Northeast Fisheries Science Center Reference Document 06-18

Environmental Preferences of Atlantic Herring under Changing Harvest Regimes

by Kevin D. Friedland, John E. O'Reilly,
Jonathan A. Hare, Grayson B. Wood,
William J. Overholtz, and Matthew D. Cieri

August 2006

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ABSTRACT

The meso-scale distribution of filter-feeding fishes, such as Atlantic herring, is usually associated with oceanographic features. These species are often concentrated along fronts, which demarcate boundaries between water masses and are frequently areas of increased primary and secondary production. Fishing operations can use these oceanographic features as a predictive tool to find fish more efficiently. These habitat features are also partly responsible for the local availability of fish, which can be an important factor if a fishery is allocated regionally or by fleets. The distribution of the Atlantic herring purse seine fleet was studied to evaluate the response of the fish to oceanographic features. Catch rates were compared to remotely-sensed sea surface temperature, chlorophyll concentration, primary production rate, and frontal occurrence probability. Temperature, chlorophyll, and primary production were poor predictors of catch location, whereas frontal probability was associated with fishing. This association changed dramatically in 1995 when purse seine fishers seemed to target and find fish in distinctly different oceanographic conditions. This transition in the distribution of purse seine effort was coincident with the increased activity of the mid-water trawl fleet in the Gulf of Maine, suggesting that gear interaction may have influenced the selection of target fishing areas.

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INTRODUCTION

The distribution and local availability of fish can be influenced by environmental effects, thus masking changes in stock condition and harvest interaction (Gillis and Frank 2001). This is of particular concern with migratory species such as Atlantic herring (*Clupea harengus harengus*), which are a highly mobile species capable of significant annual migrations and within-season movements. Thus, movement of stock components may confound assessments by varying their availability to various fishing operations.

There is growing concern that changes in local availability of Gulf of Maine herring on traditional fishing grounds has resulted in significant relocation of fishing operations. Neal (2003) suggests that spawning by coastal herring has progressively decreased over the last two decades and that herring are not as abundant in Maine waters. This is posited as a result of the fish spawning later in the season, while still geographically centered on the traditionally identified core spawning areas of eastern Maine and New Brunswick. These data are in contrast to a general picture of high stock abundance coming from stock assessment data and fishery independent surveys (Overholtz et al. 2005). Thus, we are faced with a complex set of issues relating to the local availability of the species and the potential influence of a range of factors capable of causing stock components to migrate at variance to the stock complex.

Herring, like other pelagic species, appear to use gradient search strategies to find plankton food concentration. However, our interpretations of herring distribution must also take into account the behaviors associated with spawning, thus drawing on the information on the areal extent and timing of spawning, as well as the magnitude of spawning (Smith and Morse 1993). Zooplankton distribution is likely to be a predictor of herring distribution, considering the importance of zooplankton in the diet of both larvae and adults (Sherman and Honey 1971, Sherman and Perkins 1971). Larval herring feed on smaller copepods (*Psuedocalanus* sp., *Paracalanus parvus*, and *Centropages typicus*), while adult herring feed predominantly on euphausiids, copepods, and chaetognaths (Reid et al. 1999).

Changes in the distribution and abundance of prey can affect the feeding ecology of herring (Foy and Norcross 1999), suggesting a potential linkage to the observed decrease in size-at-age for herring on the Northeast Shelf (Overholtz et al. 2005). Relationships to zooplankton data would provide the opportunity to evaluate whether these decreases in size-at-age are related to changes in prey abundance, distribution, and community composition. Smith and Morse (1993) used ichthyoplankton data to document the fall and rise of herring on Georges Bank. However, despite the utility of plankton studies in describing decadal patterns in abundance, local scale distribution cannot be explained with the historically collected zooplankton data owing to its lack of spatial and temporal resolution (Jossi et al. 2003).

Remotely-sensed oceanographic data offer proxy variables that can be related to the distribution of herring food resources, and thus allow tests of hypotheses relating environmental condition and local availability. From a variety of data sources it is clear the annual phytoplankton production cycle in the Gulf of Maine is out of phase with that observed for Georges Bank and the Middle Atlantic Bight (O'Reilly and Zetlin 1998, Yoder et al. 2002). In the Gulf of Maine, the fall phytoplankton bloom is superior to the spring bloom, whereas on Georges Bank and in the Middle Atlantic Bight, the annual peak in phytoplankton biomass is observed during the spring bloom in March. Phytoplankton chlorophyll levels throughout the July-September period are also significantly higher in the Gulf of Maine than in Georges Bank and Middle Atlantic Bight. These high levels of phytoplankton standing stocks and primary production in the Gulf during summer and early fall coincide with the period of intense feeding, growth, and spawning of herring in the region. Moreover, there is considerable interannual variability in the meso-scale distributional patterns of sea surface temperature and primary production within the Gulf during the summer, and particularly so during the October fall bloom.

Oceanographic fronts, which are regions of sharp gradients in temperature or density, are well known to have a concentrating effect on a range of marine organisms and have been examined on both micro- and meso-scale spatial dimensions. Fronts provide structure within the water column that often results in the upwelling of nutrients and subsequent stimulation of primary production. Fronts can also form density barriers that can serve to concentrate primary consumers, which forage for species like herring. Fronts are more easily synoptically measured than are zooplankton patterns, thus they are features that serve as a proxy variable for zooplankton abundance, which may not be measured as effectively.

Zinkevitch (1967) analyzed the data from the foreign fleets fishing on the Northeast Shelf and showed that set frequency for herring was concentrated in frontal regions along Georges Bank and the Middle Atlantic Bight. Fronts have also been associated with pre-spawning aggregations of herring (Maravelias 1997), which may be of significance to the historical fishing patterns in the Gulf of Maine. The Gulf has a complex set of frontal patterns associated with bathymetry, vigorous tidal mixing, and the overarching pattern of circulation. Frontal associations for migratory tuna in the Gulf suggest that the frontal associations that may involve herring could form a complex trophic cascade (Schick et al. 2004).

The Northeast U.S. Shelf Large Marine Ecosystem is complex and highly dynamic, and known to have variable inter-annual and spatial patterns of hydrography and primary and secondary production. In light of the documented rebuilding and recent large population estimates of herring from stock assessments (Overholtz et al. 2005), the goal of this investigation is to examine a range of physical and biological oceanographic datasets in an exploratory fashion to develop hypotheses about potential factors affecting the local availability of herring. The specific objectives of this study are to examine the correspondence between spatial patterns in oceanographic parameters and the distributional patterns of herring catch in the Gulf of Maine. We will also seek to analyze these patterns in the context of changing fisheries regimes where the manner of harvest may influence the local abundance patterns of the stock.

METHODS

Atlantic herring vessel trip report data

Currently the vessel trip report database has approximately 80,000 records or trips reporting herring. Some gears reported in the database have consistently produced large catches of herring over wide geographic areas and over relevant time periods; these gears will provide the basis for our analyses. The most active gear in the database is purse seines, which have targeted herring over the full temporal extent of the database, 1960-2004 (Table 1). Purse seine catches and trips provide a depiction of the distribution of herring schools along the Maine coast. Fishing areas for this gear are reported by ten minute squares; thus fine scale oceanographic features may not be useful in analyzing the behavior of this gear. Stop seines and weirs were a major gear in the fishery until the availability of herring juveniles changed and the fishery was first reduced in the 1980s and ended in the 1990s. A number of oceanographic and biologic datasets could be re-examined to study changes in the historical fishery.

The contemporary fishery includes trawl gears that both target herring and take herring as by-catch. The principal targeting gear is mid-water trawls. These trip reports have specific latitude and longitude locations and lend themselves to analyses of fine scale oceanographic features such as fronts. The non-target gears, such as groundfish and shrimp otter trawls, do not have concentrated catches of herring, but since they are not targeting herring, their catch rate data may be useful as a relative index of abundance. These non target gears, which sample over broad areas, may be useful in testing assumptions related to the data from targeted gears, which sample over smaller areas. Of the gears targeting herring, we focused on the catches of the purse seine fleet that operates along the Maine coast. This fleet provides a long time series of data that exceeds the time periods of coverage associated with the oceanographic datasets.

Sea surface temperature

Daily high resolution (4 km/pixel) maps of the distribution of sea surface temperature (SST) throughout the Northeast U.S. Continental Shelf Ecosystem have been generated by combining nighttime SST data from three polar orbiting satellite sensors: NOAA's satellites equipped with AVHRR sensors, and NASA's MODIS terra and Aqua SST sensors. All data were obtained from NASA JPL (http://podaac.jpl.nasa.gov/). AVHRR data were processed using the Pathfinder method and covered the period from 1985 through July 2005. MODIS Terra SSTs were available from Feb. 2000 to the present and MODIS Aqua SSTs from July 2002 through the present. By combining SST data from two or more sensors after 2000, we were able to increase the number of good (cloud-free) SST estimates and ecosystem coverage. Nighttime SST data were used exclusively to avoid unrepresentative SSTs in daytime scenes resulting from diurnal heating. Our resulting 4 km SST time series, encompassing the period from January 1985 to the present, was binned to 10' squares to match the spatial resolution of the vessel trip report data.

Chlorophyll and primary productivity estimates

Since September 1997, remotely-sensed satellite data from the SeaWiFS ocean color sensor has provided us with daily synoptic views of surface concentrations of chlorophyll throughout the Northeast Continental Shelf Ecosystem. The concentration of chlorophyll, the dominant green pigment in phytoplankton, is considered an index of phytoplankton abundance and biomass. Our daily average chlorophyll time series was developed from 4,765 1 km-resolution scenes of the Northeast acquired by SeaWiFS from September 1997 through July 2005. As with SST, the chlorophyll data were binned to 10' squares to match the resolution of the vessel trip report data.

We were also interested in exploring relationships between patterns in the level of phytoplankton primary production and herring distributions. Our estimates of daily phytoplankton primary production are based on remotely-sensed SST, chlorophyll, and PAR (photosynthetically active radiation) from SeaWiFS, and the VGPM2a model, a variation of the vertically generalized productivity model (VGPM) developed by Behrenfeld and Falkowski (1997). The conventional method used for measuring phytoplankton primary production is the ^{14}C-uptake method. While the *in situ* ^{14}C-uptake method provides a precise estimate of primary productivity, this method is expensive and labor-intensive, and consequently it is difficult to obtain sufficient spatial and temporal coverage to assess annual variability and long-term trends. At present, combining remotely-sensed data from satellites with productivity algorithms (Campbell et al. 2002) represents the only feasible method for resolving seasonal, annual and climate-related variability of primary productivity throughout large marine ecosystems. Our daily primary productivity time series spans the period from September 1997 to present, beginning with the first available chlorophyll maps from SeaWiFS.

We consider our satellite-based estimates of primary production to be reliable because the general spatial and seasonal patterns of primary production developed from contemporary satellite data and the VGPM2a model (O'Reilly and Ducas 2004) agree well with historical patterns based on *in situ* measurements of ^{14}C-uptake made during MARMAP surveys of the Northeast from 1977 through 1987 (O'Reilly et al. 1987).

Frontal probability

Remote sensing not only provides data on sea surface temperature and chlorophyll, but also provides information on sea surface temperature gradients (i.e., fronts). Many pelagic species aggregate in the vicinity of fronts, and we evaluate the hypothesis that herring catches are associated with frontal locations and that changes in frontal locations are related to changes in the distribution of the herring fishery in the Gulf of Maine. We use a data set developed by satellite oceanographers at the University of Rhode Island Graduate School of Oceanography (Ullman and Cornillon 1999). The fronts dataset is limited to the years 1985 to 2000. It was necessary to retrieve all the original sea surface temperature images used to identify the fronts, so an estimate of good pixels could be made for each data bin. Good pixels are cloud-free ocean surface pixel locations where a sea surface temperature could be estimated by the satellite radiometer. Frontal probability is simply the ratio of frontal pixels identified in the fronts database to good pixels available from the original sea surface temperature image.

Data analyses

The catch data were linked with mean sea surface temperature, chlorophyll, primary productivity, and frontal probability for each trip location by standard 10' square. With the data linked, we examined the range of each parameter associated with the fishery and the correlation between the catch and the respective parameters. The most obvious limitation of these analyses is that they only sample the temperature, chlorophyll, and fronts data where the fishery occurs; thus if the distribution of the fishery is being affected by a coastal gradient, the data from the trip locations may not characterize the gradient. Therefore, we also examined the full meso-scale gradients of these parameters by examining the parameters where the fishery occurred annually versus where the fishery had occurred during the time series.

RESULTS

Atlantic herring purse seine catch

The purse seine fishery occurs primarily during the summer with most of the catch landed during the months of July through October (Figure 1). The fishery targets adult herring for the bait markets, which in turn supplies lobster fishers. The bait fishery can extend well into the fall to satisfy the needs of the export lobster fishery. Only in some years has the fishery duration been constrained by the quota. Over the last decade, the number of purse seine trips has declined, reflecting the lower number of vessels participating in the fishery (Table 2). The contemporary purse seine fleet comprises only four boats, down from over ten vessels just a decade ago. The average landings per trip have increased slightly during the peak months of the fishery, possibly reflecting the effect of decreased competition for fish (Table 3). Landings from individual trips have ranged from 0 to 11,725 mt. Most trips land less than 100 mt and the distribution of trip size appears to be log normal (Figure 2). The presence of zero and low tonnage catches in the database suggests that the dynamic range of the data may be sufficient to evaluate and contrast associations between low versus high catch rate areas and oceanographic conditions.

The purse seine fleet has utilized most of the coastal ocean from eastern Maine to Massachusetts Bay. We unitized the reported location of individual trips to study the distribution of the fishery and considered ways of characterizing the central tendency of the fishery distribution and indices that characterize the range as well. The distribution of the fishery within the area encompassing all catch locations is a function of the time period over which catches are summed and the factors affecting the search decisions and success of the participants in the fishery. Our first characterization of distribution of the fishery was to compute mean catch-weighted longitude and latitude by month and year. We restricted our analysis to the used purse seine trip data from the Gulf of Maine, eliminating records south of 42°N from the analysis. These data show that the fishery has been centered all along the western Gulf of Maine (Figure 3). The early season fishery (catches made during May) is distributed more to the south and west compared to the summer fishery catch of July and August. In time series, these data suggest that during the collapse of the stock, most of the fishing activity was further to the south and west. The time series of catch-weighted mean longitude show that the contemporary fishery is occurring around 69°W, whereas during the years of the stock collapse, the fishery was closer to 70°W (Figure 4). The catch-weighted mean latitude data show a similar trend over time with the contemporary fishery occurring mostly around 44°N and the historic fishery occurring around 43°N (Figure 5). We are limited to the contemporary fishery (since 1985) for our comparisons to the principal oceanographic datasets; it clear the fishery is now constrained to a more narrow range of both longitude and latitude. Despite this narrowing of the range of the mean locations, there has been a dramatic increase in the number of 10' square boxes visited by the fishery beginning in 1996 (Figure 6).

Sea surface temperature

Sea surface temperature of trip locations generally follows the seasonal pattern of temperatures in the Gulf of Maine. SST associated with May trip locations averaged 7°C and increase to a mean of approximately 13°C during the August fishery (Figure 7). The inter-quartile range for the August fishery captured temperatures in excess of 15°C. Trip location temperatures began to decrease with fall cooling during September into October.

We examined the relationship between herring catch and sea surface temperature from two perspectives, within the area fishing occurred and between areas where fishing occurred versus where it had occurred during the time series. For the first part of the analysis, the relationship between the mean catch of herring by ten minute square and the mean sea surface temperature of the square was analyzed. There are no significant trends between herring catch and sea surface temperature (Figure 8). There is a tendency for correlation to be mostly positive in the late season months, but few of these correlations are significant.

For the second part of the analysis, the sea surface temperature in ten minute squares where fishing occurred was compared to the temperature in squares where fishing had occurred during the time series. In a given year, the fishery will occur typically in one-fourth of the squares where trips have occurred. The sea surface temperature in the fishery versus the unvisited squares area was similar for all years and months, with no systematic differences between areas (Figure 9).

Chlorophyll and primary production

Chlorophyll *a* at trip locations also shows a monthly pattern most likely reflecting the fall bloom. Mean chlorophyll-a is approximately 2 mg/m^3 from May to July and increases to 4 mg/m^3 during August and September (Figure 10). Primary production is more highly patterned showing a progressive seasonal increase (Figure 11).

The distribution of the fishery versus chlorophyll *a* concentration and primary production rate was analyzed in the same way as sea surface temperature. Correlation between catch and chlorophyll *a* was non-significant and without trend (Figure 12). Likewise, chlorophyll *a* was not significantly different in the fished versus the un-fished areas (Figure 13). There were some significant correlations between catch and primary production rate, but there were both positive and negative correlations, suggesting they were not meaningful (Figure 14). There was also a slight tendency for primary production to be higher in un-fished areas during early- to mid-summer (Figure 15).

Frontal probability

The probability of SST fronts increased seasonally, with the most fronts evident in September sea surface temperature scenes (Figure 16). Most correlations between catch and frontal probability are positive and all significant correlations are also positive (Figure 17). The most striking trend occurs with the September data, where the period 1985 to 1992 yielded seven significant correlations. The correlation between catch and frontal probability appears to have been stronger in the early part of the time series; at some point in the mid-1990s the correlations tended to be more neutral or negative.

Distribution related to fronts is also seen in the analysis of fronts in areas fished versus un-fished. During the summer months, fishing occurred in lower frontal probability areas during the early part of the time series, but switched to higher frontal probability areas again during the 1990s (Figure 18). This switch in frontal probability associated with fishing is most dramatic in the August data, where nearly all the years prior to 1995 show fishing in low frontal probability areas and years after 1994 show fishing in high frontal areas.

This result is inconsistent with the idea that fishing is responding solely to the distribution of fronts. In fact, when we consider when mid-water trawlers entered the fishery, we see a relationship between the intensity of mid-water trawler trips and the August frontal probabilities associated with the purse seine fleet (Figure 19). It would appear that before mid-water trawlers were fishing herring in the Gulf of Maine, the purse seine fleet concentrated their effort in low frontal probability regions but found greater success fishing in the higher probability frontal areas within these regions. After the mid-water trawlers entered the fishery, the purse seine fleet appears to have selected higher frontal probability regions to search for fish, and its success is no longer related to the distribution of fronts within these areas.

However, these observations must be tempered by the fact that there has been change in the environment with respect to the distribution of fronts. The distribution of fronts in the Gulf of Maine has changed over time, in particular during the month of August, where the western segment of the Gulf started to have more fronts develop in the early 1990s (Figure 20). The environmental change from low to high front years does not match the 1994-1995 transition seen in the fisheries data, nor does it address the spatial issue of where fishing occurred, but it does maintain the possibility of an environmentally driven causality.

DISCUSSION

Most coastal pelagic fish species are migratory, moving toward the equator in winter and toward the poles in summer (Fréon and Misund 1999). Spawning and feeding activities are embedded within these seasonal movements, and the specific patterns vary among species and among local populations within species. The habitat of these species is described by a combination of abiotic (temperature, salinity, fronts) and biotic (food availability, predator distribution) variables related to the oceanography and bathymetry of their ecosystems. Fishing targets individuals at different points in the life cycle and seasonal cycle; this intersection determines the distribution of the fishing relative to the distribution of the species.

Within this context, Atlantic herring move seasonally within the Gulf of Maine, and three general migratory patterns are recognized and associated with general stock structure (Sindermann 1979). Herring in Nova Scotian waters spawn in the late-summer and fall along the southwestern coast and overwinter along the northeastern coast. Georges Bank/Nantucket Shoals herring overwinter south of Cape Cod, spend the spring and summer in the Gulf of Maine, and spawn in the fall. The movements of herring that spawn along coastal Maine are less well known; overwintering likely occurs in the vicinity of or south of Cape Cod, while spring and summer are spent in the Gulf of Maine and spawning occurs in the fall. The amount of mixing among stocks is unknown. Given the general importance of environmental factors in defining pelagic fish habitat, the distribution of herring likely changes interannually in response to environmental variation in the Gulf of Maine, and potentially in areas to the south (e.g., Mid-Atlantic) and north (e.g., Nova Scotia).

U.S. fishing in the Gulf of Maine targets the coastal Gulf of Maine and Georges Bank/Nantucket Shoals herring and is primarily composed of purse seiners and mid-water trawlers (Overholtz et al. 2005). Our study focused on the purse seine fishery and our results suggest that the extent of the ecosystem used by the purse seine fleet has increased over the past decade. This change coincides with a change in reporting for all fisheries, so it may be an artifact of reporting practices. However, it also coincides with the large increase in fishing by mid-water trawlers, thus it may reflect more dispersed schools of fish caused by the interaction of the gears.

Another factor in the interpretation of the catch data is the effect of spawning closures on the distribution of catches. Spawning closures are made by area and at different times each year. The closures are based on within-season samples, thus the timing of closures is not the same each year. When there is the potential for a closure, there is evidence that smaller fish are targeted to avoid triggering a closure; this targeting of smaller fish could result in a change in the distribution of the fishery. These factors have to be taken into account before drawing any conclusion about the environmental analysis presented here.

Our analyses indicate that sea surface temperature and characteristics of primary production are not an important determinant of success or location of the purse seine fishery. Although several studies have indicated that temperature is important factor in the distribution of herring (Maravelias and Reid 1997, Corten 2001), we found no effect. Temperature in and of itself is more of a regional-scale feature and is probably too coarse a parameter to be related to the fishery within the Gulf of Maine and within the fishing season. In looking at the range of temperature of the fishery, we see that it varies seasonally and reflects the range of temperature tolerances of the fish itself. As with sea surface temperature, neither plankton parameter appears to be correlated to the location or intensity of fishing. Again this is in contrast to other studies (Maravelias and Reid 1997, Corten 2001), but not unexpected because we are examining data within the Gulf of Maine and within the fishing season. Further, since herring do not directly consume phytoplankton, a direct link is not likely. However, if we were able to examine zooplankton abundances on the same temporal and spatial scales as herring catches, we would expect to see an association (see Maravelias and Reid 1997, Corten 2001, Kvamme et al. 2003).

Our results suggest that fronts play an important role in the distribution of herring, and similar results have been found in other studies. Off the coast of South Africa, anchovy (*Engraulisi capensis*) and round herring (*Etrumeus whiteheadi*) tend to concentrate around fronts, whereas sardine (*Sardinops sagax*) show no aggregation near fronts (Agenbag et al. 2003). In the North Sea, Atlantic herring (*Clupea harengus*) tended to avoid stratified and frontal areas (Maravelias and Reid 1997). In the Gulf of Maine, frontal probability appears to be positively related to the selection of fishing area and the success or intensity of catch. However, the dramatic changes in the fishery relative to fronts in the mid-1990s suggests that other factors are influencing the distribution and catch of the purse-seine fishery. In fact, the dominant change in the purse-seine fishery catch data co-occurs with the initiation of the midwater trawler fishery. Thus, the changes in the purse-seine fishery are linked to the mid-water trawl fishery, but we cannot rule out the possibility of an environmental influence related to the intensity and distribution of fronts in the Gulf of Maine.

The analyses presented here indicate that fishery-dependent data may be influenced by management changes in a fishery (e.g., closures), interactions between fisheries (e.g., purse seiners and mid-water trawled), and the environmental variables that define habitat (e.g., fronts). Additionally, the fishery-dependent data examined here could be influenced by differences in abundance and migration of local populations that use the Gulf of Maine during the spring, summer, and early fall (see Sinclair 1988, McQuinn 1998). We show that the distribution of the purse-seine fishery has changed dramatically relative to the distribution of fronts in the Gulf of Maine. The time of this change coincided with the beginning of the mid-water trawl fishery, suggesting an interaction between the fisheries. However, there has also been an underlying change in the distribution of fronts. Previous studies defining pelagic fish habitat using fishery-dependent data have tried to limit the influence of the fishery on the analyses of environmental variables (Agenbag et al. 2003), but ultimately these analyses are still influenced by fishery dynamics. Future approaches could define the environmental effects using fishery-independent data (e.g., Kvamme et al. 2003) and then examine the interaction between fisheries using fishery dependent data, taking into account the previously defined environmental effects.

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Table 1. Inventory of gears in the vessel trip report data reporting herring.

GEAR	DATABASE RECORDS	PERCENT
PURSE SEINE HERRING	25048	31
STOP SEINE	20698	25
OTTER TRAWL BOTTOM FISH	8871	11
WEIR	7429	9
OTTER TRAWL MIDWATER	6339	8
OTTER TRAWL MIDWATER PAIRED	4932	6
OTTER TRAWL BOTTOM SHRIMP	3842	5
HANDLINE	1605	2
GILL NET FIXED OR ANCHORED	1551	2
GILL NET RUN AROUND	575	1
GILL NET DRIFT SMALL MESH	286	0
POUND NET	220	0
TRAP	88	0
OTHER GEAR	67	0
SCOTTISH SEINE	26	0
POT & TRAP LOBSTER	22	0
GILL NET DRIFT LARGE MESH	19	0
DREDGE SCALLOP SEA	4	0
POT & TRAP SHRIMP	2	0
POT & TRAP CRAB OTHER	2	0

Table 2. Distribution by year and month of effort for purse seine gear from the vessel trip report data.

	Number of Trips												
	Month												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	Total
1985	29	55	34	18	2	13	43	84	77	77	18	22	472
1986	24	59	82	26	14	9	109	100	169	83	71	58	804
1987	42	52	50	29	26	42	136	139	125	105	50	45	841
1988	54	74	87	48	19	36	93	105	116	34	58	34	758
1989	48	41	48	34	3	29	43	160	94	56	16	6	578
1990	63	40	58	25	60	78	130	119	113	77	53	52	868
1991	6	10	4	7	7	129	243	117	125	109	11	6	774
1992	5	6	4	21	19	57	94	119	144	157	100	14	740
1993	3			26	81	114	120	161	157	158	62	15	897
1994	2	2		19	55	107	139	104	106	159	104	31	828
1995	7	7	5	23	24	27	99	137	137	155	20	4	645
1996	17			7	55	98	153	184	214	106	46	23	903
1997	24			31	48	94	151	142	112	111	56	40	809
1998	3	1	1	34	41	46	86	88	66	42	24	6	438
1999				8	48	83	103	111	99	56	34	21	563
2000				8	44	74	122	105	47	39			439
2001				17	26	43	61	73	67	37	4		328
2002				7	3	49	84	76	64	45	16		344
2003		1			3	29	45	82	78	38	18		294
2004					4	31	53	61	66	35	12		262
Total	327	348	373	388	582	1188	2107	2267	2176	1679	773	377	12585

Table 3. Distribution by year and month of catch per trip for purse seine gear from the vessel trip report data.

Average Catch per Trip

YEAR	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total
1985	59	47	63	66	120	22	66	56	47	60	80	72	57
1986	65	47	44	40	51	34	43	47	54	41	48	32	46
1987	44	73	81	66	84	52	44	40	47	62	54	79	55
1988	52	60	65	64	59	73	63	58	59	80	86	55	63
1989	58	94	113	195	60	80	99	66	64	92	245	345	92
1990	67	106	131	129	47	39	47	40	53	48	84	68	62
1991	817	659	521	397	55	51	57	60	69	67	768	1089	97
1992	1300	796	1390	461	36	37	44	52	50	66	100	345	97
1993	984			38	39	36	42	59	51	59	95	274	59
1994	385	82		151	52	46	56	64	49	66	65	147	64
1995	673	562	577	133	27	28	48	53	49	51	220	459	76
1996	91			102	50	40	46	45	57	71	57	56	53
1997	64			80	49	56	65	76	87	93	106	59	75
1998	92	370	145	57	51	56	64	44	39	64	52	38	54
1999				47	63	58	62	83	80	75	65	71	71
2000				28	46	69	75	72	65	64			67
2001				41	33	47	64	73	74	74	58		63
2002				45	69	41	67	53	68	56	63		58
2003		6			12	48	46	61	68	68	77		61
2004					22	54	73	79	79	97	72		76
Total	116	108	105	111	49	49	56	58	59	66	93	111	67

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Figure 1. Mean proportion of the purse seine catch taken by month.

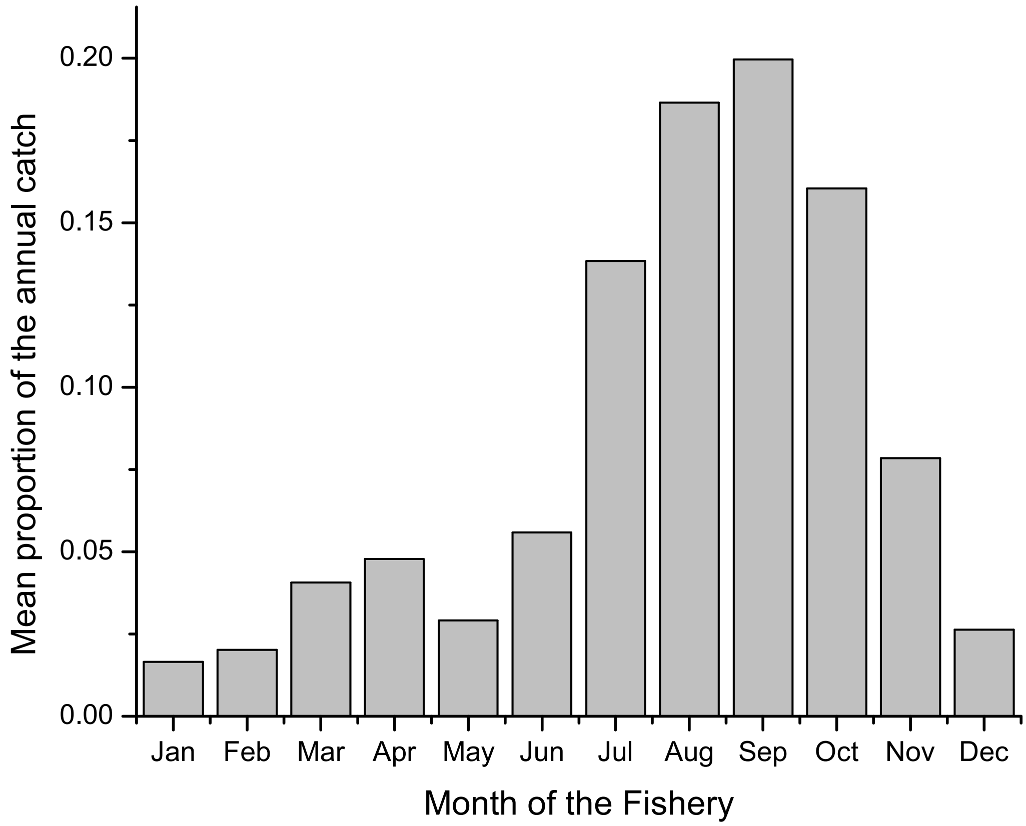


Figure 2.   Frequency of catch for trips < 100 mt and from locations north of 42°N.

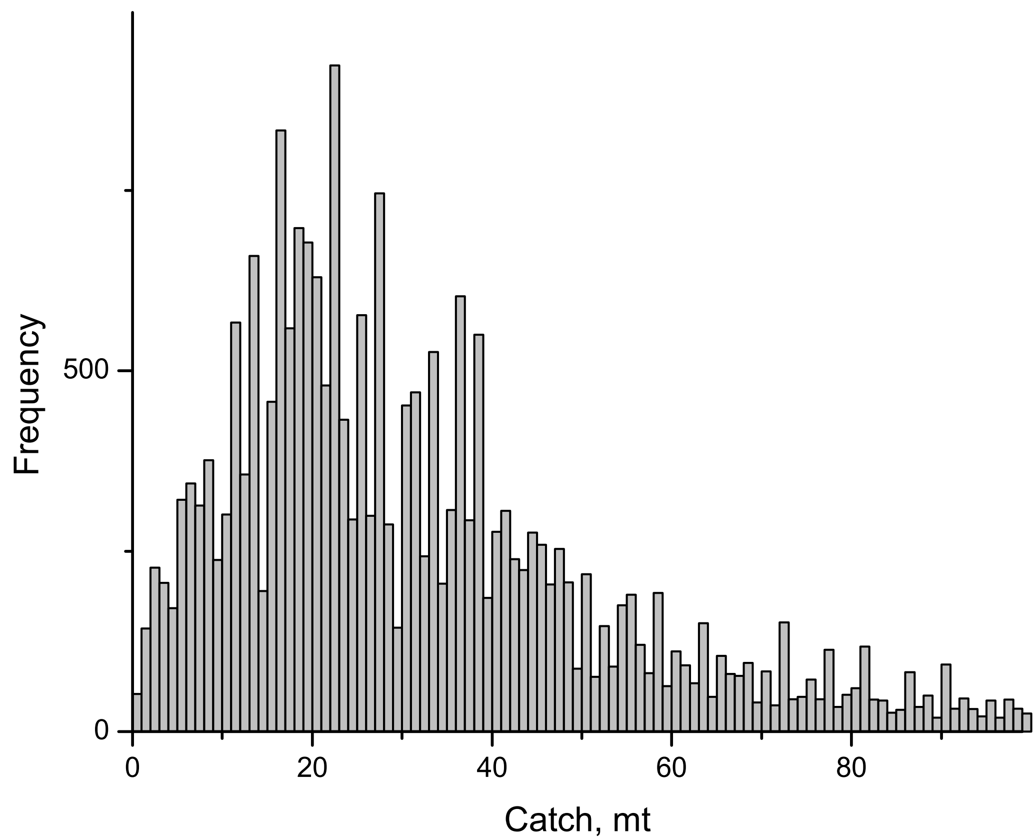


Figure 3. Catch-weighted mean longitude and latitude of purse seine catches by year and month. Label denotes catch year.

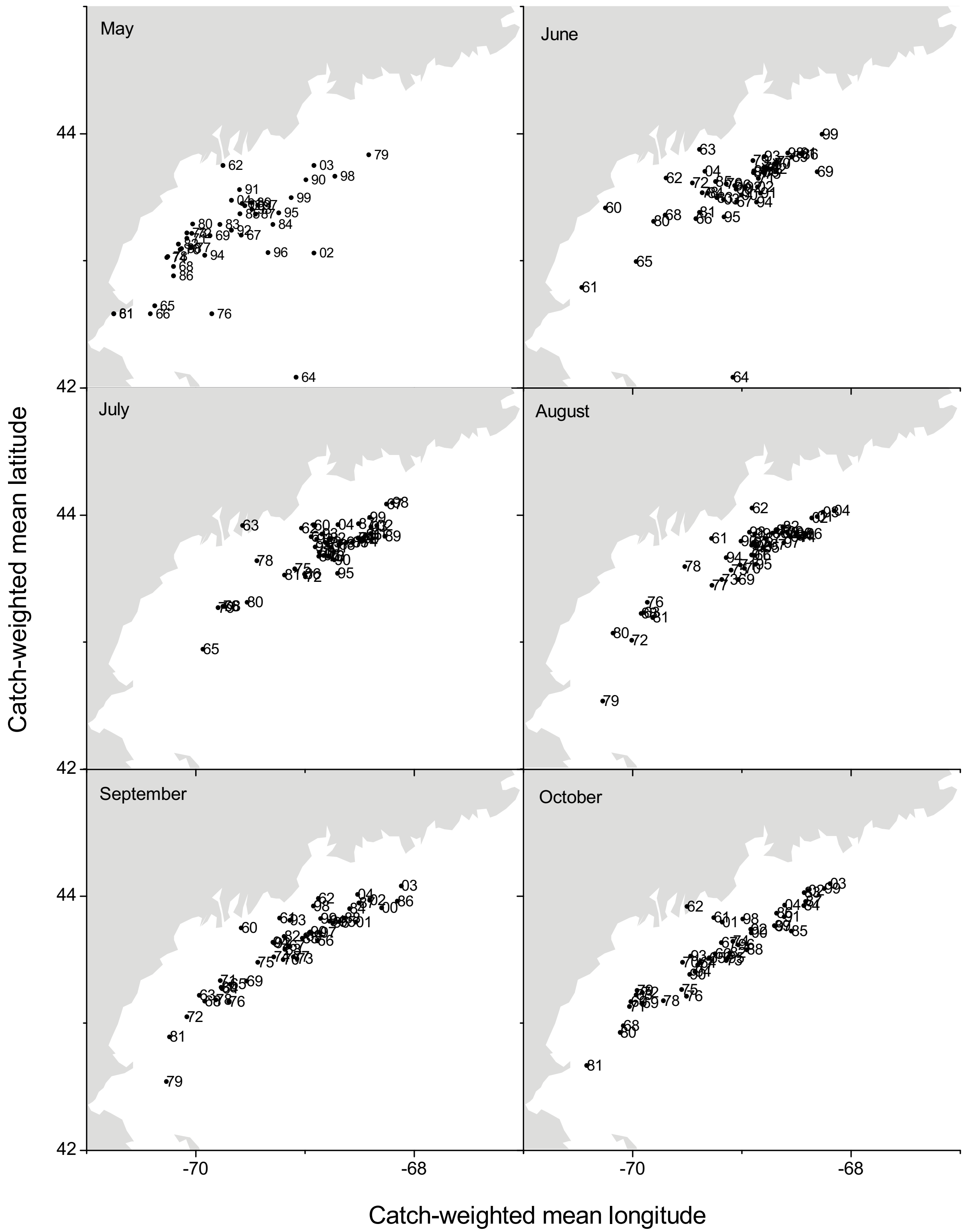


Figure 4. Time series of catch-weighted mean longitude by month.

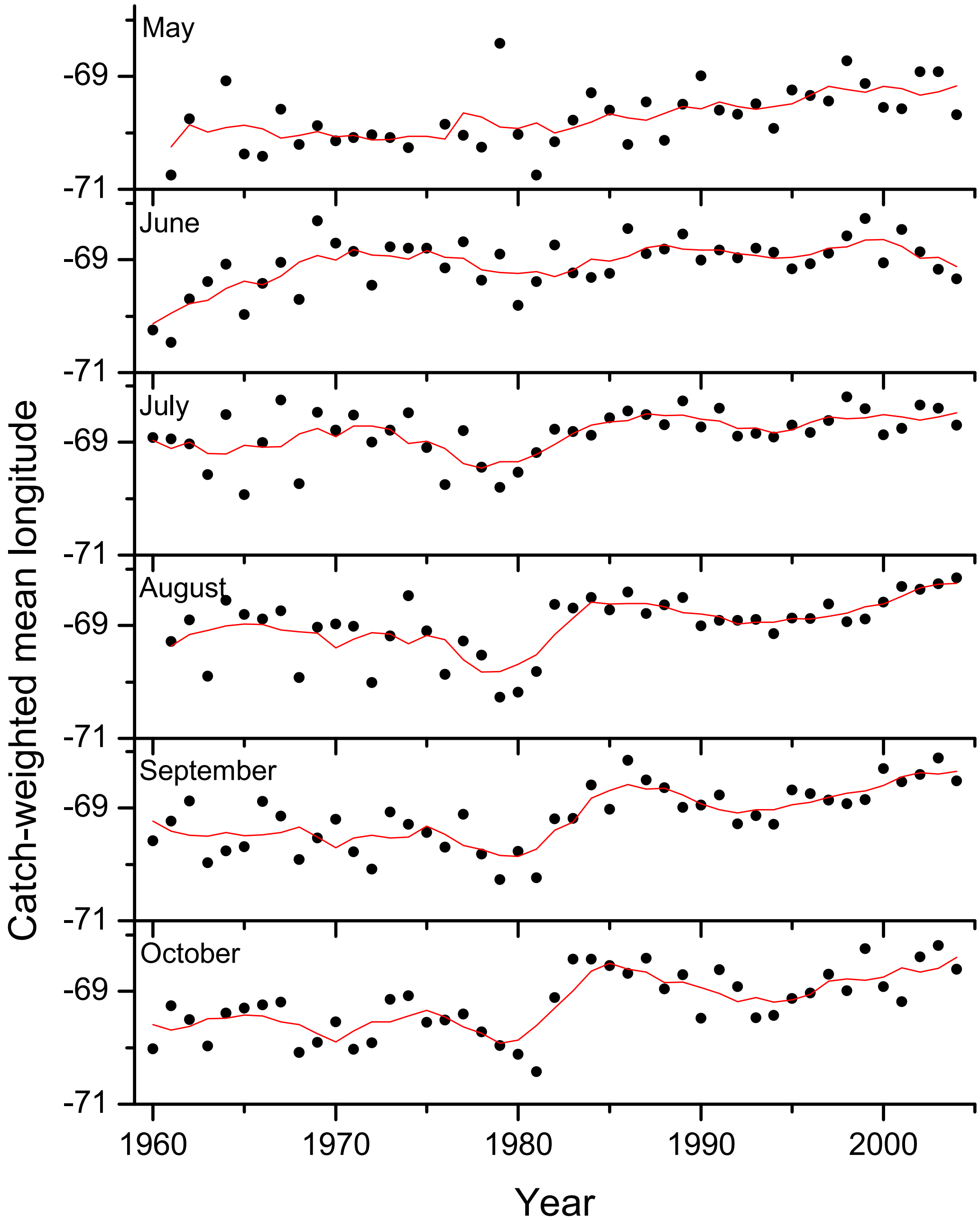


Figure 5. Time series of catch-weighted mean latitude by month.

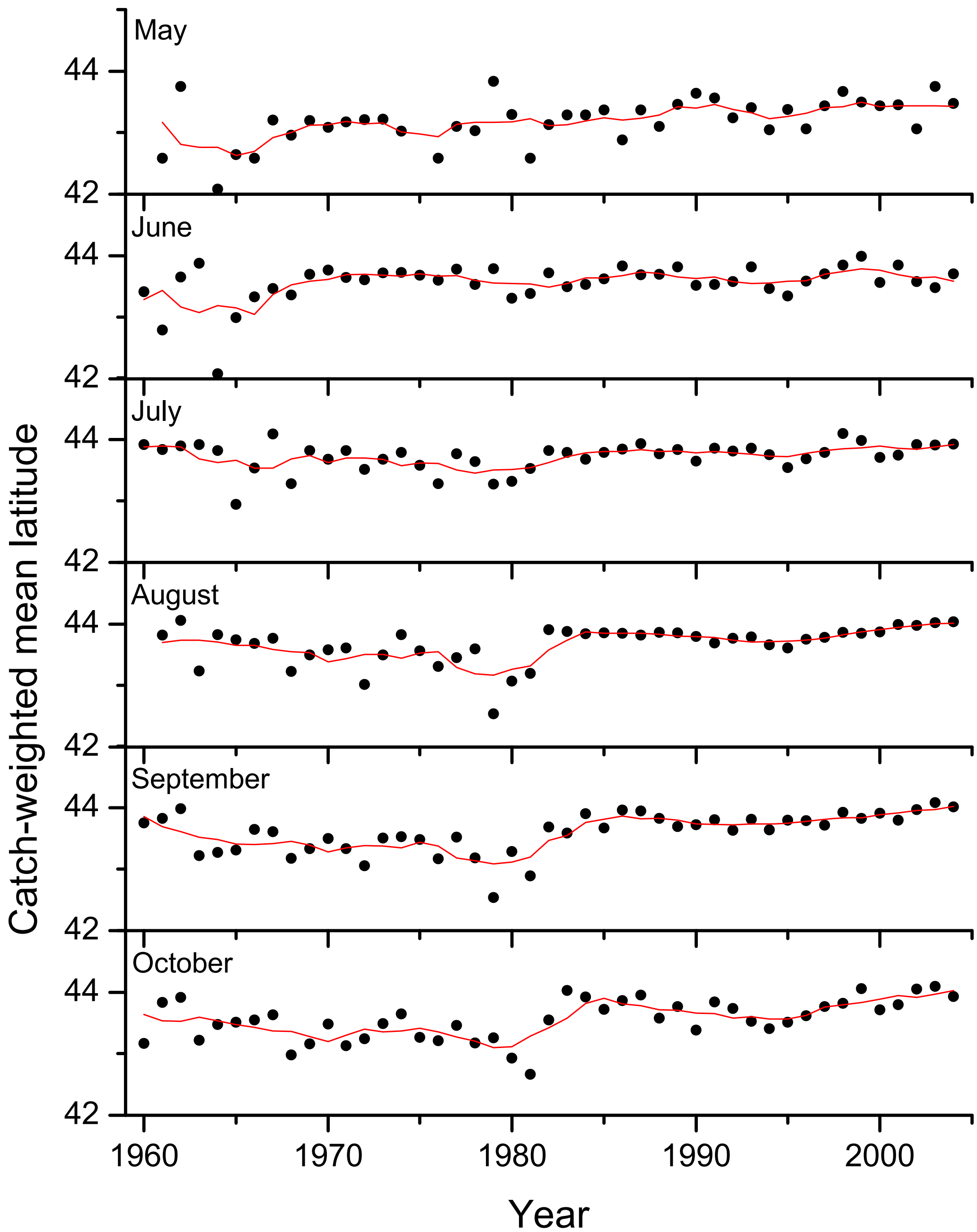


Figure 6. Number of 10-minute squares (boxes) used by the purse seine fleet by year.

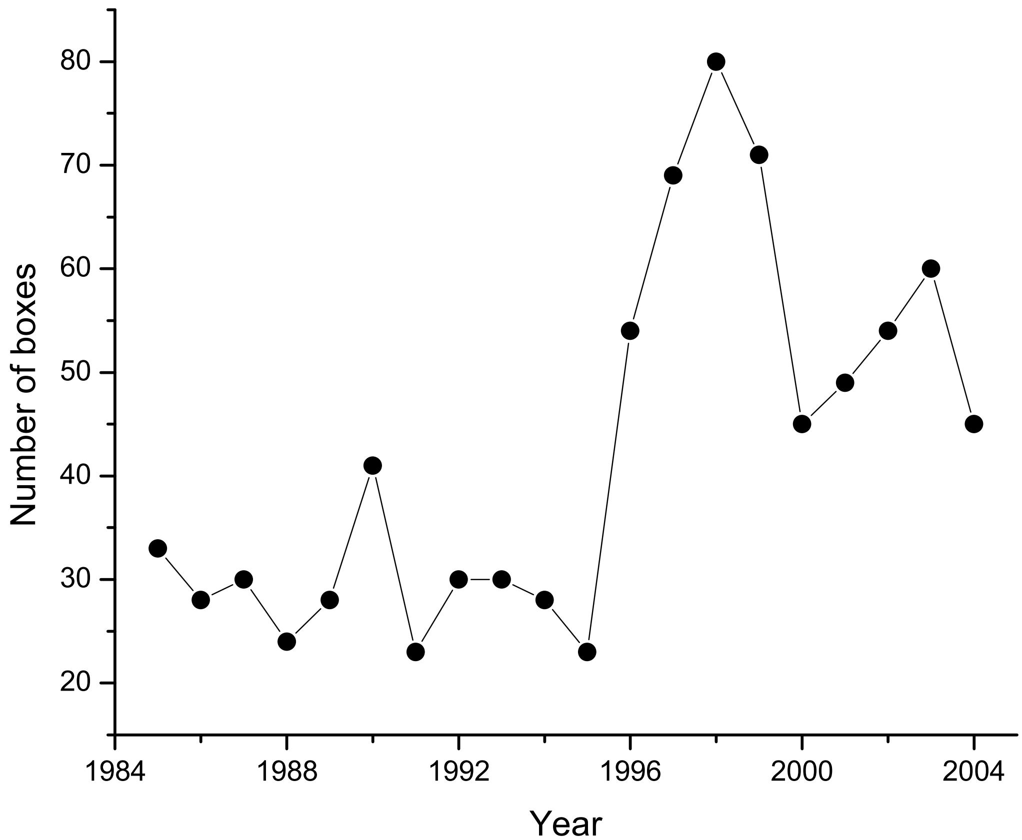


Figure 7. Box plot of sea surface temperature of purse seine trip locations by month. Box is inter-quartile range, □ is the mean, × defines the 1-99% confidence interval.

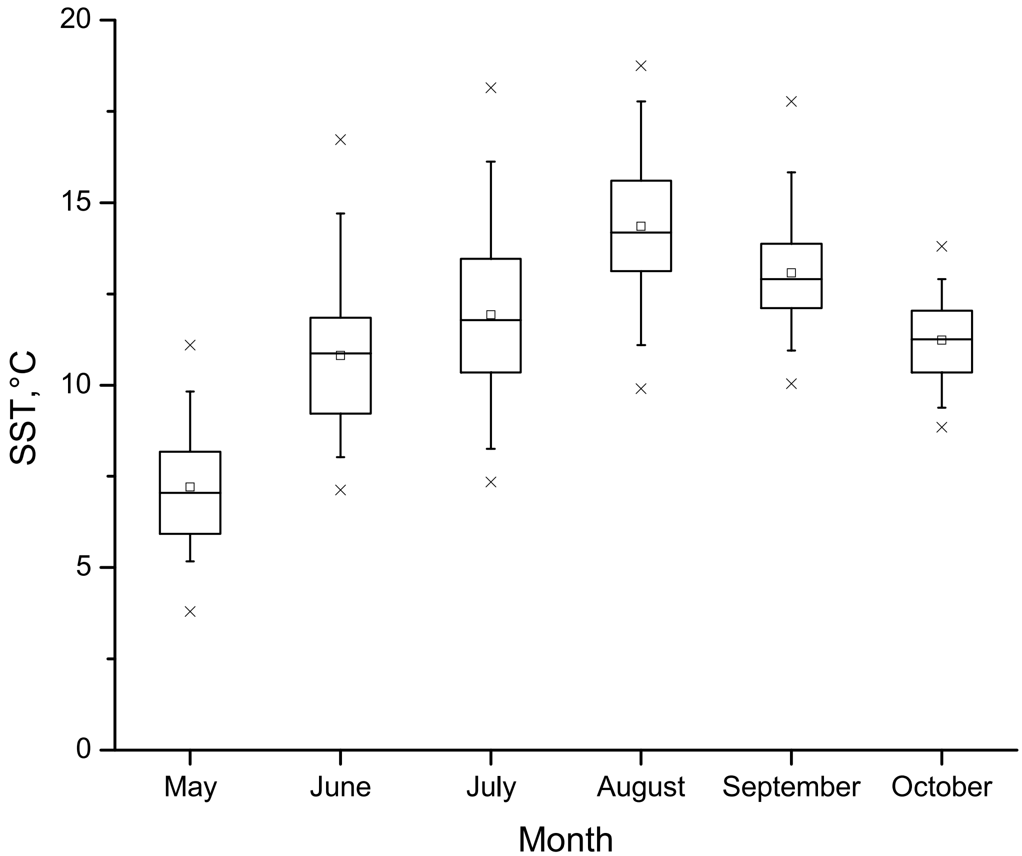


Figure 8. Correlation between sea surface temperature and herring catch by 10 minute square, year, and month. The number of 10-minutes square that had herring trips for each cell is provided. Significant correlations are denoted with a filled circle.

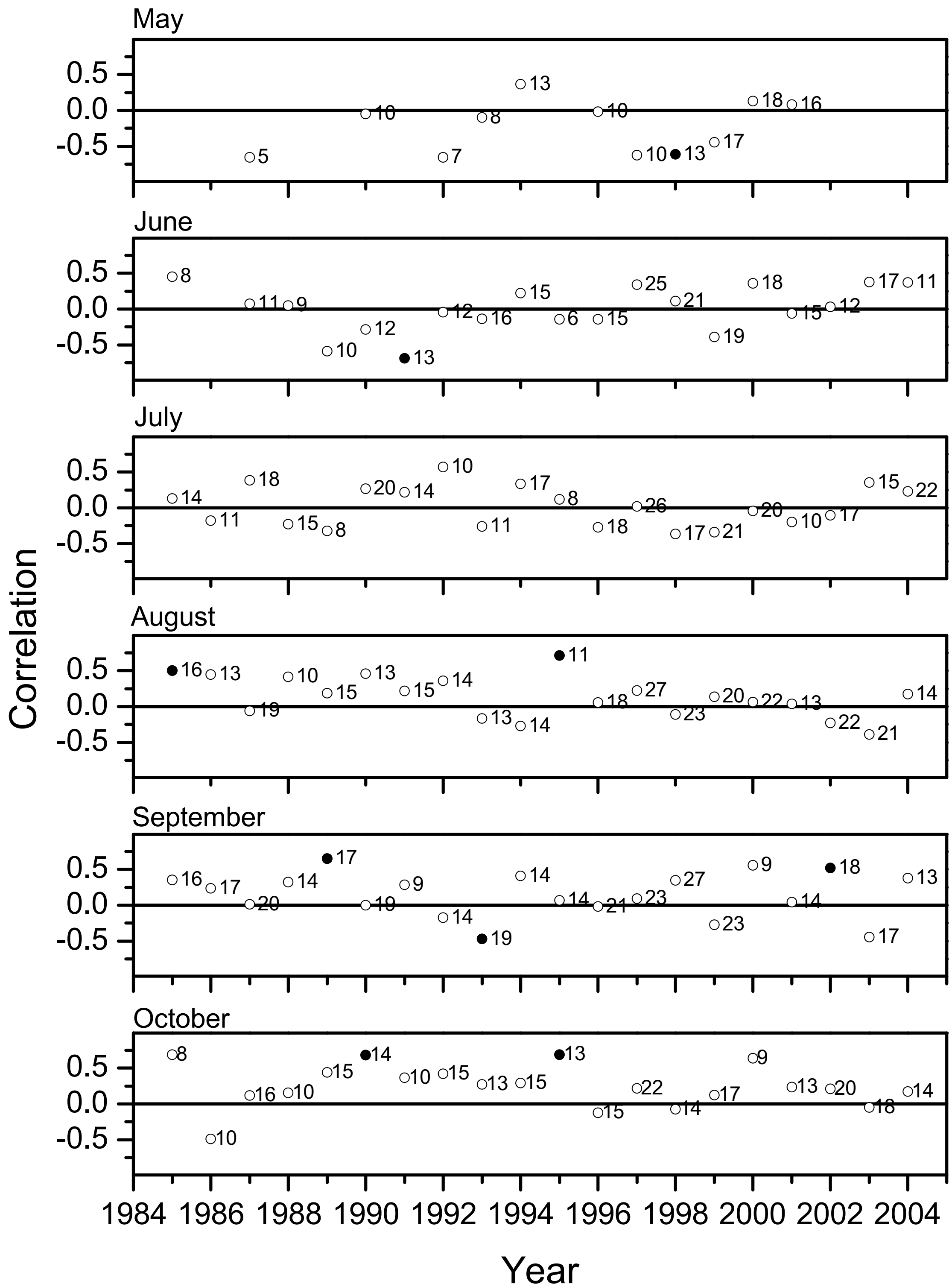


Figure 9. Temperature where purse seine fishing occurred versus temperature in areas with no fishing by year and month, limited to locations where fishing had occurred at least once during the time series. Error bars are 95% confidence intervals.

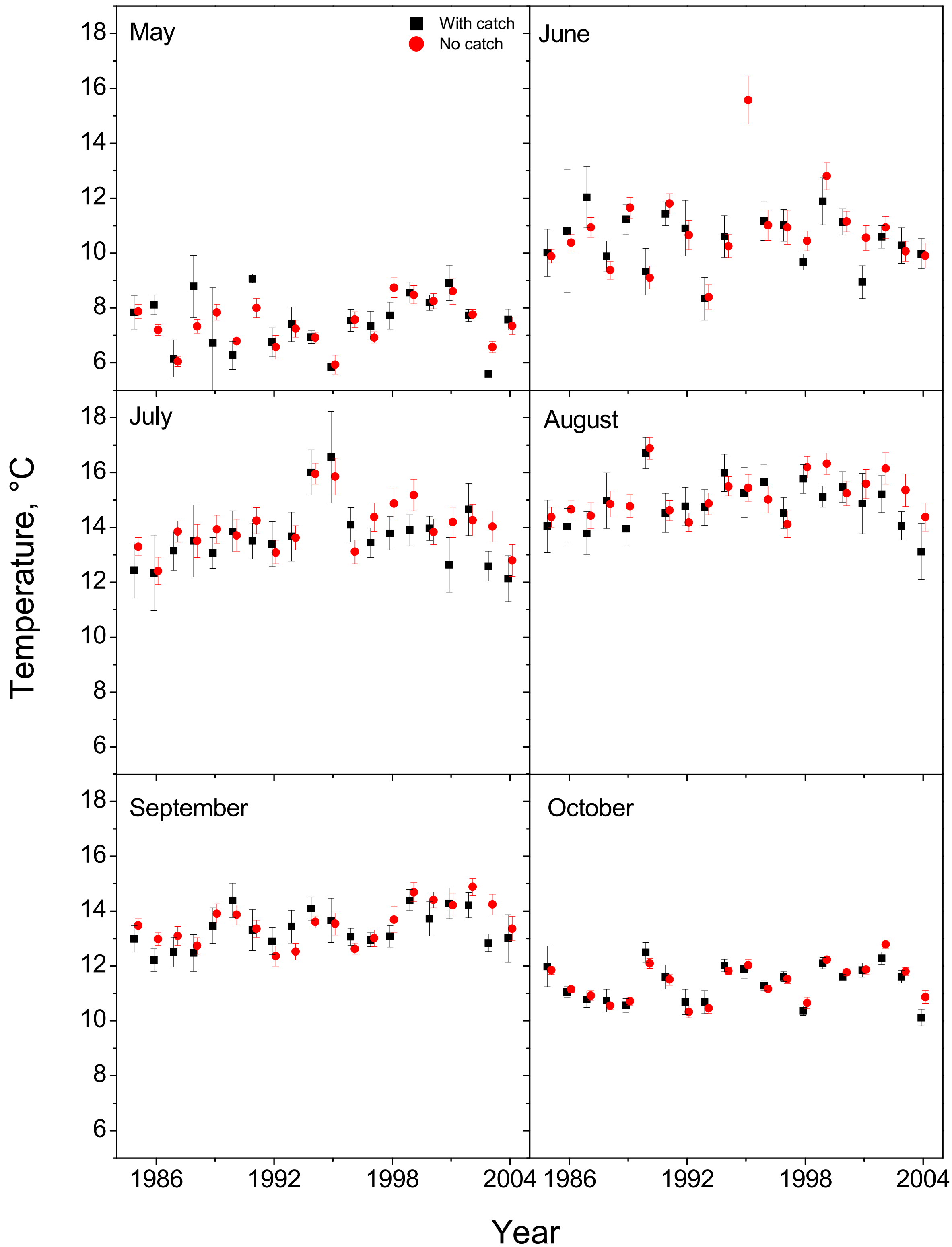


Figure 10. Box plot of chlorophyll *a* (mg/m^3) of purse seine trip locations by month. Box is inter-quartile range, □ is the mean, × defines the 1-99% confidence interval.

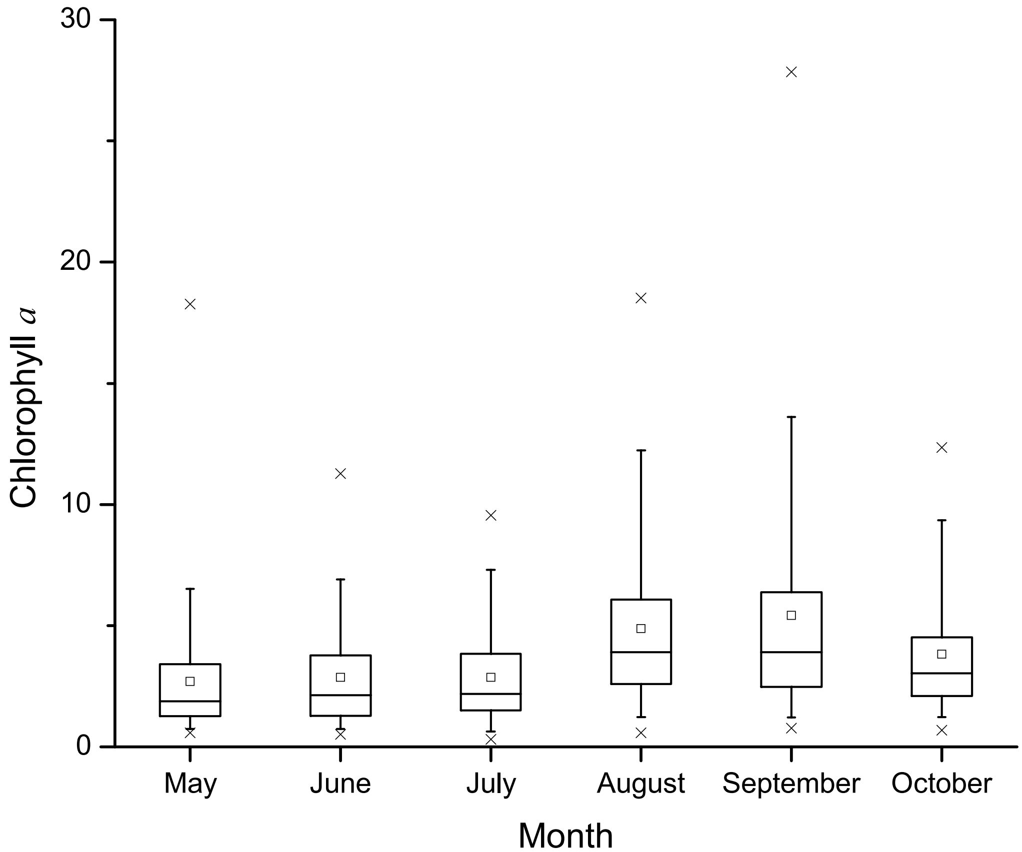


Figure 11. Box plot of primary production (g C/m^2/day) of purse seine trip locations by month. Box is inter-quartile range, □ is the mean, × defines the 1-99% confidence interval.

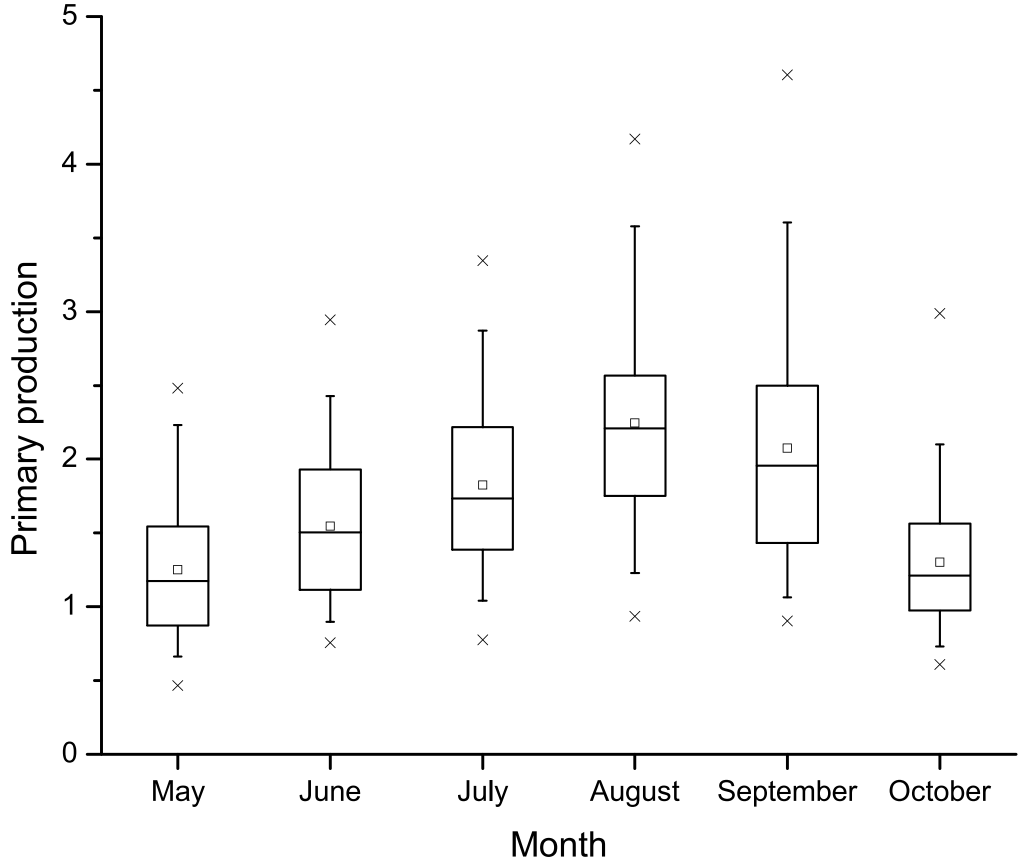


Figure 12. Correlation between chlorophyll *a* and herring catch by 10-minute square, year, and month. The number of 10-minute squares that had herring trips for each cell is provided. Significant correlations are denoted with a filled circle.

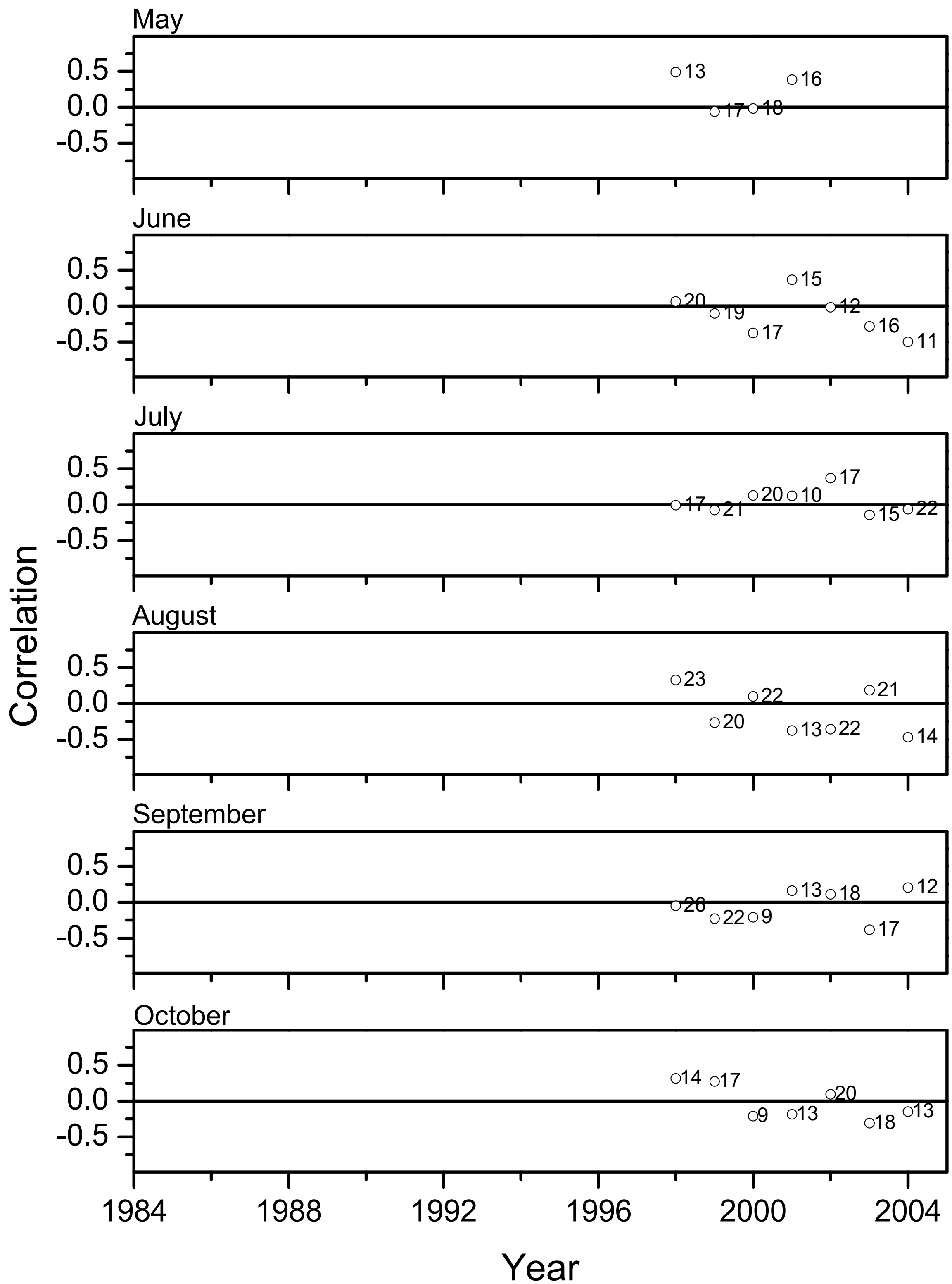


Figure 13. Chlorophyll *a* where purse seine fishing occurred versus chlorophyll *a* in areas with no fishing by year and month, limited to locations where fishing had occurred at least once during the times series. Error bars are 95% confidence intervals.

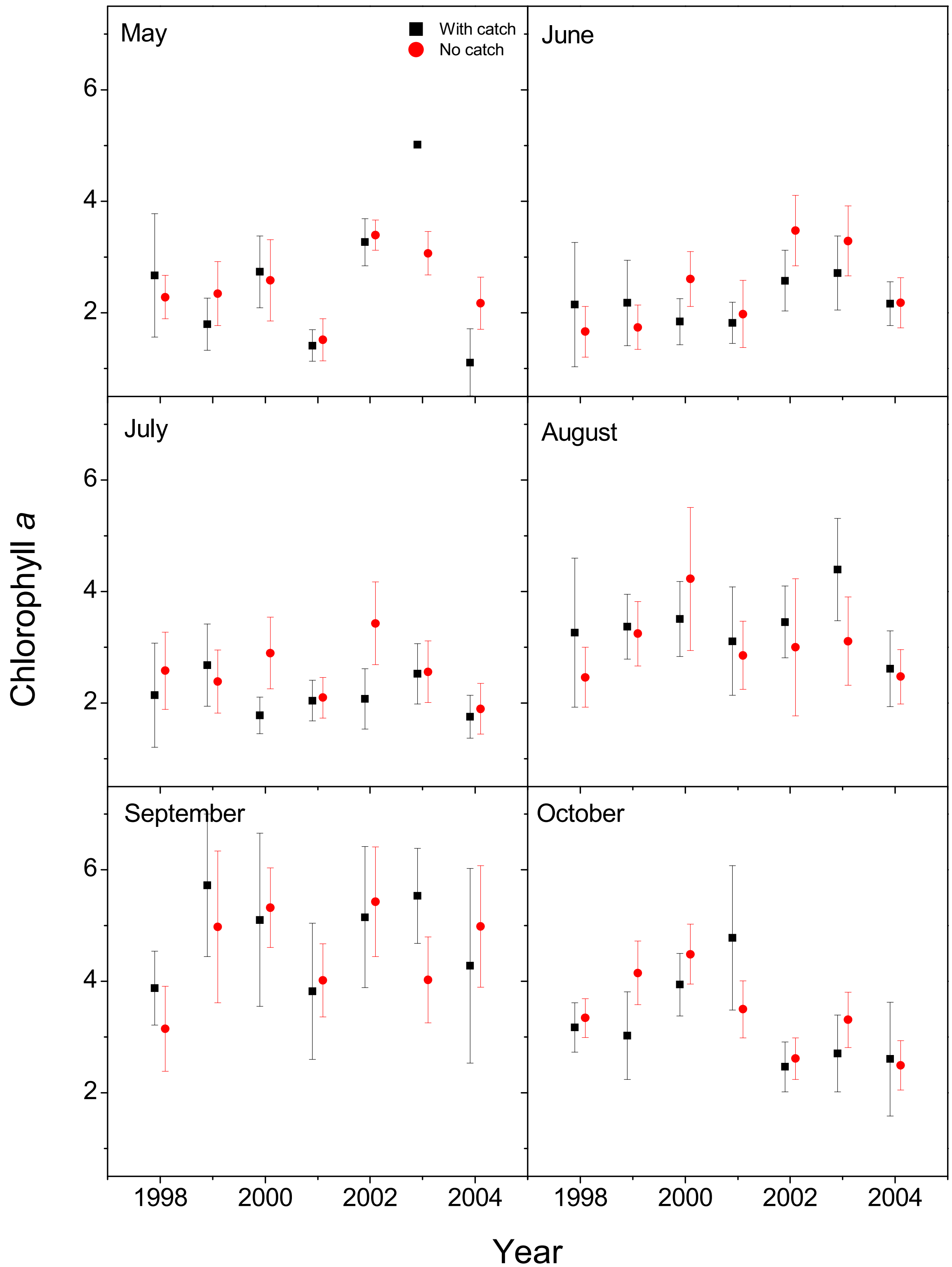


Figure 14. Correlation between primary productivity (mg C $m^{-2}d^{-1}$) and herring catch by 10-minute square, year, and month. The number of 10-minute squares that had herring trips for each cell is provided. Significant correlations are denoted with a filled circle.

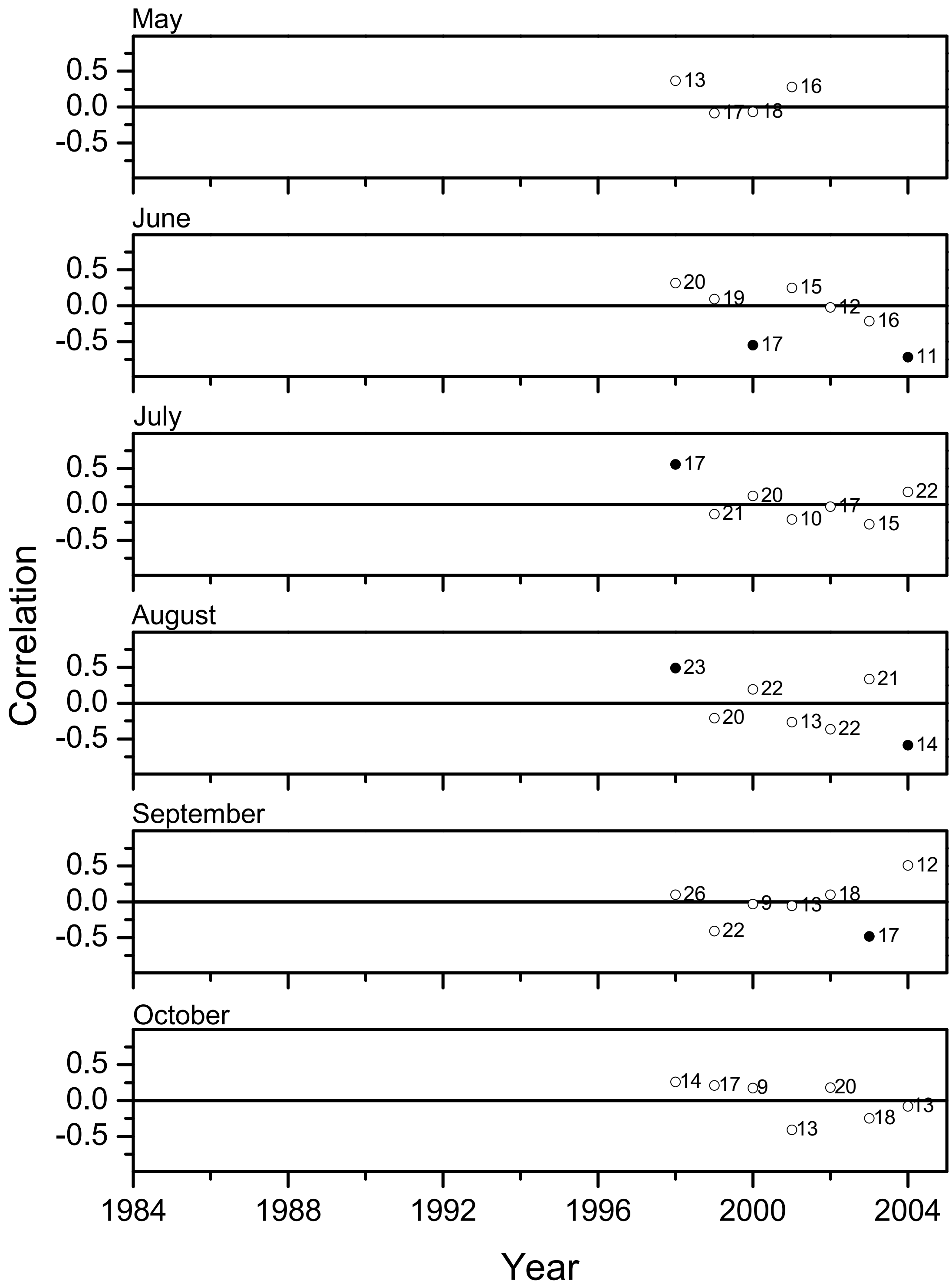


Figure 15. Primary production where purse seine fishing occurred versus primary production in areas with no fishing by year and month, limited to locations where fishing had occurred at least once during the time series. Error bars are 95% confidence intervals.

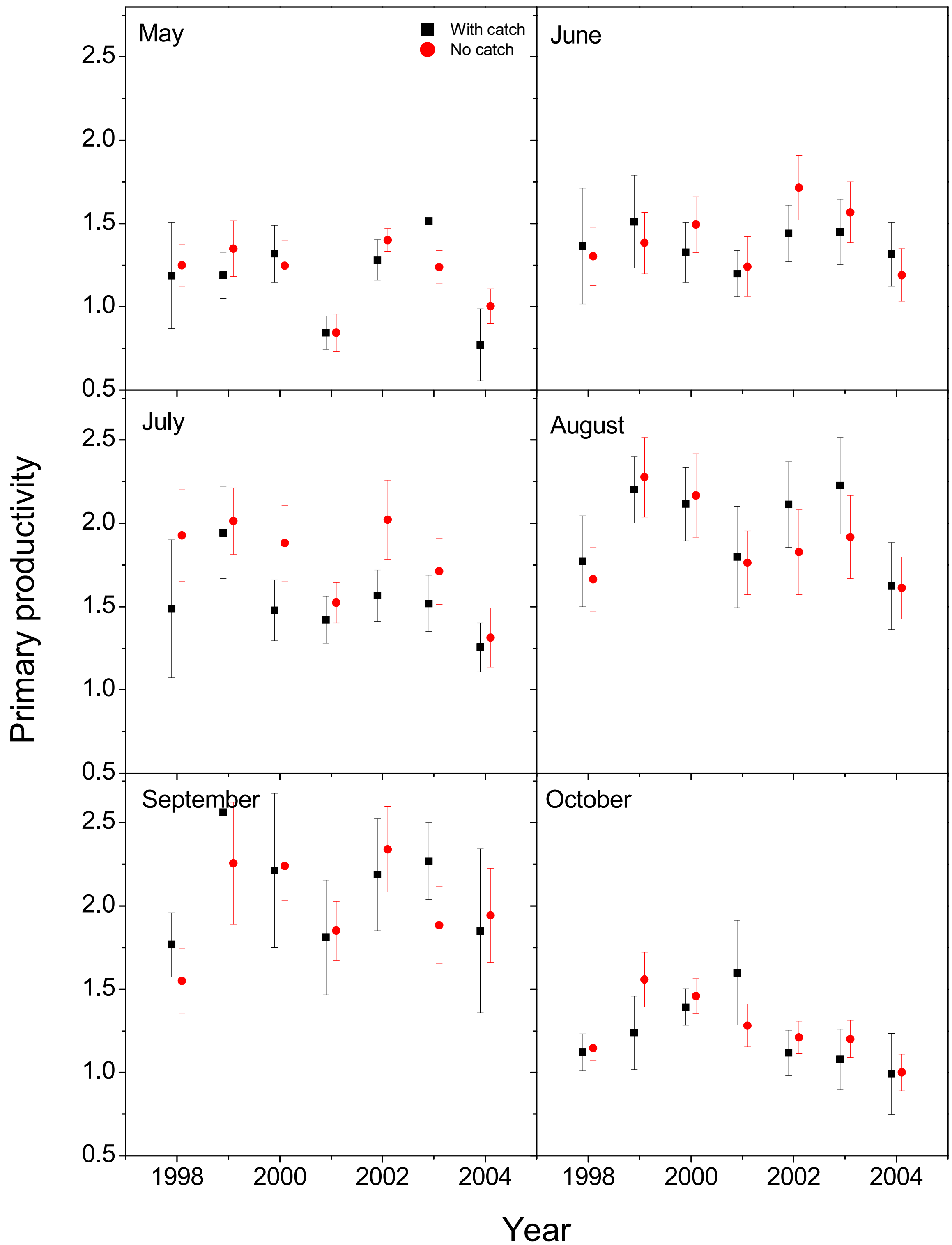


Figure 16. Box plot of frontal probability of purse seine trip locations by month. Box is inter-quartile range, □ is the mean, × defines the 1-99% confidence interval.

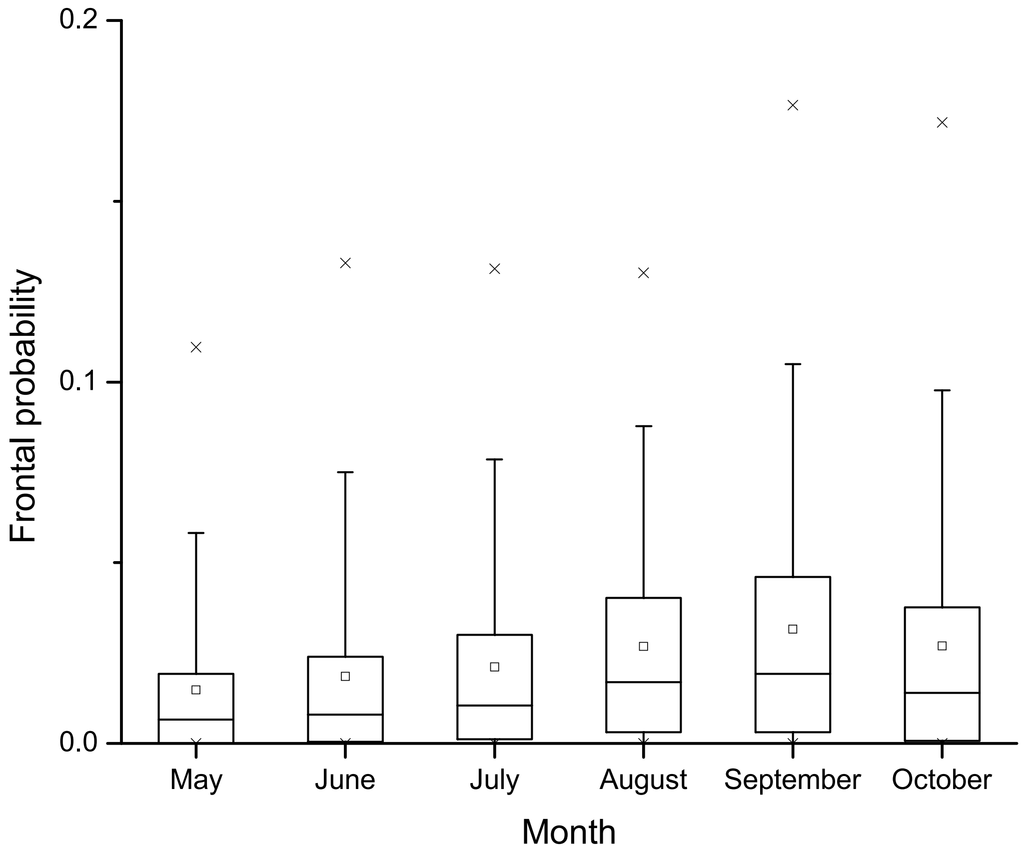


Figure 17. Correlation between frontal probability and herring catch by 10-minute square, year, and month. The number of 10-minute squares that had herring trips for each cell is provided. Significant correlations are denoted with a filled circle.

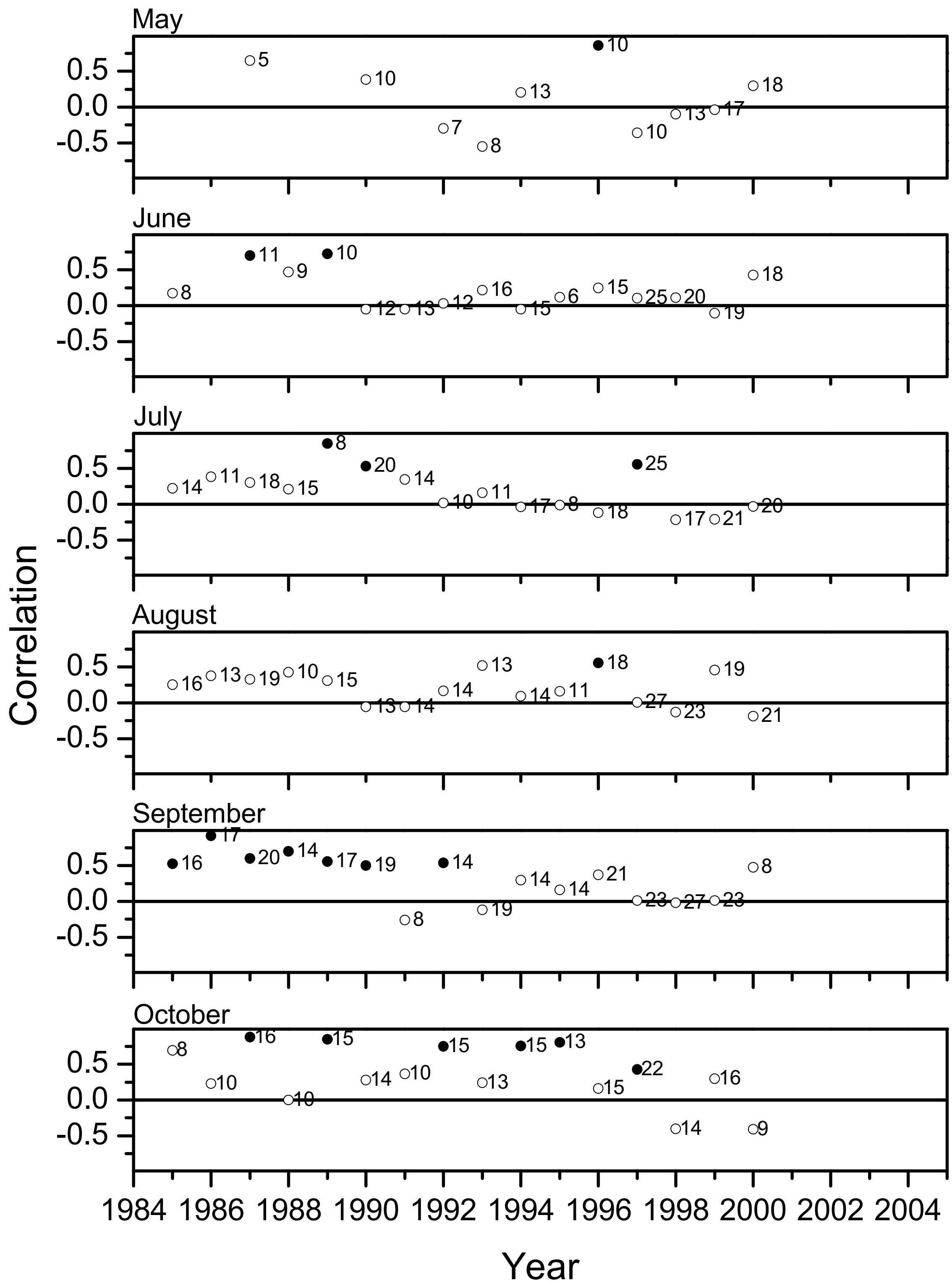


Figure 18. Frontal probability where purse seine fishing occurred versus frontal probability in areas with no fishing by year and month, limited to locations where fishing had occurred at least once during the time series. Error bars are 95% confidence intervals.

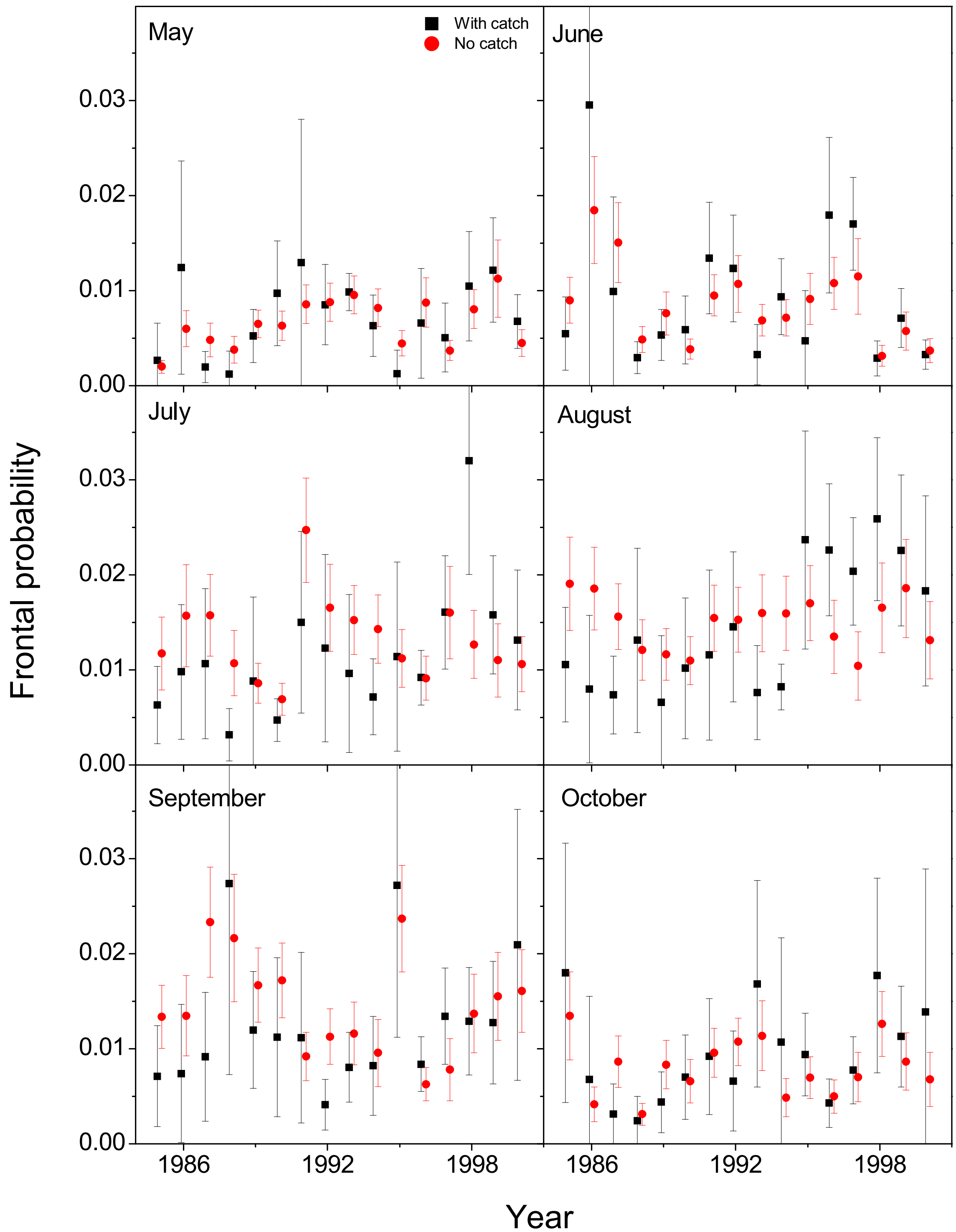


Figure 19. The number of mid-water trawl trips by year (top) and the ratio of frontal probability for areas with and without fishing for August by year (bottom).

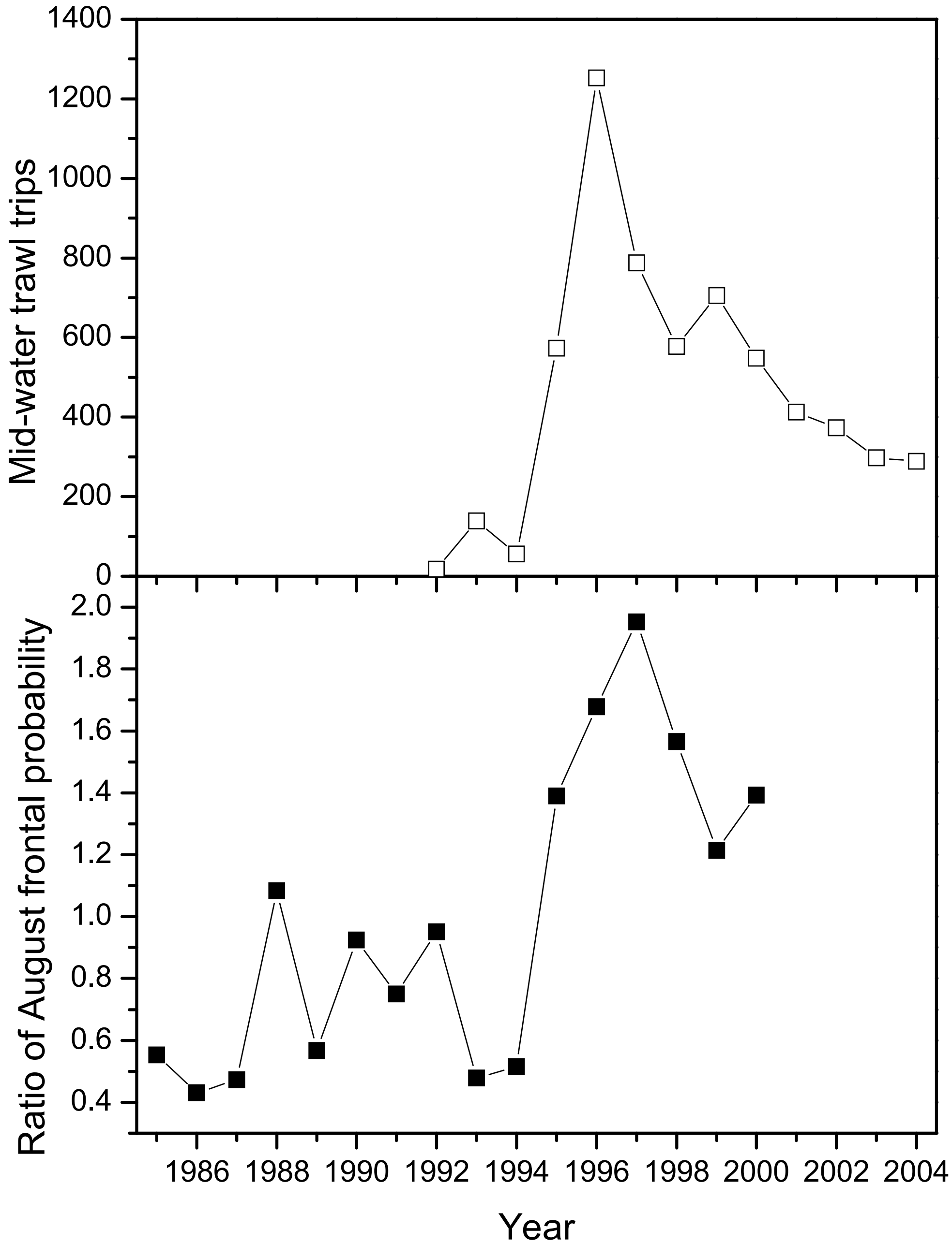
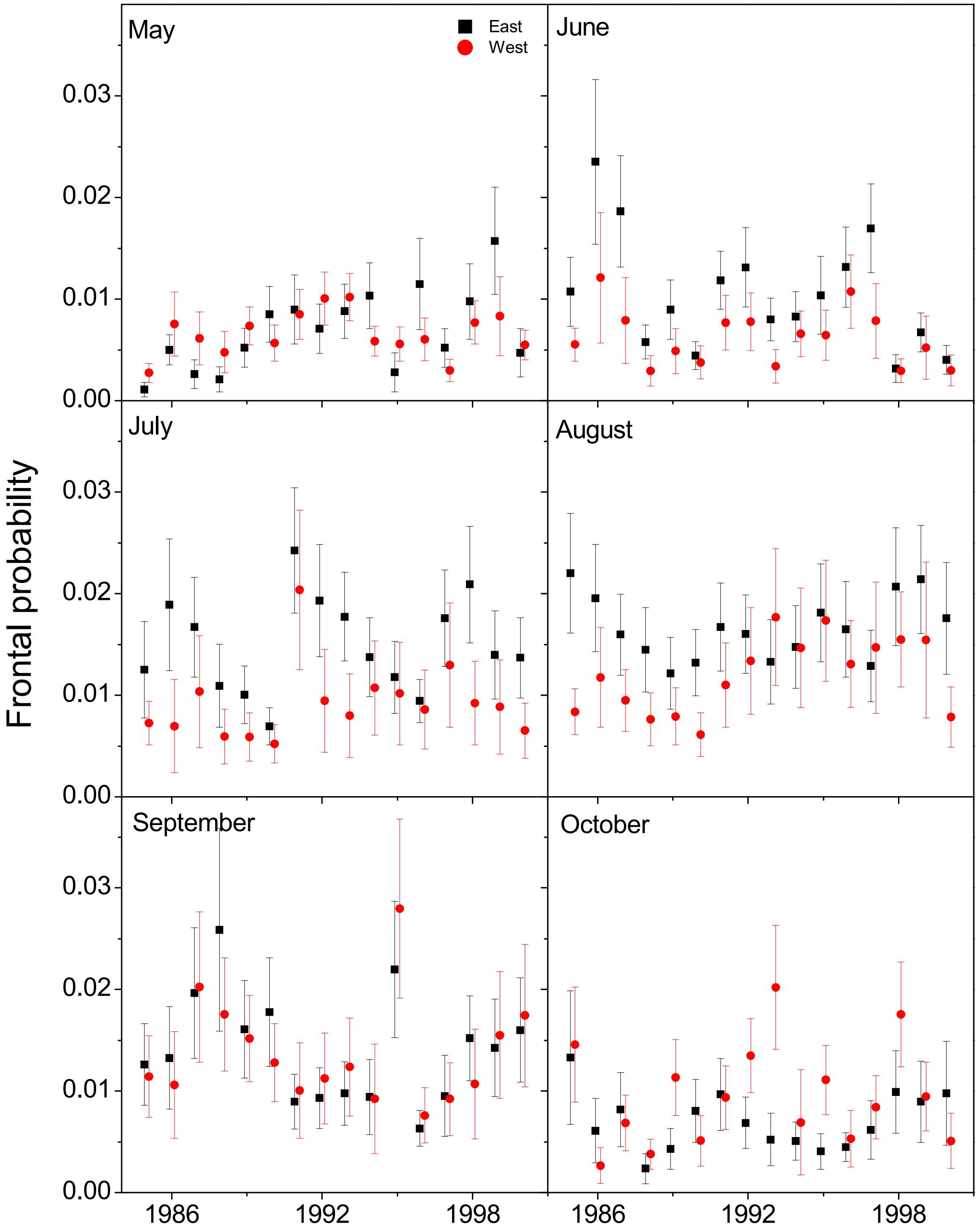


Figure 20. Frontal probability for eastern and western Gulf of Maine by month and year. Error bars are 95% confidence intervals.



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Publications and Reports of the Northeast Fisheries Science Center

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

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

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

OBTAINING A COPY: To obtain a copy of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, or to subscribe to the *Resource Survey Report*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2350) or consult the NEFSC webpage on "Reports and Publications" (*http://www.nefsc.noaa.gov/nefsc/publications/*).