely, inaccurate reporting could lead to overharvesting of smaller stocks if catch of those stocks were misreported as catch from a different stock area.

The analyses covered in this paper focus on catch accounting errors associated with the reporting the catch of one stock of the same species in another stock area. This type of error can arise from inaccuracies in either catch or area reporting. In the Northeast U.S., dealer weighout data are assumed to be a census of commercial landings amounts. Commercial landings are allocated to management units (i.e., stock areas) using the reported catch by statistical areas recorded on the vessel trip reports (VTRs; Wigley et al. 2008). Current VTR regulations require that on completion of a fishing trip, a logbook report must be submitted which documents the total catch by species for each statistical area in which fishing occurred (Title 50 of the U.S. Congressional Federal Register, Part 648.7). Past analyses have shown that inaccurate reporting of catch by statistical area occurs (Palmer and Wigley 2007, 2009). Most frequently this inaccuracy takes the form of underreporting the number of statistical areas fished, though other types of fishing and reporting practices can also contribute to catch reporting errors including overreporting the number of statistical areas fished and placing the catch in an area that was not fished, or accurately reporting fishing locations, but erroneously reporting catch (Fig. 1).

While reporting catch to incorrect statistical areas does not necessarily translate to the misclassification of commercial landings to stock areas, the potential exists, and the magnitude of these effects on the apportionment of commercial landings is largely unknown. The most reliable source of fisheries-dependent catch and effort data in the Northeast U.S. are available from the information collected by at-sea fisheries observers (including at-sea monitors, or ASMs, which were a new class of observers trained specifically for monitoring the groundfish fishery under sector management beginning in May 2010). However, because these data are limited in their coverage (e.g., generally 1- 28% of trips, with the coverage rate higher post-sector implementation; Wigley et al. 2011, 2012, 2013, 2014, 2015,2016) they cannot provide the synoptic coverage necessary to allocate commercial landings to stock area with any regularity. Since passage of Framework 42 to the Multispecies FMP (NEFMC 2006), vessel monitoring systems (VMS) have been required for nearly the entirety of the groundfish fleet. For the groundfish fleet, VMS provides 30-60 minute polling of a vessel's position; however, these data provide no information on where the catch occurs. Using vessel speed windows, VMS data can be used to infer fishing locations, and though elucidation of catch locations is more problematic, it can be inferred through basic assumptions about species catchability at the identified fishing locations (e.g., an assumption of constant catch per unit effort across all fishing locations). While such methods are simple, they have been demonstrated to achieve estimates of stock-level catches closer to that of observer data when compared to the self-reported information on VTRs (Palmer and Wigley 2007, 2009). Given the demonstrated performance of these methods, they are useful for examining general trends in reporting patterns over time.

Fundamentally, this paper is an update of the analyses first presented in Palmer and Wigley (2007, 2009). Unlike the original papers which examined the errors associated with all 8 of the species managed as split stocks in the Northeast U.S., this paper focuses only on the allocated groundfish species managed through the Multispecies FMP – Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), and winter flounder (*Pseudopleuronectes americanus*). Each of the 4 species is managed as 3 separate stock units (Table 1). While windowpane flounder (*Scophthalmus aquosus*) is also managed through the Multispecies FMP, landings of windowpane flounder have been prohibited since 2010, and quota has never been allocated to the groundfish sectors. Additionally, while the original paper included an analysis of reporting patterns among the scallop dredge fishery, this current analysis is restricted to large mesh otter trawl, large mesh sink gillnet, and benthic longline – the principal gear types used in the groundfish fishery. Using methods identical to those in Palmer and Wigley (2007, 2009), this paper extends the analysis from January 1, 2007 through April 30, 2016 (the end of the 2015 fishing year). The primary focus of this paper is to examine reporting patterns pre- and post-sector implementation on May 1, 2010; specifically: (1) have VTR reporting patterns changed over time?; and, (2) how have changes in VTR reporting affected the landings estimates of the allocated multistock groundfish species?

MATERIALS AND METHODS

Data Sources

VTR logbook trip, gear, and species catch data were extracted from the Northeast Fisheries Science Center (NEFSC) VTR database from calendar year 2007 to April 30, 2016. The time period was selected to fully encapsulate fishing years 2008 to 2015; including 2 full fishing years before sector implementation allows for a comparison of changes in reporting and fishing behavior related to the transition to the sector management system. The analytical datasets were post-processed to remove any overlapping trips (i.e., trips taken by the same vessel with a date of sail occurring before the date of landing of a previous trip). Overlaps occur because of VTR reporting and/or data entry errors. This process resulted in the removal of ≤2.2% of the total annual reported VTR trips (<0.5% from 2010 on).

Of the remaining trips, only those trips where at least 1 of the 4 study species were reported as landed catch were retained in the dataset (Atlantic cod, haddock, yellowtail flounder, and winter flounder). Because the focus was on assessing the impact of statistical area reporting errors on the apportionment of commercial landings to statistical area, discards were not included in these analyses. Attempts were made to convert landed weights to live weight in kilograms (kg)by using standard NEFSC conversion factors; however, the existing VTR species coding scheme lacks grade information (e.g., gutted, headed and gutted) for the 4 study species in question. Absent this information, the fish were assumed landed round (i.e., not gutted), which is likely not true for the majority of cod and haddock landings. The VTR dataset was further restricted to include only the 3 major gear types responsible for species landings in the region: otter trawl, sink gillnet, and benthic longline. Otter trawl gears included the standard fish otter trawl (OTF) as well as the haddock separator trawl and Ruhle trawl, both of which are modifications of the standard otter trawl. These gears are designed to minimize bycatch of certain species, such as cod. The use of modified trawl gear is required inside certain special access areas such as portions of the Eastern U.S./Canada Resource Sharing Area (e.g., Northern Windowpane Flounder Accountability Measure Area; NEFMC 2012). VTR species landings were then assigned to a stock area based on the statistical area fished reported on the logbook (Table 1). The final VTR subsets contained between 6,157 and 21,353 trips per year (excluding the partial 2016 data; Table 2). The large decline in the number of trips from 2007 to 2015 is reflective of the gradual attrition of the groundfish fleet over time (Thunberg and Correia 2015).

All available VMS data were extracted from the NEFSC VMS database for each vessel and assigned to the appropriate VTR trip by matching on the vessel permit number and assigning all VMS point locations with dates between the sailing and landing date reported on the VTR. To optimize the matching of VMS positional information, VTR date times were presumed to be recorded in local time and adjusted to universal time (UT) with proper adjustments to account for daylight savings time. The average vessel speed was calculated by dividing the haversine distance (Sinnott 1984) by the time difference between consecutive VMS positions. All positions were assigned to a National Marine Fisheries Service (NMFS) statistical area (Fig. 2). Summaries of the number of VTR-VMS matched trips by year are presented in Table 3.

The overall matching rate between VTR and VMS data generally improved over time going from 72-88% in the period 2007 to 2010 and 92-97% in the period 2011 to April 30, 2016 (Table 2). It is not clear why the matching improved over this time period since VMS units have been required on all federal groundfish vessels since 2006. It is possible that improved accuracy over time with respect to the vessel permit numbers reported on VTRs could explain the higher match between VTR and VMS positional data, but this is speculative. The VTR-VMS matched set captures approximately 95% of the total species landings present in the VTR data from 2007 to April 30, 2016 (Table 3). Yellowtail flounder in years 2012 to 2015 are an exception, with the VTR-VMS matched set containing little more than 50% of the total landings present in the VTR data. This discrepancy is attributable to the presence of a large amount of landings in the VTR data from trips fishing U.S. quota allocations for Grand Bank yellowtail flounder in these years. The Grand Banks stock is outside the U.S. Exclusive Economic Zone (Fig. 2) and not part of the groundfish complex managed through the Northeast Multispecies FMP. Within the matched VTR-VMS analytical set, the majority of species landings are attributable to trawl gear, despite a sizable fraction of trips and vessels fishing sink gillnet gear and to a much lesser extent, benthic longline gear (Fig. 3). Cod landings are an exception where sink gillnet made up over a third of the landings in the early part of the time series, though this fraction has declined over time.

Fisheries observer data, including both Northeast Fisheries Observer Program (NEFOP) and ASM data, were extracted from the NEFSC Observer Database System (OBDBS) and matched to the

VTR-VMS matched analytical data set. Hauls that were not observed were excluded from the analysis since effort and catch estimates for unobserved hauls are obtained directly from the captain and therefore are not necessarily an independent observation from the captain's self-reported information on the VTR. Trip matches were established by using the vessel hull number (vessel permit number was not populated in the OBDBS data until 2011), date of sailing, and date landed as reported on the VTR; trips with multiple matches were removed from the analyses. Similar to VTR date times, observer date times are presumed to be recorded in local time, so adjustments were made for both UT and daylight savings time to facilitate matching with the VTR-VMS analytical data set. Summaries of the number of matches by year are included in Table 2. The variability in the match to observer data is reflective of both the increase in coverage resulting from the addition of ASMs in May 2010 and changes in the required level of ASM coverage over time (e.g., NEFMC 2016). There has been a general decline in the level of ASM coverage required of the groundfish fishery since the high point in fishing year 2010 (May 1, 2010 – April 30, 2011). For all matched trips the associated haul duration, statistical area fished, species, and retained catch weights were also extracted; retained catch weights were converted to live weight in kilograms (kg) by using standard NEFSC conversion factors.

VMS Method for Identification of Fishing Effort and Catch Apportionment

An in-depth description of the development of the methods employed in this paper is provided in Palmer and Wigley (2007), though the basic methods are described here. By using the VMS positional data, fishing activity was inferred from the calculated average vessel speeds with the following speed windows: trawl gear (2 to 4 knots), sink gillnet (0.1 to 1.3 knots), and benthic longline (0.1 to 1.3 knots). Each VMS position characterized as a fishing location was then assigned to the appropriate statistical area (Fig. 2).

Statistical areas fished were compared across data sources to assess whether the statistical areas derived from VMS-defined fishing activity represented an improvement over VTR reported statistical areas relative to observer data. Excluding unobserved hauls from the observer data set could potentially lower the level of area fished matching between VTR or VMS and observer data, so these comparisons were repeated with unobserved hauls included to quantify the impacts. Trips were broken into 2 categories: single area trips (fishing occurs in only 1 statistical area per trip) and multiarea trips (fishing occurs in more than 1 statistical area per trip). Because all stock boundaries are divided along statistical area boundaries, correct reporting of multi-area trips are of the greatest concern. These are the trips having the potential to fish on multiple stocks of fish in a single trip and where errors in the reporting of statistical area(s) may lead to incorrect estimates of stock removals. For each trip, the levels of agreement between the observer, VMS, and VTR statistical areas were categorized as in agreement ("Complete"), not in agreement ("None") or in partial agreement ("Partial"; at least 1 statistical area was in agreement, but not all). Agreement levels were contingent on agreement among both the number of statistical areas reported and the identity of those statistical areas. For example, if a VTR reports that fishing occurred in statistical areas 515 and 521 and VMS positions suggest that fishing occurred in 515 and 521, then the trip would be considered to be in agreement ("Complete"). If the VTR reported fishing in 515 and the VMS data suggest fishing occurred in 515 and 521, then the trip would be considered to be in partial agreement ("Partial"). If the VTR reported fishing in 515 and the VMS data suggest fishing occurred only in 521, then the trip would not be considered to be in agreement ("None"). The same analysis was repeated on the larger set of VMS and VTR matched trips. The time spent fishing per statistical area was then determined by summing up the time intervals associated with each identified

VMS "fishing" polling position (e.g., for vessels with hourly polling, each polling position equals 1 hour).

On June 30, 2011, NMFS began allowing groundfish vessel captains to file their VTRs with approved electronic logbooks. A portion of the groundfish fleet had been using electronic logbooks to collect haul-by-haul self-reported data as part of a NEFSC Cooperative Research project dating back to 2002 (Palmer et al. 2007). The approval of electronic VTR (eVTR) submission in 2011 allowed these vessels to have the research data they were already collecting fulfill their VTR reporting requirements. Typically the electronic logbooks were wired directly to the vessel's global positioning system (GPS) so that the entry of fishing locations (and statistical area) was obtained automatically from the GPS unit when captain entered a tow record into the electronic logbook. Between 2011 and 2015 there was an increase in both the number of vessels and number of trips in the analytical set reporting their VTR data at the haul-level as opposed to the more aggregated subtrip level required by VTR requirements (Fig. 4). The observer-VTR and VTR-VMS area agreement on multiarea trips was examined for the subset of the groundfish fleet using haul-by-haul electronic logbooks to evaluate whether there was evidence that haul-by-haul reporting improved VTR area reporting. Haul-by-haul VTRs were identified by cross referencing the trip identifiers with the NEFSC Fishing Vessel [Electronic] Trip Reports (FVTR) database and selecting trips where the REPORT_SOURCE='HBH' (HBH=haul-by-haul). While haul-by-haul reporting does not by itself prevent inaccurate area reports, it may limit inaccuracies caused by recall bias that would occur when captains fill out the traditional paper VTRs at the completion of the fishing trip.

In addition to examining course-level reporting patterns (e.g., presence absence of statistical areas fished), finer scale effort metrics were compared between VTR and VMS to determine both (a) whether the VMS method could generally replicate effort metrics such as days fished per statistical area, and (b) whether there was evidence of improvement in the level of agreement between VTR and VMS over time that might indicate general improvements in the quality of VTR data. VMS-based methods are only useful for capturing the fishing effort expended during the trip (i.e., the setting and hauling of gear); however, for fixed gear such as sink gillnet and benthic longline, the effective fishing effort can be much greater than the expended effort during the trip as the gear soaks between the setting and hauling of the gear. This is particularly true for sink gillnet gear where the soak duration can span days between successive fishing trips on which the gear is first set and subsequently hauled. For this reason, these comparisons were restricted to otter trawl gear. One of the key questions is whether VMS methods can effectively partition effort to statistical area when fishing effort spans multiple areas – given this, all comparisons were restricted to trips that fished in multiple statistical areas. Days fished were calculated from the VTR data by multiplying the reported number of hauls by the average reported haul duration (reported in hours, but divided by 24). Annual distributions of trip-level days fished per statistical area as well as annual aggregate estimates of days fished per statistical area were compared along with the differences in the proportion of a trip spent per statistical area.

For all identified fishing activity for a given trip, the total species landings reported on the VTR were then apportioned to statistical areas based on the estimated fraction of total time spent fishing per statistical area (Equation 1).

$$(1) \qquad \hat{L}_{si} = \left(\sum_i l_{si}\right) \bullet \left(\frac{t_i}{\sum_i t_i}\right)$$

where: $\hat{L}_{si}$ = VMS prorated trip landings for species *s*, statistical area *i* (kg), l_{si} = trip landings for species *s* in statistical area, *i*, as derived from VTR reports (kg), and t_i = time spent fishing in statistical area, *i*, as derived from VMS positional data (days). VMS-estimated stock landings were then calculated by summing the landings across the statistical areas that constitute the respective stock areas (Table 1).

The VMS-based apportionment method assumes a constant species landings per unit effort (LPUE) at all fishing locations (i.e., species catch is distributed only as a function of the time spent fishing in each stock area). This assumption neglects species habitat preferences (e.g., sediment composition, water depth, and temperature) which would invalidate the homogenous distribution assumption of the VMS method. Palmer and Wigley (2009) compared overall stock allocations between VMS and observer and concluded that there was no statistical difference between the 2 (i.e., VMS apportionment was unbiased). That analysis was however aggregated across species, stocks, and years such that differences that may exist at finer scales would have been obscured. Here, the VMS-observer comparison is further evaluated by examining the relative stock apportionments on matched trips fishing in multiple stock areas by species, stock and year. Additionally, the trip-level landings differences between observer and VMS are compared to the differences between VTR and VMS to evaluate whether any differences between observer and the VMS-based method are small relative to the differences that exist between VTR reported landings and VMS estimated landings.

The impacts of inaccurate VTR catch-area reporting were evaluated in several ways. First, the trip-level distributions of the differences between the VTR-reported stock landings and the VMS-estimated stock landings were compared by year. The annual distributions were inspected for time series trends to determine whether there was evidence of shifts in the VTR reporting patterns before and after sector implementation. Second, the magnitude of the VTR reporting error was estimated by summing the differences between the VTR-reported stock landings and the VMS-estimated stock landings. Assuming the distribution of the differences was unbiased, the differences between VMS and VTR should sum to zero. Third, the relative error was estimated by calculating the ratio of the sum of differences to the VTR-reported stock landings. This exercise was repeated on both a calendar year and fishing year basis as the former is more relevant for stock assessments and the latter more relevant for in-season quota monitoring. And finally, to further evaluate potential impacts on the ability to effectively monitor commercial groundfish quotas, the estimated VTR landings error was added to the official end-of-year catch estimates generated by the NMFS Greater Atlantic Fisheries Regional Office (available from https://www.greateratlantic.fisheries.noaa.gov/aps/monitoring/nemultispecies.html). The adjusted catch estimates were then compared to the established sub-ACLs for the commercial groundfish fishery in a given year (Sarah Heil, NMFS GARFO, pers. comm. August 5, 2016). For cod and haddock, the Eastern Georges Bank sub-ACL is considered a subset of the larger Georges Bank quota – a separate sub-ACL is not established for only the Western Georges Bank area. For this reason both Eastern and Western Georges Bank estimated errors were combined into a single Georges Bank stock for all fishing year comparisons. The Eastern Georges Bank was still evaluated independently . since it does have a separate quota.

RESULTS

Complete agreement in the recorded statistical area fished between observer and VTR averaged 94% for single-area trips, but only 27.5% for multiarea trips (Table 4). There was a general trend of improved agreement for multiarea trips over time with agreement being greater after sector implementation. A large increase (≈16%) was seen between 2014 and 2015 such that by the end of the time series the level of agreement between the 2 data sources on multiarea trips was greater than 40%. The cause for the large increase in unknown, but may be partly attributable to changes in VTR reporting requirements over time. Prior to 2012, the VTR instructions provided no guidance on how to report catch and effort on tows that crossed statistical area boundaries (e.g., Fig. 1, example D). In February 2012, the instructions were revised requiring vessel captains to apportion catch based on the time spent in each statistical area on tows that crossed boundaries. In December 2014 the instructions were again revised requiring that captains report the statistical area associated with the location of the start of the tow haul back – a protocol that is consistent with observer protocols. This change only impacted the reporting of tows crossing statistical area boundaries, and since the incidence rate of these tows is low (<10% of all hauls) and it is unknown if the fleet actually changed its reporting practices when the instructions were revised, it is not clear what impact, if any, this might have had on the observed trends.

The level of agreement between observer and VMS estimates was similar for single-area trips (92%), but much greater for multiarea trips (average of 65%; Table 5). No obvious time series trends are apparent in either the single or multiarea VMS-observer comparisons which suggests that the method has performed consistently over the time series. To evaluate whether the exclusion of unobserved hauls from the observer data set contributed to the low match rate, the VTR- and VMS-observer comparisons were repeated with the inclusion of all hauls with, but this time only small improvements seen in the match rates (average improvement of 1% complete agreement in multiarea trips with a range of -1 to 6%).

Similar to the observer-VTR comparisons, the VTR-VMS comparisons exhibit a general trend of improved agreement in multiarea trips over time but average only 14% agreement over the time series (Table 6). The level of agreement for singlearea trips is high (average of 94%). These comparisons were repeated on only the subset of trips that were observed trips to determine whether there was evidence that VTR reporting practices improved when the vessel was carrying an observer. The average agreement for multiarea trips was marginally higher on observed trips (18% vs. 14%; Tables 6 and 7); however, overall the results were similar both in terms of trends and magnitude suggesting very little improvement in VTR area reporting practices on observed trips. While the level of complete agreement for multiarea trips is low, there is a high degree of partial agreement and very low incidence of no agreement, particularly since 2010 (<2.5%; Table 8) indicating that at least 1 of the statistical areas fished was correctly reported on the VTR. Also notable is the large increase in the percentage of multiarea trips over time going from 19% (3,308 multiarea trips out of 17,083 trips) in 2007 to 42% by 2015 (2,381 multiarea trips out of 5,731 trips). The large relative increase in the proportion of multiarea trips translated into increases in the percentage of trips fishing in multiple stock areas (Fig. 5); for example only approximately 5% of the trips landing cod and haddock fished in multiple stock areas before sector management (i.e., before May 2010) compared to more than 15% of the trips after sector implementation. The landings of these species by vessel ton class (TC) over time was evaluated to determine if the multiarea/stock trends were reflective of changes in vessel behavior or changes in the characteristics of the underlying fleet. For both cod and haddock there was a large decline in the landings contribution of TC 1 and 2 (1-50 gross tons) vessels over time and a corresponding increase in the landings of TC 3 and 4 (51-500 gross tons; Fig. 6). The larger vessels are more likely to have longer trips and fish in multiple statistical areas on single trip.

While the use of haul-by-haul electronic logbooks to submit VTR data has increased over time, it constitutes a small fraction of the VTRs filed annually (e.g., of the 5,731 VTR-VMS matched trips in the analytical set in 2015, only 482 (8.4%) were filed with haul-by-haul eVTR applications). The accuracy of statistical area reporting on haul-by-haul eVTR was considerably better than the fleetwide reporting patterns. There was a 2.0 to 4.5 times improvement in the level of complete agreement in the reported statistical area fished when fishing in multiple statistical area among the haul-by-haul eVTRs compared to the fleet-wide reporting trends (Fig. 7). The patterns were relatively consistent among both the observer-VTR comparisons and the VTR-VMS comparisons. While compelling, these results do not definitively demonstrate that use of haul-by-haul eVTR will improve VTR reporting practices. Those vessels that report haul-by-haul eVTR constitute a self-selected group of vessels who choose to participate in the NEFSC's Cooperative Research Study Fleet program, and they are financially compensated for their participation, with compensation contingent on meeting certain data quality standards. These incentives make it difficult to evaluate whether broader use of haul-by-haul eVTR could lead to improved compliance with VTR area reporting requirements. It could be that the financial compensation provides sufficient incentives to pay careful attention to accurate reporting or that the vessels that choose to participate in the program are those inherently more likely to report VTRs accurately. Additional research is needed in this area to determine whether wider use of haul-by-haul eVTRs could substantially improve the quality of VTR area reporting.

The distributions of annual VTR and VMS otter trawl days fished estimates were reasonably close, with little differences among the box plot whiskers (Fig. 8). The outlier distributions were slightly tighter among the VTR estimates relative to the VMS estimates, particularly from 2010 onward. Annual aggregate estimates of days fished were nearly identical between VMS and VTR (Fig. 9), with the points closely following the 1:1 identity line. In some of the years there are some statistical areas falling off the 1:1 identity line, though these are mostly statistical areas in the 600-series (Fig. 2), which generally contribute very little to the overall groundfish landings with the possible exception of the Southern New England/Mid-Atlantic flounder stocks. The distribution in the differences in the proportion of fishing time spent per statistical areas between VTR and VMS was much tighter post-2010 compared to pre-2010 (Fig. 10), indicating improved agreement between VTR and VMS-based effort estimates after sector implementation and paralleling the trends seen in the other analyses supportive of some improvements in VTR area reporting.

Comparisons of the stock apportionment between VMS and observer sources showed mixed results. If the assumption of constant LPUE used in the VMS-based method was valid, or at least did not lead to biased estimates of stock-level landings, it would be expected that the distribution of differences between VMS and observer sources would be median unbiased. For many of the stocks, this assumption holds, though for some there appears to be some bias in the VMS-based stock apportionment estimates (Fig. 11). These biases include a general tendency to over-allocate landings to the Gulf of Maine cod and haddock stocks (and under-allocate to the Western Georges Bank stocks) as well as a tendency to over-allocate to the Southern New England/Mid-Atlantic winter flounder stock (and under-allocate to the Georges Bank stock). While this indicates that the VMS method is not always able to achieve stock apportionment percentages identical to observer data, the differences in stock-level landings estimates between observer and VMS generally have better agreement than VTR and VMS comparisons, discussed next (Fig. 12).

Distributions of the trip-level differences between VTR-reported and VMS-estimated stock landings exhibit a notable shift for many key stocks after sector implementation in 2010 (Fig. 11). These trends are most notable for Eastern Georges Bank cod, with very little evidence of bias before 2010, but an obvious negative difference from 2010-2015 (indicating underreporting on the VTR). Similar patterns are seen for Gulf of Maine cod from 2013-2015, Gulf of Maine haddock from 2012-2015, Georges Bank yellowtail flounder from 2011-2013, and Southern New England/Mid-Atlantic winter flounder from 2010-2014. Note that any underreporting must be offset by overreporting of another stock of the same species, such that there is a reciprocal response in the distributions of 1 or more stocks of the same species. These same shifts are evident in the aggregate stock-level landings comparisons between VTR-reported and VMS-estimated amounts (Fig. 14). Putting the differences in a relative context, some of these differences can be large (e.g., VMS-estimated stock landings more than 2 times the VTR reported landings; Fig. 15). For example, landings of Eastern Georges Bank cod were estimated to be greater than 10 times the VTR-reported landings in 2012 and 2013. Relative errors were also calculated on a fishing year basis to better align with time periods used for in-season quota monitoring (Fig. 16), though these patterns closely follow the calendar year patterns.

While discussing preliminary results of this work with members of the fishing industry, it was hypothesized that the large estimated errors observed for Eastern Georges Bank cod could be attributable to the use of the required separator trawl gear when fishing in this area. The use of gears that are designed to limit the catch of cod when inside the Eastern Georges Bank area would invalidate the constant LPUE assumption when vessels fished both inside and outside the Eastern Georges Bank area on a single trip and did not use the separator trawl gear when outside of the Eastern Georges Bank area. The distributions of percent stock apportion between VMS and observer (Fig. 11) suggest that the constant LPUE assumption of the VMS-method still achieves results similar to those using observer data. The hypothesis was also examined by comparing the differences in landing amounts between observer and VMS, as well as between VTR and VMS on both observed and unobserved trips (Fig. 17). Not surprisingly the differences in landings amounts between observer and VMS showed similar patterns to the percent apportionment comparisons. When trips were observed, the difference between VTR reported amounts and VMS-estimated amounts were generally small (mean differences < 250 kg/trip), though these differences became large (mean difference > 500 kg/trip) when trips were not observed, with a notable shift in the distributions beginning in 2010. Collectively, these results provide no evidence that the large estimated errors among Eastern Georges Bank cod landings are an artifact of the VMS method, rather they suggest that the errors are real and that there is a notable difference in the accuracy of VTR reporting when the vessel is carrying an observer.

Adding the estimated VTR catch-area reporting error (i.e., the sum of the differences between the VTR-reported stock landings and the VMS-estimated stock landings) to official end-of-year reported catch had only minimal impacts on the majority of the stock examined. However, for 3 stocks (Eastern Georges Bank cod, Gulf of Maine Atlantic cod, and Gulf of Maine haddock), the addition of the estimated error resulted in revised catch estimates that, if the VMS estimates are correct, exceeded the annual sub-ACL for the commercial groundfish fishery in 2 or more years (Fig. 18). Southern New England/Mid-Atlantic winter flounder was an unallocated stock with no retention allowed in fishing years 2010-2012; consequently, while the estimated landings errors for this stock were large, the net impact on the overall catch estimates was relatively small and does not appear to be sufficient to have caused the sub-ACL to be exceeded in any of the years. It should be pointed out that theoretically, there should have been no landings of this stock; however, ignorance of the regulations or errors in species or area reporting could explain the small amount of landings reported.

VTR-reported landings represent hail weights (i.e., good-faith estimate) of the landed fish product offloaded to the seafood dealer. It is known that VTR hail weights are generally lower than the scale weights obtained by the seafood dealer (Palmer et al. 2007) and are not adjusted to live weight (e.g., species like cod and haddock are typically landed gutted). Both stock assessments and quota monitoring are based on the estimated live weight of landings, so errors estimated solely from VTR data may underestimate the total error in terms of biomass. A comparison of VTR reported annual species pounds suggests that VTR landings estimates are about 20-40% lower than the live weight estimates for cod and haddock and 10-20% lower for the flounder species (Fig. 19). Given this finding, if the VMS method is correctly estimating the directionality of catch error, the actual magnitude of the error may be greater than estimated (ignoring other uncertainties with the VMS method).

In an effort to understand the scope of reporting errors in terms of the number of vessels, the cumulative distribution of the estimated error was plotted as a function of the number of contributing vessels. This exercise was performed on 4 example stock and year combinations when the relative error was estimated to be large: Eastern Georges Bank cod in 2013, Gulf of Maine Atlantic cod in 2015, Gulf of Maine haddock in 2013, and Southern New England/Mid-Atlantic winter flounder in 2012. The difference between the trip-level VTR and VMS estimated stock landings (Fig. 13) was summed by year and vessel permit, and then all vessel permits having a negative error (VTR landings < VMS landings) were extracted and ranked in ascending order by magnitude of error. From this list, the cumulative percent contribution of each vessel was plotted as a function of the ascending rank of the vessels with those vessels responsible for 80% of the error highlighted. In the 4 examples examined, the number of vessels responsible for 80% of the error ranged from 13 to 22 (Fig. 20).

DISCUSSION

Incorrect VTR catch-area reporting is an established problem in Northeast U.S fisheries that was first documented and quantified in 2007 (Palmer and Wigley 2007). Over the past decade, marginal improvements have been made in improving the accuracy of VTR area reporting, though reporting errors continue to be problematic as evidenced by the fact that there remains less than 50% agreement between the area reported on the VTR compared to that recorded by the observer on multiarea trips (Table 4). The overall impacts of catch-area reporting errors are estimated to be small for the majority of stocks examined and unlikely to substantially impact resource monitoring and stock assessment efforts; however, for some stocks the estimated errors are large (greater than 2 times the VTR reported landings), and an increase in the magnitude of the errors appears to coincide with the shift to sector management in fishing year 2010 (e.g., Eastern Georges Bank cod) or when quotas for certain stocks were reduced or became limiting for the fishery (e.g., Gulf of Maine cod in 2013 and Gulf of Maine haddock in 2012). The magnitudes of some of the estimated errors suggest that catch reporting errors are deserving of more attention. However, VTR catch-area reporting is only one possible source of catch error, and all sources must be considered to gain a full understanding of how catch reporting patterns impact the management of the groundfish resource.

VMS data indicate where it is likely that fishing effort is occurring but provide no information on catch composition. A critical assumption of the VMS-based apportionment is that the proportion of species caught across multiple stock areas on a fishing trip is only a function of the time spent fishing in each stock area. Palmer and Wigley (2009) concluded that, while there was considerable variability between VMS-based apportionment and observer data, there was no evidence of bias. The results here do not necessarily support this conclusion; there is evidence that the VMS method cannot reliably replicate the stock apportionments obtained from observer data (Fig. 9). For some stocks (e.g., Gulf of Maine cod and haddock) the direction of the bias is consistent with the estimated catch-area error suggesting that the estimated VTR landings errors may be partly an artifact of the VMS method. However, the differences between observer and VMS estimated landings are small relative to the differences that exist between VTR reported landings and VMS estimated landings, suggesting that the estimated errors capture some component of true catch-area reporting error. For other stocks, such as Eastern Georges Bank cod, there is no indication that the VMS method is producing unreliable results (Figs. 9 and 14), so the estimated errors are unlikely an artifact and likely represent reporting errors.

The performance of the VMS method relative to observer data highlights that more sophisticated methods for interpreting VMS data are needed to fully understand the impacts of catch-area reporting patterns. While the VMS method achieves area-fished estimates much closer to observer data relative to VTR, complete agreement on multiarea trips was never better than 75% in any year and averaged only 66% over the time series (Table 5). There is room for improvement in the VMS-based methods, specifically with respect to the detection of fishing effort and estimation of the spatial catch distributions. The VMS method relies on simple speed windows, which have a demonstrated tendency to overestimate the amount of fishing by incorrectly classifying nonfishing effort as fishing (Palmer and Wigley 2007, 2009). Over the years more sophisticated methods have been developed for analyzing and interpreting VMS data, which may offer improvements in the detection of fishing effort. These methods include the use of mixture distribution models (e.g., Marin et al. 2005), spline interpolation techniques (e.g., Hintzen et al. 2010; Russo et al. 2011), artificial neural networks (Joo et al. 2011) and Bayesian models (Vermard et al. 2010; Bez et al. 2011). The use of groundfish habitat models (e.g., Rooper et al. 2005) and an improved understanding of the drivers of fishery catches (Jannot and Holland 2013) could be used to improve the estimation of catch distributions.

The various uncertainties and shortcomings of the existing VMS apportionment method point out that this is not a replacement for accurate VTR-based apportionment. However, the results do show that VMS data along with observer data can and should be used as a tool to monitor the accuracy and completeness of VTRs and guide efforts to improve the quality of VTRs and compliance with VTR requirements. The methods described here are valuable tools for highlighting vessels that repeatedly exhibit suspicious reporting patterns and warrant a more detailed investigation of catch-area reporting practices. Looking at vessel reporting patterns over time can easily identify patterned behavior and how behavior may change on observed vs. unobserved trips (e.g., via heat maps, Fig. 21). Other types of analytical tools can be used to more definitively evaluate the accuracy of vessel catch-area reports; for example, comparing vessel-reported LPUE to observed LPUE from trips with the same gear type, statistical area, and season can easily identify trips where the VTR-reported catch is likely inaccurate (Fig. 22). The number of vessels substantially contributing to the estimated errors in stock-level landings is small (fewer than 25 vessels in the cases examined). Targeted monitoring of these vessels combined with outreach and education to correct the reporting problems could mitigate the impacts of VTR catch-area reporting on stock assessments and in-season quota monitoring efforts. At a minimum there should be agreement in the reported area fished between observer and VTR data on observed trips.

While this paper has focused on the impacts of catch-area reporting at the stock-level, it is critical that the data are captured correctly at the finer scale of statistical areas (i.e., the level of resolution required by federal regulations) as these data serve many other analytical needs beyond stock assessments and quota monitoring. This paper only considers the impact on fish resource monitoring; however, the spatial accuracy of VTR reports is also critical for monitoring fishery interactions with protected species such as sea turtles (e.g., Murray 2004, 2005, 2006; Orphanides and Bisak 2006) and marine mammals (Belden et al. 2006). When these data are used at finer spatial scales, the accuracy of VTR reports becomes increasingly important. While VMS data can be used to monitor compliance with VTR area fished requirements, assessing and ensuring the accurate reporting of catch (Fig. 1, example C) on unobserved trips is a difficult task. The problem of catch-area reporting errors could also be solved through changes in fisheries management measures; these measures could include restricting vessels to fishing in only 1 statistical area unless carrying an observer or requiring 100% observer coverage.

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Table 1. Statistical areas shown in Fig. 2 used to define species stock units for the four species examined.

Species	Stock area	Statistical areas
	Eastern Georges Bank (EGB)	551, 552, 561, 562
Atlantic cod *(Gadus morhua)*	Western Georges Bank (WGB)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 640
	Gulf of Maine (GOM)	464, 465, 467, 511 - 515
	Eastern Georges Bank (EGB)	551, 552, 561, 562
Haddock *(Melanogrammus aeglefinus)*	Western Georges Bank (WGB)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 640
	Gulf of Maine (GOM)	464, 465, 467, 511 - 515
	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
Yellowtail flounder *(Limanda ferruginea)*	Cape Cod/Gulf of Maine (GOM)	464, 465, 467, 511, 512, 513, 514, 515, 521
	Southern New England/Mid-Atlantic (SNE)	526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 640
	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
Winter flounder *(Pseudopleuronectes americanus)*	Gulf of Maine (GOM)	464, 465, 467, 511, 512, 513, 514, 515
	Southern New England/Mid-Atlantic (SNE)	521, 526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 640

Table 2. Summary of the vessel trip report (VTR), vessel monitoring system (VMS), and observer data sets in terms of number of trips and number of vessels from 2007 to 2016. *Note that 2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Category	Number of trips	Number of Vessels	Matching/coverage rate
2007	VTR dataset	112,964	2,404	
	VTR subset	19,971	586	
	VMS-VTR matched set	17,083	532	0.86
	Observer-VMS-VTR matched set	619	266	0.03
2008	VTR dataset	106,711	2,281	
	VTR subset	21,353	549	
	VMS-VTR matched set	15,389	482	0.72
	Observer-VMS-VTR matched set	558	251	0.03
2009	VTR dataset	105,455	2,155	
	VTR subset	19,922	497	
	VMS-VTR matched set	17,089	448	0.86
	Observer-VMS-VTR matched set	800	279	0.04
2010	VTR dataset	103,540	2,170	
	VTR subset	13,916	437	
	VMS-VTR matched set	12,200	392	0.88
	Observer-VMS-VTR matched set	2,041	276	0.15
2011	VTR dataset	98,463	2,023	
	VTR subset	11,611	377	
	VMS-VTR matched set	10,740	332	0.92
	Observer-VMS-VTR matched set	2,705	274	0.23
2012	VTR dataset	96,065	1,998	
	VTR subset	11,834	360	
	VMS-VTR matched set	10,873	316	0.92
	Observer-VMS-VTR matched set	2,511	250	0.21
2013	VTR dataset	85,385	1,883	
	VTR subset	8,883	319	
	VMS-VTR matched set	8,163	289	0.92
	Observer-VMS-VTR matched set	1,364	218	0.15
2014	VTR dataset	82,599	1,843	
	VTR subset	8,017	293	
	VMS-VTR matched set	7,374	267	0.92
	Observer-VMS-VTR matched set	1,579	209	0.20
2015	VTR dataset	78,788	1,794	
	VTR subset	6,157	264	
	VMS-VTR matched set	5,731	237	0.93
	Observer-VMS-VTR matched set	974	175	0.16
2016*	VTR dataset	11,265	1,076	
	VTR subset	1,574	169	
	VMS-VTR matched set	1,526	160	0.97
	Observer-VMS-VTR matched set	205	80	0.13

Table 3. Species-level summary of the Vessel Monitoring System (VMS) dataset and vessel trip reports (VTR) subset compared to total VTR landings (mt) from 2007 to 2016. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Species	Total VTR landings (mt)	VTR subset (mt)	Percent of total (%)	VMS matched set (mt)	Percent of total (%)
2007	Atlantic cod *(Gadus morhua)*	6,278	6,185	98.5	5,844	94.5
	Haddock *(Melanogrammus aeglefinus)*	3,072	3,067	99.8	3,028	98.7
	Yellowtail flounder *(Limanda ferruginea)*	1,676	1,669	99.6	1,633	97.8
	Winter flounder *(Pseudopleuronectes americanus)*	2,512	2,368	94.2	2,121	89.6
2008	Atlantic cod *(Gadus morhua)*	7,022	6,952	99.0	5,028	72.3
	Haddock *(Melanogrammus aeglefinus)*	5,218	5,213	99.9	4,155	79.7
	Yellowtail flounder *(Limanda ferruginea)*	1,627	1,610	99.0	1,253	77.8
	Winter flounder *(Pseudopleuronectes americanus)*	2,231	2,125	95.2	1,940	91.3
2009	Atlantic cod *(Gadus morhua)*	7,232	7,041	97.4	6,323	89.8
	Haddock *(Melanogrammus aeglefinus)*	4,859	4,843	99.7	4,792	99.0
	Yellowtail flounder *(Limanda ferruginea)*	1,575	1,561	99.1	1,508	96.6
	Winter flounder *(Pseudopleuronectes americanus)*	1,989	1,903	95.7	1,868	98.2
2010	Atlantic cod *(Gadus morhua)*	6,407	6,274	97.9	5,794	92.4
	Haddock *(Melanogrammus aeglefinus)*	7,968	7,848	98.5	7,819	99.6
	Yellowtail flounder *(Limanda ferruginea)*	1,254	1,242	99.0	1,204	96.9
	Winter flounder *(Pseudopleuronectes americanus)*	1,424	1,390	97.6	1,379	99.2
2011	Atlantic cod *(Gadus morhua)*	6,272	6,147	98.0	6,011	97.8
	Haddock *(Melanogrammus aeglefinus)*	4,832	4,557	94.3	4,537	99.5
	Yellowtail flounder *(Limanda ferruginea)*	1,712	1,655	96.7	1,647	99.5
	Winter flounder *(Pseudopleuronectes americanus)*	1,922	1,872	97.4	1,865	99.6
2012	Atlantic cod *(Gadus morhua)*	3,861	3,809	98.7	3,748	98.4
	Haddock *(Melanogrammus aeglefinus)*	1,763	1,586	89.9	1,581	99.7
	Yellowtail flounder *(Limanda ferruginea)*	2,294	1,575	68.7	1,559	99.0
	Winter flounder *(Pseudopleuronectes americanus)*	2,215	2,180	98.4	2,171	99.6
2013	Atlantic cod *(Gadus morhua)*	1,795	1,770	98.6	1,738	98.2
	Haddock *(Melanogrammus aeglefinus)*	1,585	1,530	96.6	1,528	99.9
	Yellowtail flounder *(Limanda ferruginea)*	1,996	1,087	54.5	1,064	97.9
	Winter flounder *(Pseudopleuronectes americanus)*	2,562	2,510	98.0	2,497	99.5
2014	Atlantic cod *(Gadus morhua)*	1,868	1,843	98.7	1,822	98.8
	Haddock *(Melanogrammus aeglefinus)*	3,723	3,599	96.7	3,597	100.0
	Yellowtail flounder *(Limanda ferruginea)*	1,664	906	54.4	890	98.2
	Winter flounder *(Pseudopleuronectes americanus)*	1,804	1,765	97.8	1,750	99.1
2015	Atlantic cod *(Gadus morhua)*	1,188	1,160	97.7	1,154	99.5
	Haddock *(Melanogrammus aeglefinus)*	4,579	4,401	96.1	4,400	100.0
	Yellowtail flounder *(Limanda ferruginea)*	1,112	583	52.4	564	96.7
	Winter flounder *(Pseudopleuronectes americanus)*	1,539	1,522	98.9	1,510	99.2
2016*	Atlantic cod *(Gadus morhua)*	576	570	98.9	569	99.8
	Haddock *(Melanogrammus aeglefinus)*	1,239	1,236	99.7	1,236	100.0
	Yellowtail flounder *(Limanda ferruginea)*	206	206	99.6	202	98.4
	Winter flounder *(Pseudopleuronectes americanus)*	88	88	99.1	87	99.0

Table 4. Percentage of complete agreement between statistical areas fished recorded by fishery observers (including at-sea monitors) and the statistical areas fished reported on vessel trip reports (VTR) from matched fishing trips from 2007 and 2016. Complete agreement is defined as a match on both the number of areas fished and the identity of areas fished. Trip subcategories (single-area vs. multi-area) are based on the observer-reported number of statistical areas fished. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Single-area trip	Multi-area trip
2007	92.2%	16.9%
2008	91.8%	15.9%
2009	94.7%	22.5%
2010	95.7%	19.7%
2011	95.8%	25.0%
2012	96.7%	25.2%
2013	95.1%	28.9%
2014	94.9%	27.9%
2015	91.8%	43.8%
2016*	92.4%	49.2%
Average	94.1%	27.5%
Minimum	91.8%	15.9%
Maximum	96.7%	49.2%

Table 5. Percentage of complete agreement between statistical areas fished recorded by fishery observers (including at-sea monitors) and the statistical areas fished estimated using vessel monitoring system (VMS) data from matched fishing trips from 2007 and 2016. Complete agreement is defined as a match on both the number of areas fished and the identity of areas fished. Trip subcategories (single-area vs. multi-area) are based on the observer-reported number of statistical areas fished. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Single-area trip	Multi-area trip
2007	90.8%	75.4%
2008	87.5%	65.3%
2009	91.7%	64.4%
2010	96.0%	63.3%
2011	95.1%	68.0%
2012	96.3%	65.7%
2013	91.8%	68.9%
2014	90.5%	65.8%
2015	88.4%	63.8%
2016*	91.0%	54.1%
Average	91.9%	65.5%
Minimum	87.5%	54.1%
Maximum	96.3%	75.4%

Table 6. Percentage of complete agreement between statistical areas fished reported on vessel trip reports (VTR) and the statistical areas fished estimated using vessel monitoring system (VMS) data from matched fishing trips from 2007 to 2016. Complete agreement is defined as a match on both the number of areas fished and the identity of areas fished. Trip subcategories (single-area vs. multi-area) are based on the VMS-estimated number of statistical areas fished. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Single-area trip	Multi-area trip
2007	92.0%	6.5%
2008	91.0%	4.3%
2009	93.7%	6.2%
2010	95.4%	11.9%
2011	95.4%	15.8%
2012	96.8%	16.1%
2013	94.5%	18.4%
2014	95.2%	19.7%
2015	91.9%	21.1%
2016*	92.4%	24.3%
Average	93.8%	14.4%
Minimum	91.0%	4.3%
Maximum	96.8%	24.3%

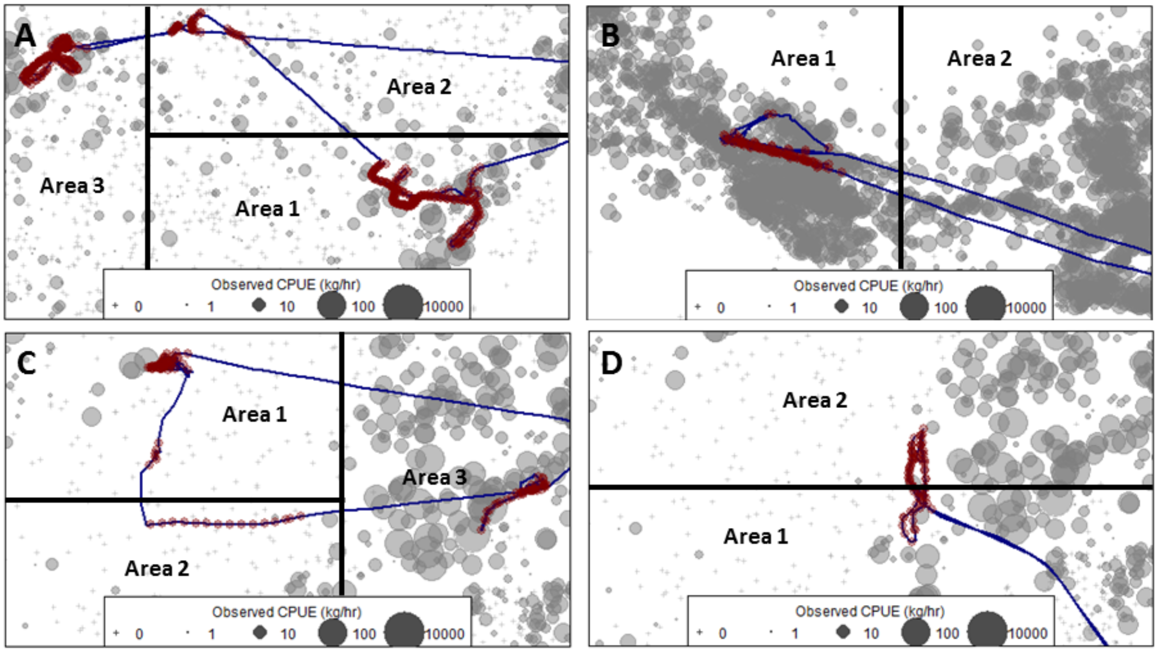
Table 7. Percentage of complete agreement between statistical areas fished reported on vessel trip reports (VTR) and the statistical areas fished estimated by using vessel monitoring system (VMS) data from matched fishing trips that were monitored by an observer from 2007 to 2016. Complete agreement is defined as a match on both the number of areas fished and the identity of areas fished. Trip subcategories (single-area vs. multarea) are based on the VMS-estimated number of statistical areas fished. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Single-area trip	Multi-area trip
2007	92.9%	14.1%
2008	91.1%	11.3%
2009	95.6%	13.1%
2010	96.0%	14.5%
2011	95.9%	17.4%
2012	97.1%	17.6%
2013	95.6%	19.1%
2014	96.2%	19.1%
2015	93.9%	24.4%
2016*	93.2%	25.0%
Average	94.8%	17.6%
Minimum	91.1%	11.3%
Maximum	97.1%	25.0%

Table 8. Detailed summary of the agreement levels between statistical areas recorded on vessel trip reports (VTR) and the statistical areas fished as determined by using vessel monitoring system (VMS) positional data from matched fishing trips from 2007 to 2016. Trip subcategories (single-area vs. multiarea) are based on the VMS-estimated number of statistical areas fished. *2016 data are incomplete and only include trips landing through April 30, 2016 – the end of the 2015 fishing year.

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2007	Single area	13,775	Complete	12,667	92.0
			None	1088	7.9
			Partial	20	0.1
	Multi-area	3,308	Complete	214	6.5
			None	123	3.7
			Partial	2,971	89.8
2008	Single area	12,765	Complete	11,621	91.0
			None	1132	8.9
			Partial	12	0.1
	Multi-area	2,624	Complete	113	4.3
			None	156	5.9
			Partial	2,355	89.7
2009	Single area	14,120	Complete	13,225	93.7
			None	882	6.2
			Partial	13	0.1
	Multi-area	2,969	Complete	183	6.2
			None	186	6.3
			Partial	2,600	87.6
2010	Single area	9,535	Complete	9,097	95.4
			None	428	4.5
			Partial	10	0.1
	Multi-area	2,665	Complete	318	11.9
			None	142	5.3
			Partial	2,205	82.7
2011	Single area	7,950	Complete	7,587	95.4
			None	344	4.3
			Partial	19	0.2
	Multi-area	2,790	Complete	442	15.8
			None	53	1.9
			Partial	2,295	82.3

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2012	Single area	8,097	Complete	7,841	96.8
			None	244	3.0
			Partial	12	0.1
	Multi-area	2,776	Complete	447	16.1
			None	52	1.9
			Partial	2,277	82.0
2013	Single area	5,317	Complete	5,025	94.5
			None	263	4.9
			Partial	29	0.5
	Multi-area	2,846	Complete	523	18.4
			None	58	2.0
			Partial	2,265	79.6
2014	Single area	4,735	Complete	4,509	95.2
			None	179	3.8
			Partial	47	1.0
	Multi-area	2,639	Complete	520	19.7
			None	43	1.6
			Partial	2,076	78.7
2015	Single area	3,350	Complete	3,079	91.9
			None	230	6.9
			Partial	41	1.2
	Multi-area	2,381	Complete	502	21.1
			None	49	2.1
			Partial	1,830	76.9
2016*	Single area	811	Complete	749	92.4
			None	58	7.2
			Partial	4	0.5
	Multi-area	715	Complete	174	24.3
			None	17	2.4
			Partial	524	73.3



Example trip	Example type	Area	Reported effort (days fished)	VMS estimated effort (days fished)	Reported catch (kg)	VMS estimated catch (kg)
A	Under-reporting	1		0.5		125
		2	3	2	1000	500
		3		1.5		375
B	Over-reporting	1	1	2	0	2000
		2	1	0	2000	
C	Misreporting	1	1	1	0	200
		2	1	1	0	200
		3	0.5	0.5	500	100
D	Legal, but problematic	1	1	0.5	300	150
		2		0.5		150

Figure 1. Examples of fishing trip track lines and reporting behaviors which contribute to the misallocation of commercial landings to stock area. The blue lines represent the track line of the fishing trip recorded from regular vessel monitoring system (VMS) polls, and the red dots represent polls indicative of fishing activity (i.e., falling within the specified speed ranges). The gray bubbles provide ancillary information on the spatial distribution of observed catch. The inset table summarizes the types of reporting trends associated with each example trip. Data presented are for illustration only and do not represent actual fishing trips but are reflective of actual behavior.

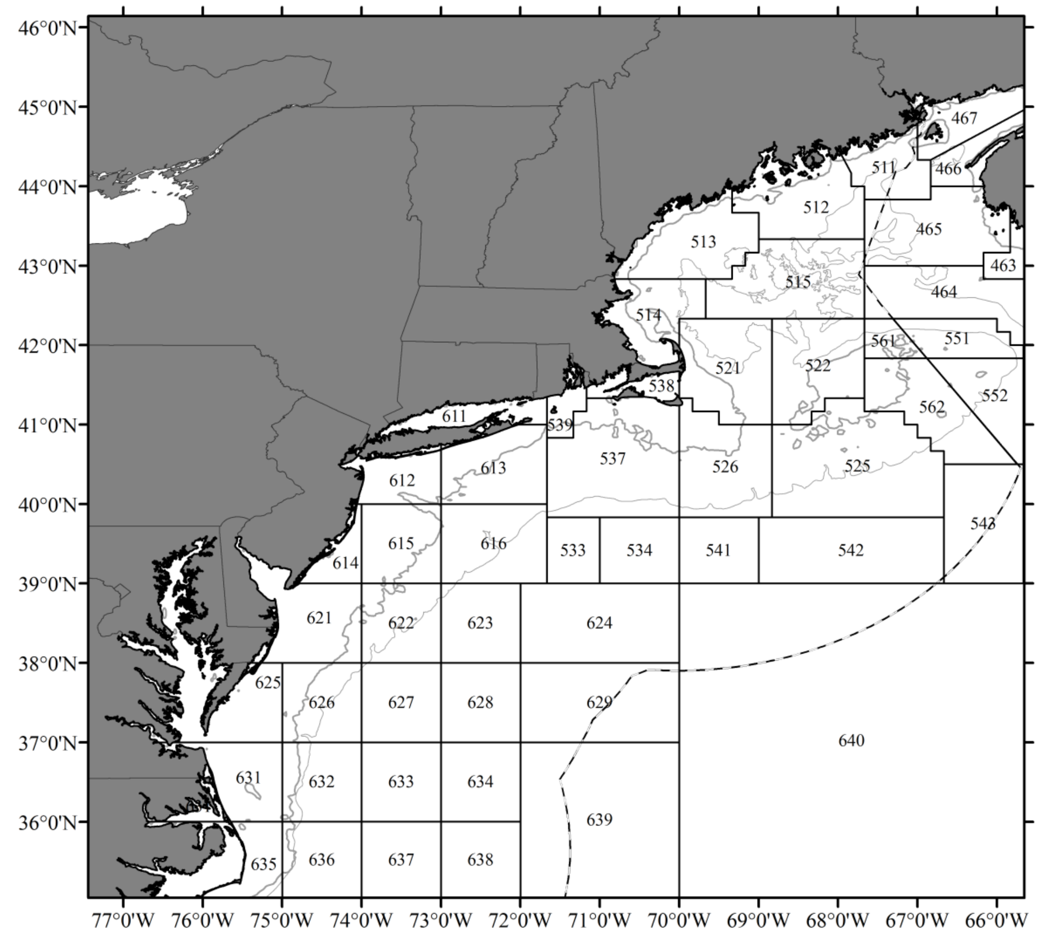


Figure 2. Statistical areas used for commercial fisheries data collection by the National Marine Fisheries Service in the Northeast Region. The 50 and 100 meter bathymetric lines are shown in light gray, and the U.S. Exclusive Economic Zone is indicated by the dashed black line.

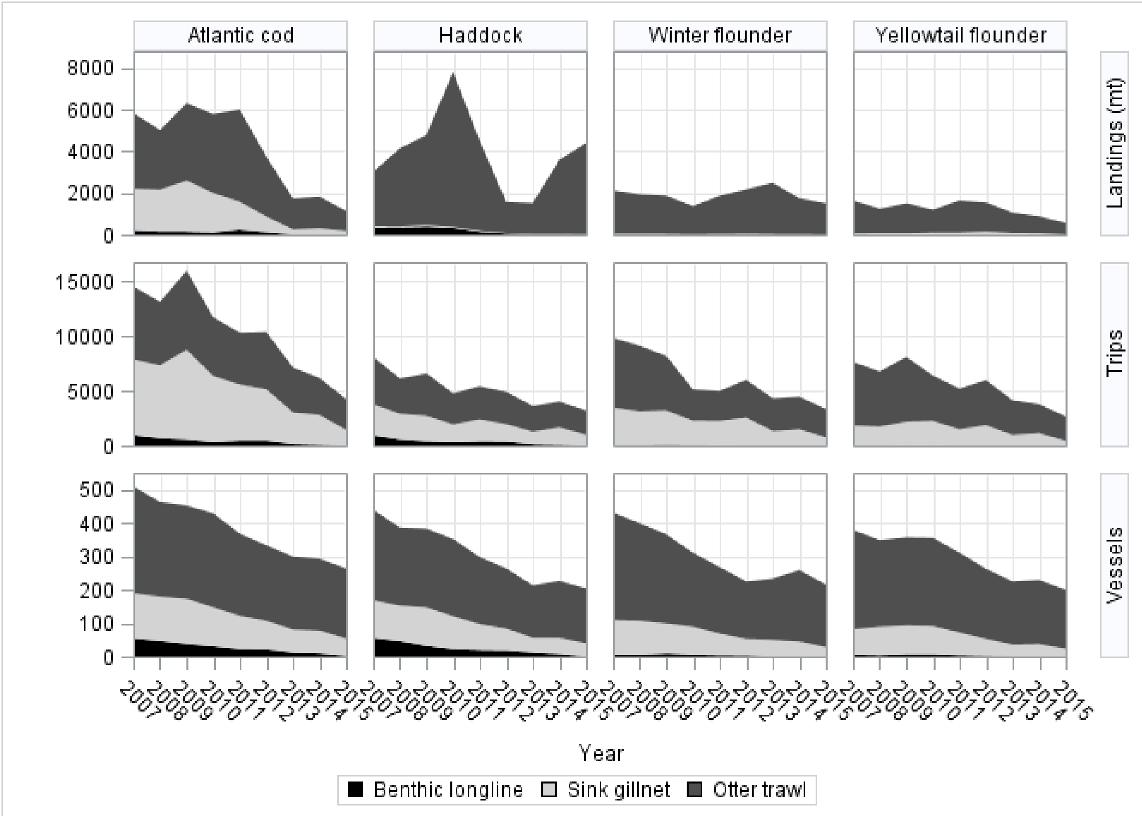


Figure 3. Summary of data included in the matched vessel trip reports - vessel monitoring system -analytical set by species, gear type, and year. Data are summarized in terms of landings, trips and number of unique vessel permits.

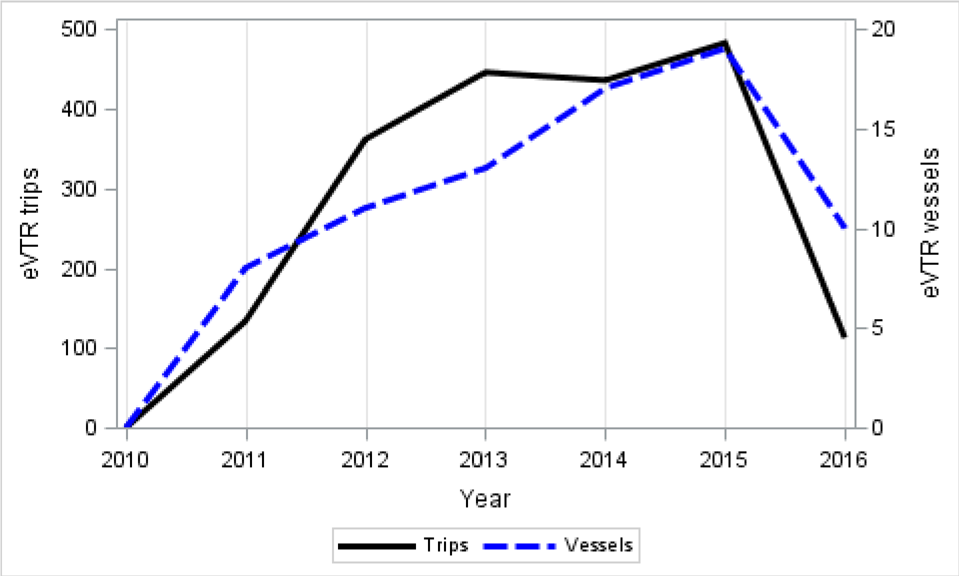


Figure 4. Use of electronic logbooks to submit haul-by-haul vessel trip reports (eVTR) between 2010 and 2016. Note that eVTR use was not approved for use until June 30, 2011 and that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

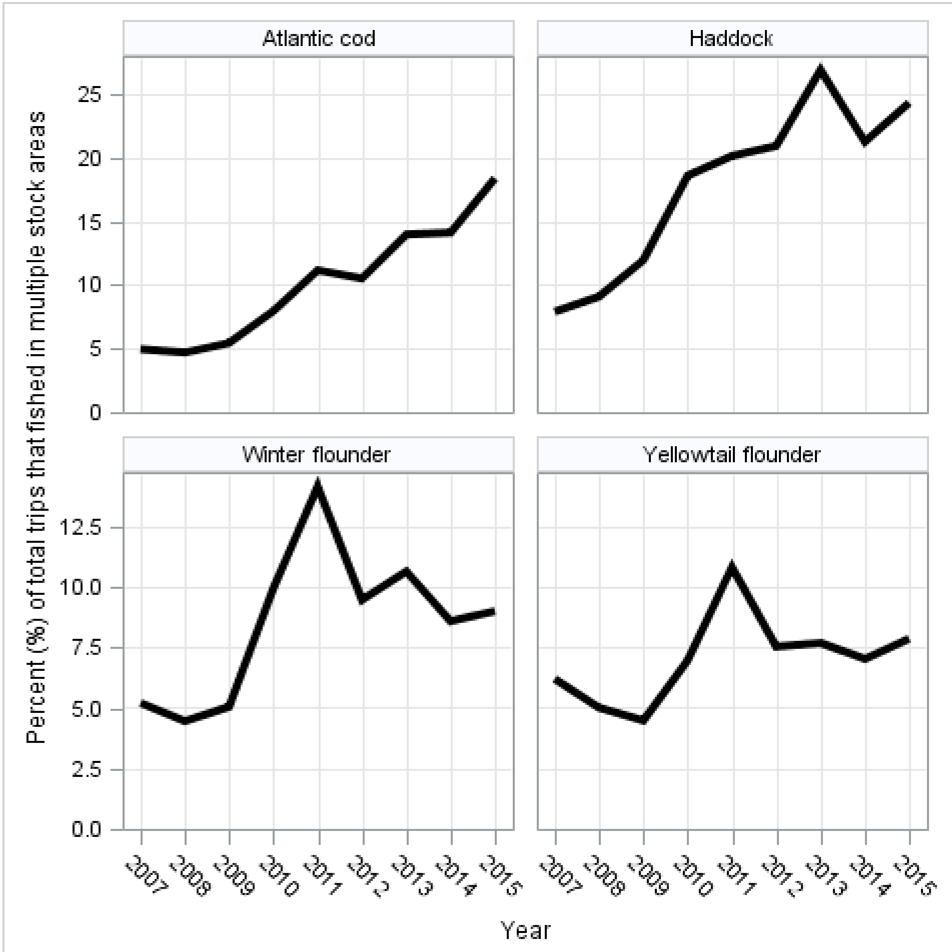


Figure 5. Percent of total trips landing Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), or yellowtail flounder (*Limanda ferruginea*) that fished in multiple stock areas between 2007 and 2015 as determined from vessel monitoring system (VMS) data.

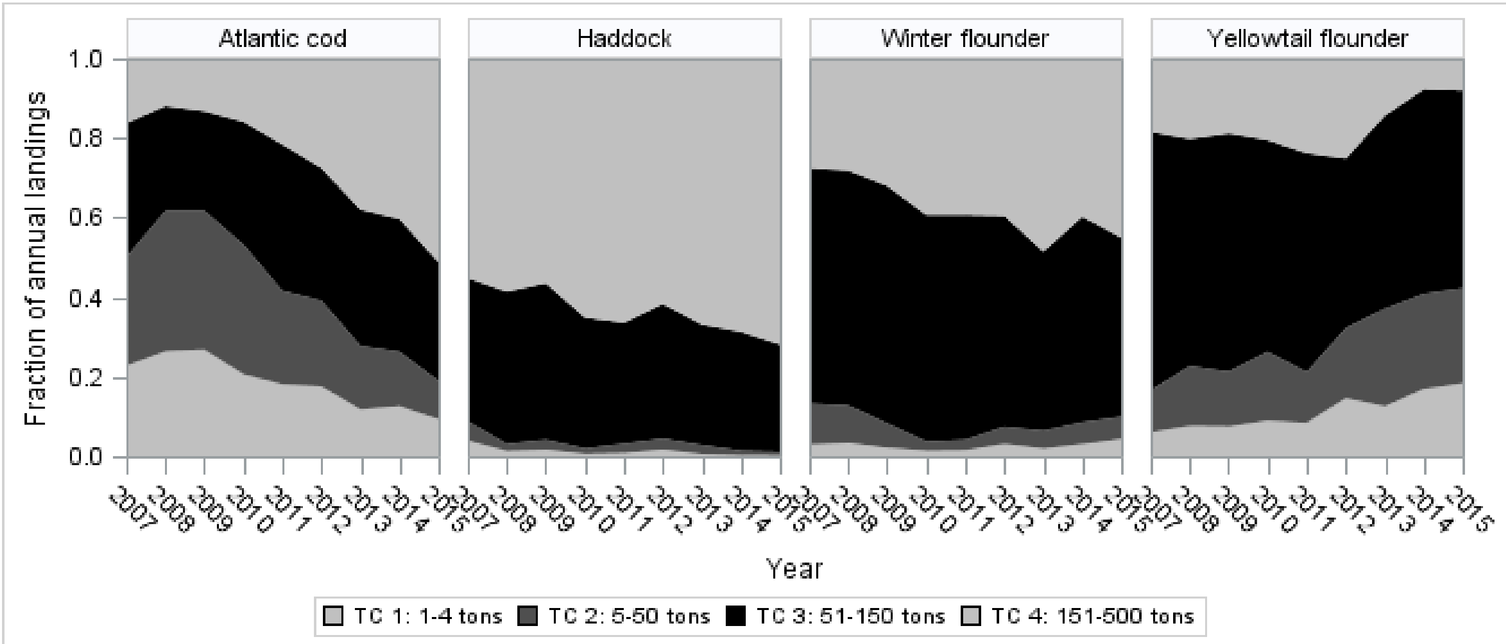


Figure 6. Fraction of total landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), or yellowtail flounder (*Limanda ferruginea*) by vessel ton class between 2007 and 2015.

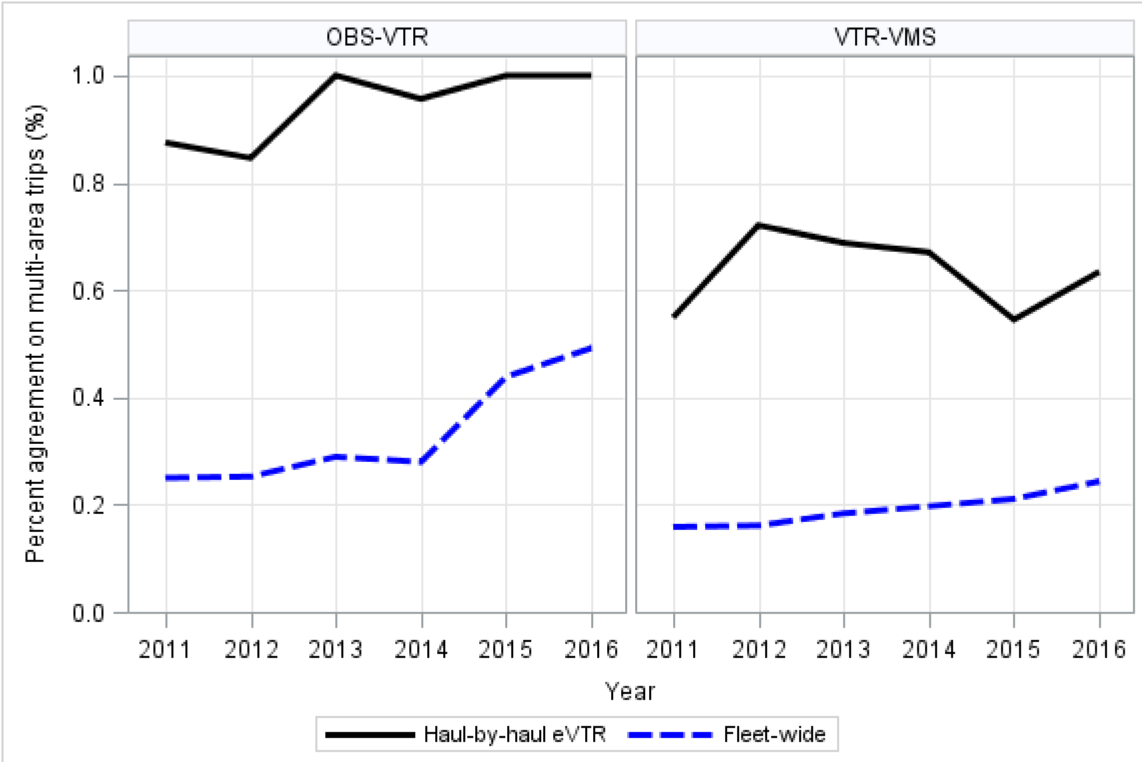


Figure 7. Level of percent agreement in the area fished reported on the vessel trip report (VTR) for trips fishing in multiple statistical areas compared between the entire groundfish fleet (fleetwide) and those vessels reporting haul-by-haul VTR data electronically (haul-by-haul eVTR). Both observer (OBS)-VTR and VTR-vessel monitoring system (VMS) comparisons are shown. The fleetwide estimates are from Tables 4 and 6. Note that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

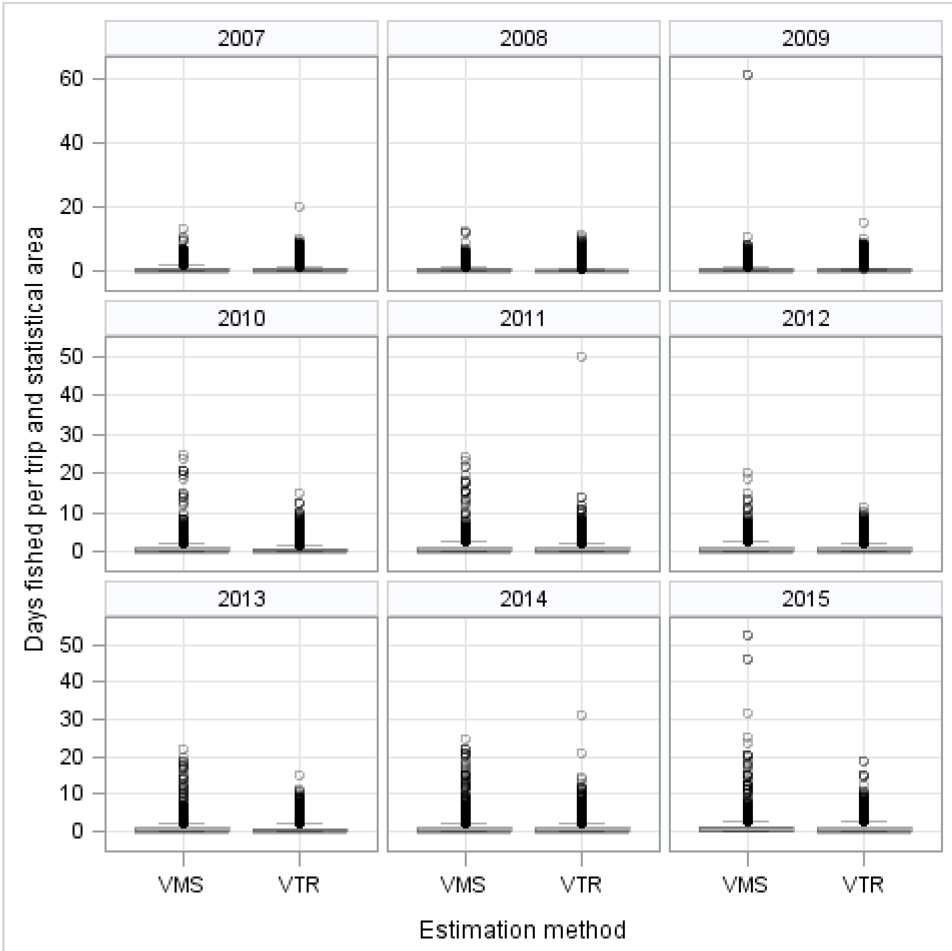


Figure 8. Box plot distributions of the otter trawl days fished per statistical area and trip from both vessel trip report (VTR) and vessel monitoring system (VMS) data sources by year. The analysis only includes trips fishing otter trawl gear and fishing in multiple statistical areas on a single trip.

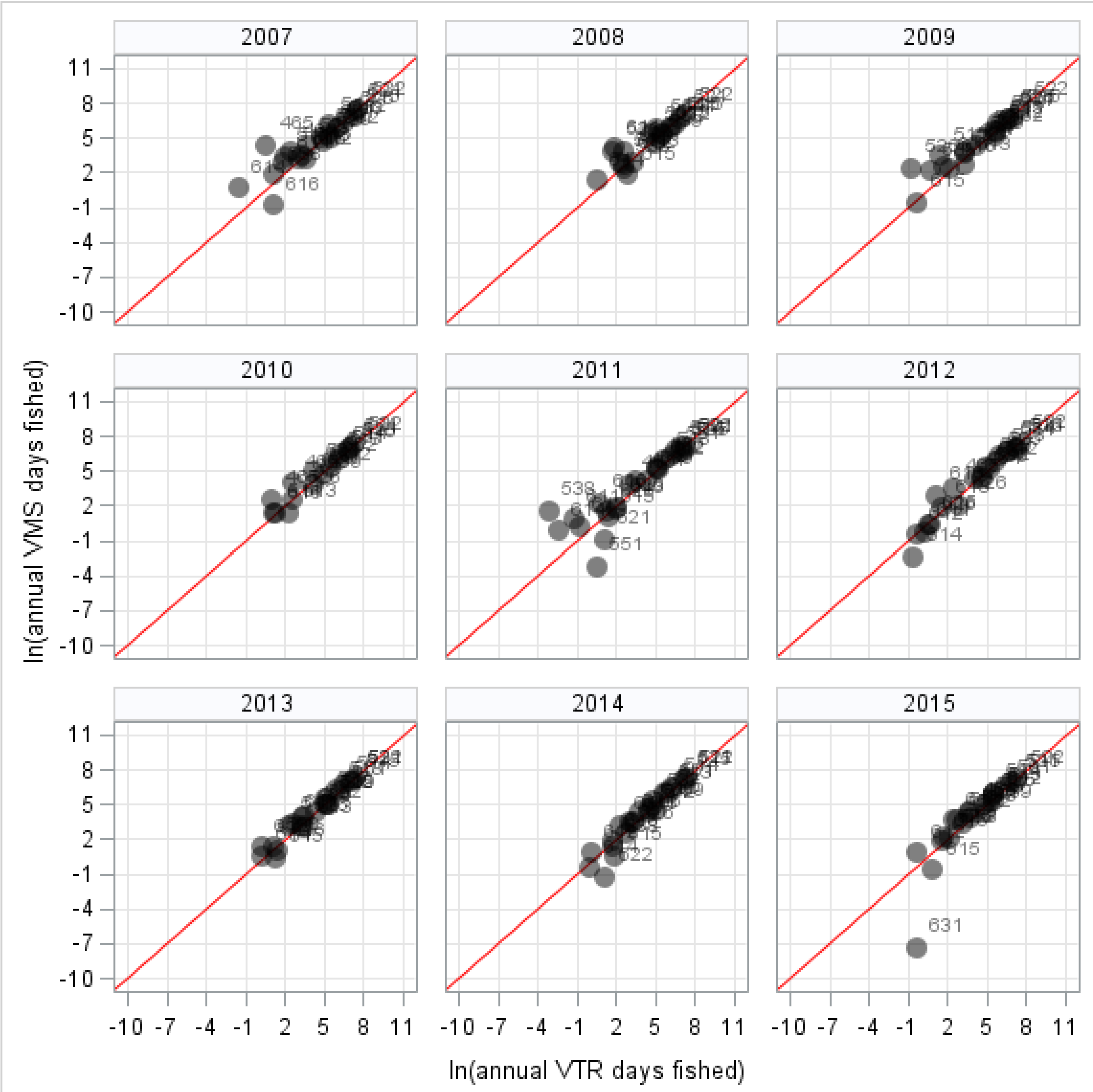


Figure 9. Scatter plot comparing the natural log (ln) of total annual days fished estimated from vessel trip report (VTR) reports and from vessel monitoring system (VMS) data by statistical area from 2007 to 2015. Each dot represents a single statistical area. The analysis only includes trips fishing otter trawl gear and fishing in multiple statistical areas on a single trip. The solid red line represents the 1:1 identity line where VMS and VTR estimates are equal.

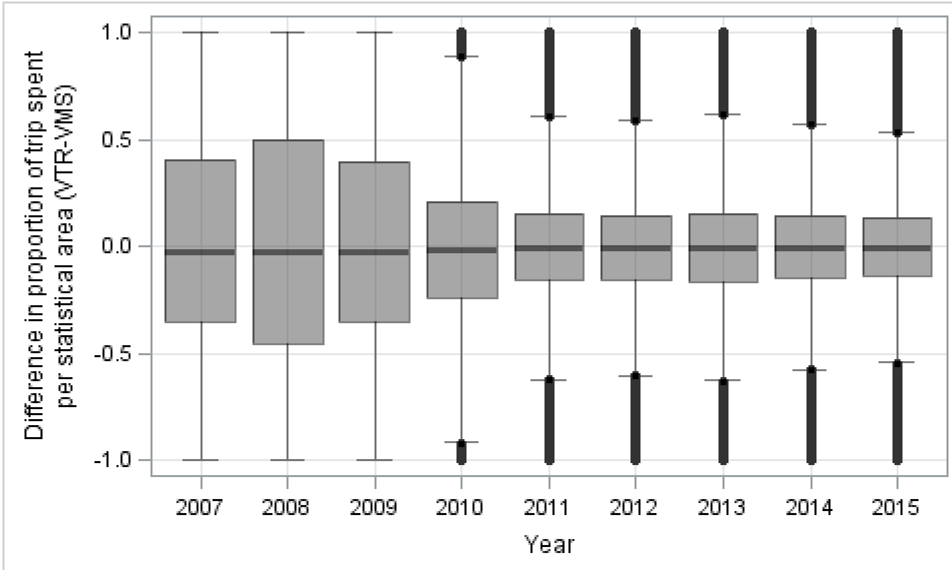


Figure 10. Box plot distribution of the differences in the proportion of a trip spent fishing per statistical area between vessel trip report (VTR) and vessel monitoring system (VMS) methods by year. The analysis only includes trips fishing otter trawl gear and fishing in multiple statistical areas on a single trip.

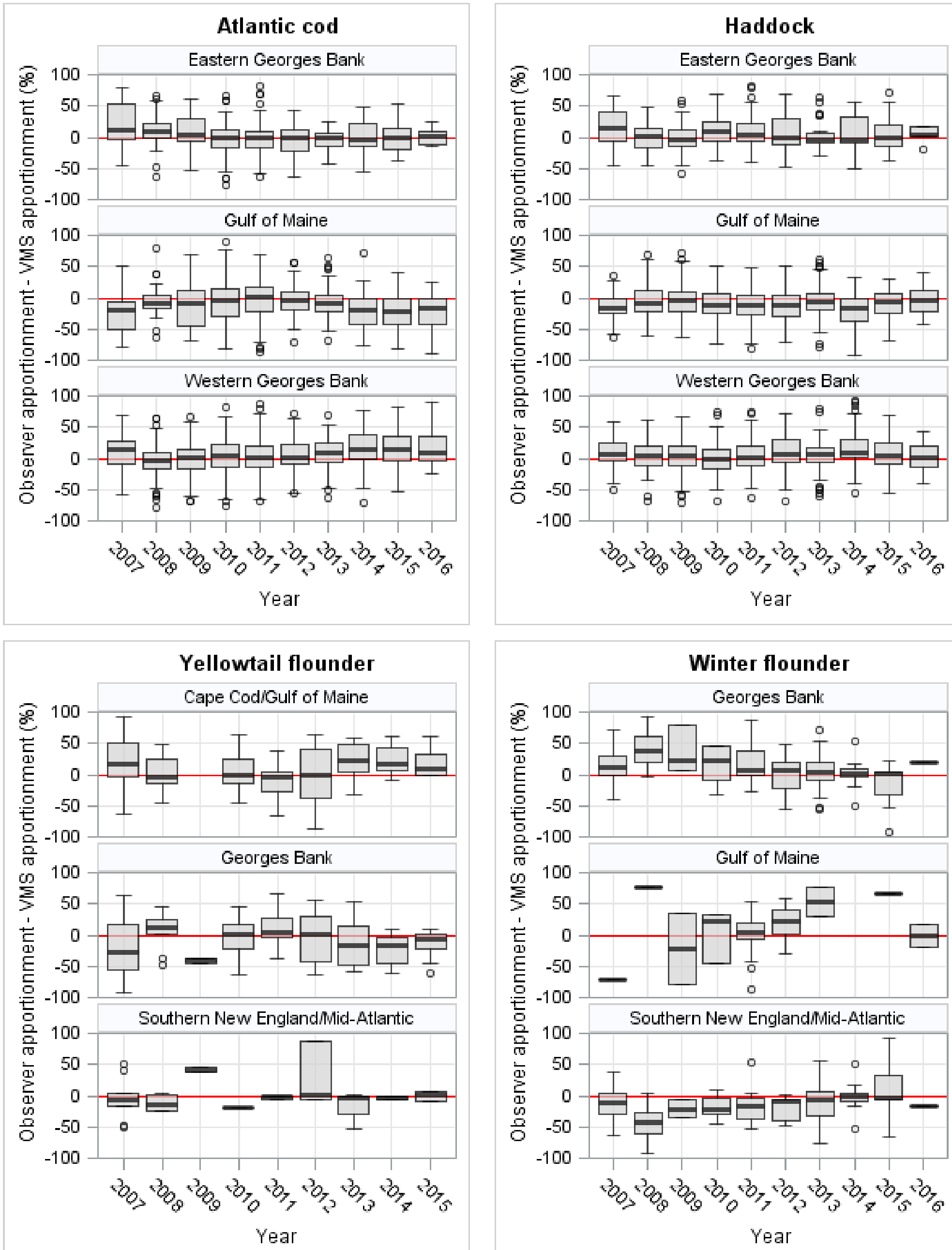


Figure 11. Box plot distribution of trip-level differences between the vessel monitoring system (VMS) estimated stock apportionment (%) and the observer recorded apportionment (%) of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) between 2007 and 2015. Note that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

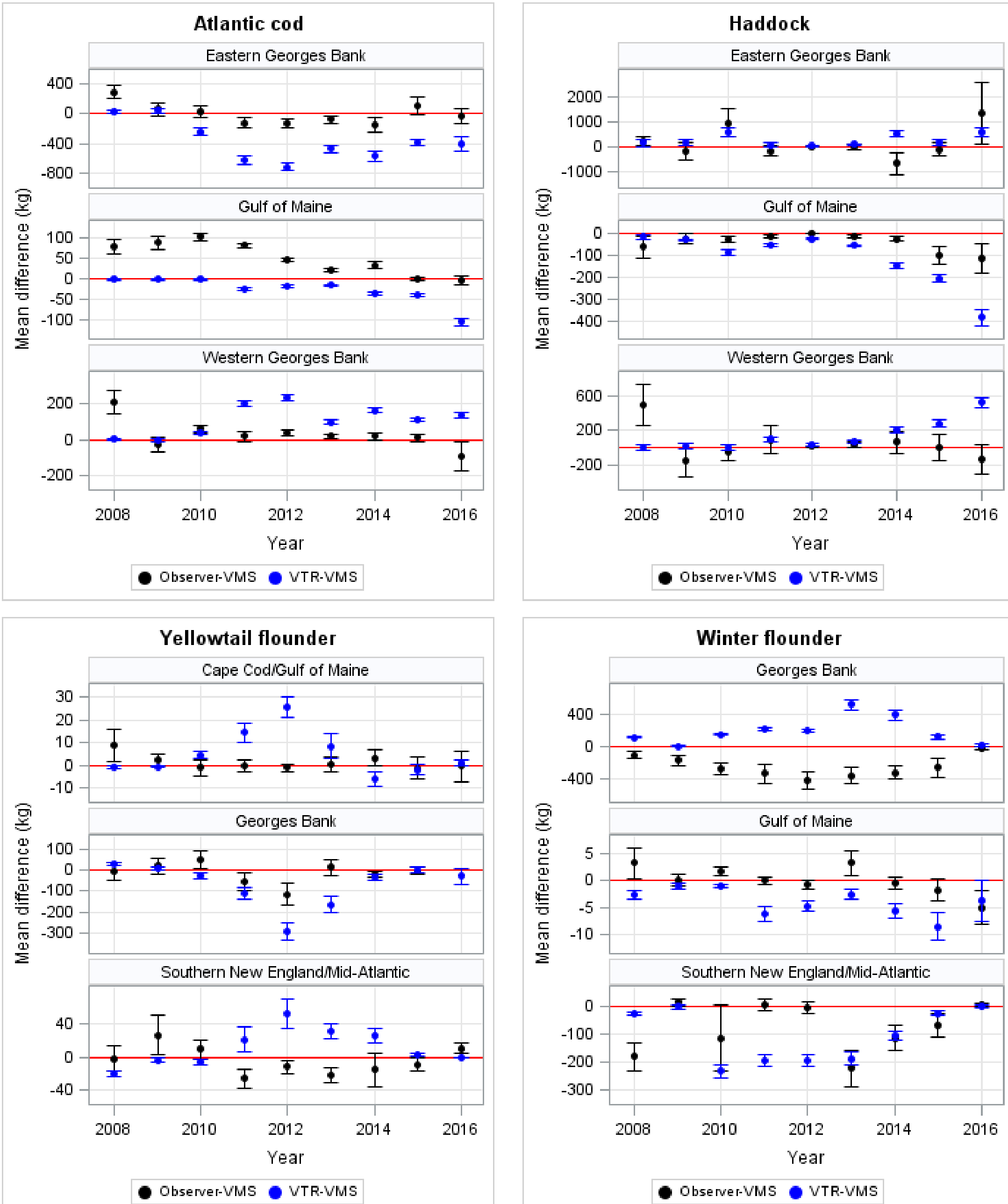


Figure 12. Mean differences (± standard error) between observer and vessel monitoring system (VMS) estimated trip landings (blue) and vessel trip report (VTR) and VMS estimated landings (black) of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) between 2007 and 2016. Note that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

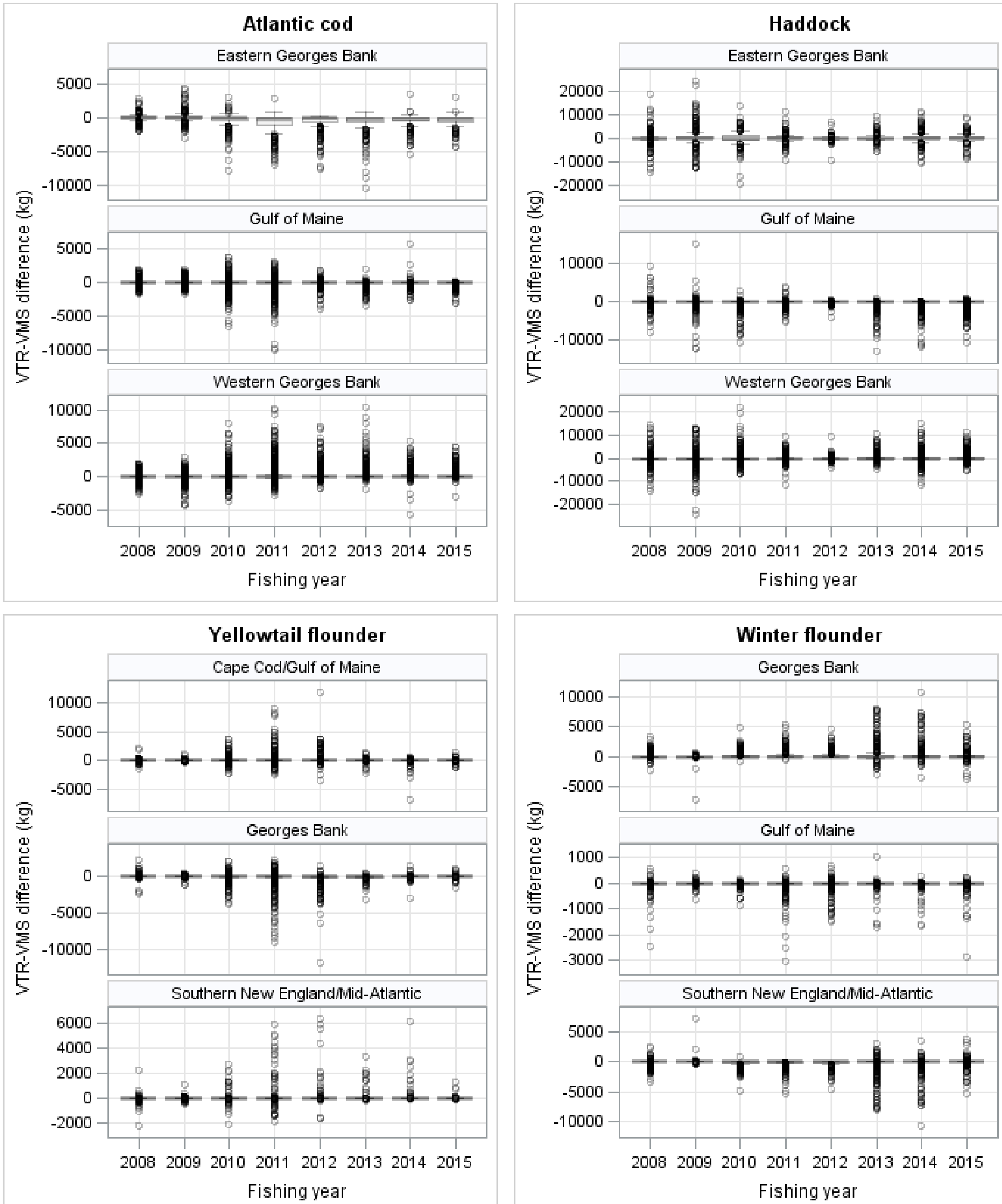


Figure 13. Box plot distribution of trip-level differences between the vessel trip report (VTR) reported stock-level landings and the vessel monitoring system (VMS)-estimated landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) between fishing years 2008 and 2015.

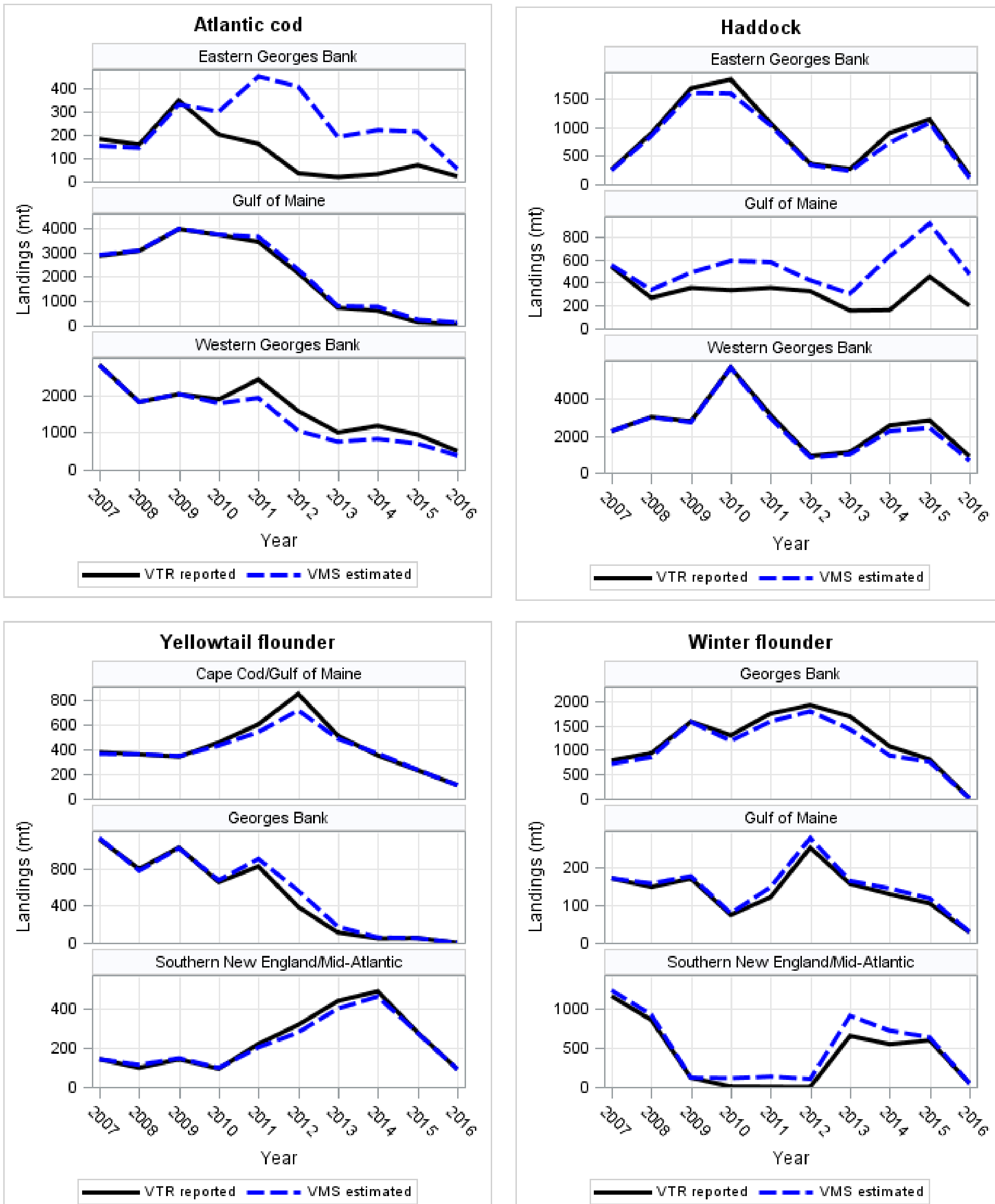


Figure 14. Comparison of the vessel trip report (VTR)-reported landings to the vessel monitoring system (VMS)-estimated landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) landings between 2007 and 2016. Note that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

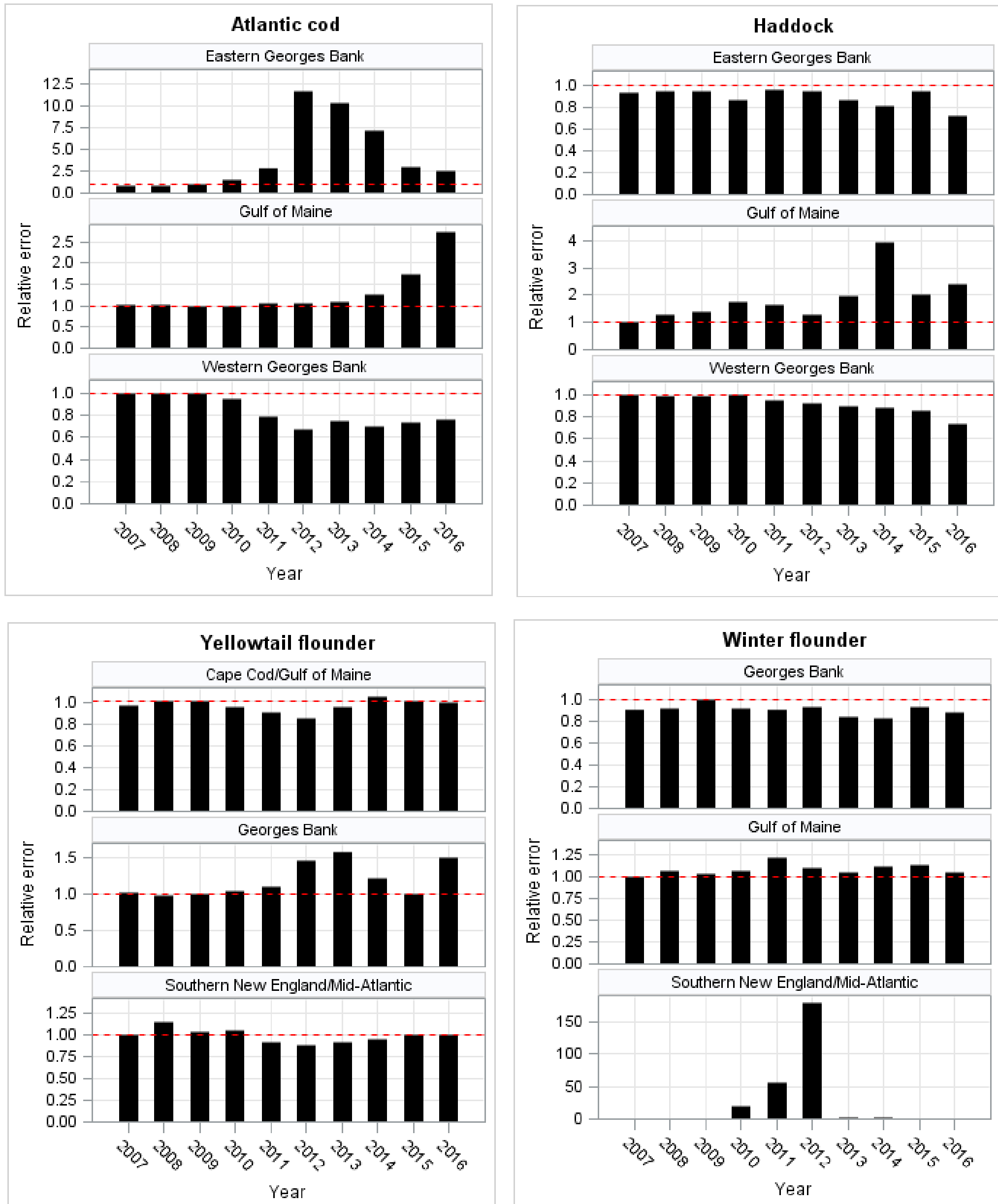


Figure 15. Estimated relative error of landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) landings between 2007 and 2016. Relative error is calculated as vessel monitoring system (VMS)-estimated landings/ vessel trip report (VTR)-reported landings. Note that 2016 is a partial year and only includes data through the end of fishing year 2015 (April 30, 2016).

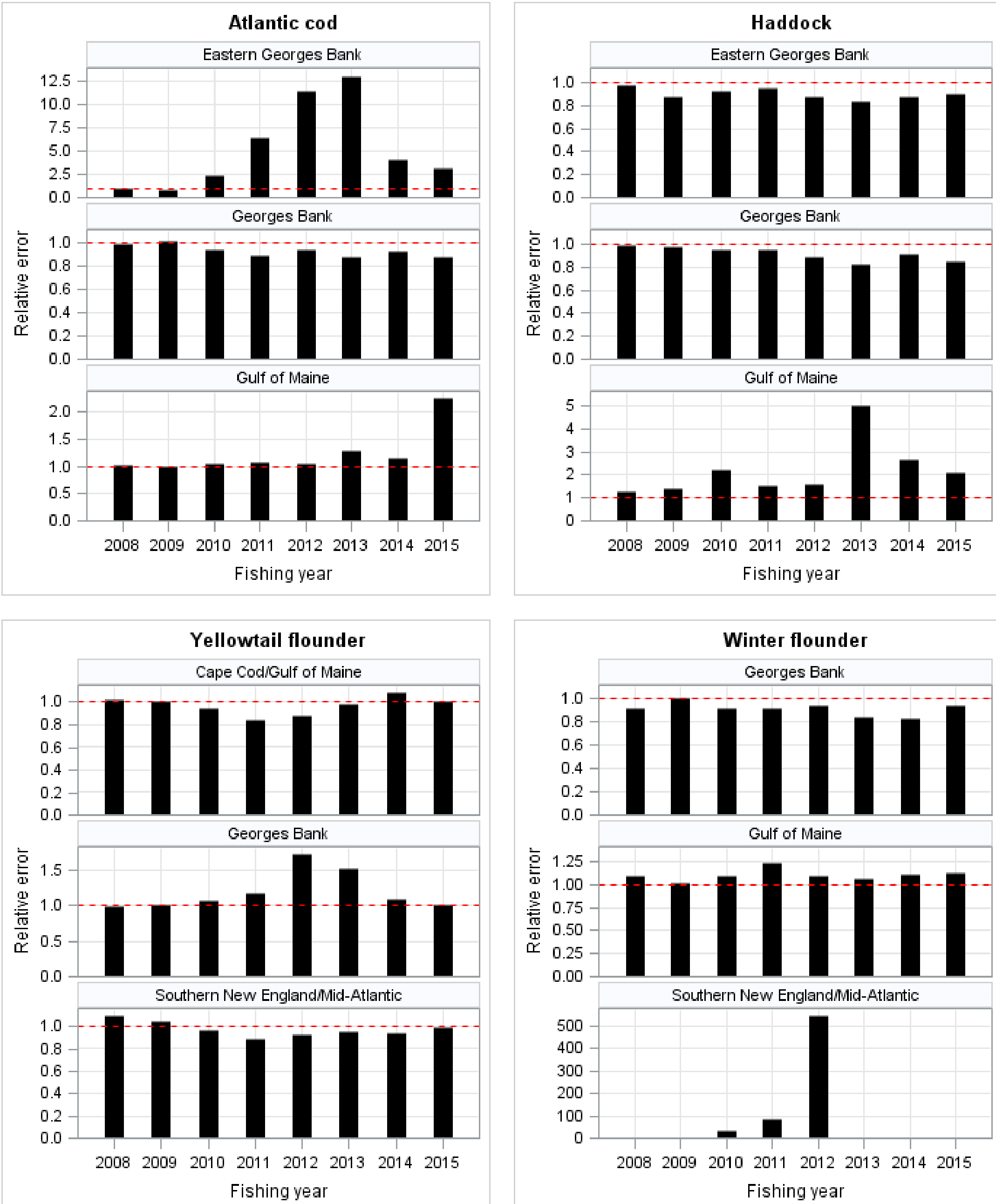


Figure 16. Estimated relative error of landings Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Limanda ferruginea*) landings between fishing years 2008 and 2015. Relative error is calculated as vessel monitoring system (VMS)-estimated landings/ vessel trip report (VTR)-reported landings.

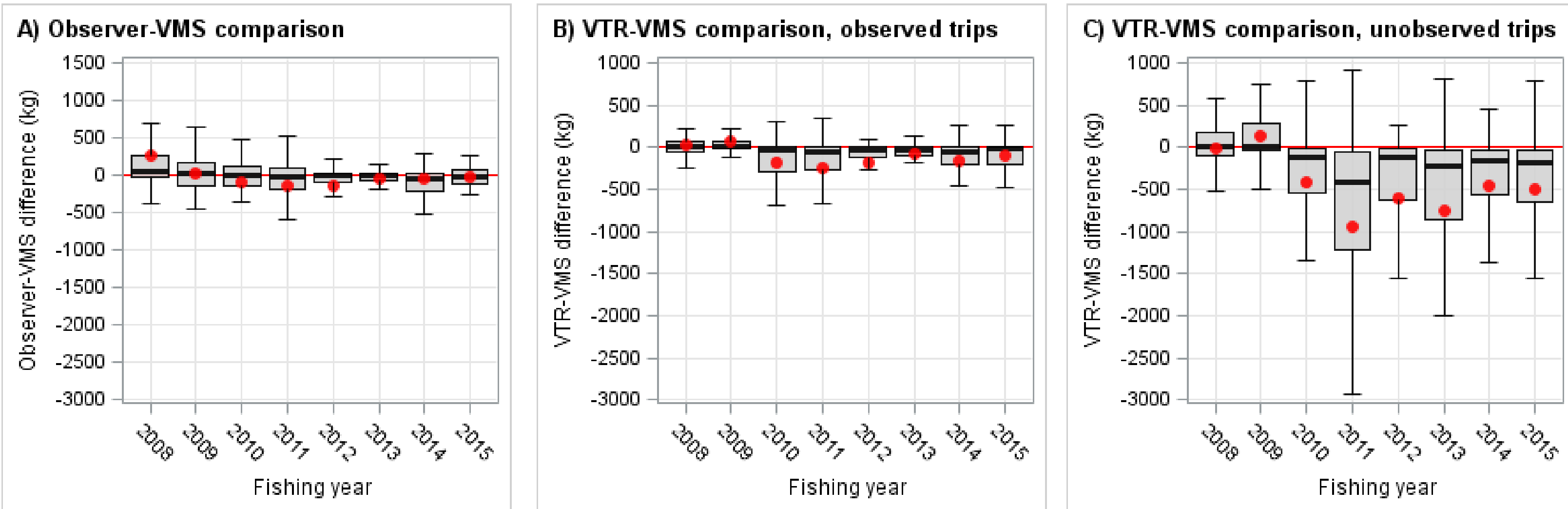


Figure 17. Box plot distribution of differences between Observer, vessel monitoring system (VMS), and vessel trip report (VTR) landings (kg) estimates of Eastern Georges Bank cod in fishing years 2008 to 2015. Panels: (A) Observer landings compared to VMS-estimated landings; (B) VTR landings compared to VMS-estimated landings on observed trips only; and (C) VTR landings compared to VMS-estimated landings on unobserved trips only. The horizontal black bars represent the median values, and the red dots represent the mean values.

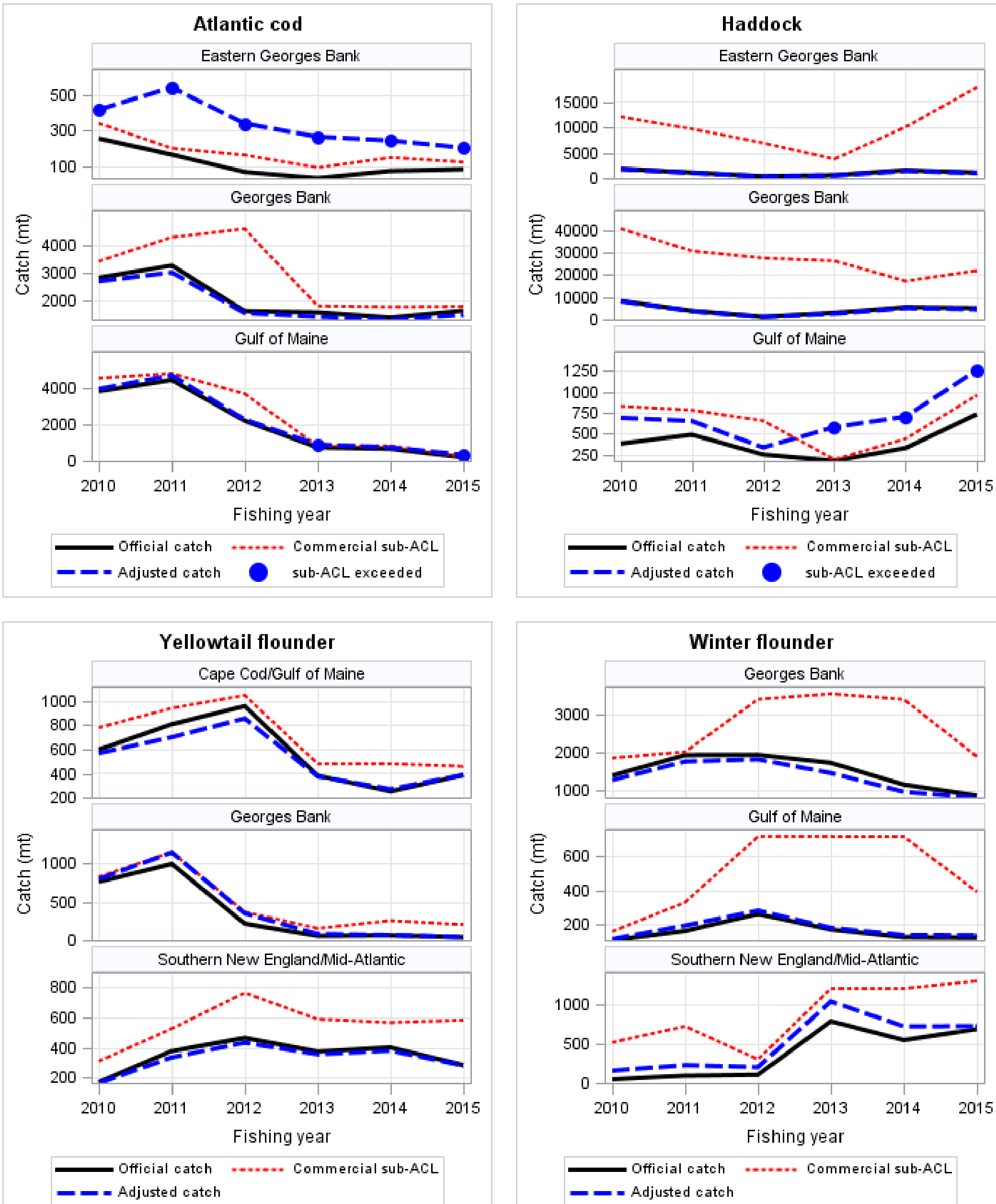


Figure 18. Potential impact of vessel trip report (VTR) catch-area reporting errors on catch estimates of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), and winter flounder (*Pseudopleuronectes americanus*) in fishing years 2010-2015. Error-adjusted catch is shown relative to the official reported catch and commercial subcomponent of the Annual Catch Limit (sub-ACL). Instances where error-adjusted catch exceeded the sub-ACL are highlighted with a blue dot.

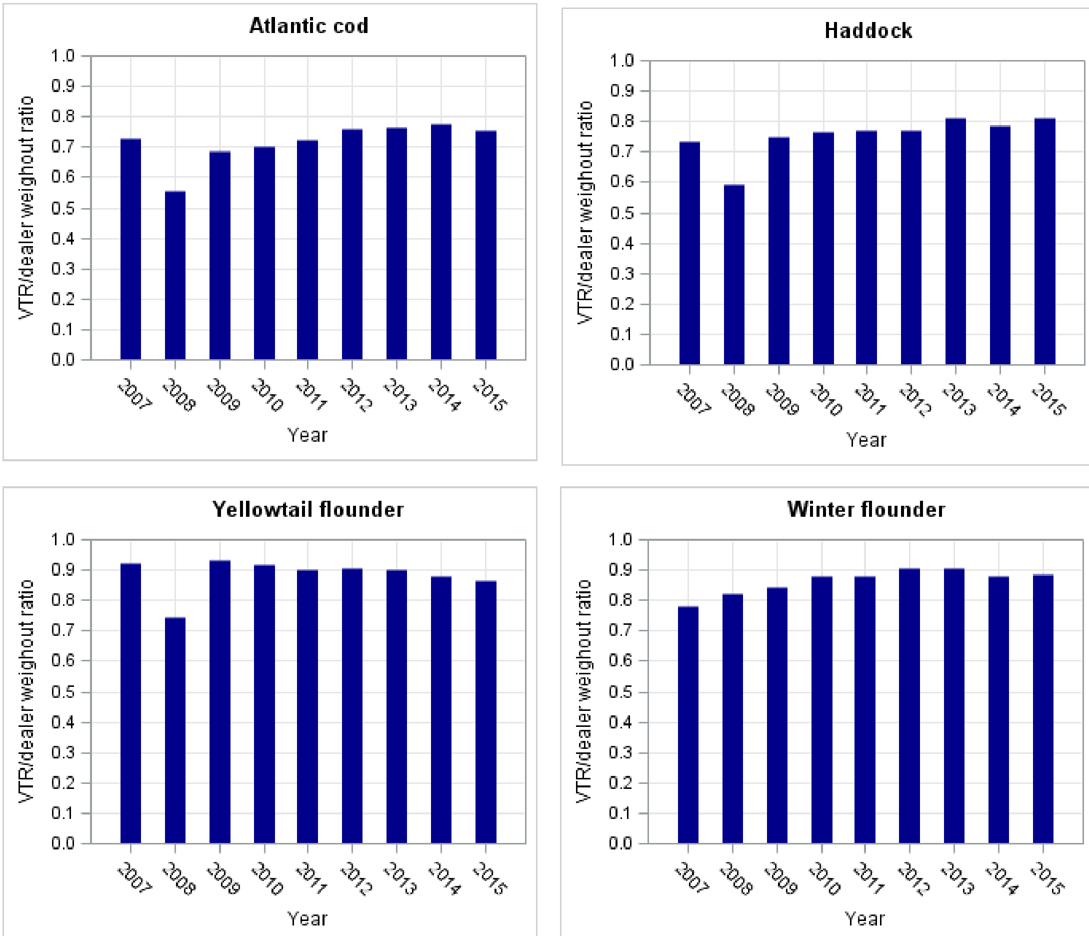


Figure 19. Ratio of vessel trip report (VTR)-reported landings to dealer weighout landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), and winter flounder (*Pseudopleuronectes americanus*) landings between 2007 and 2015.

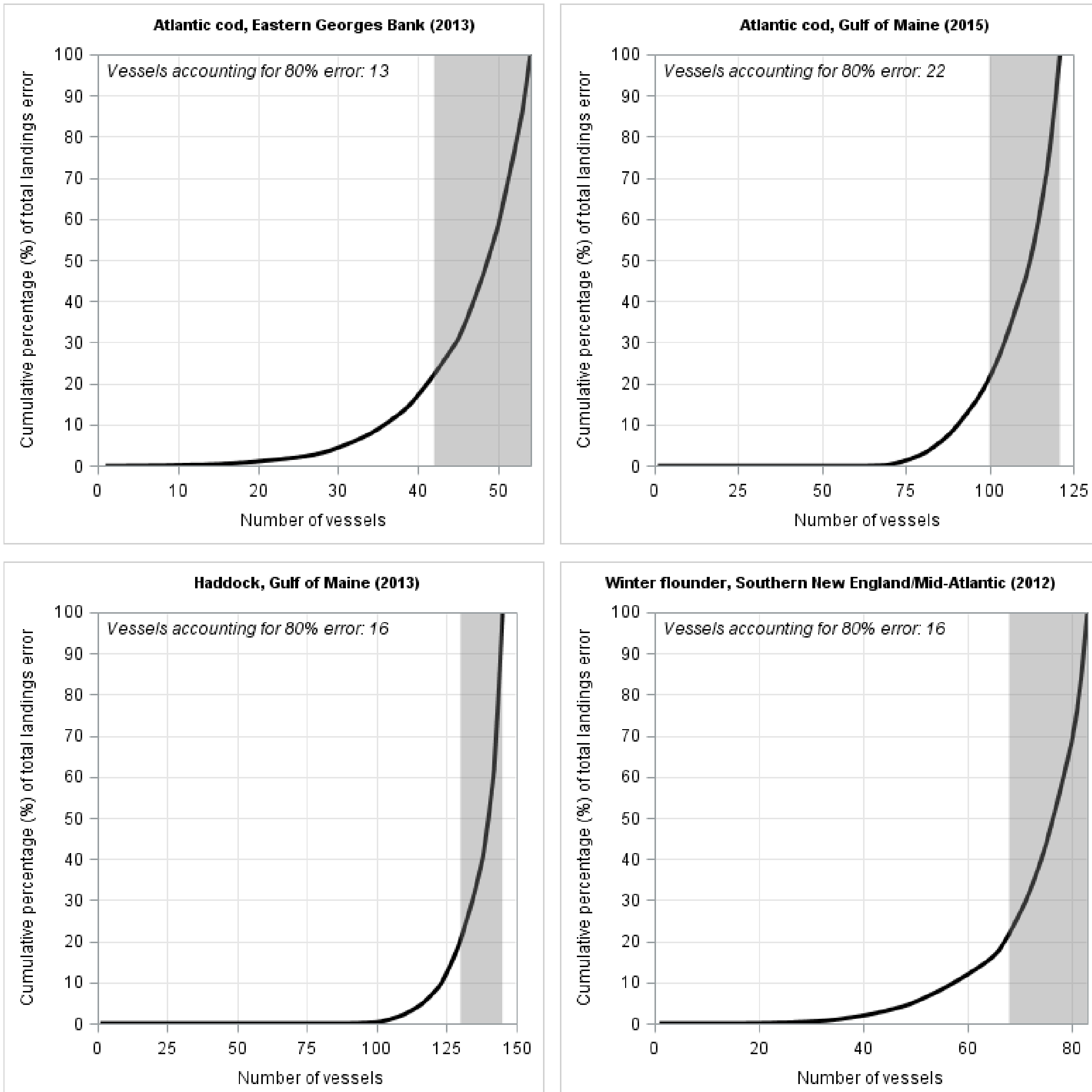


Figure 20. Four examples of the cumulative percentage of estimated landings error as a function of the number of vessels. Each example highlights a calendar year in which there was a large estimated error in the reported stock-level landings of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and winter flounder (*Pseudopleuronectes americanus*). The gray band indicates those vessels responsible for 80% of the estimated error with the actual number of vessels being displayed in the inset of each panel.

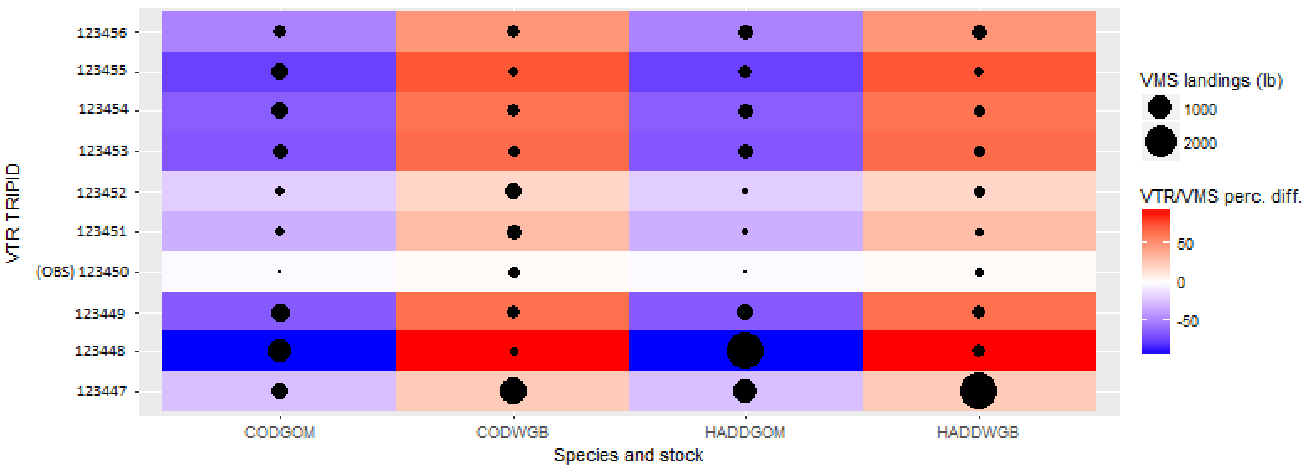


Figure 21. Example of a heat map showing the trip-level percent difference between vessel trip report (VTR) report stock-level landings and vessel monitoring system (VMS)estimated landings for all split-stock groundfish species. The estimated VMS landings (kg) are shown in black circles. Trips that were observed are indicated with the "(OBS)" flag on the y-axis. Species-stock identification is on the x-axis (CODGOM=Gulf of Maine Atlantic cod (Gadus morhua), CODWGB=Western Georges Bank Atlantic cod (Gadus morhua), HADDGOM=Gulf of Maine haddock (Melanogrammus aeglefinus), HADDWGB=Western Georges Bank haddock (Melanogrammus aeglefinus)). *These are example data and do not reflect actual vessel data.*

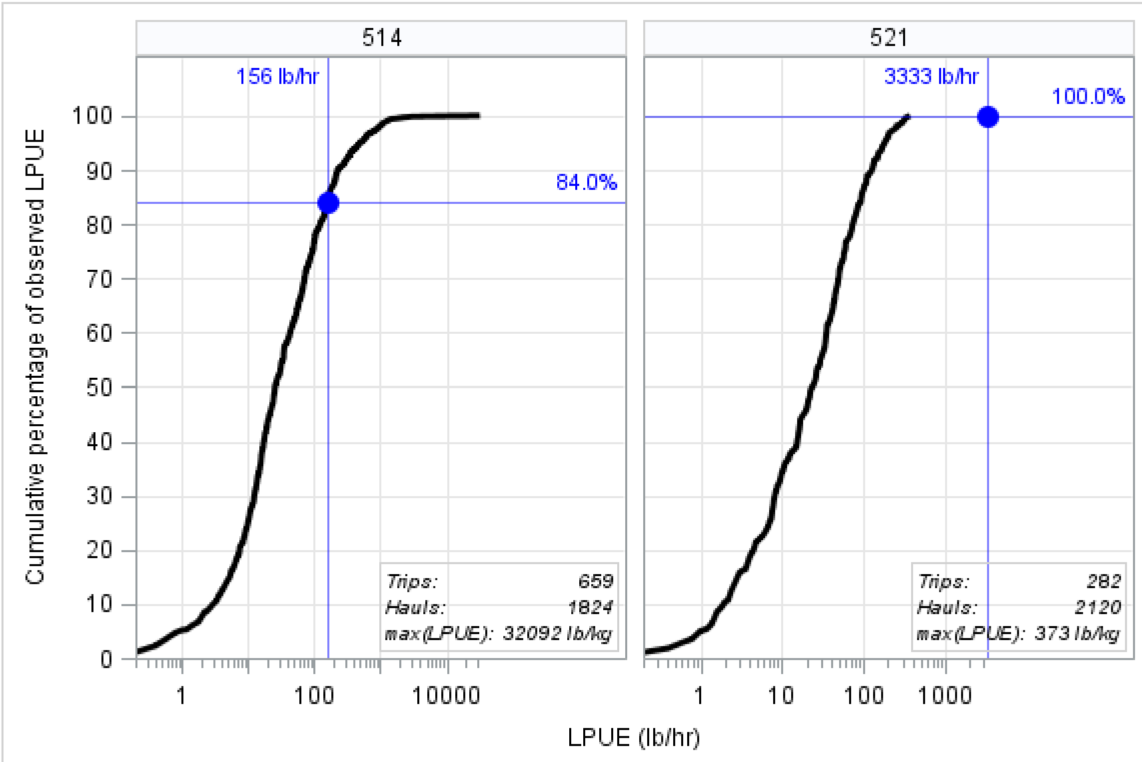


Figure 22. Example of a method to determine the statistical likelihood of the landings per unit effort (LPUE) calculated from vessel trip reports (VTR) given observed trips fishing with the same gear type, same statistical area, and same calendar quarter. Each panel compares the VTR-reported LPUE to the distribution of observed LPUE for a single statistical area (statistical areas 514 and 521 in this example). The black line represents the cumulative distribution of observed LPUE and the blue dot indicates the VTR-reported LPUE. The actual VTR-reported LPUE and the corresponding percentile are reported in the blue text. The inset indicates the number of observed trips and hauls on which the cumulative distribution is based as well as the maximum observed LPUE. In this example, the VTR-reported LPUE for statistical area 521 appears to be unlikely, falling in the 100th percentile and almost ten times larger than the maximum observed LPUE. ***These are example data and do not reflect actual vessel data.***

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Clearance

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Manuscripts must have an abstract and table of contents, and (if applicable) lists of figures and tables. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area" and/or "Experimental Apparatus," "Methods," "Results," "Discussion," "Conclusions," "Acknowledgments," and "Literature/References Cited."

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review and most issues receive copy editing.

Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a regularly-issued, quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. This report undergoes internal review, but receives no technical or copy editing.

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