

Groundfish Plan Development Team Document

Modelling Discard Incentives for Northeast Multispecies (Groundfish) Stocks #1a

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[Introduction](#)

Quantifying total removals is an important data requirement for successful fisheries management. Primarily, total removals are important for determining what future stock sizes will be, and for quota-managed fisheries, to ensure catch is within total catch limits. However, it is easier to measure catch that is retained than catch that is discarded at sea. Catch may be discarded for a variety of reasons, including low market value, regulations prohibit retention, or quota limits have been reached. In some fisheries discarded catch can comprise a significant portion of total removals, so it is important to accurately estimate discards. In U.S. fisheries, this is typically accomplished by deploying human observers on some, or all, fishing trips.

In fisheries with less than 100 percent observer coverage, managers and scientists allocate significant resources to estimate unobserved discards. Often, though, we lack the terminology to communicate precisely what we are estimating. This is particularly problematic in multispecies fisheries where regulations simultaneously require discarding specific species or sizes of fish but also prohibit discarding of other species or sizes of fish. Such is the case in the Northeast Multispecies groundfish fishery.

The fishery includes 17 quota allocated stocks and 5 non-allocated stocks occurring in three distinct ecosystems, delineated by managers into four broad stock areas including: Gulf of Maine (GOM), southern New England/Mid-Atlantic (SNE/MA), and both western and eastern areas of Georges Bank (inshore, and offshore GB). Minimum size limits require discarding undersized fish; yet the fishery as a whole is managed by a quota-based system that requires landing all fish above the minimum size to determine when catch limits are met. Yearly observer coverage ranges from 14% to 32% meaning in some years up to 86% of trips are unobserved (GARFO 2019, Table 1).

Discard rates on observed trips are used to estimate discards on unobserved trips but, importantly, a primary observer duty is to estimate legal discards, i.e., undersized fish and prohibited species. We suggest the term “mandatory discards” to describe this estimate. An ancillary observer duty is to report instances of non-compliance for subsequent NOAA Office of Law Enforcement (OLE) action. Because of this compliance role, illegal discarding of legal-sized fish (termed here “prohibited discards”) is generally assumed not to occur on observed trips, though instances have been reported (NOAA OLE, 2019; see Attachment 1). Without observers onboard, it is very difficult to enforce mandatory landing requirements since sufficient evidence, such as fish length, is rarely acquired before a fish is thrown overboard. Enforcement

cannot always make this determination even if they are on scene (NOAA OLE, 2019). The lack of compliance enforcement leaves unobserved trips vulnerable to an unknown level of voluntary compliance with landing requirements.

Prohibited discarding may severely undermine efforts to estimate total removals and ensure catches stay within limits, but this behavior may be economically rational. This is because in any quota-based fishery there exists some incentive to discard legal sized fish, perhaps to highgrade or avoid constraints imposed by small quota allocations (Arnason 1994). In tradeable quota programs, this incentive is a function of the costs and benefits associated with the retention of each individual fish based largely upon differences in quota prices and expected landing prices. Therefore, the focus on estimating mandatory discards has consequences on the precision and accuracy of total discard and total catch estimates given that the costs and benefits of prohibited discarding on observed trips may not be the same as those on unobserved trips. Theoretically, this stems from the economics of crime that suggests that, among other factors, the willingness to engage in illegal activities is a function of the likelihood of being caught and the severity of punishment (Becker, 1968).

When an observer is not on board, the likelihood that illegal discarding might be detected is thought to be very small, which reduces any potential ‘cost’ of this illegal activity (NOAA OLE, 2019). Therefore, when benefits of discarding are large, catches may be underreported as result. Furthermore, when fishermen are not accountable to their limits and can evade quota constraints by discarding, this undermines the effectiveness of the quota lease market, particularly for those who are less able, or less willing, to discard illegally.

Here, we describe the economic factors that influence a fisherman’s decision to discard illegally by adapting previous theoretical models (Arnason 1994, 2001) to describe the Northeast Multispecies fishery. We then parametrize the model using information from fishing trips 2007-2017 in order to explore how discard incentives change year to year and across stocks. We use results to inform a discussion about what factors influence discard incentives most, and how the discard incentive model might be used retrospectively or prospectively as an indicator of biased catch data.

Methods

We model the incentive to discard a pound of stock i on a trip k (Id_{ik}) on unobserved trips as the difference between the costs associated with landing one additional pound of fish (q , in live pounds) and the costs associated with discarding that unit, standardized by the total ex-vessel value (Equation 1).

$$Id_{ik} = [(Cl_i(q_i) - Cd(q_i))/(pf_i * q_i)]_k. \quad [1]$$

Costs of landing (Cl , Equation 2) include the cost of leasing quota for that unit of fish¹ (pq), sector and landing fees (sf , and lf , respectively), and any costs associated with on board handling such as the labor of properly gutting and icing the fish, which all together are per unit costs of labor (ClL). In the model, we specify sector fees by sector (sectors 5, 22 and 26 do not have fees, other sectors' fees range between \$.035 and \$.075 per pound) and landing fees are a constant at \$.05 per pound, a typical fee charged dockside by dealers. The cost of labor associated with landing is also modeled as a constant at \$.01 per pound. It is difficult to approximate the true marginal labor cost of landing (which includes all pre-processing, such as gutting, dressing, and putting on ice) realistically this would vary by trip depending on realized crew shares, the total pounds landed, trip duration, and even target species since roundfish and flatfish stocks require different amounts of pre-processing (such as gutting). Murphy et al. (2018) report that between years 2007-2015 the value of the median crew share ranges from \$0 to \$665 per crew member per day depending on vessel size, but the fleetwide median has been relatively stable at \$400 per day. In addition, average groundfish landings per day absent are approximately 2,600 pounds. One groundfish observer estimated that one hour per every twelve hours fishing is spent pre-processing. Combining these pieces of information, our approximation of marginal labor costs appears to be reasonable, since this back-of-the envelope calculation would estimate that if all 2,600 fish were pre-processed in one hour the marginal pre-processing cost could be approximated as \$.013/lb. In 2015, the highest crew shares were observed for the largest vessel size class would yield a marginal labor cost of landing of \$.02/lb.

$$Cl_i(q_i)_k = \{pq_i * q_i + (1 - \delta_k)[(\sum_{j=1}^n pq_j * r_j) * q_i] + ClL(q_i) + sf * q_i + lf * q_i\}_k, \quad [2]$$

In addition, we also include a term that represents the cost of quota for all other stocks associated with landing an additional pound of fish. In New England, on unobserved trips a discard rate is applied based on observed discards within each strata (sector, gear, stock). Therefore, we model this as the proportion of unobserved tows (δ , set at 0 for unobserved trips) multiplied by the discard ratio (r) which are back calculated by stock and trip using the year end imputed rate as the discards of all stocks within the same broad stock area ($disc_j$) over the quantity kept landings on trip k (q_k , Equation 3).

$$r_j = disc_j / q_k. \quad [3]$$

Costs of discarding (Cd) include the revenue forgone when not landing one unit of fish (ex-vessel value), as well as the labor costs associated with discarding the fish (CdL). As we focus on illegal discarding, we add the probability of detection ($p(d)$) and the magnitude of sanction associated with illegally discarding fish (s , Equation 4). Labor costs of discarding are assumed to be near zero because there are very few marginal costs associated with discarding outside of sorting, which occurs whether a fish is landed or discarded. We set this at a conservatively high value at \$.005 per pound. The probability of detection and sanction are modeled together as a

¹ We commonly refer to quota prices and quota costs throughout this work but this only includes the costs of leasing quota. Permanent sale of quota is not allowed except through the sale of the entire fishing permit.

constant, which we set at a combined cost of \$5 for stock landings more than \$20 and \$0 for any landings less than \$20—simply because on trips with low landings this parameter becomes strongly influential. We believe this is conservative granted that the probability of detection for illegally discarding legal sized fish at sea is likely zero or close to zero on unobserved trips, which counteracts even a high possible sanction, noting that here this could represent a sanction of \$20,000 with a 0.25% probability of being detected. King and Sutinen (2010) found that for the NE groundfish fishery in 2006 the average sanction for all violations was \$20,000, but the average settlement fine was around \$10,000. In addition, according to OLE, out of 12 reported incidents of prohibited discarding on both observed trips and unobserved trips (out of which 8 were generated by observers), the strongest action taken has been 1 written warning over the last two years. This supports other information from OLE that even on observed trips it is very difficult to acquire enough evidence to issue violations (NOAA OLE, 2019), and supports our rationale for including a low expected cost for prohibited discarding.

$$Cd_i(q_i)_k = [pf_i * q_i + Cdl(q_i) + p(d) * s]_k \quad [4]$$

Incentives are estimated separately for each allocated groundfish stock and each groundfish trip over fishing years 2007-2017. Trip information is selected for trips from the GARFO DMIS database. Ex-vessel prices are calculated at the NESPP4 (market/grade) level from information of total value and landed pounds for each grade on a given trip. Landed stocks with ex-vessel prices greater than \$10 or less than \$.05 per pound for each of the 17 allocated stocks were removed as outliers from the dataset.

Quota lease prices are estimated with a hedonic price model using methods described in Murphy et al. 2018. For fishing years 2011-2016 quota prices are estimated by stock for each quarter of the fishing year using inter (between) sector and intra (within) sector trades of both fish for fish and fish for cash as reported in sector end of fishing year reports. For quarters with minimal trading volume, the model estimates a quota price of zero. In cases with non-zero prices in adjacent quarters we adjust estimated prices by substituting prices from the surrounding quarters in the same fishing year (Table 2). In other instances, such as where estimated quota prices appear anomalous (e.g., high prices for low utilization stocks), prices were adjusted to the median reported cash trade value. Prices for fishing year 2010 and 2017 are estimated annually due to fewer reported trades and no information on within sector trades². The value of quota for fishing years 2007-2009 (pre sectors) is assumed to be zero.

Sector NEFS IX trips were excluded from results because vessels in this sector were found guilty of strategic misreporting and therefore landings information is known not to be accurate. Strategic misreporting likely affected the quota market as well, but we did not attempt to adjust for this.

² 2017 quota prices will be updated to quarterly modeled prices (including inter sector trade data) after sector year end reports are submitted.

Model assumptions:

The discard incentive model assumes that:

- landings are representative of underlying discard incentives (e.g. the model will not estimate discard incentives for stocks that are not reported as landed);
- landings data are known without error (e.g. no species substitution or other misreporting);
- modeled quarterly inter- and intra-sector quota prices adequately capture the instantaneous quota cost faced by fishermen during a trip;
- quota price encapsulates the marginal value of quota, where
- the marginal value of leased quota is equal to that of allocated quota (e.g. not incorporating an “endowment” effect);
- expectations of landed fish prices are adequately captured by ex-vessel prices received on each trip.
- quota prices and ex vessel prices are unaffected by illegal discarding or misreporting; (the benefit of discarding includes the marginal value of quota for that stock and the discards associated with landing an additional unit of fish, noting that this does not explicitly include the marginal value of landing any fish accessible in the future and enabled through discarding the fish in question);
- the probability of detection and the associated sanction are perceived by fishermen to be low;
- costs of labor of discarding and labor of landing are constant; and
- there is no shadow value of biomass, i.e., discarded catch cannot be harvested again.³

Results:

Modeled quota prices follow general trends in single stock cash reported trades (Figure 1). Instances where these diverge are due to the influence of fish for fish trades and/or basket trades, where numerous stocks are included with one overall cash price. Price estimates for 2010 may be biased high due to a lack of data on within sector trades. Generally, estimated quota prices increase for stocks and years with higher quota utilization rates (Figure 2) following expectations from general economic theory.

Our model shows that discard incentives for many stocks increased with the implementation of the sector system (fishing year 2010), reflecting the influence of non-zero quota costs (Figure 3). Stocks which have not seen much change in discard incentives include several lower-value or low-utilization stocks such as both GB haddock stocks, pollock, and redfish (see Figure 6 for

³ Arnason (1994) believed this was negligible.

trends in ex-vessel prices, Figure 7 for trends in utilization). However, for other stocks trends since have not been consistent, due primarily to the interactions of fluctuating ACLs, quota prices, and ex-vessel prices. The imputed cost of quota for sublegal discards, which for most stocks is somewhere between 0 to 3 cents per pound of landed stock, contributes somewhat less to the incentive to discard legal-sized fish. Other model parameters we estimate as constants likely do not affect changes over time, such as the probability of detection and associated sanction, labor costs, or landing fees because cumulatively these are nearly negligible in contrast to ex-vessel and quota price (all other costs of landing, besides the cost of quota, sum to roughly 10 cents per pound, regardless of stock).

Between 2010 and 2017, almost every year had at least one stock that was landed with a positive discard incentive. In 2010, approximately half of all GB yellowtail flounder landings were modeled to have a positive discard incentive (Figure 4) and the ratio was nearly as high for the SNE/MA yellowtail flounder stock, for which mean quota prices nearly matched mean ex-vessel prices in that year. In 2011, sub-ACLs were increased for all three yellowtail stocks, as well as several other stocks with relatively low allocations, including witch flounder, plaice, and winter flounder. Highly-utilized stocks including GOM cod also saw sub-ACL increases in that year, resulting in very low quantities landed with positive discard incentives (Figure 4) and relatively few trips landing any stock with a positive discard incentive (Figure 8). In 2012, quota prices jumped for the eastern GB cod stock as well as GB yellowtail flounder, resulting in about 20% of landings in that year with a positive discard incentive. From 2013 to 2015, discard incentives are estimated to be highest for yellowtail and cod stocks, with around 20% of landed GOM cod having a positive discard incentive between 2015 and 2017. Starting in 2016, quota for GB cod west was allowed to be converted to GB cod east quota, and in 2014 a similar provision allowed GB haddock west quota to be converted into GB haddock east quota (FW 55 and 51, respectively). The quota conversion for GB cod west is likely reflected in the increase in quota price, and the corresponding increase in discard incentive, in recent years. Other stocks with positive discard incentive landings include witch flounder, plaice, and in some years, GB and GOM winter flounder. GOM haddock also sees higher discard incentives, generally corresponding to years where the difference between ex-vessel price and modeled quota prices are smallest.

Overall, the model suggests that the percentage of trips landing at least one stock with a positive discard incentive has increased since 2010 (Figure 6). This is most true for trips landing GOM cod, noting a particularly strong increase in discard incentives for trips in 2015 (Figure 7). In addition, between 20 to 30 percent of landings between 2014 and 2017 had a positive discard incentive for GOM cod (Figure 4). Comparing quota prices and ex-vessel prices over time, trends seem to match well, with higher proportions of positive discard incentive stocks appearing when average annual quota prices exceed 40 to 50 percent of ex-vessel price (Figure 5, Figure 6).

The discard incentive model may have advantages over other metrics of constraining stocks. When comparing utilization trends with modeled discard incentives, utilization alone does not describe our results, reflecting the imperfect relationship between quota price and utilization. For example, American plaice has been nearly fully utilized since 2012, yet landings and trips with a

positive discard incentive have increased over time. Changing ACLs may also serve as another indicator since highly utilized, low allocation stocks may be inferred as constraining—but we see that for example, in 2013 witch flounder experienced a drop in its ACL and was near fully utilized, but discard incentives did not change much from 2012. This illustrates that while utilization and the total allocation certainly are related to quota prices, the exact nature may be difficult to predict, complicating expectations of how discard incentives might change in a given year.

Discussion:

Our results show that under sectors, cod and yellowtail flounder stocks have had the highest discard incentives overall, but incentives vary considerably year to year. These stocks are also currently considered to be experiencing overfishing, and are overfished (GARFO, 2019, Table 3). Discard incentives change by stock and fishing year, therefore any bias in catch data resulting from illegal discarding of legal sized fish is unlikely to be consistent in either direction or magnitude over time (Figure 3, Figure 4). Quota prices and ex-vessel prices are primary drivers of discard incentives in any year, therefore an understanding of these two factors are important considerations for the design of management measures seeking to reduce inaccuracies in true catch. Improved tracking on inter- and intra-sector quota prices and individual quota holdings may assist with enforcement as noted by OLE (NOAA OLE 2019).

These findings beg the question: if it was not economically rational to land 20% of all GOM cod in 2016, why were they landed? Assumptions and generalizations in our model may overestimate discard incentives for those who do not lease in much quota or who receive higher ex-vessel prices, and at the margin where labor costs are over or underestimated, but our model also misses other, non-economic reasons that fishermen may choose to comply with regulations even when it is less profitable to do so. Social determinants of compliance include sense of morality, peer perceptions, and judgments about the rules in place (Jagers, Berlin, and Jentoft 2012). However, King and Sutinen (2010) in a 2007 survey found that these normative factors play a weak role in the groundfish fishery; fishermen were found to doubt justifications for management decisions, and believed schedules and rebuilding targets to be arbitrary and unfair. Furthermore, they found that fishing violations, such as fishing illegally, were detected and prosecuted at low enough levels that the economic incentive *not* to comply with regulations was \$4,334 per trip. Therefore, it may be reasonable to assume that our estimates of landings with positive discard incentives represent the lower bound of the total discard-incentivized catch.

Finally, our model may *underestimate* (and rather significantly, at that) the true incentive to illegally discard legal sized fish, for two reasons. First is the endogeneity problem noted in the model assumptions: the very problem the model aims to detect is self-attenuated by discarding all of a given stock, eliminating that trip from our results, and also by the feedback loop created by the fact that illegal discarding reduces demand for quota and consequently impacts quota prices. The second reason is that our model focuses on the marginal incentive for each fish in isolation. In fact, a pound of fish discarded obtains a benefit equal not only the quota value of that pound of fish and the other marginal parameter contributions, but also obtains the benefit of

allowing access to covariate stocks on future tows and trips. The value of this additional fishing opportunity obtained by discarding is difficult to incorporate into a marginal model such as this, but is likely another primary driver of prohibited discarding.

The current model may be a useful indicator of risk, but more work is needed to fully characterize the magnitude of noncompliance in the northeast groundfish fishery. Updating previous work on attitudes about compliance would be helpful to better balance normative motivations against strictly economic incentives, as well as ground truth assumptions in our model about perceptions about probability of detection. Furthermore, predictive models of catch would permit comparisons of catch compositions for at-risk stocks over time in order to estimate underreported catch. This work is needed to accurately estimate the impact of noncompliance on total catch estimates.

References:

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- Murphy T, Ardini G, Vasta M, Kitts A, Demarest C, Walden J, Caless D. 2018. 2015 Final Report on the Performance of the Northeast Multispecies (Groundfish) Fishery (May 2007 – April 2016). US Dept Commer, Northeast Fish Sci Cent Ref Doc. 18-13; 128 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at <http://www.nefsc.noaa.gov/nefsc/publications/>

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NOAA Office of Law Enforcement. 2019. Unlawful discarding of Regulated Northeast Multispecies. Report to the Groundfish Plan Development Team. April 9th 2019.

Figures and Tables

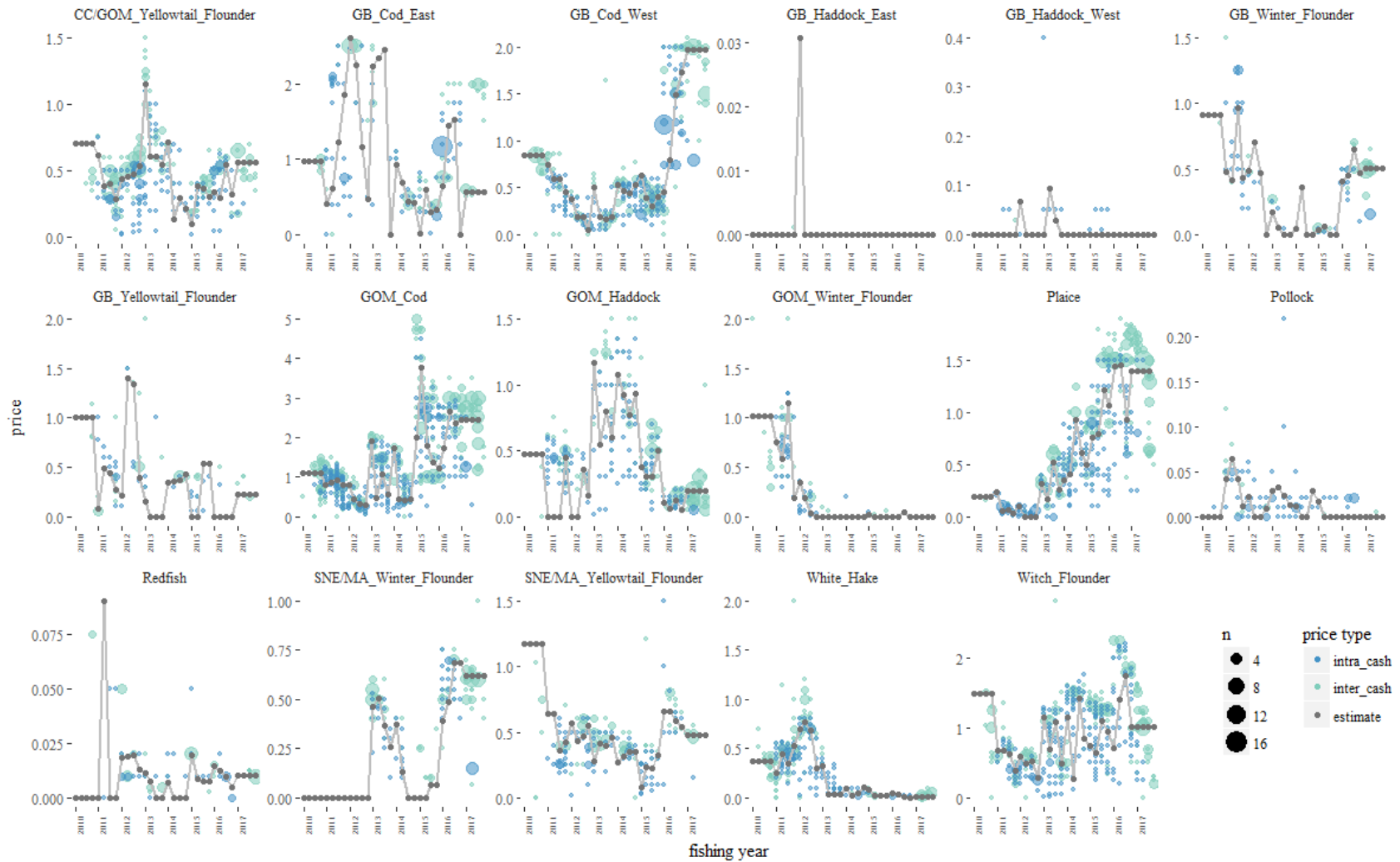


Figure 1. Estimated quota prices and sector reported single stock fish for cash trade prices by fishing year, quarter. Note that the Y-axis values differ for each stock.

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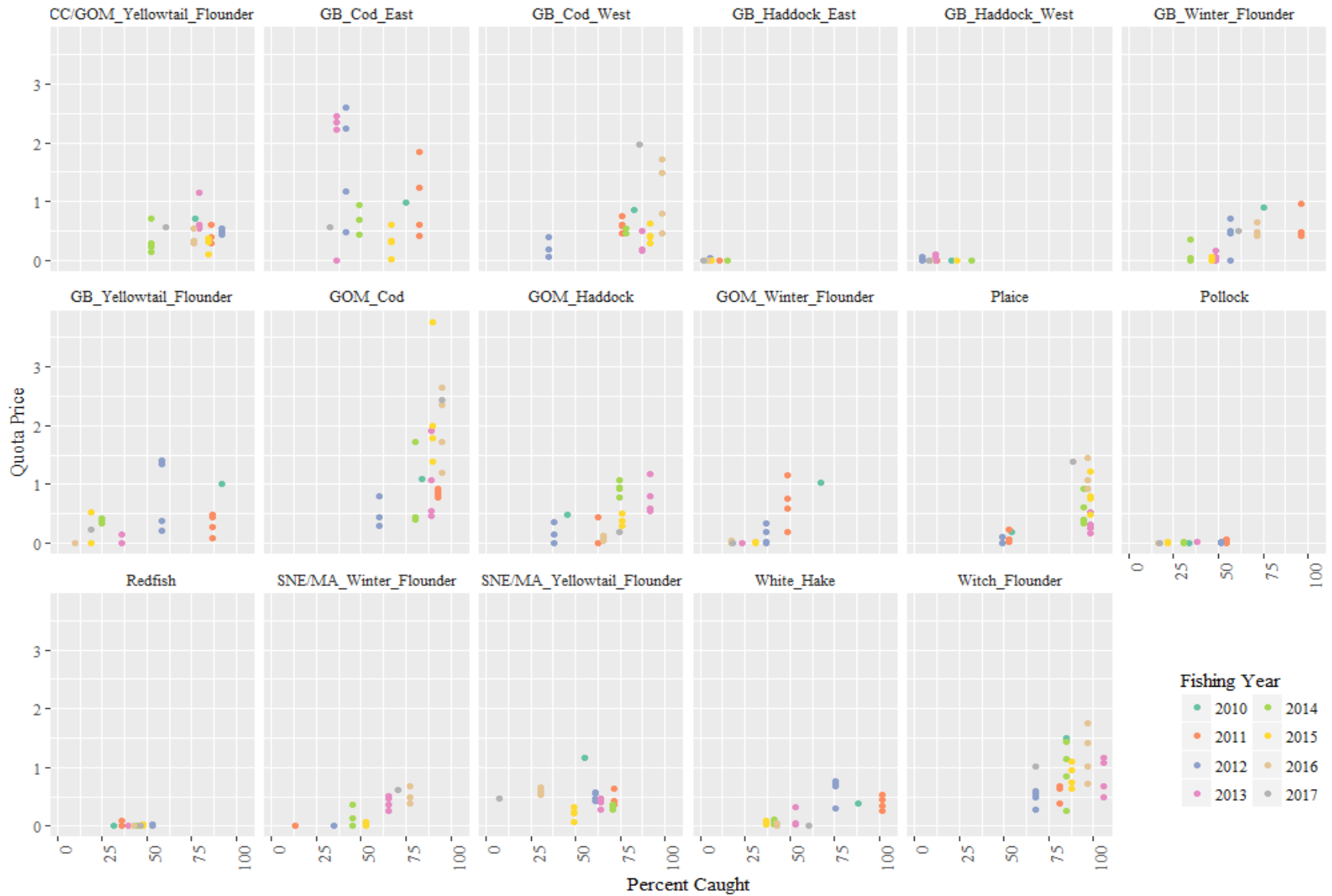


Figure 2. Percent of quota caught and estimated quota prices.

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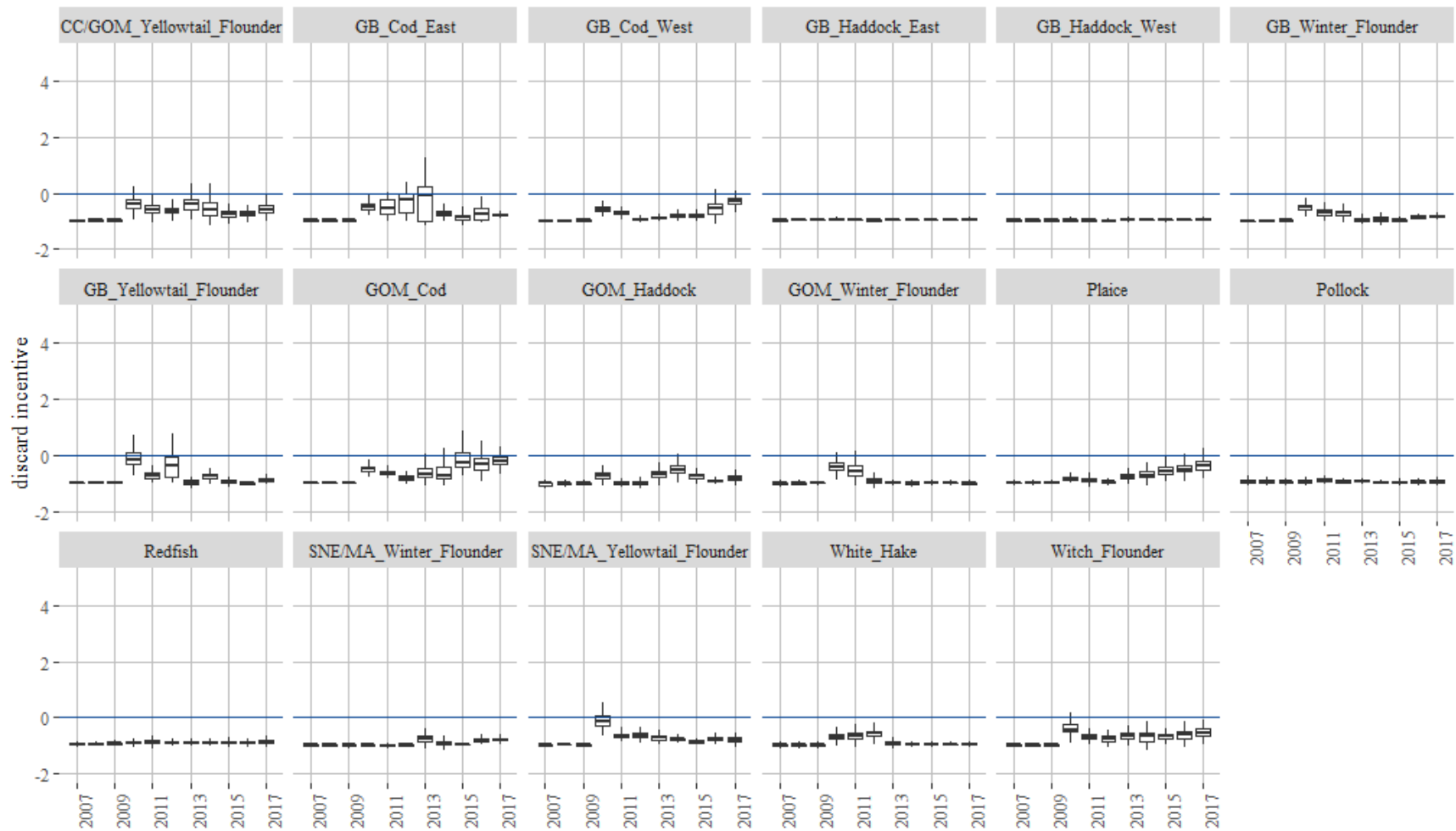


Figure 3. Estimated discard incentives for all unobserved trips fishing years 2007-2017. The boxplot 'box' shows the median, 25th percentile and 75th percentile of the distribution, the whiskers show the "min" and "max" values (defined as 1.5x the upper or lower quartiles), outliers (anything beyond 1.5 times the interquartile range) not shown for clarity.

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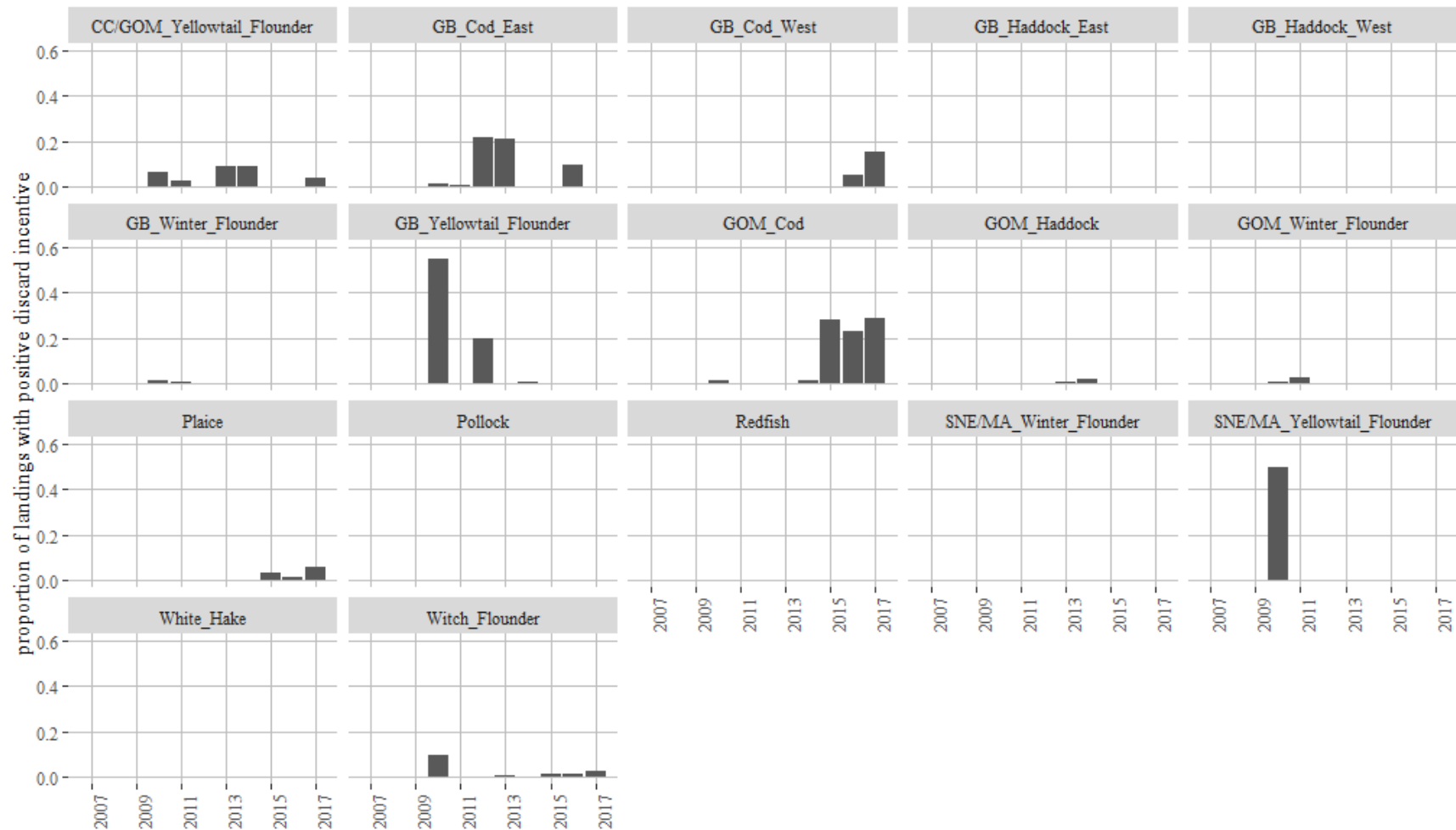


Figure 4: Proportion of landings with a positive discard incentive in each year 2007-2017 and for each allocated stock.

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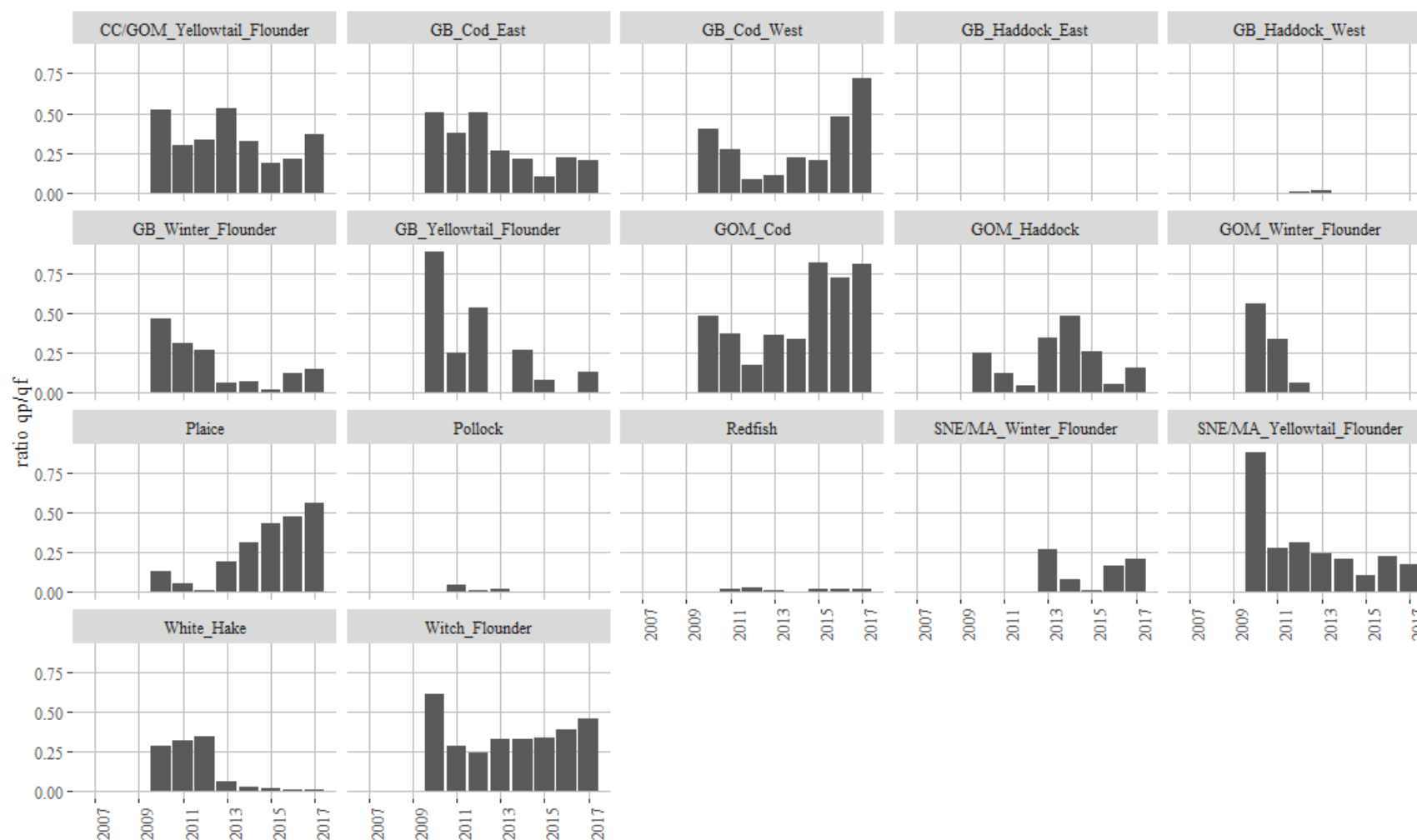


Figure 5: Ratio of modelled average annual quota price to ex-vessel price for each stock and year 2007-2017. *starting in 2016 quota for GB cod west was allowed to be converted into GB cod east quota, and in 2014 a similar provision allowed GB haddock west quota to be converted into GB haddock east quota (FW 55 and 51, respectively).

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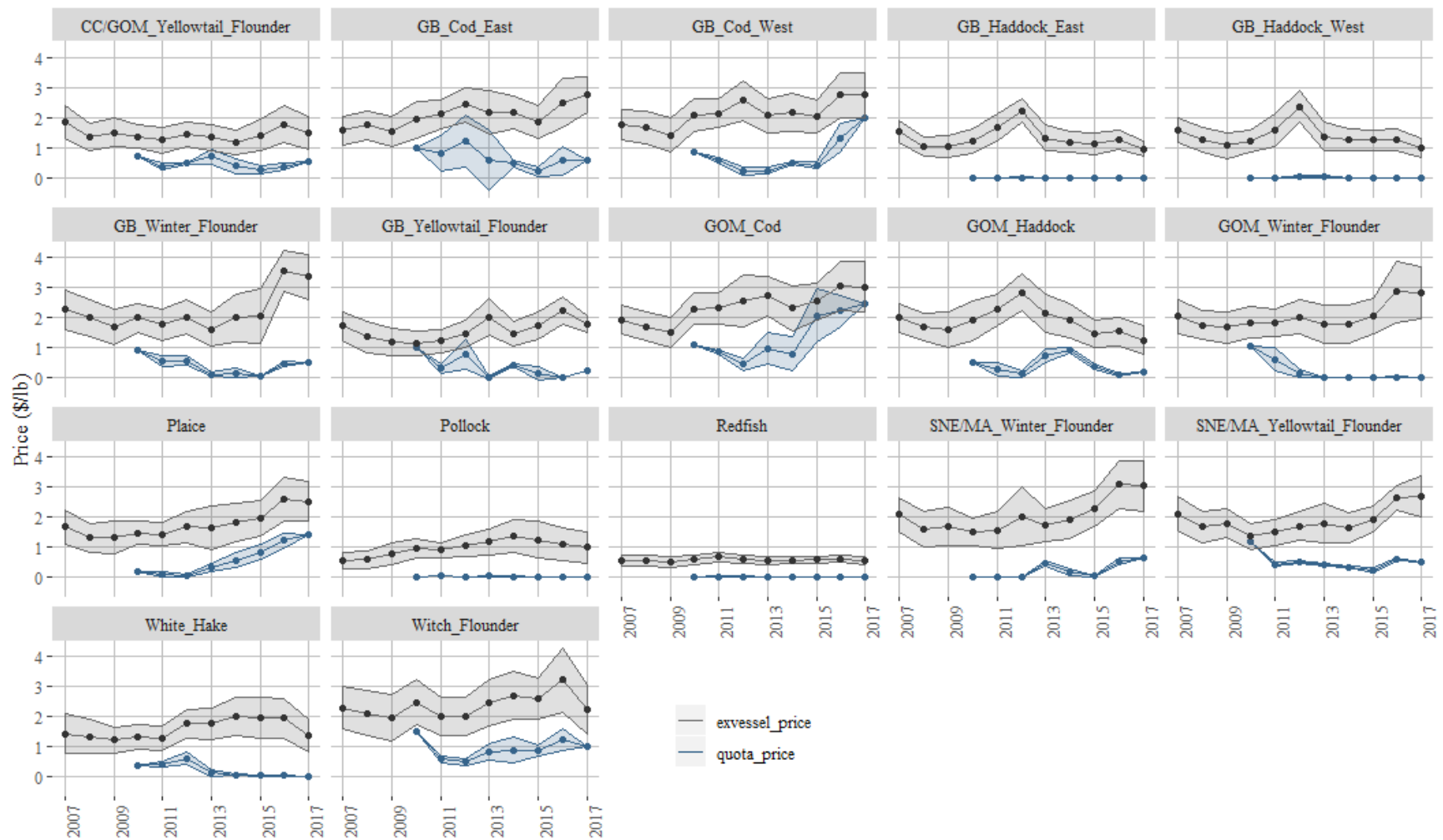


Figure 6: Mean annual ex-vessel price and quota price trends over time 2007-2017.*starting in 2016 quota for GB cod west was allowed to be converted into GB cod east quota, and in 2014 a similar provision allowed GB haddock west quota to be converted into GB haddock east quota (FW 55 and 51, respectively).

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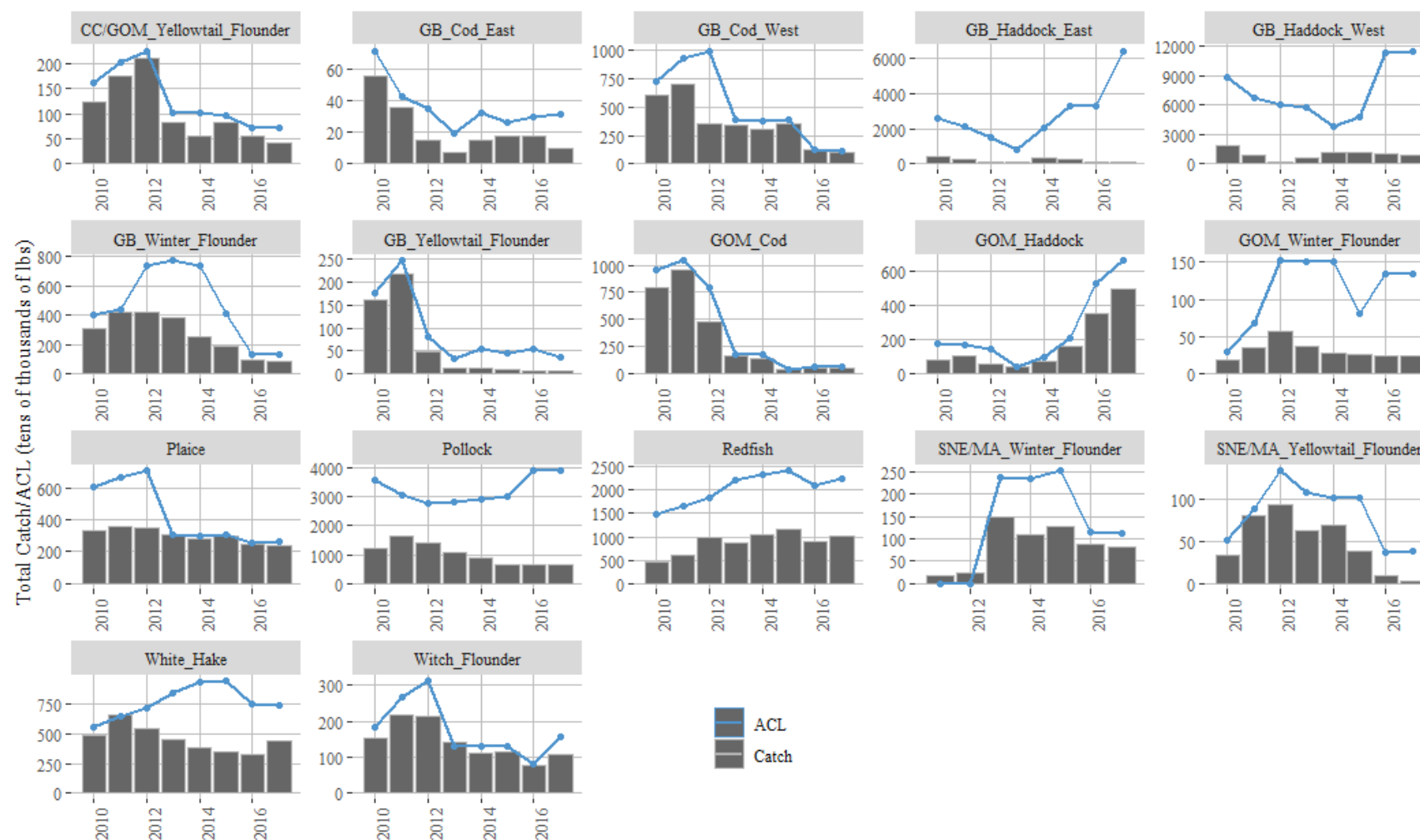


Figure 7: Utilization trends 2010-2017 showing the proportion of the commercial groundfish sub-ACL harvested by the sector program in each year. Note each panel has different y axis.

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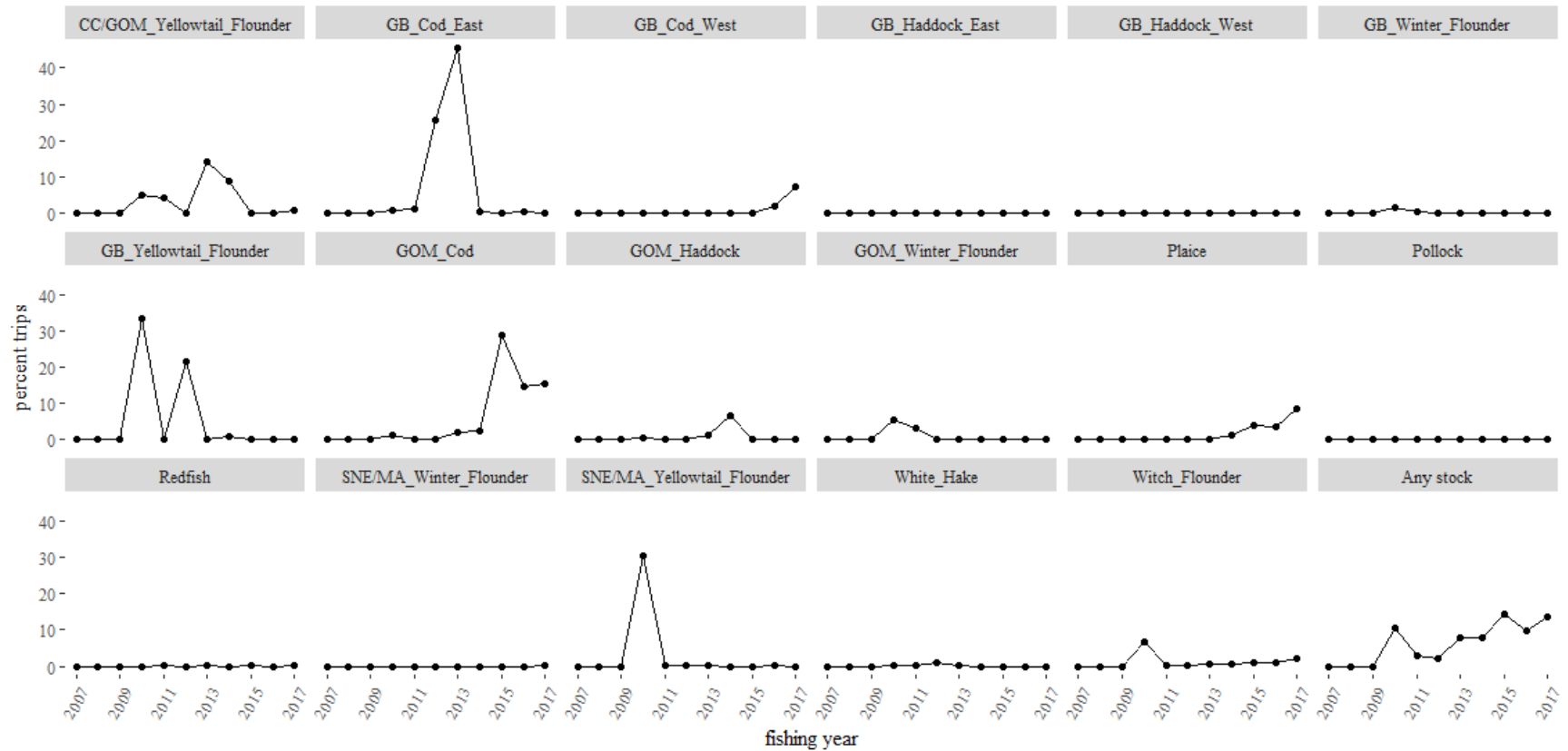


Figure 8. Percent of trips landing listed stock with positive discard incentive on that stock. All stocks plotted on 0-40 Y-axis.

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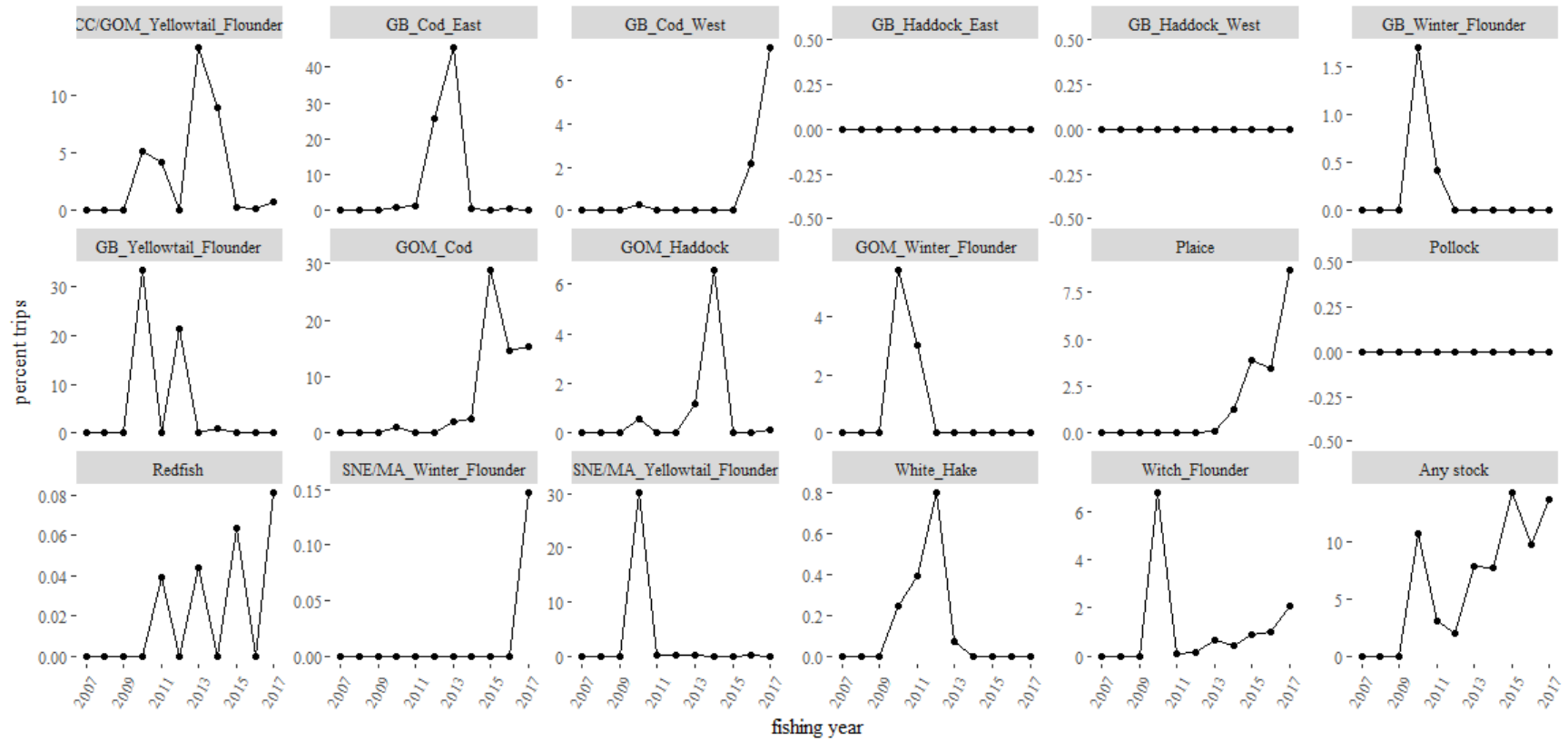


Figure 9. Percent of trips landing listed stock with positive discard incentive on that stock. All stocks plotted with differing Y-axis by stock.

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Shapefile: NE_Multispecies_Broad_Stock_Areas.shp

Posted to Website: 3/15/2015

This shapefile includes the NMFS Regulated Areas in Northeast and Mid-Atlantic Waters depicted below. The dataset can be downloaded from the GARFO GIS website at <http://www.greateratlantic.fisheries.noaa.gov/gis>.

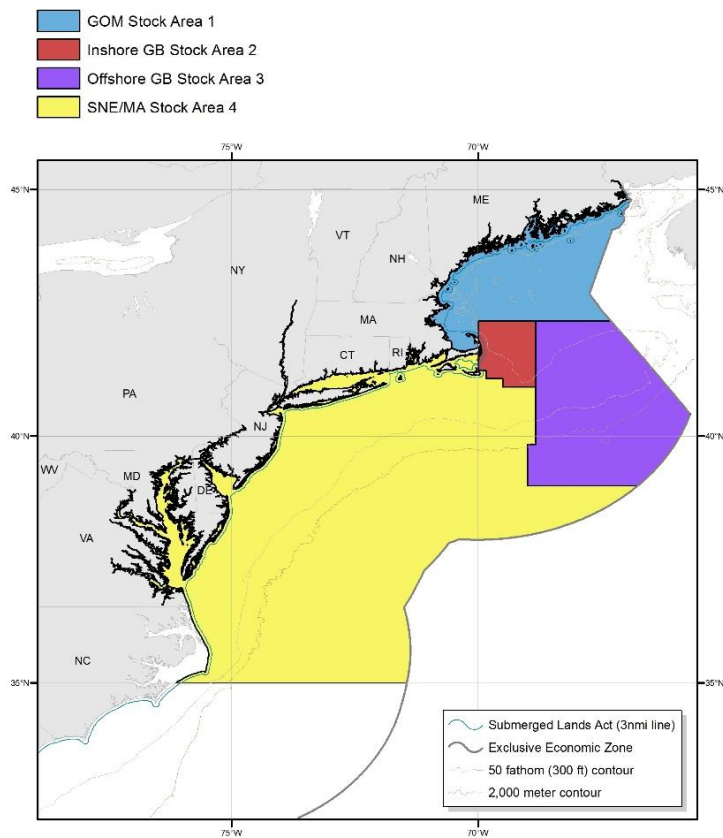


Figure 10. Broad stock areas

(https://www.greateratlantic.fisheries.noaa.gov/educational_resources/gis/data/shapefiles/NE_Multispecies_Broad_Stock_Areas/NE_Multispecies_Broad_Stock_Areas_MAP.jpg)

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Table 1: Adapted from GARFO ASM requirements summary FY 2019. *FY 2018 realized coverage not yet updated

Fishing year	NEFOP target coverage rate	ASM target coverage level	Total target coverage level	Realized coverage level
FY 2010	8%	30%	38%	32%
FY 2011	8%	30%	38%	27%
FY 2012	8%	17%	25%	22%
FY 2013	8%	14%	22%	20%
FY 2014	8%	18%	26%	25.7%
FY 2015	8%	20%	24%	19.8%
FY 2016	8%	10%	14%	14.8%
FY 2017	8%	8%	16%	14.1%
FY 2018	5%	10%	15%	n/a*

Table 2. Substitution method for applicable quarters with model estimated zero quota price

Quarter with estimated zero price	Substituted quarter price (non zero)
Q1	Q2
Q2	Average of Q1, Q3
Q3	Average of Q2, Q4
Q4	Q3

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Table 3. Stock status

Stock	2017 Assessment	
	Overfishing?	Overfished?
GB Cod	Unknown	Yes
GOM Cod	Yes	Yes
GB Haddock	No	No
GOM Haddock	No	No
GB Yellowtail Flounder	Yes	Yes
SNE/MA Yellowtail Flounder	Yes	Yes
CC/GOM Yellowtail Flounder	Yes	Yes
American Plaice	No	No
Witch Flounder	Unknown	Yes
GB Winter Flounder	No	Approaching ²
GOM Winter Flounder	No	Unknown
SNE/MA Winter Flounder	No	Yes
Acadian Redfish	No	No
White Hake	No	No
Pollock	No	No
Northern Windowpane Flounder	No	Yes
Southern Windowpane Flounder	No	No
Ocean Pout	No	Yes
Atlantic Halibut	No	Yes
Atlantic Wolffish	No	Yes

Table 3: Stock Status table from GARFO (2019)

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Appendix:

Table A-1. Summary information for discard incentive model. Modelled quota costs, ex-vessel value, sublegal discard cost, as well as landing and discarding costs all represent trip-level means.

Fishing Year	Stock	Pounds landed	Quota costs (modelled \$)		Ex vessel value(\$)		Quota cost of sublegal discards (\$/trip)		Cost of landing (\$/trip Cl)		Cost of discarding (\$/trip Cd)		Discard Incentive (per trip)	
			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2007	CC/GOM Yellowtail	140.95	NA	NA	262.17	460.66	NA	NA	8.46	13.72	266.21	462.68	-0.99	0.05
2008	CC/GOM Yellowtail	126.67	NA	NA	171.30	331.70	NA	NA	7.60	12.38	174.93	333.66	-0.98	0.06
2009	CC/GOM Yellowtail	130.62	NA	NA	196.70	290.22	NA	NA	7.84	11.39	200.47	292.35	-0.98	0.05
2010	CC/GOM Yellowtail	304.46	215.63	568.52	415.05	1105.15	9.17	33.62	252.99	660.03	419.69	1109.75	-0.38	0.22
2011	CC/GOM Yellowtail	266.04	99.03	275.54	331.57	995.57	5.47	19.80	129.19	360.01	335.87	1000.10	-0.53	0.26
2012	CC/GOM Yellowtail	356.98	171.54	432.20	509.20	1298.88	6.73	23.07	210.82	519.08	514.33	1303.69	-0.60	0.14
2013	CC/GOM Yellowtail	282.63	199.47	360.87	377.50	754.75	3.41	9.22	228.45	415.24	382.38	758.22	-0.33	0.33
2014	CC/GOM Yellowtail	213.78	83.46	183.60	253.02	705.67	2.37	7.16	105.46	229.91	257.01	708.92	-0.52	0.38
2015	CC/GOM Yellowtail	443.90	118.33	213.15	624.51	1116.80	7.72	15.61	166.86	284.35	630.67	1120.50	-0.73	0.16
2016	CC/GOM Yellowtail	383.98	145.54	266.92	681.56	1270.14	8.06	16.17	188.87	338.76	687.40	1273.87	-0.72	0.14
2017	CC/GOM Yellowtail	263.19	147.47	261.12	396.93	754.92	6.12	11.50	177.28	309.90	402.22	757.63	-0.54	0.25
2007	GB_Cod_East	2072.30	NA	NA	3240.59	2533.27	NA	NA	124.34	111.02	3255.91	2541.96	-0.97	0.01
2008	GB_Cod_East	1693.99	NA	NA	2955.40	2817.56	NA	NA	101.64	90.97	2968.82	2824.67	-0.97	0.02
2009	GB_Cod_East	1967.95	NA	NA	3025.11	2492.14	NA	NA	118.08	91.55	3039.94	2498.85	-0.97	0.02
2010	GB_Cod_East	1377.02	1348.77	1889.69	2668.41	3431.85	25.34	47.78	1497.42	2108.18	2680.29	3440.62	-0.46	0.16
2011	GB_Cod_East	579.09	466.42	671.53	1221.71	1989.55	9.70	27.34	526.50	757.87	1229.55	1994.34	-0.51	0.26
2012	GB_Cod_East	187.97	230.93	294.96	455.79	998.24	1.24	2.07	246.77	318.43	461.63	1000.38	-0.34	0.37

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			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2013	GB_Cod_East	196.95	115.15	152.78	429.31	929.87	0.51	0.87	128.81	151.88	435.04	931.86	-0.24	0.64
2014	GB_Cod_East	465.14	219.39	546.41	1013.42	2429.84	2.28	12.45	257.31	664.85	1020.54	2436.19	-0.71	0.16
2015	GB_Cod_East	757.05	150.53	347.73	1400.89	2914.41	2.67	6.21	204.26	426.96	1409.52	2922.09	-0.84	0.13
2016	GB_Cod_East	871.03	489.54	1138.93	2169.36	4123.63	4.00	6.83	557.74	1244.73	2178.60	4130.82	-0.72	0.28
2017	GB_Cod_East	752.29	430.41	810.70	2092.01	3973.23	2.77	4.64	485.37	903.26	2100.72	3980.18	-0.78	0.07
2007	GB_Cod_West	1795.79	NA	NA	3166.49	4147.33	NA	NA	107.75	145.46	3180.11	4159.13	-0.99	0.05
2008	GB_Cod_West	1470.52	NA	NA	2463.16	3454.65	NA	NA	88.23	125.51	2475.07	3464.76	-0.99	0.05
2009	GB_Cod_West	1548.46	NA	NA	2202.92	3025.46	NA	NA	92.91	127.23	2215.37	3035.16	-0.98	0.04
2010	GB_Cod_West	1515.17	1291.46	2150.03	3163.37	5187.51	17.65	37.69	1440.39	2391.26	3175.74	5199.68	-0.55	0.13
2011	GB_Cod_West	1972.02	1174.99	2281.91	4197.91	7492.87	12.15	35.37	1354.58	2602.06	4212.50	7511.34	-0.70	0.11
2012	GB_Cod_West	986.78	225.03	616.09	2525.92	5344.23	6.12	23.38	311.26	779.46	2535.57	5354.97	-0.92	0.07
2013	GB_Cod_West	1067.64	251.00	604.89	2218.23	3821.33	4.90	18.90	338.88	756.99	2228.21	3831.67	-0.88	0.07
2014	GB_Cod_West	982.52	484.13	861.23	2135.20	3448.49	4.14	10.79	566.02	1004.17	2144.64	3456.88	-0.77	0.10
2015	GB_Cod_West	1101.03	464.98	950.36	2250.04	3974.98	4.69	12.04	556.55	1114.88	2260.26	3985.69	-0.79	0.09
2016	GB_Cod_West	548.80	725.50	1236.12	1510.47	2155.73	4.45	10.07	774.43	1300.77	1517.87	2159.79	-0.55	0.24
2017	GB_Cod_West	584.73	1155.65	1798.43	1603.47	2266.36	4.18	14.01	1207.48	1875.71	1611.13	2270.87	-0.28	0.19
2007	GB_Haddock_East	3136.54	NA	NA	4838.95	8230.56	NA	NA	188.19	334.26	4859.60	8257.77	-0.98	0.03
2008	GB_Haddock_East	8970.81	NA	NA	9188.60	13042.11	NA	NA	538.25	806.46	9238.41	13105.87	-0.96	0.03
2009	GB_Haddock_East	14287.19	NA	NA	14890.52	17902.24	NA	NA	857.23	957.82	14966.84	17973.21	-0.95	0.03
2010	GB_Haddock_East	9714.63	0.00	0.00	11788.19	14170.84	86.40	92.74	825.44	880.14	11841.74	14223.81	-0.93	0.03
2011	GB_Haddock_East	5122.47	0.00	0.00	8571.47	13935.17	36.40	66.22	403.08	645.10	8602.08	13979.36	-0.96	0.03
2012	GB_Haddock_East	1833.36	25.68	58.33	4106.34	5967.01	16.49	38.98	174.02	257.90	4120.42	5980.63	-0.97	0.03
2013	GB_Haddock_East	4967.91	0.00	0.00	6587.74	8131.93	19.57	33.99	348.18	456.65	6617.48	8162.79	-0.95	0.04
2014	GB_Haddock_East	8913.79	0.00	0.00	10634.63	13917.27	29.33	40.63	688.74	937.17	10684.10	13972.92	-0.95	0.05
2015	GB_Haddock_East	8038.37	0.00	0.00	8988.77	11532.83	21.72	27.33	579.17	855.90	9033.91	11588.01	-0.95	0.04
2016	GB_Haddock_East	3992.91	0.00	0.00	5040.01	8964.16	16.30	29.40	278.04	456.63	5064.80	8999.00	-0.95	0.03
2017	GB_Haddock_East	4499.52	0.00	0.00	4278.57	9283.22	27.97	66.25	327.62	657.73	4305.71	9330.93	-0.93	0.06

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			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2007	GB_Haddock_West	3076.92	NA	NA	4826.96	9987.44	NA	NA	184.61	389.50	4846.67	10018.94	-0.99	0.05
2008	GB_Haddock_West	3841.95	NA	NA	4894.94	10698.35	NA	NA	230.52	492.67	4918.46	10737.31	-0.98	0.05
2009	GB_Haddock_West	4554.14	NA	NA	4878.71	9282.72	NA	NA	273.25	541.57	4905.82	9324.13	-0.98	0.05
2010	GB_Haddock_West	6118.16	0.00	0.00	7532.12	15568.08	54.87	125.43	545.12	1078.79	7567.38	15629.71	-0.96	0.06
2011	GB_Haddock_West	3089.06	0.00	0.00	4929.22	12019.77	12.67	49.04	262.90	666.49	4949.32	12060.00	-0.98	0.05
2012	GB_Haddock_West	833.62	26.95	145.58	1968.22	5135.25	3.76	13.31	96.01	311.70	1977.03	5147.02	-0.99	0.06
2013	GB_Haddock_West	2886.77	92.62	294.83	3977.76	8056.25	10.89	28.47	321.73	702.27	3996.91	8086.48	-0.95	0.06
2014	GB_Haddock_West	5306.92	0.00	0.00	6621.46	13203.37	15.31	34.67	403.50	778.76	6652.51	13255.67	-0.96	0.06
2015	GB_Haddock_West	4024.85	0.00	0.00	5009.12	11869.04	16.04	39.75	316.92	745.48	5033.65	11918.10	-0.96	0.06
2016	GB_Haddock_West	5649.64	0.00	0.00	7086.81	13938.56	36.37	92.17	443.13	889.03	7119.68	13997.77	-0.96	0.05
2017	GB_Haddock_West	6589.44	0.00	0.00	6596.36	11681.13	48.37	107.74	518.89	858.94	6633.98	11738.20	-0.93	0.06
2007	GB_Winter	1966.43	NA	NA	4430.15	4633.98	NA	NA	117.99	121.50	4444.78	4643.59	-0.99	0.04
2008	GB_Winter	2253.12	NA	NA	4482.23	4296.58	NA	NA	135.19	123.07	4498.26	4306.18	-0.99	0.04
2009	GB_Winter	3536.00	NA	NA	5861.61	6761.45	NA	NA	212.16	264.23	5884.09	6781.41	-0.98	0.04
2010	GB_Winter	3065.12	2786.52	3830.15	6048.49	8536.59	39.03	70.05	3101.52	4268.93	6068.59	8556.96	-0.48	0.17
2011	GB_Winter	4027.12	2176.52	3275.89	7073.64	9787.83	22.82	38.68	2550.75	3787.74	7098.56	9815.78	-0.66	0.16
2012	GB_Winter	6178.00	3350.29	4040.92	12447.66	13570.66	64.78	149.81	3958.44	4722.03	12483.39	13601.76	-0.73	0.15
2013	GB_Winter	6214.90	667.91	1035.20	9959.71	11251.57	36.62	61.66	1231.79	1603.32	9995.58	11283.74	-0.91	0.09
2014	GB_Winter	3802.68	537.50	1246.98	7541.70	9578.62	13.05	25.05	884.04	1600.41	7565.46	9601.53	-0.92	0.11
2015	GB_Winter	3702.39	158.10	257.33	7564.28	10950.29	14.46	23.84	487.94	769.69	7587.48	10973.62	-0.96	0.06
2016	GB_Winter	2384.96	1065.43	1222.87	8423.95	10286.78	16.40	24.92	1290.78	1487.19	8440.78	10300.61	-0.84	0.05
2017	GB_Winter	2761.07	1397.21	1883.20	9234.69	12481.29	11.67	16.67	1655.17	2232.58	9253.35	12499.29	-0.83	0.07
2007	GB_Yellowtail	2040.42	NA	NA	3469.27	4805.01	NA	NA	122.43	154.18	3484.17	4817.40	-0.98	0.04
2008	GB_Yellowtail	2439.25	NA	NA	3266.97	3039.41	NA	NA	146.36	127.11	3283.99	3048.67	-0.97	0.04
2009	GB_Yellowtail	2218.85	NA	NA	2598.95	2113.40	NA	NA	133.13	105.33	2614.78	2120.94	-0.96	0.05
2010	GB_Yellowtail	1867.60	1879.86	2666.41	2124.40	2660.78	24.51	50.95	2076.76	2960.49	2138.47	2672.85	-0.07	0.40
2011	GB_Yellowtail	2498.72	748.25	1395.25	2994.36	4822.47	12.42	24.40	986.50	1749.03	3011.58	4841.38	-0.72	0.15

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			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2012	GB_Yellowtail	1148.81	885.95	1920.96	1669.02	3414.49	6.76	21.70	998.84	2135.60	1679.39	3426.83	-0.37	0.43
2013	GB_Yellowtail	532.67	7.72	18.40	1069.29	4591.71	1.51	4.62	57.13	217.98	1076.30	4602.99	-0.96	0.10
2014	GB_Yellowtail	477.40	184.31	685.26	690.77	1964.62	3.04	13.58	230.79	849.73	697.69	1972.64	-0.73	0.17
2015	GB_Yellowtail	353.64	51.08	300.36	607.42	1334.57	1.49	3.64	82.62	337.41	613.77	1338.32	-0.92	0.16
2016	GB_Yellowtail	449.60	0.00	0.00	994.33	2930.20	1.61	3.96	43.49	128.85	1000.95	2936.94	-1.00	0.05
2017	GB_Yellowtail	898.44	205.09	575.97	1571.93	4368.20	3.37	9.20	292.33	824.76	1580.47	4381.10	-0.87	0.09
2007	GOM_Cod	594.72	NA	NA	1143.67	906.66	NA	NA	35.68	26.75	1151.57	908.80	-0.98	0.03
2008	GOM_Cod	671.40	NA	NA	1133.51	942.86	NA	NA	40.28	30.85	1141.80	945.27	-0.98	0.03
2009	GOM_Cod	766.90	NA	NA	1137.70	988.57	NA	NA	46.01	33.96	1146.49	991.09	-0.97	0.02
2010	GOM_Cod	995.35	1082.01	1430.06	2258.39	3043.27	17.93	50.27	1188.67	1563.39	2268.27	3049.62	-0.46	0.18
2011	GOM_Cod	876.70	738.93	1144.86	2012.16	2963.79	13.82	29.28	830.96	1275.87	2021.49	2970.34	-0.60	0.10
2012	GOM_Cod	482.78	212.04	380.40	1225.72	2178.23	5.57	19.61	260.41	463.95	1233.03	2182.71	-0.80	0.10
2013	GOM_Cod	280.99	271.50	632.48	758.02	1507.99	2.91	9.36	298.37	676.17	764.18	1510.75	-0.58	0.44
2014	GOM_Cod	293.09	228.45	400.90	673.33	1121.03	2.20	6.57	255.71	452.40	679.60	1124.27	-0.61	0.28
2015	GOM_Cod	121.77	249.88	400.49	306.57	478.37	1.55	3.55	261.90	417.81	311.83	479.55	-0.08	0.46
2016	GOM_Cod	190.06	417.64	745.39	577.37	1037.63	2.85	9.64	437.01	777.34	583.16	1039.22	-0.29	0.27
2017	GOM_Cod	174.56	425.37	704.75	525.83	868.82	2.88	7.47	443.30	733.05	531.53	870.28	-0.16	0.24
2007	GOM_Haddock	121.38	NA	NA	240.73	899.42	NA	NA	7.28	30.50	244.59	902.33	-1.02	0.07
2008	GOM_Haddock	145.28	NA	NA	242.67	949.14	NA	NA	8.72	41.71	246.26	952.96	-1.01	0.07
2009	GOM_Haddock	182.44	NA	NA	288.51	1596.12	NA	NA	10.95	69.60	291.90	1601.60	-1.00	0.07
2010	GOM_Haddock	221.18	105.14	533.74	415.82	1937.80	4.92	34.05	128.62	649.29	420.03	1943.60	-0.71	0.16
2011	GOM_Haddock	200.63	55.76	535.18	451.44	2379.47	3.57	17.10	76.91	657.61	455.87	2385.74	-0.97	0.11
2012	GOM_Haddock	101.61	12.69	45.89	287.19	745.98	1.55	9.29	22.44	67.05	291.29	747.84	-0.99	0.09
2013	GOM_Haddock	119.22	86.79	229.27	254.24	676.88	1.31	7.76	97.13	259.88	258.12	679.12	-0.65	0.19
2014	GOM_Haddock	201.17	180.65	560.45	378.36	1271.97	1.71	6.64	196.79	608.71	382.66	1275.56	-0.45	0.28
2015	GOM_Haddock	521.09	195.13	793.99	756.06	2292.53	4.67	33.53	237.36	977.12	762.05	2302.14	-0.74	0.13
2016	GOM_Haddock	1172.75	98.77	259.70	1779.72	3977.37	12.01	30.40	197.48	477.79	1789.47	3990.84	-0.92	0.08

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			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2017	GOM_Haddock	1509.36	286.36	638.49	1873.86	3864.05	15.69	39.42	419.21	922.72	1885.38	3880.27	-0.79	0.13
2007	GOM_Winter	59.77	NA	NA	121.05	318.07	NA	NA	3.59	10.20	124.06	319.70	-1.01	0.07
2008	GOM_Winter	58.28	NA	NA	101.08	338.79	NA	NA	3.50	11.56	103.52	340.52	-1.00	0.06
2009	GOM_Winter	54.77	NA	NA	90.50	337.70	NA	NA	3.29	12.53	92.58	339.50	-1.00	0.07
2010	GOM_Winter	52.01	53.17	133.30	94.83	233.55	1.58	6.03	59.61	149.05	97.34	235.22	-0.39	0.22
2011	GOM_Winter	67.69	40.80	118.12	122.72	327.68	1.70	6.40	48.84	136.35	125.76	329.36	-0.56	0.26
2012	GOM_Winter	105.57	13.74	45.72	211.84	564.98	2.29	8.86	25.85	73.72	215.53	566.95	-0.90	0.12
2013	GOM_Winter	128.20	0.00	0.00	227.64	541.60	2.09	8.86	14.03	34.55	231.25	543.89	-0.97	0.07
2014	GOM_Winter	115.35	0.00	0.00	204.16	851.11	1.34	6.08	12.25	59.76	207.41	854.42	-0.99	0.08
2015	GOM_Winter	144.31	0.60	2.60	296.02	598.15	2.69	7.37	16.93	34.36	299.97	600.38	-0.98	0.07
2016	GOM_Winter	162.09	1.14	8.04	460.17	954.26	3.84	8.86	20.28	41.34	464.74	956.30	-0.99	0.06
2017	GOM_Winter	161.23	0.00	0.00	451.48	1288.64	4.12	14.90	19.30	59.06	456.28	1291.31	-1.00	0.06
2007	Plaice	298.41	NA	NA	494.65	1387.79	NA	NA	17.90	52.64	498.90	1392.74	-1.00	0.06
2008	Plaice	361.21	NA	NA	468.91	1401.44	NA	NA	21.67	68.50	473.39	1407.53	-0.99	0.06
2009	Plaice	426.79	NA	NA	559.07	1645.68	NA	NA	25.61	75.92	563.79	1652.24	-0.98	0.06
2010	Plaice	603.97	116.65	300.40	881.79	2215.41	6.01	15.84	167.02	420.66	887.76	2223.75	-0.82	0.21
2011	Plaice	459.92	38.39	130.26	654.45	1931.54	2.64	7.38	74.99	217.28	659.46	1938.89	-0.87	0.12
2012	Plaice	444.60	10.71	58.66	737.65	2009.06	2.64	7.58	46.54	134.69	743.01	2015.77	-0.94	0.07
2013	Plaice	590.14	182.89	441.12	961.71	2225.85	3.78	9.36	229.66	532.22	967.78	2232.68	-0.76	0.13
2014	Plaice	645.11	363.21	809.23	1166.14	2336.86	4.50	10.49	416.02	899.53	1172.78	2343.58	-0.65	0.19
2015	Plaice	858.66	718.03	1268.40	1670.32	2902.99	7.17	17.38	789.51	1378.24	1678.56	2910.44	-0.50	0.24
2016	Plaice	847.23	1030.65	1766.55	2186.16	3724.51	10.52	21.12	1105.56	1879.42	2194.58	3731.61	-0.44	0.22
2017	Plaice	769.64	1076.26	1934.54	1927.93	3665.14	8.02	21.85	1144.73	2056.18	1936.04	3672.22	-0.30	0.32
2007	Pollock	1755.41	NA	NA	936.33	2853.56	NA	NA	105.32	312.99	948.86	2877.33	-0.92	0.08
2008	Pollock	1905.41	NA	NA	1093.42	2980.84	NA	NA	114.32	324.86	1106.87	3005.15	-0.93	0.07
2009	Pollock	1409.66	NA	NA	1091.96	3095.75	NA	NA	84.58	243.81	1102.88	3114.79	-0.95	0.06
2010	Pollock	1713.70	0.00	0.00	1602.16	3818.97	12.91	36.66	148.97	356.02	1614.78	3839.07	-0.93	0.08

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Fishing Year	Stock	Pounds landed	Quota costs (modelled \$)		Ex vessel value(\$)		Quota cost of sublegal discards (\$/trip)		Cost of landing (\$/trip Cl)		Cost of discarding (\$/trip Cd)		Discard Incentive (per trip)	
			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2011	Pollock	1755.86	70.74	195.30	1571.04	3954.91	10.47	32.40	224.31	578.37	1583.97	3977.72	-0.87	0.07
2012	Pollock	1927.05	18.48	87.60	1995.13	4774.86	11.61	44.31	183.67	530.26	2008.96	4799.89	-0.94	0.07
2013	Pollock	2065.49	47.88	101.88	2384.32	4834.29	10.65	32.63	220.11	471.92	2399.07	4856.20	-0.93	0.06
2014	Pollock	1850.59	17.53	63.62	2498.70	4850.40	9.34	30.54	170.44	357.67	2512.50	4868.37	-0.96	0.06
2015	Pollock	1820.88	4.98	26.05	2252.31	4379.77	12.02	38.01	163.78	344.10	2265.83	4397.73	-0.96	0.06
2016	Pollock	2321.83	0.00	0.00	2543.88	4944.76	17.12	48.66	196.40	429.97	2559.79	4968.58	-0.96	0.07
2017	Pollock	2247.22	0.00	0.00	2191.42	4488.22	17.82	66.25	200.66	453.50	2206.81	4511.57	-0.94	0.08
2007	Redfish	552.48	NA	NA	304.05	1021.91	NA	NA	33.15	123.29	309.37	1032.36	-0.95	0.07
2008	Redfish	638.53	NA	NA	337.69	1304.68	NA	NA	38.31	174.00	343.32	1319.56	-0.95	0.07
2009	Redfish	696.12	NA	NA	336.56	1283.39	NA	NA	41.77	186.19	342.27	1299.15	-0.94	0.07
2010	Redfish	1432.36	0.00	0.00	820.28	2892.84	9.79	40.59	117.91	453.91	830.07	2922.34	-0.90	0.08
2011	Redfish	1394.36	18.23	141.31	920.16	4083.95	5.90	26.12	125.91	503.38	929.53	4115.14	-0.88	0.10
2012	Redfish	2137.75	37.46	155.51	1281.73	5133.88	11.77	92.34	210.93	864.62	1294.92	5176.61	-0.89	0.08
2013	Redfish	2240.06	11.16	55.00	1180.57	3861.41	10.67	44.05	193.84	692.46	1194.54	3899.91	-0.90	0.09
2014	Redfish	3176.08	7.51	52.98	1777.57	5640.82	15.69	56.23	263.63	827.52	1796.40	5690.80	-0.90	0.07
2015	Redfish	4919.05	57.66	192.21	2832.19	8439.65	20.99	67.97	457.37	1273.17	2860.24	8510.88	-0.88	0.09
2016	Redfish	4915.88	49.99	171.44	2940.39	8829.78	26.30	98.28	468.67	1374.88	2968.65	8904.09	-0.89	0.08
2017	Redfish	5506.34	56.02	155.01	2981.12	8486.35	27.29	70.99	539.82	1434.37	3012.26	8561.32	-0.87	0.11
2007	SNE/MA_Winter	658.31	NA	NA	1366.02	3250.22	NA	NA	39.50	98.43	1373.82	3258.28	-1.00	0.05
2008	SNE/MA_Winter	547.79	NA	NA	877.62	2633.26	NA	NA	32.87	115.00	884.63	2642.38	-1.00	0.05
2009	SNE/MA_Winter	449.62	NA	NA	753.60	2265.55	NA	NA	26.98	89.10	759.24	2272.87	-1.01	0.06
2010	SNE/MA_Winter	83.72	0.00	0.00	126.43	513.08	0.21	0.51	7.93	39.22	128.85	515.84	-0.99	0.08
2011	SNE/MA_Winter	44.89	0.00	0.00	69.84	124.67	0.29	0.63	4.49	8.32	73.37	125.94	-1.00	0.08
2012	SNE/MA_Winter	30.36	0.00	0.00	61.05	130.48	0.20	0.48	2.97	5.64	63.32	131.99	-0.98	0.07
2013	SNE/MA_Winter	841.86	383.87	1313.67	1452.60	4341.69	4.16	24.22	457.67	1519.37	1461.25	4354.44	-0.74	0.13
2014	SNE/MA_Winter	653.33	102.45	347.97	1245.46	4149.07	1.50	5.53	158.63	508.51	1252.96	4160.89	-0.91	0.12
2015	SNE/MA_Winter	700.40	14.51	67.55	1587.43	5392.54	2.22	12.15	75.55	210.68	1595.47	5403.46	-0.97	0.05

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Fishing Year	Stock	Pounds landed	Quota costs (modelled \$)		Ex vessel value(\$)		Quota cost of sublegal discards (\$/trip)		Cost of landing (\$/trip CI)		Cost of discarding (\$/trip Cd)		Discard Incentive (per trip)	
			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2016	SNE/MA_Winter	719.59	364.99	987.06	2203.60	6443.31	6.27	28.27	429.21	1159.73	2211.78	6453.05	-0.78	0.08
2017	SNE/MA_Winter	710.58	439.33	1296.99	2146.25	6513.79	4.79	21.14	499.83	1458.13	2154.27	6523.86	-0.76	0.10
2007	SNE/MA_Yellowtail	285.81	NA	NA	599.78	667.88	NA	NA	17.15	22.12	605.85	669.92	-0.99	0.04
2008	SNE/MA_Yellowtail	301.70	NA	NA	504.95	501.71	NA	NA	18.10	19.20	510.99	503.59	-0.98	0.04
2009	SNE/MA_Yellowtail	268.06	NA	NA	478.04	451.71	NA	NA	16.08	18.13	484.14	453.32	-0.99	0.02
2010	SNE/MA_Yellowtail	727.93	850.84	1185.25	973.52	1169.87	9.86	21.38	927.93	1289.13	982.01	1174.59	-0.09	0.27
2011	SNE/MA_Yellowtail	1123.82	465.49	518.48	1657.96	1829.74	6.37	13.94	575.17	629.79	1668.31	1835.58	-0.64	0.13
2012	SNE/MA_Yellowtail	951.14	491.82	454.65	1603.80	1558.65	11.84	20.74	592.31	545.44	1613.39	1562.78	-0.61	0.13
2013	SNE/MA_Yellowtail	693.44	294.24	434.64	1230.63	1581.30	3.46	15.25	361.69	531.20	1238.72	1586.13	-0.72	0.11
2014	SNE/MA_Yellowtail	903.30	304.13	526.86	1480.15	2336.56	2.66	6.65	391.75	687.99	1489.27	2344.73	-0.77	0.08
2015	SNE/MA_Yellowtail	528.37	109.91	172.70	1016.65	1570.00	0.81	2.65	160.27	250.06	1023.80	1574.63	-0.86	0.07
2016	SNE/MA_Yellowtail	178.33	105.44	167.61	471.67	746.43	1.34	4.60	122.47	193.01	476.56	748.44	-0.75	0.11
2017	SNE/MA_Yellowtail	54.93	26.13	57.09	147.18	330.64	0.35	1.43	31.37	67.89	150.83	331.92	-0.80	0.11
2007	White_Hake	409.37	NA	NA	578.15	1432.52	NA	NA	24.56	59.35	583.47	1437.62	-0.99	0.07
2008	White_Hake	388.37	NA	NA	514.98	1370.73	NA	NA	23.30	60.13	520.34	1375.82	-0.99	0.07
2009	White_Hake	464.79	NA	NA	561.02	1496.68	NA	NA	27.89	71.95	566.73	1502.92	-0.98	0.07
2010	White_Hake	796.79	299.71	736.52	1059.67	2604.55	6.10	17.11	361.78	874.93	1067.34	2614.31	-0.66	0.17
2011	White_Hake	801.36	329.36	842.77	1026.44	2558.43	4.01	9.76	392.67	975.44	1034.40	2567.90	-0.64	0.16
2012	White_Hake	726.57	443.60	899.18	1270.77	2623.79	4.03	9.64	502.86	1005.64	1278.62	2631.28	-0.56	0.20
2013	White_Hake	890.68	103.73	357.82	1567.88	3019.42	4.63	12.45	173.18	452.99	1576.70	3027.94	-0.90	0.12
2014	White_Hake	792.12	52.14	138.68	1571.72	3360.62	4.26	13.87	112.64	268.24	1579.87	3369.69	-0.95	0.07
2015	White_Hake	970.09	38.07	116.74	1876.73	3815.01	6.36	24.63	112.33	256.06	1885.75	3825.34	-0.96	0.06
2016	White_Hake	1053.07	25.32	65.24	2030.67	3351.17	9.14	19.81	110.06	200.20	2040.19	3360.67	-0.96	0.06
2017	White_Hake	1485.73	17.27	33.48	2020.09	3672.25	12.70	29.23	141.21	261.26	2031.55	3686.12	-0.94	0.06
2007	Witch_Flounder	302.77	NA	NA	690.68	1721.14	NA	NA	18.17	47.93	695.44	1725.62	-1.00	0.05
2008	Witch_Flounder	292.95	NA	NA	614.52	1433.77	NA	NA	17.58	43.64	619.14	1437.96	-1.00	0.05
2009	Witch_Flounder	305.05	NA	NA	592.81	1302.22	NA	NA	18.30	41.24	597.42	1306.23	-0.99	0.05

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Fishing Year	Stock	Pounds landed	Quota costs (modelled \$)		Ex vessel value(\$)		Quota cost of sublegal discards (\$/trip)		Cost of landing (\$/trip Cl)		Cost of discarding (\$/trip Cd)		Discard Incentive (per trip)	
			MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
2010	Witch_Flounder	296.67	441.61	913.92	727.89	1439.37	3.84	9.42	468.91	967.57	732.66	1443.14	-0.37	0.28
2011	Witch_Flounder	298.45	172.55	423.61	597.11	1355.27	2.49	7.40	199.22	484.74	601.60	1359.64	-0.70	0.13
2012	Witch_Flounder	289.98	140.92	337.03	581.40	1273.01	2.41	5.57	166.74	394.57	586.19	1276.98	-0.74	0.14
2013	Witch_Flounder	292.68	238.27	447.56	719.95	1311.18	2.11	4.91	263.48	491.46	724.89	1314.69	-0.64	0.16
2014	Witch_Flounder	269.73	236.61	480.89	725.69	1266.29	2.13	5.24	260.06	518.40	730.45	1269.56	-0.66	0.20
2015	Witch_Flounder	326.27	280.30	466.71	837.57	1248.49	3.19	7.54	309.42	509.32	843.04	1251.70	-0.66	0.20
2016	Witch_Flounder	257.20	319.54	539.21	826.50	1295.02	3.51	7.38	343.81	574.60	831.64	1297.67	-0.61	0.20
2017	Witch_Flounder	384.17	391.06	641.86	854.80	1240.87	4.62	11.59	426.92	698.41	860.79	1244.40	-0.51	0.23
** all values have not been adjusted for inflation														

Table A-2: Annualized marginal discarding incentive and marginal parameter values by stock. Ex-vessel price and quota price represent weighted means. Prices have not been adjusted for inflation.

Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2007	CC/GOM Yellowtail	1.86	NA	NA	0.06	1.89	-1.83
2008	CC/GOM Yellowtail	1.35	NA	NA	0.06	1.38	-1.32
2009	CC/GOM Yellowtail	1.51	NA	NA	0.06	1.53	-1.47
2010	CC/GOM Yellowtail	1.36	0.71	0.03	0.83	1.38	-0.55
2011	CC/GOM Yellowtail	1.25	0.37	0.02	0.49	1.26	-0.78
2012	CC/GOM Yellowtail	1.43	0.48	0.02	0.59	1.44	-0.85

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2013	CC/GOM Yellowtail	1.34	0.71	0.01	0.81	1.35	-0.54
2014	CC/GOM Yellowtail	1.18	0.39	0.01	0.49	1.20	-0.71
2015	CC/GOM Yellowtail	1.41	0.27	0.02	0.38	1.42	-1.04
2016	CC/GOM Yellowtail	1.77	0.38	0.02	0.49	1.79	-1.30
2017	CC/GOM Yellowtail	1.51	0.56	0.02	0.67	1.53	-0.85
2007	GB Cod East	1.56	NA	NA	0.06	1.57	-1.51
2008	GB Cod East	1.74	NA	NA	0.06	1.75	-1.69
2009	GB Cod East	1.54	NA	NA	0.06	1.54	-1.48
2010	GB Cod East	1.94	0.98	0.02	1.09	1.95	-0.86
2011	GB Cod East	2.11	0.81	0.02	0.91	2.12	-1.21
2012	GB Cod East	2.42	1.23	0.01	1.31	2.46	-1.14
2013	GB Cod East	2.18	0.58	0.00	0.65	2.21	-1.55
2014	GB Cod East	2.18	0.47	0.00	0.55	2.19	-1.64
2015	GB Cod East	1.85	0.20	0.00	0.27	1.86	-1.59
2016	GB Cod East	2.49	0.56	0.00	0.64	2.50	-1.86
2017	GB Cod East	2.78	0.57	0.00	0.65	2.79	-2.15
2007	GB Cod West	1.76	NA	NA	0.06	1.77	-1.71
2008	GB Cod West	1.68	NA	NA	0.06	1.68	-1.62
2009	GB Cod West	1.42	NA	NA	0.06	1.43	-1.37
2010	GB Cod West	2.09	0.85	0.01	0.95	2.10	-1.15
2011	GB Cod West	2.13	0.60	0.01	0.69	2.14	-1.45
2012	GB Cod West	2.56	0.23	0.01	0.32	2.57	-2.25
2013	GB Cod West	2.08	0.24	0.00	0.32	2.09	-1.77
2014	GB Cod West	2.17	0.49	0.00	0.58	2.18	-1.61
2015	GB Cod West	2.04	0.42	0.00	0.51	2.05	-1.55
2016	GB Cod West	2.75	1.32	0.01	1.41	2.77	-1.35

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2017	GB Cod West	2.74	1.98	0.01	2.07	2.76	-0.69
2007	GB Haddock East	1.54	NA	NA	0.06	1.55	-1.49
2008	GB Haddock East	1.02	NA	NA	0.06	1.03	-0.97
2009	GB Haddock East	1.04	NA	NA	0.06	1.05	-0.99
2010	GB Haddock East	1.21	0.00	0.01	0.08	1.22	-1.13
2011	GB Haddock East	1.67	0.00	0.01	0.08	1.68	-1.60
2012	GB Haddock East	2.24	0.01	0.01	0.09	2.25	-2.15
2013	GB Haddock East	1.33	0.00	0.00	0.07	1.33	-1.26
2014	GB Haddock East	1.19	0.00	0.00	0.08	1.20	-1.12
2015	GB Haddock East	1.12	0.00	0.00	0.07	1.12	-1.05
2016	GB Haddock East	1.26	0.00	0.00	0.07	1.27	-1.20
2017	GB Haddock East	0.95	0.00	0.01	0.07	0.96	-0.88
2007	GB Haddock West	1.57	NA	NA	0.06	1.58	-1.52
2008	GB Haddock West	1.27	NA	NA	0.06	1.28	-1.22
2009	GB Haddock West	1.07	NA	NA	0.06	1.08	-1.02
2010	GB Haddock West	1.23	0.00	0.01	0.09	1.24	-1.15
2011	GB Haddock West	1.60	0.00	0.00	0.09	1.60	-1.52
2012	GB Haddock West	2.36	0.03	0.00	0.12	2.37	-2.26
2013	GB Haddock West	1.38	0.03	0.00	0.11	1.38	-1.27

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2014	GB Haddock West	1.25	0.00	0.00	0.08	1.25	-1.18
2015	GB Haddock West	1.24	0.00	0.00	0.08	1.25	-1.17
2016	GB Haddock West	1.25	0.00	0.01	0.08	1.26	-1.18
2017	GB Haddock West	1.00	0.00	0.01	0.08	1.01	-0.93
2007	GB Winter	2.25	NA	NA	0.06	2.26	-2.20
2008	GB Winter	1.99	NA	NA	0.06	2.00	-1.94
2009	GB Winter	1.66	NA	NA	0.06	1.66	-1.60
2010	GB Winter	1.97	0.91	0.01	1.01	1.98	-0.97
2011	GB Winter	1.76	0.54	0.01	0.63	1.76	-1.13
2012	GB Winter	2.01	0.54	0.01	0.64	2.02	-1.38
2013	GB Winter	1.60	0.11	0.01	0.20	1.61	-1.41
2014	GB Winter	1.98	0.14	0.00	0.23	1.99	-1.76
2015	GB Winter	2.04	0.04	0.00	0.13	2.05	-1.92
2016	GB Winter	3.53	0.45	0.01	0.54	3.54	-3.00
2017	GB Winter	3.34	0.51	0.00	0.60	3.35	-2.75
2007	GB Yellowtail	1.70	NA	NA	0.06	1.71	-1.65
2008	GB Yellowtail	1.34	NA	NA	0.06	1.35	-1.29
2009	GB Yellowtail	1.17	NA	NA	0.06	1.18	-1.12
2010	GB Yellowtail	1.14	1.01	0.01	1.11	1.15	-0.03
2011	GB Yellowtail	1.20	0.30	0.00	0.39	1.21	-0.81
2012	GB Yellowtail	1.45	0.77	0.01	0.87	1.46	-0.59
2013	GB Yellowtail	2.01	0.01	0.00	0.11	2.02	-1.91
2014	GB Yellowtail	1.45	0.39	0.01	0.48	1.46	-0.98
2015	GB Yellowtail	1.72	0.14	0.00	0.23	1.74	-1.50
2016	GB Yellowtail	2.21	0.00	0.00	0.10	2.23	-2.13
2017	GB Yellowtail	1.75	0.23	0.00	0.33	1.76	-1.43

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2007	GOM Cod	1.92	NA	NA	0.06	1.94	-1.88
2008	GOM Cod	1.69	NA	NA	0.06	1.70	-1.64
2009	GOM Cod	1.48	NA	NA	0.06	1.49	-1.43
2010	GOM Cod	2.27	1.09	0.02	1.19	2.28	-1.08
2011	GOM Cod	2.30	0.84	0.02	0.95	2.31	-1.36
2012	GOM Cod	2.54	0.44	0.01	0.54	2.55	-2.01
2013	GOM Cod	2.70	0.97	0.01	1.06	2.72	-1.66
2014	GOM Cod	2.30	0.78	0.01	0.87	2.32	-1.45
2015	GOM Cod	2.52	2.05	0.01	2.15	2.56	-0.41
2016	GOM Cod	3.04	2.20	0.02	2.30	3.07	-0.77
2017	GOM Cod	3.01	2.44	0.02	2.54	3.04	-0.51
2007	GOM Haddock	1.98	NA	NA	0.06	2.02	-1.96
2008	GOM Haddock	1.67	NA	NA	0.06	1.70	-1.64
2009	GOM Haddock	1.58	NA	NA	0.06	1.60	-1.54
2010	GOM Haddock	1.88	0.48	0.02	0.58	1.90	-1.32
2011	GOM Haddock	2.25	0.28	0.02	0.38	2.27	-1.89
2012	GOM Haddock	2.83	0.12	0.02	0.22	2.87	-2.65
2013	GOM Haddock	2.13	0.73	0.01	0.81	2.17	-1.35
2014	GOM Haddock	1.88	0.90	0.01	0.98	1.90	-0.92
2015	GOM Haddock	1.45	0.37	0.01	0.46	1.46	-1.01
2016	GOM Haddock	1.52	0.08	0.01	0.17	1.53	-1.36
2017	GOM Haddock	1.24	0.19	0.01	0.28	1.25	-0.97
2007	GOM Winter	2.03	NA	NA	0.06	2.08	-2.02
2008	GOM Winter	1.73	NA	NA	0.06	1.78	-1.72
2009	GOM Winter	1.65	NA	NA	0.06	1.69	-1.63
2010	GOM Winter	1.82	1.02	0.03	1.15	1.87	-0.73
2011	GOM Winter	1.81	0.60	0.03	0.72	1.86	-1.14
2012	GOM Winter	2.01	0.13	0.02	0.24	2.04	-1.80

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2013	GOM Winter	1.78	0.00	0.02	0.11	1.80	-1.69
2014	GOM Winter	1.77	0.00	0.01	0.11	1.80	-1.69
2015	GOM Winter	2.05	0.00	0.02	0.12	2.08	-1.96
2016	GOM Winter	2.84	0.01	0.02	0.13	2.87	-2.74
2017	GOM Winter	2.80	0.00	0.03	0.12	2.83	-2.71
2007	Plaice	1.66	NA	NA	0.06	1.67	-1.61
2008	Plaice	1.30	NA	NA	0.06	1.31	-1.25
2009	Plaice	1.31	NA	NA	0.06	1.32	-1.26
2010	Plaice	1.46	0.19	0.01	0.28	1.47	-1.19
2011	Plaice	1.42	0.08	0.01	0.16	1.43	-1.27
2012	Plaice	1.66	0.02	0.01	0.10	1.67	-1.57
2013	Plaice	1.63	0.31	0.01	0.39	1.64	-1.25
2014	Plaice	1.81	0.56	0.01	0.64	1.82	-1.17
2015	Plaice	1.95	0.84	0.01	0.92	1.95	-1.04
2016	Plaice	2.58	1.22	0.01	1.30	2.59	-1.29
2017	Plaice	2.50	1.40	0.01	1.49	2.52	-1.03
2007	Pollock	0.53	NA	NA	0.06	0.54	-0.48
2008	Pollock	0.57	NA	NA	0.06	0.58	-0.52
2009	Pollock	0.77	NA	NA	0.06	0.78	-0.72
2010	Pollock	0.93	0.00	0.01	0.09	0.94	-0.86
2011	Pollock	0.89	0.04	0.01	0.13	0.90	-0.77
2012	Pollock	1.04	0.01	0.01	0.10	1.04	-0.95
2013	Pollock	1.15	0.02	0.01	0.11	1.16	-1.05
2014	Pollock	1.35	0.01	0.01	0.09	1.36	-1.27
2015	Pollock	1.24	0.00	0.01	0.09	1.24	-1.15
2016	Pollock	1.10	0.00	0.01	0.08	1.10	-1.02
2017	Pollock	0.98	0.00	0.01	0.09	0.98	-0.89
2007	Redfish	0.55	NA	NA	0.06	0.56	-0.50

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2008	Redfish	0.53	NA	NA	0.06	0.54	-0.48
2009	Redfish	0.48	NA	NA	0.06	0.49	-0.43
2010	Redfish	0.57	0.00	0.01	0.08	0.58	-0.50
2011	Redfish	0.66	0.01	0.00	0.09	0.67	-0.58
2012	Redfish	0.60	0.02	0.01	0.10	0.61	-0.51
2013	Redfish	0.53	0.00	0.00	0.09	0.53	-0.45
2014	Redfish	0.56	0.00	0.00	0.08	0.57	-0.48
2015	Redfish	0.58	0.01	0.00	0.09	0.58	-0.49
2016	Redfish	0.60	0.01	0.01	0.10	0.60	-0.51
2017	Redfish	0.54	0.01	0.00	0.10	0.55	-0.45
2007	SNE/MA Winter	2.08	NA	NA	0.06	2.09	-2.03
2008	SNE/MA Winter	1.60	NA	NA	0.06	1.61	-1.55
2009	SNE/MA Winter	1.68	NA	NA	0.06	1.69	-1.63
2010	SNE/MA Winter	1.51	0.00	0.00	0.09	1.54	-1.44
2011	SNE/MA Winter	1.56	0.00	0.01	0.10	1.63	-1.53
2012	SNE/MA Winter	2.01	0.00	0.01	0.10	2.09	-1.99
2013	SNE/MA Winter	1.73	0.46	0.00	0.54	1.74	-1.19
2014	SNE/MA Winter	1.91	0.16	0.00	0.24	1.92	-1.67
2015	SNE/MA Winter	2.27	0.02	0.00	0.11	2.28	-2.17
2016	SNE/MA Winter	3.06	0.51	0.01	0.60	3.07	-2.48
2017	SNE/MA Winter	3.02	0.62	0.01	0.70	3.03	-2.33
2007	SNE/MA Yellowtail	2.10	NA	NA	0.06	2.12	-2.06

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2008	SNE/MA Yellowtail	1.67	NA	NA	0.06	1.69	-1.63
2009	SNE/MA Yellowtail	1.78	NA	NA	0.06	1.81	-1.75
2010	SNE/MA Yellowtail	1.34	1.17	0.01	1.27	1.35	-0.07
2011	SNE/MA Yellowtail	1.48	0.41	0.01	0.51	1.48	-0.97
2012	SNE/MA Yellowtail	1.69	0.52	0.01	0.62	1.70	-1.07
2013	SNE/MA Yellowtail	1.77	0.42	0.00	0.52	1.79	-1.26
2014	SNE/MA Yellowtail	1.64	0.34	0.00	0.43	1.65	-1.22
2015	SNE/MA Yellowtail	1.92	0.21	0.00	0.30	1.94	-1.63
2016	SNE/MA Yellowtail	2.64	0.59	0.01	0.69	2.67	-1.99
2017	SNE/MA Yellowtail	2.68	0.48	0.01	0.57	2.75	-2.17
2007	White Hake	1.41	NA	NA	0.06	1.43	-1.37
2008	White Hake	1.33	NA	NA	0.06	1.34	-1.28
2009	White Hake	1.21	NA	NA	0.06	1.22	-1.16
2010	White Hake	1.33	0.38	0.01	0.45	1.34	-0.89
2011	White Hake	1.28	0.41	0.01	0.49	1.29	-0.80
2012	White Hake	1.75	0.61	0.01	0.69	1.76	-1.07
2013	White Hake	1.76	0.12	0.01	0.19	1.77	-1.58
2014	White Hake	1.98	0.07	0.01	0.14	1.99	-1.85
2015	White Hake	1.93	0.04	0.01	0.12	1.94	-1.83
2016	White Hake	1.93	0.02	0.01	0.10	1.94	-1.83
2017	White Hake	1.36	0.01	0.01	0.10	1.37	-1.27
2007	Witch	2.28	NA	NA	0.06	2.30	-2.24
2008	Witch	2.10	NA	NA	0.06	2.11	-2.05

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Fishing year	stock	Ex-vessel price (\$/lb, pf)	Quota price (\$/lb, pq)	Quota cost of sublegal discards (\$/lb)	Cost of Landing (\$/lb)	Cost of Discarding (\$/lb)	Discard Incentive (\$/lb)
2009	Witch	1.94	NA	NA	0.06	1.96	-1.90
2010	Witch	2.45	1.49	0.01	1.58	2.47	-0.89
2011	Witch	2.00	0.58	0.01	0.67	2.02	-1.35
2012	Witch	2.00	0.49	0.01	0.57	2.02	-1.45
2013	Witch	2.46	0.81	0.01	0.90	2.48	-1.58
2014	Witch	2.69	0.88	0.01	0.96	2.71	-1.74
2015	Witch	2.57	0.86	0.01	0.95	2.58	-1.64
2016	Witch	3.21	1.24	0.01	1.34	3.23	-1.90
2017	Witch	2.23	1.02	0.01	1.11	2.24	-1.13

Unlawful discarding of Regulated Northeast Multispecies

Enforcing unlawful discarding of regulated Northeast multispecies is extremely challenging. Most investigations are reactive in nature, responding to complaints from the fishing industry or the observer program. Proactive enforcement focused on discarding can only be done at sea which adds to the complexity and presents other limitations.

The act of discarding fish can happen relatively quickly. It is easy for violators to actively look for enforcement while discarding fish at sea. NOAA's Office of Law Enforcement (OLE) receives and handles a number of discarding investigations, however, OLE is often unable to conclude investigations due to a lack of evidence. Even in instances where enforcement is on scene to witness a discarding violation, it can still be difficult to make a case. For example, the fish being discarded could be unmarketable or undersized which would otherwise be legal to discard. Enforcement cannot always make this determination on scene as fish are being actively discarded. To support an unlawful discard case, it would almost be necessary to either measure the fish before they are discarded or recover the fish being discarded to determine their size or disposition. Recovering discarded fish at sea would be difficult and could pose safety issues. Consequently, even if an unlawful discarding event is witnessed by enforcement, it can be difficult to make a case for these reasons.

In cases where we have been able to take some investigatory steps, there typically has to be some supporting information, such as information from crew, observer, or member of the industry. It is rare that we can initiate an investigation based on witnessing this behavior, even when conducting a patrol focused on targeting discarding violations. Most discarding incidents reported to OLE are generated from observer referrals. Most of these lack sufficient evidence for many of the reasons listed above and the data collection process utilized by the observer program.

The sector quota and leasing system does not provide enforcement with the ability to track quotas in real time. This limits enforcement's ability to use quotas as a reliable indicator of potential discarding violations. The annual quota calculations used in the sector system enables unscrupulous operators to strategically plan to discard when they believe a low probability of detection exists. This contrasts with other fisheries such as the common pool system where an overage landed on a single trip, cannot be offset by leasing additional quota.

Unlawful Discarding Incident Dispositions (Fishing years 2017 and 2018)

Total incidents –	12
Closed due to lack of evidence –	8
Ongoing investigations –	2
Written warnings –	1
Closed due to lack of resources -	1

Unlawful Discarding Incidents Reporting Source (Fishing years 2017 and 2018)

Observer generated –	8
Industry complaint -	3
Enforcement generated –	1

Unlawful Discarding Violations Penalties

Unlawful discarding investigations that result in enforcement action can be handled with either Compliance Assistance, a Written Warning, or a Notice of Violation and Assessment (NOVA). Summary settlements are another method of addressing a violation, but unlawful discarding is not included in the summary settlement schedule and therefore cannot not be applied for this offense. However, offenses associated with a discarding violations may be included in the summary settlement schedule. For example, a \$500 summary settlement could be issued for a failure to maintain, keep, or submit accurate reports.

A NOVA may be issued for an unlawful discard violation in accordance with General Counsel's Penalty Policy Schedule, which utilizes a complex matrix to determine NOVA penalty amounts. Unlawful discarding is generally considered a Level II offense, with penalties ranging from \$2,000 to \$20,000. Factors considered in assessing a civil penalty may include the nature, circumstances, extent, and gravity of the alleged violation; the respondent's degree of culpability, any history of prior violations, and ability to pay; and such other matters as justice may require.

Evaluating the Observer Effect for the Northeast U.S. Groundfish Fishery #1b (version 2)

Chad Demarest

updated April 18, 2019

****Groundfish Plan Development Team****

– DRAFT –

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Introduction

The commercial component of the Northeast U.S. Multispecies fishery comprises 20 individual fish stocks and 2 management units¹. Of these, commercial fisherman are allocated quota for 15 stocks, leaving 5 for which retention is prohibited. Fishing quota is allocated to approximately 1,000 permits and actively fished by around 200 participating commercial vessels (NEFMC 2017). The majority of the commercial fishery for groundfish (~98% of landings) is managed under the sector system whereby individual vessel owners pool stock-level quota into any one of 21 sectors, each operating as a collective, pooling the quota and allocating it to individual member fisherman. Quota for allocated stocks may be traded between sectors. Trades are remunerated in three ways: single stock trades for a given amount of money (fish-for-cash), pounds of multiple stocks traded for a single value (basket trades), and pounds of quota for one stock traded for pounds of quota of another stock with no money exchanged (swaps). All regulated groundfish species have a prescribed minimum fish size and regulations prohibit retaining fish below that size, and discarding fish above it.

Observers are deployed on participating vessels to estimate discarded catch for each of the 20 fish stocks on each trip. Observer coverage levels vary but in general observers have been onboard trips accounting for between 10-35% of all trips taken in any given fishing year. Discards on observed trips are calculated by dividing the sum of observed stock-level discards on observed tows by the total amount of retained catch on these tows. For trips with no observer coverage, discards are estimated by applying the annualized observed discard rate (stock-level discards divided by the sum of kept catch), stratified by broad stock area, sector and fishing gear. Discards count against a sector's quota after adjusting for gear and stock-based discard mortality rates. Vessels are assessed estimated discards on unobserved trips based on their strata, regardless of whether or not an individual species was reported on that trip. Sectors must have adequate quota reserves for all species in a given stock area prior to any member vessels fishing in that area. Observers have also been the primary source of enforcement for mandatory retention regulations.

As observer coverage only represents a fraction of the total fishing activity in the sector component of the commercial groundfish fishery, obvious questions arise: Does data generated on observed fishing trips reflect the activities of the whole fleet? Are estimates generated from these data unbiased? Bias may be induced by either a deployment effect, where the assignment of observers to vessels is non-random, or an observer effect, where the fishing activities on observed trips vary in detectable ways from those on unobserved trips (Benoit and Allard 2009). These two effects, deployment and observer, may act separately or in combination

¹George's Bank is divided into a "west" component for which haddock and cod stocks are assessed exclusively by NOAA fisheries, and an "east" component for which these stocks together with yellowtail flounder are jointly assessed with the Canadian Department of Fisheries and Oceans under a trans-boundary management agreement.

to render data collected by on board observers biased. This paper focuses specifically on one component of the the latter effect: do individual vessels alter their behavior in response to the presence of an observer?

Fisherman may alter their fishing behavior when carrying an observer for any one of at least five reasons: (1) people may act differently as a response to simply being watched, an established phenomena referred to as the Hawthorne Effect (McCambridge et al. 2018); (2) fisherman may not want to impart their individual discarding preferences on the other members of their sector, an effect driven primarily by within-strata fishing practice heterogeneity; (3) observers incur costs associated with slower fish processing and handling times, carrying extra food, and general inconvenience, all of which may incentivize fisherman to make shorter trips when observers are on board; (4) catch of undersized fish varies across space and fishing in areas and at times where undersized fish are relatively less abundant may minimize discard rates, though at the cost of reduced revenues; and (5) binding quota constraints impart strong economic incentives to discard legal-sized fish when an observer is not on board and to avoid these stocks in the presence of an observer, again presumably at a cost in terms of reduced trip revenues.

Methods

This paper uses an exact matching method to determine if vessel performance along several metrics vary in a detectable way when an observer is on board, and when one is not. Following a procedure laid out by Benoit and Allard (2009), same-vessel trip sequences are analyzed to test for differences among various metrics. These trip sequences take the form of either: (1) three unobserved trips in a row (UUU), or (2) one observed trip between unobserved trips (UOU). To attenuate the possibility of interpreting seasonal effects as behavioral effects, only trips occurring within 45 days of each other are included. Trips are not repeated in multiple sequences. Vessels with less than two sequences are excluded from the analysis.

Triplet sequences are winnowed to pairs by taking the difference of either the leading or lagging trip with respect to the middle trip. The variable U in equation (1) and U^1 in equation (2), below, are selected randomly as either the leading or trailing trip in the triplet sequence, while the middle trip in the sequence is always the reference trip (O or U^1 , below). To mitigate against regulatory changes affecting fishing behavior within sequences while maximizing the number of OU pairs, sequences overlapping the start of a new fishing year (May 1 of each year) select only the lead or lag pair that occurs in the same FY as the reference trip.

Differences are calculated as

$$\Delta O_{yfv} = (O - U/U)_{yfv} * 100$$

(Equation 1)

$$\Delta U_{yfv} = (U^1 - U^2/U)_{yfv} * 100$$

(Equation 2)

where y is a fishing year, f is fishing vessel and v is any one of the metrics evaluated. U is the mean unobserved value for each year, vessel and metric combination.

Metrics evaluated, v , are:

1. Trip duration
2. Kept catch
3. Total revenue
4. Kept groundfish
5. Kept non-groundfish
6. Groundfish average price
7. Opportunity cost of quota

8. Number of groundfish market categories included in kept catch

The difference between the median values for ΔU 's and O 's is calculated as

$$(M_{\Delta U - \Delta O})_{yfv} = \text{median}(\Delta U)_{yfv} - \text{median}(\Delta O)_{yfv}$$

(Equation 3)

Differences between observed and unobserved trips are tested in three ways: (1) location differences are observed in $M_{\Delta U - \Delta O}$, with 95% confidence intervals estimated using bootstrap sampling (1,000 replicates) from the U_{yfv} and O_{yfv} values, where a lack of overlap with zero implies a 95% probability that the true median values for each population are significantly different²; (2) the Kolmogorov-Smirnov statistic is used to test for general differences in shape of the U_{yfv} and O_{yfv} distributions; and (3) the Kuiper statistic is used to test for differences in the extremities of the distributions (Conover 1980).

Multiple hypothesis tests are performed with the Kolmogorov-Smirnov (KSA) and Kuiper (KA) statistics. For these, a p-value of 0.005 is considered to be significant. As always, statistical significance should be considered in light of the data and research question. All p-values are reported.

Data

Vessel Trip Report (VTR) and Commercial Fishery Dealer (CFDBS) data are combined to construct trip-level data using the Data Matching and Imputation System (DMIS) database [cite needed]. Trips with an Allocation Management System (AMS) declaration code of "NMS" are included in the initial dataset³. Only vessels fishing with trawl or gillnet gears are retained. Observer trips are matched by a step-wise algorithm, focusing on permit number, VTR serial number, days-at-sea (DAS) identification number, date and time sailed. For the sector years, both Northeast Fishery Observer Program (NEFOP) and at-sea monitoring (ASM) data are matched.

U and O values are extracted from these data, and annual fishing year (May 1 – April 30) data sets are built with same-vessel two-trip sequences.

Trips in the United States-Canada Resource Sharing Agreement Area (USCA area) are removed from the pre-sector (FY 2007-2009) dataset, as these trips were subject to observer coverage at higher rates than trips outside the area. All trips fishing with extra large mesh (ELM) and targeting non-groundfish are excluded for all years, as are all trips by vessels enrolled in the Common Pool from 2010-2017⁴. All excluded trips and their corresponding triplets are retained and, to better understand the potential drivers of observer effects, are analyzed separately in the future.

Results

Results are reported at two levels of aggregation:

- regulatory regime, as
 - pre-sector years (FY's 2007-2009),

²"Location" refers to the central tendency of the data, in this case the median values, and has no geographic connotation here.

³"NMS" is the code denoting trips made under the Northeast Multispecies Fishery Management Plan.

⁴In 2015 the New England Fishery Management Council exempt gillnet vessels fishing with mesh larger than 10 inches in certain areas near the coast from ASM coverage, as these trips had a documented history of catch very little groundfish. These trips are subject to NEFOP coverage, however.

- initial sector years (FY’s 2010-2012),
- intermediate sector years (FY’s 2013-2015),
- contemporary sector years (FY’s 2016-2018)⁵; and
- gear type, distinguishing between trawl and gillnet gears⁶.

Results at the fishing year (FY) level, further disaggregated by gillnet and trawl, are estimated for context. Separate analyses have also been completed for single-day and multi-day trips, as well as a stock-level analysis of kept catch for 15 individual groundfish stocks.

Tests for differences in central tendency

Equations (1) and (2) are scaled by each vessel’s mean annual values and median value differences are represented as percentages. For example, a median value of -0.04 for the kept catch variable implies that vessels catch roughly 4% less fish on an observed trip, relative to a neighboring unobserved trip by that same vessel, as measured across all vessels in the dataset. If the bootstrapped 95% confidence intervals fail to overlap with zero, the value is interpreted as significant using the confidence interval test. With eight metrics evaluated over four time stanzas, there are 32 units evaluated for observer effects. However, in the first stanza, before the sector system, there were no tradeable quota allocations.

Trawl vessels

For trawl vessels, 18 bootstrapped 95% confidence intervals failed to overlap zero. In the pre-sector years, three of seven metrics are significant under this test. In the three sector stanzas, 15 metrics are significant and nine are not.

Trawl vessels catch less fish when an observer is onboard. In the stanzas after 2009, they fish for less time and land less groundfish. Statistical significance is obtained for kept catch in all four stanzas, and for trip duration, groundfish kept catch and total revenues in the three post-2009 stanzas. Groundfish average prices are statically higher for three of the four stanzas, the exception being the period from 2010-2012. Composition of groundfish catch on observed and unobserved trips appears to be different. In the second and third time stanzas, groundfish vessels landed less high quota value stocks on observed trips, while in the final stanza the median differential is zero. Based on the reductions in catch and fishing time on observed trips after 2009, the changes in response to observer presense appear to be related to incentives embedded in catch accountability and quota constraints.

⁵FY 2018 data are complete through February 28 and inclusive of the first 10 full months of the fishing year.

⁶Trawl gears include the Vessel Trip Report (VTR) codes ‘OHS’, ‘OTB’, ‘OTC’, ‘OTF’, ‘OTM’, ‘OTO’, ‘OTR’, ‘OTS’, and ‘OTT’. Gillnet gears include the codes ‘GNR’, ‘GNS’, and ‘GNT’.

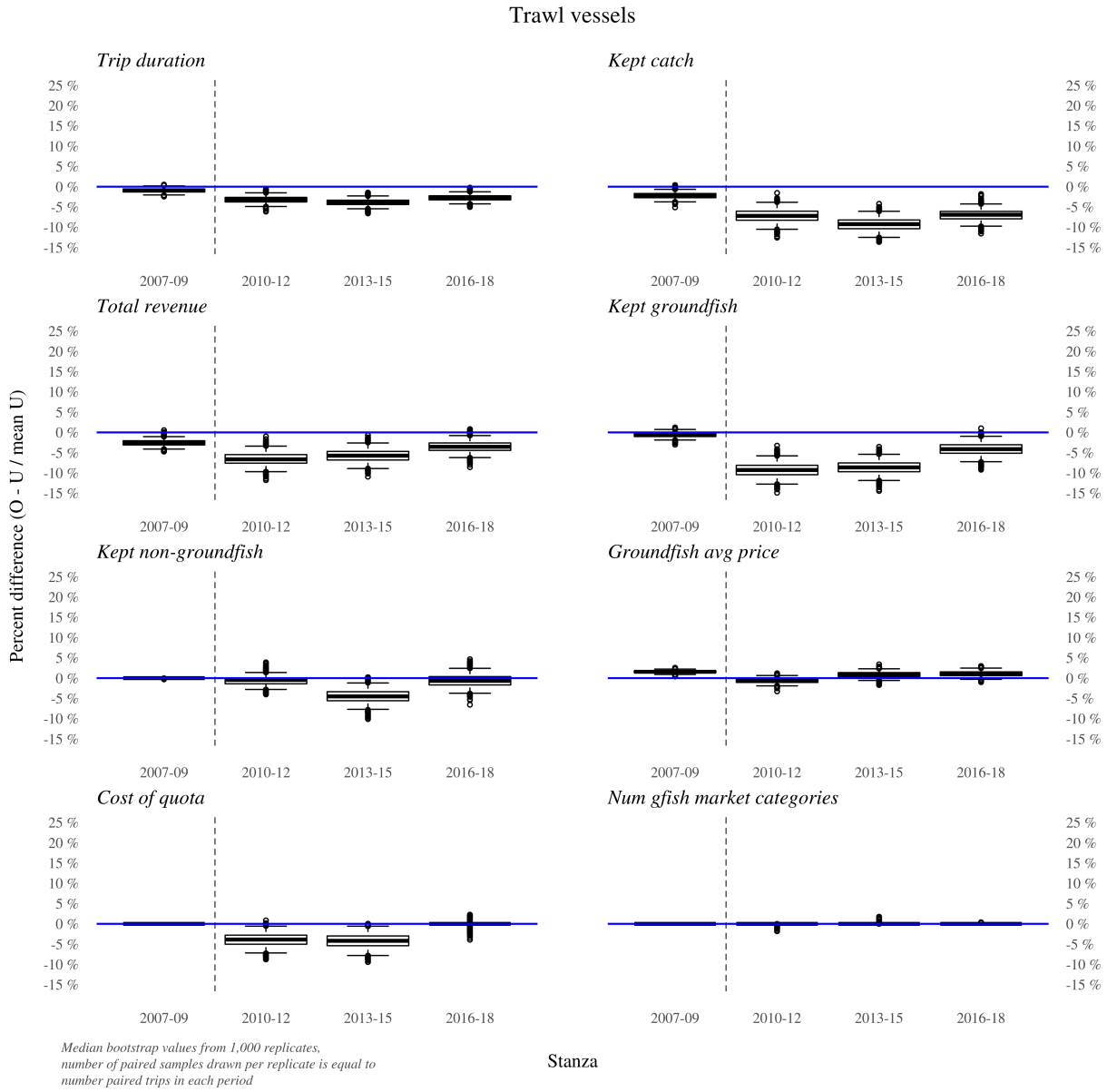


Figure 1: Results of bootstrap analysis, observed and unobserved same-vessel paired trips by stanza

Table 1: Stanza 1, 2007-2009

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish		-1.9 %	-0.6 %	0.5 %	10,844	726
Trawl	Number groundfish market categories		0 %	0 %	0 %	10,844	726
Trawl	Groundfish avg price	*	0.9 %	1.6 %	2.3 %	10,845	726
Trawl	Kept catch	*	-3.7 %	-2.2 %	-0.7 %	10,845	726
Trawl	Kept non-groundfish		0 %	0 %	0 %	10,845	726
Trawl	Opportunity cost of quota		0 %	0 %	0 %	10,845	726
Trawl	Total revenue	*	-4.1 %	-2.6 %	-1.1 %	10,845	726
Trawl	Trip duration		-2 %	-0.9 %	0 %	10,845	726

Table 2: Stanza 2, 2010-2012

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-12.6 %	-9.3 %	-5.9 %	2,787	1,413
Trawl	Number groundfish market categories		-0.4 %	0 %	0 %	2,787	1,413
Trawl	Groundfish avg price		-1.9 %	-0.6 %	0.6 %	2,787	1,413
Trawl	Kept catch	*	-10.2 %	-7.2 %	-4.1 %	2,787	1,413
Trawl	Kept non-groundfish		-3.3 %	-0.4 %	1.7 %	2,787	1,413
Trawl	Opportunity cost of quota	*	-7.3 %	-3.9 %	-0.8 %	2,787	1,411
Trawl	Total revenue	*	-9.4 %	-6.6 %	-3.4 %	2,787	1,413
Trawl	Trip duration	*	-4.9 %	-3.2 %	-1.6 %	2,787	1,413

Table 3: Stanza 3, 2013-2015

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-12 %	-8.6 %	-5.4 %	2,920	954
Trawl	Number groundfish market categories		0 %	0 %	0.1 %	2,920	954
Trawl	Groundfish avg price		-0.5 %	0.8 %	2.3 %	2,920	954
Trawl	Kept catch	*	-12.3 %	-9.2 %	-6.1 %	2,920	954
Trawl	Kept non-groundfish	*	-7.9 %	-4.5 %	-1.4 %	2,920	954
Trawl	Opportunity cost of quota	*	-8 %	-4.2 %	-0.6 %	2,920	954
Trawl	Total revenue	*	-8.8 %	-5.7 %	-2.8 %	2,920	954
Trawl	Trip duration	*	-5.5 %	-3.8 %	-2.3 %	2,920	954

Table 4: Stanza 4, 2016-2018

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-7 %	-4.1 %	-1.2 %	2,805	799
Trawl	Number groundfish market categories		0 %	0 %	0 %	2,805	799
Trawl	Groundfish avg price		-0.2 %	1.1 %	2.4 %	2,805	799
Trawl	Kept catch	*	-9.9 %	-6.9 %	-4.3 %	2,805	799
Trawl	Kept non-groundfish		-3.5 %	-0.7 %	2.5 %	2,805	799
Trawl	Opportunity cost of quota		-1.7 %	0 %	1 %	2,805	799
Trawl	Total revenue	*	-6.3 %	-3.5 %	-0.7 %	2,805	799
Trawl	Trip duration	*	-4.2 %	-2.7 %	-1.3 %	2,805	799

Gillnet vessels

For gillnet vessels the picture is less clear-cut. 13 units in total have 95% confidence intervals that fail to overlap with zero. Pre-sector, from 2007-2009, four metrics were significant and three were not. Under sector management, the three stanzas from 2010-2018, nine are significant and thirteen are not. However, in the most recent stanza (FY 2016-2018), six of the eight metrics yield significant differences in bootstrapped confidence intervals, and a seventh (number of groundfish market categories), while statistically insignificant, shows a trend toward more market categories landed on observed trips.

Gillnet vessels consistently make shorter trips, generate less revenue and appear to retain slightly less catch overall in the presence of an observer. There is a trend in later stanzas toward more groundfish and less non-groundfish on observed trips for these vessels, indicating that observers affect the mix of species landed. More groundfish market categories in the last stanza may indicate differential groundfish targeting, or perhaps high-grading of specific species. The most striking result is that, in the last stanza, with an observer on board the same gillnet vessels have a 17% higher opportunity cost of quota than when they do not. Statistically different behavior in response to an observer is nearly equally prevalent for gillnet and trawl vessels, though the nature of the response does differ between the two. This may be an artifact of smaller sample sizes (fewer number of paired trips, particularly in the later stanzas) which attenuate the model's power to discern effects. The distinction in response before and after the implementation of sectors is less clear cut for gillnetters than for trawlers, noting that gillnet vessels demonstrated a stronger behavioral response than trawlers before sectors. Finally, during the contemporary sector years (fourth stanza) a trend of less non-groundfish landed, more groundfish and, in particular, more high quota value species landed is noteworthy.

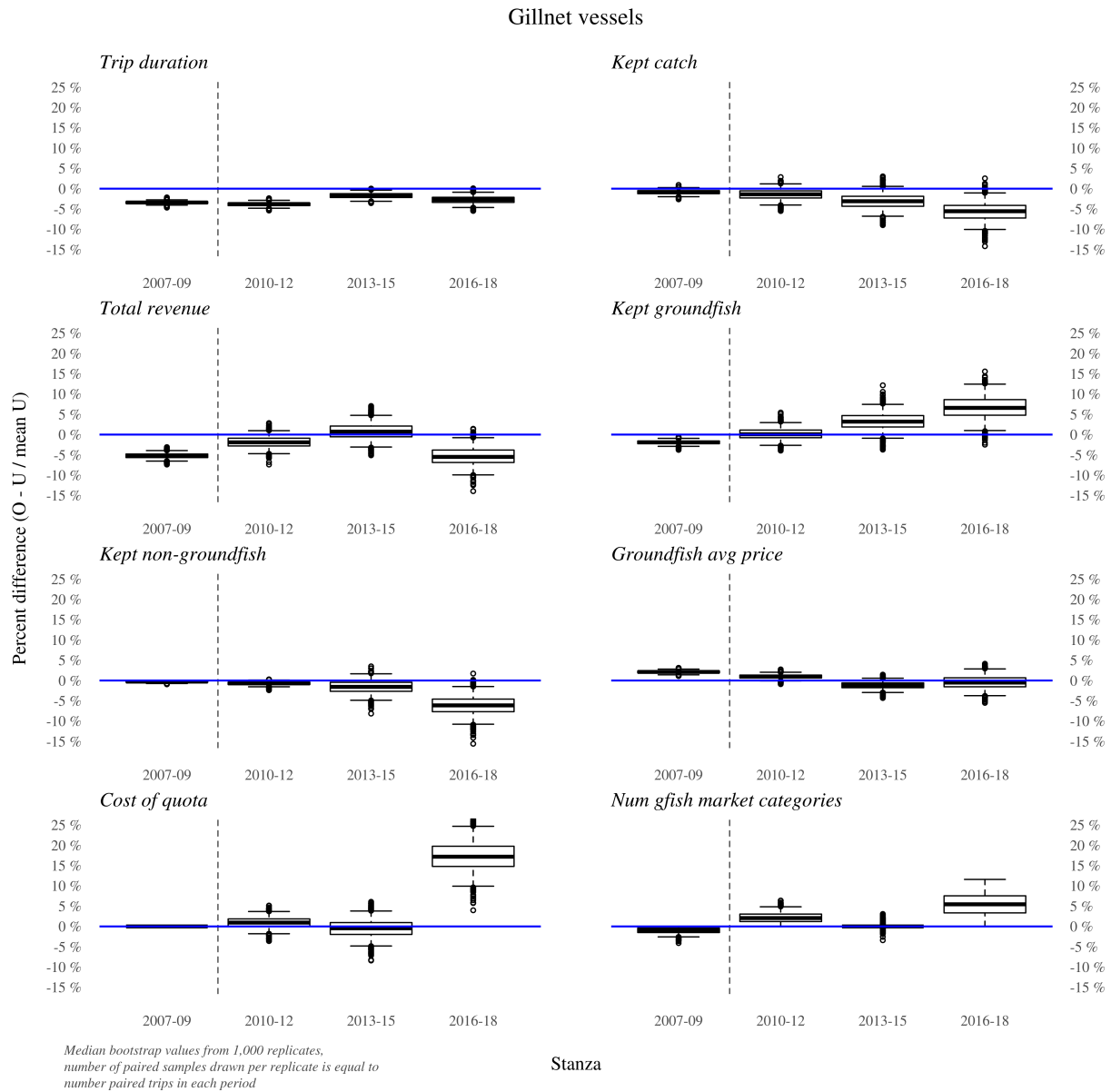


Figure 2: Results of bootstrap analysis, observed and unobserved same-vessel paired trips by stanza

Table 5: Stanza 1, 2007-2009

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish	*	-2.9 %	-1.9 %	-1 %	10,782	531
Gillnet	Number groundfish market categories		-2.8 %	-1 %	0 %	10,782	531
Gillnet	Groundfish avg price	*	1.5 %	2.1 %	2.8 %	10,782	531
Gillnet	Kept catch		-1.9 %	-0.8 %	0.1 %	10,782	531
Gillnet	Kept non-groundfish		-0.6 %	-0.3 %	0 %	10,782	531
Gillnet	Opportunity cost of quota		0 %	0 %	0 %	10,782	531
Gillnet	Total revenue	*	-6.5 %	-5.2 %	-4 %	10,782	531
Gillnet	Trip duration	*	-4.2 %	-3.4 %	-2.7 %	10,782	531

Table 6: Stanza 2, 2010-2012

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish		-2.4 %	0.1 %	3.2 %	2,609	1,330
Gillnet	Number groundfish market categories		0 %	2.1 %	4.9 %	2,609	1,330
Gillnet	Groundfish avg price		-0.2 %	1 %	2 %	2,609	1,330
Gillnet	Kept catch		-4.1 %	-1.4 %	1 %	2,609	1,330
Gillnet	Kept non-groundfish		-1.6 %	-0.7 %	0 %	2,609	1,330
Gillnet	Opportunity cost of quota		-1.8 %	0.9 %	3.8 %	2,609	1,330
Gillnet	Total revenue		-4.7 %	-1.9 %	1.1 %	2,609	1,330
Gillnet	Trip duration	*	-4.8 %	-3.8 %	-2.8 %	2,609	1,330

Table 7: Stanza 3, 2013-2015

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish		-0.9 %	3.2 %	7.6 %	1,622	434
Gillnet	Number groundfish market categories		-0.9 %	0 %	1.4 %	1,622	434
Gillnet	Groundfish avg price		-2.9 %	-1.2 %	0.4 %	1,622	434
Gillnet	Kept catch		-6.5 %	-3.1 %	0.4 %	1,622	434
Gillnet	Kept non-groundfish		-5.1 %	-1.6 %	1.2 %	1,622	434
Gillnet	Opportunity cost of quota		-5 %	-0.5 %	4.2 %	1,622	434
Gillnet	Total revenue		-3 %	0.7 %	4.9 %	1,622	434
Gillnet	Trip duration	*	-3 %	-1.7 %	-0.4 %	1,622	434

Table 8: Stanza 4, 2016-2018

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish	*	1.1 %	6.6 %	12.2 %	833	277
Gillnet	Number groundfish market categories		0 %	5.5 %	10.3 %	833	277
Gillnet	Groundfish avg price		-3.4 %	-0.5 %	2.7 %	833	277
Gillnet	Kept catch	*	-10.6 %	-5.6 %	-1 %	833	277
Gillnet	Kept non-groundfish	*	-10.8 %	-6.1 %	-1.5 %	833	277
Gillnet	Opportunity cost of quota	*	10.2 %	17.2 %	24.7 %	833	277
Gillnet	Total revenue	*	-9.6 %	-5.5 %	-1.1 %	833	277
Gillnet	Trip duration	*	-4.5 %	-2.7 %	-1 %	833	277

Tests for differences in distribution shape

The Kolmogorov-Smirnov (K-S) test, a nonparametric test evaluating the difference between cumulative distribution functions of two independent samples, U and O , is sensitive to differences in location and shape. Generally, at a 0.005 significance level this test finds fewer significant differences in distribution shapes than the bootstrap confidence interval method for changes in location.

The Kuiper (K) test, another nonparametric test, is similar to the K-S but evaluates in an additive way both positive and negative differences in the cumulative distribution functions of the U and O values. It is more sensitive, therefore, to changes in the tails of the distributions in question.

Trawl vessels

Of the 31 evaluated units, 12 are significant under the Kolmogorov-Smirnov test and 22 under the Kuiper test. In the pre-sector stanza, three of seven units have statistically significant differences in distribution shape (K-S) and, for all seven units, the tails of the U and O distributions are significantly different under the Kuiper test. In the three sector stanzas, nine units exhibit significantly different distributions under the K-S test, with 16 significantly different distributions under the Kuiper test.

The K-S test highlights similar units to the bootstrapped confidence intervals, namely kept catch, trip duration and kept groundfish. The Kuiper test, however, reveals differences in U and O distribution shapes for opportunity cost of quota (three sector stanzas) and number of groundfish market categories (all four stanzas).

Table 9: Stanza 1, 2007-2009

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Trawl	Kept groundfish		0.179	*	0.002	10,844	726
Trawl	Number groundfish market categories	*	0.001	*	0.000	10,844	726
Trawl	Groundfish avg price	*	0.002	*	0.000	10,845	726
Trawl	Kept catch	*	0.002	*	0.000	10,845	726
Trawl	Kept non-groundfish		0.102	*	0.000	10,845	726
Trawl	Total revenue		0.169		0.031	10,845	726
Trawl	Trip duration		0.066	*	0.005	10,845	726

Table 10: Stanza 2, 2010-2012

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Trawl	Kept groundfish	*	0.000	*	0.000	2,787	1,413
Trawl	Number groundfish market categories		0.149	*	0.000	2,787	1,413
Trawl	Groundfish avg price		0.272		0.029	2,787	1,413
Trawl	Kept catch	*	0.000	*	0.004	2,787	1,413
Trawl	Kept non-groundfish		0.625	*	0.002	2,787	1,413
Trawl	Opportunity cost of quota		0.101	*	0.000	2,787	1,411
Trawl	Total revenue	*	0.003		0.021	2,787	1,413
Trawl	Trip duration		0.007	*	0.001	2,787	1,413

Table 11: Stanza 3, 2013-2015

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Trawl	Kept groundfish	*	0.000	*	0.002	2,920	954
Trawl	Number groundfish market categories		0.426	*	0.000	2,920	954
Trawl	Groundfish avg price		0.251		0.059	2,920	954
Trawl	Kept catch	*	0.001	*	0.004	2,920	954
Trawl	Kept non-groundfish		0.128		0.448	2,920	954
Trawl	Opportunity cost of quota		0.013	*	0.000	2,920	954
Trawl	Total revenue		0.016		0.077	2,920	954
Trawl	Trip duration	*	0.000	*	0.000	2,920	954

Table 12: Stanza 4, 2016-2018

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Trawl	Kept groundfish	*	0.002	*	0.002	2,805	799
Trawl	Number groundfish market categories		0.127	*	0.000	2,805	799
Trawl	Groundfish avg price		0.180		0.346	2,805	799
Trawl	Kept catch	*	0.000	*	0.001	2,805	799
Trawl	Kept non-groundfish		0.649		0.443	2,805	799
Trawl	Opportunity cost of quota		0.178	*	0.000	2,805	799
Trawl	Total revenue		0.032		0.073	2,805	799
Trawl	Trip duration	*	0.000	*	0.000	2,805	799

Gillnet vessels

Only six of 31 units are significant under the Kolmogorov-Smirnov test and 9 under the Kuiper test for gillnet vessels. In the pre-sector stanza, three of seven units have statistically significant differences in distribution shape for both the K-S and Kuiper tests. In the three sector stanzas, three of 24 possible units exhibit significantly different U and O distributions under the K-S test, and 6 under the Kuiper test.

As with trawl vessels, the K-S test here highlights, when significant, difference similar to the bootstrapped confidence intervals. And also like with trawl vessels, the Kuiper test reveals differences in U and O distribution shapes for the number of groundfish market categories in all four stanzas.

Table 13: Stanza 1, 2007-2009

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Gillnet	Kept groundfish		0.104		0.179	10,782	531
Gillnet	Number groundfish market categories		0.111	*	0.000	10,782	531
Gillnet	Groundfish avg price		0.012		0.027	10,782	531
Gillnet	Kept catch		0.722		0.456	10,782	531
Gillnet	Kept non-groundfish	*	0.001	*	0.000	10,782	531
Gillnet	Total revenue	*	0.002		0.007	10,782	531
Gillnet	Trip duration	*	0.002	*	0.001	10,782	531

Table 14: Stanza 2, 2010-2012

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Gillnet	Kept groundfish		0.594		0.070	2,609	1,330
Gillnet	Number groundfish market categories	*	0.001	*	0.000	2,609	1,330
Gillnet	Groundfish avg price		0.161		0.645	2,609	1,330
Gillnet	Kept catch		0.182		0.108	2,609	1,330
Gillnet	Kept non-groundfish		0.006	*	0.000	2,609	1,330
Gillnet	Opportunity cost of quota		0.239		0.025	2,609	1,330
Gillnet	Total revenue		0.612		0.917	2,609	1,330
Gillnet	Trip duration	*	0.000	*	0.000	2,609	1,330

Table 15: Stanza 3, 2013-2015

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Gillnet	Kept groundfish		0.137		0.018	1,622	434
Gillnet	Number groundfish market categories		0.942	*	0.000	1,622	434
Gillnet	Groundfish avg price		0.314		0.210	1,622	434
Gillnet	Kept catch		0.228		0.222	1,622	434
Gillnet	Kept non-groundfish		0.223		0.043	1,622	434
Gillnet	Opportunity cost of quota		0.167		0.028	1,622	434
Gillnet	Total revenue		0.110		0.010	1,622	434
Gillnet	Trip duration		0.034	*	0.004	1,622	434

Table 16: Stanza 4, 2016-2018

Gear	Variable	KS \leq 0.005	p(KS)	K \leq 0.005	p(K)	n Unobserved	n Observed
Gillnet	Kept groundfish		0.144		0.101	833	277
Gillnet	Number groundfish market categories		0.077	*	0.000	833	277
Gillnet	Groundfish avg price		0.702		0.486	833	277
Gillnet	Kept catch		0.040		0.033	833	277
Gillnet	Kept non-groundfish		0.041		0.100	833	277
Gillnet	Opportunity cost of quota	*	0.004		0.013	833	277
Gillnet	Total revenue		0.032		0.053	833	277
Gillnet	Trip duration		0.092		0.019	833	277

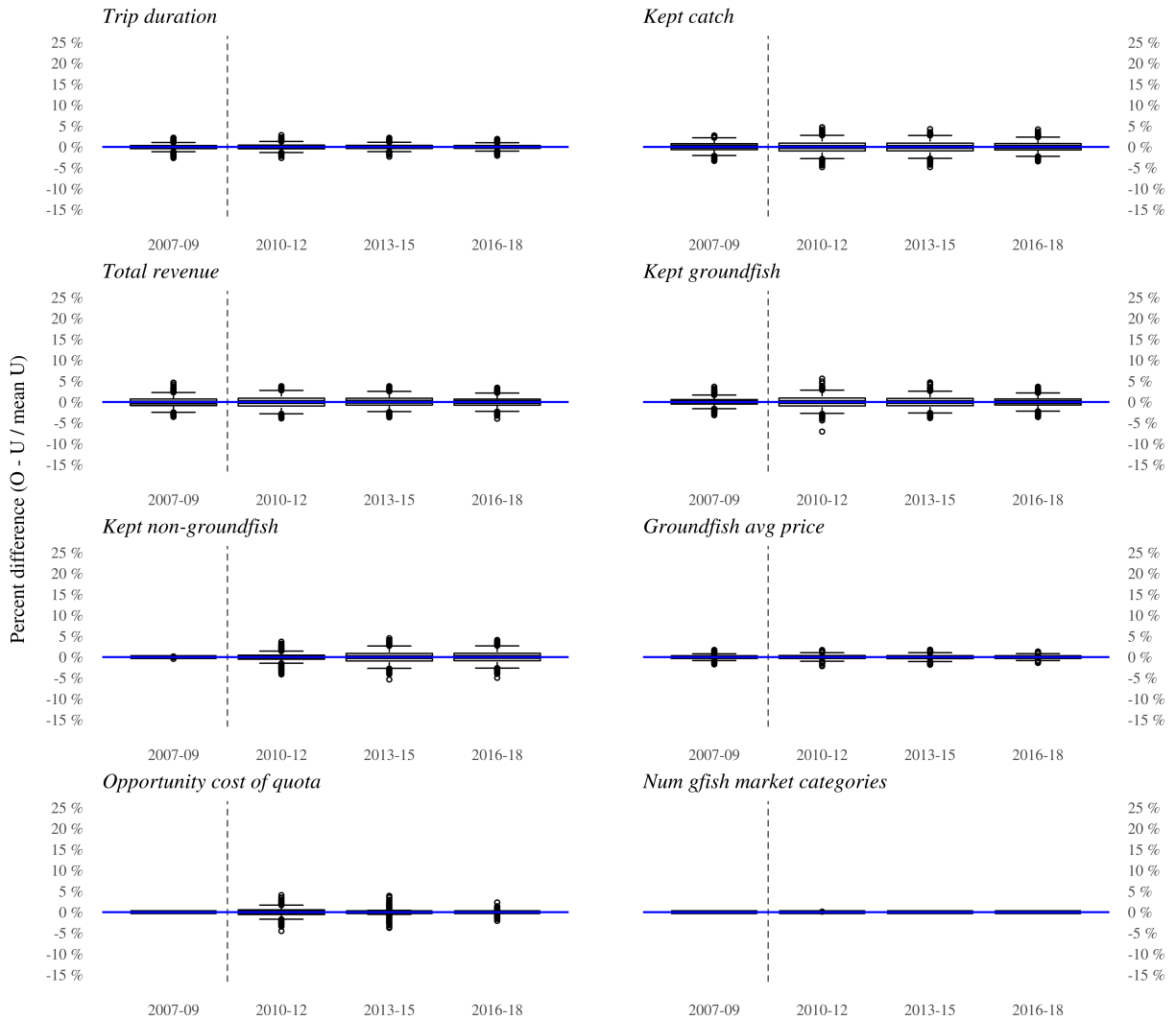
Discussion

It is clear that fishing vessels engaged in the groundfish fishery alter their behavior in response to observers. Estimated confidence intervals for U and O values overlap with zero for only a handful of the metrics evaluated across stanzas or fishing years. Generally, the most pronounced effects are seen across trip duration, kept catch, kept groundfish, trip revenue and opportunity cost of quota. Observer presence has the smallest affect on the number of groundfish market categories and non-groundfish average prices, but, particularly in the former, even here we see differences in the tails of the distributions.

No treatment model

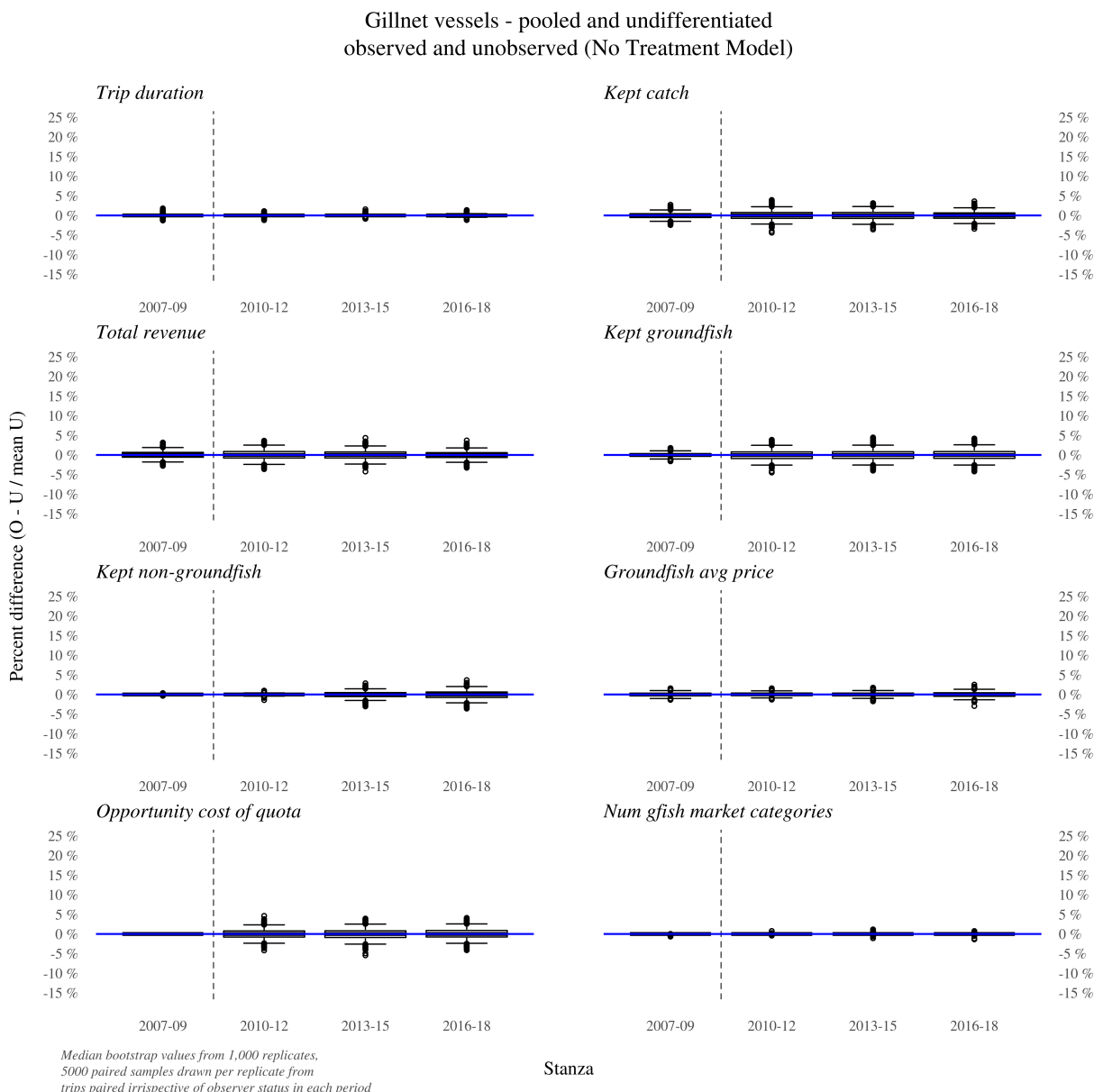
In an effort to demonstrate that the effects estimated here are, in fact, the result of observer presence and not driven by underlying variability in trip-level data driven by unobserved factors, the model was run as previously described, but with assignment to triplets (U and O) made irrespective of actual observer status. As one would expect, the No Treatment estimates across all metrics and stanzas are median-centered on zero with little variance in the two distributions. This demonstrates that the observed variation between U and O triplets in the primary (treatment) model is almost certainly a function of observer presence. See Appendix (forthcoming) for details.

Trawl vessels - pooled and undifferentiated
observed and unobserved (No Treatment Model)



Median bootstrap values from 1,000 replicates,
5000 paired samples drawn per replicate from
trips paired irrespective of observer status in each period

Stanza



Differences across time

Incentives to alter fishing behavior have varied across time. Prior to sector implementation discards had no direct cost to fisherman and trip limits required discarding certain species. These factors may have reduced the incentive to alter fishing practices in response to an observer, noting that gillnet vessels did demonstrate a significant behavioral response prior to sectors. Gillnet vessels, however, are also more likely to have encounters with marine mammals and have other gear-specific requirements (i.e. pingers) that may further affect responses to observers independent of quota-based management and associated regulations.

After full sector implementation, the accountability of discards and the application of sector/gear specific discard rates to unobserved trips, together with the potential catch of constraining stocks and the high opportunity cost of quota associated with landing such stocks, increased the incentive to change behavior. We see this most dramatically in the contemporary sector stanza for gillnet vessels, but the trend from lower quota costs on observed trip toward zero difference on trawl vessels may reflect a similar response.

The two-sided problem

Incentives to alter behavior in response to an observer may induce less effort, catch, etc...or more, as some vessels fish longer (or shorter) trips or otherwise alter their fishing practices due to quota allocations, fishing preferences, or other factors. One vessel may attempt to minimize observed discarding of flatfish at the expense of cod, while another vessel may take the exact opposite approach. Such offsetting behavior could change the central tendency of the $M_{\Delta U - \Delta O}$ distribution very little, but affect its shape, particularly at the tails. Number of market categories for groundfish and opportunity cost of quota differ at the tails for both gillnet and trawl vessels. These distribution differences may point toward highgrading and/or circumventing mandatory fish retention regulations.

More broadly, the two-sided nature of the problem is important to understand because directionally opposite responses to observer presence attenuates the central tendency test and some may view location differences on the order of 5-10% as trivial when, taken in context, they represent large and statistically significant differences between observed and unobserved populations.

To better understand the influence of positive and negative observer responses, we estimated median annual (FY) values across each of the eight metrics for all vessels represented in the matched pair data, subtracting each vessel's annual median U value from its median O to get a median difference in observed behavior. An example of the distribution of vessel-level observer effects by FY, in this case for opportunity cost of quota, can be seen below.

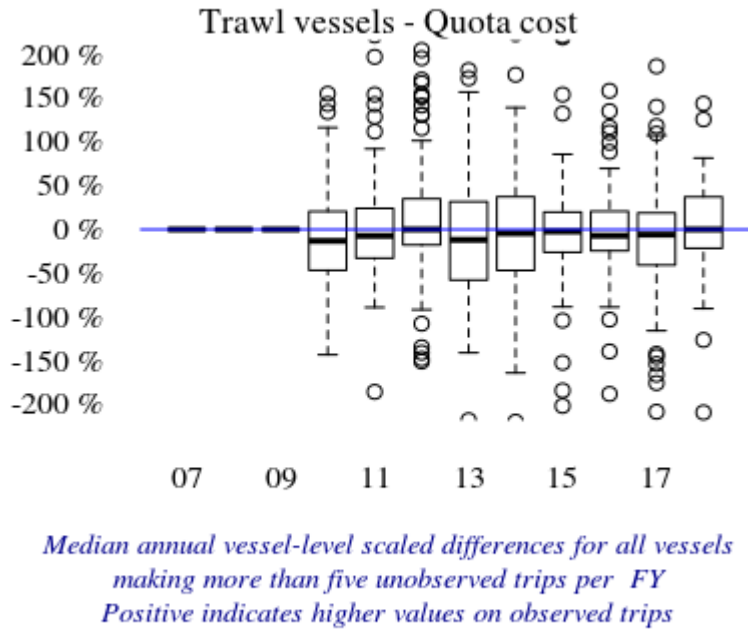


Figure 3: Distribution of vessel-level median annual observer effects, trawl)

These plots make clear the point that over the course of a year, some vessels persistently shift their behavior in response to observer in a positive direction, others the opposite.

The effect of these off-setting behaviors may be that a large amount of catch can be taken by vessels that persistently alter behavior in one direction or the other. To test this, and to better understand how much fishing activity may be affected, we take two sub-sets of vessels—those that exhibit a $\pm 15\%$ median annual

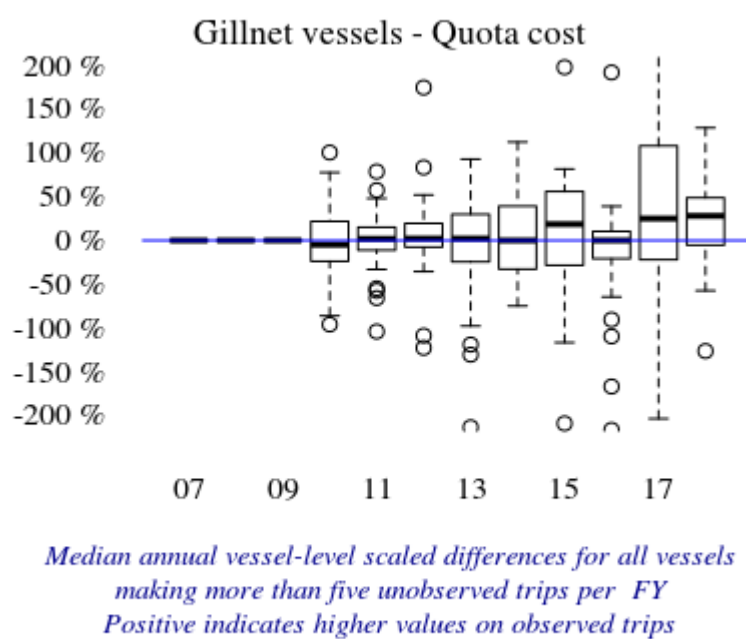


Figure 4: Distribution of vessel-level median annual observer effects, gillnet)

difference in behavior (observer effect) for each metric, and those with a $\pm 30\%$ difference—and estimate the proportion of vessels and groundfish catch accounted for annually by these sets. We find that across a range of metrics, vessels with an annual observer effect response of $\pm 15\%$ or more account for roughly 20-30% of the groundfish vessels, and roughly 50-60% of the groundfish catch. Vessels with a $\pm 30\%$ response account for 10-20% of the vessels and 30-40% of the catch. Vessels exhibiting these levels of observer effect for the opportunity cost of quota metric, in particular, represent the largest share of groundfish catch, from 40-80% depending on threshold and year. It is important to note that, even in the case of no observer effect, the nature of fishing and its underlying variability would likely result in some vessels fitting into one or both of these threshold categories. Further analysis of, for example, the extra-large mesh fishery, which has no quota-based incentives that may benefit from observer effects, may shed more light on the question of underlying variability versus strategic behavioral responses.

Last word

These analyses point toward a consistent pattern of different fishing behaviors when an observer is on board. The Benoit and Allard method isolates vessel effects by focusing on the differences in behavior in response to an observer *for the same vessel*. The data show a clear trend for three key metrics—in almost all circumstances vessels appear to retain less fish, fish for less time and obtain lower revenues when an observer is on board. Gillnet vessels retain substantially more groundfish, at a higher opportunity cost of quota, in the most recent time stanza. The distributions of U and O pairs is substantially different at the tails for the number of groundfish market categories landed, pointing toward highgrading by a subset of the fleet. Persistent differences such as higher average groundfish prices with an observer on board (trawl vessels) and emerging differences like a greater number of market categories retained with an observer (gillnet vessels) indicate that the composition of catch on observed trips is different. This suggests that data collected by observers are not merely a compressed representation of unobserved fishing practices but, rather, they are non-representative along critical dimensions such as proportions and quantities of discarded fish, legally and perhaps illegally, and fish retained.

\begin{table}[t]

\caption{Vessel median observer effects $> \pm 15\%$ and 30% , proportion of total and proportion of groundfish landed}

FY	Variable	N vsls	Vsls, $> \pm 15\%$	% gfish caught ± 15	Vsls, $> \pm 30\%$	% gfish caught ± 30
2007	gfish_lbs	564	125	0.35	90	0.27
2007	gfish_mcat	564	91	0.22	53	0.11
2007	gfish_price	564	77	0.29	32	0.13
2007	k_all	564	114	0.38	86	0.28
2007	non_gfish_lbs	564	92	0.26	75	0.23
2007	total_value	564	124	0.39	91	0.28
2007	trip_dur	564	89	0.30	57	0.17
2008	gfish_lbs	527	129	0.31	91	0.23
2008	gfish_mcat	527	117	0.27	61	0.12
2008	gfish_price	527	81	0.25	54	0.17
2008	k_all	527	137	0.35	95	0.26
2008	non_gfish_lbs	527	113	0.38	80	0.28
2008	total_value	527	134	0.38	90	0.25
2008	trip_dur	527	101	0.30	59	0.15
2009	gfish_lbs	476	114	0.51	79	0.35
2009	gfish_mcat	476	107	0.33	60	0.18
2009	gfish_price	476	88	0.36	48	0.24
2009	k_all	476	120	0.51	86	0.33
2009	non_gfish_lbs	476	118	0.48	93	0.33
2009	total_value	476	124	0.46	86	0.30
2009	trip_dur	476	102	0.40	63	0.25
2010	gfish_lbs	377	96	0.55	56	0.26
2010	gfish_mcat	377	72	0.27	33	0.14
2010	gfish_price	377	56	0.36	22	0.18
2010	k_all	377	95	0.48	66	0.33
2010	non_gfish_lbs	377	82	0.49	64	0.37
2010	quota_cost	377	103	0.53	76	0.43
2010	total_value	377	99	0.49	63	0.32
2010	trip_dur	377	64	0.43	31	0.22
2011	gfish_lbs	362	113	0.54	80	0.43
2011	gfish_mcat	362	61	0.23	22	0.09
2011	gfish_price	362	49	0.29	18	0.08
2011	k_all	362	98	0.41	58	0.30
2011	non_gfish_lbs	362	79	0.41	55	0.29
2011	quota_cost	362	99	0.45	61	0.30
2011	total_value	362	108	0.48	68	0.28
2011	trip_dur	362	64	0.35	32	0.22

\end{table}

\begin{table}[t]
\caption{Vessel median observer effects > +/- 15% and 30%, proportion of total and proportion of
groundfish landed}

FY	Variable	N vsls	Vsls, > +/-15%	% gfish caught +/-15	Vsls, > +/-30%	% gfish caught +/-30
2012	gfish_lbs	352	131	0.67	87	0.44
2012	gfish_mcat	352	75	0.27	29	0.09
2012	gfish_price	352	77	0.44	41	0.20
2012	k_all	352	122	0.62	75	0.45
2012	non_gfish_lbs	352	115	0.59	91	0.48
2012	quota_cost	352	113	0.61	79	0.43
2012	total_value	352	125	0.65	72	0.37
2012	trip_dur	352	90	0.53	52	0.34
2013	gfish_lbs	305	102	0.62	67	0.43
2013	gfish_mcat	305	62	0.26	31	0.10
2013	gfish_price	305	65	0.49	27	0.25
2013	k_all	305	100	0.63	72	0.49
2013	non_gfish_lbs	305	95	0.66	62	0.36
2013	quota_cost	305	105	0.73	84	0.60
2013	total_value	305	92	0.61	52	0.35
2013	trip_dur	305	64	0.55	36	0.31
2014	gfish_lbs	280	85	0.70	60	0.45
2014	gfish_mcat	280	52	0.32	26	0.14
2014	gfish_price	280	57	0.51	32	0.24
2014	k_all	280	80	0.64	48	0.39
2014	non_gfish_lbs	280	71	0.53	55	0.41
2014	quota_cost	280	95	0.71	72	0.49
2014	total_value	280	90	0.67	56	0.39
2014	trip_dur	280	66	0.54	31	0.21
2015	gfish_lbs	250	75	0.55	56	0.37
2015	gfish_mcat	250	50	0.18	27	0.11
2015	gfish_price	250	46	0.42	24	0.19
2015	k_all	250	76	0.52	63	0.41
2015	non_gfish_lbs	250	82	0.63	63	0.45
2015	quota_cost	250	80	0.46	59	0.36
2015	total_value	250	76	0.47	51	0.28
2015	trip_dur	250	63	0.52	41	0.35
2016	gfish_lbs	230	67	0.56	46	0.29
2016	gfish_mcat	230	39	0.14	19	0.05
2016	gfish_price	230	46	0.42	20	0.16
2016	k_all	230	82	0.70	51	0.40
2016	non_gfish_lbs	230	69	0.56	53	0.32
2016	quota_cost	230	78	0.74	44	0.41
2016	total_value	230	73	0.54	41	0.35
2016	trip_dur	230	50	0.66	20	0.12

\end{table}

\begin{table}[t]
\caption{Vessel median observer effects > +/- 15% and 30%, proportion of total and proportion of
groundfish landed}

FY	Variable	N vsls	Vsls, > +/-15%	% gfish caught +/-15	Vsls, > +/-30%	% gfish caught +/-30
2017	gfish_lbs	213	73	0.63	50	0.35
2017	gfish_mcat	213	42	0.17	14	0.06
2017	gfish_price	213	48	0.43	24	0.12
2017	k_all	213	67	0.59	43	0.28
2017	non_gfish_lbs	213	73	0.63	48	0.44
2017	quota_cost	213	76	0.60	54	0.43
2017	total_value	213	72	0.61	49	0.44
2017	trip_dur	213	52	0.66	25	0.46
2018	gfish_lbs	198	50	0.31	39	0.25
2018	gfish_mcat	198	45	0.20	13	0.05
2018	gfish_price	198	37	0.25	15	0.09
2018	k_all	198	58	0.51	28	0.34
2018	non_gfish_lbs	198	51	0.64	27	0.39
2018	quota_cost	198	58	0.69	39	0.44
2018	total_value	198	51	0.46	33	0.20
2018	trip_dur	198	36	0.42	18	0.22

\end{table}

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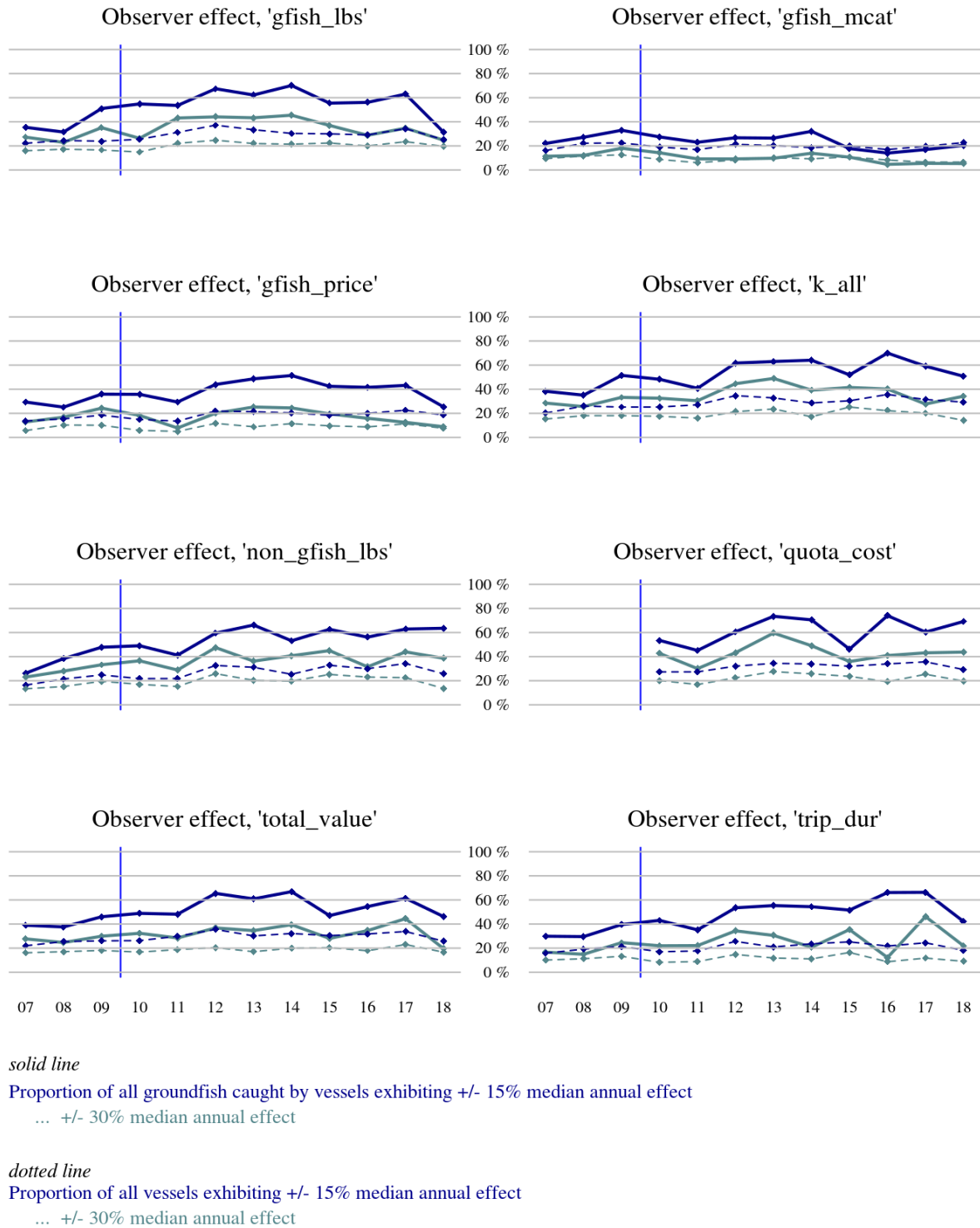


Figure 5: Proportion of vessels and catch accounted for by vessels with median annual observer effect greater than +/- 15 and 30%

Comparison of sector vessel landings effort ratios between observed and unobserved trips by gear
and broad stock area

#1d

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Introduction

With insufficient catch monitoring, incentives - produced from the multispecies (groundfish) fishery output control sector-based management system - can cause observer effects. Incentives, which vary both spatially and temporally, to fish differently when on observed trips will change with the degree of stock specific constraints. These constraints on the fishery should be reflected in the lease prices for stock specific quota, if the system operates as designed, such that fishing effort decreases as stock constraints increase when lease prices make fishing less profitable. Monitoring coverage at-sea based on the current precision standard assumes observed trips are representative of unobserved trips. However, stronger incentives exist to avoid constraining stocks on observed trips as lease prices increase. Therefore, as a stock becomes more constraining to a sector, the incentives for an observer effects increase. However, there are gear targeting, spatial, temporal, and logistical limits to avoiding constraining stocks in a multispecies fishery. If constraining stocks - that produce incentives for observer effects - lead to unseen legal size discards on unobserved trips, then this should result in differences in stock landings-per-unit-effort between observed and unobserved trips in a multispecies fishery.

Objective

The objective of this analysis is to compare landings to effort ratios on observed and unobserved trips in the groundfish fishery to determine whether the landings composition changed in the presence of an observer. This analysis assumes that any potential differences in the landing to effort ratios are not caused by an observer deployment effect.

Methods

A comparison of allocated groundfish stock landings to effort ratios was done between observed and unobserved trips by broad stock area (Figure 1) and by gear type (gillnet and trawl gear). Two ratios were examined:

$$Ratio = \sum landing / \sum Kept all and \sum landing / \sum days absent$$

The analyses were done by broad stock area to account for differences in quotas and incentives for species that are managed as multiple stocks (winter flounder, yellowtail flounder, cod, and haddock).

Multi-Stock Broad Stock Area Definition

Gulf of Maine cod = Gulf of Maine (GOM) broad stock area

Georges Bank cod = Georges Bank (GB), 521, and Southern New England (SNE) broad stock areas

Gulf of Maine haddock = GOM broad stock area

Georges Bank haddock = GB, 521, and SNE broad stock areas

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Gulf of Maine/Cape Cod yellowtail flounder = GOM and 521 broad stock areas

Georges Bank yellowtail flounder = GB broad stock area

Southern New England yellowtail flounder = SNE broad stock area

Gulf of Maine winter flounder = GOM broad stock area

Georges Bank winter flounder = GB broad stock area

Southern New England winter flounder = SNE and 521 broad stock areas

Potential effects from unit stocks (witch flounder, American plaice, pollock, redfish, white hake) should be reflected in all broad stock areas. However, the landing of a unit stock in a particular broad stock area could be low.

Data was selected using dealer data where a direct match of a dealer trip can be made with a vessel trip report (VTR) trip for both area and effort in the AA tables (Alevel = A and Elevel = A). The dealer data was further limited to trips by trawl and gillnet gear which landed at least some allocated groundfish (kept > 0). Trips were limited to groundfish sector vessels within each year that have been observed at least once over the course of a year. Common pool vessels and Sector IX were omitted from the comparison. Sector IX data was omitted due to known misreporting within this sector.

Effort was defined using two different metrics for the ratio comparisons:

1. An effort proxy was defined as sum of kept catch of all species (K_{all}), similar to how effort is defined for discard estimation in monitoring and assessments and,
2. Days absent (DA) on a trip was also used as a proxy for relative trip effort.

Gillnet gear ratios were only compared for the Gulf of Maine broad stock area where most of the groundfish gillnet effort occurs. The Southern New England (SNE) broad stock area was not included in the analysis due to the lack of groundfish effort.

Results

Tables 1-6 compare observed and unobserved groundfish landings to effort ratios by broad stock area. Tables 1-3 compare the raw ratios from observed and unobserved trips, while Tables 4-6 compare the ratios on a relative basis (unobserved relative to observed trips; unobserved ratio / observed ratio).

Differences in the landing ratios between observed and unobserved trips suggest that observed trips are not representative of unobserved trips. The tables are color coded to help illustrate potential patterns in the data. Yellow cells consistently landed more fish on observed trips relative to unobserved trips among effort metrics (K_{all} and DA) and between gear types (gillnet and trawl) within a broad stock area, while gray cells saw more fish on unobserved trips relative to observed trips. The comparisons among gear types only apply to the Gulf of Maine, where catch ratios were compared for both trawls and gillnets. The results from the Gulf of Maine stock area suggests that there were more cod landings seen on observed trips relative to unobserved trips despite incentives to avoid cod on observed trips due to low ACLs from 2015 to 2017 (Table 7). This difference was consistent across effort metrics (K_{all} and DA) and gear types. However, the magnitude of the

difference was at times relatively small. In the GB and the 521 broad stock areas, it seems that more haddock are landed on unobserved relative to observed trips. The differences in the haddock ratios may have less to do with the influences of haddock which was not constraining but perhaps more a function of other potentially constraining stocks on these trips. However, a clear strong constraining stock could not be clearly identified in GB or the 521 broad stock areas with these ratios.

Discussion

The management system was designed to limit fishing effort as the catch of a stock approaches the catch limit. However, if these economic incentives are instead leading to discarding of legal size fish, fishing effort and mortality may not be fully reduced as designed. In addition, if legal size discarding is occurring on unobserved trips, this behavior should be reflected in differences in the stock landing to effort relationships. Observer effects caused from constraining stocks should also produce biases for non-constraining stocks in the multispecies fishery. These effects will also change with changes in quotas over time and among stock areas. In addition, the true constraint of a stock specific quota for the fishery also depends on appropriateness of the implemented quota relative to the true abundance. Constraints for limiting stocks in poor condition should limit fishing effort over the course of the fishing year in order to promote rebuilding of the stock. A stock quota set too low relative to the true abundance should produce a greater constraint on effort. This would therefore also result in higher incentives for observer effects. Therefore, interpretation of the discrepancies in the landing to effort ratios between observed and unobserved trips can be complicated by multiple factors.

Quota constraints - which produce incentives for observer effects - do seem to produce differences in the landings-per-unit-effort between observed and unobserved trips, assuming that observers are deployed randomly on trips. However, the magnitude of the difference among the ratio comparisons are difficult to interpret. Since there are also incentives to avoid constraining stocks on observed trips, there are likely different degrees of incentives by permit percent sector contribution (PSC). Incentives can change over time and stock area, the constraints' depend on the true underlying stock abundance/distribution, and the fishery gear targeting ability. Therefore, the magnitude of the differences in the landings to effort relationships between observed and unobserved trips is likely not an accurate estimation of the true extent of the potential missing removals.

Conclusion

In summary, discrepancies exist between observed and unobserved trips, when comparing landing to effort ratios. These differences suggest that observed trips are not representative of unobserved trips. Interpretation of the magnitude of these differences is uncertain due to the potential inherent biases caused by incentives to avoid limiting stocks on observed trips.

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Table 1. Gulf of Maine stock area allocated groundfish stock landings comparison of observed and unobserved landings to effort ratios from 2011 to 2017. Flatfish (relative to roundfish) are not caught well with gillnet gear and are not shown.

Gulf of Maine trawl kept to kall ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	873	ob	0.21	0.07	0.03	0.20	0.08	0.01	0.15	0.03	0.02
2011	2300	un	0.22	0.07	0.02	0.21	0.10	0.01	0.14	0.03	0.03
2012	1009	ob	0.15	0.06	0.03	0.20	0.13	0.02	0.13	0.05	0.04
2012	3052	un	0.12	0.05	0.02	0.24	0.21	0.02	0.10	0.04	0.04
2013	543	ob	0.09	0.09	0.02	0.23	0.14	0.02	0.13	0.05	0.05
2013	2121	un	0.06	0.07	0.02	0.27	0.22	0.01	0.12	0.04	0.03
2014	519	ob	0.06	0.07	0.02	0.26	0.20	0.02	0.11	0.04	0.04
2014	1630	un	0.05	0.07	0.02	0.23	0.26	0.01	0.11	0.03	0.03
2015	331	ob	0.02	0.10	0.07	0.16	0.26	0.01	0.10	0.04	0.03
2015	1275	un	0.01	0.08	0.06	0.14	0.36	0.01	0.10	0.03	0.02
2016	262	ob	0.02	0.08	0.12	0.11	0.27	0.01	0.08	0.03	0.03
2016	1347	un	0.01	0.07	0.13	0.15	0.27	0.01	0.08	0.02	0.02
2017	237	ob	0.02	0.06	0.17	0.14	0.17	0.01	0.11	0.03	0.01
2017	1677	un	0.01	0.06	0.14	0.16	0.26	0.01	0.10	0.02	0.01

Gulf of Maine gillnet kept to kall ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1371	ob	0.30	-	0.01	0.35	0.01	-	0.09	-	-
2011	3423	un	0.25	-	0.01	0.40	0.01	-	0.09	-	-
2012	1112	ob	0.20	-	0.00	0.32	0.00	-	0.10	-	-
2012	3298	un	0.17	-	0.00	0.37	0.01	-	0.12	-	-
2013	484	ob	0.10	-	0.00	0.51	0.01	-	0.12	-	-
2013	2094	un	0.08	-	0.00	0.47	0.02	-	0.16	-	-
2014	736	ob	0.09	-	0.00	0.42	0.01	-	0.10	-	-
2014	1831	un	0.09	-	0.01	0.38	0.01	-	0.09	-	-
2015	286	ob	0.04	-	0.00	0.38	0.01	-	0.05	-	-
2015	954	un	0.04	-	0.01	0.39	0.02	-	0.08	-	-
2016	185	ob	0.06	-	0.00	0.19	0.01	-	0.10	-	-
2016	839	un	0.06	-	0.01	0.30	0.01	-	0.10	-	-
2017	144	ob	0.05	-	0.00	0.19	0.01	-	0.06	-	-
2017	863	un	0.04	-	0.01	0.23	0.01	-	0.06	-	-

Gulf of Maine trawl kept to days absent ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	873	ob	742	247	98	707	295	25	529	120	77
2011	2300	un	829	265	90	787	385	39	519	129	125
2012	1009	ob	480	192	78	631	392	58	409	150	118
2012	3052	un	462	212	87	936	851	70	415	154	159
2013	543	ob	280	274	75	713	432	56	392	146	160
2013	2121	un	255	293	62	1100	921	59	497	149	138
2014	519	ob	270	312	102	1119	855	70	448	169	153
2014	1630	un	218	352	97	1100	1218	56	509	150	125
2015	331	ob	69	394	267	662	1052	55	406	166	118
2015	1275	un	56	446	314	767	1897	57	515	161	108
2016	262	ob	93	344	488	462	1129	60	337	125	127
2016	1347	un	76	389	752	861	1520	54	482	131	129
2017	237	ob	103	356	1012	817	985	68	661	152	79
2017	1677	un	66	391	984	1093	1808	52	710	122	103

Gulf of Maine gillnet kept to days absent ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1371	ob	668	-	27	796	20	-	196	-	-
2011	3423	un	604	-	20	957	22	-	217	-	-
2012	1112	ob	411	-	9	644	9	-	200	-	-
2012	3298	un	374	-	9	783	20	-	254	-	-
2013	484	ob	201	-	6	1046	18	-	250	-	-
2013	2094	un	156	-	5	870	29	-	297	-	-
2014	736	ob	246	-	12	1119	39	-	257	-	-
2014	1831	un	230	-	14	990	33	-	247	-	-
2015	286	ob	110	-	14	1080	39	-	137	-	-
2015	954	un	93	-	22	1038	54	-	221	-	-
2016	185	ob	227	-	15	694	46	-	345	-	-
2016	839	un	161	-	25	827	35	-	266	-	-
2017	144	ob	171	-	12	677	27	-	210	-	-
2017	863	un	127	-	24	773	37	-	194	-	-

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Table 2. Georges Bank stock area allocated groundfish stock landings comparison of observed and unobserved landings to effort ratios from 2011 to 2017.

Georges Bank trawl kept to kall ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	105	ob	0.116	0.050	0.325	0.041	0.012	0.127	0.022	0.025	0.078
2011	457	un	0.096	0.038	0.323	0.067	0.039	0.137	0.026	0.021	0.076
2012	79	ob	0.093	0.074	0.085	0.026	0.021	0.182	0.026	0.033	0.072
2012	486	un	0.126	0.057	0.133	0.047	0.039	0.185	0.022	0.030	0.041
2013	59	ob	0.088	0.047	0.126	0.029	0.026	0.273	0.035	0.023	0.014
2013	389	un	0.080	0.039	0.173	0.045	0.076	0.244	0.030	0.020	0.025
2014	61	ob	0.103	0.053	0.289	0.017	0.030	0.127	0.040	0.024	0.004
2014	349	un	0.123	0.051	0.311	0.033	0.070	0.131	0.024	0.017	0.016
2015	33	ob	0.116	0.058	0.185	0.005	0.006	0.182	0.018	0.016	0.018
2015	333	un	0.104	0.032	0.299	0.042	0.067	0.098	0.029	0.015	0.012
2016	27	ob	0.184	0.021	0.153	0.063	0.078	0.063	0.023	0.011	0.001
2016	293	un	0.070	0.027	0.195	0.070	0.159	0.068	0.019	0.010	0.006
2017	40	ob	0.031	0.019	0.096	0.051	0.087	0.039	0.028	0.026	0.003
2017	295	un	0.029	0.024	0.201	0.037	0.199	0.058	0.019	0.015	0.008

Georges Bank trawl kept to days absent ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	105	ob	538	233	1507	192	58	588	104	117	363
2011	457	un	584	229	1968	410	238	832	155	128	465
2012	79	ob	438	346	399	120	99	854	122	156	340
2012	486	un	606	274	640	225	187	887	107	142	196
2013	59	ob	308	165	442	103	92	952	121	81	50
2013	389	un	350	172	754	198	331	1065	132	89	109
2014	61	ob	423	217	1182	69	122	520	162	100	17
2014	349	un	696	285	1752	188	396	739	138	98	90
2015	33	ob	472	236	754	19	23	741	74	65	74
2015	333	un	594	185	1707	237	380	559	164	83	66
2016	27	ob	1117	128	927	382	470	383	139	66	6
2016	293	un	473	181	1324	472	1077	458	128	71	42
2017	40	ob	218	131	671	355	611	276	198	179	21
2017	295	un	232	197	1623	298	1608	466	151	123	67

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Table 3. Mix broad stock area (521) allocated groundfish stock landings comparison of observed and unobserved landings to effort ratios from 2011 to 2017. SNE/MA winter flounder was a no possession stock in 2011 and 2012 and therefore are not shown.

Mixed stock statistical area 521 trawl kept to kall ratios.

number		Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
year	of trips										
2011	153	ob	0.212	0.031	0.048	0.339	0.107	-	0.080	0.039	0.013
2011	558	un	0.295	0.034	0.054	0.233	0.102	-	0.079	0.039	0.021
2012	103	ob	0.141	0.059	0.023	0.277	0.139	-	0.121	0.058	0.003
2012	570	un	0.151	0.054	0.035	0.271	0.141	-	0.102	0.044	0.031
2013	75	ob	0.140	0.079	0.143	0.132	0.084	0.124	0.073	0.041	0.016
2013	549	un	0.117	0.079	0.128	0.139	0.153	0.069	0.083	0.036	0.016
2014	75	ob	0.092	0.089	0.168	0.076	0.129	0.106	0.069	0.040	0.007
2014	472	un	0.121	0.068	0.229	0.103	0.146	0.046	0.064	0.032	0.007
2015	73	ob	0.101	0.062	0.181	0.057	0.245	0.101	0.045	0.026	0.005
2015	400	un	0.107	0.063	0.181	0.078	0.201	0.081	0.044	0.027	0.012
2016	52	ob	0.056	0.062	0.215	0.087	0.143	0.080	0.039	0.027	0.018
2016	373	un	0.084	0.037	0.288	0.086	0.157	0.056	0.035	0.020	0.005
2017	38	ob	0.051	0.027	0.269	0.060	0.084	0.157	0.043	0.019	0.023
2017	420	un	0.039	0.027	0.367	0.087	0.147	0.045	0.053	0.014	0.003

Mixed stock statistical area 521 trawl kept to days absent ratios.

number		Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
year	of trips										
2011	153	ob	1235	183	280	1979	624	-	468	228	74
2011	558	un	1773	204	327	1403	616	-	475	236	129
2012	103	ob	758	318	126	1496	747	-	655	315	16
2012	570	un	788	281	184	1413	735	-	530	231	163
2013	75	ob	565	318	575	532	339	502	292	164	64
2013	549	un	511	345	558	605	669	301	362	156	70
2014	75	ob	318	310	583	263	449	366	240	137	25
2014	472	un	585	326	1104	496	704	222	307	154	31
2015	73	ob	365	226	654	206	886	366	165	93	19
2015	400	un	448	264	756	324	838	339	183	114	50
2016	52	ob	259	286	986	400	658	366	181	123	83
2016	373	un	526	233	1797	536	977	346	216	124	31
2017	38	ob	310	164	1633	367	507	953	261	116	140
2017	420	un	306	210	2839	675	1136	346	409	109	24

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Table 4. Gulf of Maine stock area allocated groundfish stock landings relative comparison of unobserved landings to effort ratios to observed ratios (unobserved ratios/observed ratios) from 2011 to 2017. Flatfish (relative to roundfish) are not caught well with gillnet gear and are not shown.

Gulf of Maine trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.03	0.99	0.84	1.03	1.20	1.42	0.90	0.99	1.49
2012	0.75	0.86	0.87	1.16	1.69	0.94	0.79	0.80	1.05
2013	0.68	0.80	0.62	1.15	1.59	0.79	0.95	0.77	0.64
2014	0.72	1.01	0.86	0.88	1.28	0.71	1.02	0.80	0.73
2015	0.63	0.87	0.90	0.89	1.38	0.79	0.97	0.74	0.70
2016	0.60	0.83	1.14	1.38	0.99	0.66	1.05	0.77	0.75
2017	0.54	0.93	0.82	1.13	1.56	0.64	0.91	0.68	1.10

Gulf of Maine gillnet kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.85	-	0.70	1.13	1.03	-	1.04	-	-
2012	0.85	-	0.93	1.14	2.04	-	1.19	-	-
2013	0.86	-	0.95	0.92	1.79	-	1.32	-	-
2014	0.96	-	1.26	0.90	0.86	-	0.98	-	-
2015	0.93	-	1.76	1.05	1.50	-	1.76	-	-
2016	0.91	-	2.06	1.52	0.98	-	0.98	-	-
2017	0.80	-	2.15	1.23	1.47	-	0.99	-	-

Gulf of Maine trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.12	1.08	0.92	1.11	1.30	1.54	0.98	1.07	1.62
2012	0.96	1.10	1.12	1.48	2.17	1.20	1.01	1.02	1.35
2013	0.91	1.07	0.83	1.54	2.13	1.06	1.27	1.02	0.86
2014	0.81	1.13	0.96	0.98	1.42	0.79	1.13	0.89	0.81
2015	0.82	1.13	1.18	1.16	1.80	1.03	1.27	0.97	0.92
2016	0.81	1.13	1.54	1.87	1.35	0.90	1.43	1.05	1.01
2017	0.64	1.10	0.97	1.34	1.84	0.76	1.07	0.80	1.30

Gulf of Maine gillnet kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.90	-	0.75	1.20	1.10	-	1.11	-	-
2012	0.91	-	0.99	1.22	2.17	-	1.27	-	-
2013	0.78	-	0.85	0.83	1.61	-	1.19	-	-
2014	0.94	-	1.24	0.88	0.85	-	0.96	-	-
2015	0.85	-	1.61	0.96	1.37	-	1.61	-	-
2016	0.71	-	1.61	1.19	0.77	-	0.77	-	-
2017	0.74	-	1.99	1.14	1.36	-	0.92	-	-

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Table 5. Georges Bank stock area allocated groundfish stock landings relative comparison of unobserved landings to effort ratios to observed ratios (unobserved ratios/observed ratios) from 2011 to 2017.

Georges Bank trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.83	0.75	0.99	1.62	3.14	1.08	1.14	0.84	0.98
2012	1.36	0.78	1.57	1.83	1.85	1.02	0.87	0.89	0.57
2013	0.91	0.83	1.37	1.55	2.89	0.90	0.87	0.88	1.73
2014	1.20	0.95	1.08	1.99	2.37	1.03	0.62	0.71	3.92
2015	0.90	0.56	1.61	9.07	12.02	0.54	1.58	0.91	0.63
2016	0.38	1.26	1.27	1.10	2.04	1.07	0.82	0.96	6.31
2017	0.93	1.30	2.10	0.73	2.28	1.47	0.66	0.60	2.76

Georges Bank trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.09	0.98	1.31	2.13	4.12	1.42	1.50	1.10	1.28
2012	1.38	0.79	1.60	1.86	1.88	1.04	0.88	0.91	0.58
2013	1.14	1.04	1.71	1.94	3.62	1.12	1.09	1.10	2.16
2014	1.65	1.31	1.48	2.74	3.26	1.42	0.85	0.98	5.40
2015	1.26	0.78	2.26	12.72	16.85	0.75	2.22	1.28	0.89
2016	0.42	1.41	1.43	1.23	2.29	1.20	0.92	1.07	7.07
2017	1.07	1.50	2.42	0.84	2.63	1.69	0.77	0.69	3.18

Table 6. Mix broad stock area (521) allocated groundfish stock landings relative comparison of unobserved landings to effort ratios to observed ratios (unobserved ratios/observed ratios) from 2011 to 2017. SNE/MA winter flounder was a no possession stock in 2011 and 2012 and therefore are not shown.

Mixed stock statistical area 521 trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.39	1.08	1.13	0.69	0.96	-	0.98	1.00	1.69
2012	1.08	0.92	1.51	0.98	1.02	-	0.84	0.76	10.37
2013	0.84	1.00	0.90	1.05	1.82	0.56	1.15	0.88	1.01
2014	1.32	0.76	1.36	1.36	1.13	0.43	0.92	0.81	0.92
2015	1.06	1.01	1.00	1.37	0.82	0.80	0.96	1.06	2.28
2016	1.49	0.60	1.34	0.99	1.09	0.70	0.88	0.74	0.27
2017	0.77	1.00	1.36	1.44	1.76	0.28	1.23	0.74	0.13

Mixed stock statistical area 521 trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.44	1.11	1.17	0.71	0.99	-	1.02	1.03	1.74
2012	1.04	0.88	1.46	0.94	0.98	-	0.81	0.73	10.02
2013	0.90	1.08	0.97	1.14	1.97	0.60	1.24	0.95	1.09
2014	1.84	1.05	1.89	1.89	1.57	0.60	1.28	1.12	1.28
2015	1.23	1.17	1.16	1.58	0.95	0.93	1.11	1.22	2.63
2016	2.03	0.81	1.82	1.34	1.49	0.95	1.19	1.01	0.37
2017	0.99	1.28	1.74	1.84	2.24	0.36	1.57	0.94	0.17

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Table 7. Groundfish US ACLs from 2010 to 2020.

stock	Annual Catch Limit (US ACL)										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GB cod	3,620	4,540	4,861	1,907	1,867	1,886	730	637	1519	1741	
GOM cod	8,088	8,545	6,700	1,470	1,470	366	473	473	666	666	666
GB Haddock	42,768	32,611	29,260	27,936	18,312	23,204	53,309	54,574	46,312	55,249	
GOM Haddock	1,197	1,141	958	274	641	1,375	3,430	4,285	12,409	11,803	9,626
GB Yellowtail Flounder	1,021	1,416	547.8	209	318	240	261	201	206	103	
SNE Yellowtail Flounder	470	641	936	665	665	666	256	256	65	66	66
CC/GOM Yellowtail Flounder	822	992	1,104	523	523	524	409	409	490	490	490
Plaice	3,006	3,280	3,459	1,482	1,442	1,470	1,235	1,272	1,649	1,532	1,420
Witch Flounder	899	1,304	1,563	751	751	751	441	839	948	948	948
GB Winter Flounder	1,955	2,118	3,575	3,641	3,493	1,952	650	683	787	787	787
GOM Winter Flounder	231	524	1,040	1,040	1,040	489	776	776	428	428	428
SNE/MA Winter Flounder	605	842	603	1,612	1,612	1,607	749	749	700	700	700
Redfish	7,226	7,959	8,786	10,462	10,909	11,393	9,837	10,514	10,986	11,208	11,357
White Hake	2,697	3,138	3,465	3,974	4,417	4,484	3,572	3,467	2,794	2,794	2,794
Pollock	18,929	16,166	14,736	14,921	15,304	15,878	20,374	20,374	38,204	38,204	38,204
Northern Windowpane Flounder	161	161	163	144	144	144	177	170	86	86	86
Southern Windowpane Flounder	225	225	381	527	527	527	599	599	457	457	457
Ocean Pout	253	253	240	220	220	220	155	155	120	120	120
Halibut	69	76	83	96	106	97	119	119	100	100	100
Wolffish	77	77	77	65	65	65	77	77	84	84	84

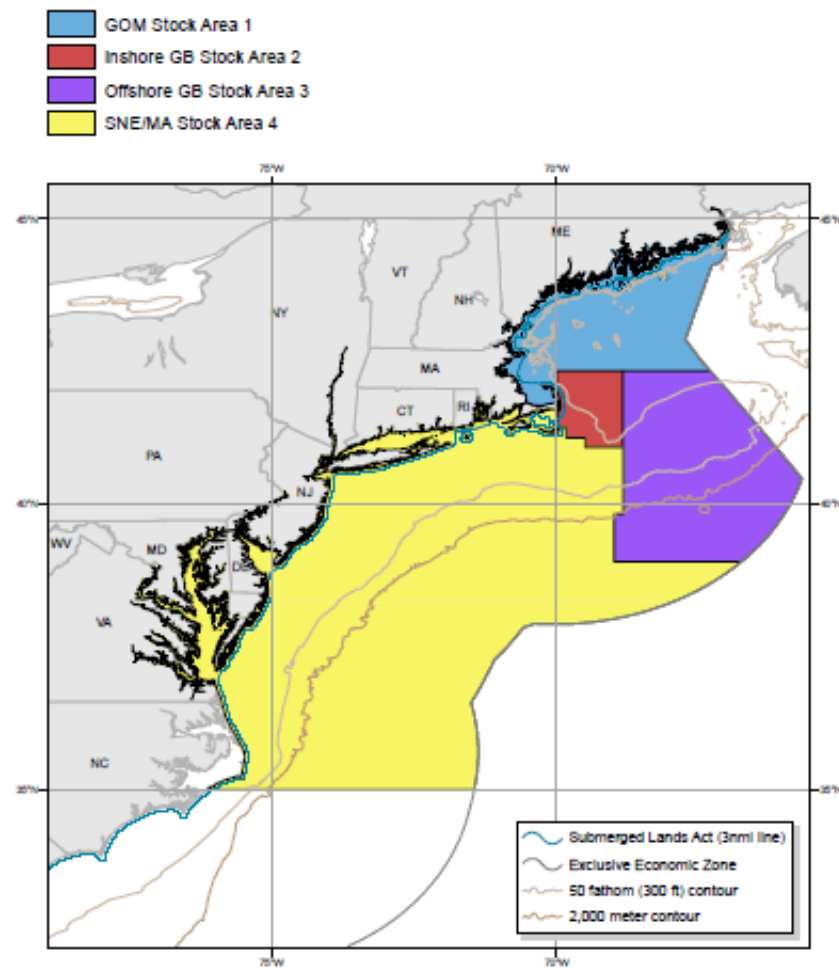


Figure 1. Multispecies broad stock area map. Inshore Georges Bank (GB) stock area 2 is statistical area 521.

Predicting Gulf of Maine (GOM) cod catch on Northeast Multispecies (groundfish) sector trips: #1c implications for observer bias and fishery catch accounting

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–DRAFT–

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The National Marine Fisheries Service (NMFS) estimates total groundfish catch across 20 stocks for the Northeast multispecies (groundfish) sector fleet by integrating several sources of information on landings and discards. Landings are reported by dealers for all trips, while discards are known only for ~15–30% of trips in a given year that are selected to carry a fisheries observer from the Northeast Fisheries Observer Program (NEFOP) or the At-Sea Monitoring Program (ASM). Under the assumption that trips can be randomly selected for observation and that the observed fishing activity and harvest outcomes are representative of behavior across the fleet (within defined strata), rates of discarding are calculated and applied to unobserved trips to obtain estimates of the unobserved discards in the fishery. Total catch for a given stock is then the summation of reported landings, observed discards, and the estimated discards on unobserved trips.

Evidence that observed trips are *not* representative of the effort across the fleet has been presented by the Groundfish Plan Development Team (PDT), calling into question the accuracy of the catch estimation methods used by NMFS to monitor the fishery. An increase in the amount of landed groundfish catch on unobserved trips, for example, suggests differences in catch rates that cannot be easily assessed given that total catches (landings + discards) are not known with certainty for unobserved trips (discards are estimated). Other Groundfish PDT work has quantified the incentives to modify fishing behavior in the presence of constraining stocks (e.g., Atlantic cod), which could result in spatial/temporal avoidance on observed trips and illegal discarding of legal-sized fish on unobserved trips. While both empirical and anecdotal evidence suggests that observed trips are not representative, the resulting implications of observer bias on total catch estimation have not been quantified.

Here, we used observed trips in the Gulf of Maine (GOM) stock area to model cod catch while accounting for typical effort attributes (e.g., total kept catch, vessel size, trip length) in addition to spatial and temporal covariance in catch. Using this predictive model, we then predicted total catch (kept + discarded) on unobserved trips and compared the summed predictions across a fishing season to the catch estimates for sectors reported by NMFS. Discrepancies suggest the potential for unreported catch.

Methods

Data

The catch data came from the Greater Atlantic Regional Fisheries Office (GARFO) database known as the Data Matching & Identification System (DMIS) which integrates multiple sources of information including dealer records, Vessel Trip Reports (VTRs), and NEFOP/ASM observer records for all commercial fisheries trips. The data were limited to groundfish trips (or subtrips) taken by sector vessels in fishing years (FY)

2011, 2013, 2015, and 2017 using otter trawls (OTF) or gillnets (GNS) in the GOM stock area (as defined by the VTR). These years were chosen as a reasonable representation of the sector management program (implemented in 2010). Subtrips are defined as fishing effort in a single NMFS statistical area (and gear), allowing for a focus exclusively on GOM effort, and landings from OTF and GNS vessels comprise >95% of cod catch for sector vessels. Records were also limited to those trips with a VTR-recorded latitude and longitude location, which included >99% of available trips. Finally, we further limited the data to those trips with reported landings of >0 lbs for cod. This last choice reflected a desire to simplify the modeling by removing the encounter process (i.e., whether a trip encountered cod), recognizing that any trips with unreported cod would be missed.

For each fishing year and gear type, the data were split between observed and unobserved trips. Total cod catch on an observed trip included the landings (i.e., kept catch) reported by the dealer and the discards recorded by the observer. Unobserved trips had discards assigned by DMIS according to a rate as calculated by observed trips within the same stratum (i.e., gear, stock area), consistent with the Standardized Bycatch Reporting Methodology (Wigley et al. 2007).

Model fitting: observed trips

The predictive model of cod catch was built using the observed trips for each gear and fishing year combination. The model included fixed effects representing attributes of fishing effort and random effects for variation according to vessel permit, space, and time. The spatial and temporal effects were modeled with predictive processes (PPs) to estimate covariances in space and time and partition variation that could be attributed to either dimension (Viana et al. (2013); Finley et al. (2009)).

Total cod catch (discards + landings), y_i , for each trip i was modeled as a Poisson random variable such that:

$$y_i \sim \text{Poisson}(\mu_i)$$

$$\log(\mu_i) = \mathbf{X}\boldsymbol{\beta} + \nu_j + \omega_1(s_i) + \omega_2(t_i) + \epsilon_i$$

where \mathbf{X} is a vector of predictors for trip i taken by vessel j , and $\boldsymbol{\beta}$ is the vector of fixed effects on the log scale. The model also included a random effect for vessel, ν_j ; the spatial PP for residual variation due to space, $\omega_1(s_i)$; and the temporal PP for residual variation due to the date of the trip, $\omega_2(t_i)$. Random error not attributed to vessel, space, or time was estimated by ϵ_i , which was modeled by a mean-zero normal distribution with variance σ_ϵ^2 . We used a Poisson distribution for expected catch, $E[y_i]$, to accommodate increased variance at larger quantities.

The fixed effects in \mathbf{X} included: 1) intercept; 2) total kept catch; 3) pollock, 4) haddock, 5) winter flounder, and 6) yellowtail flounder landings; 7) trip length and 8) squared trip length; 9) vessel tonnage and 10) squared vessel tonnage. Both trip length and vessel tonnage included squared terms to accommodate non-linear relationships. These covariates were chosen to represent attributes of fishing effort that might correlate with cod catch. The covariates representing catch/landings were log10-transformed (after adding 1). All covariates for the fixed effects were standardized to have mean of 0 and unit variance.

The random effects for space and time relied on spatial and temporal PPs, respectively, that were estimated at a reduced resolution in comparison to the observed data (Viana et al. 2013). The spatial PP was defined at 224 knots spaced on a 15-km grid restricted to where active fishing was recorded (e.g., Fig. 1). The temporal PP was defined at 25 knots spaced every 2 weeks throughout the fishing year. We specified Gaussian processes on the spatial and temporal knots with covariances that were a function of distance (in space or time). Following Viana et al. (2013), one can define a generic covariance function between 2 locations:

$$C(x_a, x_b | \phi) = \sigma^2 \rho(x_a, x_b | \phi)$$

where $\rho(x_a, x_b | \phi) = \exp[-|d_{ab}|/\phi]$ is the correlation between locations x_a and x_b , and d_{ab} is the distance between the locations; σ^2 is the random effect variance; and ϕ is a scale parameter controlling the rate

of decay in correlation between points as distance increases. By using coarse-scale spatial/temporal knots on which to define the Gaussian processes, the computational burden of the modeling procedure is greatly reduced. The Gaussian processes were therefore defined as:

$$\begin{aligned}\omega_1(s^*) &\sim GP(0, \sigma_s^2 \rho(s_a, s_b | \phi_s)) \\ \omega_2(t^*) &\sim GP(0, \sigma_t^2 \rho(t_a, t_b | \phi_t))\end{aligned}$$

Further details for how the Gaussian processes estimated on the knots relate to the random effects $\omega_1(s)$ and $\omega_2(t)$ estimated for the observed data can be found in Viana et al. (2013) and Finley et al. (2009).

We fit the models using a Bayesian approach and estimated the posterior distributions of parameters via Markov chain Monte Carlo (MCMC) methods with JAGS (Plummer 2003) and R (R Core Team 2018). We used standard vague priors for most parameters, with slightly-informative priors for the scale parameters, $\phi_s \sim Ga(3, 0.066)$, and $\phi_t \sim Ga(3, 0.033)$; and for the spatial and temporal random variances, $\sigma_s \equiv \sigma_t \propto T(\mu = 0, \tau = 1, \nu = 5) [\sigma > 0]$. The latter specification indicates a scaled Half Student-T distribution, which can be useful for constraining variance parameters (Rankin et al. 2016). We also used a highly informative prior for the residual variance (i.e., standard deviation for ϵ_i) such that $\sigma_\epsilon \sim N(0.7, \sigma^2 = 0.0225)$; this prior was chosen after some initial model fitting to stabilize the residual variance estimate. The models were run for 6,000 iterations over 3 chains after an adaption phase of 6,000, resulting in posterior distributions of 18,000 values. Convergence was achieved by examining trace plots and ensuring that the potential scale reduction factor was < 1.1 for all parameters (Gelman and Rubin 1992).

Model predictions: unobserved trips

We used the parameter estimates from each model to predict the cod catch on unobserved trips. The linear functions of expected catch were straightforward for the 10 $\hat{\beta}$ estimates (9 covariates with intercept) and vessel-specific random effects, $\hat{\nu}_j$. For vessels with no observed trips (and, hence, no estimated random effect), the vessel-specific random effect was set to 0. For the spatial and temporal random effects, distance matrices were calculated between all unobserved trips and the spatial and temporal knot locations so that expected values of $\hat{\omega}_1(s_i)$ and $\hat{\omega}_2(t_i)$ for each trip i could be calculated. Random error as estimated by $\hat{\sigma}_\epsilon$ was also added to the predictions to capture the full uncertainty in the model. The predictions for all individual trips were summed to estimate a total predicted cod catch for each gear and year, across the full posterior distribution of parameter estimates.

We also made predictions for the observed trips to illustrate how well the models could predict total cod catch without the observation-specific deviations, $\hat{\epsilon}_i$. All other fixed- and random-effect parameter estimates across the full posterior distributions were used as with the unobserved trips. Random error was re-inserted according to estimates of $\hat{\sigma}_\epsilon$ to account for over-dispersion.

Finally, the entire model fitting and prediction process was replicated for pollock to help contextualize the patterns observed for cod. Pollock is an abundant species that is not overfished and has not had a constraining quota during the period of analysis. The only differences in model structure were the species landings included as predictors (haddock, white hake, winter flounder, redfish). The full modeling results for pollock are not presented here, aside from the final predictions of total catch for observed and unobserved trips.

Results

Decreases in the observed catch (discards + landings) of cod between 2011 and 2017 are apparent for vessels using otter trawls and gillnets (Figs. S1–S8 in Supplement 1). The number of observed and unobserved trips also decreased over time (Table 1). Sample sizes for the predictive models ranged from a high of 1,489 trawl trips in 2011 to a low of 183 gillnet trips in 2017.

Table 1: Number of observed and unobserved sector trips taken in the Gulf of Maine with cod landings >0 lbs.

Gear	FY	Observed	Unobserved
OTF	2011	1193	2735
	2013	561	1768
	2015	437	1311
	2017	384	1353
GNS	2011	1489	3416
	2013	555	2059
	2015	295	839
	2017	183	763

Full model results are presented in Supplement 2. The fixed effects estimates varied by gear type and year (Figs. 2–3). Some species had a strong positive relationship with expected cod catch each year (e.g., pollock (β_3) for gillnets), while others had variable relationships (e.g., yellowtail (β_6) in 2017 was negative for gillnets and positive for otter trawls). Kept all (β_2) was a relatively strong predictor of cod catch for otter trawls across all years but decreased gradually for gillnets from 2011 to 2017. Trip length and vessel tonnage were not strongly associated with cod catch, likely due to the effect of kept all.

The amount of random variation explained by spatial location (σ_s) decreased over time for both otter trawl and gillnet vessels (Figs. 4–5). Vessel-specific variation (σ_ν) was as large as temporal variation (σ_t) for most years across both gear types. The patterns in residual spatial variation in observed cod catch (conditional on total kept catch, trip length, etc.) were stronger in the earlier years for both gear types (Figs. 6–7). The spatial patterns also changed between the gear types in later years. For example, in 2017 there appeared to be greater relative catch for inshore otter trawl trips while for gillnet trips, higher relative catches occurred farther offshore. Temporal variation exhibited different patterns between the gear types, and often across years within a gear type (Fig. 8).

The predictions of total cod catch for observed trips were fairly accurate even after removing the trip-specific random effects (ϵ_i) and re-inserting random error (Table 2, Fig. 9). The percentage differences between the reported catch and the posterior mode of predictions was <5% for 6 of the 8 models. The highest difference was in 2013 for otter trawls, where the model under-predicted total catch by 13%.

Table 2: Reported vs. model-predicted cod catch (mt) for **observed** trips, with percentage of reported by which posterior mode differs.

Gear	FY	Reported catch	Posterior distribution				% Diff.
			Mode	2.5%	50%	97.5%	
OTF	2011	819.70	852.25	743.23	849.64	967.96	4
	2013	102.64	89.57	75.59	92.57	114.11	-13
	2015	23.26	21.61	17.73	21.77	26.31	-7
	2017	34.95	36.53	28.93	37.51	48.29	5
GNS	2011	391.03	378.55	339.36	378.47	422.27	-3
	2013	54.72	52.78	45.78	53.87	62.96	-4
	2015	18.16	17.53	14.61	18.16	22.14	-3
	2017	18.79	18.36	13.91	18.76	25.67	-2

The predictions of total cod catch for unobserved trips exhibited a trend across time for gillnets with no apparent pattern for otter trawls (Table 3, Fig. 10). The discrepancy for gillnets increased over the years, with model predictions suggesting greater estimates of cod catch than that which was reported. In 2017, the posterior mode of total catch was 68% larger than the reported catch. For otter trawls, the differences between modes and reported catches were never >15% and varied in direction across the years.

Table 3: Reported vs. model-predicted cod catch (mt) for **unobserved** trips, with percentage of reported by which posterior mode differs.

Gear	FY	Reported catch	Posterior distribution				% Diff.
			Mode	2.5%	50%	97.5%	
OTF	2011	1786.65	2063.37	1829.05	2076.19	2322.05	15
	2013	365.44	333.12	276.58	339.97	416.49	-9
	2015	81.01	78.74	65.61	80.63	97.20	-3
	2017	123.72	140.08	114.71	144.61	177.96	13
GNS	2011	989.78	985.43	888.04	990.10	1110.04	0
	2013	189.80	207.54	174.06	211.30	259.75	9
	2015	50.81	71.45	57.63	74.80	97.14	41
	2017	54.39	91.11	66.66	96.77	143.19	68

The predictions for pollock suggested that our regression models were not as accurate at predicting catch for this species Supplement 3. For observed trips, model predictions were typically higher than reported catch (*always* for gillnets), suggesting a positive bias that was unaccounted for by the fixed effects and structured random effects. As a result, the predictions for unobserved trips are difficult to assess. It should be noted that the relative relationships between the reported catch and the predicted catch were similar between observed and unobserved trips.

Discussion

The predictive models leveraged information from observer data to estimate relationships between cod catch (landings + discards) and measures of effort, other species landings, and random variation attributed to space, time, and vessel. The models fit the observed data well, suggesting that predictions of total cod catch (across a fleet) using structured information might be useful for understanding discrepancies in expected and reported catch.

It appears that discrepancies for gillnet vessels could be indicative of unreported catch, which has increased over time. This assumes that observed trips can adequately represent unobserved trips with regards to “pre-catch” behavior – the manner in which gear is fished and effort expended. We modeled pre-catch behavior using several attributes of effort (e.g., kept all, location) that were expected and shown to influence catch outcomes. If other important attributes of effort were not modeled explicitly, then catch per unit effort (CPUE) of cod estimated by the observed trips may not accurately predict expected catch on unobserved trips. Under the assumption that estimated CPUE is representative, the predicted discrepancies indicate the potential unreported catch that may be attributed to differences in “post-catch” behavior (e.g., non-compliance with discarding regulations mandating retainment of legal-sized fish).

For otter trawls, the erratic pattern of predicted vs. reported cod catch is difficult to explain. It is possible that important pre-catch behavior specific to mobile gear was missing from the model structure (e.g., tow speed, tow length), which would invalidate the transfer of inferences on CPUE from observed trips to unobserved trips. This uncertainty illustrates the general difficulty of measuring fishing effort using limited information at coarse scales, compared to detailed haul-level reporting.

Additional caveats of the modeling process necessitate tempered conclusions. Other statistical distributions for expected catch on a trip (e.g., quasi-Poisson, negative binomial) may provide a better fit to the catch data, though the random error should have been useful at capturing over-dispersion and helping adjust predictions. The scales of the spatial and temporal knots were not explored and other choices may have been better able to estimate the covariances in each dimension. In particular, the majority of fishing effort is expended in a small proportion of the GOM relatively close to shore (e.g., Fig. S1), suggesting that a finer spatial resolution might pick up more nuanced variation in space. This caveat also highlights the limitations of using a single, self-reported latitude and longitude for each subtrip of effort, which likely prevents fine-scale spatial inferences and induces additional uncertainties.

The reduction in effort and observer coverage across time also increases uncertainty for models from later years. For example, the sample size of observed trips for gillnets was almost an order of magnitude smaller in 2017 ($n=183$) compared to 2011 ($n=1,489$) (Table 1). A larger model that combines multiple years of data and leverages parameter pooling across years might yield more accurate parameter estimation. Nevertheless, the added complexity of statistical modeling would not overcome any deficiencies in the sampling design or violations regarding the validity of inferences from observed trips to unobserved trips.

The predicted cod catch was 40% and 68% greater than the reported catch in 2015 and 2017, respectively, for unobserved gillnet trips. The time period coincides with highly constraining quotas for the species. These numbers overwhelm the potential error attributed to sub-legal discard estimation that otherwise serves as the target for observer coverage in the fishery. While the modeling effort presented here cannot prove the existence of unreported catch on unobserved trips, it provides an approximation to the scale of the problem.

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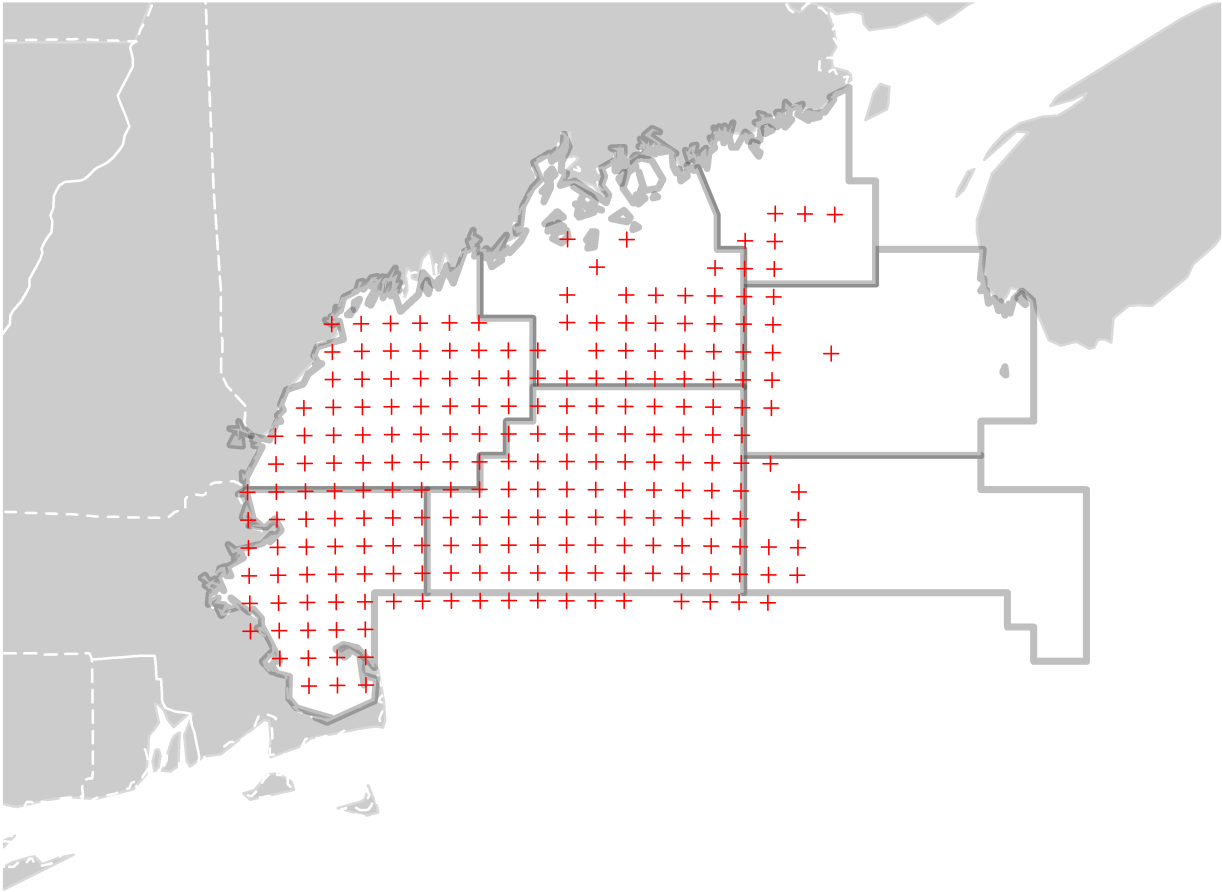


Figure 1: Gulf of Maine broad stock area with NMFS statistical areas for reference and location of the $n=224$ spatial knots spaced at 15 km used for modeling spatial covariance.

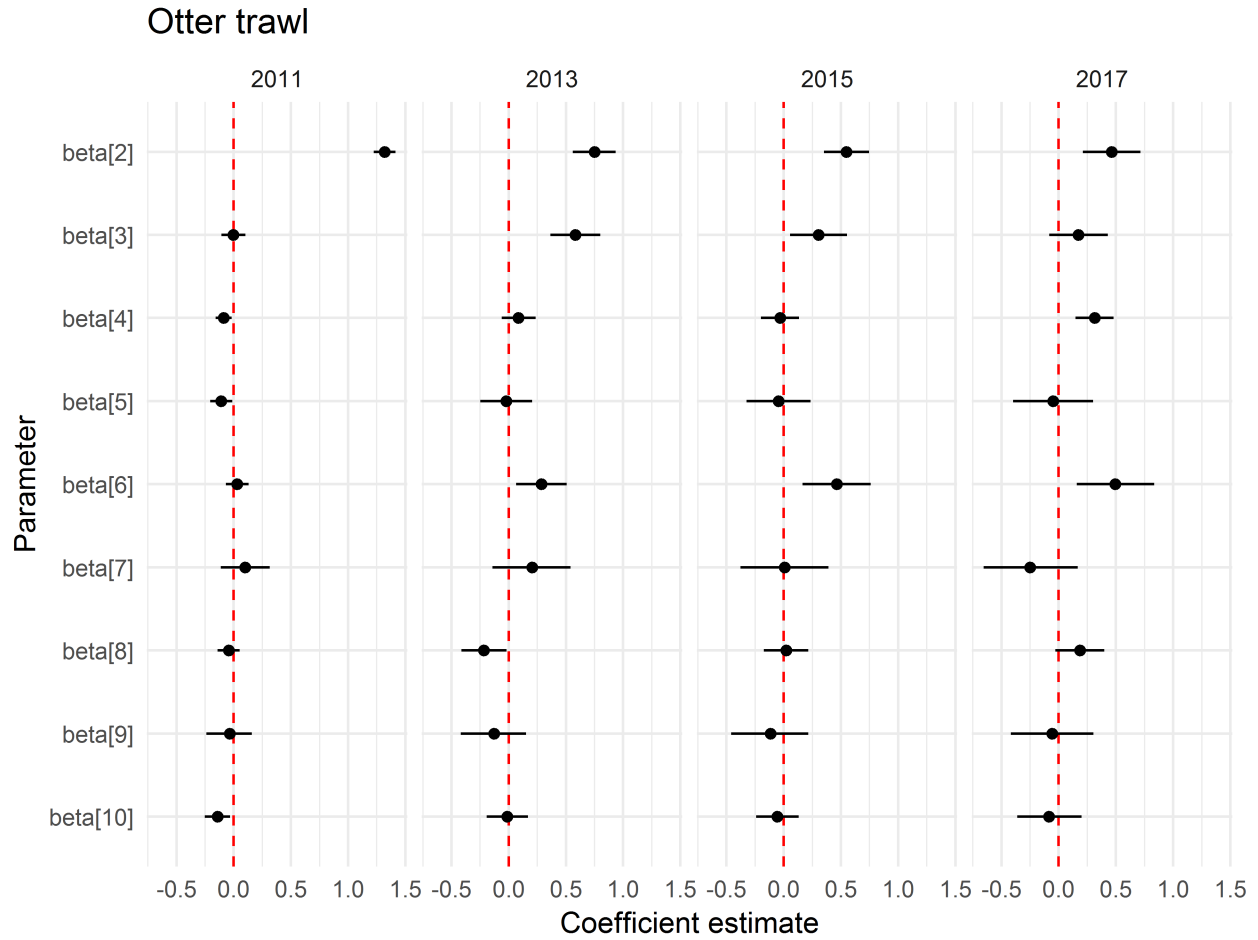


Figure 2: Parameter estimates for log-scale models of GOM cod catch on otter trawl vessels. The fixed effects (β) correspond to the following (absent the intercept): 2) kept all; 3) pollock; 4) haddock; 5) winter flounder; 6) yellowtail flounder; 7) trip length; 8) squared trip length; 9) vessel tonnage; 10) squared vessel tonnage.

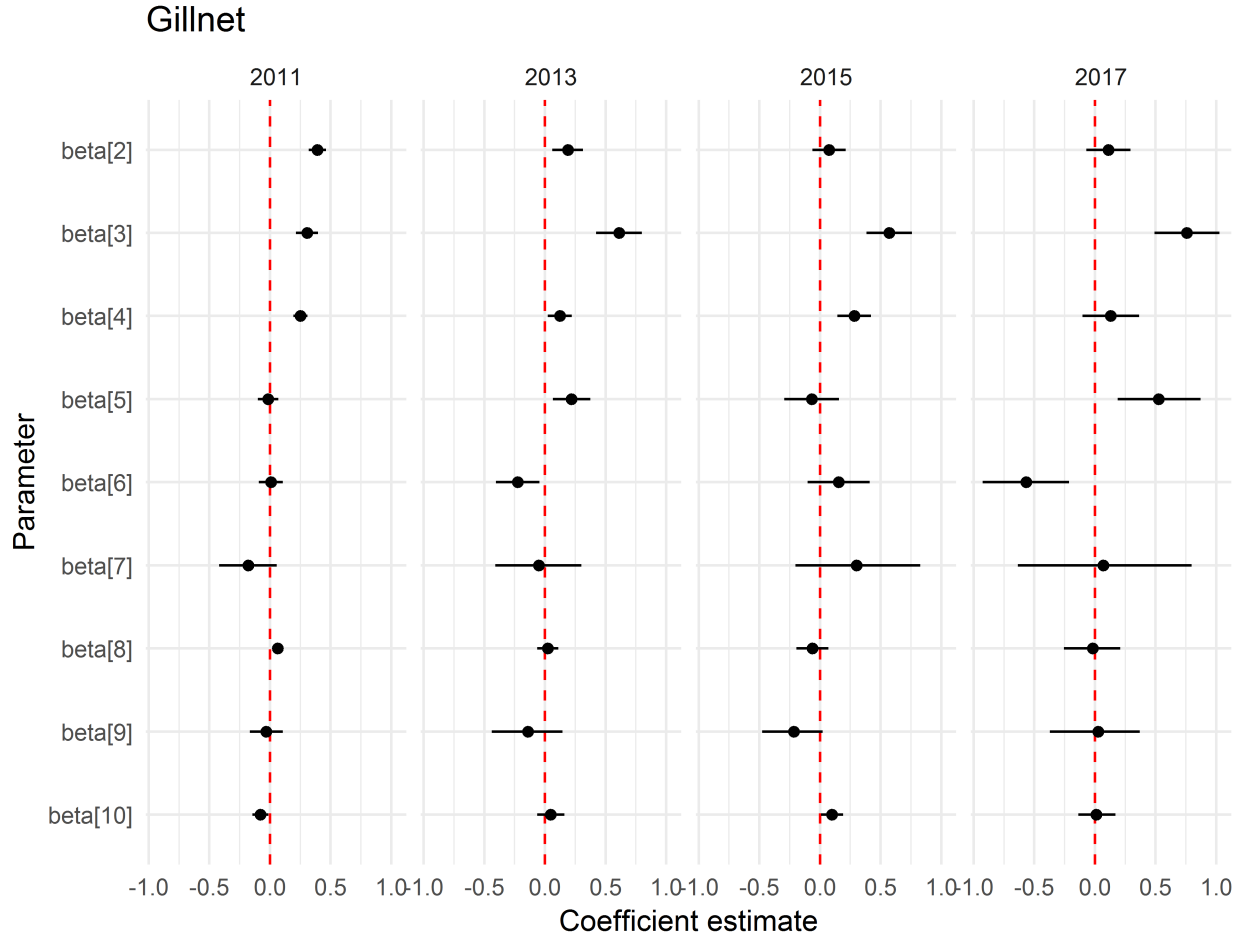


Figure 3: Parameter estimates for log-scale models of GOM cod catch on gillnet vessels. The fixed effects (β) correspond to the following (absent the intercept): 2) kept all; 3) pollock; 4) haddock; 5) winter flounder; 6) yellowtail flounder; 7) trip length; 8) squared trip length; 9) vessel tonnage; 10) squared vessel tonnage.

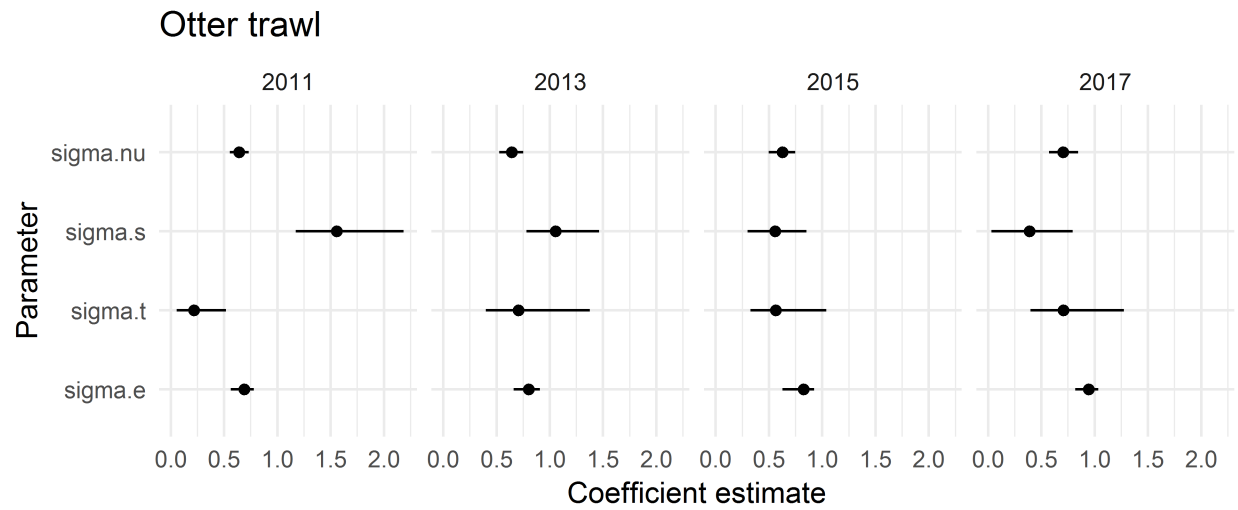


Figure 4: Parameter estimates for log-scale models of GOM cod catch on otter trawl vessels. The variance (standard deviation) estimates correspond to random effects for vessel (σ_ν), space (σ_s), time (σ_t), and residual (σ_ϵ).

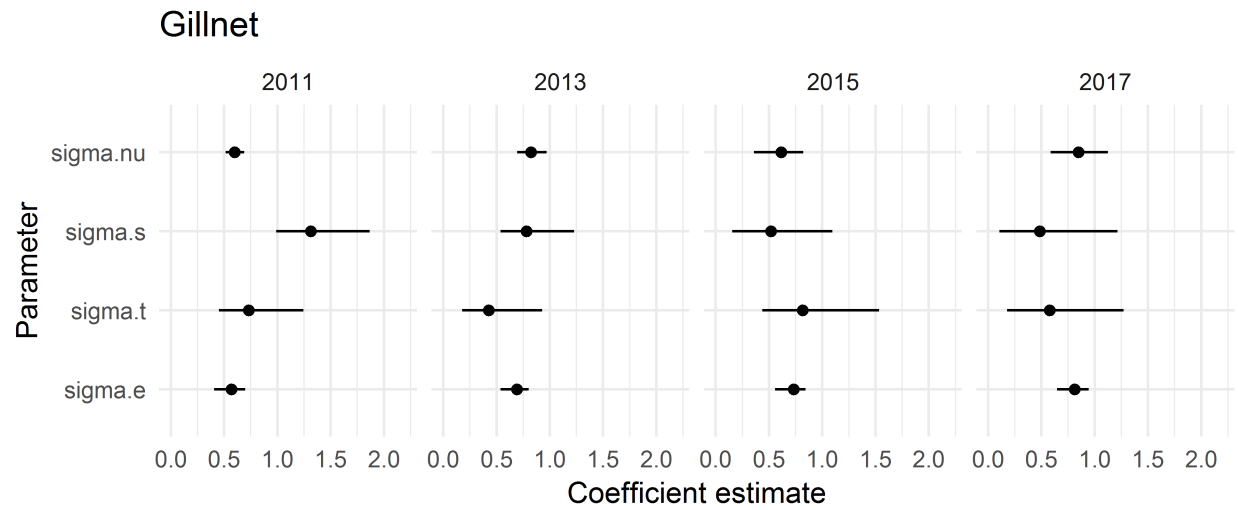


Figure 5: Parameter estimates for log-scale models of GOM cod catch on gillnet vessels. The variance (standard deviation) estimates correspond to random effects for vessel (σ_ν), space (σ_s), time (σ_t), and residual (σ_ϵ).

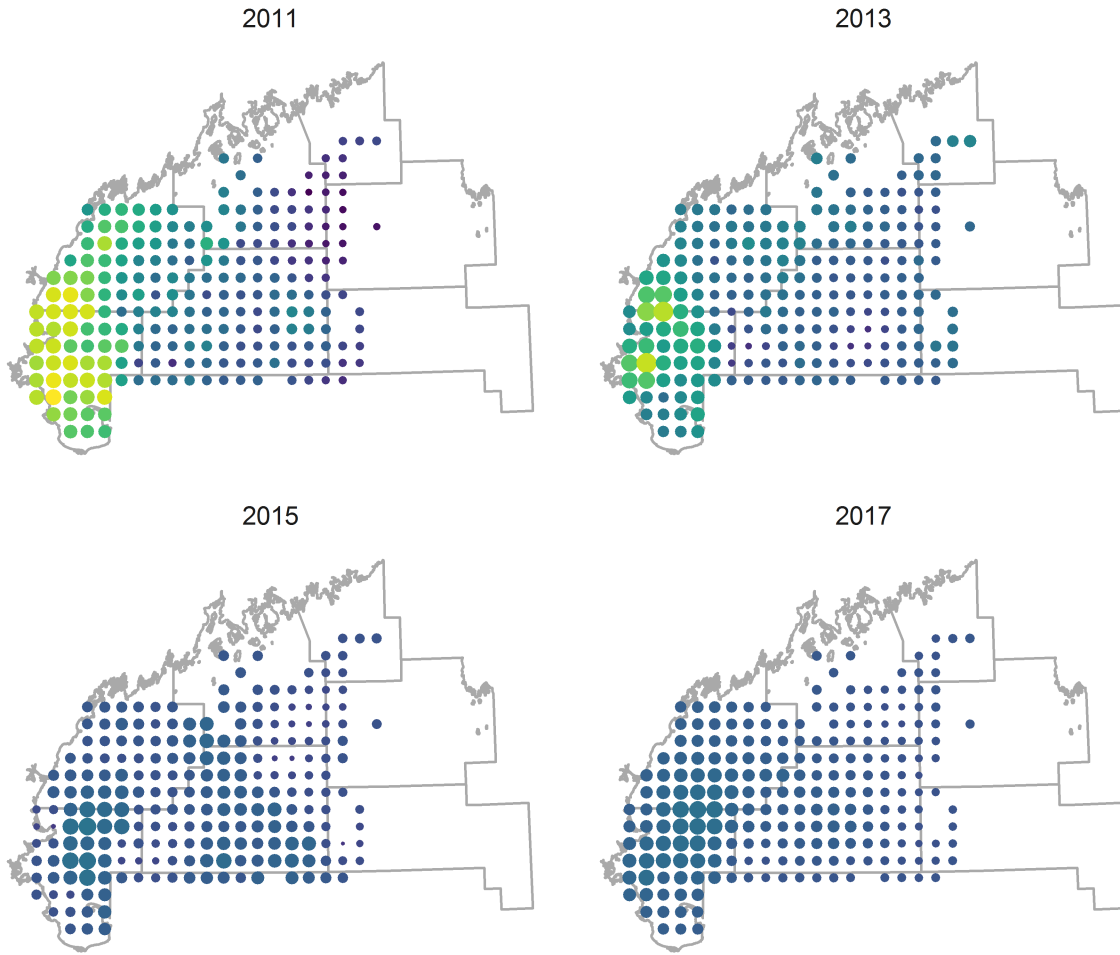


Figure 6: Relative spatial variation in cod catch unexplained by predictors of effort on observed trips taken by sector vessels using otter trawls in the Gulf of Maine during fishing years 2011, 2013, 2015, and 2017. Circle color represents relative variation across years (lighter = higher catch) while circle size represents variation within a year (larger = higher catch).

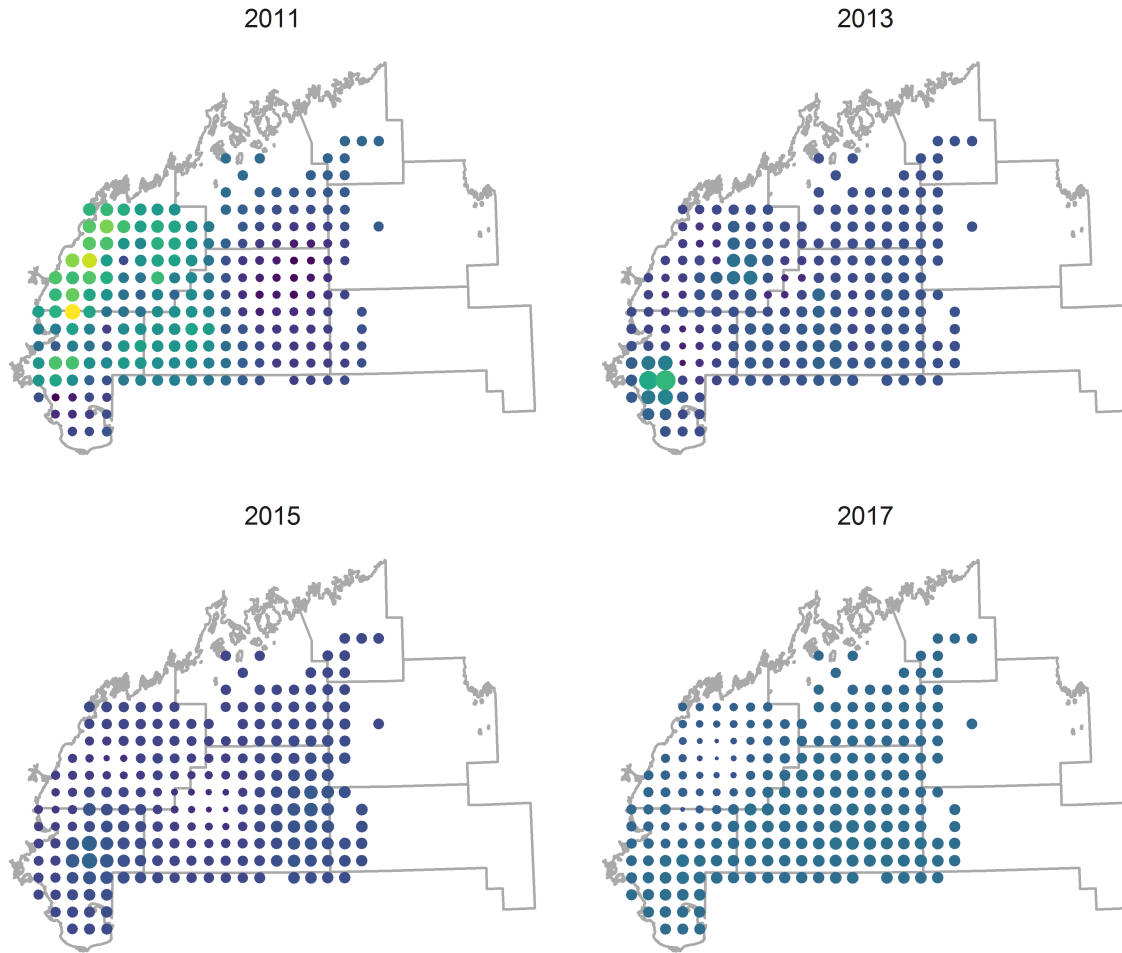


Figure 7: Relative spatial variation in cod catch unexplained by predictors of effort on observed trips taken by sector vessels using gillnets in the Gulf of Maine during fishing years 2011, 2013, 2015, and 2017. Circle color represents relative variation across years (lighter = higher catch) while circle size represents variation within a year (larger = higher catch).

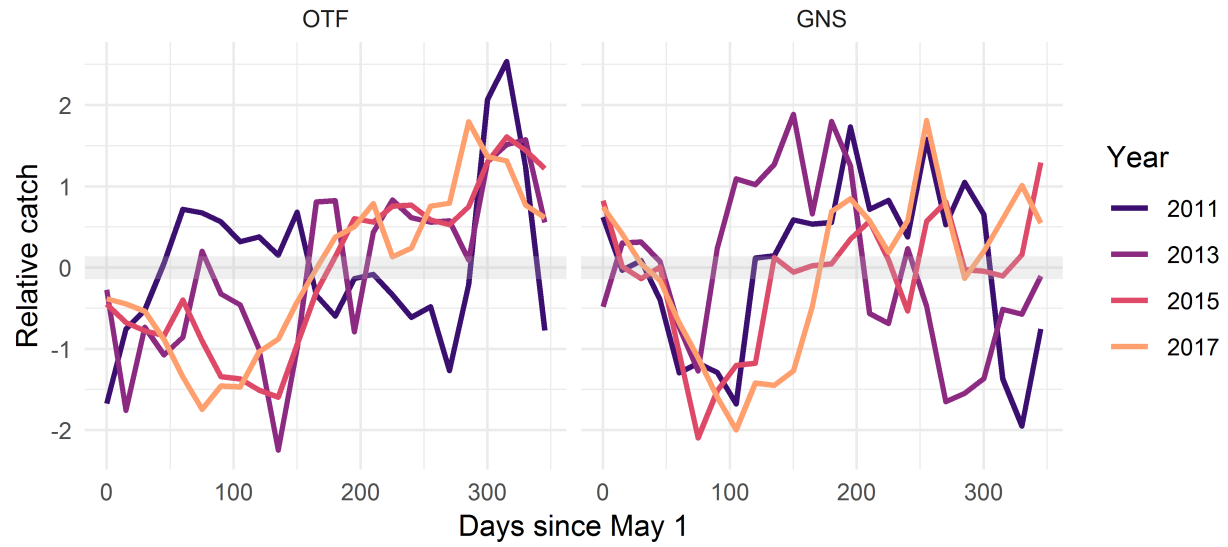


Figure 8: Relative temporal variation in cod catch unexplained by predictors of effort on observed trips taken by sector vessels using otter trawls and gillnets in the Gulf of Maine during fishing years 2011, 2013, 2015, and 2017.

GOM Cod catch on observed trips

Model predictions (gray) vs. GARFO estimate (red)

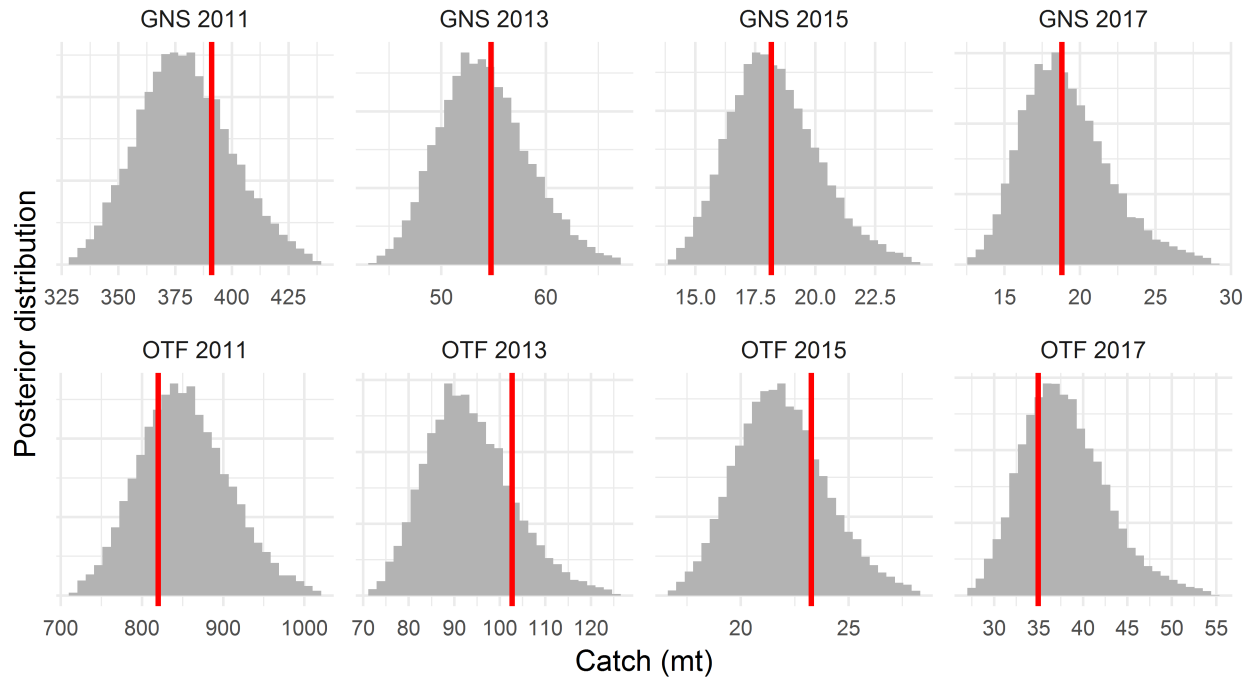


Figure 9: Model predictions of total cod catch (landed + discarded) compared to reported catch (red) on **observed** trips. While observed trips were used to fit the models, estimates of ϵ_i (residual variation) were not used to make predictions. Gear types included otter trawls (OTF) and gillnets (GNS).

GOM Cod catch on unobserved trips

Model predictions (gray) vs. GARFO estimate (red)

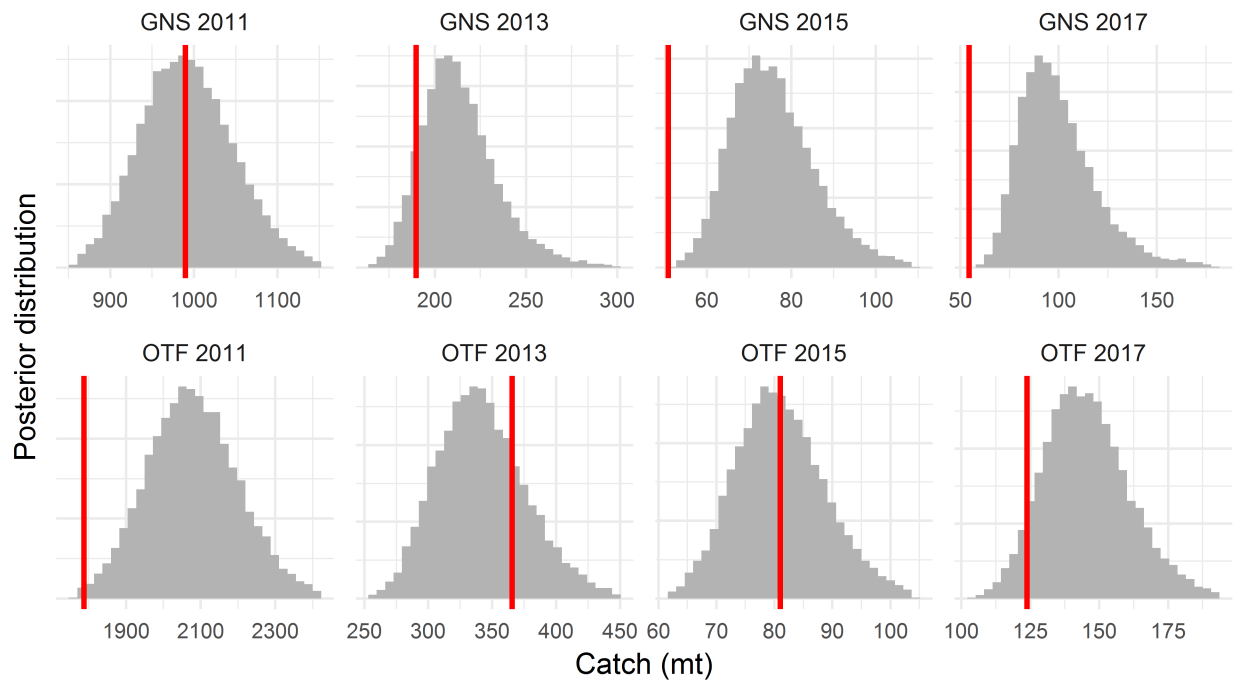


Figure 10: Model predictions of total cod catch (landed + discarded) compared to reported catch (red) on **unobserved** trips. Parameter estimates of fixed and structured random effects from the models for observed trips were used to make predictions. Gear types included otter trawls (OTF) and gillnets (GNS).

Supplement 1 - Observed cod catch

Observed cod catch in 2011

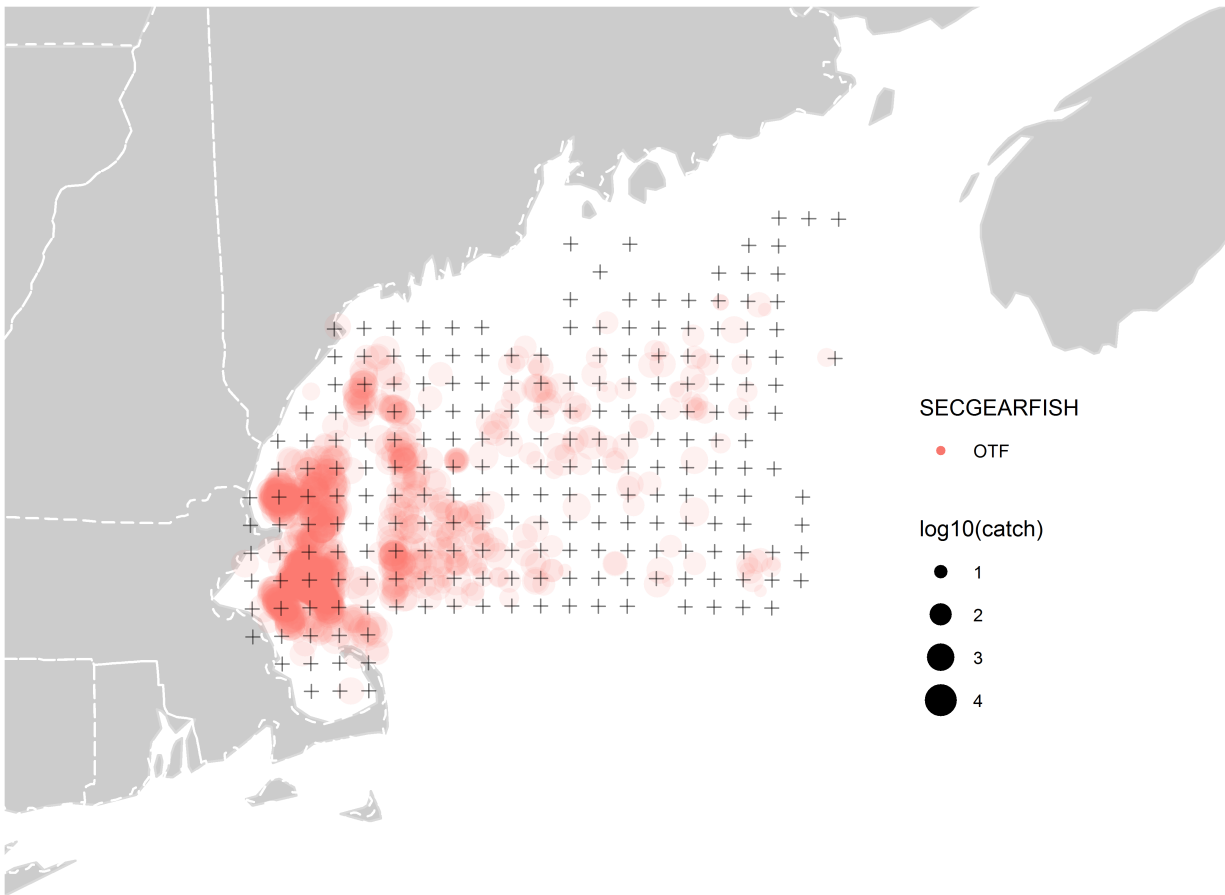


Figure S1: Cod catch (discards + landings) on observed trips by sector vessels using otter trawls in the Gulf of Maine during 2011. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2013

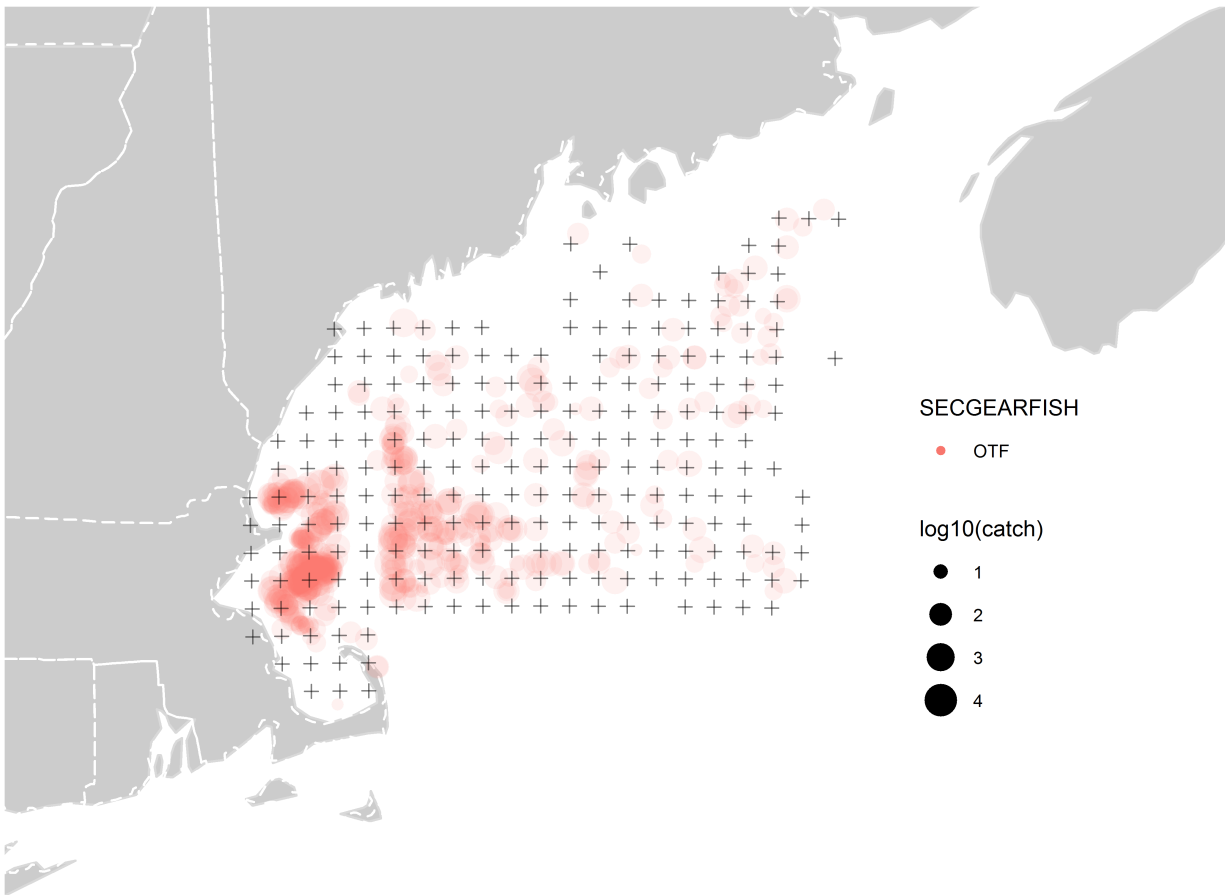


Figure S2: Cod catch (discards + landings) on observed trips by sector vessels using otter trawls in the Gulf of Maine during 2013. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2015

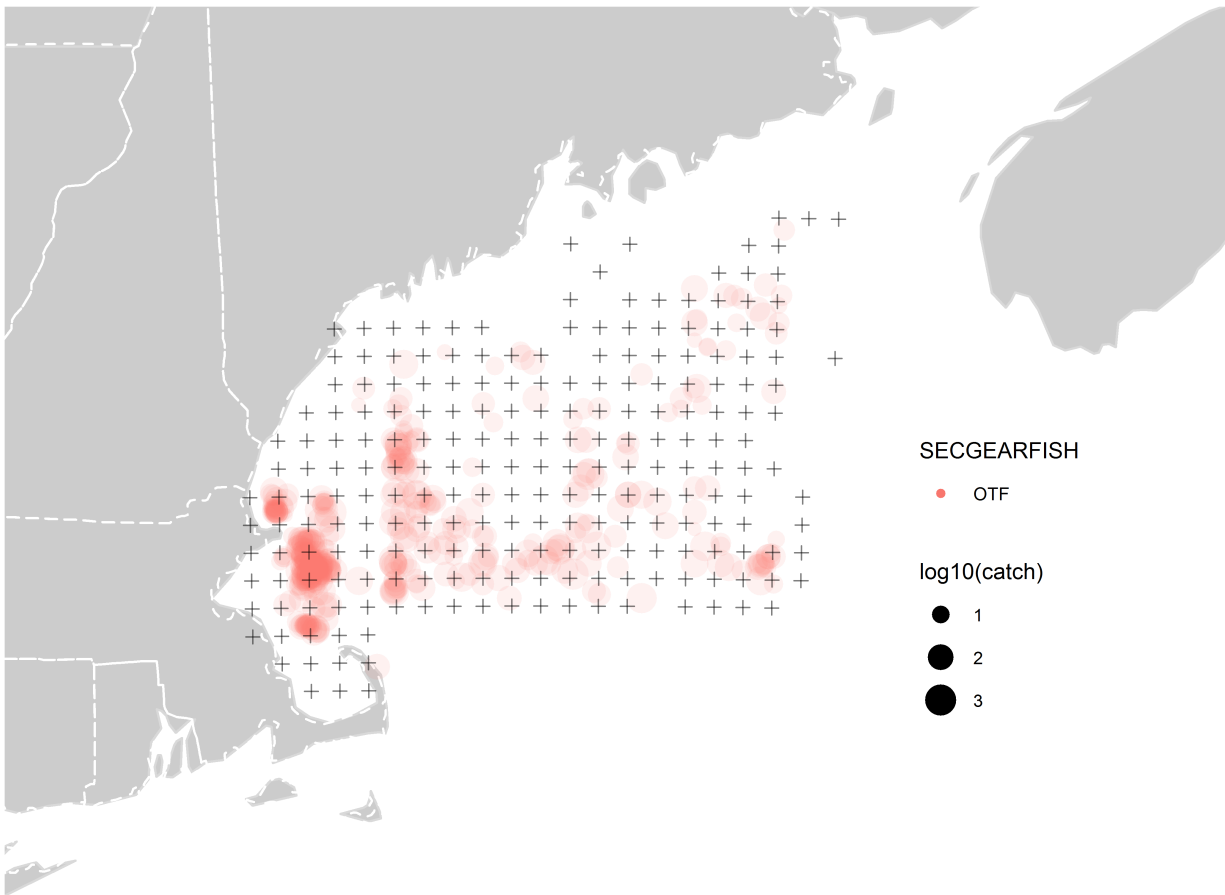


Figure S3: Cod catch (discards + landings) on observed trips by sector vessels using otter trawls in the Gulf of Maine during 2015. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2017

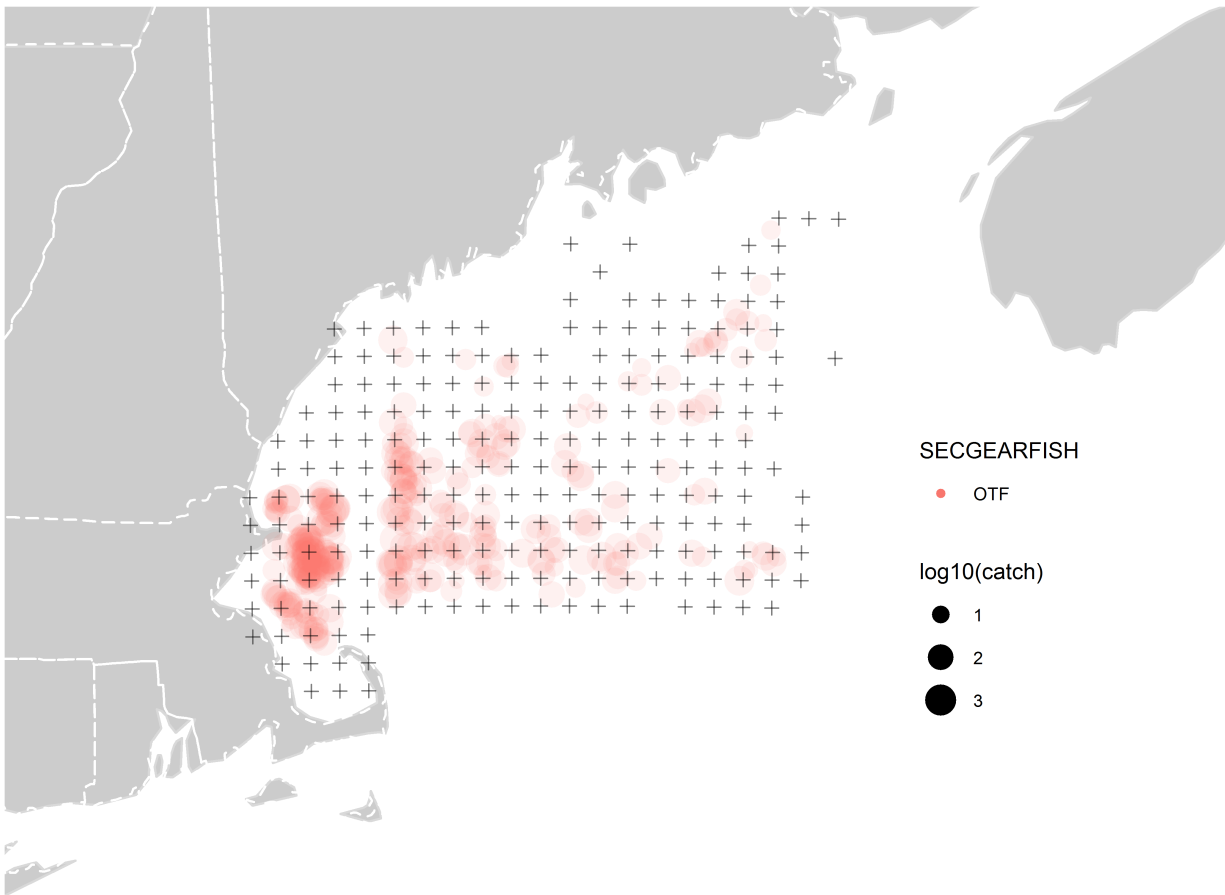


Figure S4: Cod catch (discards + landings) on observed trips by sector vessels using otter trawls in the Gulf of Maine during 2017. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2011

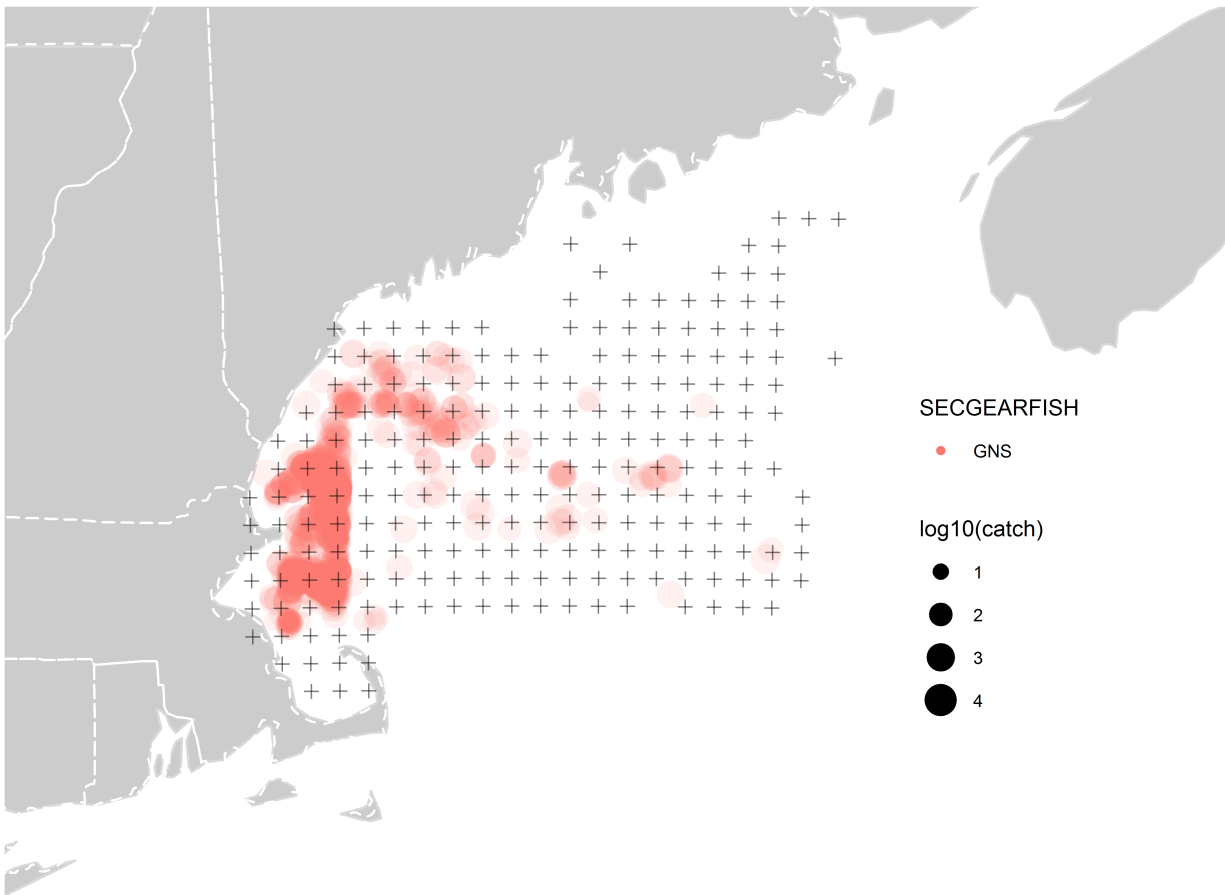


Figure S5: Cod catch (discards + landings) on observed trips by sector vessels using gillnets in the Gulf of Maine during 2011. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2013

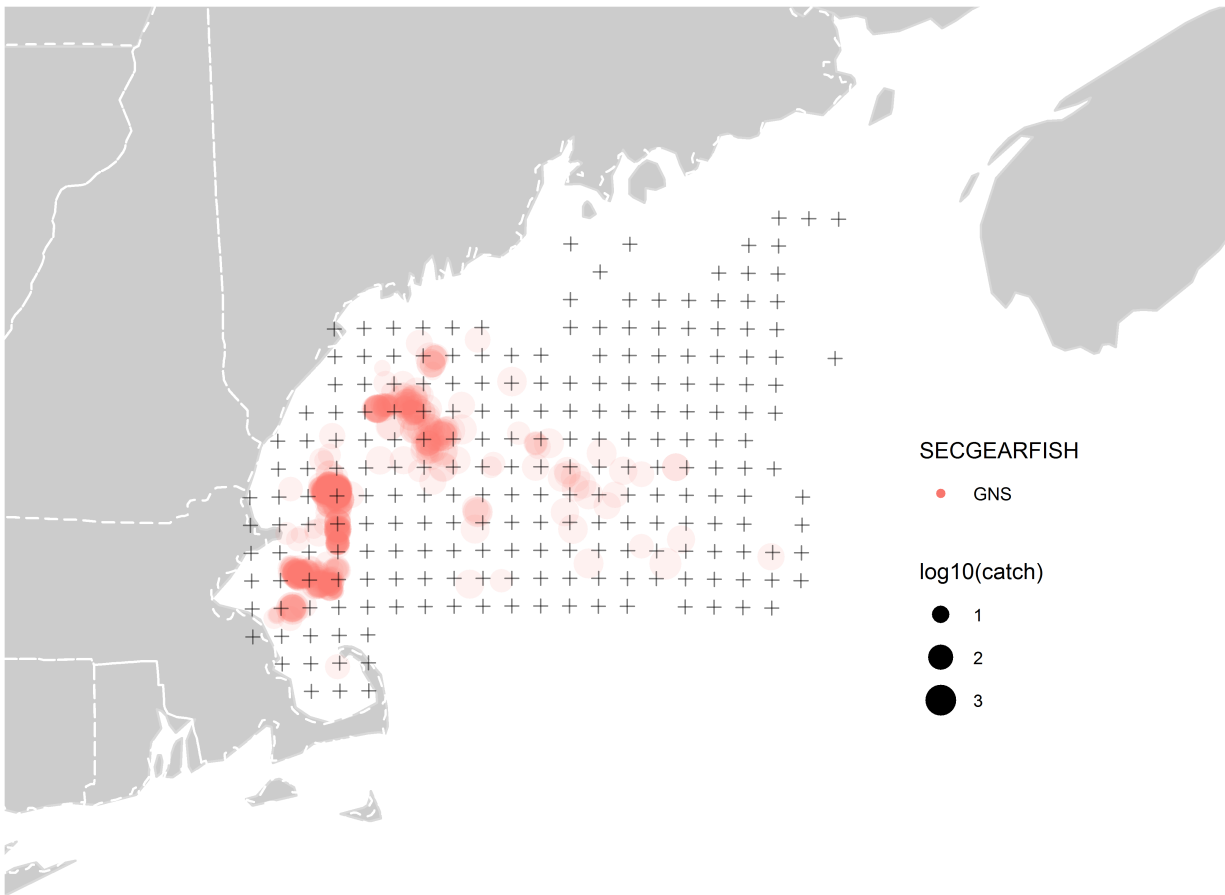


Figure S6: Cod catch (discards + landings) on observed trips by sector vessels using gillnets in the Gulf of Maine during 2013. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2015

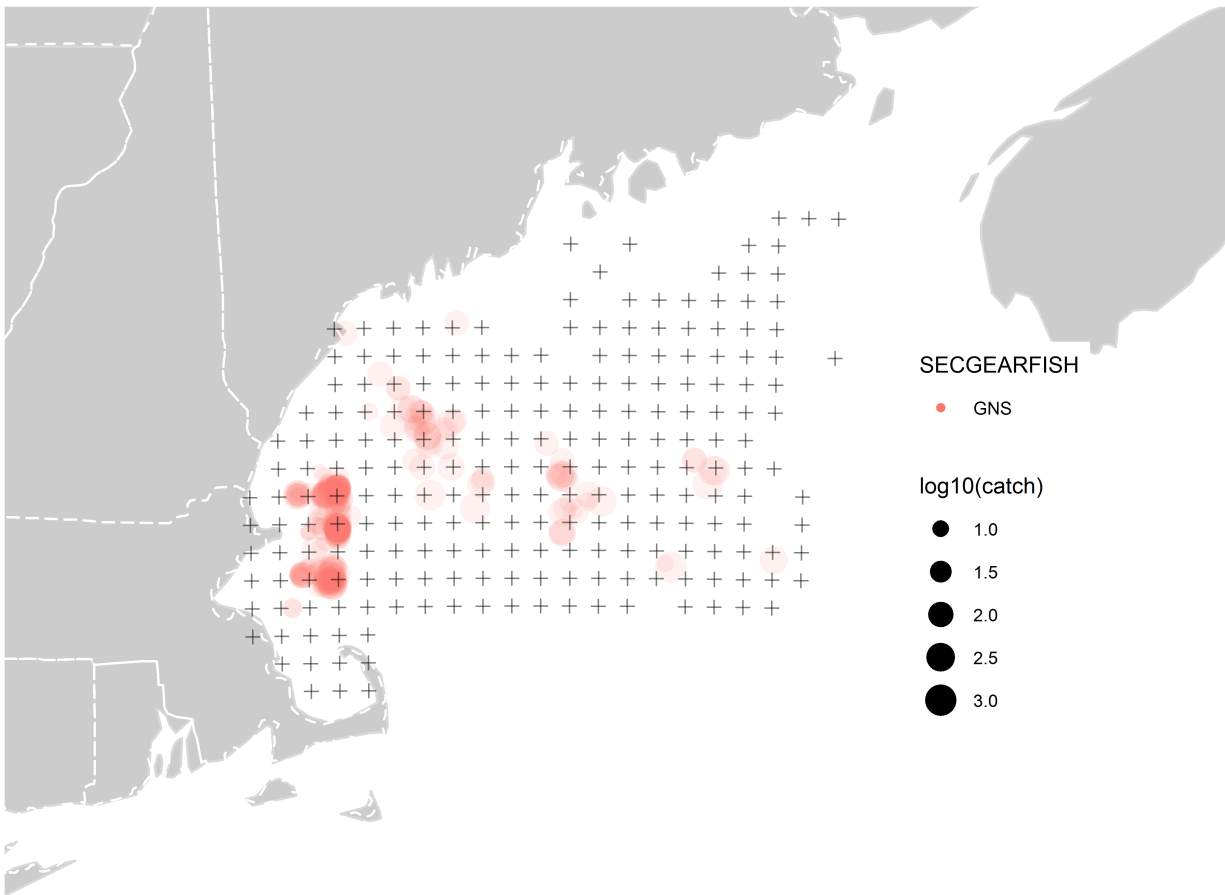


Figure S7: Cod catch (discards + landings) on observed trips by sector vessels using gillnets in the Gulf of Maine during 2015. Crosses represent the 15-km resolution grid used in the predictive model.

Observed cod catch in 2017

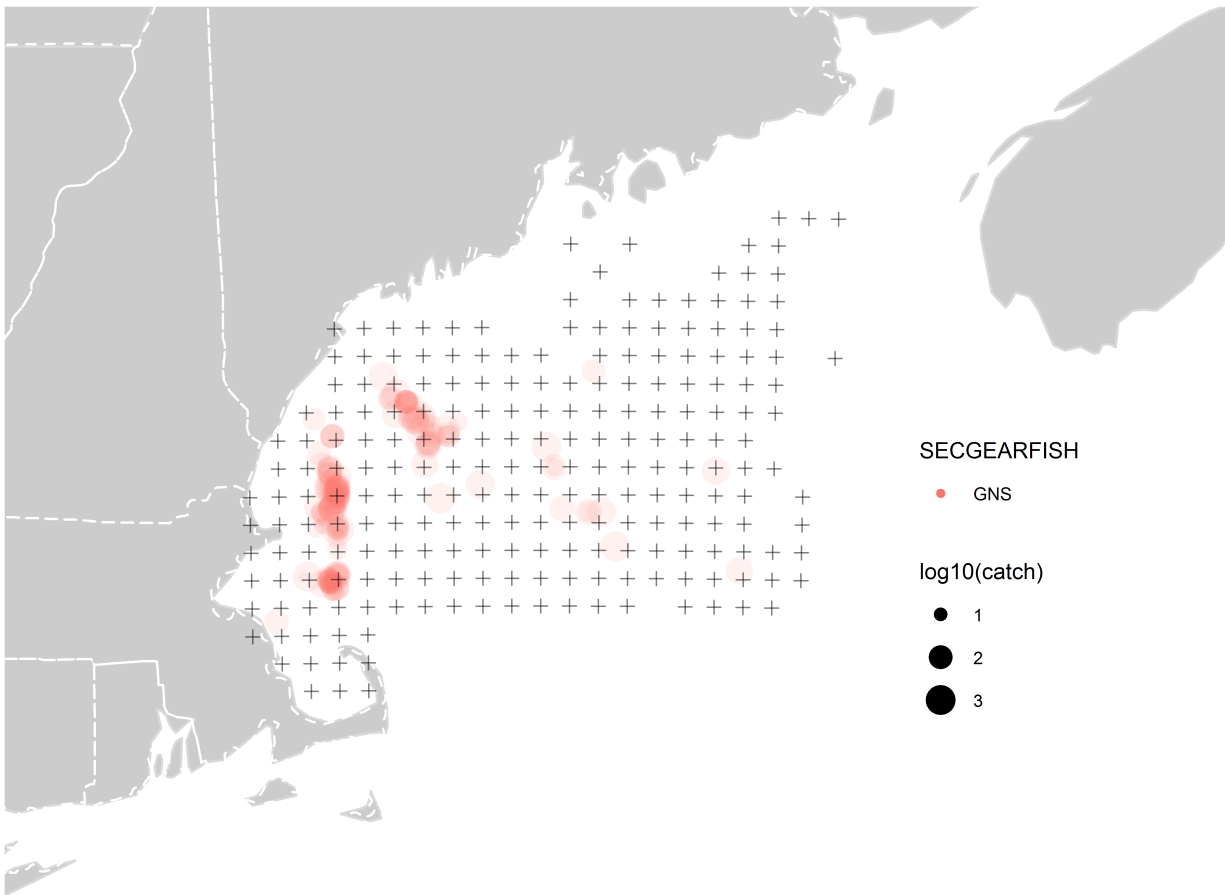


Figure S8: Cod catch (discards + landings) on observed trips by sector vessels using gillnets in the Gulf of Maine during 2017. Crosses represent the 15-km resolution grid used in the predictive model.

Supplement 2 - Parameter estimates

Table S1: Parameter estimates for GOM cod catch. The fixed effects (beta) correspond to the following: 1) intercept; 2) kept all; 3) pollock; 4) haddock; 5) winter flounder; 6) yellowtail flounder; 7) trip length; 8) squared trip length; 9) vessel tonnage; 10) squared vessel tonnage. The variance (standard deviation) estimates correspond to random effects for vessel (nu), space (s), time (t), and residual (e). The phi parameters are scale values of the distance function for decreasing covariance in space (phi.s = km) and time (phi.t = days).

gear	year	par	mean	sd	lower95	median	upper95
OTF	2011	beta[1]	4.564	0.784	2.922	4.597	6.042
OTF	2011	beta[2]	1.319	0.048	1.224	1.319	1.413
OTF	2011	beta[3]	-0.003	0.053	-0.107	-0.003	0.102
OTF	2011	beta[4]	-0.089	0.036	-0.158	-0.088	-0.018
OTF	2011	beta[5]	-0.109	0.049	-0.206	-0.109	-0.013
OTF	2011	beta[6]	0.030	0.051	-0.069	0.030	0.131
OTF	2011	beta[7]	0.100	0.108	-0.112	0.099	0.314
OTF	2011	beta[8]	-0.043	0.049	-0.140	-0.043	0.051
OTF	2011	beta[9]	-0.036	0.101	-0.238	-0.035	0.158
OTF	2011	beta[10]	-0.142	0.056	-0.252	-0.142	-0.031
OTF	2011	sigma.e	0.472	0.074	0.561	0.690	0.779
OTF	2011	sigma.nu	0.414	0.058	0.553	0.642	0.731
OTF	2011	phi.s	71.146	24.394	35.915	66.471	130.715
OTF	2011	sigma.s	2.588	0.876	1.171	1.557	2.185
OTF	2011	phi.t	80.373	49.598	16.349	69.918	201.457
OTF	2011	sigma.t	0.070	0.078	0.055	0.217	0.517
OTF	2013	beta[1]	4.522	0.589	3.327	4.529	5.694
OTF	2013	beta[2]	0.750	0.095	0.561	0.750	0.936
OTF	2013	beta[3]	0.583	0.111	0.364	0.584	0.800
OTF	2013	beta[4]	0.086	0.075	-0.060	0.085	0.235
OTF	2013	beta[5]	-0.020	0.116	-0.248	-0.020	0.206
OTF	2013	beta[6]	0.286	0.113	0.066	0.286	0.507
OTF	2013	beta[7]	0.203	0.176	-0.143	0.204	0.542
OTF	2013	beta[8]	-0.216	0.101	-0.414	-0.216	-0.018
OTF	2013	beta[9]	-0.131	0.145	-0.419	-0.128	0.153
OTF	2013	beta[10]	-0.013	0.092	-0.192	-0.014	0.169
OTF	2013	sigma.e	0.638	0.097	0.662	0.801	0.907
OTF	2013	sigma.nu	0.413	0.074	0.524	0.641	0.751
OTF	2013	phi.s	41.183	16.574	19.711	37.688	84.857
OTF	2013	sigma.s	1.175	0.392	0.780	1.054	1.462
OTF	2013	phi.t	67.192	46.842	7.971	57.068	183.913
OTF	2013	sigma.t	0.635	0.484	0.399	0.706	1.375
OTF	2015	beta[1]	3.862	0.454	2.921	3.868	4.740
OTF	2015	beta[2]	0.548	0.099	0.353	0.548	0.745
OTF	2015	beta[3]	0.302	0.126	0.056	0.303	0.554
OTF	2015	beta[4]	-0.032	0.085	-0.199	-0.032	0.134
OTF	2015	beta[5]	-0.045	0.141	-0.324	-0.045	0.235
OTF	2015	beta[6]	0.463	0.152	0.164	0.463	0.761
OTF	2015	beta[7]	0.007	0.197	-0.377	0.007	0.392
OTF	2015	beta[8]	0.020	0.099	-0.174	0.021	0.214
OTF	2015	beta[9]	-0.116	0.172	-0.459	-0.114	0.215
OTF	2015	beta[10]	-0.057	0.095	-0.241	-0.058	0.132

OTF	2015	sigma.e	0.666	0.115	0.627	0.825	0.924
OTF	2015	sigma.nu	0.395	0.080	0.496	0.627	0.746
OTF	2015	phi.s	25.414	15.310	7.338	21.598	66.064
OTF	2015	sigma.s	0.339	0.169	0.298	0.558	0.851
OTF	2015	phi.t	118.338	54.685	43.179	107.951	253.060
OTF	2015	sigma.t	0.388	0.266	0.327	0.564	1.037
OTF	2017	beta[1]	3.936	0.579	2.740	3.942	5.079
OTF	2017	beta[2]	0.463	0.128	0.211	0.464	0.715
OTF	2017	beta[3]	0.171	0.131	-0.083	0.171	0.431
OTF	2017	beta[4]	0.315	0.085	0.146	0.316	0.480
OTF	2017	beta[5]	-0.048	0.178	-0.397	-0.048	0.300
OTF	2017	beta[6]	0.493	0.174	0.158	0.493	0.833
OTF	2017	beta[7]	-0.248	0.211	-0.655	-0.250	0.167
OTF	2017	beta[8]	0.186	0.110	-0.030	0.186	0.397
OTF	2017	beta[9]	-0.056	0.185	-0.419	-0.057	0.303
OTF	2017	beta[10]	-0.084	0.143	-0.361	-0.085	0.199
OTF	2017	sigma.e	0.885	0.103	0.817	0.942	1.035
OTF	2017	sigma.nu	0.503	0.099	0.573	0.705	0.844
OTF	2017	phi.s	55.695	30.616	7.670	51.016	128.652
OTF	2017	sigma.s	0.194	0.172	0.032	0.389	0.793
OTF	2017	phi.t	111.238	51.655	36.305	102.270	233.774
OTF	2017	sigma.t	0.599	0.396	0.396	0.706	1.275
GNS	2011	beta[1]	4.874	0.711	3.386	4.894	6.247
GNS	2011	beta[2]	0.391	0.037	0.319	0.392	0.463
GNS	2011	beta[3]	0.305	0.046	0.215	0.305	0.395
GNS	2011	beta[4]	0.251	0.029	0.193	0.251	0.309
GNS	2011	beta[5]	-0.016	0.043	-0.100	-0.016	0.068
GNS	2011	beta[6]	0.007	0.050	-0.092	0.007	0.105
GNS	2011	beta[7]	-0.179	0.122	-0.419	-0.179	0.056
GNS	2011	beta[8]	0.062	0.021	0.022	0.062	0.103
GNS	2011	beta[9]	-0.031	0.069	-0.166	-0.031	0.105
GNS	2011	beta[10]	-0.079	0.034	-0.144	-0.078	-0.013
GNS	2011	sigma.e	0.323	0.082	0.407	0.568	0.696
GNS	2011	sigma.nu	0.360	0.053	0.516	0.597	0.688
GNS	2011	phi.s	39.096	15.541	19.710	35.216	78.313
GNS	2011	sigma.s	1.863	0.643	0.988	1.314	1.867
GNS	2011	phi.t	86.421	44.190	30.928	76.352	196.155
GNS	2011	sigma.t	0.623	0.362	0.451	0.729	1.246
GNS	2013	beta[1]	4.459	0.430	3.579	4.469	5.296
GNS	2013	beta[2]	0.188	0.065	0.061	0.188	0.315
GNS	2013	beta[3]	0.611	0.095	0.422	0.611	0.799
GNS	2013	beta[4]	0.123	0.051	0.022	0.123	0.222
GNS	2013	beta[5]	0.219	0.078	0.065	0.220	0.373
GNS	2013	beta[6]	-0.225	0.091	-0.403	-0.225	-0.046
GNS	2013	beta[7]	-0.051	0.182	-0.410	-0.051	0.300
GNS	2013	beta[8]	0.024	0.045	-0.063	0.024	0.112
GNS	2013	beta[9]	-0.144	0.148	-0.439	-0.142	0.143
GNS	2013	beta[10]	0.047	0.057	-0.064	0.047	0.161
GNS	2013	sigma.e	0.475	0.090	0.539	0.692	0.802
GNS	2013	sigma.nu	0.685	0.117	0.693	0.822	0.969
GNS	2013	phi.s	24.671	13.834	9.652	20.761	64.388
GNS	2013	sigma.s	0.677	0.307	0.539	0.780	1.228
GNS	2013	phi.t	77.602	51.374	12.157	66.315	205.718
GNS	2013	sigma.t	0.246	0.231	0.176	0.425	0.929

GNS	2015	beta[1]	4.357	0.619	3.113	4.350	5.637
GNS	2015	beta[2]	0.075	0.070	-0.061	0.075	0.212
GNS	2015	beta[3]	0.571	0.096	0.383	0.571	0.758
GNS	2015	beta[4]	0.283	0.070	0.143	0.283	0.421
GNS	2015	beta[5]	-0.067	0.115	-0.294	-0.068	0.157
GNS	2015	beta[6]	0.153	0.130	-0.102	0.154	0.409
GNS	2015	beta[7]	0.305	0.261	-0.202	0.302	0.828
GNS	2015	beta[8]	-0.062	0.066	-0.195	-0.062	0.070
GNS	2015	beta[9]	-0.219	0.127	-0.476	-0.215	0.022
GNS	2015	beta[10]	0.100	0.046	0.009	0.099	0.191
GNS	2015	sigma.e	0.531	0.098	0.558	0.733	0.841
GNS	2015	sigma.nu	0.386	0.137	0.359	0.616	0.822
GNS	2015	phi.s	44.825	26.631	10.498	39.094	111.540
GNS	2015	sigma.s	0.368	0.339	0.155	0.520	1.096
GNS	2015	phi.t	87.385	49.409	22.135	77.556	207.843
GNS	2015	sigma.t	0.814	0.570	0.438	0.814	1.533
GNS	2017	beta[1]	4.870	0.584	3.772	4.849	6.088
GNS	2017	beta[2]	0.111	0.093	-0.071	0.111	0.293
GNS	2017	beta[3]	0.758	0.137	0.491	0.758	1.026
GNS	2017	beta[4]	0.130	0.120	-0.103	0.131	0.365
GNS	2017	beta[5]	0.526	0.173	0.188	0.526	0.870
GNS	2017	beta[6]	-0.567	0.183	-0.926	-0.566	-0.214
GNS	2017	beta[7]	0.072	0.365	-0.635	0.068	0.797
GNS	2017	beta[8]	-0.020	0.118	-0.255	-0.019	0.208
GNS	2017	beta[9]	0.017	0.189	-0.371	0.025	0.370
GNS	2017	beta[10]	0.013	0.077	-0.137	0.012	0.169
GNS	2017	sigma.e	0.660	0.119	0.646	0.813	0.944
GNS	2017	sigma.nu	0.742	0.236	0.587	0.848	1.125
GNS	2017	phi.s	43.795	25.690	8.319	39.230	106.607
GNS	2017	sigma.s	0.356	0.403	0.105	0.485	1.214
GNS	2017	phi.t	89.952	50.106	21.919	80.157	212.261
GNS	2017	sigma.t	0.456	0.431	0.179	0.576	1.272

Supplement 3 - Total pollock catch predictions

Table S2: Reported vs. model-predicted pollock catch (mt) for **observed** trips, with percentage of reported by which posterior mode differs.

Gear	FY	Reported catch	Posterior distribution				% Diff.
			Mode	2.5%	50%	97.5%	
OTF	2011	918.34	1033.47	785.78	1071.88	1421.69	13
	2013	548.34	460.57	341.19	493.03	722.94	-16
	2015	316.95	322.34	224.57	342.43	526.34	2
	2017	388.20	451.66	303.87	491.37	766.13	16
GNS	2011	562.31	664.21	528.18	671.78	855.61	18
	2013	331.07	368.62	303.99	377.69	470.74	11
	2015	135.68	165.07	97.35	187.61	342.10	22
	2017	63.26	77.20	38.84	98.95	256.69	22

Table S3: Reported vs. model-predicted pollock catch (mt) for **unobserved** trips, with percentage of reported by which posterior mode differs.

Gear	FY	Reported catch	Posterior distribution				% Diff.
			Mode	2.5%	50%	97.5%	
OTF	2011	1871.59	1793.86	1414.39	1856.95	2418.36	-4
	2013	1935.48	1430.84	1031.71	1520.90	2183.48	-26
	2015	1159.73	1100.77	801.81	1142.12	1596.86	-5
	2017	1641.09	2397.78	1638.53	2595.74	4082.72	46
GNS	2011	1642.61	2018.28	1621.21	2045.43	2602.62	23
	2013	1125.62	1501.24	1190.50	1542.43	1989.79	33
	2015	564.31	1614.06	744.25	1995.07	4911.52	186
	2017	311.01	447.34	235.18	539.05	1099.93	44

GOM Pollock catch on observed trips

Model predictions (gray) vs. GARFO estimate (red)

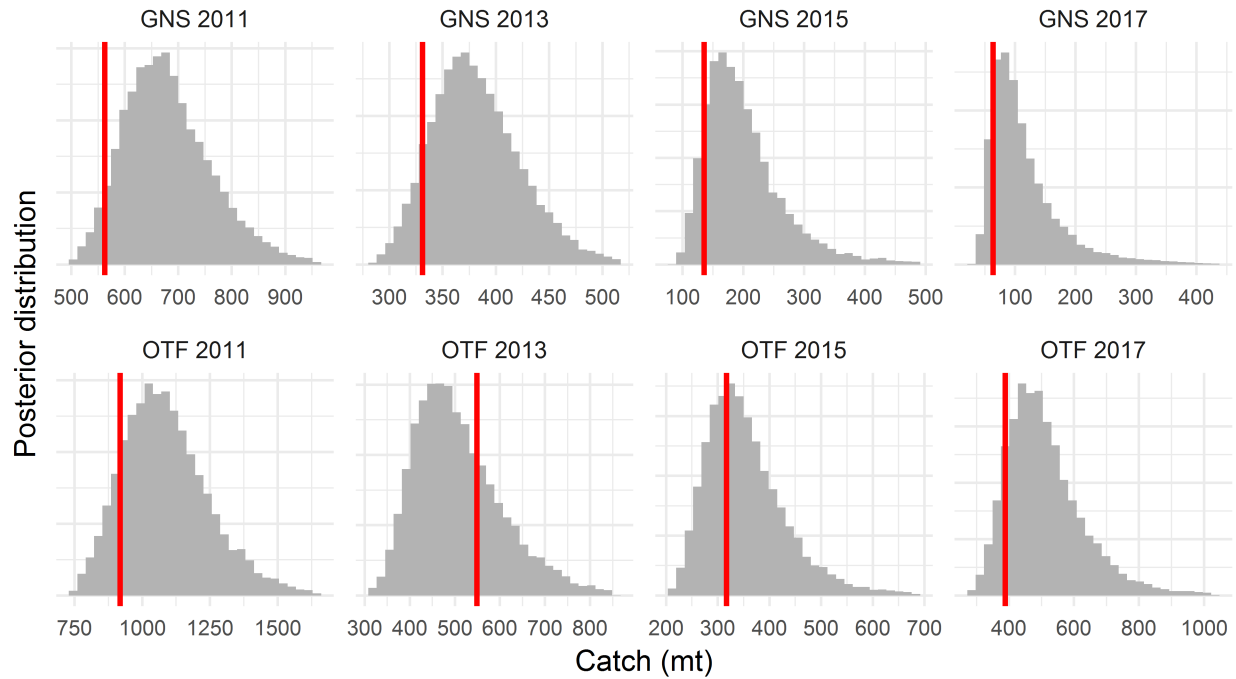


Figure S9: Model predictions of total pollock catch (landed + discarded) compared to reported catch (red) on **observed** trips. While observed trips were used to fit the models, estimates of ϵ_i (residual variation) were not used to make predictions. Gear types included otter trawls (OTF) and gillnets (GNS).

GOM Pollock catch on unobserved trips

Model predictions (gray) vs. GARFO estimate (red)

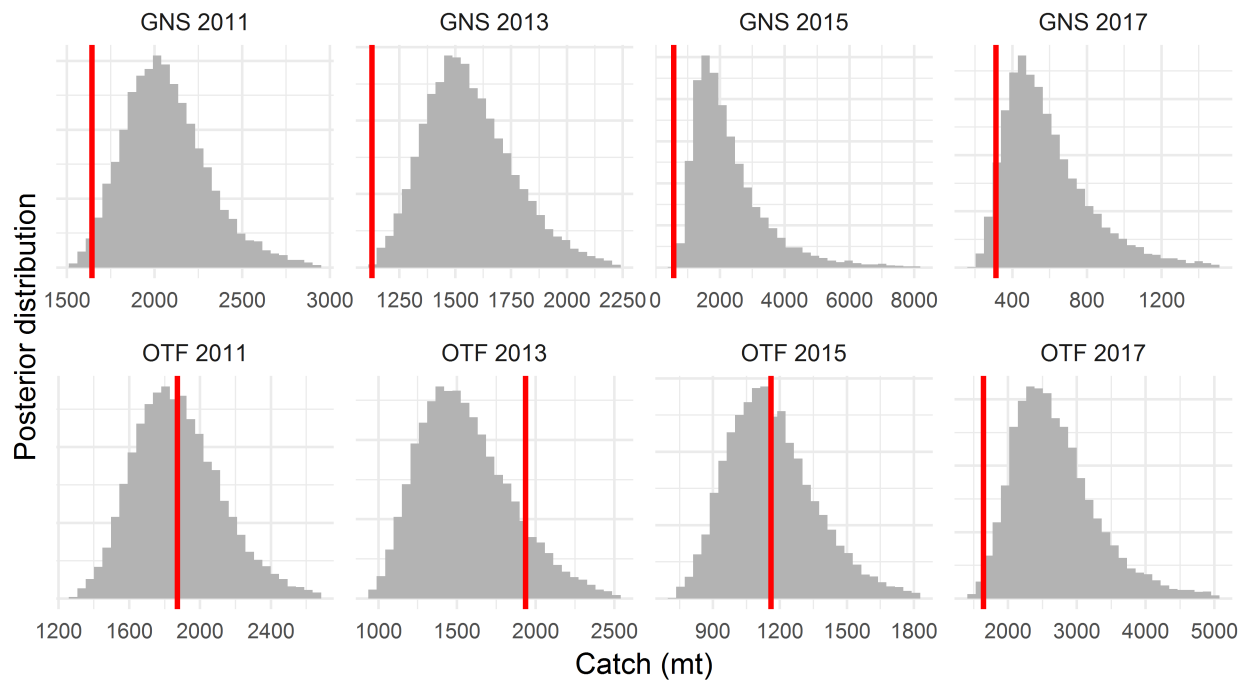


Figure S10: Model predictions of total pollock catch (landed + discarded) compared to reported catch (red) on **unobserved** trips. Parameter estimates of fixed and structured random effects from the models for observed trips were used to make predictions. Gear types included otter trawls (OTF) and gillnets (GNS).

Groundfish Plan Development Team Conclusions
Based on Monitoring Analyses Conducted

#1e

1a) Modeling discard incentives for Northeast Multispecies (groundfish) stocks

- Stocks landed with a positive discard incentive may indicate bias in the total catch estimate for that stock.
- In general, yellowtail flounder and cod stocks have the highest modeled discard incentives over time, but these are highly variable on a year to year basis.
 - All three (Georges Bank, Southern New England/Mid-Atlantic, and Gulf of Maine) yellowtail flounder stocks had higher discard incentives in earlier years (2010, 2012).
 - Both (Gulf of Maine and Georges Bank) cod stocks had higher discard incentives in recent years (2015-2017).
- Stocks with consistently low discard incentives include those with relatively low quota price to ex-vessel price ratios, including pollock, redfish, and Georges Bank haddock.
- Quota prices as a ratio of ex-vessel price drives modelled discard incentives. This ratio is the strongest theoretical predictor of bias.
- Utilization (catch: annual catch limit) is weakly related to quota price and varies by stock.
- The model can only identify when landings or trips comply with the discarding prohibition, even when it may not be economically rational to do so. The model cannot quantify the proportion of trips or catch that does not comply with the discarding prohibition.
- More precise estimates of quota prices will enhance the ability to model discard incentives under current conditions.
- There may be other social, cultural, or normative factors that may influence individuals' decisions to comply with discard rules that we do not account for in this analysis.

1b) Evaluating the Observer Effect for the Northeast U.S. Groundfish Fishery

- This analysis demonstrates that fishing vessels in the Northeast multispecies (groundfish) fishery alter their behavior in response to human observers (distinct from selection bias/observer deployment effects). The analysis documents a consistent pattern of different fishing behaviors when an observer is on board.
- Data generated on observed trips are not representative of the whole fleet.
 - Generally, the most pronounced effects are seen across trip duration, kept catch, kept groundfish, and trip revenue.
 - Observer presence has the smallest effect on the number of groundfish market categories and non-groundfish average prices, but even in these instances differences are observed.
 - The data show a trend for three key metrics, in almost all circumstances, such that when an observer is onboard, vessels appear to:
 1. Retain fewer fish,
 2. Fish for less time and,
 3. Obtain lower revenues.

- Persistent differences such as higher average groundfish prices with an observer on board (trawl vessels) and emerging differences like a greater number of market categories retained with an observer (gillnet vessels) indicate that the composition of catch on observed trips is different than unobserved trips.

1c) Predicting Gulf of Maine cod catch on Northeast Multispecies (groundfish) sector trips, implications for observer bias and fishery catch accounting

- By modeling patterns of cod catch across space, time, and other attributes of fishing effort on observed trips, predictions of expected catch on unobserved trips were compared to the reported catch on these trips.
 - For gillnet trips, predicted cod catch was increasingly higher than reported catch from 2013 to 2017. Differences between predicted and reported catch on trawl trips were variable across time without an apparent trend. For both gear types, the proportion of total catch consisting of cod decreased over time, suggesting less targeting.
 - There is some evidence that the magnitude of unreported cod catch (potentially illegal discarding) could have been >60% of reported catch on unobserved trips.
- An important caveat is that conclusions depend on validity of the model structure and predictions. If unmeasured attributes of effort (e.g. tow speed) and/or relationships between effort predictors and catch outcomes differ between observed and unobserved trips, predictions may not be valid. Differences in catch outcomes are assumed to be attributed to post-catch behavior (compliance, or lack thereof, with discarding regulations) and not pre-catch behavior (how the gear was fished).
- Results from models for pollock suggested a lack of model fit compared to those for cod, making conclusions equivocal for this species.

1d) Comparison of sector vessel landings effort ratios between observed and unobserved trips by gear and broad stock area

- Discrepancies exist between observed and unobserved trips, when comparing landing to effort ratios. Differences in the landing ratios between observed and unobserved trips suggest that observed trips are not representative of unobserved trips. This analysis assumes there are no observer deployment effects.
- For the Gulf of Maine broad stock area, this analysis demonstrates there were slightly more cod landings seen on observed trips relative to unobserved trips despite incentives to avoid cod on observed trips due to low ACLs from 2015 to 2017. This difference was consistent across effort metrics (K_{all} and DA^1) and gear types.
- For the Offshore Georges Bank broad stock area and Inshore Georges Bank broad stock area (Statistical Reporting Area 521), more haddock are consistently landed on unobserved trips relative to observed trips. The differences in the haddock ratios may have less to do with the

¹ K_{all} = sum of kept catch of all species, similar to how effort is defined for discard estimation in monitoring and assessments; DA = days absent on a trip, a proxy for relative trip effort

influences of haddock which was not constraining but perhaps more a function of other potentially constraining stocks on these trips targeting haddock.

- Documented differences in the stock landing to effort relationships reflects differences in discarding of legal sized fish on unobserved trips relative to observed trips.
- Interpretation of the magnitude of these differences is uncertain due to the potential inherent biases caused by incentives to avoid limiting stocks on observed trips.
- The magnitude of the differences in the landings to effort relationships between observed and unobserved trips is likely not an accurate estimation of the true extent of the potential missing removals.

Overall Groundfish Plan Development Team Conclusions Based on the Analyses

- All three analyses that compare observed and unobserved trip data conclude that observed trips are not representative of unobserved trips. The dimensions where observed trips differ from unobserved trips include:
 - Gulf of Maine cod catch rates,
 - Groundfish landings to effort ratios,
 - Trip duration,
 - Pounds of kept groundfish,
 - Pounds of total kept catch, and
 - Trip revenue.
- Documented differences in the stock landing to effort relationships reflect differences in discarding of legal sized fish on unobserved trips relative to observed trips.
- Despite removing Sector IX data from these analyses, fishery-wide bias is still demonstrated.
- The discard incentive model describes one mechanism to explain differences between observed and unobserved trips: the sector system increases the incentive to illegally discard legal-sized fish on unobserved trips.
- Discard incentives have varied across time and stock area. After full sector implementation, the accountability of discards and the application of sector/gear specific discard rates to unobserved trips, together with the potential catch of constraining stocks, increased the incentive to not comply with retention regulations.
- Given these conclusions, the current precision standard is not an appropriate method to set at-sea monitoring coverage levels because the assumption that observed trips are representative of unobserved trips is false.
- These analyses cannot quantify the differences between observed and unobserved trips in a way that allows for either a mathematical correction to the data or a survey design that resolves bias.
- Non-compliance with the requirement to land legal-sized fish of allocated stocks (excluding LUMF²) undermines any sampling design and should be addressed.
- While direct evidence of the incidence and magnitude of non-compliance is not captured, the documented differences in behavior are substantial enough to warrant concern that non-compliance is occurring, especially in view of incentives to be non-compliant while unobserved.
- Revisions to the monitoring program should consider ways to increase compliance or account for non-compliance. Substantially increasing the management uncertainty buffer might account for this non-compliance but would not improve our understanding of true removals and would result

² LUMF = legal-sized un-marketable fish

in foregone revenue for the fishery. Alternatively, increased monitoring and catch accounting may be one way to increase compliance and may be necessary to provide accuracy of catch.

- The analyses support more comprehensive monitoring in the fishery.

Overview

Groundfish Plan Development Team's Analysis of Groundfish Monitoring

Jamie M. Cournane, PhD

Chair of the PDT

Scientific and Statistical Committee
Sub-Panel Peer Review
April 24-25, 2019



Northeast Multispecies (Groundfish) Fishery Management Plan

New England
Fishery
Management
Council

Acadian Redfish
Sebastes fasciatus

- 13 species, 20 stocks, 2 management units
- Commercial- trawl, gillnet, and hook and line
- Recreational – hook and line
- Complex management system – catch share system (sectors), common pool, time-area management, bycatch management



Draft Amendment 23/Groundfish Monitoring

Purpose and Need Statement

To implement measures to improve reliability and accountability of catch reporting and to ensure a precise and accurate representation of catch (landings and discards).

To improve the accuracy of collected catch data. Accurate catch data are necessary to ensure that catch limits are set at levels that prevent overfishing and to determine when catch limits are exceeded. To create fair and equitable catch reporting requirements for all commercial groundfish fishermen, while maximizing the value of collected catch data and minimizing costs for the fishing industry and the National Marine Fisheries Service.



Atlantic Halibut

Hippoglossus hippoglossus

Motivation for the peer review

To ensure that any new and novel analyses of Amendment 23 issues and management alternatives get sufficient independent review.



Groundfish Plan Development Team

Groundfish Plan Development Team Analysis

1a - Methods to explore discard incentives and estimate prohibited discards of groundfish stocks.

1b - Methods to evaluate observer effects in the groundfish fishery.

1c - Methods to predict groundfish catch in the presence of observer bias.

1d - Methods to evaluate groundfish catch ratios.

1f - Groundfish PDT conclusions based on the analyses conducted

Discard Incentives for New England Groundfish Stocks

Anna Henry, Chad Demarest, and Melissa Errend

SSC sub-panel peer review

4/24/2019



NOAA
FISHERIES

Why Discard?

- Basically, when you are better off without it
- Specifically, when fish has little to no value:
 - Smaller fish, lower value grades
 - You can't keep it
- In quota-managed fisheries:
 - Not enough quota
 - Price of quota is high

Issues with Discarding

- May be significant
- Management needs to estimate to calculate total removals
- Quota systems depend on catch accounting

Discarding in NE Multispecies fishery

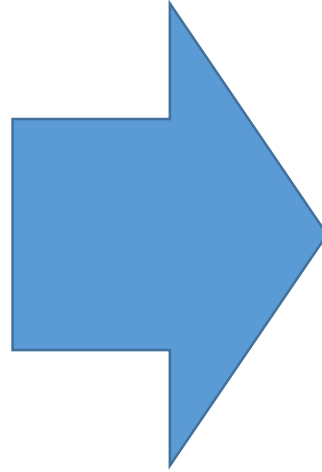
Regulations concerning discarding:

- Sub-legal fish=> mandatory discards
- Legal-sized fish=> mandatory retention
- Quota must cover all catch (sublegal discards and landings)
- Observers estimate sub-legal discard rate on 14%-32% trips
- No independent verification of discards on unobserved trips

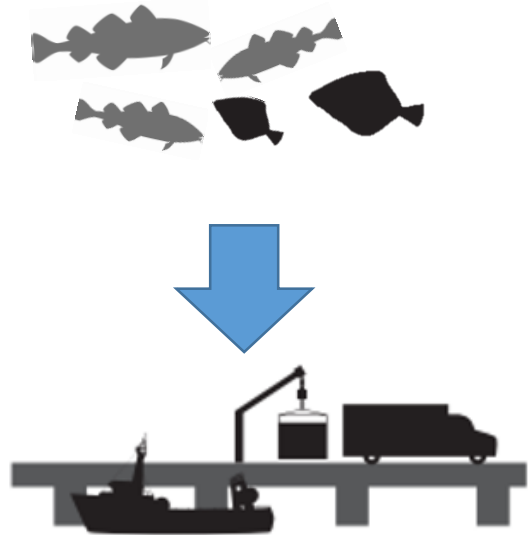
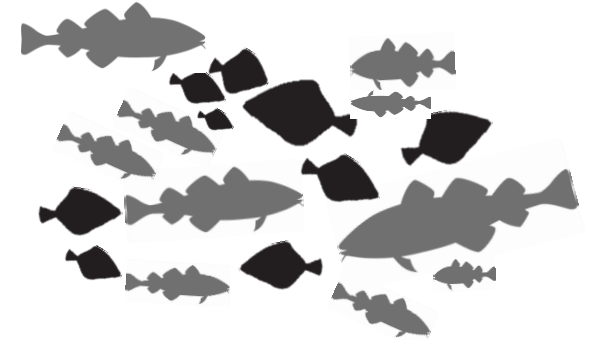
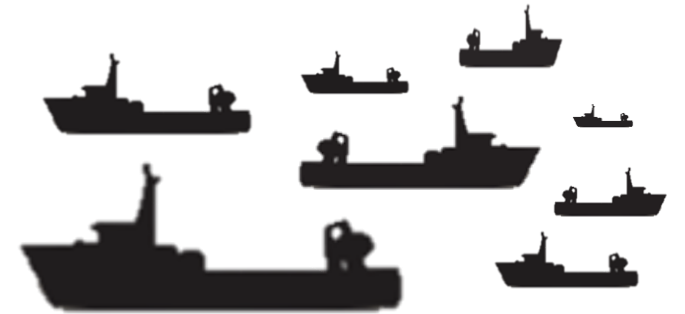
Observed trips ($\sim < 20\%$)



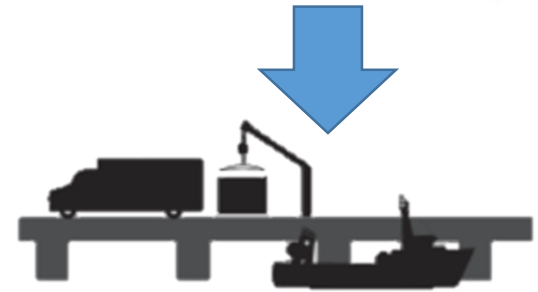
Discard rate of
sub-legals



Unobserved trips ($\sim > 80\%$)



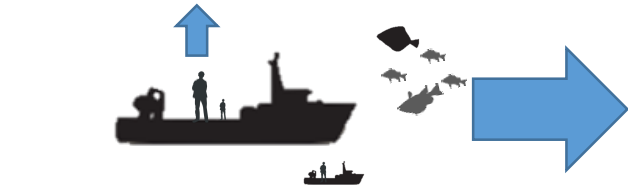
Landed catch reports by dealers



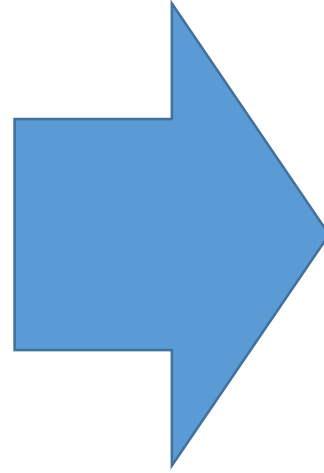
+ assumed discard rate
= total removals

Observed trips (~<20%)

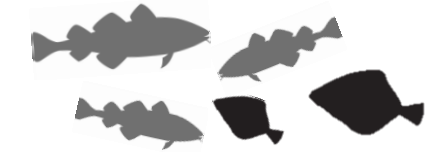
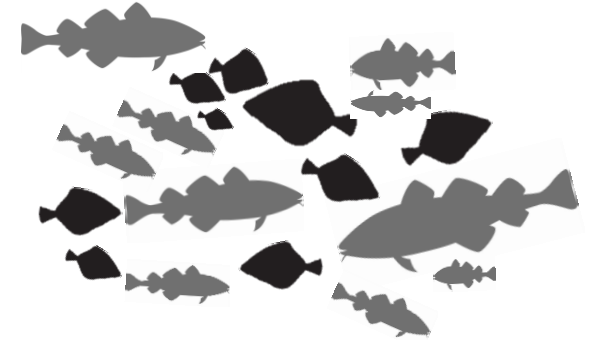
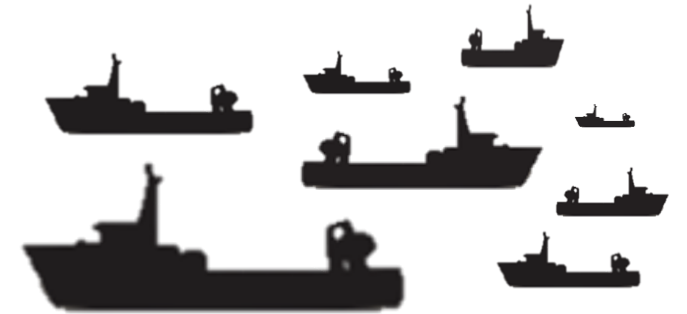
Opportunity for enforcement



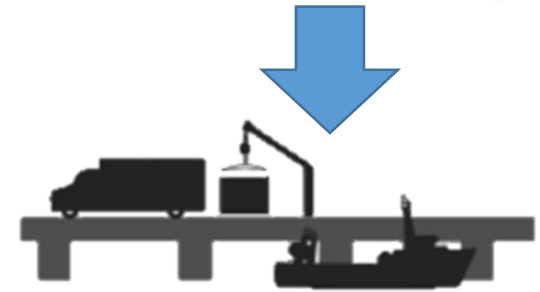
Discard rate of
sub-legals



Unobserved trips (~>80%)



Landed catch reports by dealers



+ assumed discard rate
= total removals

Observed trips (~<20%)

What is unobserved catch?

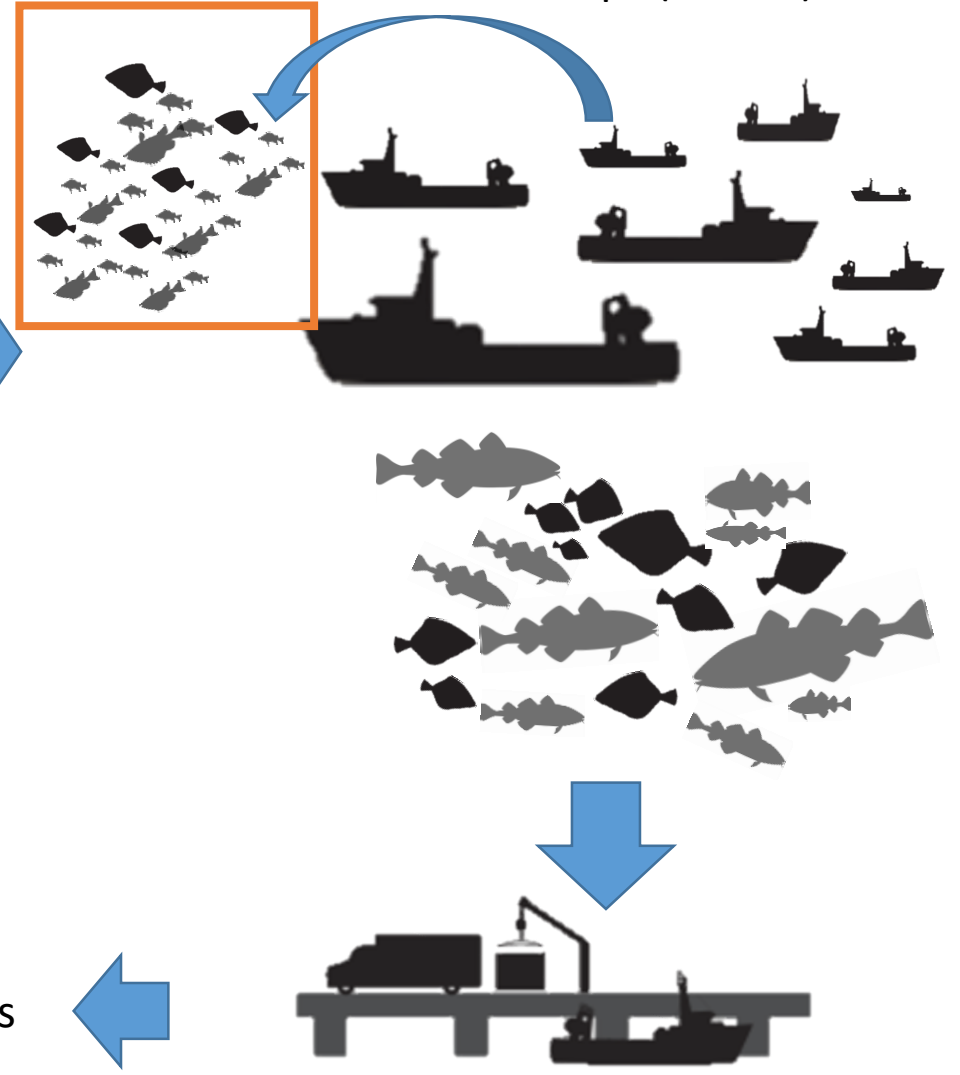
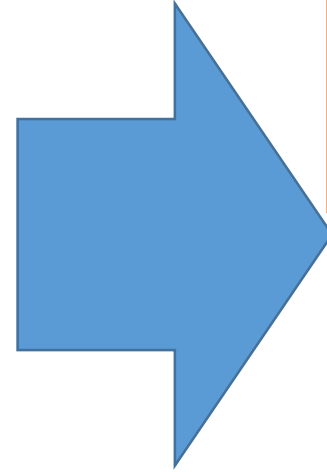
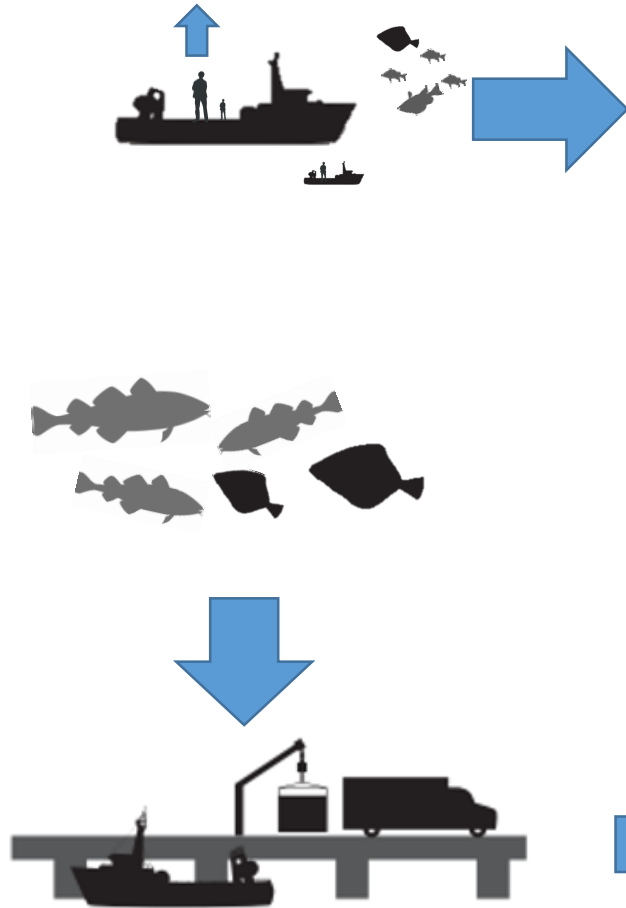
Unobserved trips (~>80%)

Opportunity for enforcement

Discard rate of
sub-legals

Landed catch reports by dealers

+ assumed discard rate
= total removals



Premise:

- Enforcement on unobserved trips may be very low if not impossible
- Opportunity for illegal discarding is greater– but when is this economically rational?

In this work, we attempt to illustrate the **economic factors** that influence decisions to illegally discard legal-sized fish in order to better understand the temporal and stock-specific dimensions of **risk for non-compliance** and any resulting **bias in the catch accounting system**.

Research Questions

- For what stocks and years may illegal discarding have been incentivized on unobserved trips 2007-2017?
- What are indicators of discard incentives?

Theoretical Approach: When is discarding legal-sized fish is rational?

$$Id_{ik} = [(Cl_i(q_i) - Cd_i(q_i)) / (p_{fi} * q_i)]_k.$$

i =stock

k =trip

q = quantity (live pounds)

p_f = ex-vessel price

Cl = cost of landing

Cd =cost of discarding

Cost of landing

$$Cl_i(q_i)_k = \left\{ pq_i * q_i + (1 - \delta_k) \left[\left(\sum_{j=1}^n pq_j * r_j \right) * q_i \right] + Cll(q_i) + sf_h * q_i + lf * q_i \right\}_k$$

$i = \text{stock}$

$k = \text{trip}$

$j = \text{stratum (sector, gear, area)}$

$h = \text{sector}$

$pq = \text{quota price}$

$q = \text{quantity (live pounds)}$

$\delta = \text{percent of tows observed}$

$r = \text{discard rate}$

$Cll = \text{cost of labor of landing}$

$sf = \text{sector fees}$

$lf = \text{landing fees}$

Cost of discarding

$$Cd_i(q_i)_k = [pf_i * q_i + Cdl(q_i) + p(d) * s]_k$$

p_f = ex-vessel price

Cdl = cost of labor of discarding

$p(d)$ = probability of detection

s = sanction associated with getting caught.

Methods

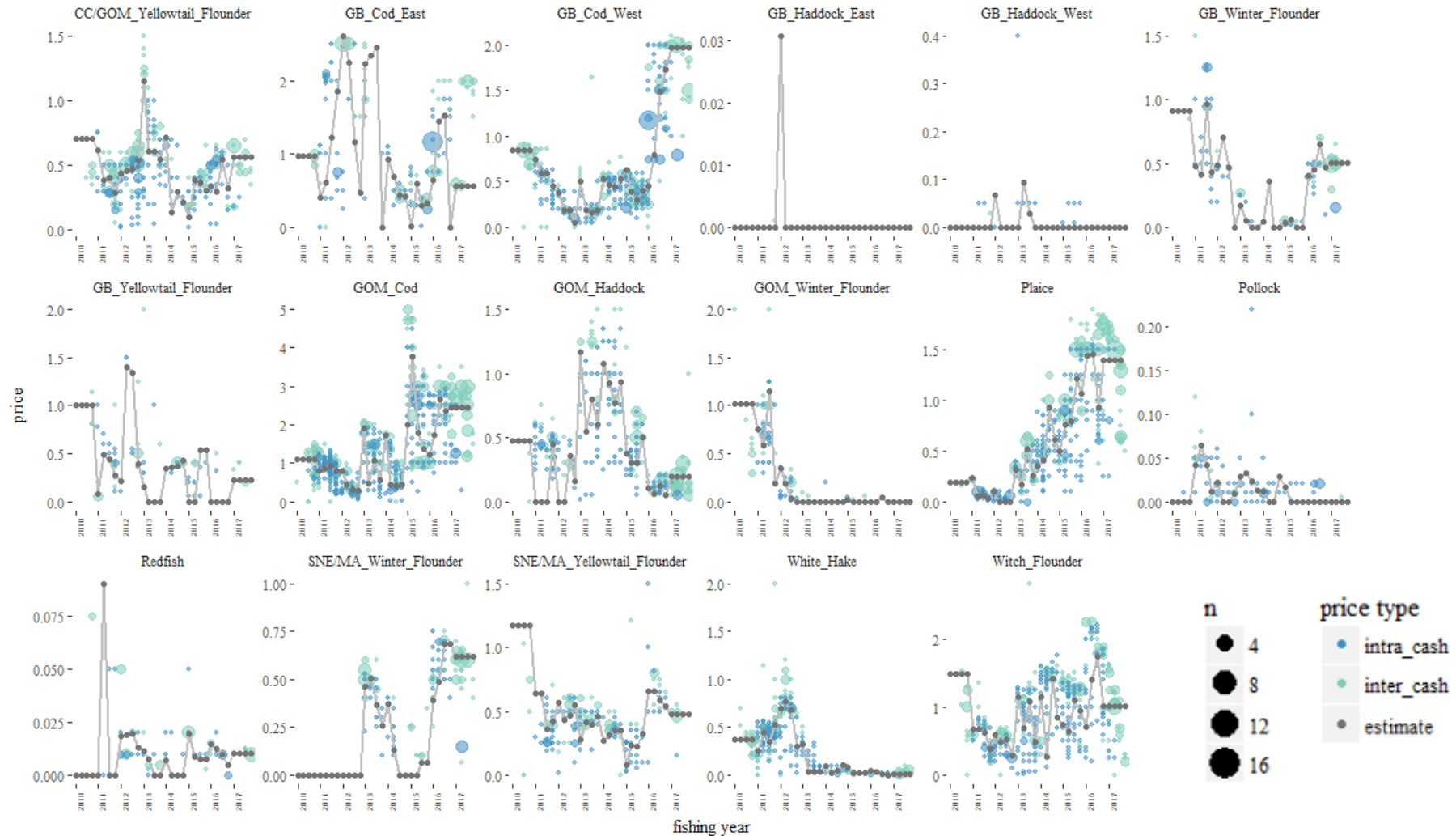
- Incentives are estimated on all unobserved trips 2007-2017 for each allocated stock
- Baseline years not reflective of different regulatory regime
- DMIS data: landings and values, discard rates
- Constants:
 - cost of labor of landing/discarding,
 - landing fees,
 - probability of detection and sanction
- Hedonic price model (Murphy et al. 2015)
 - Inter-sector quota trades are available from DMIS (all years)
 - Intra-sector quota trades are available from sector year-end reports (2011-2016)
- NEFS IX trips are removed due to known misreporting

Assumptions

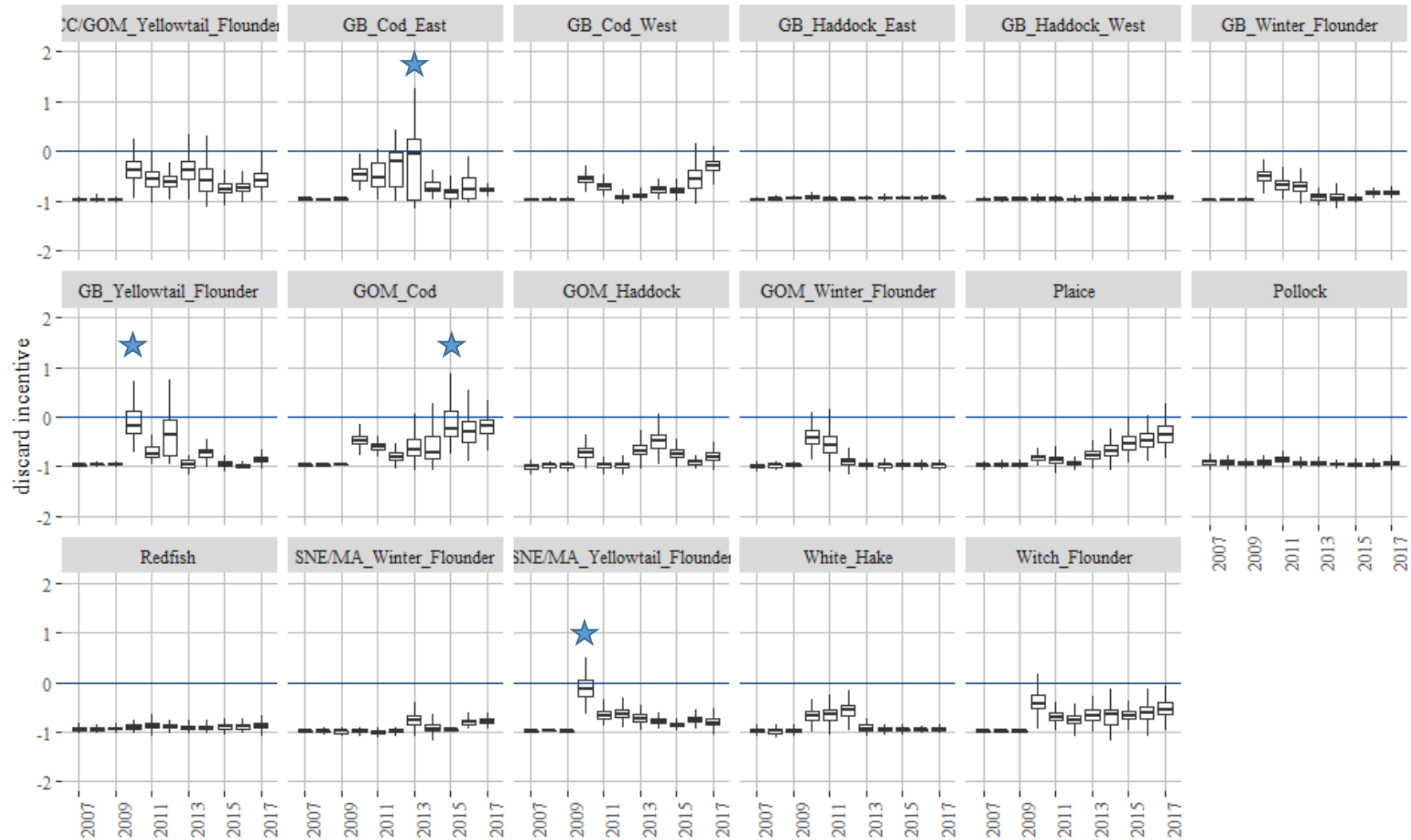
- All data are accurate
 - Landings data are accurate (no misreporting, errors, or missing data)
 - Markets are unaffected by illegal discarding or misreporting;
- Prices match expectations:
 - Modeled quota prices;
 - Ex-vessel prices;
- No “endowment” effect ;
- Probability of detection is very low;
- Costs of labor are constant;
- No shadow value of biomass

Results

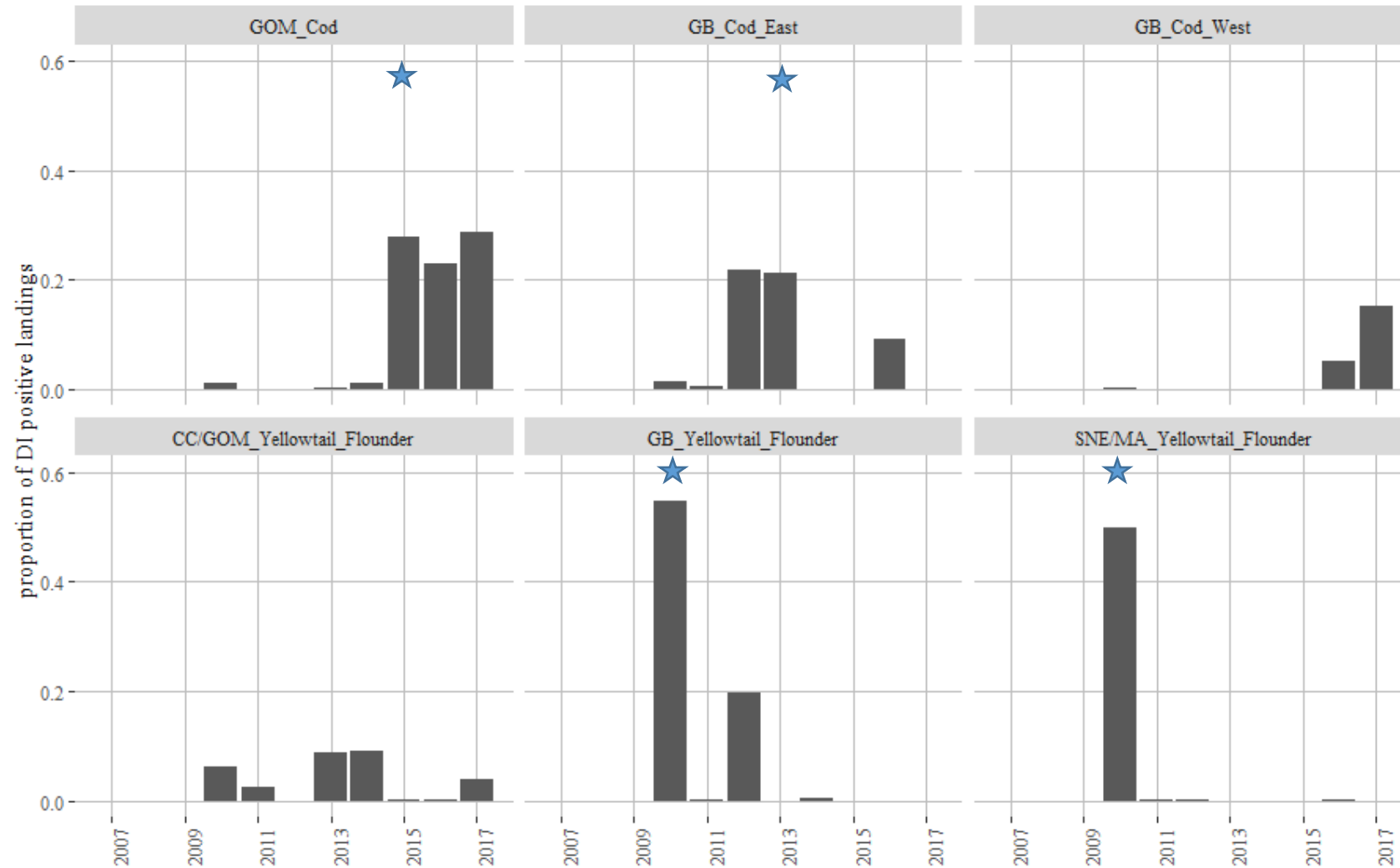
Modeled Quota Prices, inter and intra sector single-stock cash trades



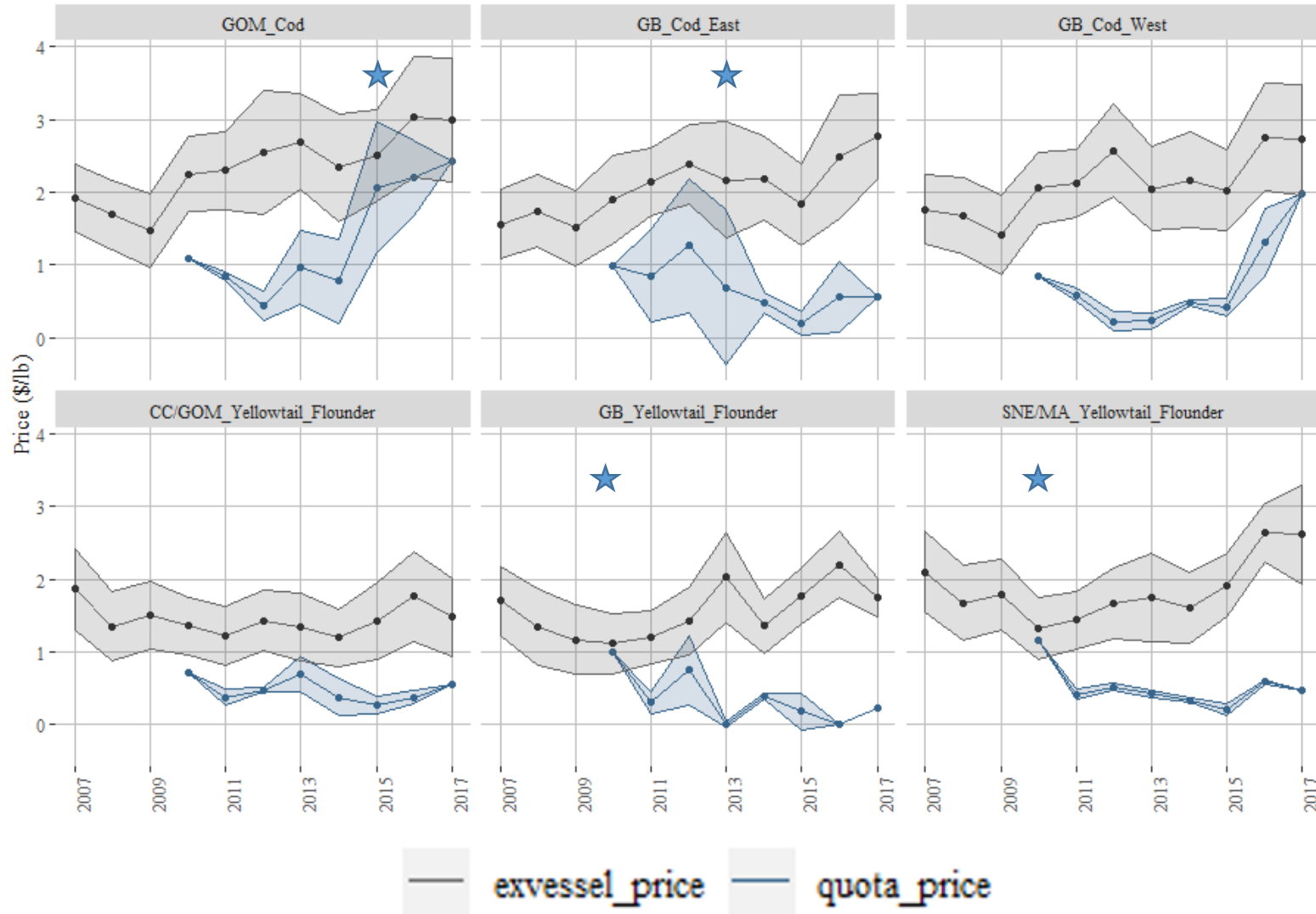
Discard incentive for each stock by trip 2007-2017



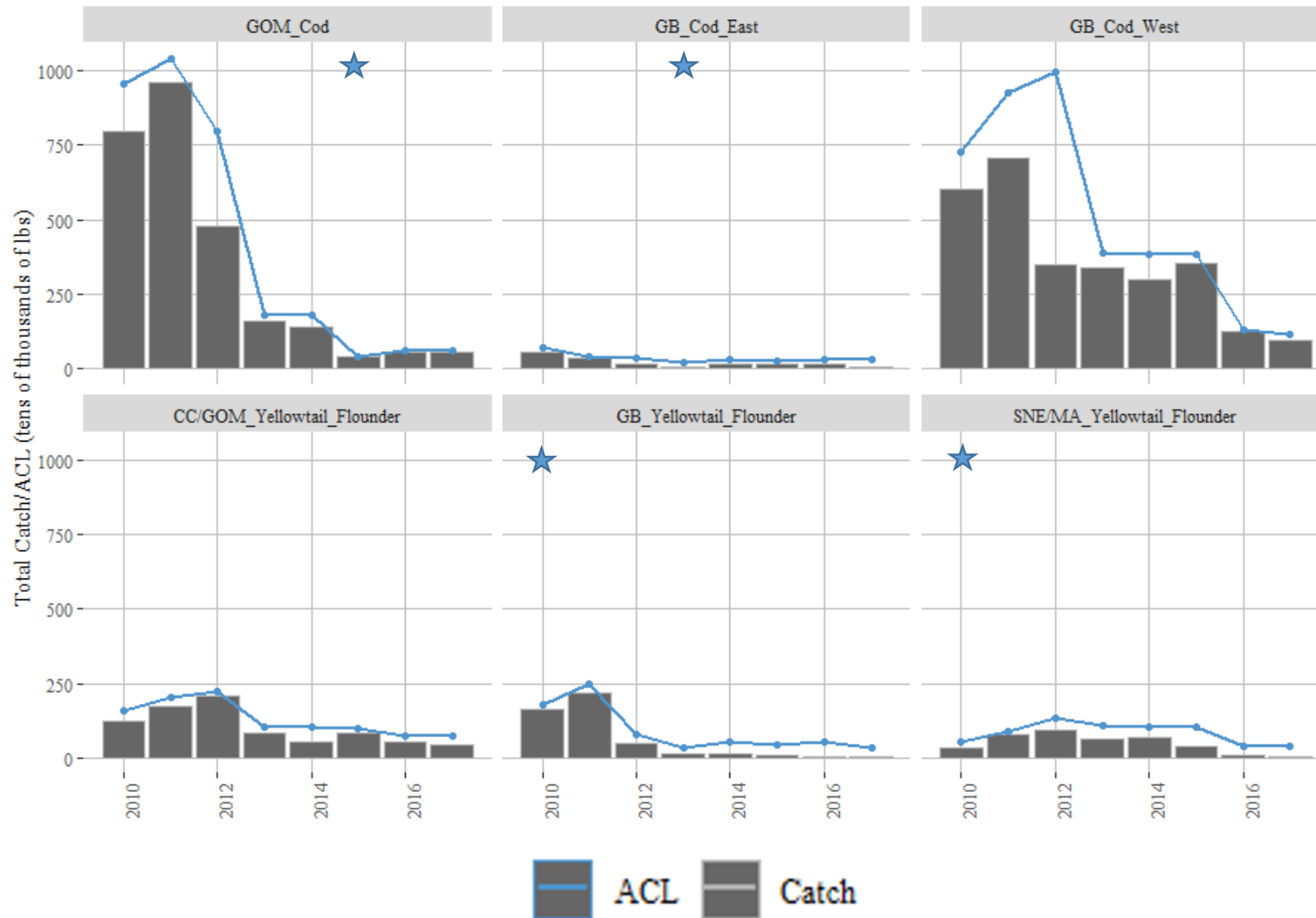
Proportion of landings with a positive discard incentive 2007-2017



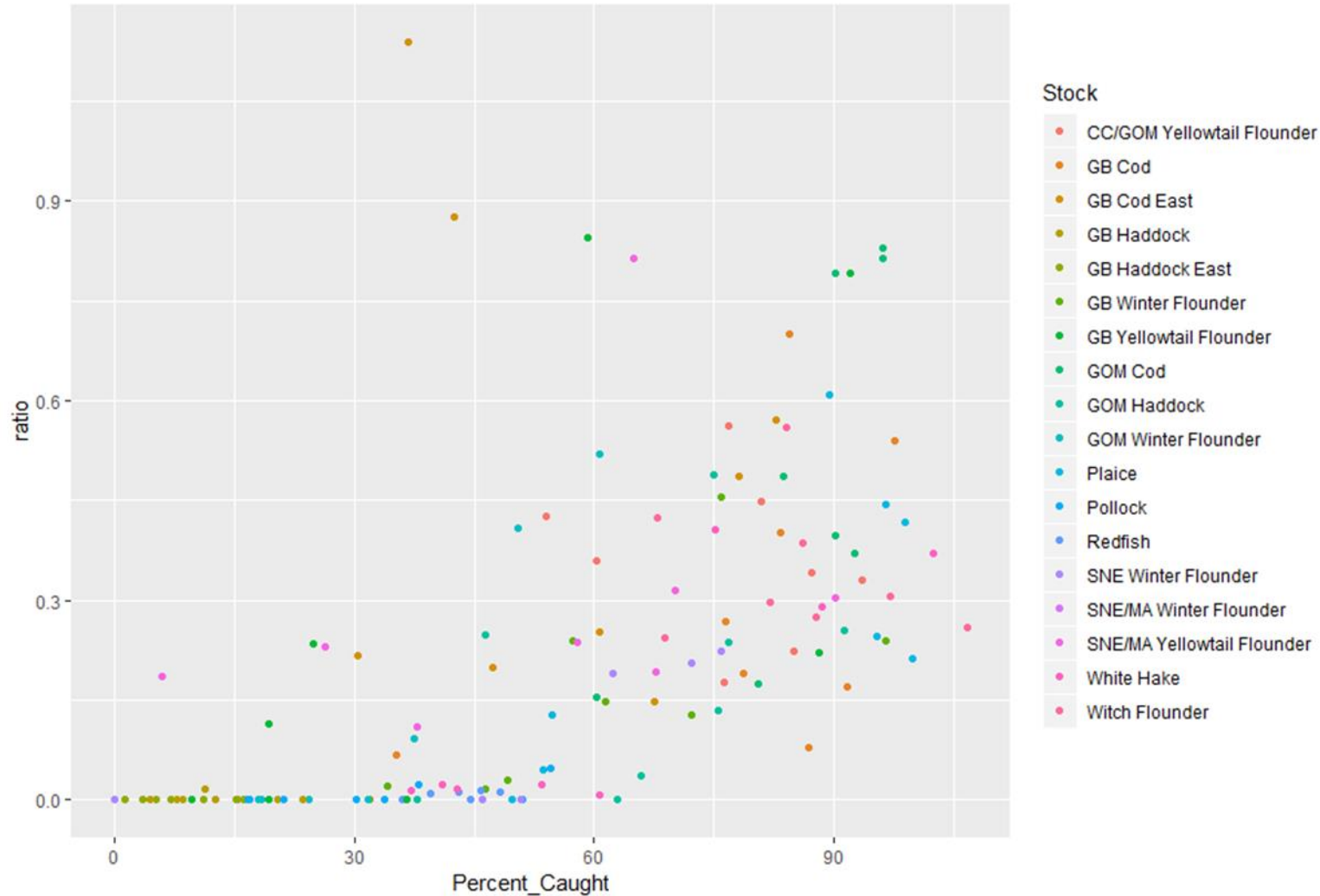
Quota prices : ex-vessel prices drive discard incentives



How does utilization correspond with discard incentives?



There is not a strong relationship between annual utilization and quota price ratios



PDT Conclusions

- Quota costs increase discard incentives for many stocks relative to baseline.
 - Highest modeled discard incentives: yellowtail flounder and cod
 - Low discard incentive stocks: pollock, redfish, and Georges Bank haddock.
- Quota price ratios drive discard incentives.
- We can't estimate unreported catch but stocks landed with a positive discard incentive may indicate risk for the total catch estimate for that stock.
- Utilization is weakly related to quota price and varies by stock, other metrics, combination of metrics needed.
- There may be other social, cultural, or normative factors that influence illegal discarding.

Strengths and Weaknesses

- Strength:
 - Identifies major components that influence discarding behavior
- Weaknesses/constraints:
 - Not predictive: cannot identify the magnitude of illegal discarding
 - Highly sensitive to modelled quota price
 - Intra-sector quota prices not available in-season
 - True value of quota likely not accurately captured by quota price, underestimates true incentive to discard

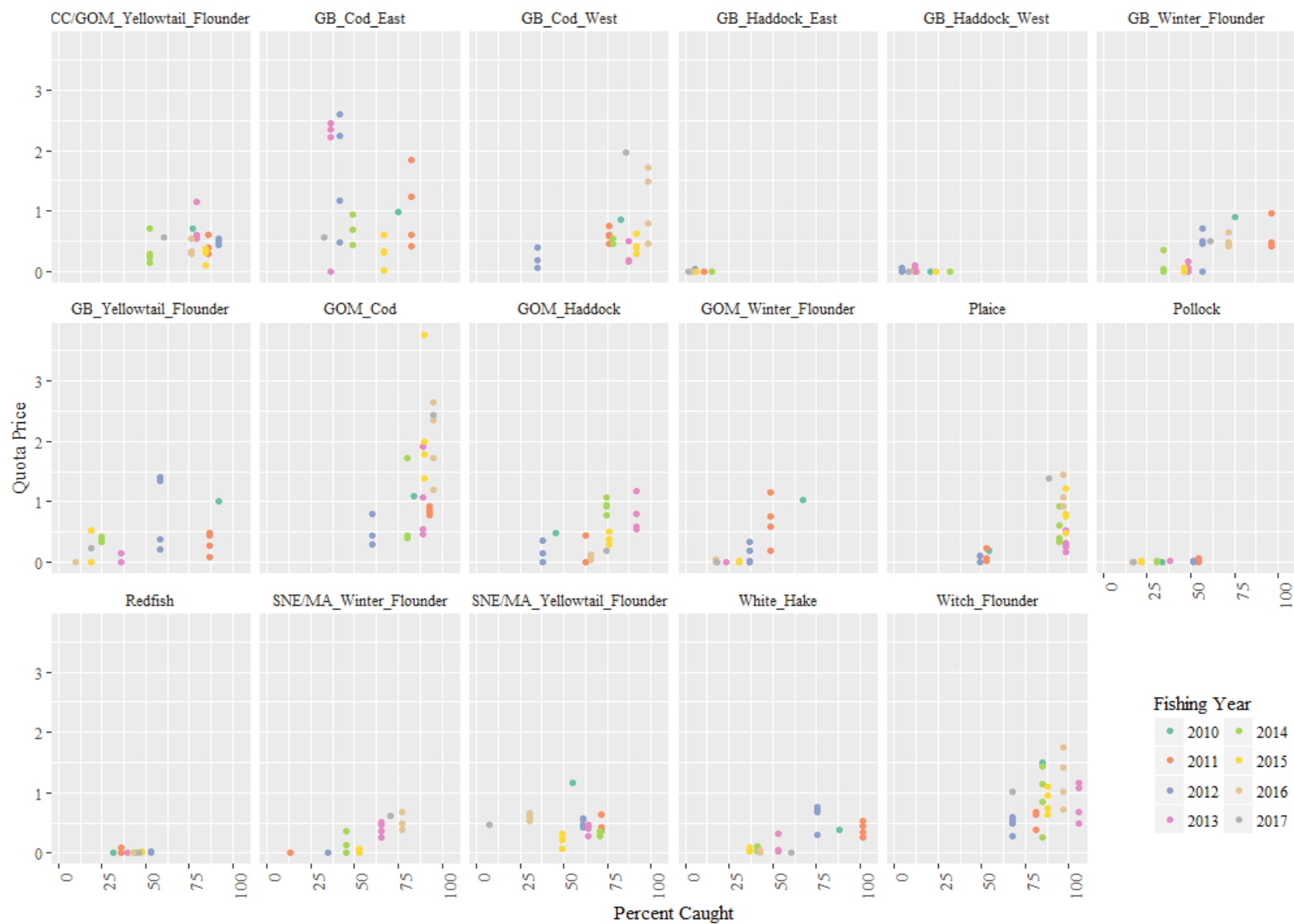
Areas for future work

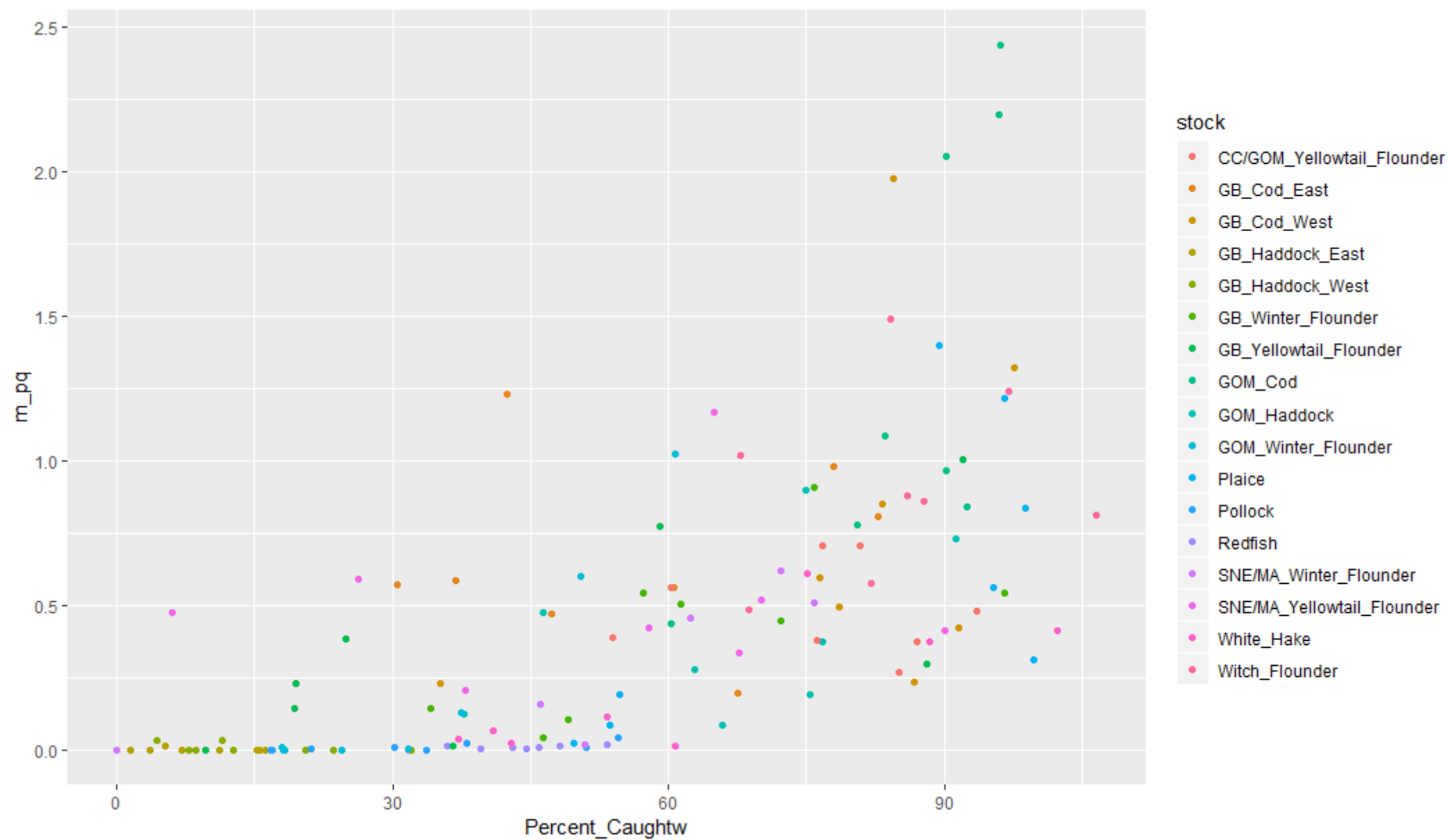
- Quota prices
 - Availability of in-season quota leasing information will enhance the ability to track, monitor, or enforce based on discard incentives.
- More modelling.
- Improved understanding of social, cultural, or normative factors.

Supplementary figures

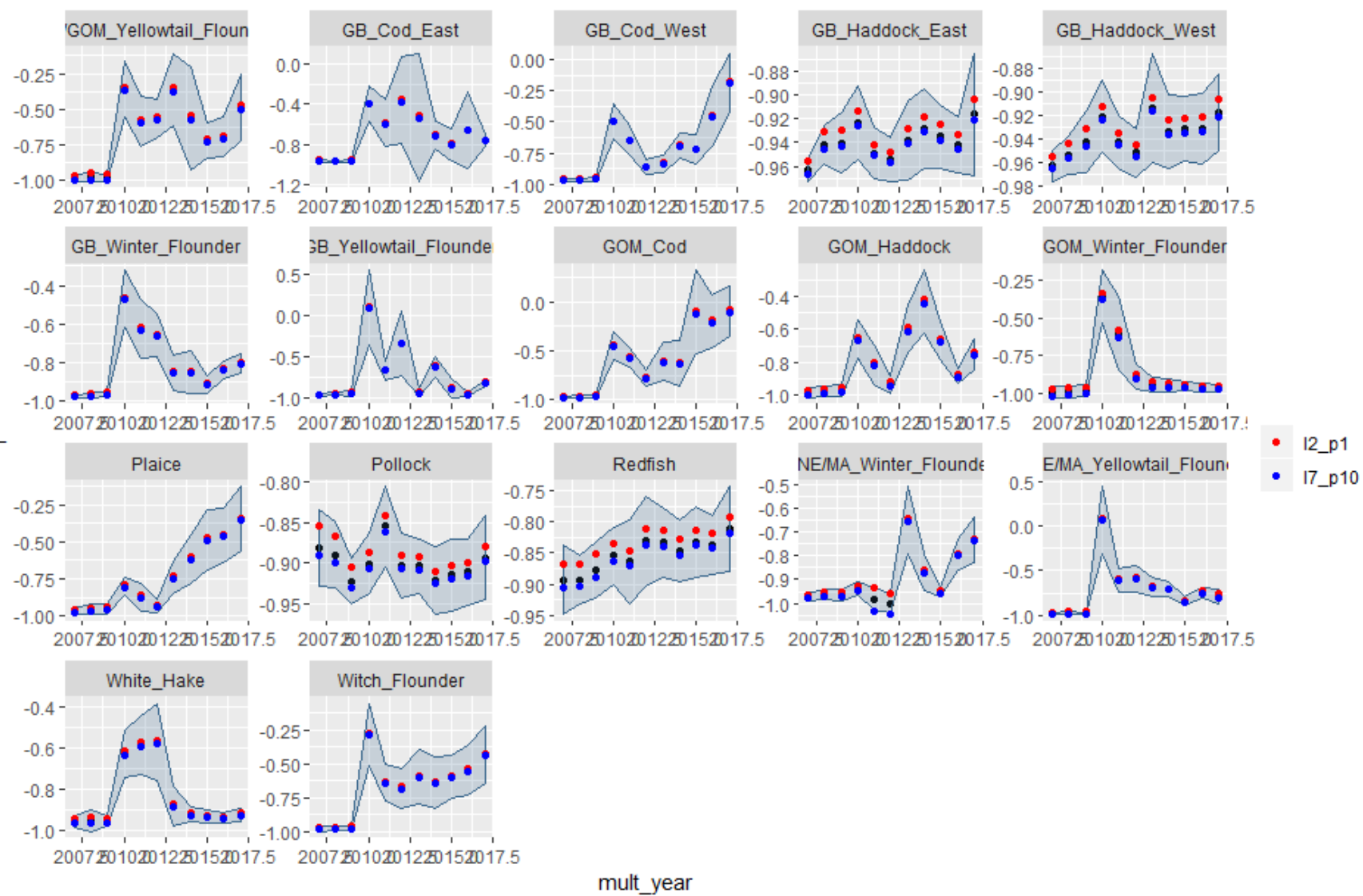
Table 3. Stock status

Stock	2017 Assessment	
	Overfishing?	Overfished?
GB Cod	Unknown	Yes
GOM Cod	Yes	Yes
GB Haddock	No	No
GOM Haddock	No	No
GB Yellowtail Flounder	Yes	Yes
SNE/MA Yellowtail Flounder	Yes	Yes
CC/GOM Yellowtail Flounder	Yes	Yes
American Plaice	No	No
Witch Flounder	Unknown	Yes
GB Winter Flounder	No	Approaching ²
GOM Winter Flounder	No	Unknown
SNE/MA Winter Flounder	No	Yes
Acadian Redfish	No	No
White Hake	No	No
Pollock	No	No
Northern Windowpane Flounder	No	Yes
Southern Windowpane Flounder	No	No
Ocean Pout	No	Yes
Atlantic Halibut	No	Yes
Atlantic Wolffish	No	Yes

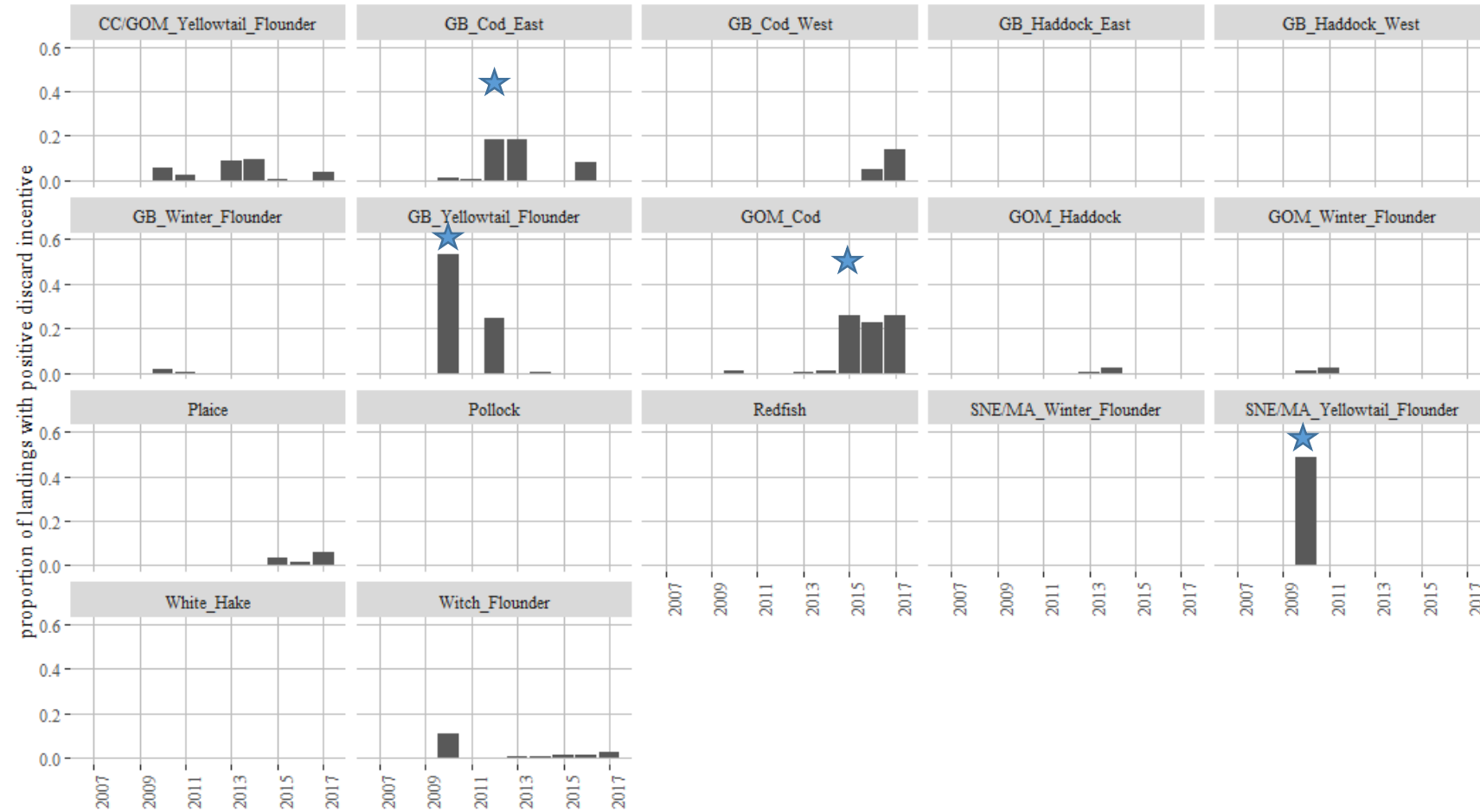




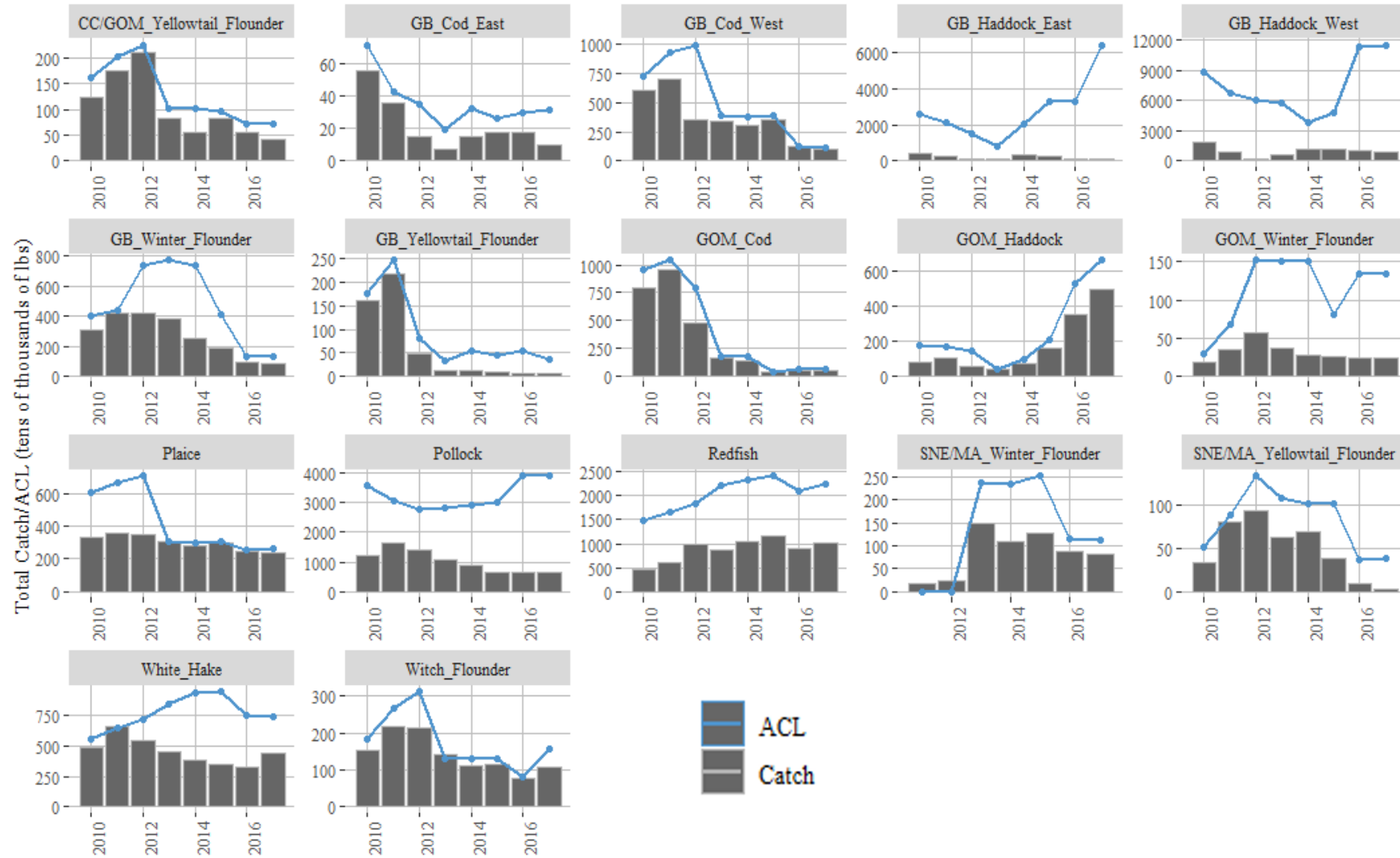




Proportion of landings with a positive discard incentive 2007-2017



Utilization as an exogenous factor does not alone explain trends



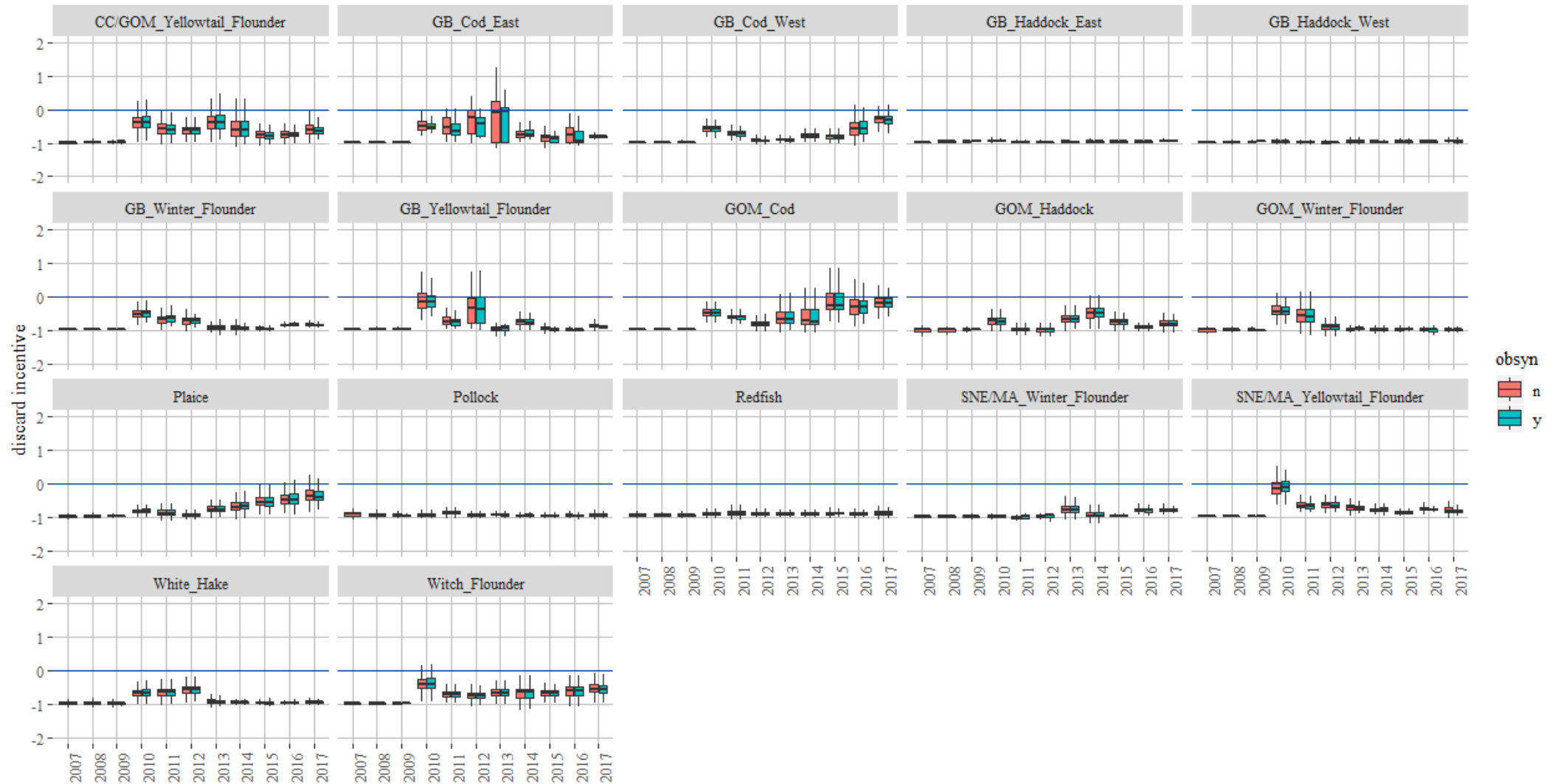
Quota prices : ex-vessel prices drive discard incentives



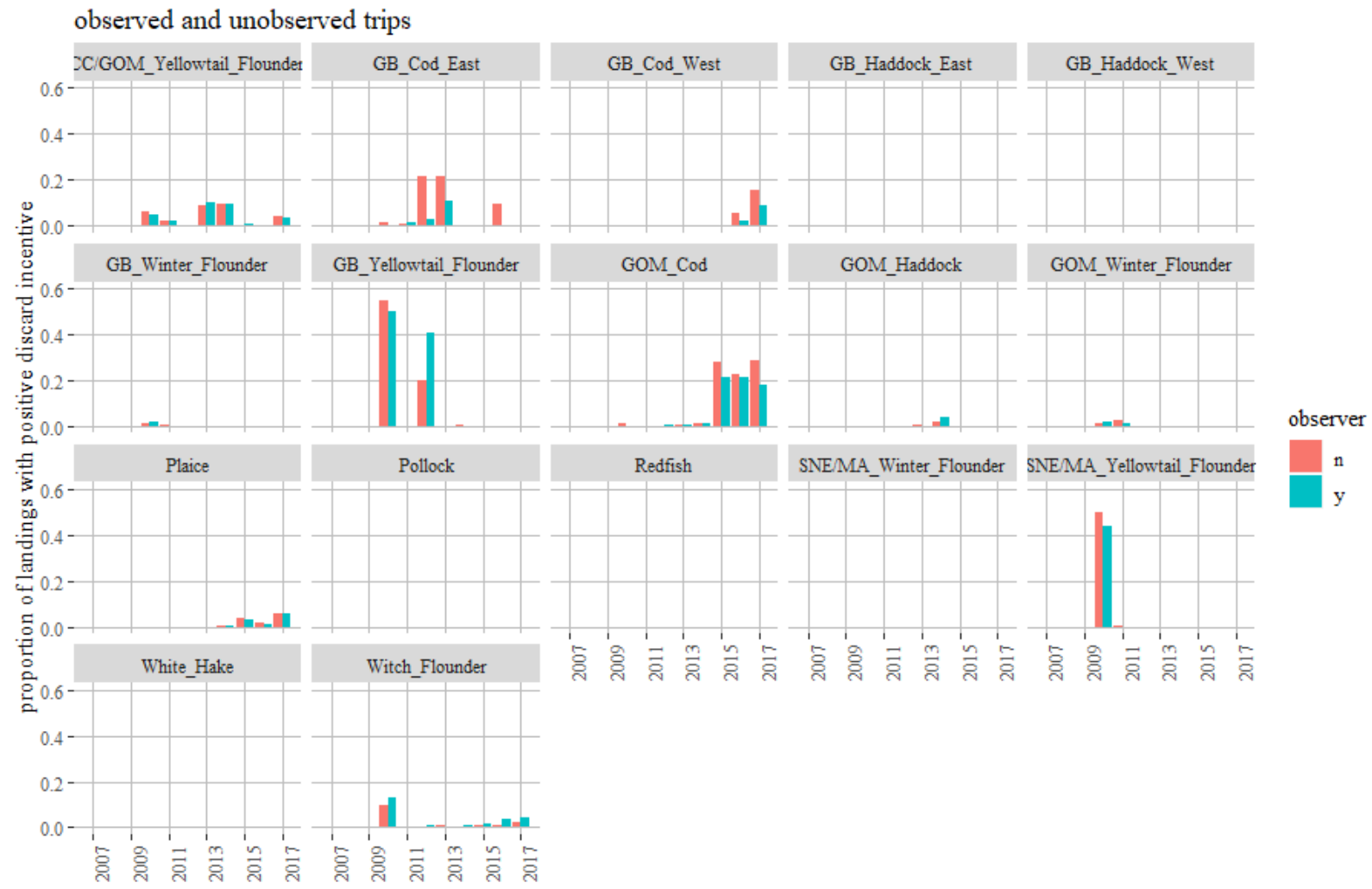
Number of single stock cash trades



Discard incentives on observed and unobserved trips (no change in model specification)



Differences in proportion of DI positive landings between observed and unobserved trips (no change in model specification)



"No ice bought or used.

Captain said target for trip was less observer coverage."

Chad Demarest
NEFSC / READ / SSB
April 24, 2019

Evidence shows that vessels behave differently in response to an observer.

- ① Hawthorne Effect
 - We act differently when we're being watched*
- ② Inconvenience costs
 - Observers incur costs associated with food, slower fish processing and general inconvenience*
- ③ Within-strata heterogeneity for discard monitoring
 - Fisherman don't want to impart their personal discard preferences on their counterparts*
- ④ Higher catch rates in areas/at times where more undersized fish are relatively more abundant
 - Fishing shifts from areas of higher juvenile abundance, or vessels use more selective methods/techniques*
- ⑤ Binding quota constraints and high-grading
 - Fish are retained that may otherwise be discarded, or certain stocks are avoided altogether when observed*

EXACT MATCHING ANALYSIS

Compares same-vessel behavior on sequential trips

Trip sequences:

- U U U: *three unobserved trips in a row*
- U O U: *one observed trip between two unobserved trips*

Paired trips:

- Randomly select either the lead or lag (last or first) trip in the sequence to compare to the center trip
- Matched pairs in two groups: U-U or O-U
- Standardize, dividing by vessel annual mean value

Data cleaning:

- Trawl and gillnet gears only
- Trips no more than 45 days apart
- Breaks at fishing year
- Trip sequences from vessels with <6 unobserved trips in a year removed

Time stanzas:

- Fishing year
- Aggregated:
 - Pre-catch shares (2007-2009)
 - Initial CS (2010-2012)
 - Intermediate CS (2013-2015)
 - Contemporary CS (2016-2017)

Metrics

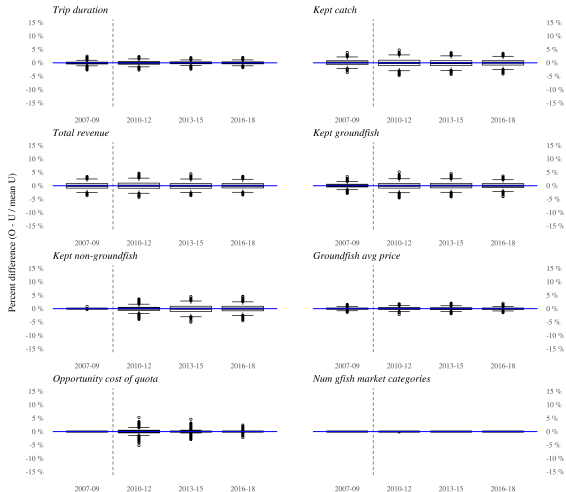
- ① Trip duration
- ② Kept catch
- ③ Total revenue
- ④ Kept groundfish
- ⑤ Kept non-groundfish
- ⑥ Groundfish average price
- ⑦ Opportunity cost of groundfish quota
- ⑧ Number of groundfish market categories included in kept catch

"I understand that we are trying to eliminate discards but it's already going on. When lease price is 1.50 on dabs and you can't make that catching them you'll see mediums and large on the auctions.

I think you see that already by what is landed...just like you don't see a lot of scrod cod just market and large.

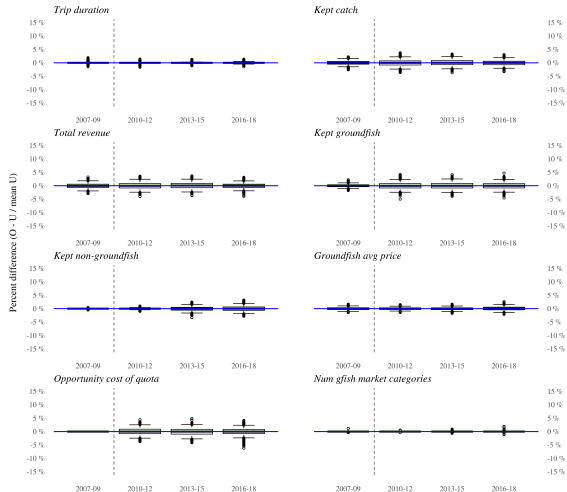
When you try to use landings for science it doesn't work."

Trawl vessels - pooled and undifferentiated
observed and unobserved (No Treatment Model)



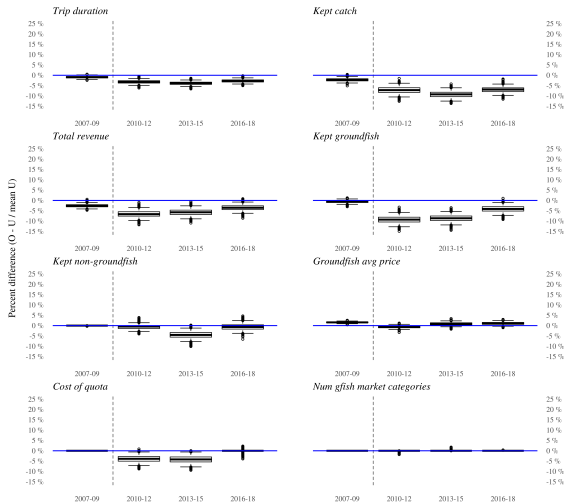
Median bootstrap values from 1,000 replicates,
5000 paired samples drawn per replicate from
trips paired irrespective of observer status in each period

Gillnet vessels - pooled and undifferentiated
observed and unobserved (No Treatment Model)



Median bootstrap values from 1,000 replicates,
5000 paired samples drawn per replicate from
trips paired irrespective of observer status in each period

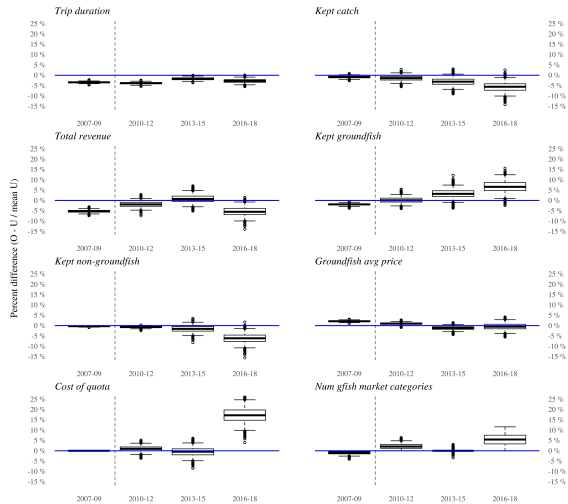
Trawl vessels



Median bootstrap values from 1,000 replicates.
number of paired samples drawn per replicate is equal to
number paired trips in each period

Stanza

Gillnet vessels



Median bootstrap values from 1,000 replicates.
number of paired samples drawn per replicate is equal to
number paired trips in each period

Stanza

Table 1: Stanza 1, 2007-2009

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish		-1.9 %	-0.6 %	0.5 %	10,844	726
Trawl	Number groundfish market categories		0 %	0 %	0 %	10,844	726
Trawl	Groundfish avg price	*	0.9 %	1.6 %	2.3 %	10,845	726
Trawl	Kept catch	*	-3.7 %	-2.2 %	-0.7 %	10,845	726
Trawl	Kept non-groundfish		0 %	0 %	0 %	10,845	726
Trawl	Opportunity cost of quota		0 %	0 %	0 %	10,845	726
Trawl	Total revenue	*	-4.1 %	-2.6 %	-1.1 %	10,845	726
Trawl	Trip duration		-2 %	-0.9 %	0 %	10,845	726

Table 2: Stanza 2, 2010-2012

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-12.6 %	-9.3 %	-5.9 %	2,787	1,413
Trawl	Number groundfish market categories		-0.4 %	0 %	0 %	2,787	1,413
Trawl	Groundfish avg price		-1.9 %	-0.6 %	0.6 %	2,787	1,413
Trawl	Kept catch	*	-10.2 %	-7.2 %	-4.1 %	2,787	1,413
Trawl	Kept non-groundfish		-3.3 %	-0.4 %	1.7 %	2,787	1,413
Trawl	Opportunity cost of quota	*	-7.3 %	-3.9 %	-0.8 %	2,787	1,411
Trawl	Total revenue	*	-9.4 %	-6.6 %	-3.4 %	2,787	1,413
Trawl	Trip duration	*	-4.9 %	-3.2 %	-1.6 %	2,787	1,413

Table 3: Stanza 3, 2013-2015

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-12 %	-8.6 %	-5.4 %	2,920	954
Trawl	Number groundfish market categories		0 %	0 %	0.1 %	2,920	954
Trawl	Groundfish avg price		-0.5 %	0.8 %	2.3 %	2,920	954
Trawl	Kept catch	*	-12.3 %	-9.2 %	-6.1 %	2,920	954
Trawl	Kept non-groundfish	*	-7.9 %	-4.5 %	-1.4 %	2,920	954
Trawl	Opportunity cost of quota	*	-8 %	-4.2 %	-0.6 %	2,920	954
Trawl	Total revenue	*	-8.8 %	-5.7 %	-2.8 %	2,920	954
Trawl	Trip duration	*	-5.5 %	-3.8 %	-2.3 %	2,920	954

Table 4: Stanza 4, 2016-2018

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Trawl	Kept groundfish	*	-7 %	-4.1 %	-1.2 %	2,805	799
Trawl	Number groundfish market categories		0 %	0 %	0 %	2,805	799
Trawl	Groundfish avg price		-0.2 %	1.1 %	2.4 %	2,805	799
Trawl	Kept catch	*	-9.9 %	-6.9 %	-4.3 %	2,805	799
Trawl	Kept non-groundfish		-3.5 %	-0.7 %	2.5 %	2,805	799
Trawl	Opportunity cost of quota		-1.7 %	0 %	1 %	2,805	799
Trawl	Total revenue	*	-6.3 %	-3.5 %	-0.7 %	2,805	799
Trawl	Trip duration	*	-4.2 %	-2.7 %	-1.3 %	2,805	799

Table 5: Stanza 1, 2007-2009

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish	*	-2.9 %	-1.9 %	-1 %	10,782	531
Gillnet	Number groundfish market categories		-2.8 %	-1 %	0 %	10,782	531
Gillnet	Groundfish avg price	*	1.5 %	2.1 %	2.8 %	10,782	531
Gillnet	Kept catch		-1.9 %	-0.8 %	0.1 %	10,782	531
Gillnet	Kept non-groundfish		-0.6 %	-0.3 %	0 %	10,782	531
Gillnet	Opportunity cost of quota		0 %	0 %	0 %	10,782	531
Gillnet	Total revenue	*	-6.5 %	-5.2 %	-4 %	10,782	531
Gillnet	Trip duration	*	-4.2 %	-3.4 %	-2.7 %	10,782	531

Table 6: Stanza 2, 2010-2012

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish		-2.4 %	0.1 %	3.2 %	2,609	1,330
Gillnet	Number groundfish market categories		0 %	2.1 %	4.9 %	2,609	1,330
Gillnet	Groundfish avg price		-0.2 %	1 %	2 %	2,609	1,330
Gillnet	Kept catch		-4.1 %	-1.4 %	1 %	2,609	1,330
Gillnet	Kept non-groundfish		-1.6 %	-0.7 %	0 %	2,609	1,330
Gillnet	Opportunity cost of quota		-1.8 %	0.9 %	3.8 %	2,609	1,330
Gillnet	Total revenue		-4.7 %	-1.9 %	1.1 %	2,609	1,330
Gillnet	Trip duration	*	-4.8 %	-3.8 %	-2.8 %	2,609	1,330

Table 7: Stanza 3, 2013-2015

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish		-0.9 %	3.2 %	7.6 %	1,622	434
Gillnet	Number groundfish market categories		-0.9 %	0 %	1.4 %	1,622	434
Gillnet	Groundfish avg price		-2.9 %	-1.2 %	0.4 %	1,622	434
Gillnet	Kept catch		-6.5 %	-3.1 %	0.4 %	1,622	434
Gillnet	Kept non-groundfish		-5.1 %	-1.6 %	1.2 %	1,622	434
Gillnet	Opportunity cost of quota		-5 %	-0.5 %	4.2 %	1,622	434
Gillnet	Total revenue		-3 %	0.7 %	4.9 %	1,622	434
Gillnet	Trip duration	*	-3 %	-1.7 %	-0.4 %	1,622	434

Table 8: Stanza 4, 2016-2018

Gear	Variable	CIs <> 0	95% CI, lower	Median	95% CI, upper	n Unobserved	n Observed
Gillnet	Kept groundfish	*	1.1 %	6.6 %	12.2 %	833	277
Gillnet	Number groundfish market categories		0 %	5.5 %	10.3 %	833	277
Gillnet	Groundfish avg price		-3.4 %	-0.5 %	2.7 %	833	277
Gillnet	Kept catch	*	-10.6 %	-5.6 %	-1 %	833	277
Gillnet	Kept non-groundfish	*	-10.8 %	-6.1 %	-1.5 %	833	277
Gillnet	Opportunity cost of quota	*	10.2 %	17.2 %	24.7 %	833	277
Gillnet	Total revenue	*	-9.6 %	-5.5 %	-1.1 %	833	277
Gillnet	Trip duration	*	-4.5 %	-2.7 %	-1 %	833	277

Differences in distribution shape - Kolmogorov-Smirnov test (K-S)

Trawl significant metrics

① Pre-Am16 (stanza 1)

- Groundfish market categories, Average groundfish price, Kept catch

② Post-Am16 (later stanzas)

- Kept groundfish, Kept catch, Total revenue (Stanza 2), Trip Duration (Stanza's 3, 4)

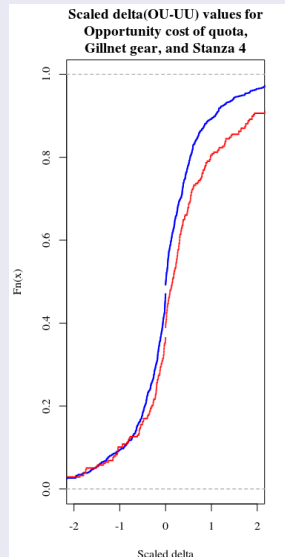
Gillnet significant metrics

① Pre-Am16

- Kept non-groundfish, Total revenue, Trip duration

② Post-Am16

- Groundfish market categories (Stanza 2), No metrics in Stanza 3, Opportunity cost of quota in Stanza 3



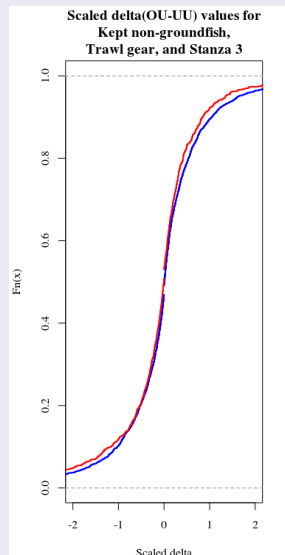
Differences in distribution shape - Kuiper test (K)

Trawl significant metrics

- ① Pre-Am16 (stanza 1)
 - All metrics except Total revenue
- ② Post-Am16 (later stanzas)
 - Similar to location test results, but also includes Opp cost of quota and Groundfish market categories for all three stanzas

Gillnet significant metrics

- ① Pre-Am16
 - Groundfish market categories, Kept non-groundfish, Trip duration
- ② Post-Am16
 - Groundfish market categories (all stanzas), Kept non-groundfish (stanza 2), Trip duration (stanzas 2,4)



The Russ Roberts Report

- Metrics considered but not reported
 - ① HerfindahlHirschman Index
 - ② Non-groundfish market categories
 - ③ Non-groundfish average price
 - ④ Number of statistical areas reported
 - ⑤ Latitude and longitude
- Influential data handling decisions
 - ① Handling sub-trips
 - Stat areas collapsed, arrayed, counted...ultimately dropped
 - Gears collapsed, arrayed, trip assigned gear with most fish reported
 - ② Outliers - excluded all raw data falling outside $2.5 * IQR$
 - ③ Seasonality and the 45 day requirement (days=14, 30, 45, 60)
 - ④ Standardizing by mean unobserved annual values
 - Minimum number of unobserved trips (n=2,3,5,10)
 - Mean vs. median
 - ⑤ To FY overlap or not to FY overlap?

Observed and unobserved trips are fundamentally different

- Vessels catch less fish and fish for less time when observers are on board
 - Effect is more pronounced for trawl vessels than gillnetters, most recent stanza notwithstanding
- On observed trips:
 - Trawl vessels keep less groundfish
 - Gillnet vessels keep less non-groundfish and more groundfish, with a time trend
 - Contemporary stanza: gillnet vessels land more market categories of groundfish on observed trips, have higher opportunity cost of quota
- Response changed with implementation of catch share system
- **Non-uniform changes across metrics (avg. price, groundfish vs. non-groundfish kept catch, opp cost of quota, market categories) imply the composition of catch is fundamentally different on observed trips**

IMPLICATIONS FOR MONITORING

Estimates derived from biased samples are wrong in ways that are difficult to interpret. The appropriate policy response may depend on the nature of the bias.

Is the motivation manipulating the discard rate, non-compliance with retention regulations, a mix...or something different?

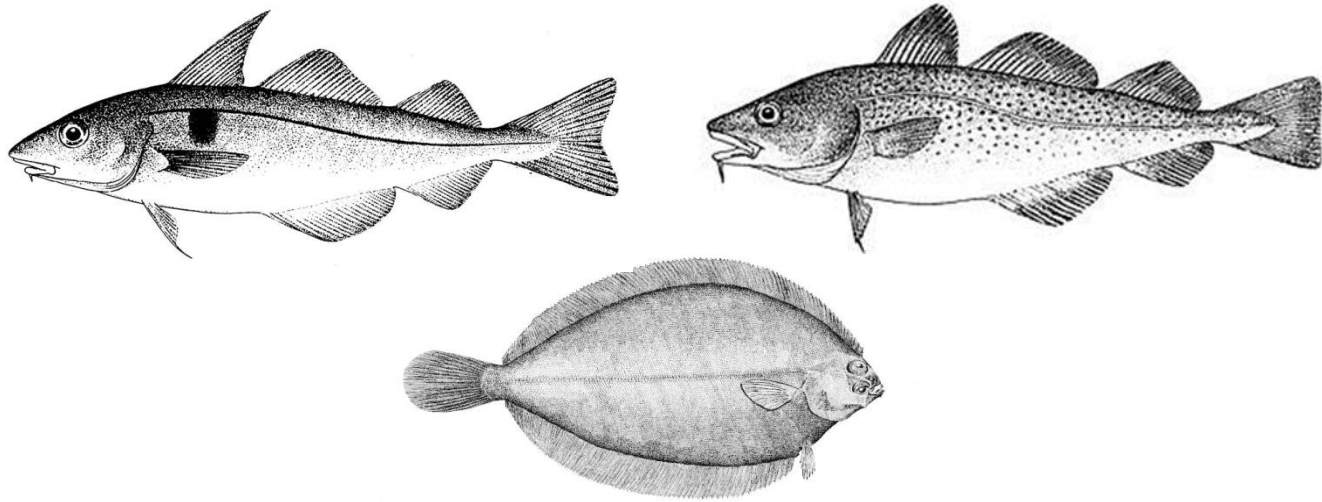
Must understand which apply, and in what proportions

- ① Hawthorne Effect
- ② Inconvenience costs
- ③ Within-strata heterogeneity for discard monitoring
- ④ Higher catch rates in areas/at times where more undersized fish are relatively more abundant
- ⑤ Binding quota constraints / high-grading

"Nice trip, captain and crew cooperative, hardly any discards on quota species—captain seemed conscious of avoiding discards with use of different gear, nets, areas.

Have a great day!"

Comparison of sector vessel landings effort ratios between observed and unobserved trips by gear and broad stock area



- GOM Stock Area 1
- Inshore GB Stock Area 2
- Offshore GB Stock Area 3
- SNE/MA Stock Area 4

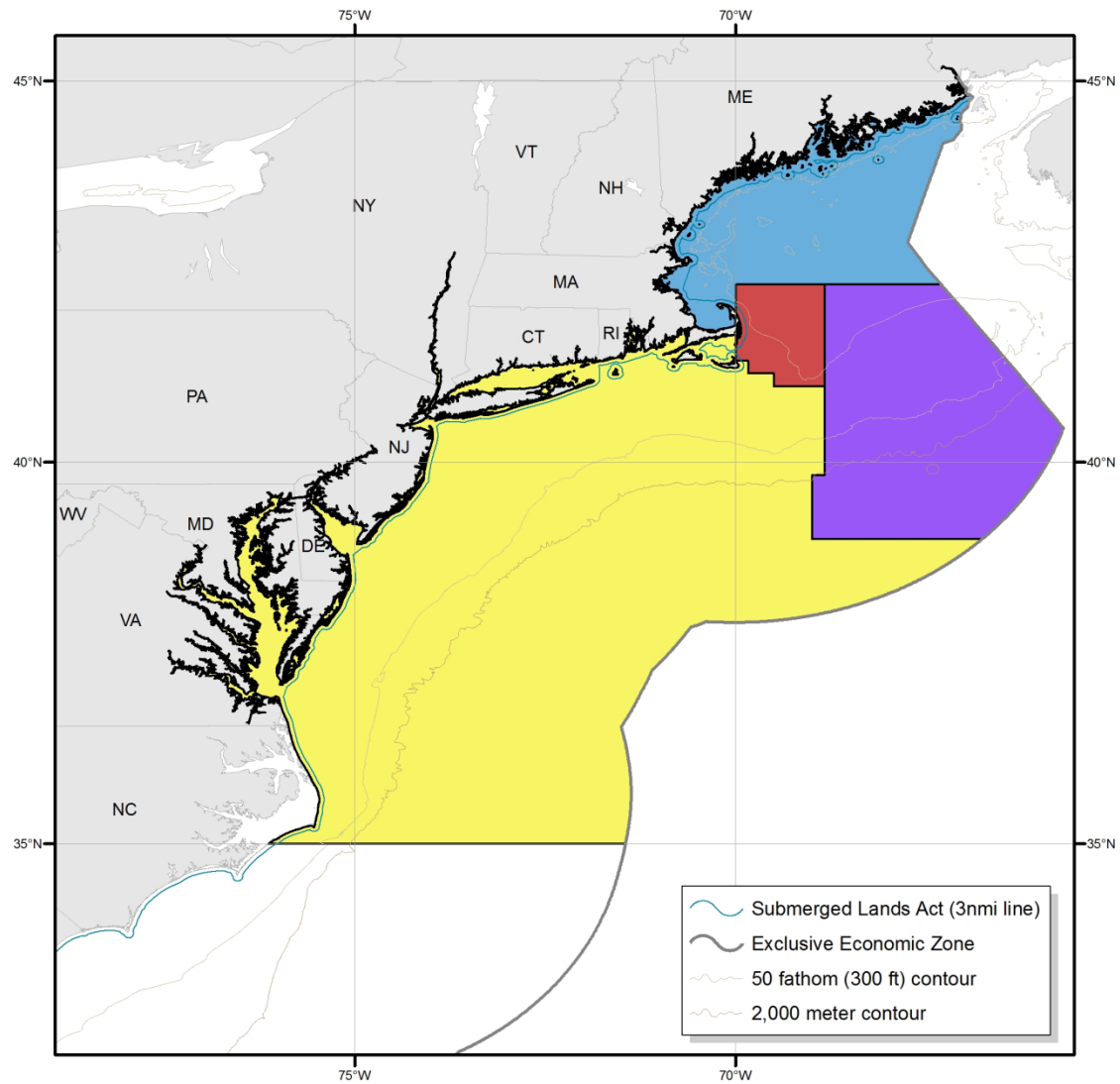


Table 7, page 9

stock	Annual Catch Limit (US ACL)										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GB cod	3,620	4,540	4,861	1,907	1,867	1,886	730	637	1519	1741	
GOM cod	8,088	8,545	6,700	1,470	1,470	366	473	473	666	666	666
GB Haddock	42,768	32,611	29,260	27,936	18,312	23,204	53,309	54,574	46,312	55,249	
GOM Haddock	1,197	1,141	958	274	641	1,375	3,430	4,285	12,409	11,803	9,626
GB Yellowtail Flounder	1,021	1,416	547.8	209	318	240	261	201	206	103	
SNE Yellowtail Flounder	470	641	936	665	665	666	256	256	65	66	66
CC/GOM Yellowtail Flounder	822	992	1,104	523	523	524	409	409	490	490	490
Plaice	3,006	3,280	3,459	1,482	1,442	1,470	1,235	1,272	1,649	1,532	1,420
Witch Flounder	899	1,304	1,563	751	751	751	441	839	948	948	948
GB Winter Flounder	1,955	2,118	3,575	3,641	3,493	1,952	650	683	787	787	787
GOM Winter Flounder	231	524	1,040	1,040	1,040	489	776	776	428	428	428
SNE/MA Winter Flounder	605	842	603	1,612	1,612	1,607	749	749	700	700	700
Redfish	7,226	7,959	8,786	10,462	10,909	11,393	9,837	10,514	10,986	11,208	11,357
White Hake	2,697	3,138	3,465	3,974	4,417	4,484	3,572	3,467	2,794	2,794	2,794
Pollock	18,929	16,166	14,736	14,921	15,304	15,878	20,374	20,374	38,204	38,204	38,204
Northern Windowpane Flounder	161	161	163	144	144	144	177	170	86	86	86
Southern Windowpane Flounder	225	225	381	527	527	527	599	599	457	457	457
Ocean Pout	253	253	240	220	220	220	155	155	120	120	120
Halibut	69	76	83	96	106	97	119	119	100	100	100
Wolffish	77	77	77	65	65	65	77	77	84	84	84

Hypothesis: If than statement

If constraining stocks that produce incentives for observer effects are causing unseen legal size discards on unobserved trips then this should result in difference in stock landings per unit effort ratios between observed and unobserved trips in a multispecies fishery.

Objective

To compare landings to effort ratios on observed and unobserved trips in the groundfish fishery to determine whether the landings composition changed in the presence of an observer.

This analysis assumes no observer deployment effects.

Methods

Effort was defined using two different metrics

- K_{all} (similar to how effort is defined for discard estimation for monitoring and assessments).
- Day absent (DA)



Methods

A comparison of allocated groundfish stock landings to effort ratios was done between observed and unobserved trips by broad stock area and by gear type (gillnet and trawl gear).

$$Ratio = \sum landing / \sum Kept all$$

and

$$Ratio = \sum landing / \sum days absent$$

Methods

- Dealer Data (AA tables) limited to trips with a direct match to VTRs (Alevel = A and Elevel = A).
- Limited to Trawl and gillnet gear (Gulf of Maine)
- Limited sector vessels which landed some groundfish. Common pool & Sector IX was omitted.
- Limited to vessels which have been observed at least once in each year.
- Limited to three Broad stock areas (Gulf of Maine, Georges Bank, and mix stock area 521).

This was done by linking the AA tables with the FSB sector tables using the VTR serial number.

land more on observed trips

land more on unobserved trips

Gulf of Maine (Table 1, page 4)

Gulf of Maine trawl kept to kall ratios.

number												winter white witch yellowtail											
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder	year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	873	ob	0.21	0.07	0.03	0.20	0.08	0.01	0.15	0.03	0.02	2011	873	ob	742	247	98	707	295	25	529	120	77
2011	2300	un	0.22	0.07	0.02	0.21	0.10	0.01	0.14	0.03	0.03	2011	2300	un	829	265	90	787	385	39	519	129	125
2012	1009	ob	0.15	0.06	0.03	0.20	0.13	0.02	0.13	0.05	0.04	2012	1009	ob	480	192	78	631	392	58	409	150	118
2012	3052	un	0.12	0.05	0.02	0.24	0.21	0.02	0.10	0.04	0.04	2012	3052	un	462	212	87	936	851	70	415	154	159
2013	543	ob	0.09	0.09	0.02	0.23	0.14	0.02	0.13	0.05	0.05	2013	543	ob	280	274	75	713	432	56	392	146	160
2013	2121	un	0.06	0.07	0.02	0.27	0.22	0.01	0.12	0.04	0.03	2013	2121	un	255	293	62	1100	921	59	497	149	138
2014	519	ob	0.06	0.07	0.02	0.26	0.20	0.02	0.11	0.04	0.04	2014	519	ob	270	312	102	1119	855	70	448	169	153
2014	1630	un	0.05	0.07	0.02	0.23	0.26	0.01	0.11	0.03	0.03	2014	1630	un	218	352	97	1100	1218	56	509	150	125
2015	331	ob	0.02	0.10	0.07	0.16	0.26	0.01	0.10	0.04	0.03	2015	331	ob	69	394	267	662	1052	55	406	166	118
2015	1275	un	0.01	0.08	0.06	0.14	0.36	0.01	0.10	0.03	0.02	2015	1275	un	56	446	314	767	1897	57	515	161	108
2016	262	ob	0.02	0.08	0.12	0.11	0.27	0.01	0.08	0.03	0.03	2016	262	ob	93	344	488	462	1129	60	337	125	127
2016	1347	un	0.01	0.07	0.13	0.15	0.27	0.01	0.08	0.02	0.02	2016	1347	un	76	389	752	861	1520	54	482	131	129
2017	237	ob	0.02	0.06	0.17	0.14	0.17	0.01	0.11	0.03	0.01	2017	237	ob	103	356	1012	817	985	68	661	152	79
2017	1677	un	0.01	0.06	0.14	0.16	0.26	0.01	0.10	0.02	0.01	2017	1677	un	66	391	984	1093	1808	52	710	122	103

Gulf of Maine gillnet kept to kall ratios.

number												winter white witch yellowtail											
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder	year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	1371	ob	0.30	-	0.01	0.35	0.01	-	0.09	-	-	2011	1371	ob	668	-	27	796	20	-	196	-	-
2011	3423	un	0.25	-	0.01	0.40	0.01	-	0.09	-	-	2011	3423	un	604	-	20	957	22	-	217	-	-
2012	1112	ob	0.20	-	0.00	0.32	0.00	-	0.10	-	-	2012	1112	ob	411	-	9	644	9	-	200	-	-
2012	3298	un	0.17	-	0.00	0.37	0.01	-	0.12	-	-	2012	3298	un	374	-	9	783	20	-	254	-	-
2013	484	ob	0.10	-	0.00	0.51	0.01	-	0.12	-	-	2013	484	ob	201	-	6	1046	18	-	250	-	-
2013	2094	un	0.08	-	0.00	0.47	0.02	-	0.16	-	-	2013	2094	un	156	-	5	870	29	-	297	-	-
2014	736	ob	0.09	-	0.00	0.42	0.01	-	0.10	-	-	2014	736	ob	246	-	12	1119	39	-	257	-	-
2014	1831	un	0.09	-	0.01	0.38	0.01	-	0.09	-	-	2014	1831	un	230	-	14	990	33	-	247	-	-
2015	286	ob	0.04	-	0.00	0.38	0.01	-	0.05	-	-	2015	286	ob	110	-	14	1080	39	-	137	-	-
2015	954	un	0.04	-	0.01	0.39	0.02	-	0.08	-	-	2015	954	un	93	-	22	1038	54	-	221	-	-
2016	185	ob	0.06	-	0.00	0.19	0.01	-	0.10	-	-	2016	185	ob	227	-	15	694	46	-	345	-	-
2016	839	un	0.06	-	0.01	0.30	0.01	-	0.10	-	-	2016	839	un	161	-	25	827	35	-	266	-	-
2017	144	ob	0.05	-	0.00	0.19	0.01	-	0.06	-	-	2017	144	ob	171	-	12	677	27	-	210	-	-
2017	863	un	0.04	-	0.01	0.23	0.01	-	0.06	-	-	2017	863	un	127	-	24	773	37	-	194	-	-

Gulf of Maine trawl kept to days absent ratios.

number												winter white witch yellowtail											
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder	year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	873	ob	742	247	98	707	295	25	529	120	77	2011	873	ob	742	247	98	707	295	25	529	120	77
2011	2300	un	829	265	90	787	385	39	519	129	125	2011	2300	un	829	265	90	787	385	39	519	129	125
2012	1009	ob	480	192	78	631	392	58	409	150	118	2012	1009	ob	480	192	78	631	392	58	409	150	118
2012	3052	un	462	212	87	936	851	70	415	154	159	2012	3052	un	462	212	87	936	851	70	415	154	159
2013	543	ob	280	274	75	713	432	56	392	146	160	2013	543	ob	280	274	75	713	432	56	392	146	160
2013	2121	un	255	293	62	1100	921	59	497	149	138	2013	2121	un	255	293	62	1100	921	59	497	149	138
2014	519	ob	270	312	102	1119	855	70	448	169	153	2014	519	ob	270	312	102	1119	855	70	448	169	153
2014	1630	un	218	352	97	1100	1218	56	509	150	125	2014	1630	un	218	352	97	1100	1218	56	509	150	125
2015	331	ob	69	394	267	662	1052	55	406	166	118	2015	331	ob	69	394	267	662	1052	55	406	166	118
2015	1275	un	56	446	314	767	1897	57	515	161	108	2015	1275	un	56	446	314	767	1897	57	515	161	108
2016	262	ob	93	344	488	462	1129	60	337	125	127	2016	262	ob	93	344	488	462	1129	60	337	125	127
2016	1347	un	76	389	752	861	1520	54	482	131	129	2016	1347	un	76	389	752	861	1520	54	482	131	129
2017	237	ob	103	356	1012	817	985	68	661	152	79	2017	237	ob	103	356	1012	817	985	68	661	152	79
2017	1677	un	66	391	984	1093	1808	52	710	122	103	2017	1677	un	66	391	984	1093	1808	52	710	122	103

Gulf of Maine gillnet kept to days absent ratios.

number								winter	white	witch	yellowtail
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	1371	ob	668	-	27	796	20	-	196	-	-
2011	3423	un	604	-	20	957	22	-	217	-	-
2012	1112	ob	411	-	9	644	9	-	200	-	-
2012	3298	un	374	-	9	783	20	-	254	-	-
2013	484	ob	201	-	6	1046	18	-	250	-	-
2013	2094	un	156	-	5	870	29	-	297	-	-
2014	736	ob	246	-	12	1119	39	-	257	-	-
2014	1831	un	230	-	14	990	33	-	247	-	-
2015	286	ob	110	-	14	1080	39	-	137	-	-
2015	954	un	93	-	22	1038	54	-	221	-	-
2016	185	ob	227	-	15	694	46	-	345	-	-
2016	839	un	161	-	25	827	35	-	266	-	-
2017	144	ob	171	-	12	677	27	-	210	-	-
2017	863	un	127	-	24	773	37	-	194	-	-

land more on observed trips

land more on unobserved trips

Georges Bank (Table 2, page 5)

Georges Bank trawl kept to kall ratios.

	number							winter	white	witch	yellowtail
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	105	ob	0.116	0.050	0.325	0.041	0.012	0.127	0.022	0.025	0.078
2011	457	un	0.096	0.038	0.323	0.067	0.039	0.137	0.026	0.021	0.076
2012	79	ob	0.093	0.074	0.085	0.026	0.021	0.182	0.026	0.033	0.072
2012	486	un	0.126	0.057	0.133	0.047	0.039	0.185	0.022	0.030	0.041
2013	59	ob	0.088	0.047	0.126	0.029	0.026	0.273	0.035	0.023	0.014
2013	389	un	0.080	0.039	0.173	0.045	0.076	0.244	0.030	0.020	0.025
2014	61	ob	0.103	0.053	0.289	0.017	0.030	0.127	0.040	0.024	0.004
2014	349	un	0.123	0.051	0.311	0.033	0.070	0.131	0.024	0.017	0.016
2015	33	ob	0.116	0.058	0.185	0.005	0.006	0.182	0.018	0.016	0.018
2015	333	un	0.104	0.032	0.299	0.042	0.067	0.098	0.029	0.015	0.012
2016	27	ob	0.184	0.021	0.153	0.063	0.078	0.063	0.023	0.011	0.001
2016	293	un	0.070	0.027	0.195	0.070	0.159	0.068	0.019	0.010	0.006
2017	40	ob	0.031	0.019	0.096	0.051	0.087	0.039	0.028	0.026	0.003
2017	295	un	0.029	0.024	0.201	0.037	0.199	0.058	0.019	0.015	0.008

Georges Bank trawl kept to days absent ratios.

	number							winter	white	witch	yellowtail
year	of trips	Observed	cod	dabs	haddock	pollock	redfish	flounder	hake	flounder	flounder
2011	105	ob	538	233	1507	192	58	588	104	117	363
2011	457	un	584	229	1968	410	238	832	155	128	465
2012	79	ob	438	346	399	120	99	854	122	156	340
2012	486	un	606	274	640	225	187	887	107	142	196
2013	59	ob	308	165	442	103	92	952	121	81	50
2013	389	un	350	172	754	198	331	1065	132	89	109
2014	61	ob	423	217	1182	69	122	520	162	100	17
2014	349	un	696	285	1752	188	396	739	138	98	90
2015	33	ob	472	236	754	19	23	741	74	65	74
2015	333	un	594	185	1707	237	380	559	164	83	66
2016	27	ob	1117	128	927	382	470	383	139	66	6
2016	293	un	473	181	1324	472	1077	458	128	71	42
2017	40	ob	218	131	671	355	611	276	198	179	21
2017	295	un	232	197	1623	298	1608	466	151	123	67

land more on observed trips

land more on unobserved trips

Mixed stock area 521 (Table 3, page 6)

Mixed stock statistical area 521 trawl kept to kall ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	153	ob	0.212	0.031	0.048	0.339	0.107	-	0.080	0.039	0.013
2011	558	un	0.295	0.034	0.054	0.233	0.102	-	0.079	0.039	0.021
2012	103	ob	0.141	0.059	0.023	0.277	0.139	-	0.121	0.058	0.003
2012	570	un	0.151	0.054	0.035	0.271	0.141	-	0.102	0.044	0.031
2013	75	ob	0.140	0.079	0.143	0.132	0.084	0.124	0.073	0.041	0.016
2013	549	un	0.117	0.079	0.128	0.139	0.153	0.069	0.083	0.036	0.016
2014	75	ob	0.092	0.089	0.168	0.076	0.129	0.106	0.069	0.040	0.007
2014	472	un	0.121	0.068	0.229	0.103	0.146	0.046	0.064	0.032	0.007
2015	73	ob	0.101	0.062	0.181	0.057	0.245	0.101	0.045	0.026	0.005
2015	400	un	0.107	0.063	0.181	0.078	0.201	0.081	0.044	0.027	0.012
2016	52	ob	0.056	0.062	0.215	0.087	0.143	0.080	0.039	0.027	0.018
2016	373	un	0.084	0.037	0.288	0.086	0.157	0.056	0.035	0.020	0.005
2017	38	ob	0.051	0.027	0.269	0.060	0.084	0.157	0.043	0.019	0.023
2017	420	un	0.039	0.027	0.367	0.087	0.147	0.045	0.053	0.014	0.003

Mixed stock statistical area 521 trawl kept to days absent ratios.

year	number of trips	Observed	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	153	ob	1235	183	280	1979	624	-	468	228	74
2011	558	un	1773	204	327	1403	616	-	475	236	129
2012	103	ob	758	318	126	1496	747	-	655	315	16
2012	570	un	788	281	184	1413	735	-	530	231	163
2013	75	ob	565	318	575	532	339	502	292	164	64
2013	549	un	511	345	558	605	669	301	362	156	70
2014	75	ob	318	310	583	263	449	366	240	137	25
2014	472	un	585	326	1104	496	704	222	307	154	31
2015	73	ob	365	226	654	206	886	366	165	93	19
2015	400	un	448	264	756	324	838	339	183	114	50
2016	52	ob	259	286	986	400	658	366	181	123	83
2016	373	un	526	233	1797	536	977	346	216	124	31
2017	38	ob	310	164	1633	367	507	953	261	116	140
2017	420	un	306	210	2839	675	1136	346	409	109	24

land more on observed trips

land more on unobserved trips

unobserved ratios/observed ratios

Gulf of Maine (Table 4, page 7)

Gulf of Maine trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.03	0.99	0.84	1.03	1.20	1.42	0.90	0.99	1.49
2012	0.75	0.86	0.87	1.16	1.69	0.94	0.79	0.80	1.05
2013	0.68	0.80	0.62	1.15	1.59	0.79	0.95	0.77	0.64
2014	0.72	1.01	0.86	0.88	1.28	0.71	1.02	0.80	0.73
2015	0.63	0.87	0.90	0.89	1.38	0.79	0.97	0.74	0.70
2016	0.60	0.83	1.14	1.38	0.99	0.66	1.05	0.77	0.75
2017	0.54	0.93	0.82	1.13	1.56	0.64	0.91	0.68	1.10

Gulf of Maine gillnet kept to kall ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.85	-	0.70	1.13	1.03	-	1.04	-	-
2012	0.85	-	0.93	1.14	2.04	-	1.19	-	-
2013	0.86	-	0.95	0.92	1.79	-	1.32	-	-
2014	0.96	-	1.26	0.90	0.86	-	0.98	-	-
2015	0.93	-	1.76	1.05	1.50	-	1.76	-	-
2016	0.91	-	2.06	1.52	0.98	-	0.98	-	-
2017	0.80	-	2.15	1.23	1.47	-	0.99	-	-

Gulf of Maine trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.12	1.08	0.92	1.11	1.30	1.54	0.98	1.07	1.62
2012	0.96	1.10	1.12	1.48	2.17	1.20	1.01	1.02	1.35
2013	0.91	1.07	0.83	1.54	2.13	1.06	1.27	1.02	0.86
2014	0.81	1.13	0.96	0.98	1.42	0.79	1.13	0.89	0.81
2015	0.82	1.13	1.18	1.16	1.80	1.03	1.27	0.97	0.92
2016	0.81	1.13	1.54	1.87	1.35	0.90	1.43	1.05	1.01
2017	0.64	1.10	0.97	1.34	1.84	0.76	1.07	0.80	1.30

Gulf of Maine gillnet kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfish	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.90	-	0.75	1.20	1.10	-	1.11	-	-
2012	0.91	-	0.99	1.22	2.17	-	1.27	-	-
2013	0.78	-	0.85	0.83	1.61	-	1.19	-	-
2014	0.94	-	1.24	0.88	0.85	-	0.96	-	-
2015	0.85	-	1.61	0.96	1.37	-	1.61	-	-
2016	0.71	-	1.61	1.19	0.77	-	0.77	-	-
2017	0.74	-	1.99	1.14	1.36	-	0.92	-	-

land more on observed trips

land more on unobserved trips

unobserved ratios/observed ratios

Georges Bank (Table 5, page 8)

Georges Bank trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfsh	winter flounder	white hake	witch flounder	yellowtail flounder
2011	0.83	0.75	0.99	1.62	3.14	1.08	1.14	0.84	0.98
2012	1.36	0.78	1.57	1.83	1.85	1.02	0.87	0.89	0.57
2013	0.91	0.83	1.37	1.55	2.89	0.90	0.87	0.88	1.73
2014	1.20	0.95	1.08	1.99	2.37	1.03	0.62	0.71	3.92
2015	0.90	0.56	1.61	9.07	12.02	0.54	1.58	0.91	0.63
2016	0.38	1.26	1.27	1.10	2.04	1.07	0.82	0.96	6.31
2017	0.93	1.30	2.10	0.73	2.28	1.47	0.66	0.60	2.76

Georges Bank trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfsh	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.09	0.98	1.31	2.13	4.12	1.42	1.50	1.10	1.28
2012	1.38	0.79	1.60	1.86	1.88	1.04	0.88	0.91	0.58
2013	1.14	1.04	1.71	1.94	3.62	1.12	1.09	1.10	2.16
2014	1.65	1.31	1.48	2.74	3.26	1.42	0.85	0.98	5.40
2015	1.26	0.78	2.26	12.72	16.85	0.75	2.22	1.28	0.89
2016	0.42	1.41	1.43	1.23	2.29	1.20	0.92	1.07	7.07
2017	1.07	1.50	2.42	0.84	2.63	1.69	0.77	0.69	3.18

Mixed stock area 521 (Table 6, page 8)

Mixed stock statistical area 521 trawl kept to kall ratios.

year	cod	dabs	haddock	pollock	redfsh	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.39	1.08	1.13	0.69	0.96	-	0.98	1.00	1.69
2012	1.08	0.92	1.51	0.98	1.02	-	0.84	0.76	10.37
2013	0.84	1.00	0.90	1.05	1.82	0.56	1.15	0.88	1.01
2014	1.32	0.76	1.36	1.36	1.13	0.43	0.92	0.81	0.92
2015	1.06	1.01	1.00	1.37	0.82	0.80	0.96	1.06	2.28
2016	1.49	0.60	1.34	0.99	1.09	0.70	0.88	0.74	0.27
2017	0.77	1.00	1.36	1.44	1.76	0.28	1.23	0.74	0.13

Mixed stock statistical area 521 trawl kept to days absent ratios.

year	cod	dabs	haddock	pollock	redfsh	winter flounder	white hake	witch flounder	yellowtail flounder
2011	1.44	1.11	1.17	0.71	0.99	-	1.02	1.03	1.74
2012	1.04	0.88	1.46	0.94	0.98	-	0.81	0.73	10.02
2013	0.90	1.08	0.97	1.14	1.97	0.60	1.24	0.95	1.09
2014	1.84	1.05	1.89	1.89	1.57	0.60	1.28	1.12	1.28
2015	1.23	1.17	1.16	1.58	0.95	0.93	1.11	1.22	2.63
2016	2.03	0.81	1.82	1.34	1.49	0.95	1.19	1.01	0.37
2017	0.99	1.28	1.74	1.84	2.24	0.36	1.57	0.94	0.17

Results

- The Gulf of Maine stock area suggests there were more cod landings seen on observed trips relative to unobserved trips despite incentives to avoid cod on observed trips due to low ALCs from 2015 to 2017. This difference was consistent across effort metrics (kall and DA) and gear types.
- For the Georges Bank broad stock area and 521 more haddock are consistently landed on unobserved trips relative to observed trips. This differences may have less to do with the influences of haddock which was not constraining but perhaps more a function of other potentially constraining stocks on these trips.

The magnitude of the difference in the ratios are difficult to interpret relative to potential missing removals since there are...

- Incentives to avoid constraining stocks on observed trips.
- Likely different degrees of incentives by vessel PSCs.
- Incentives can change over time and stock area.
- The incentive/effects dependences on the true underlining stock condition/distribution, and fishery gear targeting ability.

Conclusion

- Discrepancies exist between observed and unobserved trips, when comparing landing to effort ratios. These differences suggest that observed trips are not representative of unobserved trips.
- Interpretation of the magnitude of these differences is uncertain due to the potential inherent biases caused by incentives to avoid limiting stocks on observed trips.

ToRs

2. Are the methods adequately described and based on sound analytic techniques and statistical principles? *Page 1-2*
3. Are important uncertainties in the data and the analyses (possibly including the effects of year to year variations in fishing practices) identified, and are the impacts of these uncertainties on the analyses adequately described? *Pages 2-3*
4. Are the analyses conducted at the appropriate temporal and spatial scale such that the existence of regional or seasonal differences in monitoring performance can be identified? *Pages 4-8; Tables 1-6*
5. What are the strengths and weaknesses of the methods? Are there constraints that would hinder the use of the catch monitoring analyses? *Page 3*
6. Are the conclusions of the Plan Development Team supported by the analyses?
Page 3
7. Are there recommendations for improving the analyses, or for additional research or data collection that can help address improving groundfish monitoring?
8. Are the data, methods, and analytic tools sufficient for the Council to identify and analyze monitoring alternatives for the Northeast Multispecies Fishery Management Plan Amendment 23 management action?



Questions ?



NOAA
FISHERIES

Predicting GOM cod catch on Northeast groundfish sector trips: Implications for observer bias & fishery catch accounting

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Greater Atlantic Regional Fisheries Office*

22 Apr 2019

Estimating total groundfish catch requires integrating multiple sources of information

- Landings (kept catch) reported by dealers for all trips
- Discards observed on ~15–30% of trips
- Discards *estimated* for remaining unobserved trips

$$K + D_o + \widehat{D}_u = \text{Total Catch}$$

The more you fish, the more you discard...

- Premise of **S**tandardized **B**ycatch **R**eporting **M**ethodology

- function of effort:

$$r_{stratum} \sim \frac{d}{k_{all}}$$

- Restricted to sub-legal sized fish
- Assumes random, representative sample

Is the observed effort representative?

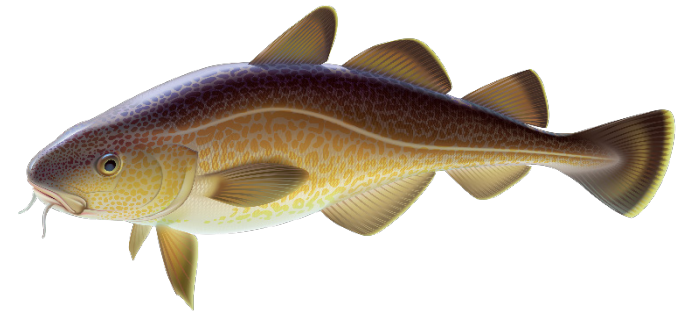
- Pre-catch behavior
 - where, when, how gear is fished
- Post-catch behavior
 - compliance with discarding regulations
e.g., retaining legal sized fish
- Evidence that catch outcomes differ suggests it is not
 - e.g., kept groundfish

Consequences of observations not being representative

- Pre-catch behavior
 - Biased estimation of sub-legal discards
- Post-catch behavior
 - Underestimate of total catch
- Sub-legal discards are small % of groundfish catch
 - e.g., <4% of GOM cod during FY 2011–2017
- So... how bad might total catch estimates be?

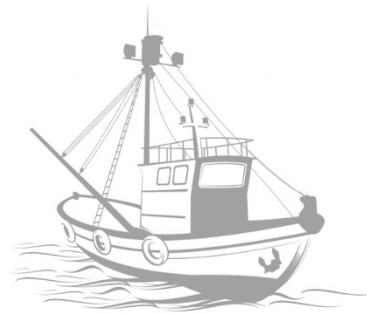
OBJECTIVE: build a predictive model of cod catch from observed trips to compare with unobserved trips

- Trip attributes:
 - Kept catch (K_{all} , pollock, haddock, winterfl, yellowtail)
 - Trip length
 - Space (VTR location)
 - Time (trip end)
- Vessel attributes:
 - Gear
 - Vessel size
 - Permit



CODGMSS_K > 0

Trips that are closer in space/time are more similar



Distance

Poisson regression with flexible spatial and temporal covariances modeled:

$$y_i \sim \text{Poisson}(\mu_i)$$

$$\log(\mu_i) = \mathbf{X}\boldsymbol{\beta} + \nu_j + \omega_1(s_i) + \omega_2(t_i) + \varepsilon_i$$

$$\omega_1(s^*) \sim \text{GP}(0, \sigma_s^2 \exp[-d / \phi_s])$$

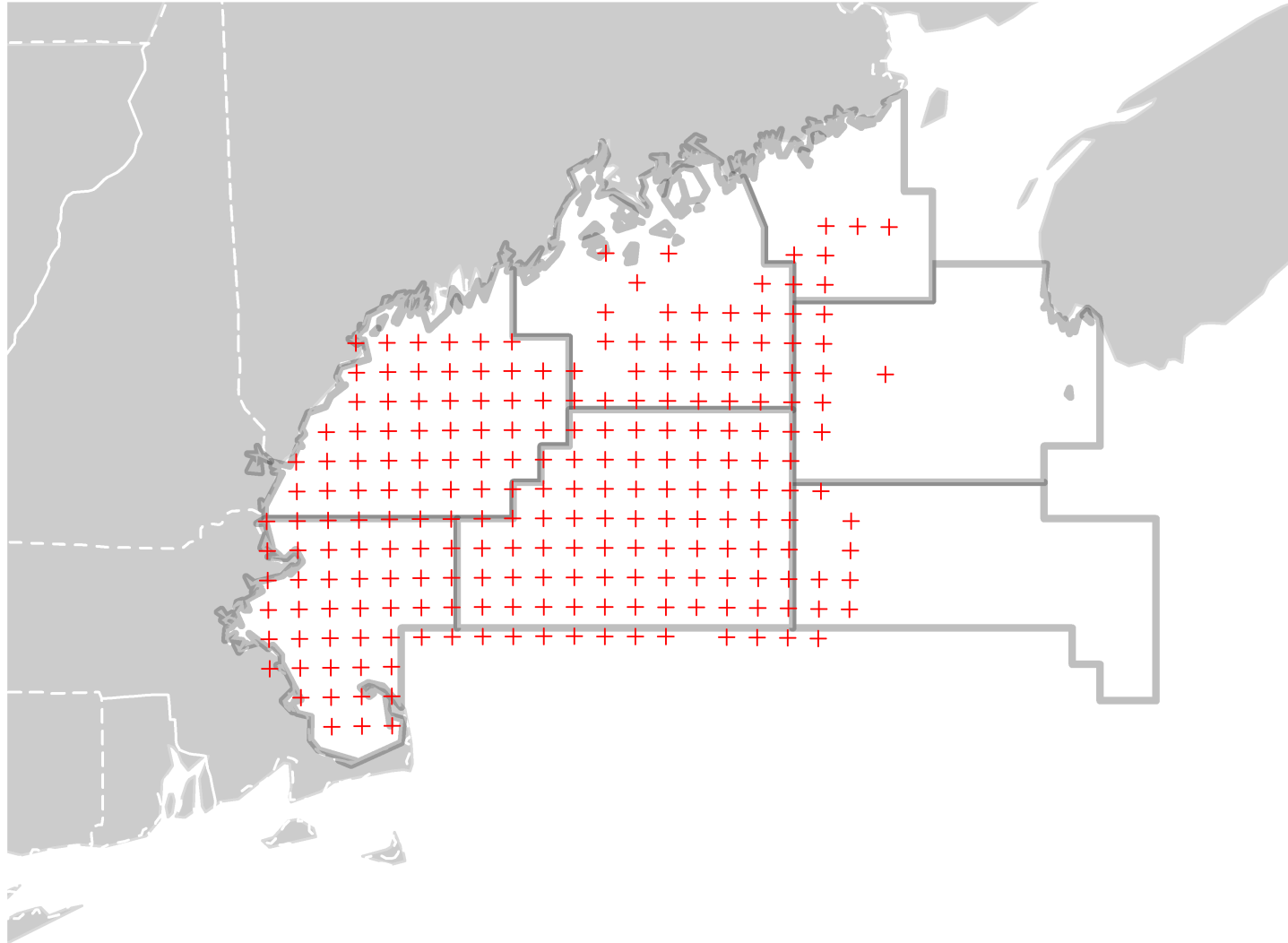
$$\omega_2(t^*) \sim \text{GP}(0, \sigma_t^2 \exp[-d / \phi_t])$$

Covariances estimated
at coarse-scale knots:

$s^* = 15 \text{ km}$

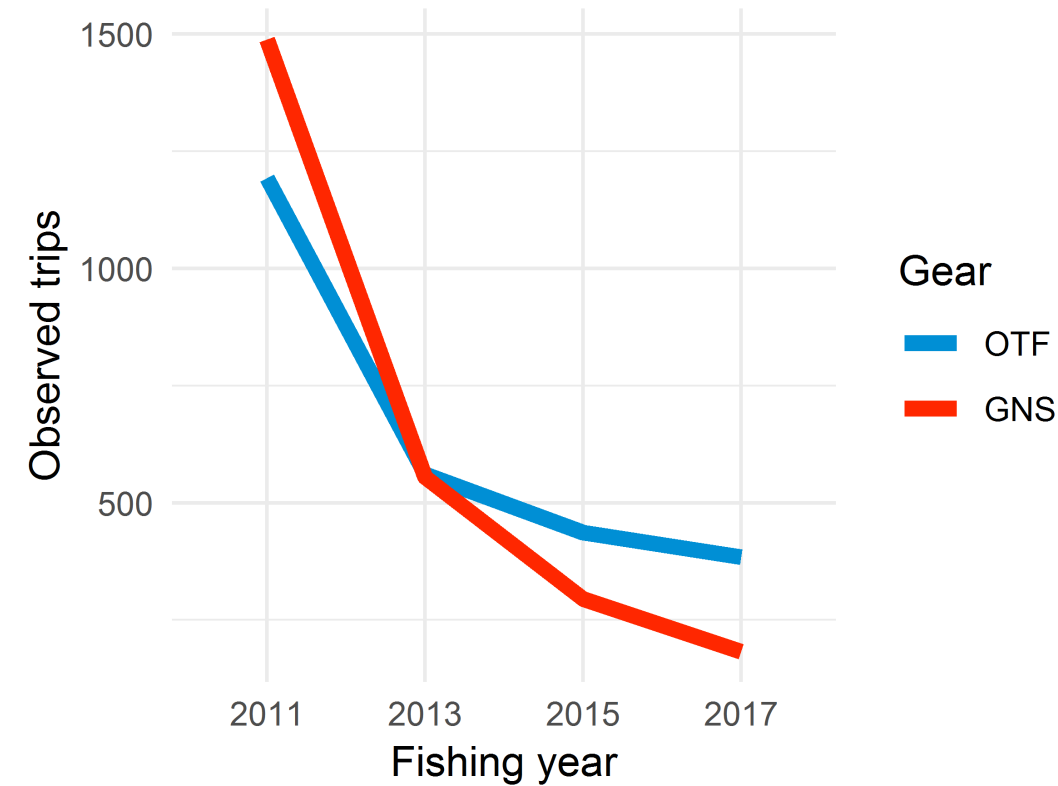
$t^* = 2 \text{ weeks}$

Spatial knots in the GOM

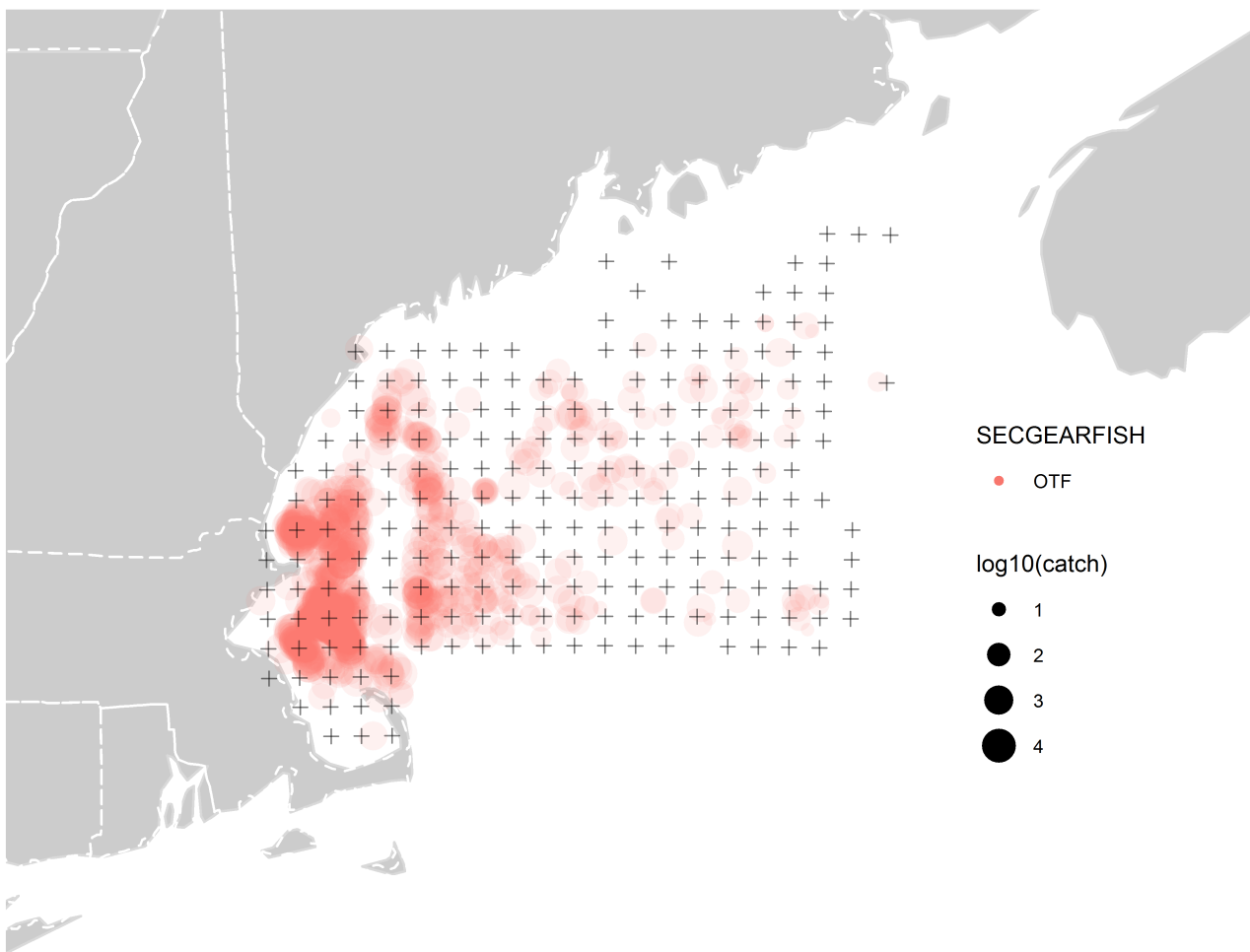
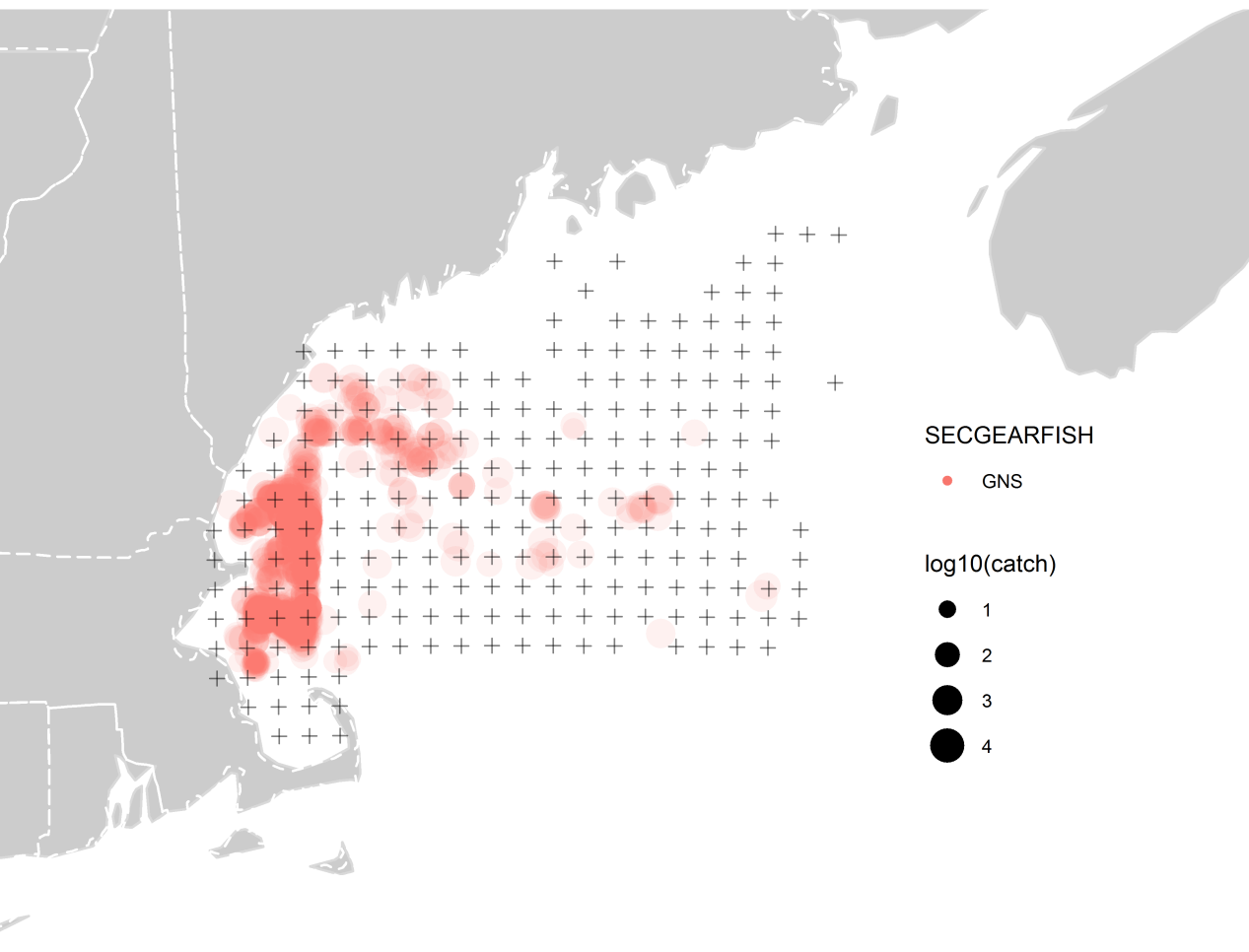


Decrease in observed trips from 2011 to 2017

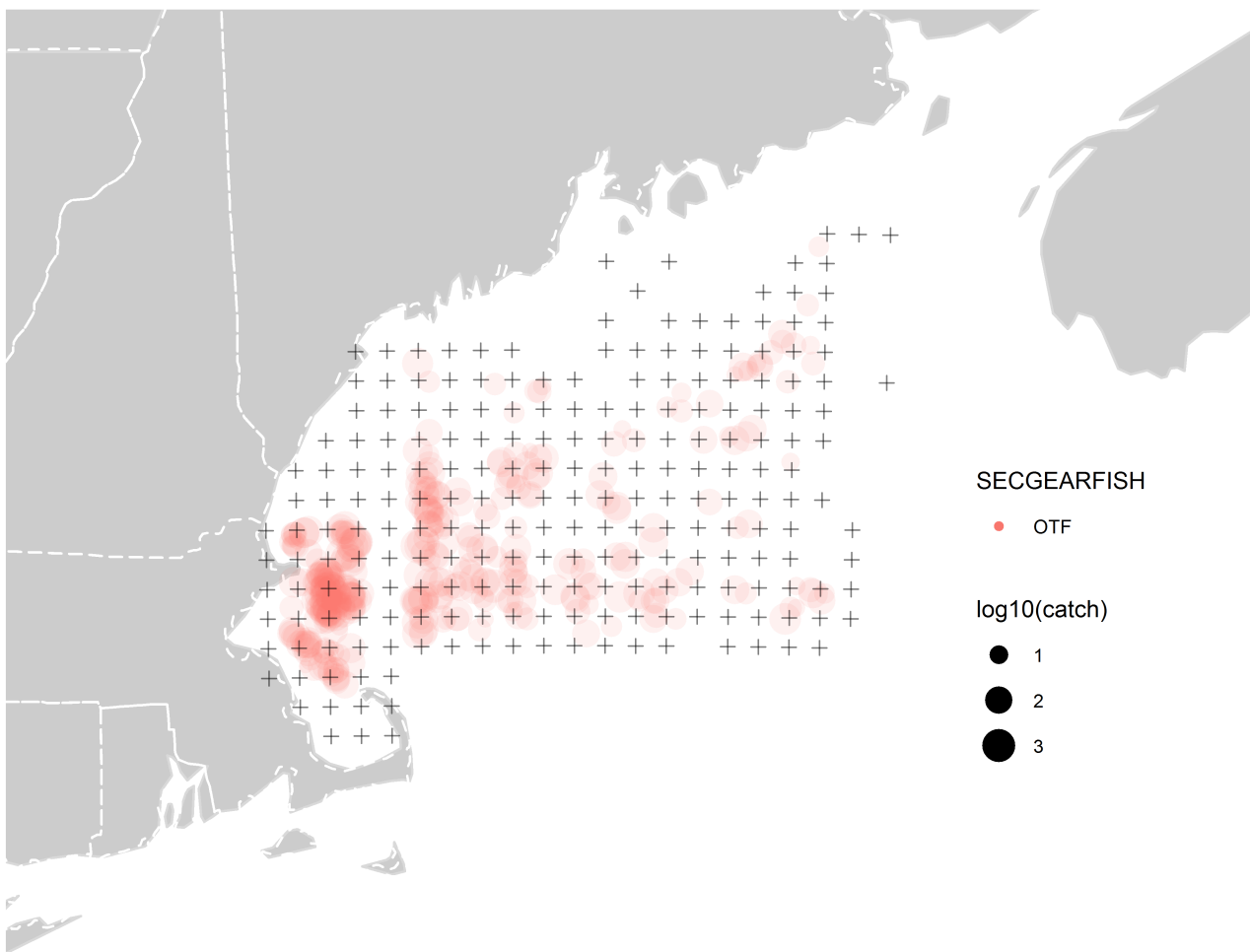
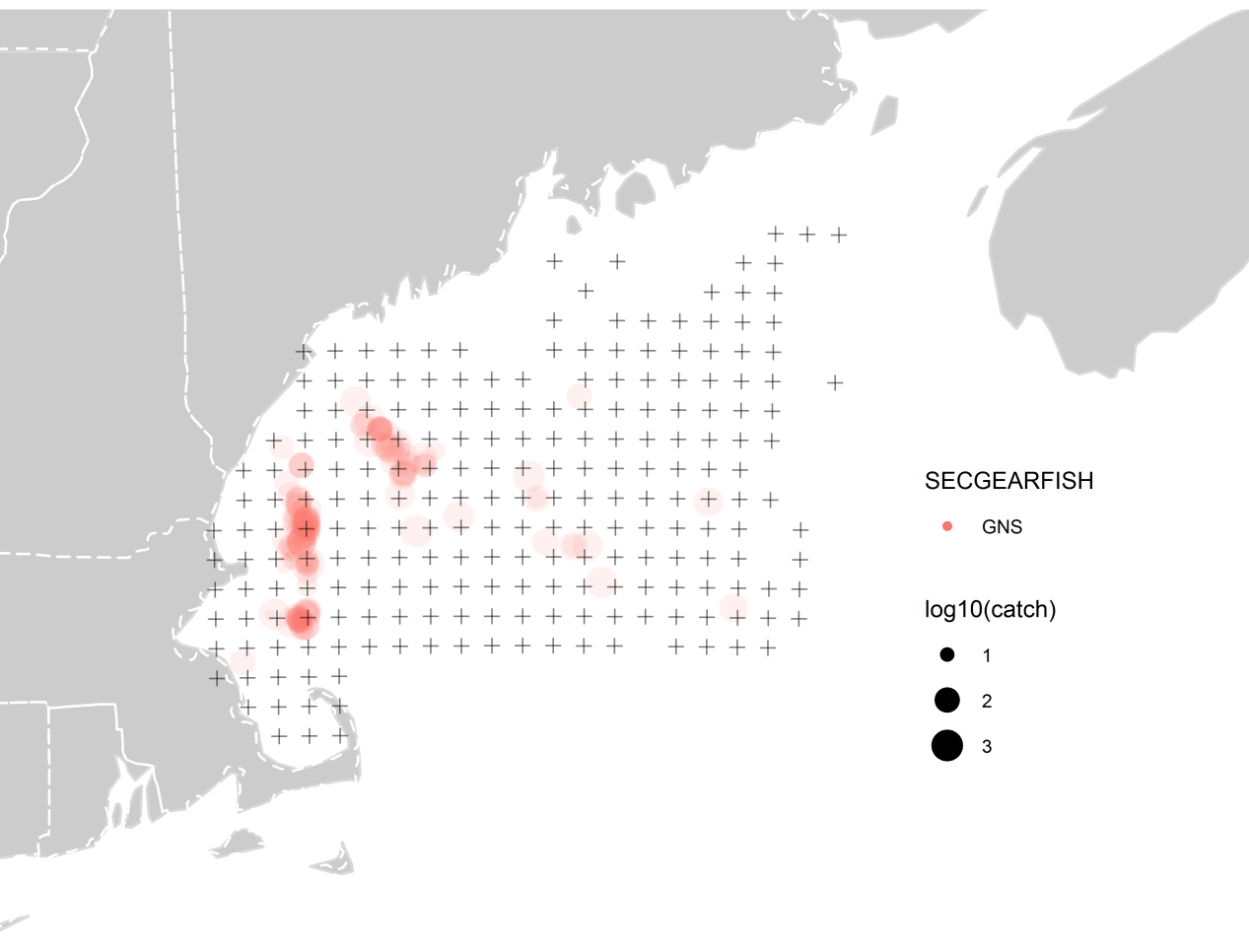
Gear	FY	Observed	Unobserved
OTF	2011	1193	2735
	2013	561	1768
	2015	437	1311
	2017	384	1353
GNS	2011	1489	3416
	2013	555	2059
	2015	295	839
	2017	183	763



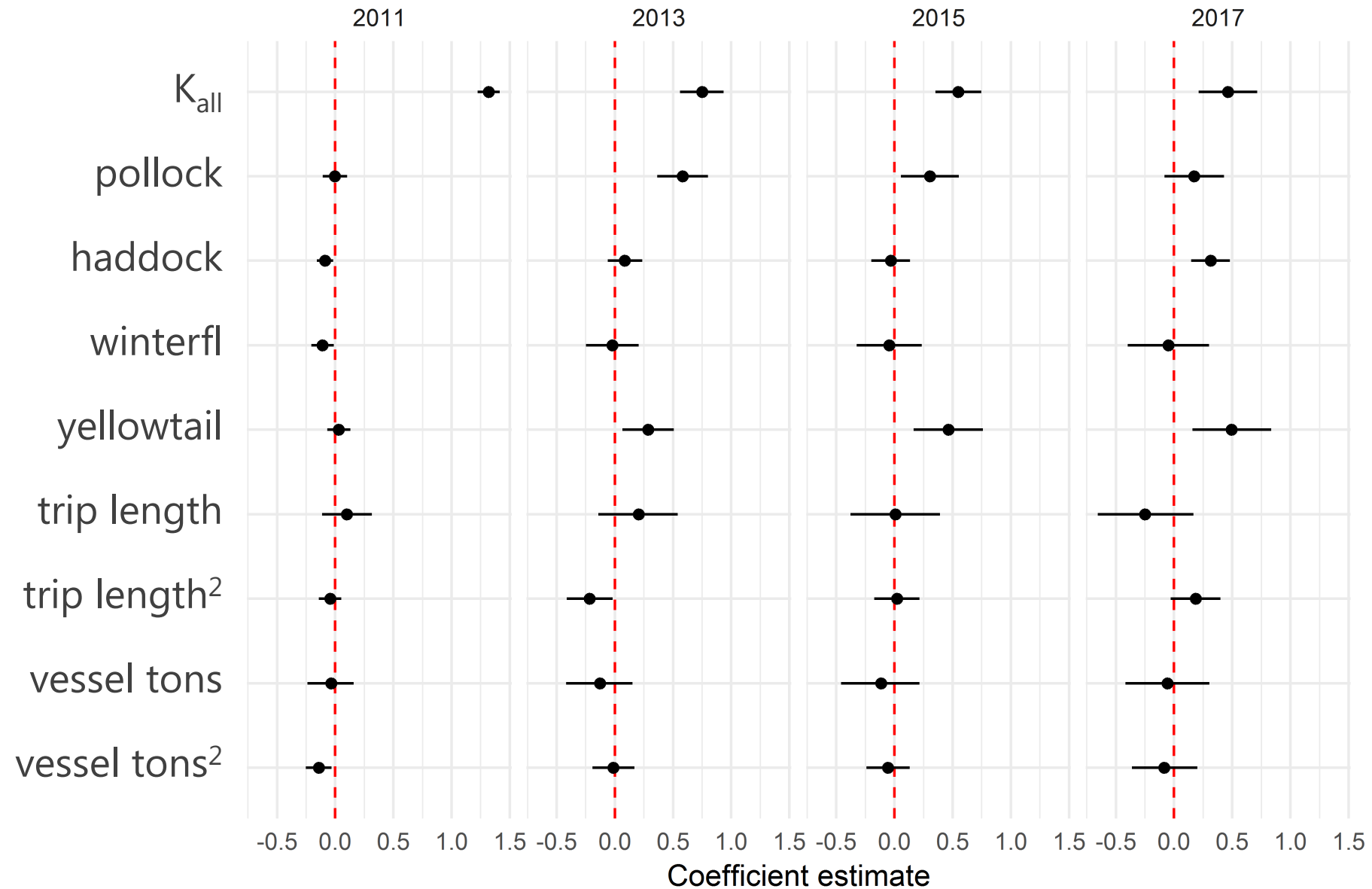
Observed cod catch in 2011



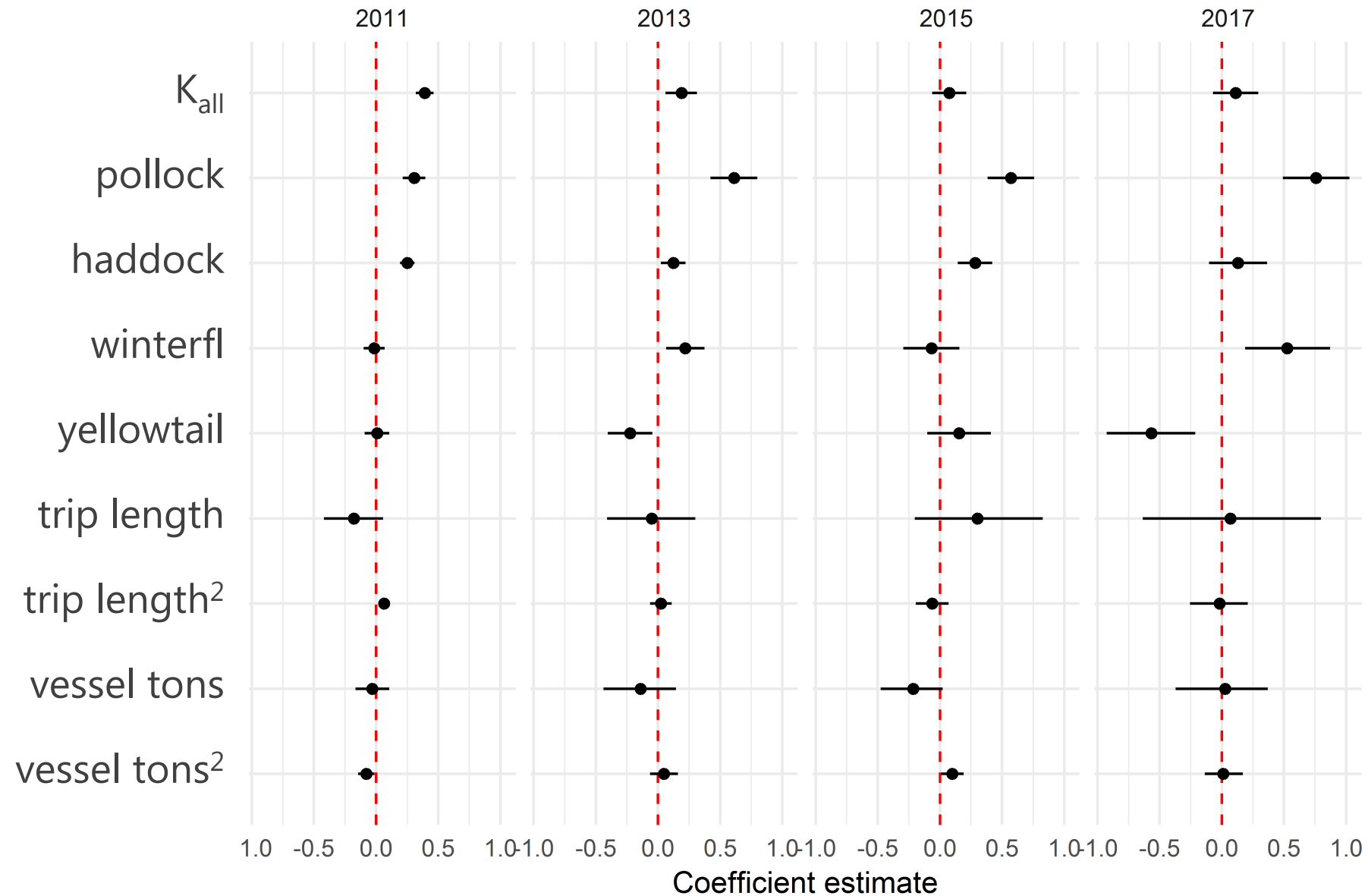
Observed cod catch in 2017



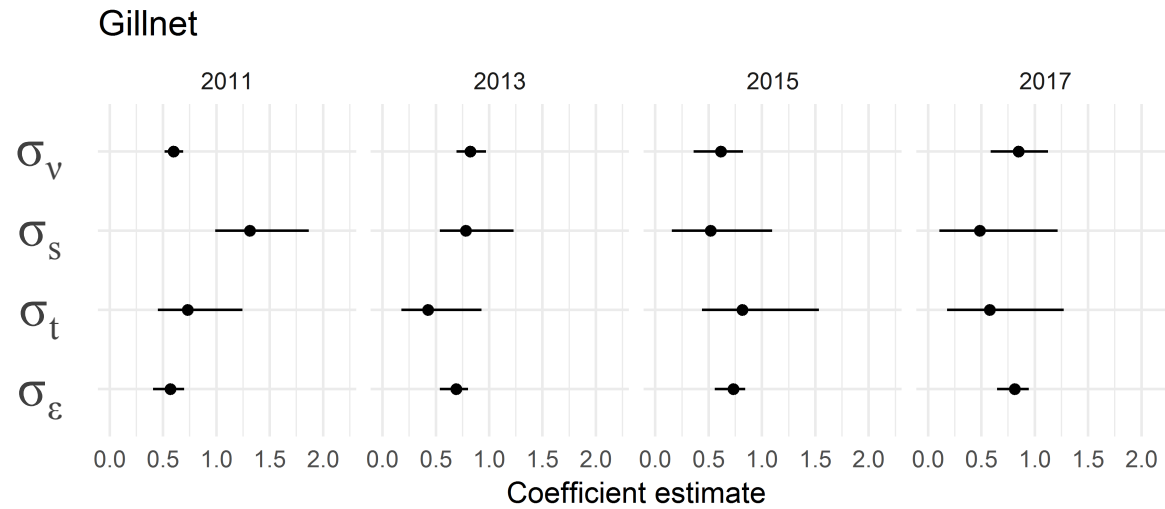
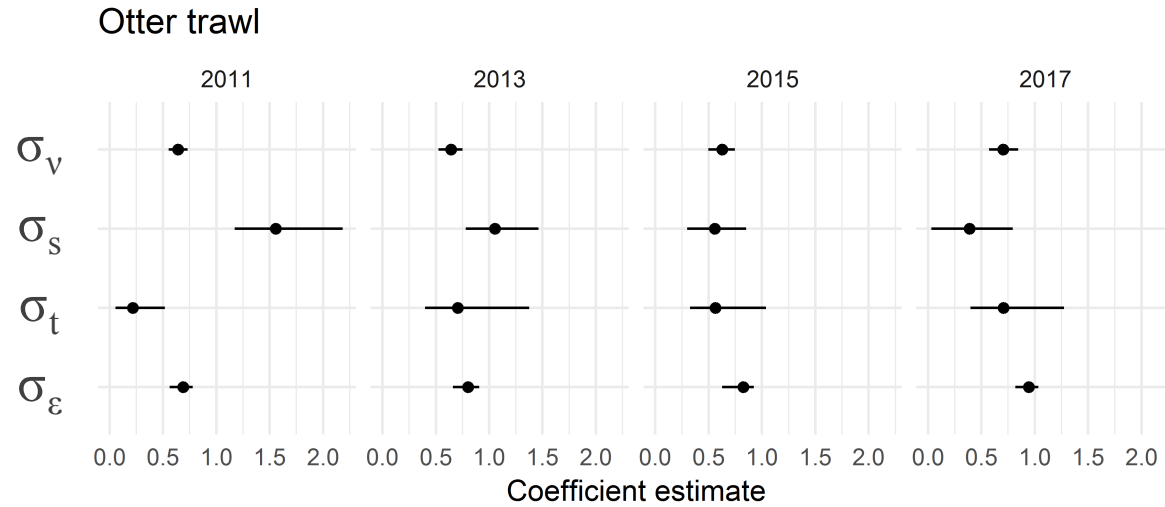
Parameter estimates for fixed effects (OTF)



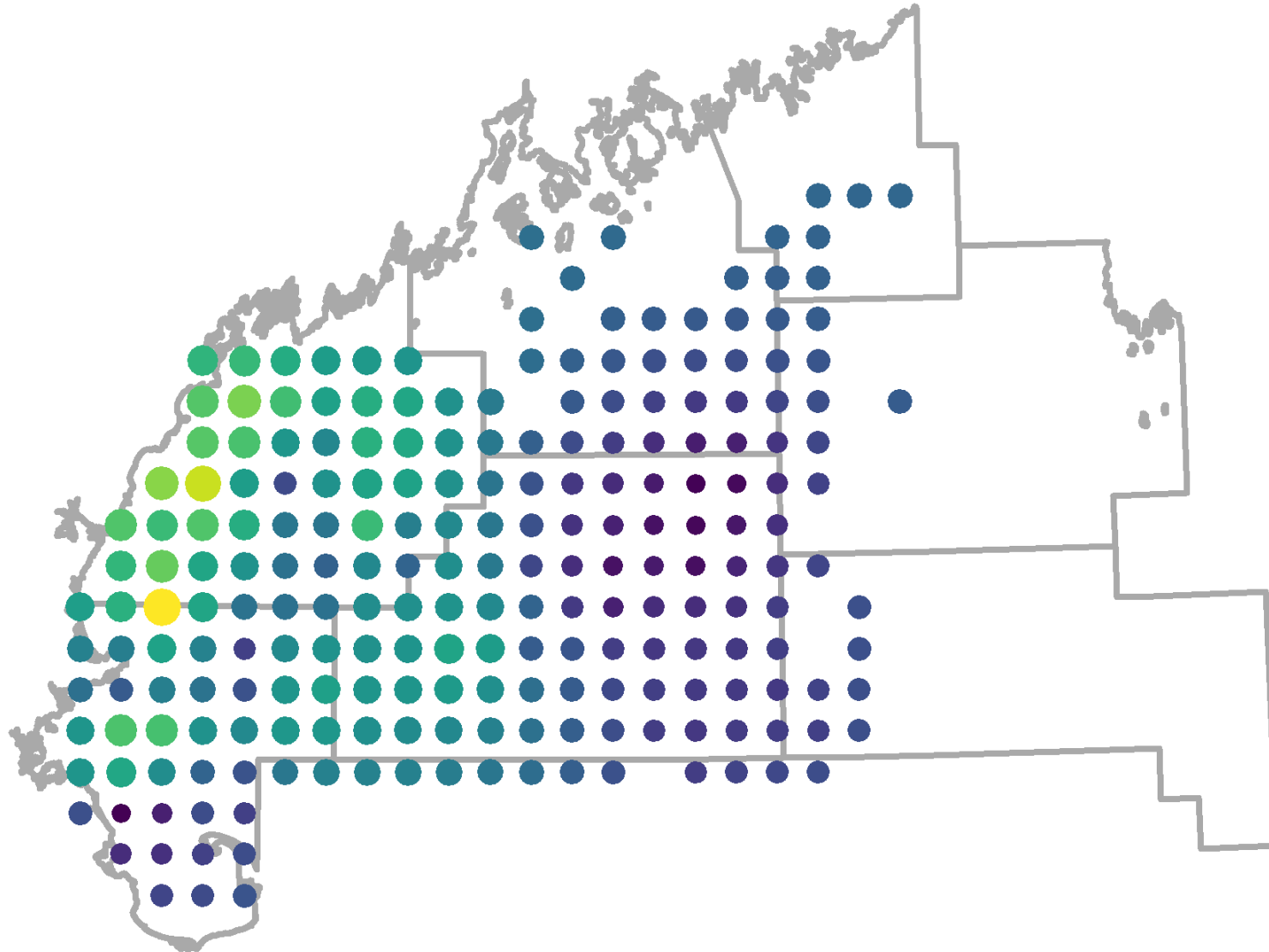
Parameter estimates for fixed effects (GNS)



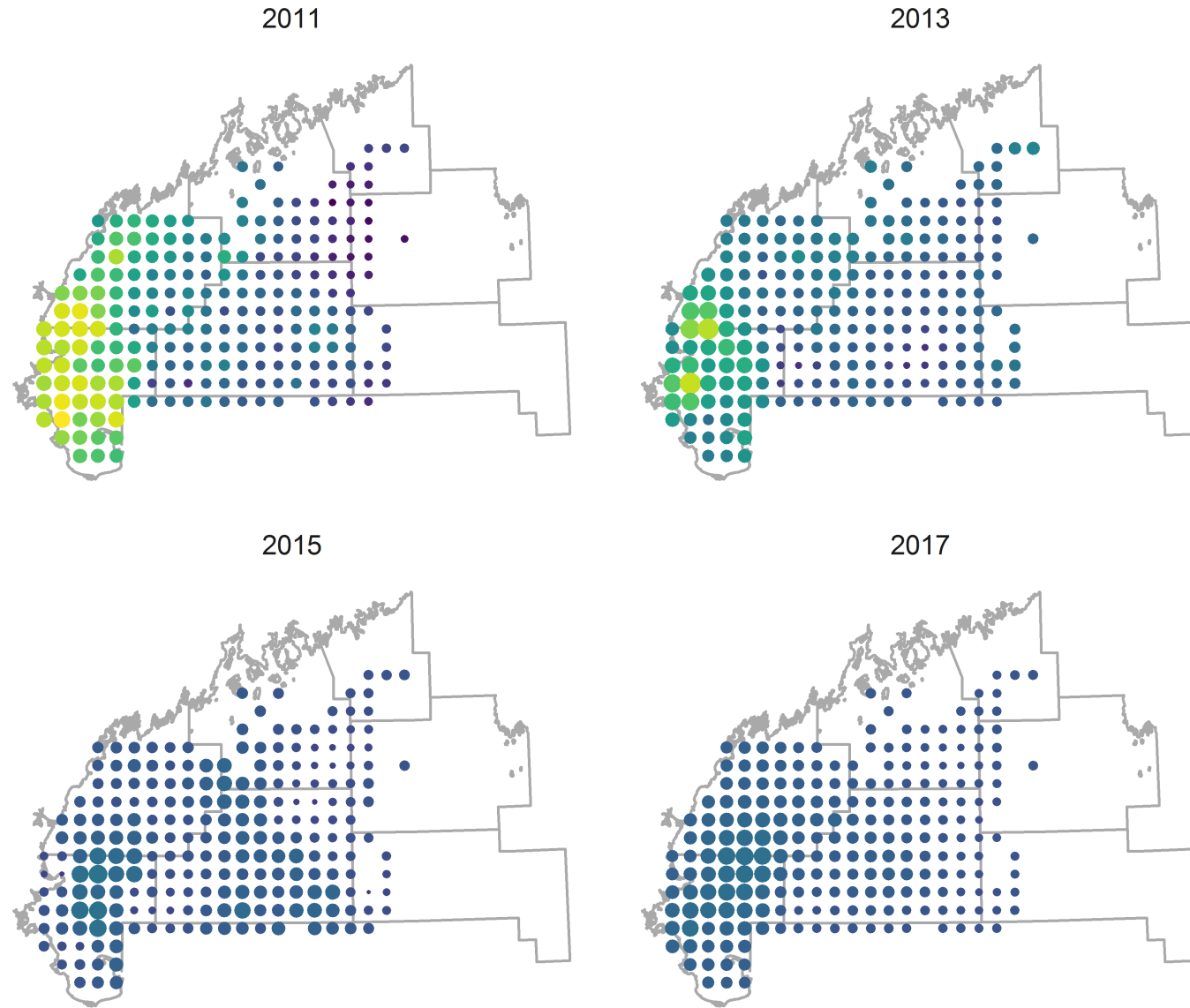
Parameter estimates for random effect variances



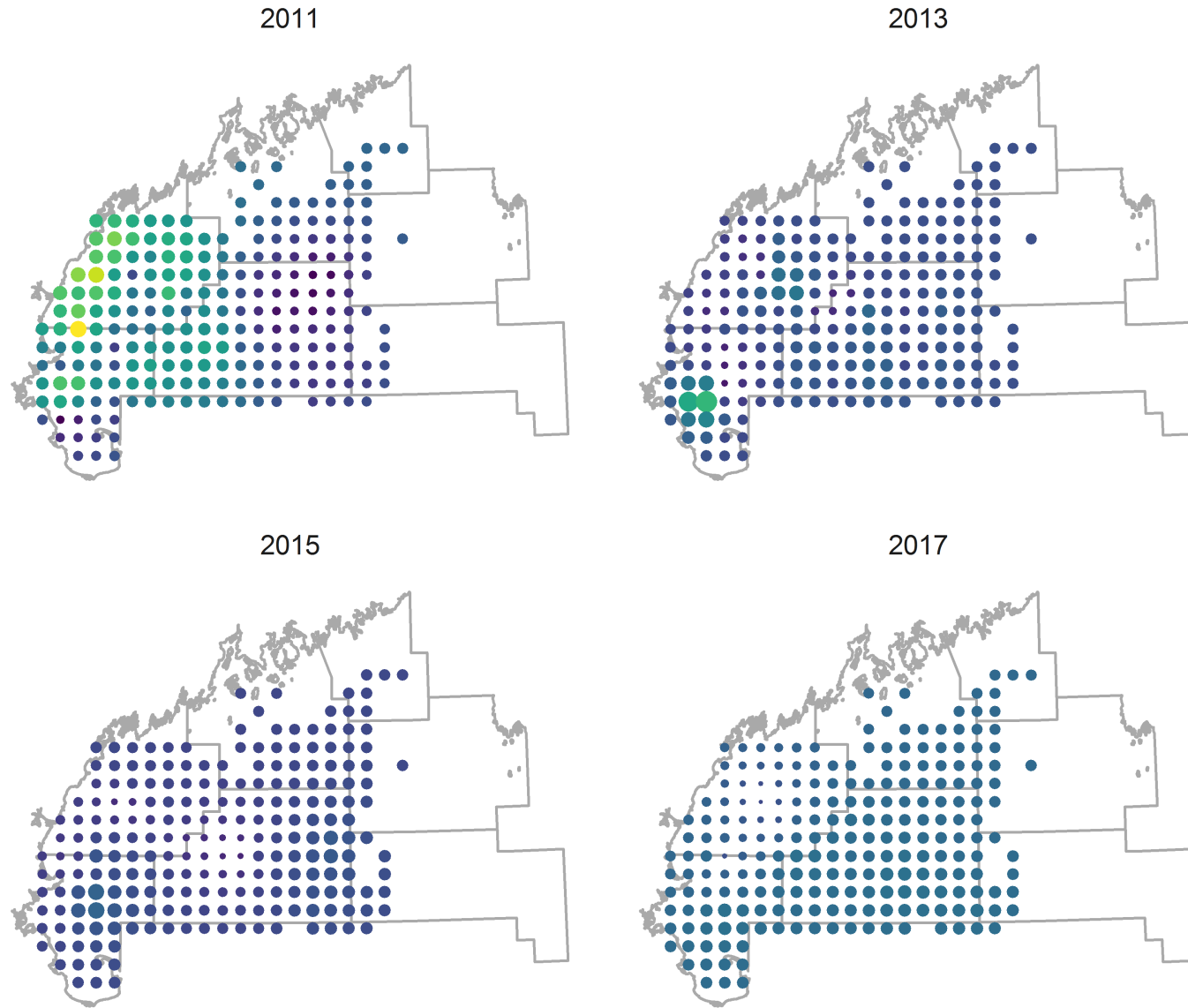
Residual spatial variation in cod catch



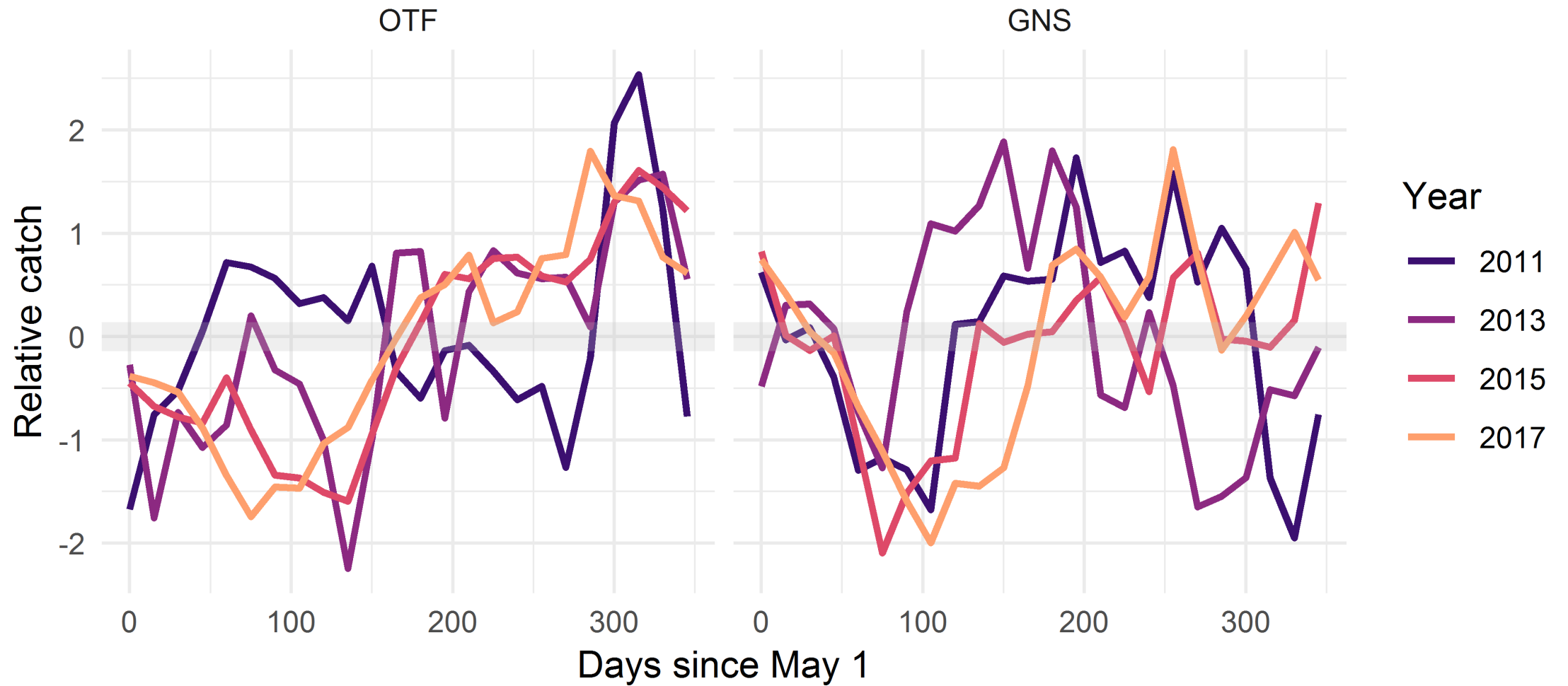
Residual spatial variation in cod catch (OTF)



Residual spatial variation in cod catch (GNS)

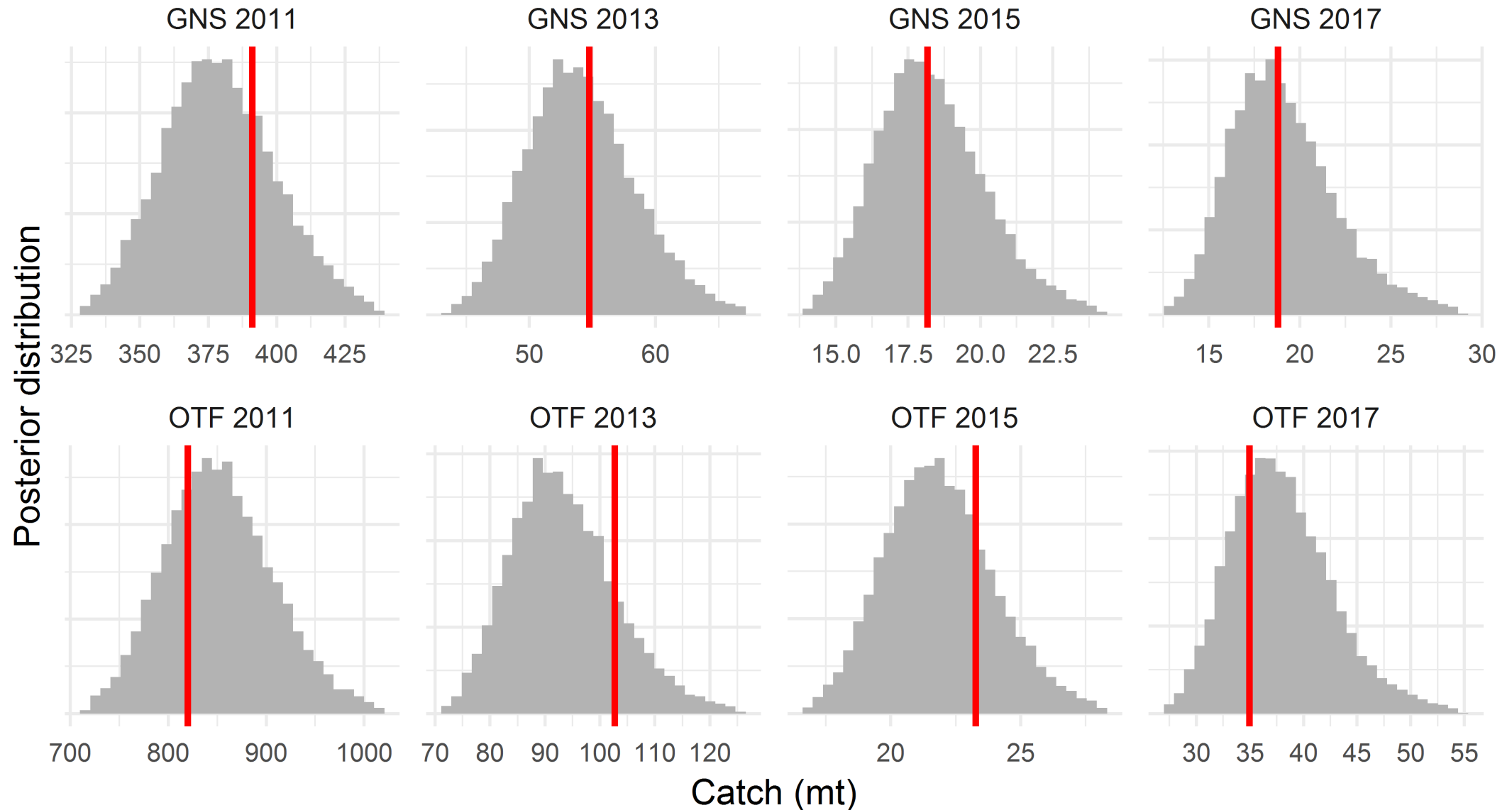


Residual temporal variation in cod catch



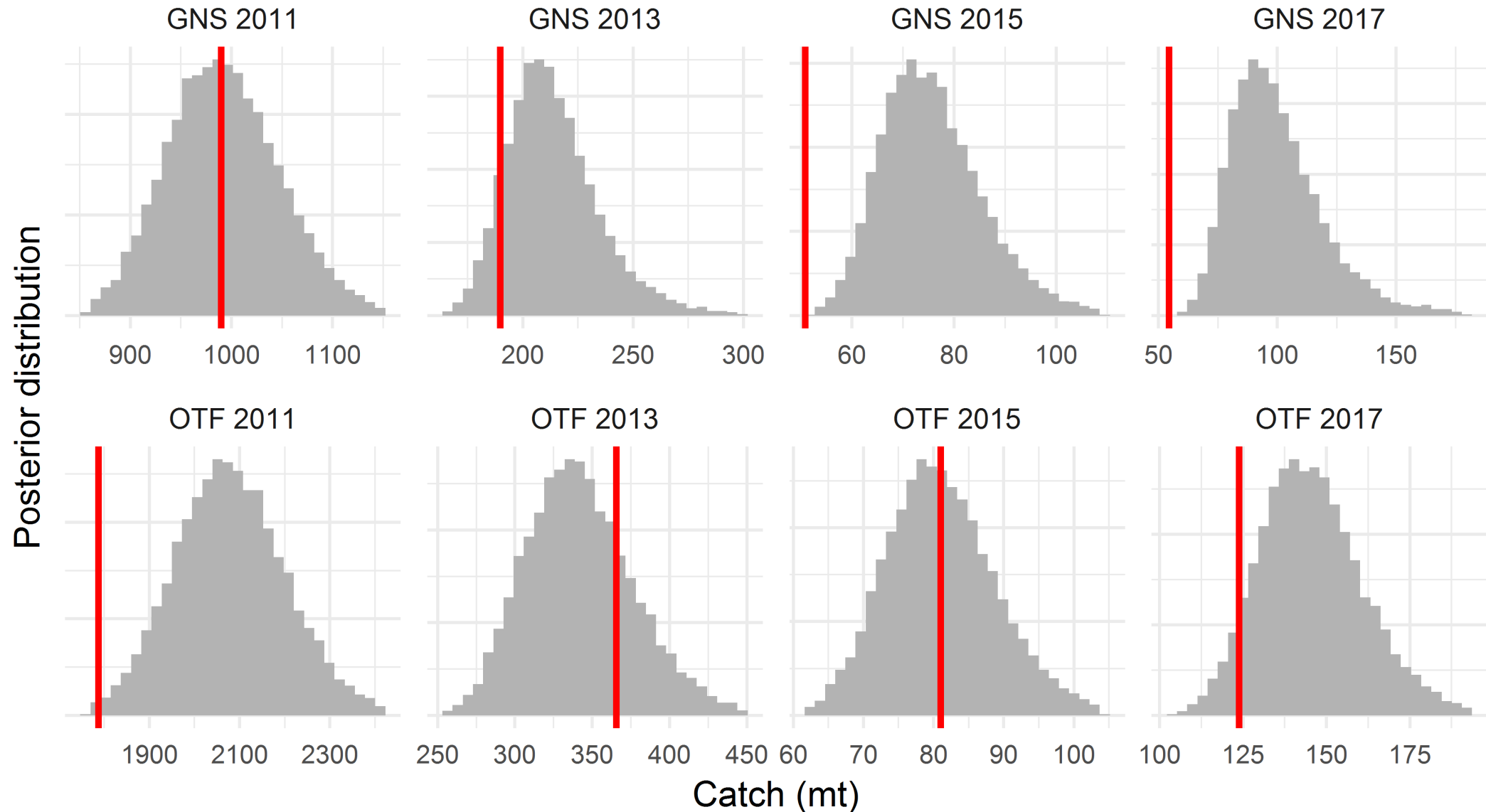
GOM Cod catch on observed trips

Model predictions (gray) vs. GARFO estimate (red)



GOM Cod catch on unobserved trips

Model predictions (gray) vs. GARFO estimate (red)



Conclusions

- Model predicted observed catch fairly well
 - corrected for overdispersion
- Unobserved gillnet catch has increased discrepancy over time
 - pre-catch behavior likely representative
 - predicted catch was 40% (2015) and 68% (2017) greater than reported
 - evidence of potential compliance problem
- Unobserved otter trawl catch has erratic pattern
 - pre-catch behavior not representative? e.g., tow depth, speed
 - CPUE on observed trips may not project to unobserved

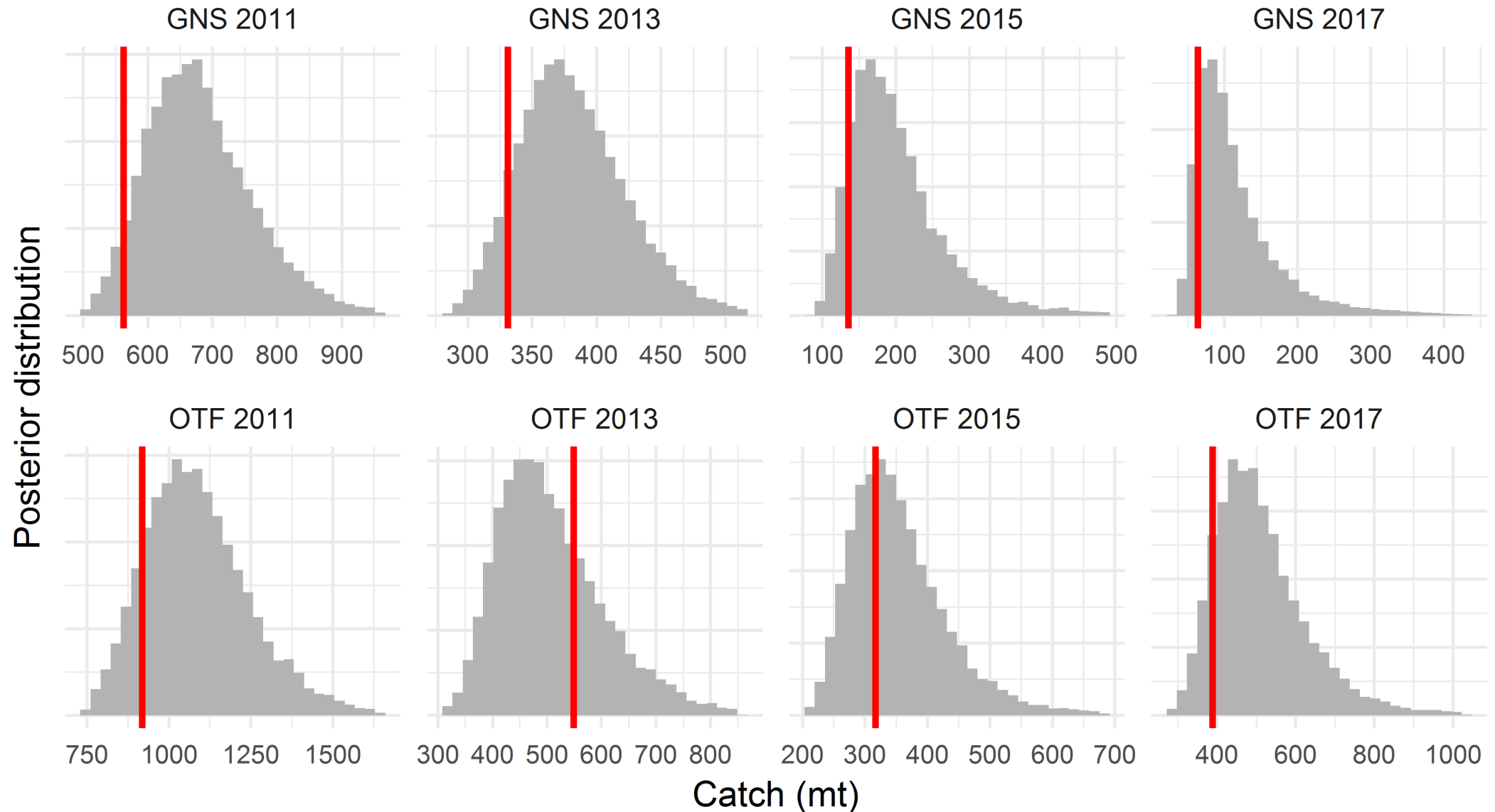
Terms of reference

2. Are the methods adequately described and based on sound analytic techniques and statistical principles? **pg.2–3**
3. Are important uncertainties in the data and the analyses (possibly including the effects of year to year variations in fishing practices) identified, and are the impacts of these uncertainties on the analyses adequately described? **pg.6**
4. Are the analyses conducted at the appropriate temporal and spatial scale such that the existence of regional or seasonal differences in monitoring performance can be identified? **pg.2–3,8**
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Pollock results...

GOM Pollock catch on observed trips

Model predictions (gray) vs. GARFO estimate (red)



GOM Pollock catch on unobserved trips

Model predictions (gray) vs. GARFO estimate (red)

