King mackerel (*Scomberomorus cavalla*) larval indices of relative abundance from SEAMAP Fall Plankton Surveys, 1986 to 2024

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King mackerel (*Scomberomorus cavalla*) larval indices of relative abundance from SEAMAP Fall Plankton Surveys, 1986 to 2024

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Abstract: *The occurrence and abundance of king mackerel larvae captured during Southeast Area Monitoring and Assessment Program (SEAMAP) resource surveys in the Gulf of America (GOA) have been used to monitor trends in the relative spawning stock size of king mackerel since 2000. Indices of relative abundance based on larval catch from SEAMAP summer and fall plankton sampling were first incorporated into the king mackerel Southeast Data, Assessment and Review (SEDAR 5) stock assessment in 2003. These indices were re-formulated using new methods and data solely from SEAMAP Fall Plankton Surveys for the SEDAR 16 stock Assessment in 2000, and updated for SEDAR 38 and SEDAR 38 Update Assessments. The larval indices presented in this document are based on identical (continuity) methods to those used for the SEDAR 38 Update Assessment and a modified (alternate core area) method to account for inconsistent spatial coverage in the terminal years of the SEAMAP Fall Plankton Survey time series. The indices incorporate the most recent data available from the 1986 to 2024.*

Introduction

The Southeast Area Monitoring and Assessment Program (SEAMAP) has supported the collection and analysis of ichthyoplankton samples from resource surveys in the Gulf of America (GOA) since 1982 with the goal of producing a long-term database on the early life stages of fishes. Occurrence and abundance of king mackerel (*Scomberomorus cavalla*) larvae captured during these surveys have been used to reflect trends in the relative spawning stock size of king mackerel since 2000 (Gledhill and Lyczkowski-Shultz, 2000). However, indices of relative spawning stocks size based on larval occurrence and abundance were not incorporated into the king mackerel stock assessment process until 2003 (SEDAR5 Assessment Reports 1-5, 2003).

The indices developed for the 2003 assessment were based on the occurrence of larvae captured in bongo net samples taken during both the SEAMAP Summer Shrimp/Bottomfish and Fall Plankton Surveys because together these two long-term resource surveys encompass the king mackerel spawning season (late April to early October) in the GOA. The Indices Working Group at the time questioned whether to include the Summer Shrimp/Bottomfish data in the index, as the survey only covers the continental shelf area of the western GOA but ultimately recommended retaining the data. They also raised concerns related to inter-annual geographic differences in sampling due to difficulties posed by weather and/or ship related failures. Final recommendations by the group included the development of procedures to adjust for spatial variability within and among the Summer Shrimp/Bottomfish and Fall Plankton Surveys and the standardization of the index with delta-lognormal methods for future consideration.

The larval indices were re-formulated using new methodology and data solely from bongo net collections taken during the Fall Plankton Surveys for the 2006 (SEDAR 16) king mackerel stock assessment (SEDAR, 2006). Prior to the assessment, the spatial distribution of sampling conducted during the Summer/Shrimp Bottomfish and Fall Plankton Surveys were examined in detail and the Summer Shrimp/Bottomfish survey was found to have consistently sampled the intended survey area in the western GOA during 12 of the 25 years in the time series (1982-2006). Lack of coverage was primarily due to the fact that prior to 2002 plankton sampling was considered a secondary objective and often curtailed in order to meet the primary objectives of the trawling portion of the survey. Therefore, data from Summer Shrimp/Bottomfish surveys was not included in the updated 2006 indices. Per the SEDAR 5 Indices Working Group recommendations, procedures were developed to account for annual variability in sampling coverage during the Fall Plankton Survey and the index standardized using the delta-lognormal method. Indices based on these recommendations were initially reviewed and accepted at the SEDAR 16 Data Workshop, and updated for the SEDAR 38 (2013) and SEDAR 38 Update (2019) Assessments (Hanisko and Lyczkowski-Shultz, 2008 and Hanisko and Lyczkowski-Shultz, 2013).

Currently, the time series of data from the Fall Plankton Survey available for analysis extends from 1986 to 2024. This document outlines the development of a king mackerel larval index for the U.S GOA continental shelf based on the same methods (continuity) used for the SEDAR 38 Update assessments and indices based on samples selected from an alternate core area to addresses gaps in spatial coverage during the last five years of the time series.

Methodology

SEAMAP Plankton Sample Methodologies

The standard sampling gear and methodology used to collect plankton samples during SEAMAP surveys were similar to those recommended by Kramer et al. (1972), Smith and Richardson (1977) and Posgay and Marak (1980). A 61 cm or 60 cm (inside diameter) bongo net fitted with 0.335 mm mesh netting was fished in a double oblique tow path from the surface to a maximum depth of 200 m or to 2-5 m off the bottom at station depths less than 200 m. Maximum bongo tow depth was calculated using the amount of wire paid out and the wire angle at the 'targeted' maximum tow depth or measured directly using an electronic depth sensor mounted on the tow cable. A mechanical flowmeter was mounted off-center in the mouth of each bongo net to record the volume of water filtered. Water volume filtered during bongo net tows ranged from ~20 to 600 m^3 but was typically 30 to 40 m^3 at the shallowest stations and 300 to 400 m^3 at the deepest stations.

Catches of larvae in bongo net samples were standardized to account for sampling effort and expressed as the number under 10 m^2 sea surface (CPUA, Catch Per Unit Area) by dividing the number of larvae by volume filtered and then multiplying the resultant by the product of 10 and maximum depth of tow. This procedure results in a less biased estimate of abundance than number per unit of volume filtered alone and permits direct comparison of abundance estimates across samples taken over a wide range of water column depths (Smith and Richardson 1977).

Sample Processing and Identification of King Mackerel Larvae

Initial processing of most SEAMAP plankton samples has been carried out at the Sea Fisheries Institute, Plankton Sorting and Identification Center (ZSIOP), in Szczecin, Poland, under a Joint Studies Agreement with the NOAA Fisheries. Fish eggs and larvae were removed from bongo net samples. Fish eggs were not identified further, whereas, larvae were identified to the lowest possible taxon, which in most cases was the family level. Body length (BL) in mm was measured and recorded.

The larvae of king mackerel are well described; and are identifiable at the smallest sizes (~2 mm) typically found in plankton samples. Few misidentifications of mackerel larvae (< 5%) were found during re-examination by Joanne Lyczkowski-Shultz of specimens initially identified at ZSIOP from samples taken in 1984-1986 and 1988-1995 prior to the first use of a SEAMAP larval index for king mackerel. Based on these earlier results no further re-examination of larvae identified as king mackerel at ZSIOP have been undertaken. Larvae identified only to the genus, *Scomberomorus sp.* or the family level, Scombridae between 1995 and 2006, were re-examined at NOAA Fisheries Southeast Fisheries Science Center's Trawl and Plankton Branch. Larvae found among those specimens that could be identified as king mackerel larvae were added to the data set. Few misidentifications were found during re-examination of specimens identified as *Scomberomorus sp.* or Scombridae from 1996 to 2006 and no further re-examination of larvae have been undertaken for samples after 2006. The SEAMAP larval indices presented here include all king mackerel larvae collected and identified from 1986 through 2024.

Standardized SEAMAP Station/Sample Data Set

The SEAMAP Fall Plankton Survey sampling area covers the northern GOA from the 10 m isobath out to the continental shelf edge within the U.S. EEZ, and originally comprised approximately 132 designated sampling sites i.e. 'SEAMAP' stations. Beginning in 1999 and continuing to the present, samples have been taken at 11 additional SEAMAP stations located off the continental shelf in the western GOA during the survey. Most stations are located at 30-nautical mile or 0.5^{o} (~56 km) intervals in a fixed, systematic, 2-dimensional (latitude-longitude) grid of transects across the GOA. Some SEAMAP stations are located at < 56 km intervals especially along the continental shelf edge, while others have been moved to avoid obstructions, navigational hazards or shallow water.

The intended sample design for SEAMAP surveys calls for a single bongo sample to be taken at each site (SEAMAP station) in the systematic grid. However, over the years additional samples have been taken using SEAMAP gear and collection methods at locations other than designated SEAMAP stations. Some locations were also sampled more than once during a survey year. In instances where more than one sample was taken at a SEAMAP station, the sample closest to the central position of the systematic grid location was selected for inclusion in the data set. When SEAMAP stations were sampled by more than one vessel during the survey, priority was given to samples taken by the NOAA Fisheries (and not the state) vessel.

Spatial coverage of the Fall Plankton Survey from 1986 to 2024 has at times been impacted due to severe weather, vessel break downs, time or other constraints (Appendix Figure 1). Sampling for both the western (> 89.25° West Longitude) and eastern (< 89.25° West Longitude) Gulf of America was reduced across the entire area from 1988 to 1991, and severely curtailed or cancelled due to tropical storms in 1998, 2005, 2008 and 2024, mechanical issues in 2015, COVID 19 in 2020 and tropical weather and mechanical issues in 2023. Spatial coverage in the western GOA has been consistent over the time series with the exception of these years. In the eastern GOA, spatial coverage has been considerably more variable. Curtailed sampling during the 1992, 2002, 2004, 2017, 2021 and 2024 surveys resulted in large portions of the eastern GOA remaining un-sampled. The majority of the curtailed sampling the eastern GOA stems from the typical west to east progression of the survey. Due to this progression, any reduction in survey time primary limits effort in the southern (Tampa, FL to Key West, FL) portion of the survey area.

Year to year variability in spatial coverage during the Fall Plankton Survey is addressed by limiting observations to samples taken at SEAMAP stations that were sampled during at least 66% of all years from which there is consistent spatial coverage respectively to the entire GOA. Following this protocol, the data for an updated SEDAR 99 index (continuity) would include all samples taken during at least 17 of the 25 years of available data with the years 1988, 1989, 1992, 1998, 2002, 2004, 2005, 2008, 2015, 2017, 2021, 2023 and 2024 excluded (Figure 1 and Appendix Figure 1). These exclusions greatly impact the last five years of the time series, leaving 2022 as the only estimate between 2019 and the 2024 SEDAR 99 Assessment terminal year.

Plankton samples from the continental shelf area south (< 27.75 degrees latitude) of Tampa Bay, FL account for 16.2% of the total sampling effort but only 4.6% of total king mackerel larval abundance. Annual estimates of the nominal proportion of positive occurrence (PPOS) and catch per unit area (CPUA) from all continuity index samples and a dataset excluding samples from the area south of Tampa Bay, FL are highly correlated, with Pearson's correlations of $r(23) = 0.96$ for PPOS and $r(23) = 0.99$ for CPUA. Given the small contribution of the south Florida shelf samples to the overall annual abundance estimates, we re-assessed year to year spatial variability to exclude SEAMAP Fall Plankton Survey effort south of 27.75 degrees latitude. Utilizing samples only from this alternate core area adds seven years of data that were previously excluded, including 2021 and 2024 in the last five years of the time series. Indices based on the alternate core area include all samples taken at SEAMAP stations sampled during at least 21 of the 32 years of available data with the years 1998, 2005, 2008, 2015, 2017 and 2023 excluded (Figure 1).

Index Construction

A delta-lognormal generalized linear model (GLM) approach was used to estimate relative abundance indices for larval king mackerel (Pennington, 1983; Bradu and Mundlak, 1970). The main advantage of using this method is allowance for the probability of zero catch (Ortiz *et al.* 2000). The index computed by this method is a mathematical combination of yearly abundance estimates from two distinct GLM models: a binomial (logistic) model which describes proportion of positive abundance values (presence/absence) and a lognormal model which describes variability in only the nonzero abundance data (*cf.* Lo *et al*. 1992).

The delta-lognormal index of relative abundance (I_y) was estimated as:

(1) $I_y = c_y p_y$,

where c_y is the estimate of mean CPUA for positive catches only for year *y*, and p_y is the estimate of mean probability of occurrence during year *y*. Both c_y and p_y were estimated using generalized linear models. Data used to estimate abundance for positive catches (*c*) and probability of occurrence (*p*) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $\ln(c) = X\beta + \varepsilon$

and

(3) $p = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}}$,

respectively, where *c* is a vector of the positive catch data, *p* is a vector of the presence/absence data, *X* is the design matrix for main effects, β is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance σ^2. Therefore, c_y and p_y were estimated for each year along with their corresponding standard errors, SE (c_y) and SE (p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated using the delta method approximation

(4) $V(I_y) \approx V(c_y) p_y^2 + c_y^2 V(p_y)$.

A covariance term is not included in the variance estimator since there is no correlation between the estimator of the proportion positive and the mean CPUA given presence. The two estimators are derived independently and have been shown to not covary for a given year (Mary Christman, MCC Statistical Consulting LLC, unpublished).

The factors Y*ear*, *Region*, *Time of Day* (TOD) and *Depth* as a continuous variable were examined as possible influences on the proportion of positive occurrence and abundance of nonzero larval abundance for both the continuity and alternate core indices (Table 1). All models were built using a backward selection procedure based on type 3 (Wald's Chi-Square) test for binomial submodels and *F* tests for the lognormal submodels with an inclusion level of significance of $\alpha = 0.05$. The factor *Depth* was initially modeled as a quadradic polynomial, and then alternatively as a linear term if not significant for the quadradic. The *Year* effect is integral to the calculation of the annual estimates and is forced into the standardization procedure regardless of significance. Performance of binomial submodels was evaluated using AIC and lognormal submodels performance evaluated based on analyses of residual scatter and QQ plots in addition to AIC. All factors and variables were fitted as fixed effects and do not include interactions. The R Statistical Software (v4.4.3 R Core Team 2025) was implemented for analysis. Binomial and lognormal GLM equivalent submodels were implement via the glmmTMB package (v1.1.14, Brooks et. Al, 2025), estimated marginal means for submodels were calculated utilizing the *emmeans* package (v1.10.7, Lenth 2025) and marginal effects for factors and continuous variables visualized using the *ggeffects* package (v2.2.0, Lüdecke 2018).

Results and Discussion

Distribution, Abundance and Size at Capture

A total of 2,439 king mackerel larvae were captured in the 2,917 bongo net samples (alternate core index samples only) during 32 Fall Plankton Surveys from 1986-2024. Captured larvae ranged from 1.3 to 38 mm BL with a mean of 3.3 mm (median = 2.9). Ninety-five percent of larvae in bongo net samples were ≤ 6.0 mm (~ 7.1 days old larvae). Larvae were taken in 29.0 % of samples with a mean CPUA of 3.5 larvae per 10 m^2 sea surface (Table 2). Larvae were captured throughout the survey area but occurred 2.1 times more often and at 3.7 times greater CPUA in the western GOA than in the eastern GOA (Table 2 and Figure 2). Daytime versus nighttime sampling closely reflected the expected ratios of light to dark, with 53.3% of samples taken during the day and 46.7% at night. Gear avoidance in bongo nets was apparent between day and night sampling. The mean abundance of king mackerel larvae was 1.5 times greater at night than during the day (Table 3). Larvae were captured over in-situ recorded station depths ranging from 5.5 to 730.1 m with a mean station depth of 60.1 m and a median station depth of 36.2 m.

Standardized Indices of Abundance

The alternate core area and continuity delta-lognormal indices of king mackerel CPUA are presented in Tables 4 and 5, Figure 4. The backward selection procedure retained the factors *Year*, *TOD*, *Region* and *Depth* as a quadratic polynomial in both the binomial and lognormal submodels (Table 6). Factor selection was identical for the continuity delta-lognormal index of abundance (Table 6). Diagnostic plots for the alternate core area and continuity lognormal submodels are shown in Figure 5 and indicate a reasonable fit to the data.

The trends of the alternate core area and continuity indices were nearly identical (Figure 4) with a Pearson's correlations of $r(23) = 0.98$ for the 25 years in common. The annual number of samples included in the alternate core area index ranged from 8 to 25 percent fewer samples than the continuity index in common years (Tables 4 and 5). However, the annual coefficient of variation of the mean for the years in common increased only by an average of 1.5% for the alternate core area index.

The alternate core area index allows us to extend the terminal year of estimates to 2024 with a minimal loss of precision over the continuity index, and is our recommendation as the primary larval index to be considered for inclusion in the assessment model (Table 4). The index shows an increase in CPUA from 1986 to a peak in 1995, relatively stable CPUA from 1996 to 2019 and then suggests a decrease in CPUA during the last 4 years of the time series (Figure 4). However, there is not enough precision in the estimates to clearly separate the decrease from the long tern stable trend since 1995.

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Table 1. Effects considered for inclusion delta-lognormal binomial and lognormal sub-models.

Factors	Levels	Description
Year (continuity)	25	1986-1997, 2000-2004, 2006-2007, 2009-2014, 2016, 2018-2019, 2022
Year (alternate core area)	31	1986-1997, 1999-2004, 2006-2007, 2009-2014, 2016, 2018-2019, 2021-2022 and 2024
Region	2	West = Western Gulf of America (>89.25 Degrees W Longitude) East = Eastern Gulf of America (< 89.25 Degrees W Longitude)
Time of Day (TOD)	2	D = Day (Sunrise to Sunset) N = Night (Sunset to Sunrise)
Depth		Water Depth

Table 2. Nominal catch per unit area (CPUA) and proportion positive of larval king mackerel in bongo net samples gulfwide (GOA) and from the west and east GOA.

Region	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
West	1604	5.19	0..27	0.39	0.01
East	1313	1.39	0.19	0..16	0.01
GOA	2917	3.48	0.17	0.29	0.01

Table 3. Nominal catch per unit area (CPUA) and proportion positive of larval king mackerel in bongo net samples by time of day.

Time of Day	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
Day	1556	2.79	0.22	0.25	0.01
Night	1361	4.26	0.27	0.34	0.02

Table 4. Alternate core area index of larval king mackerel abundance developed using the delta-lognormal (DL) model. The number of samples (*N*), nominal proportion of positive occurrence (PPOS), the DL index (number under 10 m^2 sea surface), the coefficient of variation on the mean (CV), the index (StdIndex) scaled to a mean of one for the time series, and scaled lower and upper confidence limits (StdLCL and StdUCL) for the scaled index are listed.

Year	N	PPOS	Index	CV	StdIndex	StdLCI	StdUCI
1986	88	0.0795	0.5765	0.4649	0.1454	0.0600	0.3522
1987	97	0.1856	1.6099	0.2840	0.4060	0.2326	0.7087
1988	46	0.1957	2.2525	0.3968	0.5681	0.2644	1.2205
1989	47	0.2766	3.1853	0.3209	0.8034	0.4296	1.5025
1990	58	0.2586	2.5343	0.2977	0.6392	0.3569	1.1449
1991	59	0.2542	2.4112	0.2959	0.6082	0.3407	1.0855
1992	101	0.3267	2.5829	0.1985	0.6515	0.4397	0.9652
1993	97	0.3814	4.8487	0.1814	1.2229	0.8533	1.7527
1994	102	0.3039	3.8844	0.2056	0.9797	0.6522	1.4718
1995	99	0.3535	7.8410	0.1888	1.9777	1.3603	2.8752
1996	102	0.2549	3.1531	0.2299	0.7953	0.5051	1.2521
1997	99	0.3737	5.6716	0.1806	1.4305	0.9997	2.0470
1998							
1999	102	0.3235	3.6233	0.1953	0.9139	0.6207	1.3456
2000	101	0.2277	3.5480	0.2483	0.8949	0.5487	1.4595
2001	91	0.3846	6.3741	0.1820	1.6077	1.1205	2.3065
2002	78	0.4231	5.5502	0.1919	1.3999	0.9570	2.0477
2003	99	0.3535	4.5788	0.1888	1.1549	0.7943	1.6792
2004	95	0.4105	5.6986	0.1741	1.4373	1.0172	2.0308
2005							
2006	98	0.2755	4.5998	0.2242	1.1601	0.7449	1.8068
2007	102	0.3235	5.5185	0.1966	1.3919	0.9429	2.0546
2008							
2009	102	0.2549	2.6782	0.2295	0.6755	0.4293	1.0628
2010	99	0.2323	4.1157	0.2465	1.0381	0.6386	1.6874
2011	100	0.2800	5.4881	0.2175	1.3842	0.9004	2.1279
2012	96	0.2917	3.8084	0.2194	0.9605	0.6225	1.4821
2013	100	0.2800	3.3858	0.2191	0.8539	0.5538	1.3168
2014	96	0.2708	4.7543	0.2280	1.1991	0.7644	1.8812
2015							
2016	102	0.3137	4.3158	0.2006	1.0885	0.7316	1.6195
2017							
2018	98	0.3571	5.8167	0.1876	1.4671	1.0114	2.1281
2019	87	0.3218	3.9818	0.2153	1.0043	0.6561	1.5373
2020							
2021	93	0.2258	3.3903	0.2597	0.8551	0.5130	1.4254
2022	97	0.1959	2.7420	0.2753	0.6916	0.4028	1.1875
2023							
2024	86	0.2093	2.3545	0.2817	0.5939	0.3417	1.0320

Table 5. Continuity index of larval king mackerel abundance developed using the delta-lognormal (DL) model. The number of samples (*N*), nominal proportion of positive occurrence (PPOS), the DL index (number under 10 m^2 sea surface), the coefficient of variation on the mean (CV), the index (StdIndex) scaled to a mean of one for the time series, and scaled lower and upper confidence limits (StdLCL and StdUCL) for the scaled index are listed.

Year	N	PPOS	Index	CV	StdIndex	StdLCI	StdUCI
1986	108	0.0648	0.5350	0.4625	0.1310	0.0543	0.3160
1987	118	0.1610	1.6144	0.2727	0.3953	0.2314	0.6754
1988							
1989							
1990	70	0.2429	2.8353	0.2726	0.6942	0.4064	1.1859
1991	74	0.2432	2.9850	0.2624	0.7309	0.4362	1.2246
1992							
1993	105	0.3810	4.9151	0.1693	1.2035	0.8598	1.6844
1994	122	0.2951	4.2113	0.1854	1.0312	0.7139	1.4893
1995	119	0.3613	7.7347	0.1624	1.8939	1.3715	2.6152
1996	117	0.2308	3.0950	0.2220	0.7578	0.4887	1.1752
1997	118	0.3475	5.1941	0.1677	1.2718	0.9115	1.7744
1998							
1999	117	0.3162	3.8048	0.1795	0.9316	0.6524	1.3303
2000	114	0.2281	3.8495	0.2284	0.9426	0.6004	1.4797
2001	112	0.3571	6.2156	0.1655	1.5219	1.0956	2.1141
2002							
2003	120	0.3083	4.2524	0.1811	1.0412	0.7269	1.4914
2004							
2005							
2006	111	0.2613	4.6312	0.2119	1.1340	0.7457	1.7244
2007	123	0.3008	5.7172	0.1809	1.3999	0.9778	2.0041
2008							
2009	122	0.2623	3.3677	0.1997	0.8246	0.5553	1.2246
2010	120	0.2417	4.5351	0.2118	1.1104	0.7304	1.6883
2011	121	0.2397	5.2932	0.2104	1.2961	0.8547	1.9652
2012	117	0.2393	3.4701	0.2175	0.8497	0.5527	1.3062
2013	121	0.2727	3.6269	0.1953	0.8881	0.6031	1.3077
2014	116	0.2328	4.4634	0.2216	1.0929	0.7053	1.6935
2015							
2016	123	0.2683	4.0002	0.1952	0.9795	0.6653	1.4419
2017							
2018	119	0.3025	5.2582	0.1834	1.2875	0.8948	1.8524
2019	108	0.2963	3.9872	0.1959	0.9763	0.6622	1.4393
2020							
2021							
2022	116	0.1638	2.5089	0.2727	0.6143	0.3595	1.0497
2023							
2024							

Table 6. Summary of factor selection for the delta-lognormal modeled alternate core area and continuity indices of larval king mackerel relative abundance. samples.

Alternate Core Area (1986 to 2024)

	Binomial Submodel Type 3 Tests			*Lognormal Submodel Type 3 Tests*		
Effect	*Num DF*	*Chi-Square*	*Pr > ChiSq*	*Num DF*	*F Value*	*Pr > F*
YEAR	31	74.048	<.0001	31	2.480	<0.0001
TOD	1	32.301	<.0001	1	9.938	0.0017
REGION	1	178.454	<.0001	1	52.483	<0.0001
DEPTH^2	2	65.165	<.0001	2	55.020	<0.0001

Continuity (1986 to 2022)

	Binomial Submodel Type 3 Tests			*Lognormal Submodel Type 3 Tests*		
Effect	*Num DF*	*Chi-Square*	*Pr > ChiSq*	*Num DF*	*F Value*	*Pr > F*
YEAR	24	65.663	<.0001	24	2.045	0.0024
TOD	1	37.259	<.0001	1	11.642	0.0007
REGION	1	172.657	<.0001	1	76.889	<0.0001
DEPTH^2	2	60.641	<.0001	2	47.040	<0.0001

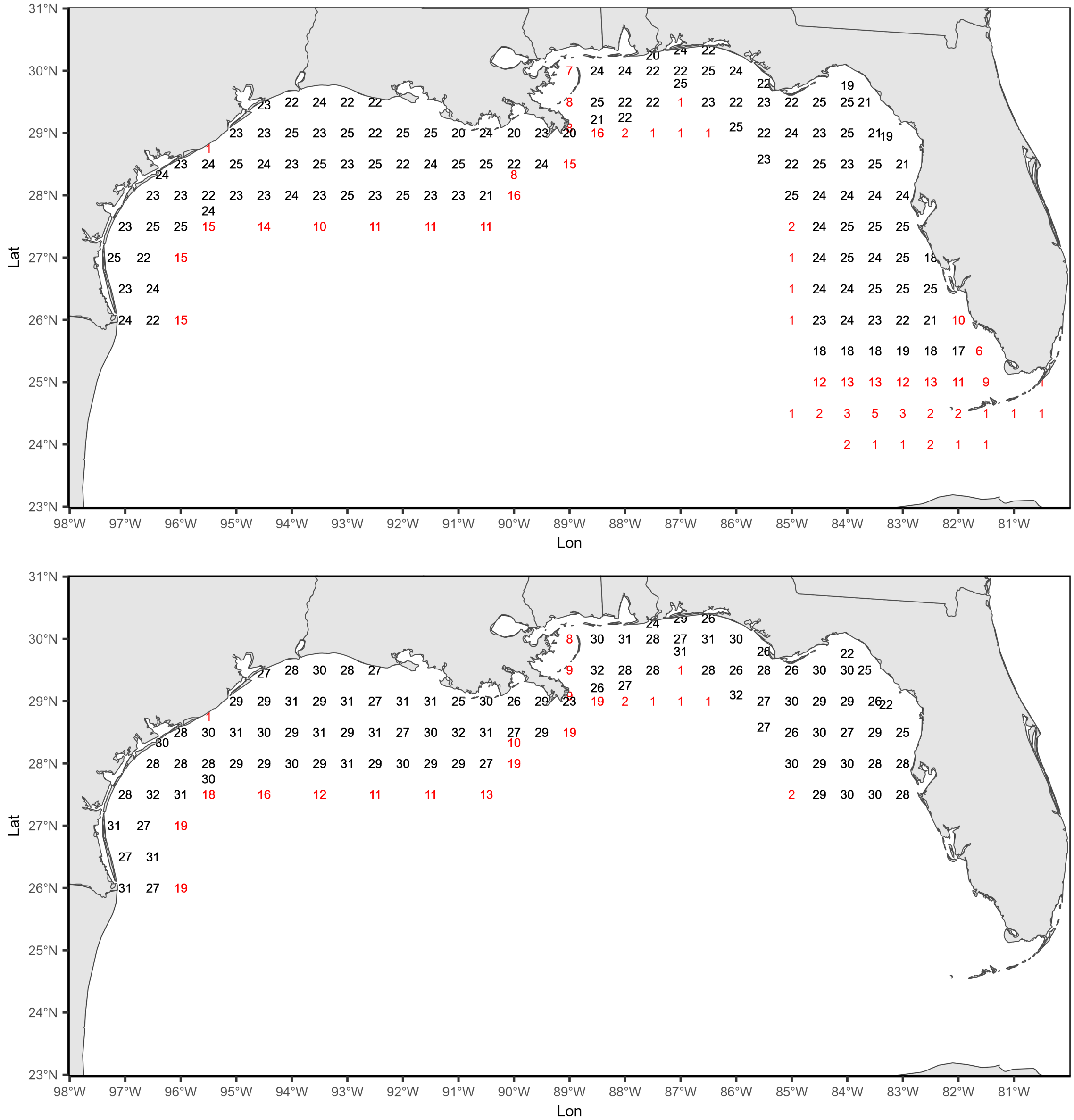


Figure 1. Number of primary bongo net samples taken at each SEAMAP systematic grid location from the annual SEAMAP Fall Plankton Surveys included in the continuity index (top) and the alternate core area index (bottom). Only locations with primary samples equal to or exceeding 17 were included in the continuity index and samples equal to or exceeding 21 were included in the alternate core area index. Numbers in black represent locations of primary samples included in the index, and those in red represent locations of primary samples excluded from the index.

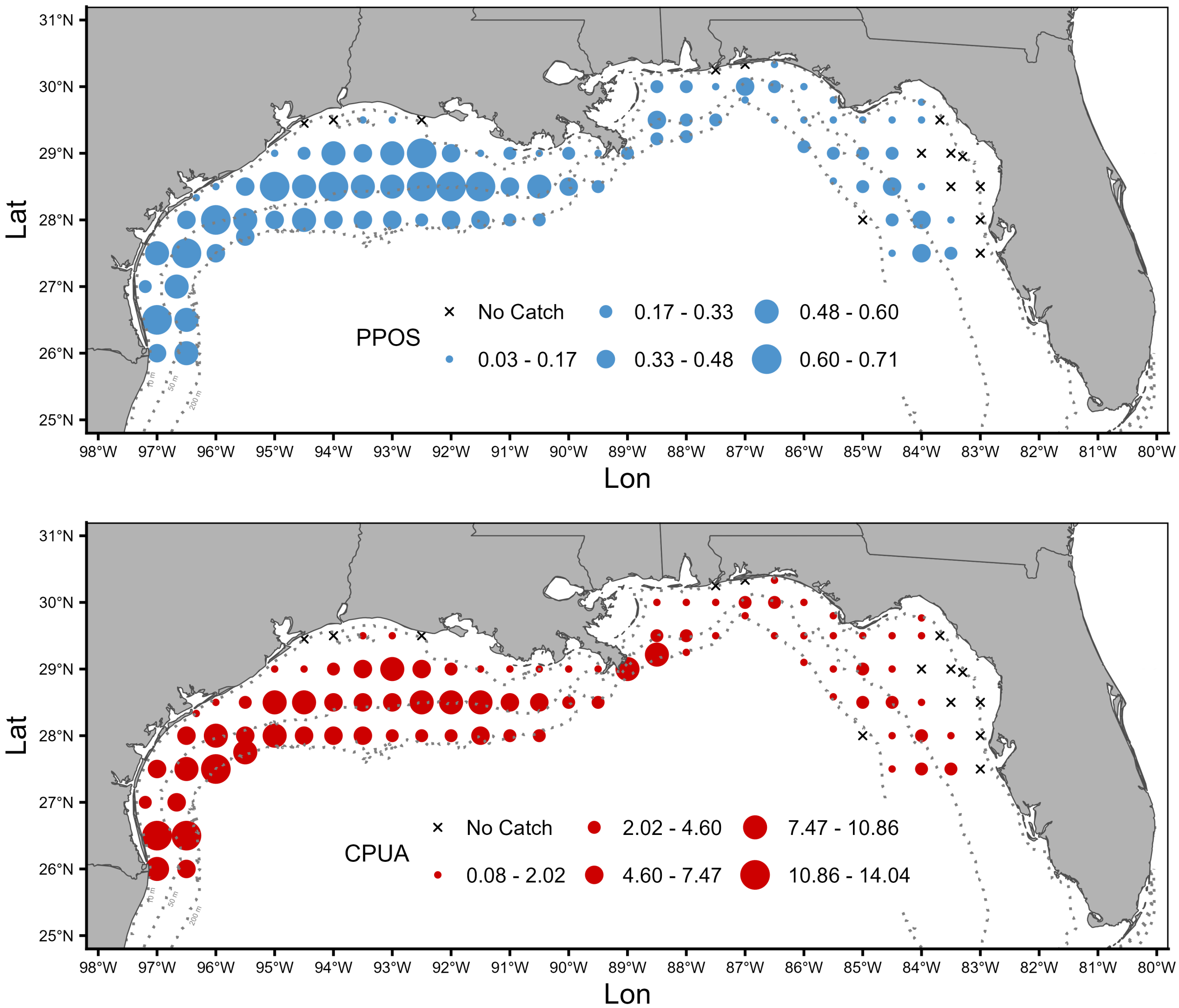


Figure 2. Larval king mackerel proportion of positive occurrence (upper) and mean catch per unit area (lower) from SEAMAP Fall Plankton Survey bongo net by SEAMAP station used to develop the alternate core indices of abundance.

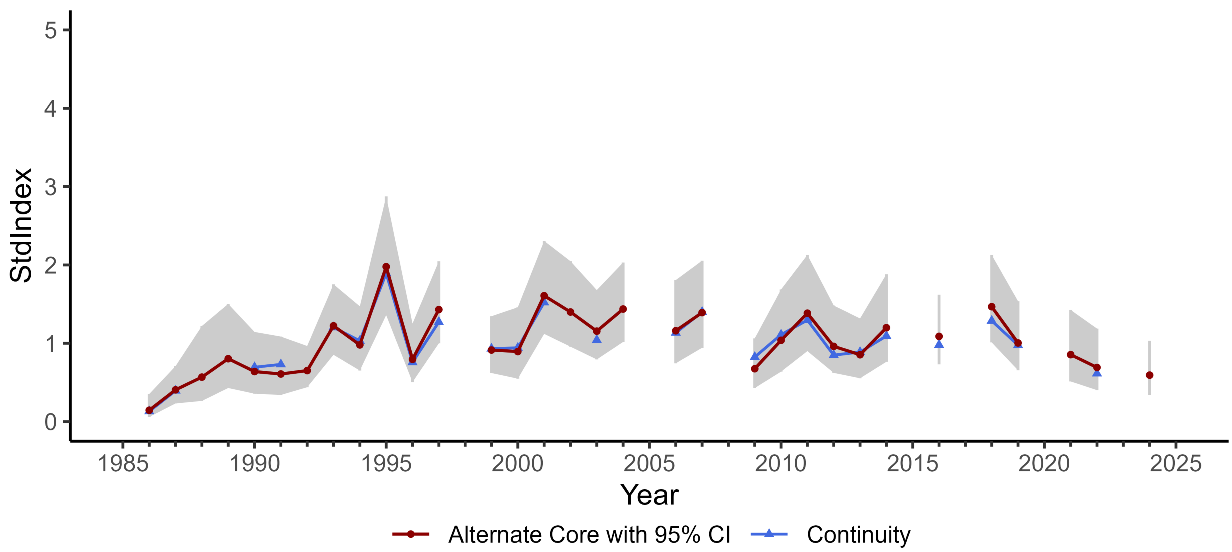


Figure 4. Alternate core area index of abundance for Gulf of America larval king mackerel captured during SEAMAP Fall Plankton Surveys from 1986 to 2024 with 95% confidence intervals in relation to the continuity index.

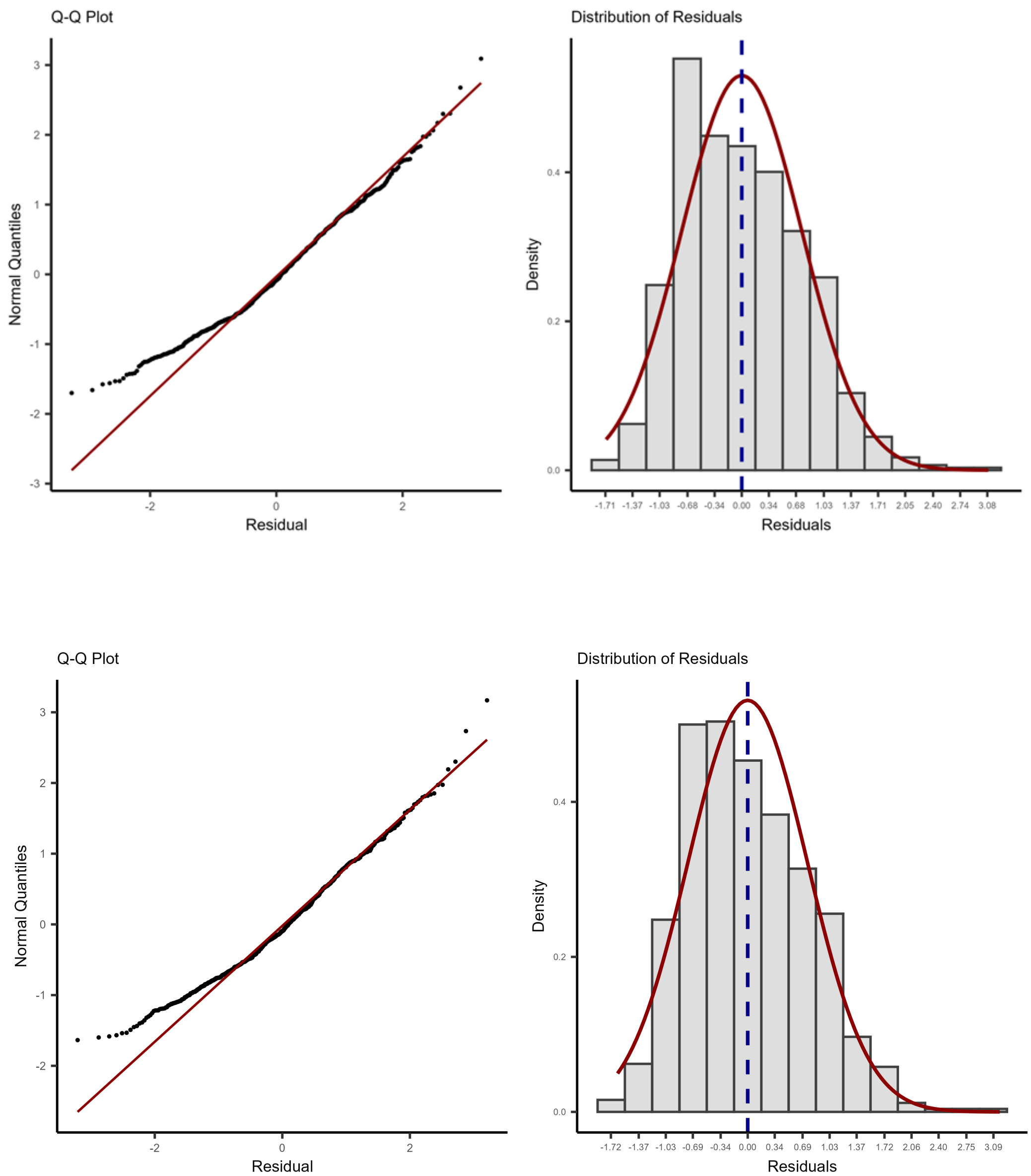
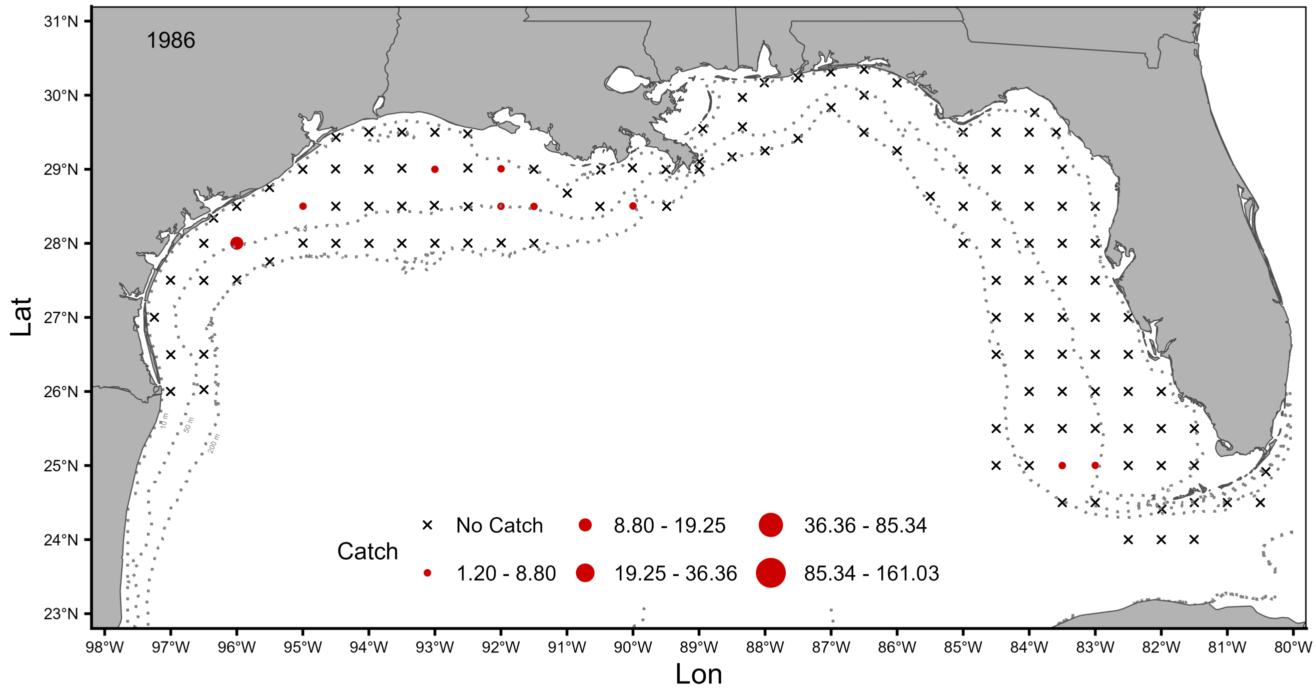


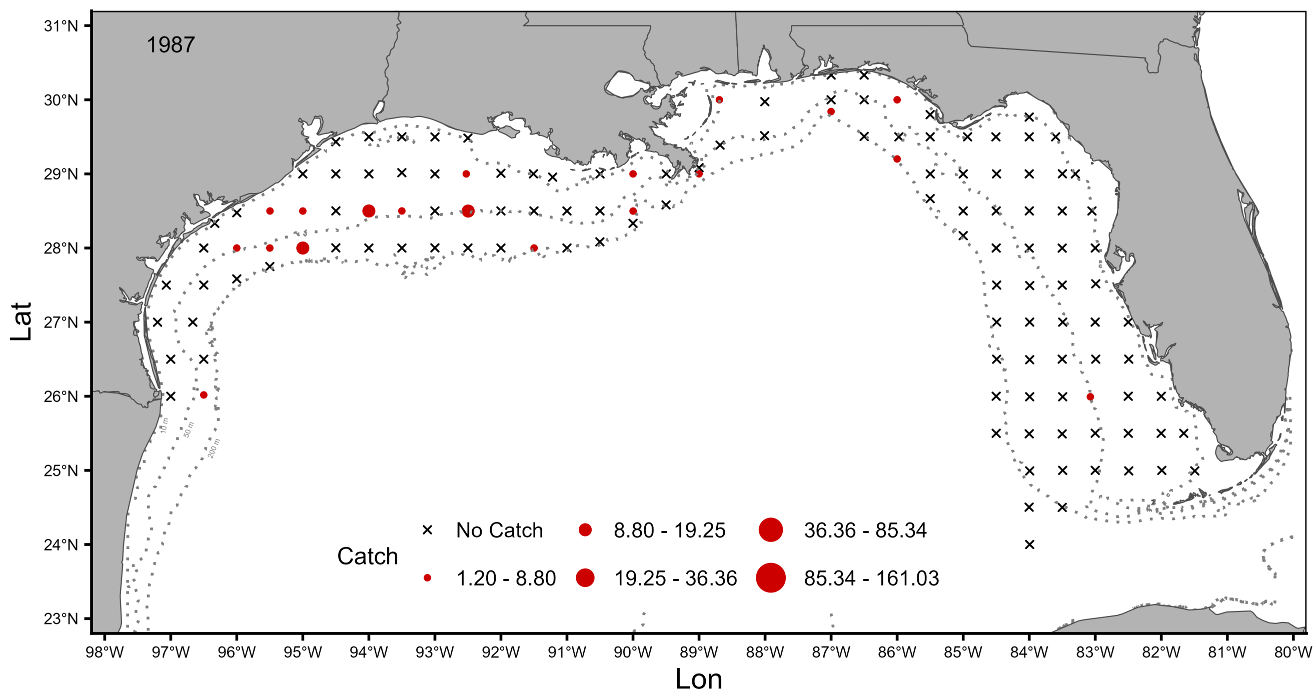
Figure 5. Diagnostic QQ-plots (left) and distribution of residuals (right) for the lognormal component of the larval king mackerel SEAMAP Fall Plankton Survey Gulf of Mexico alternate core area (top) and continuity (bottom) models.

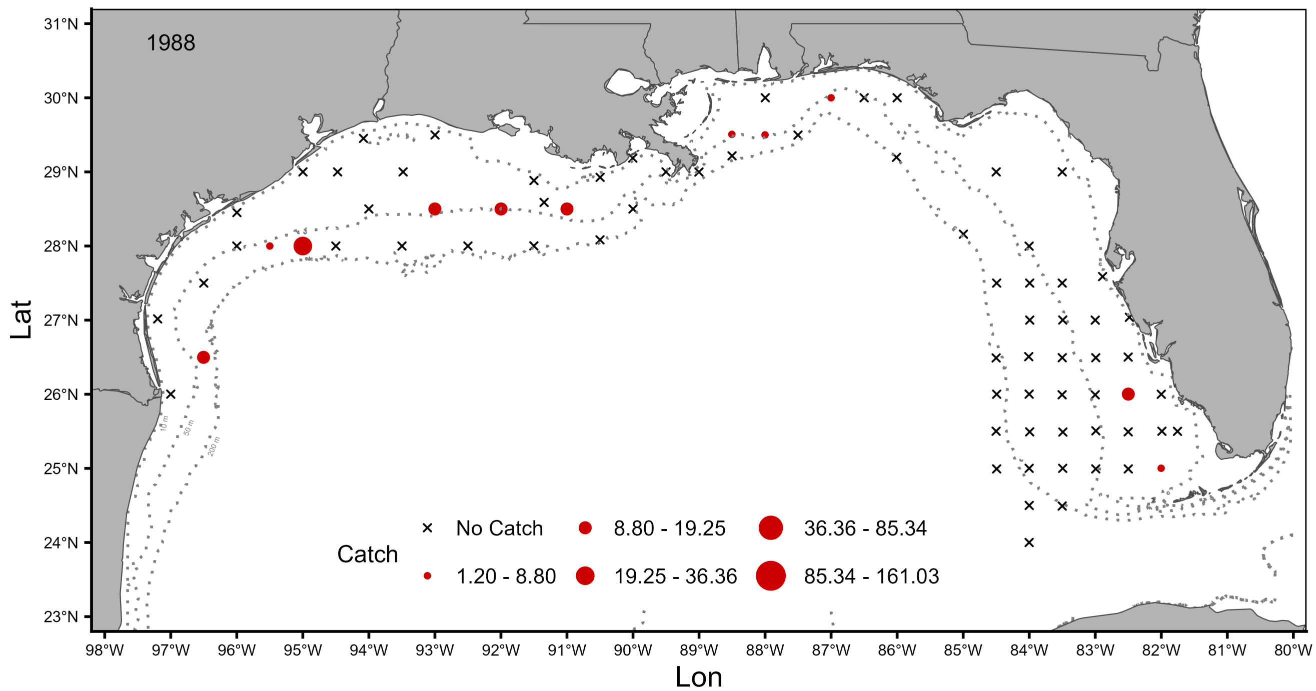
Appendix 1

Annual Distribution Maps of King Mackerel Larval Abundance from SEAMAP Fall Plankton Surveys

Appendix Figure 1. Annual survey effort and catch per unit area (CPUA) of larval king mackerel from the SEAMAP Fall Plankton Survey conducted from 1986-2024. CPUA is expressed as the number of larvae under 10 m^2.



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Lat
Lon
Catch
No Catch
1.20 - 8.80
8.80 - 19.25
19.25 - 36.36
36.36 - 85.34
85.34 - 161.03
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
97°W
96°W
95°W
94°W
93°W
92°W
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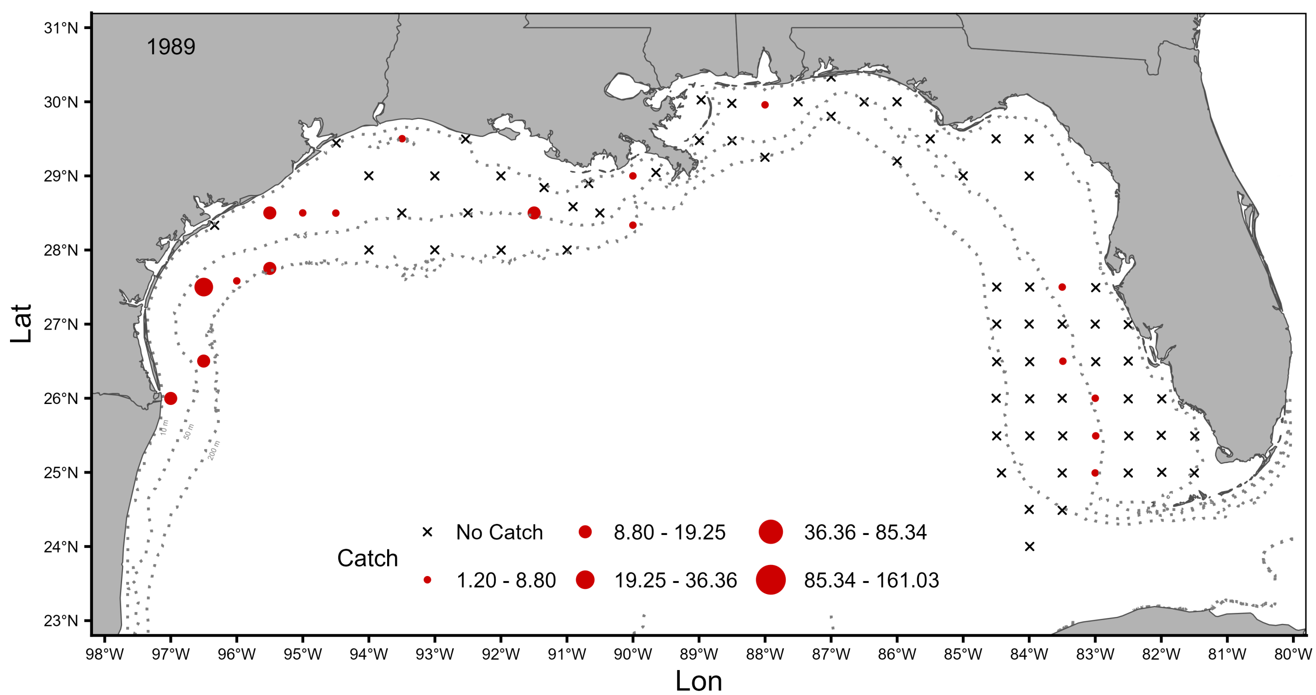
82°W
81°W
80°W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Lat
Lon
Catch
No Catch
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8.80 - 19.25
19.25 - 36.36
36.36 - 85.34
85.34 - 161.03
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
97°W
96°W
95°W
94°W
93°W
92°W
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81°W
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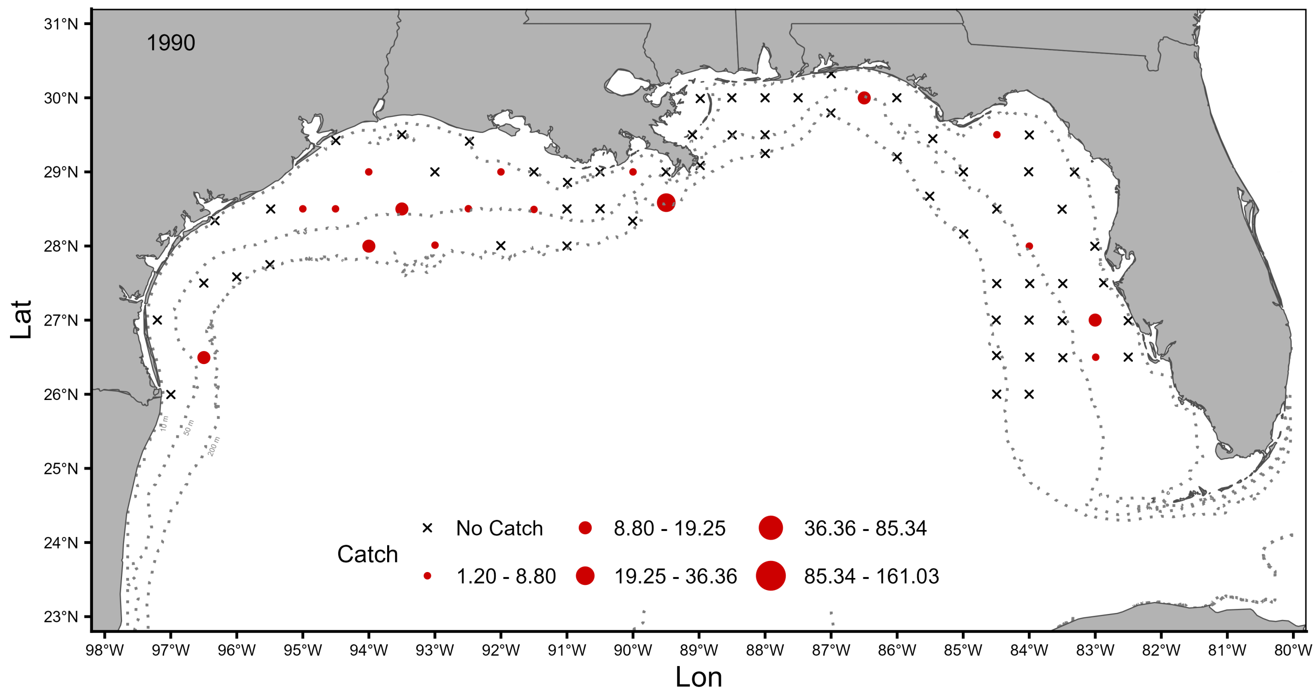
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Lat
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93°W
92°W
91°W
90°W
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
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Lon
Catch
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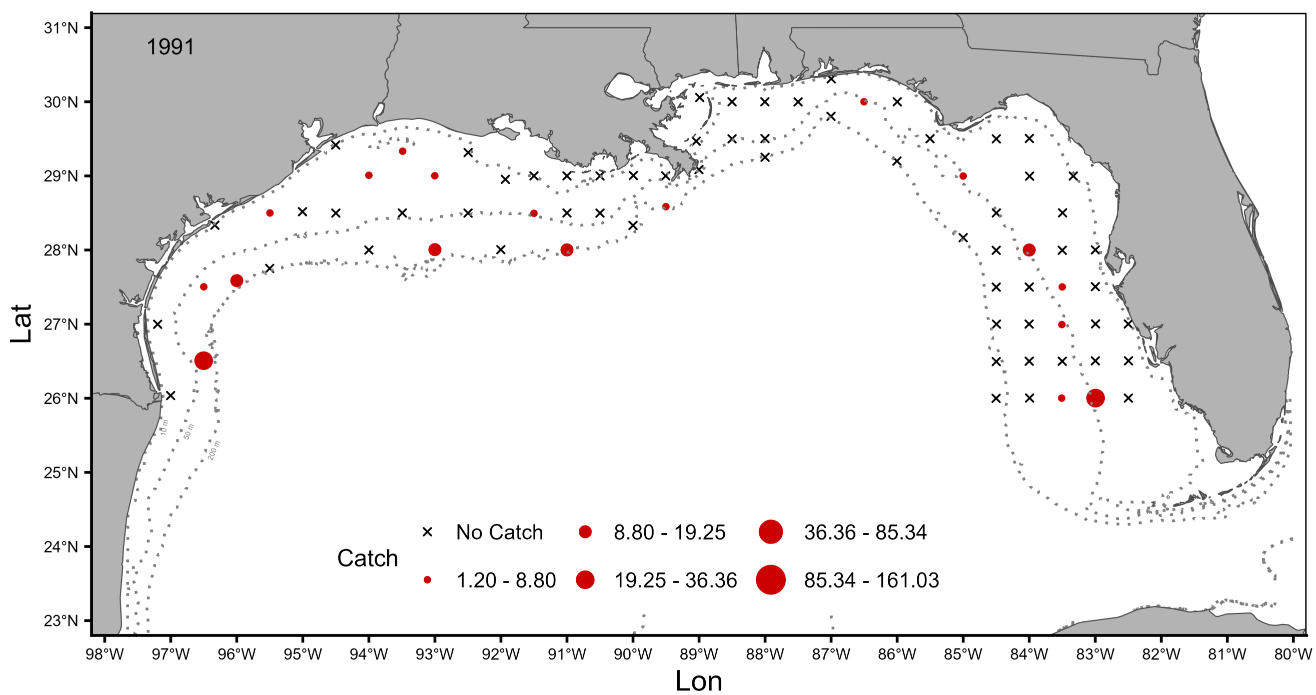
19.25 - 36.36
36.36 - 85.34
85.34 - 161.03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Lat
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95°W
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91°W
90°W
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
80°W
Lon
Catch
No Catch
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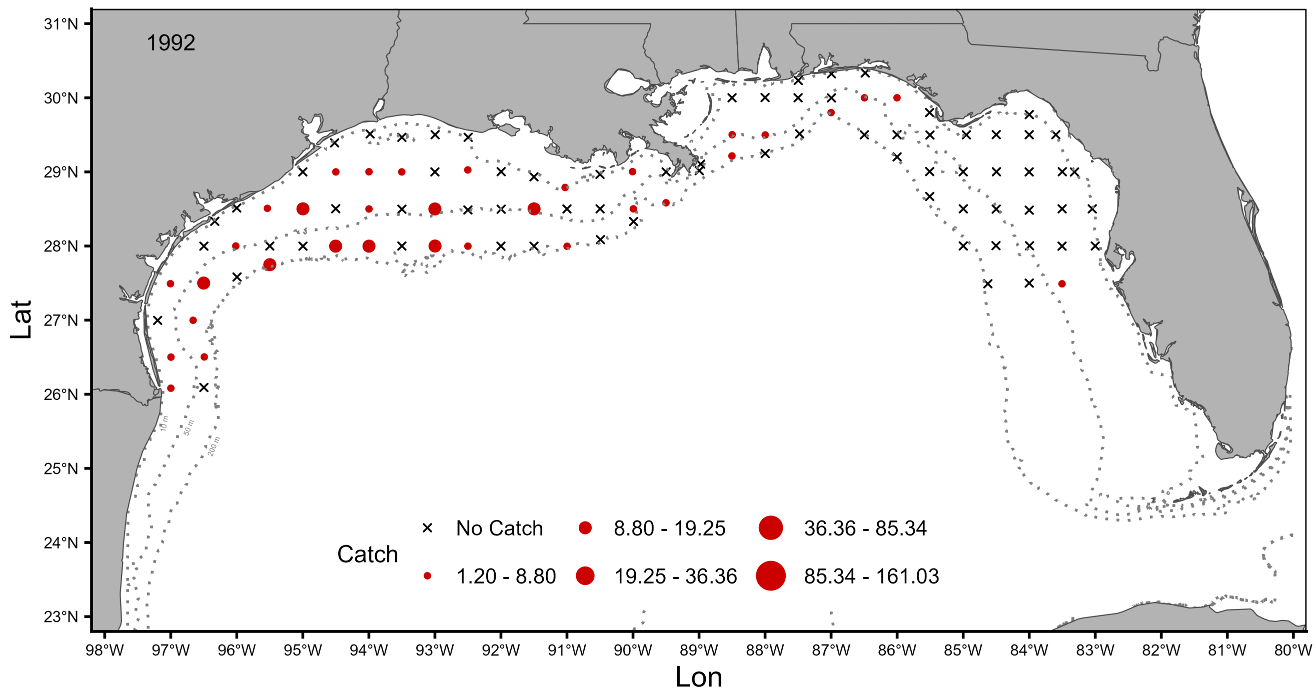
8.80 - 19.25
19.25 - 36.36
36.36 - 85.34
85.34 - 161.03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36.36 - 85.34
85.34 - 161.03
Catch
Lat
Lon
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30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
97°W
96°W
95°W
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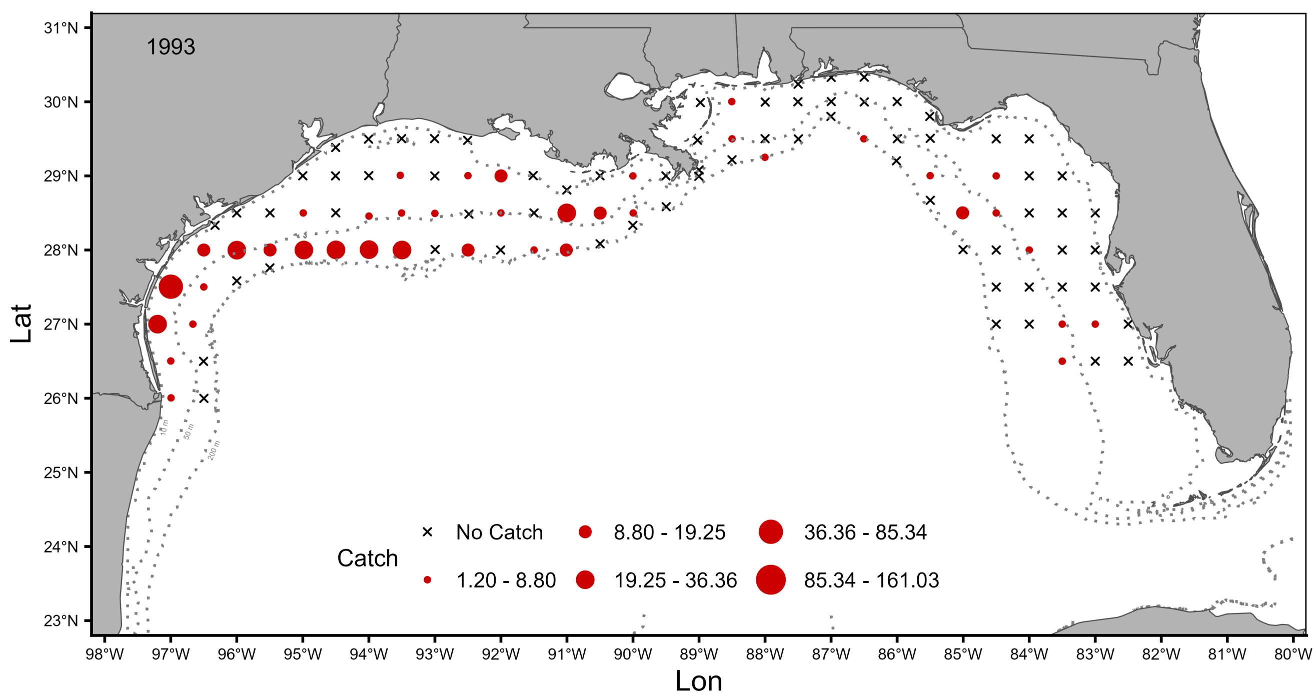
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19.25 - 36.36
36.36 - 85.34
85.34 - 161.03
Catch
Lat
Lon
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
97°W
96°W
95°W
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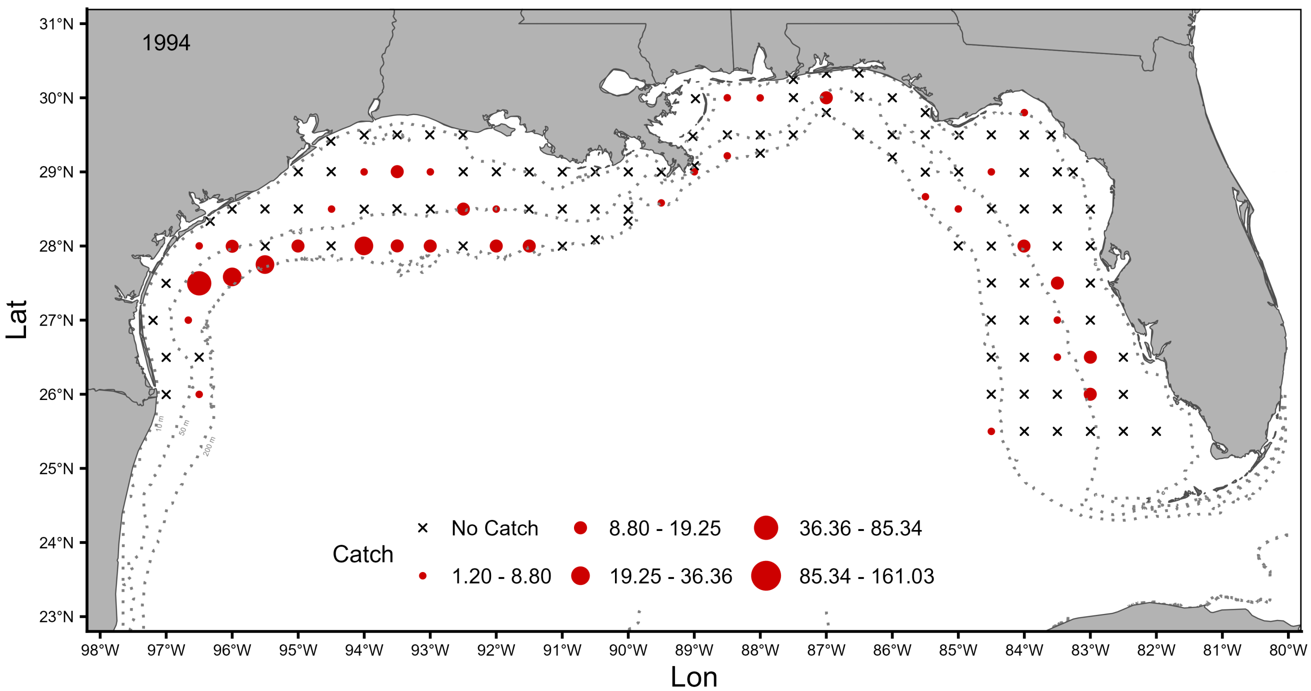
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87°W
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84°W
83°W
82°W
81°W
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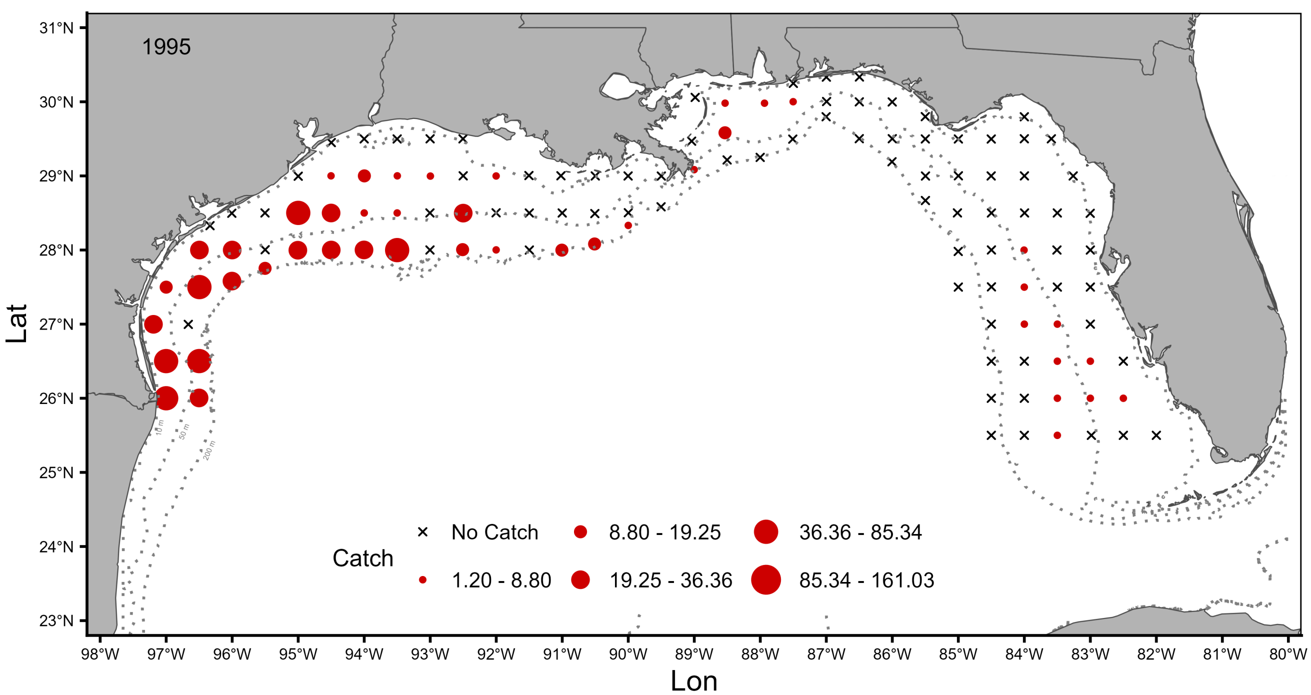
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84°W
83°W
82°W
81°W
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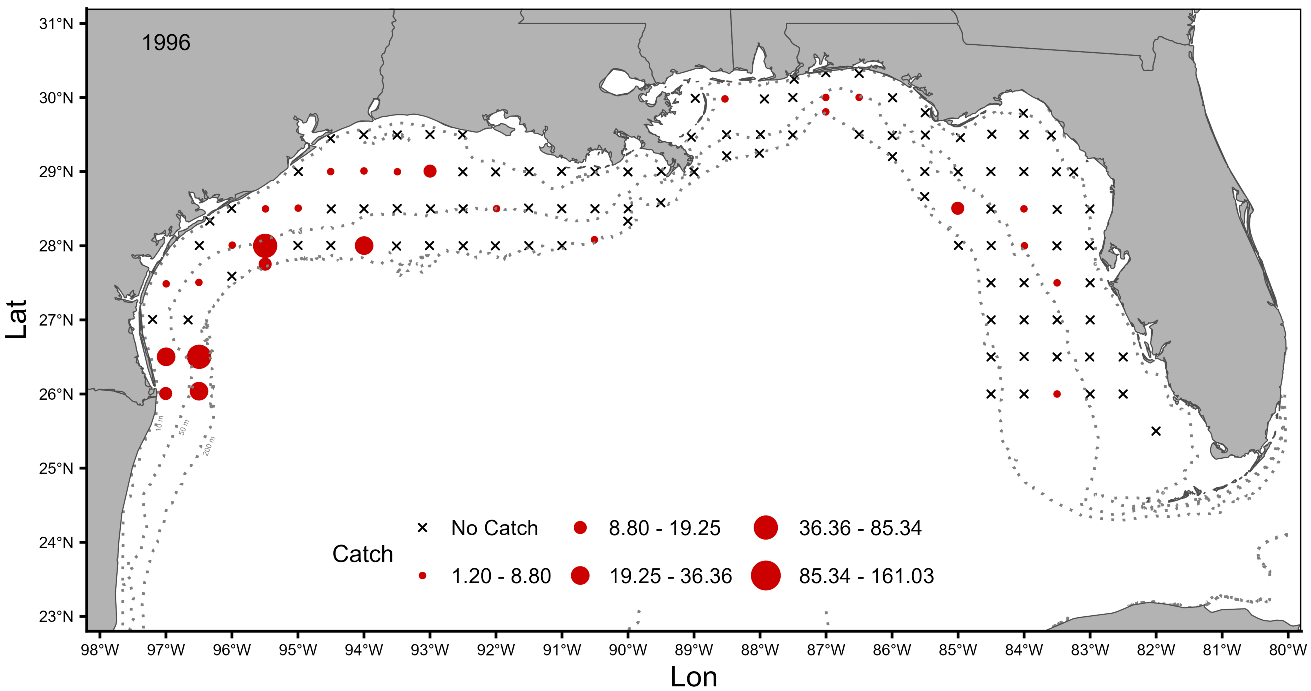
85.34 - 161.03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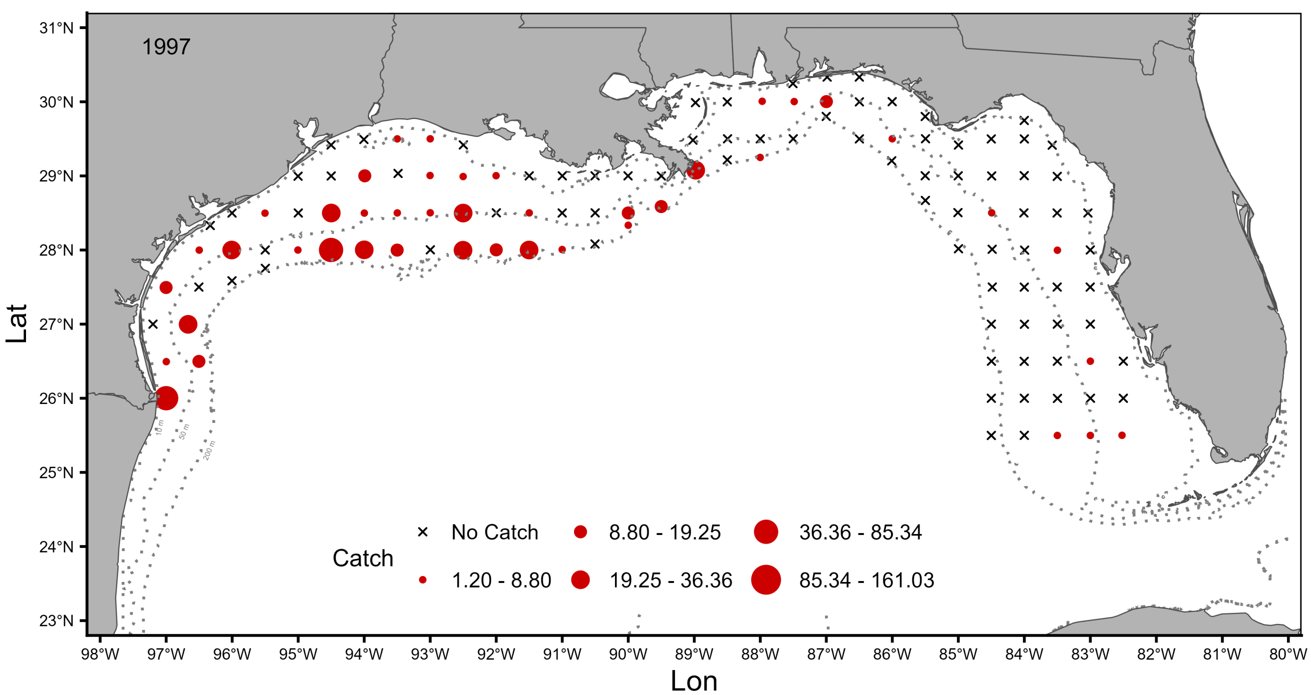
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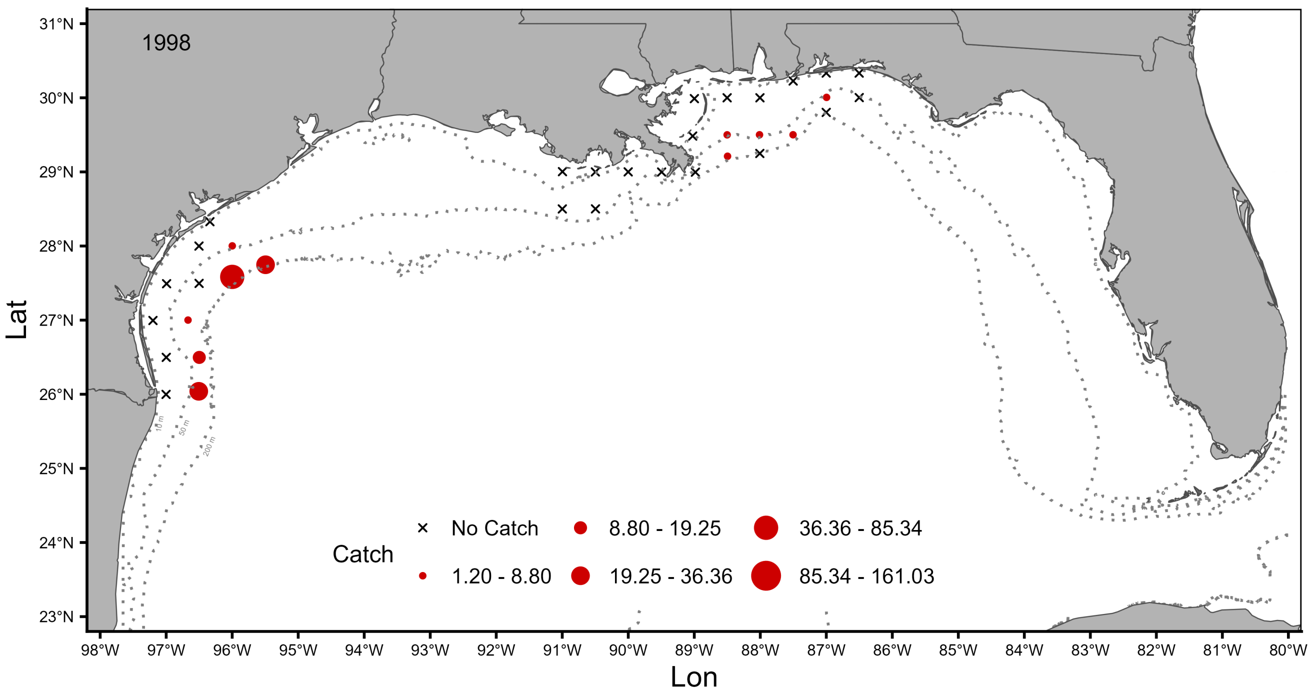
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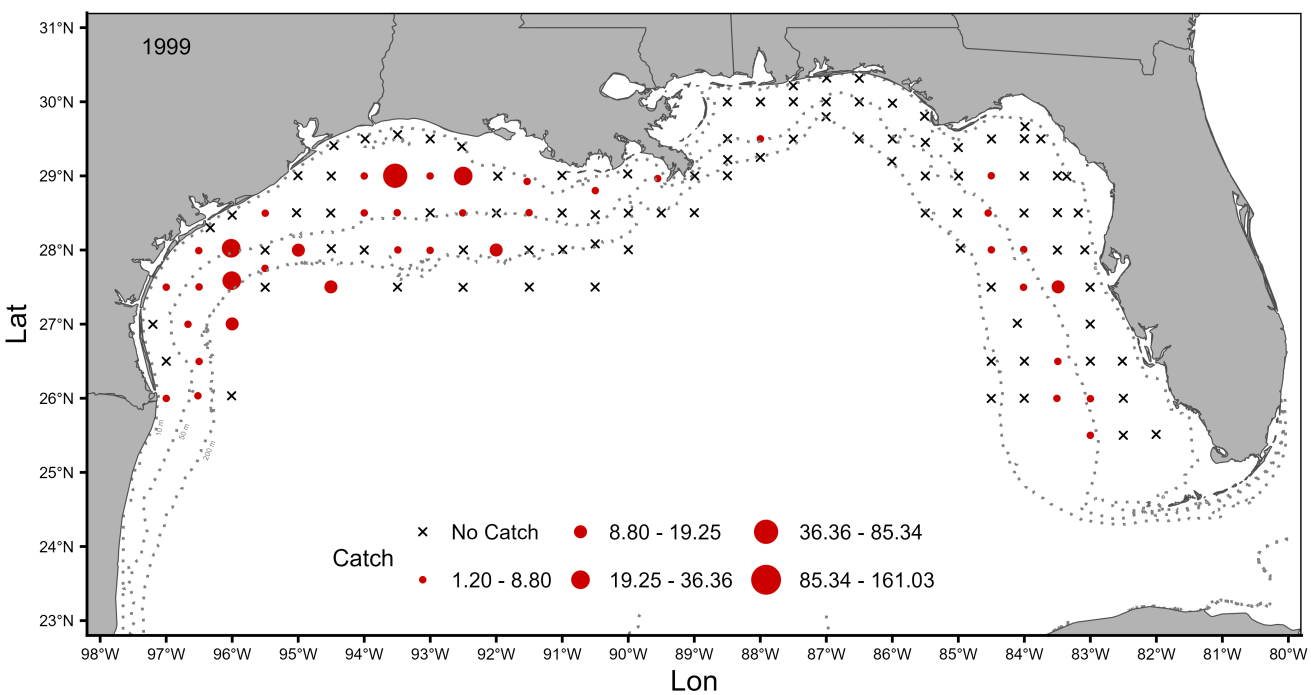
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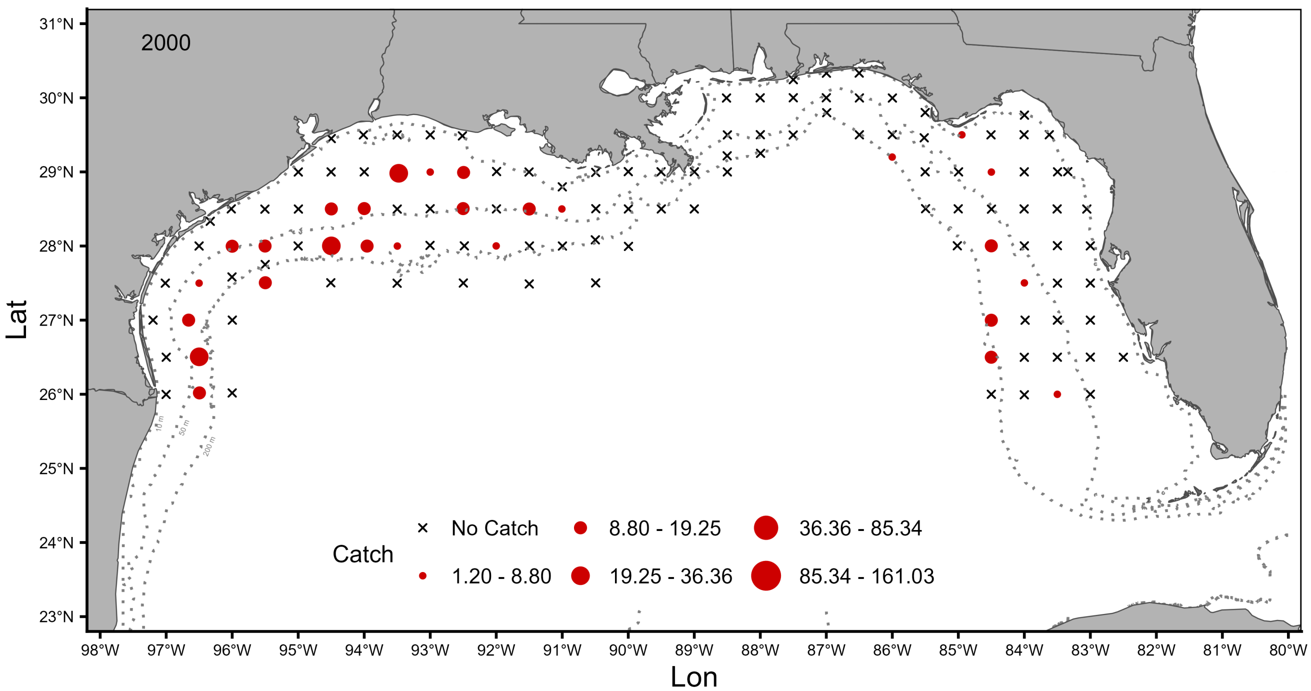
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82°W
81°W
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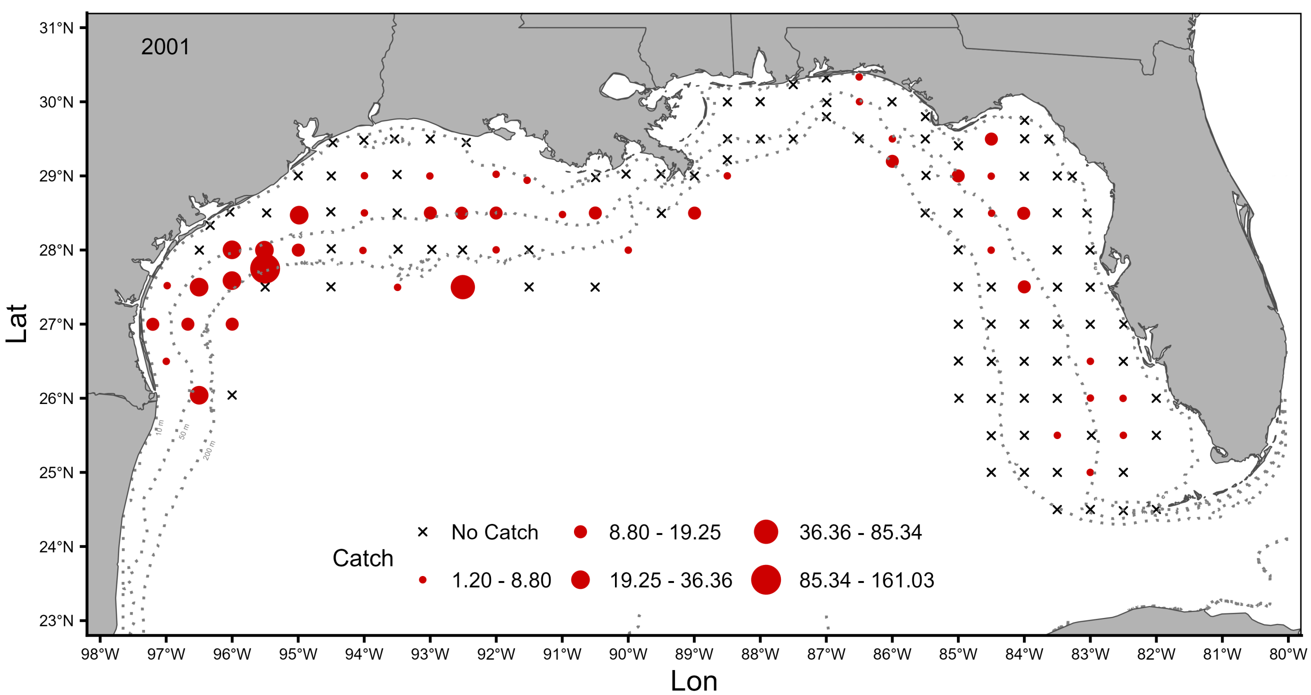
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82°W
81°W
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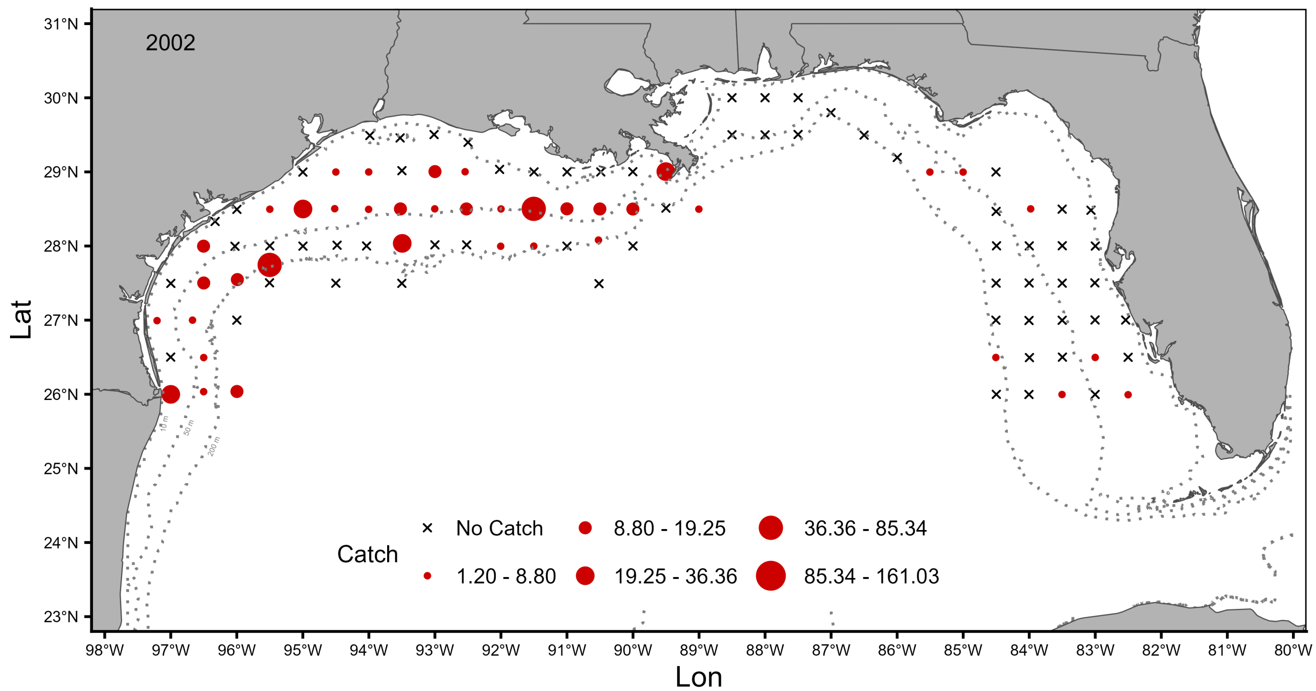
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85.34 - 161.03
Lat
Lon
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30°N
29°N
28°N
27°N
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25°N
24°N
23°N
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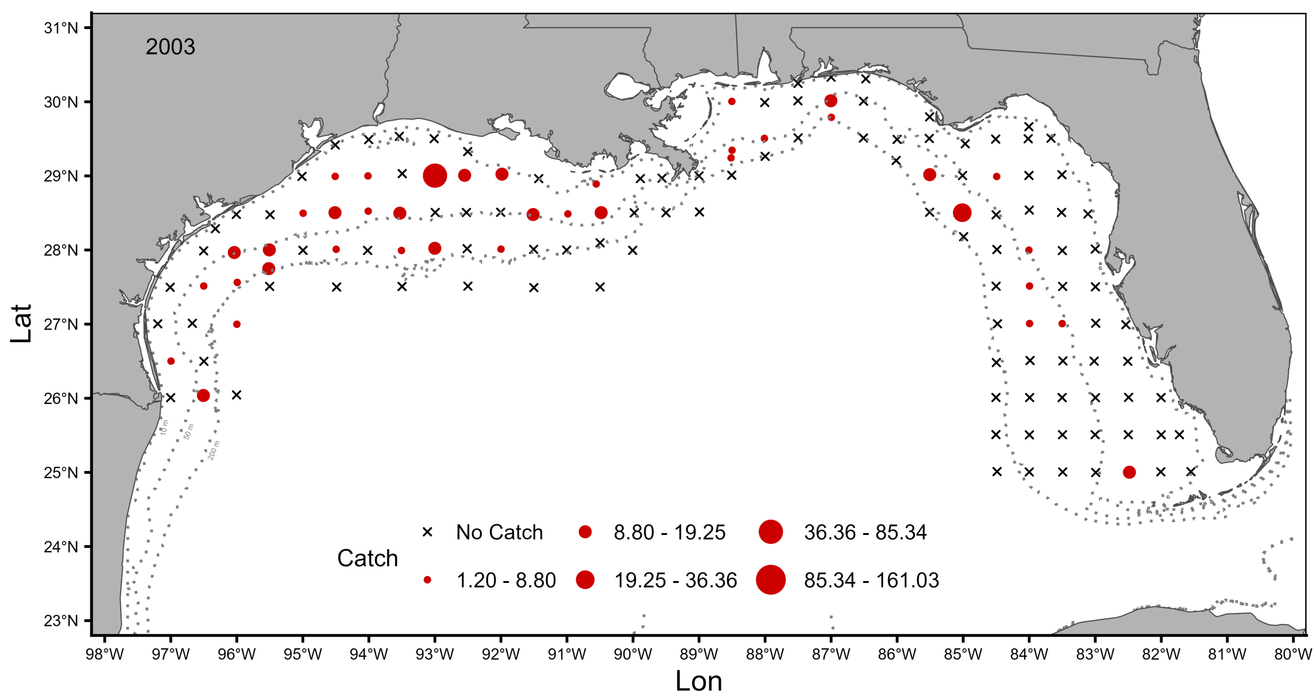
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85.34 - 161.03
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Lon
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30°N
29°N
28°N
27°N
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25°N
24°N
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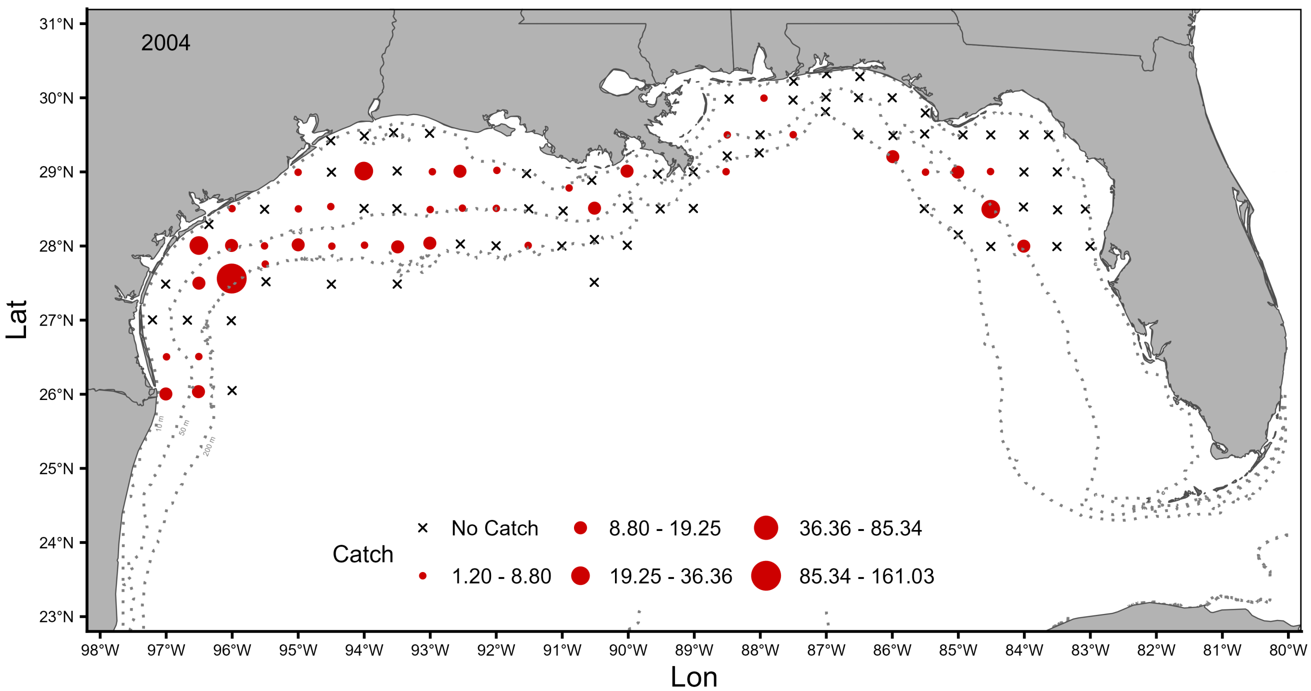
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Lon
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29°N
28°N
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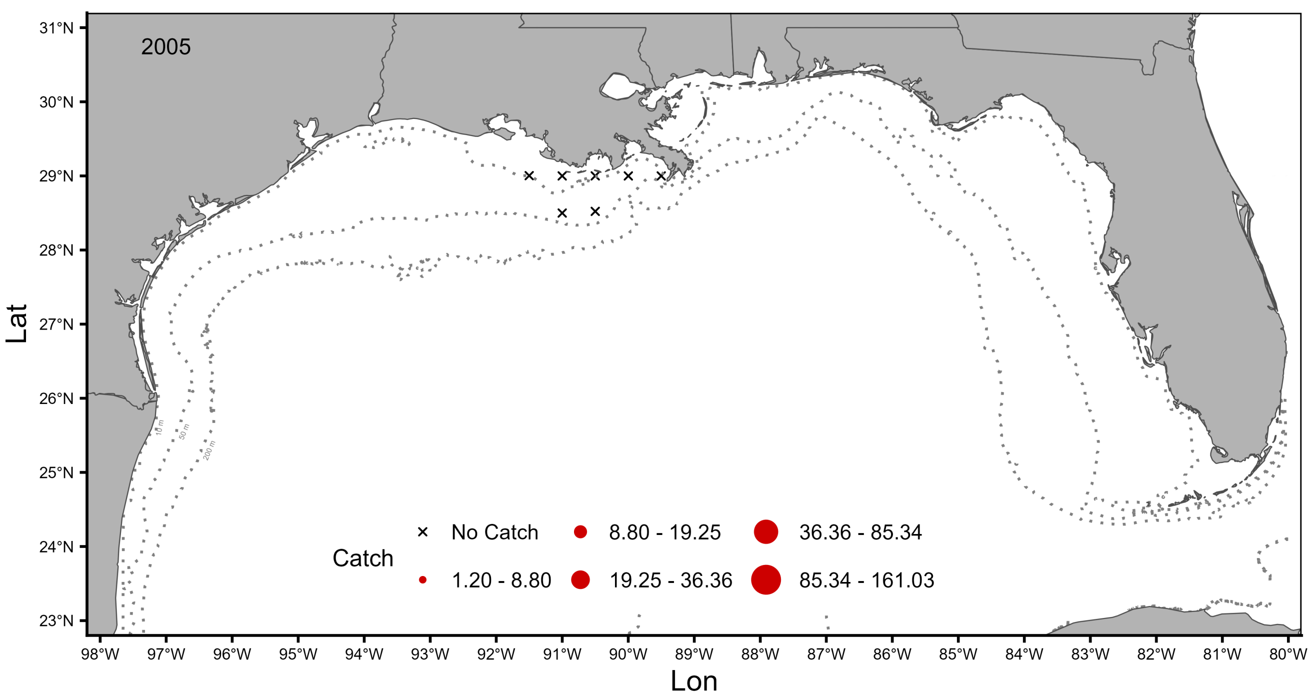
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85.34 - 161.03
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28°N
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23°N
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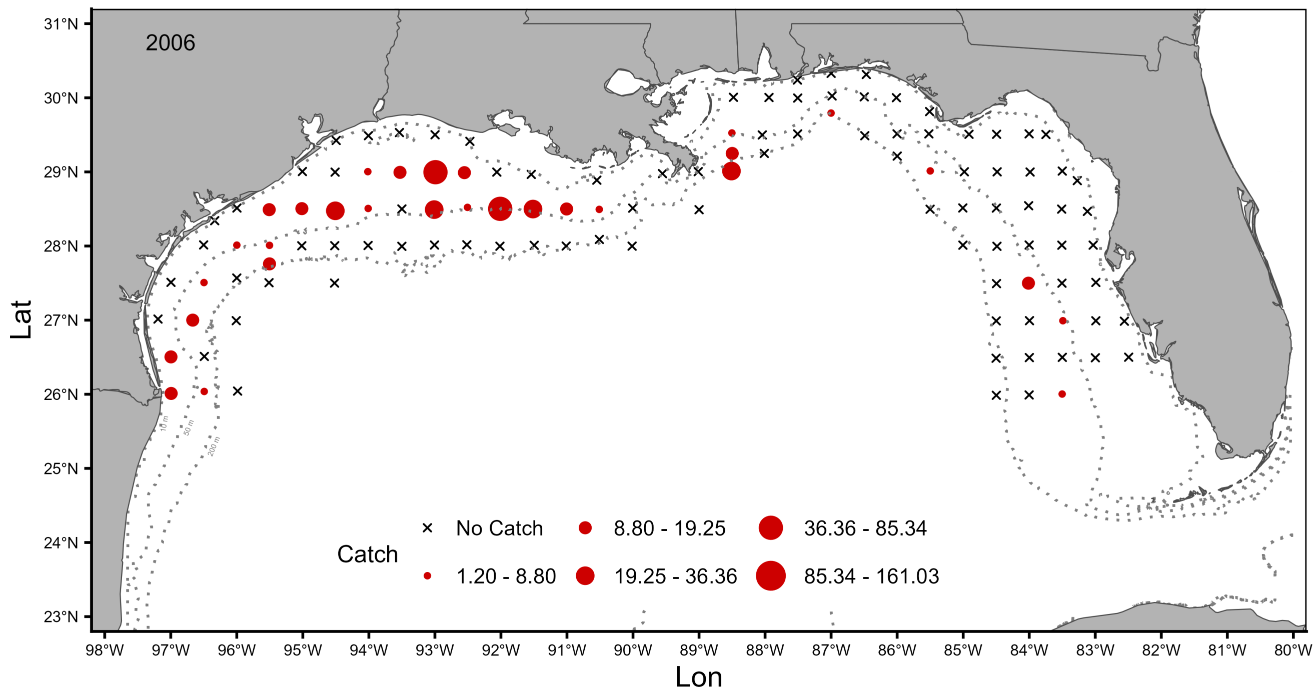
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Catch
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85.34 - 161.03
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30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
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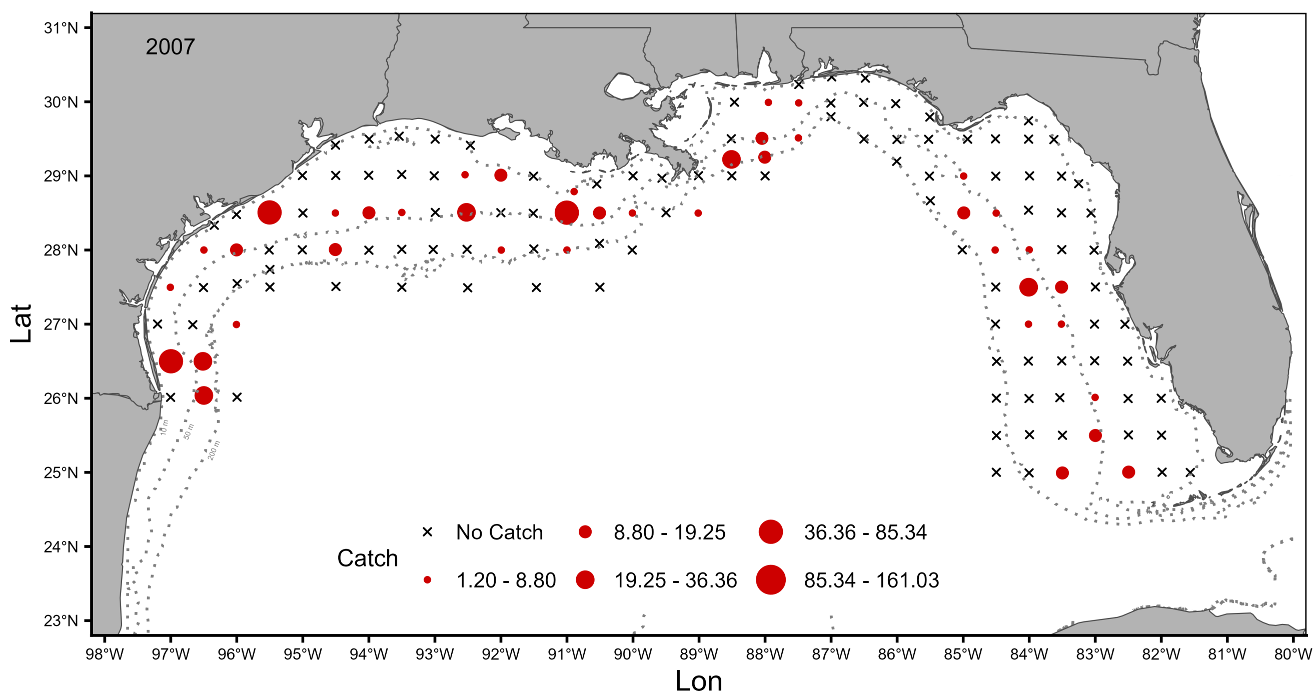
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Catch
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19.25 - 36.36
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85.34 - 161.03
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Lon
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
98°W
97°W
96°W
95°W
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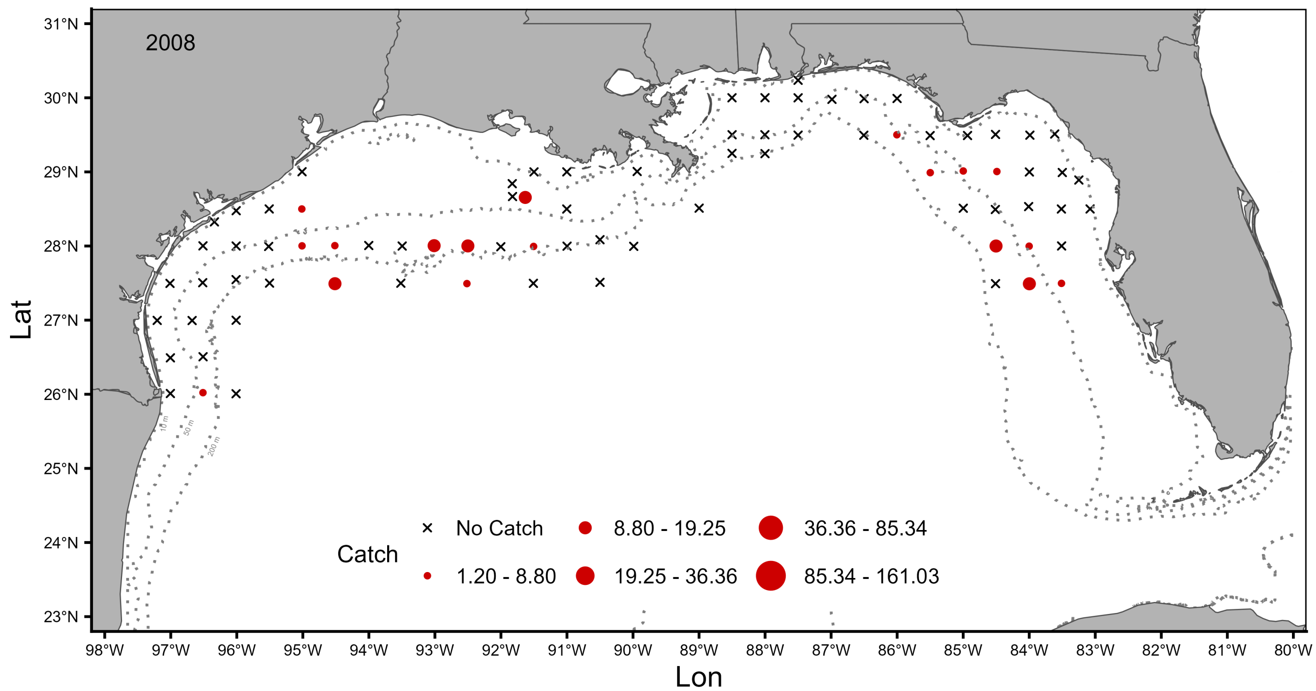
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87°W
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84°W
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82°W
81°W
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Catch
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1.20 - 8.80
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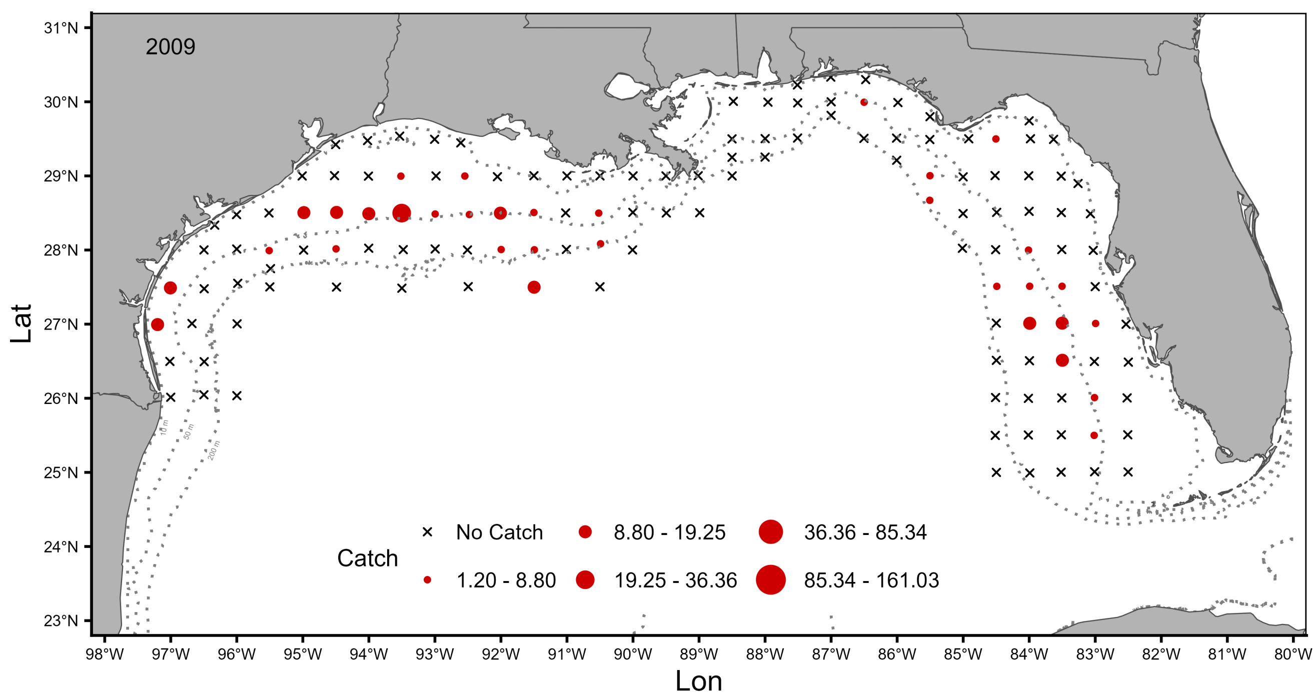
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Lat
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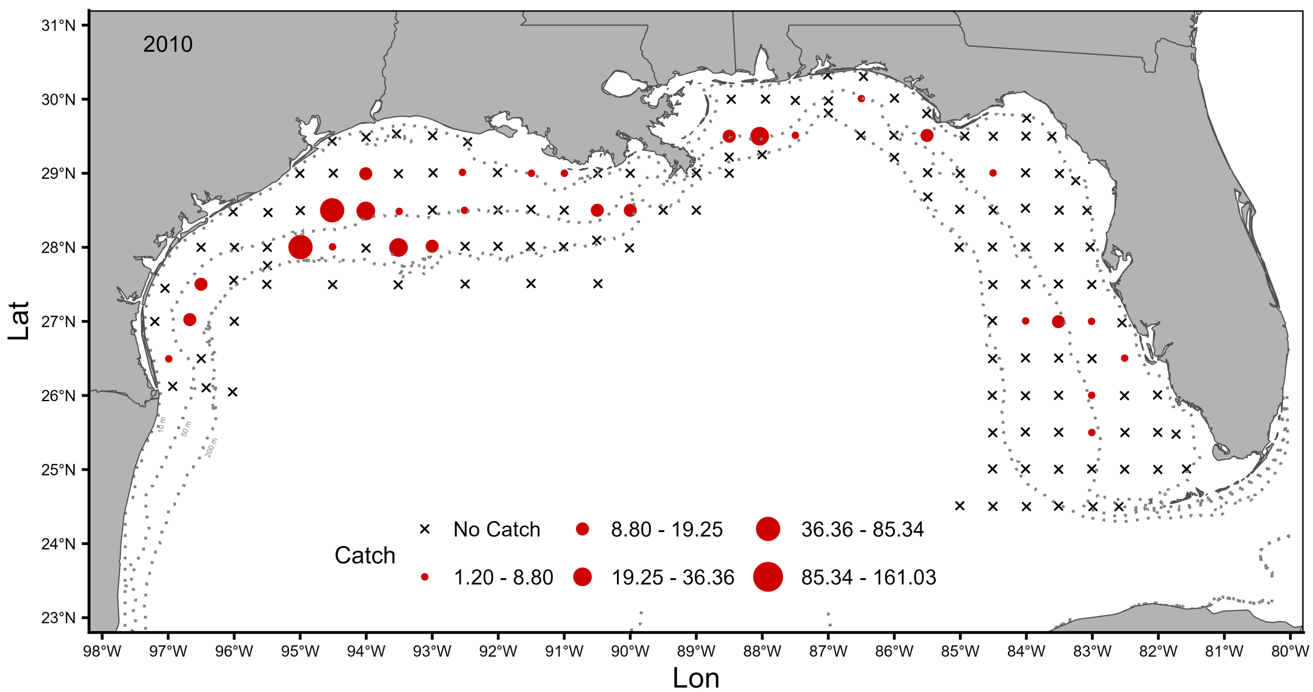
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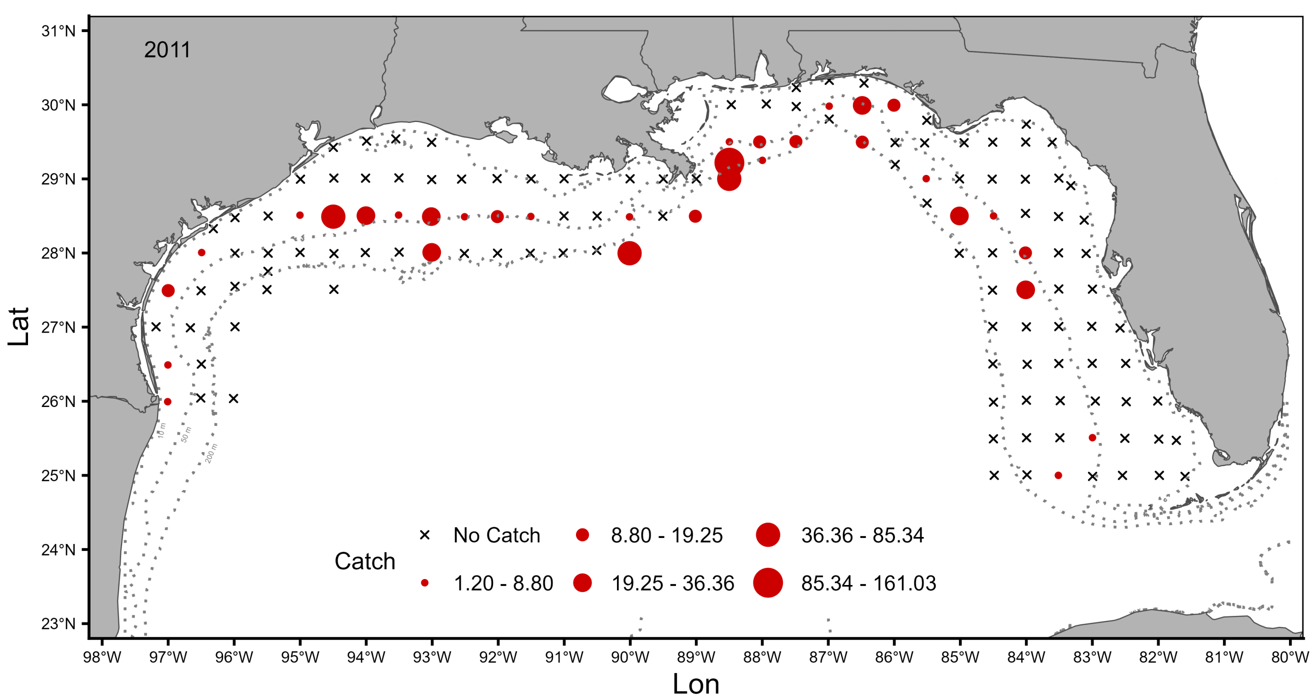
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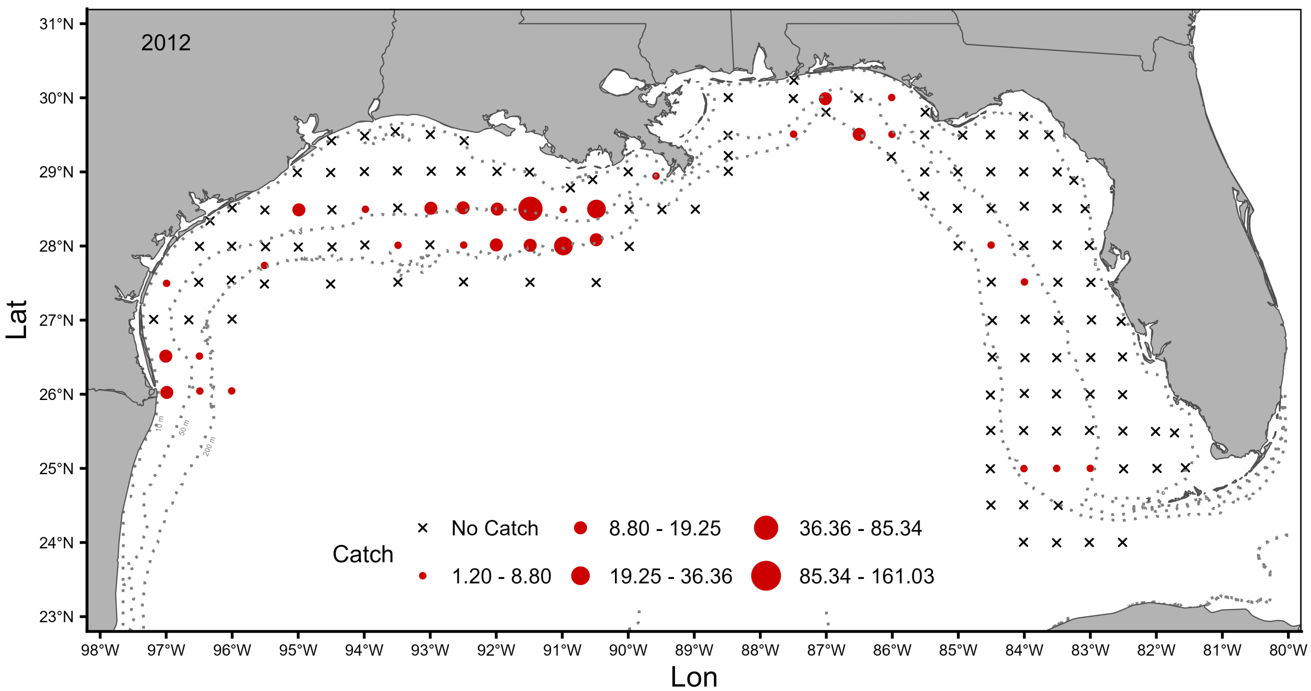
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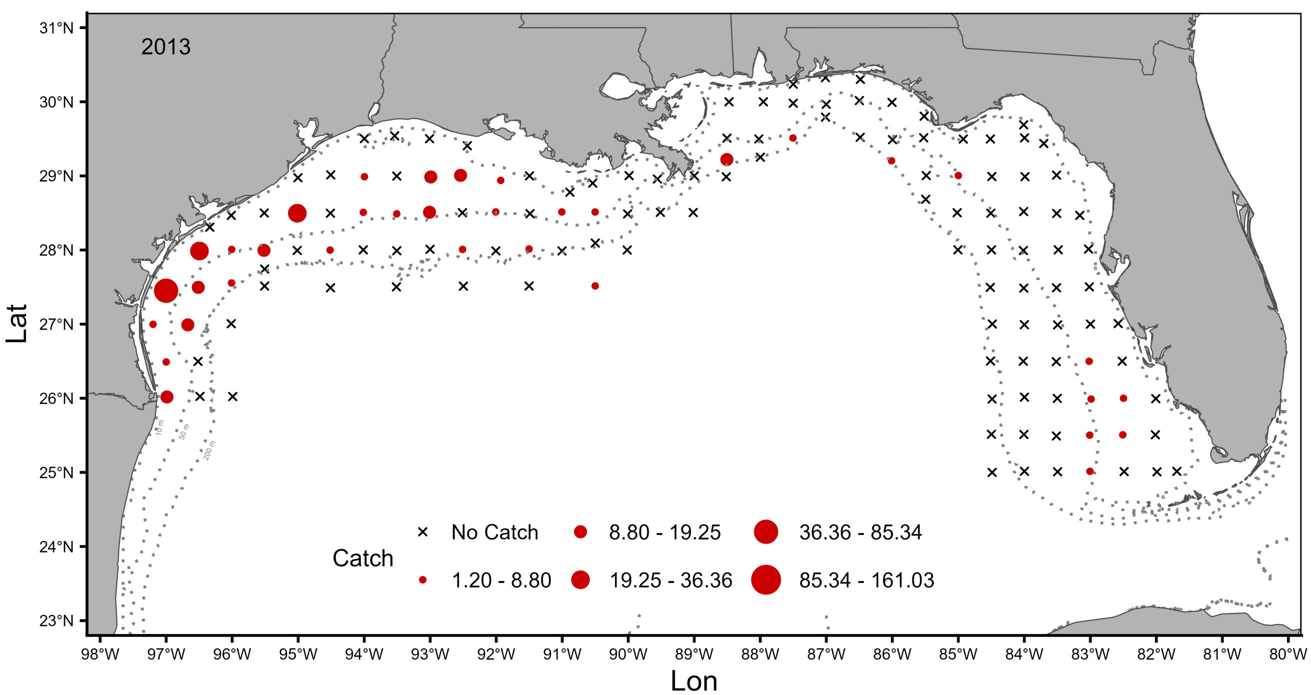
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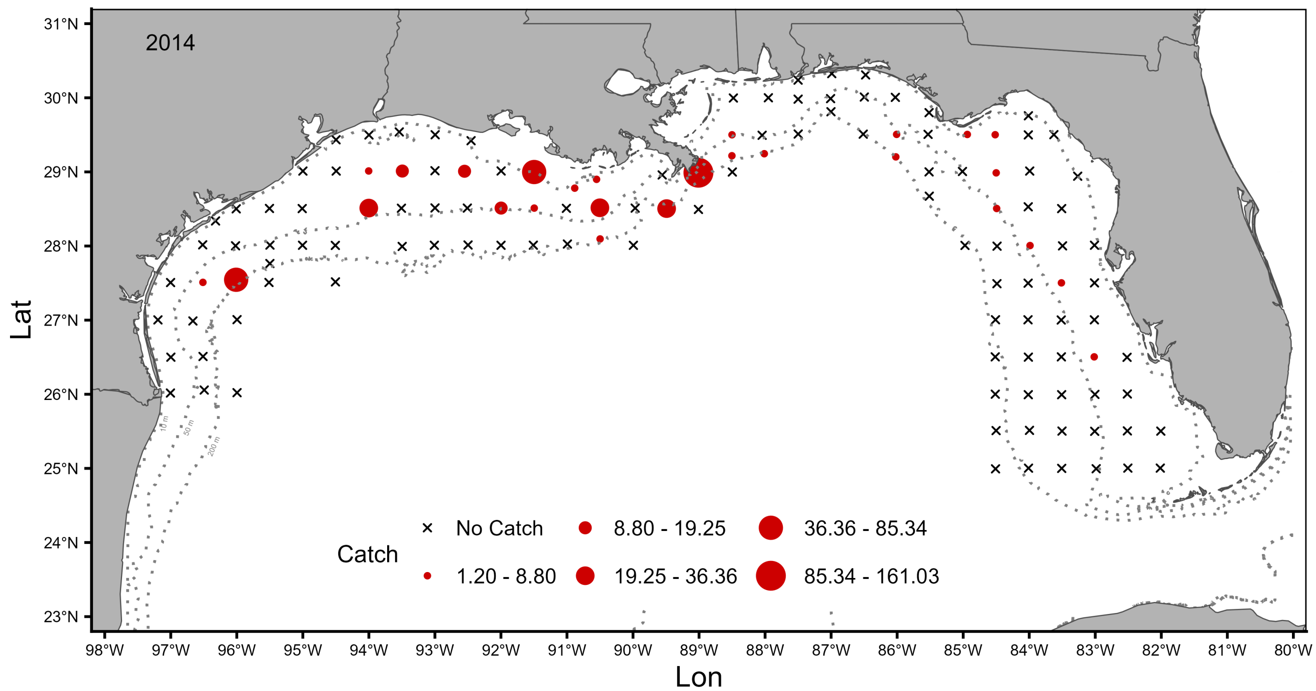
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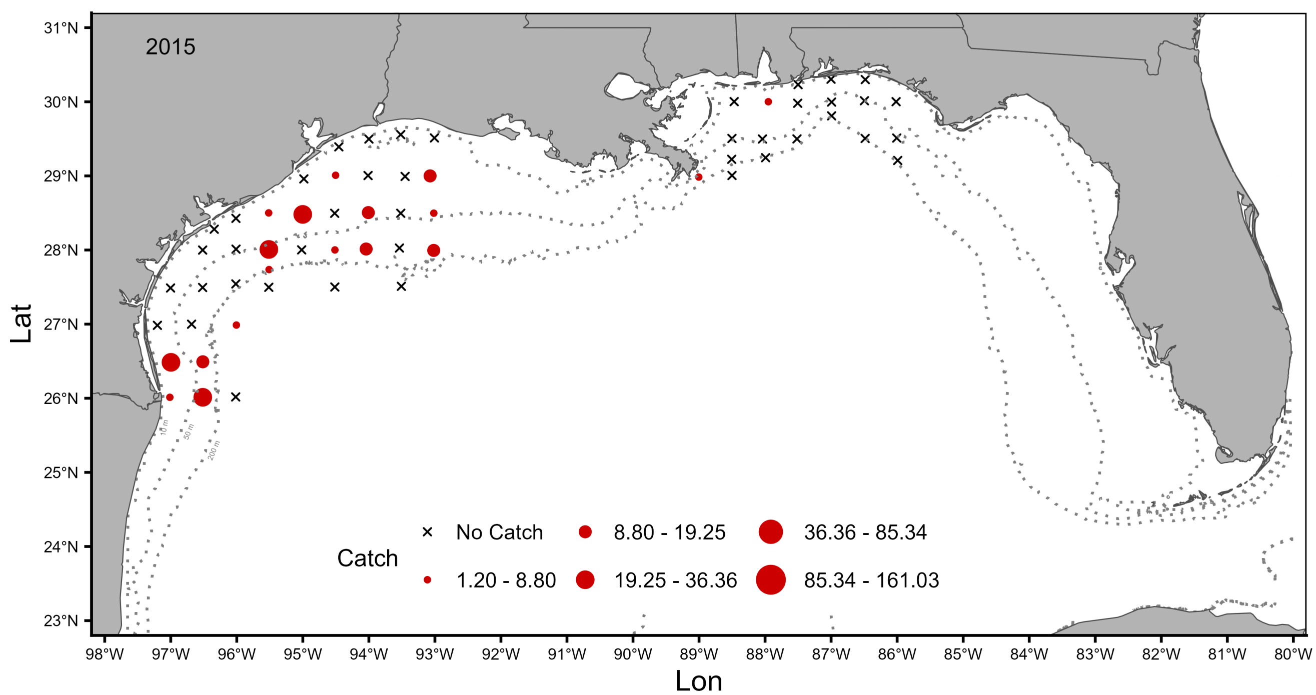
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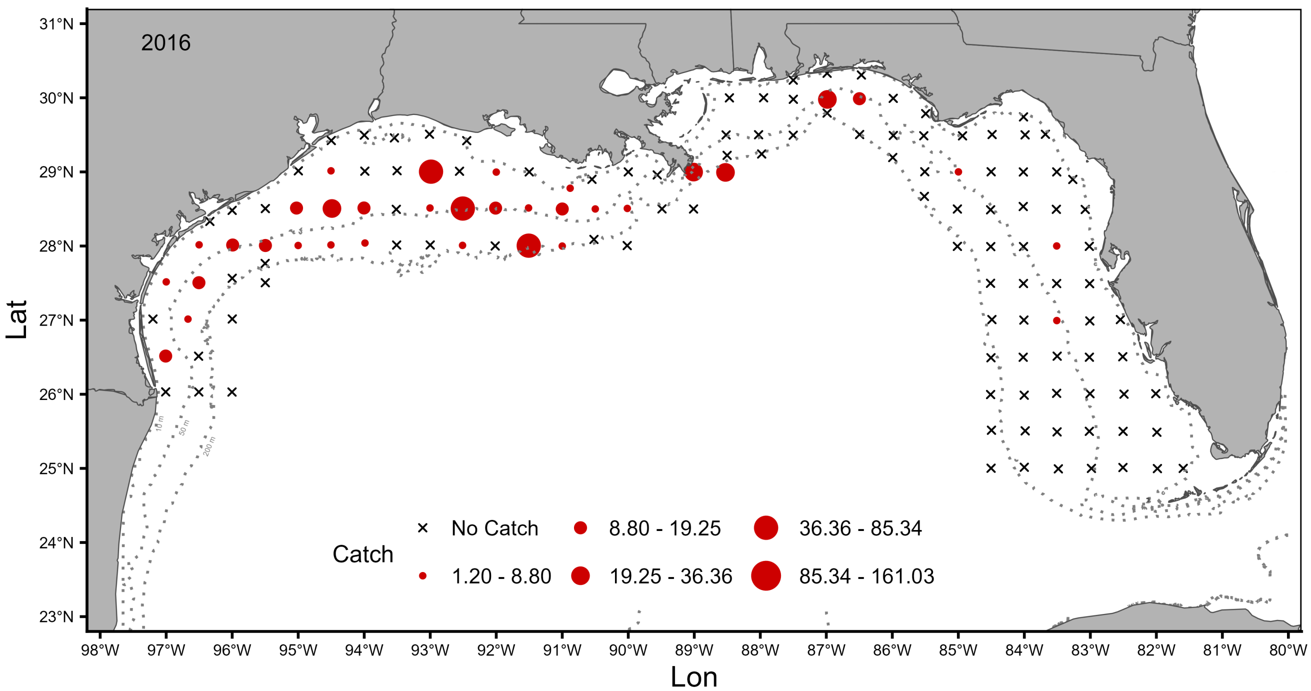
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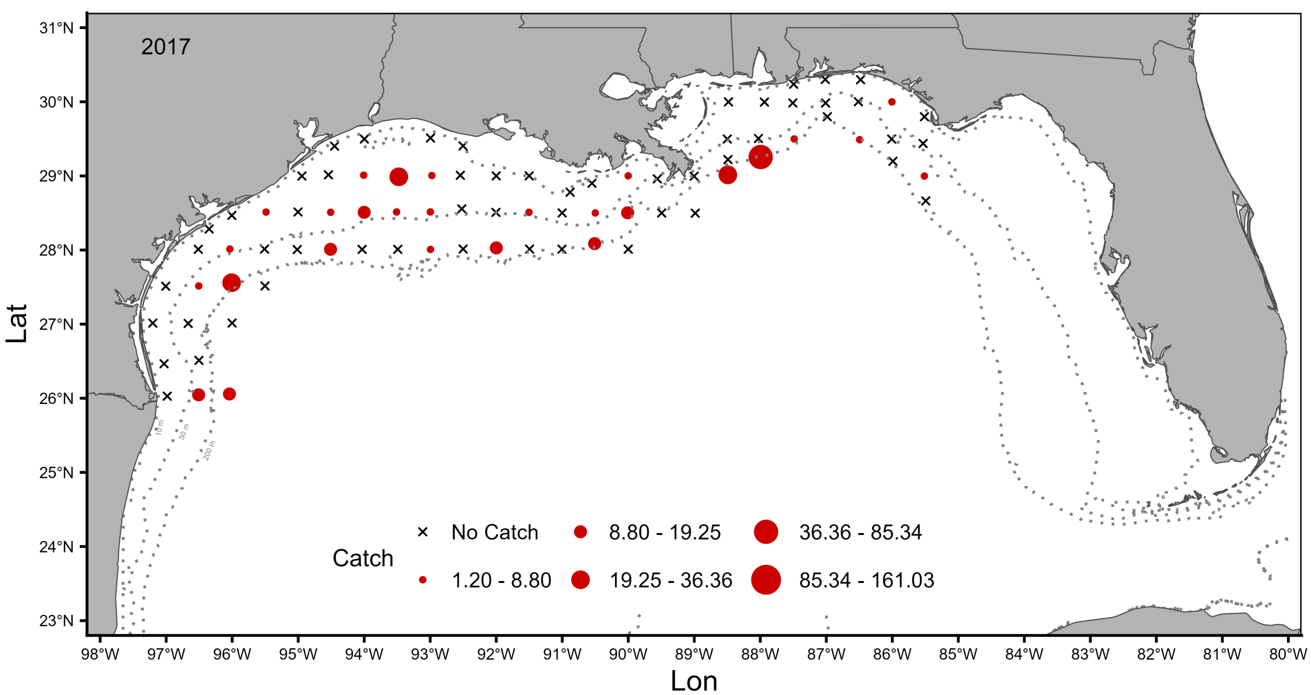
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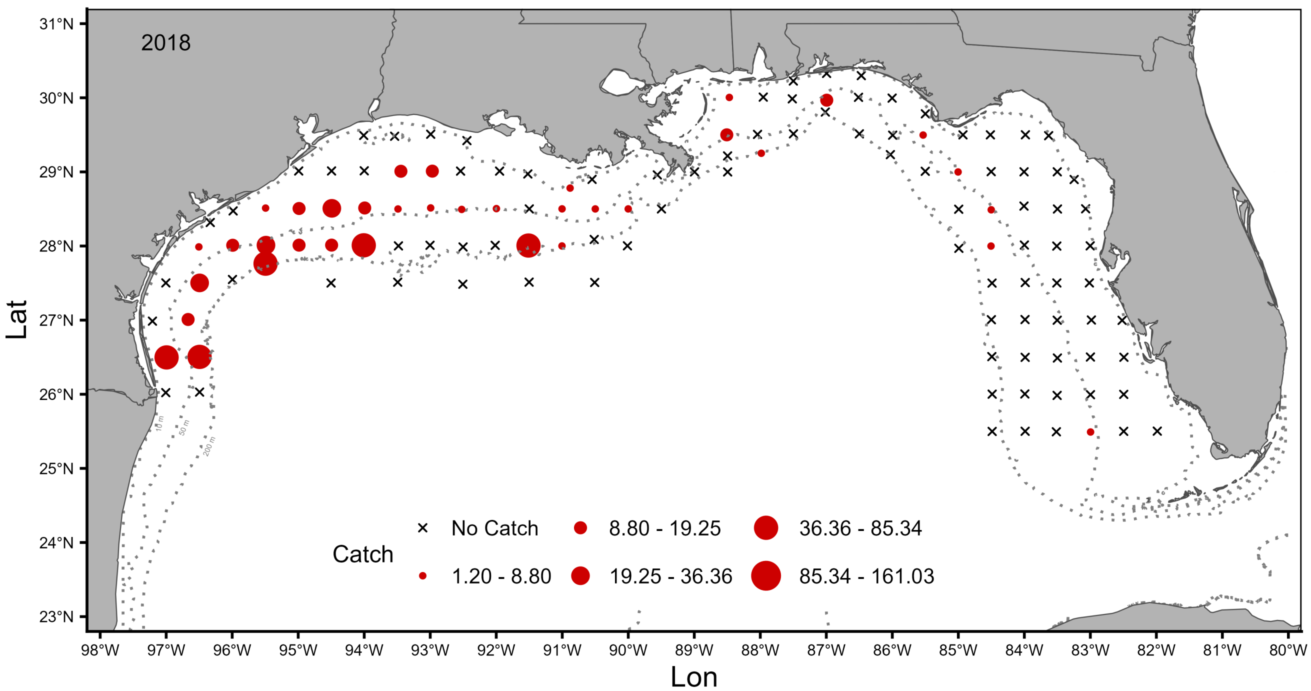
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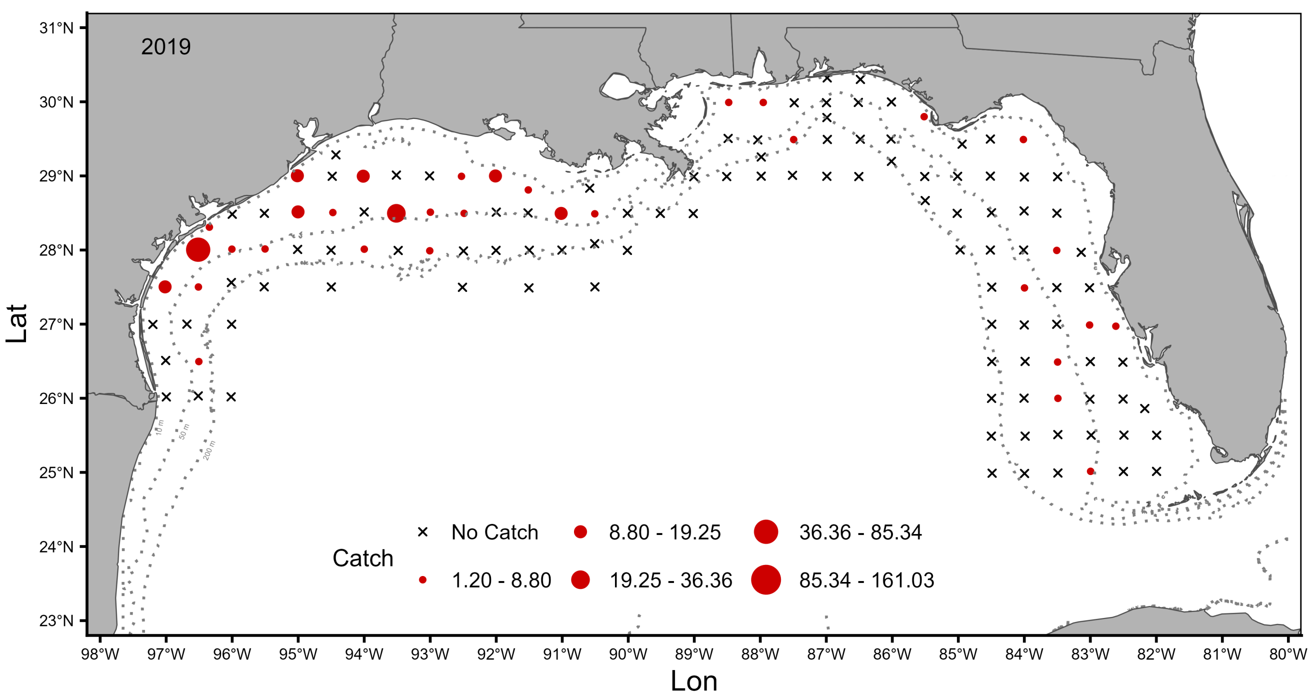
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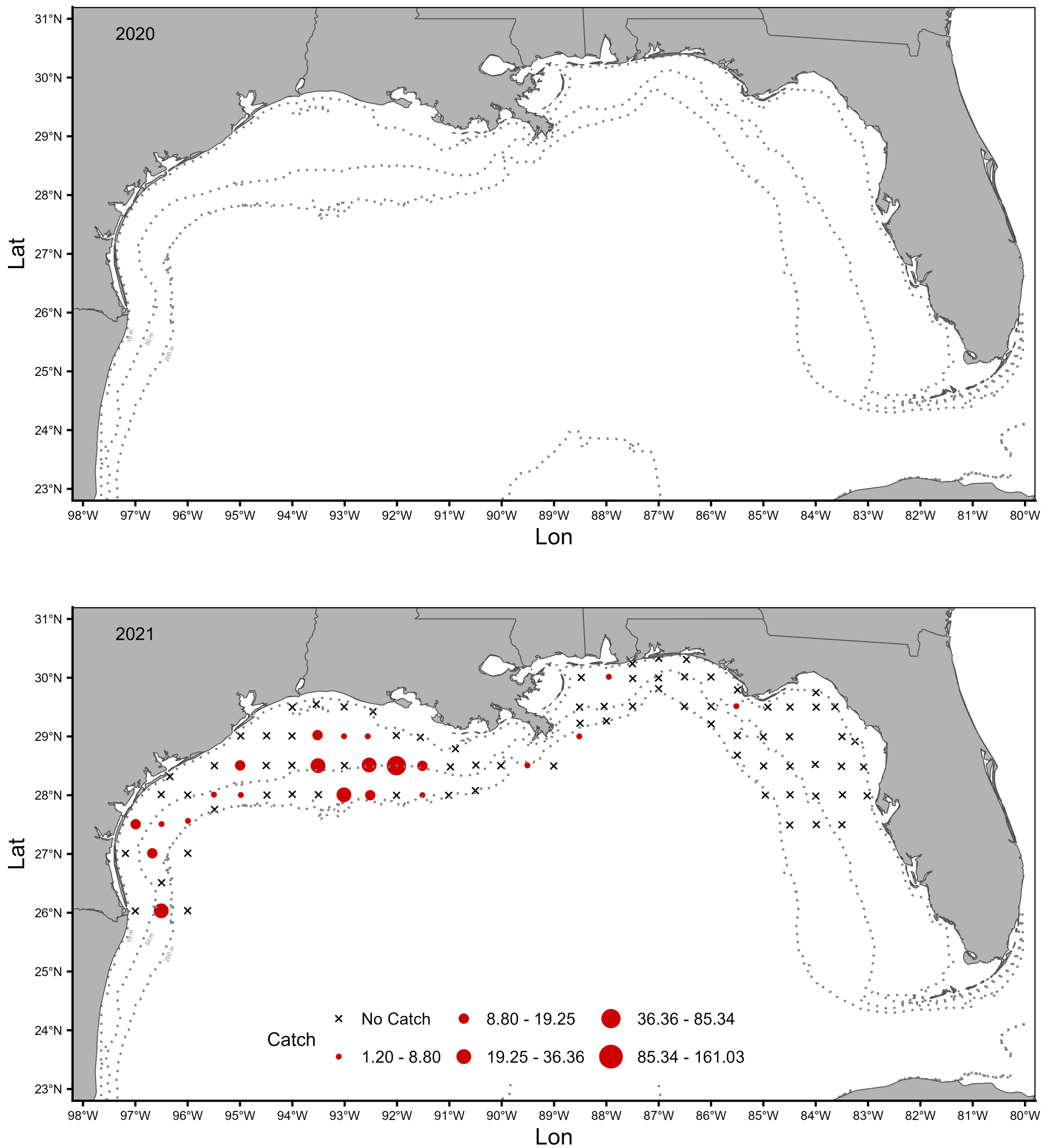
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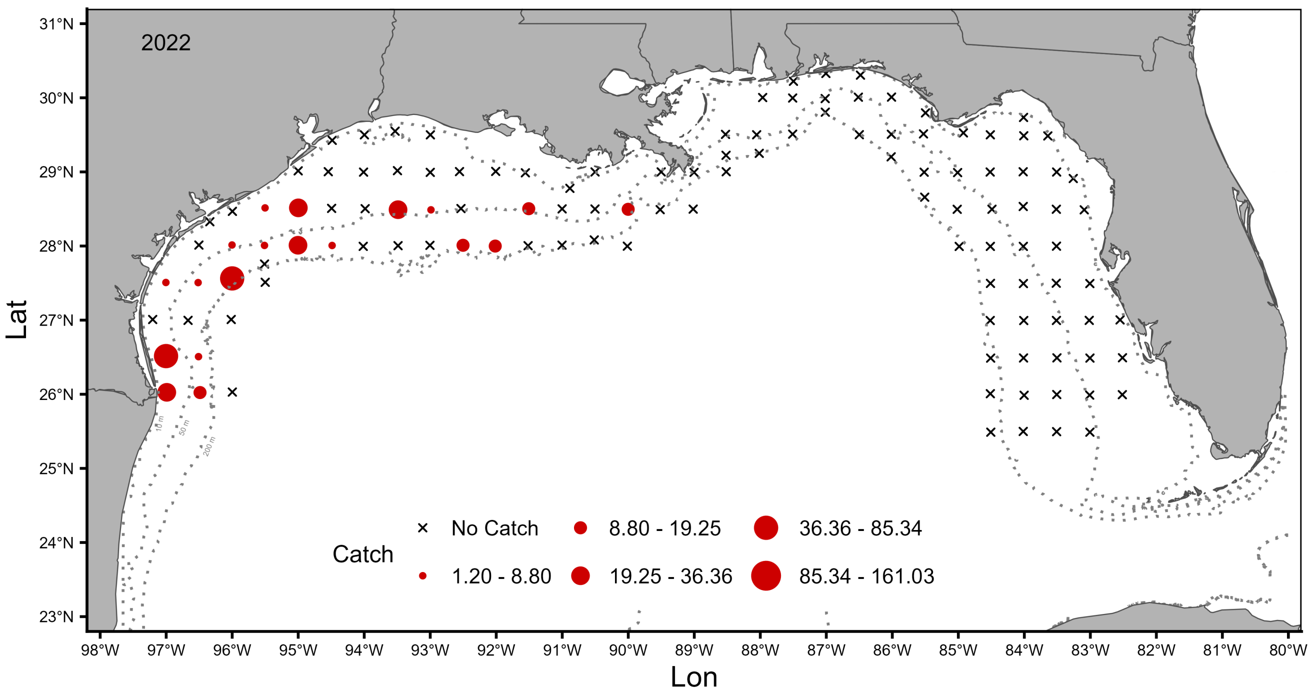
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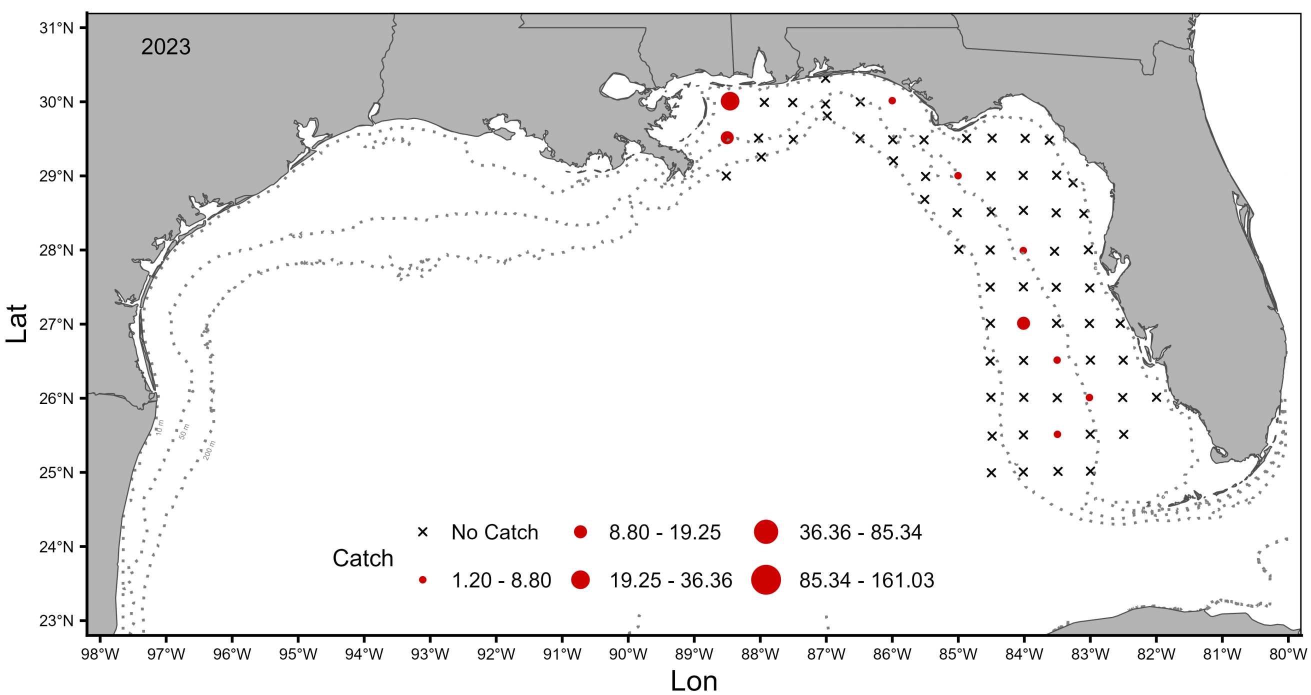
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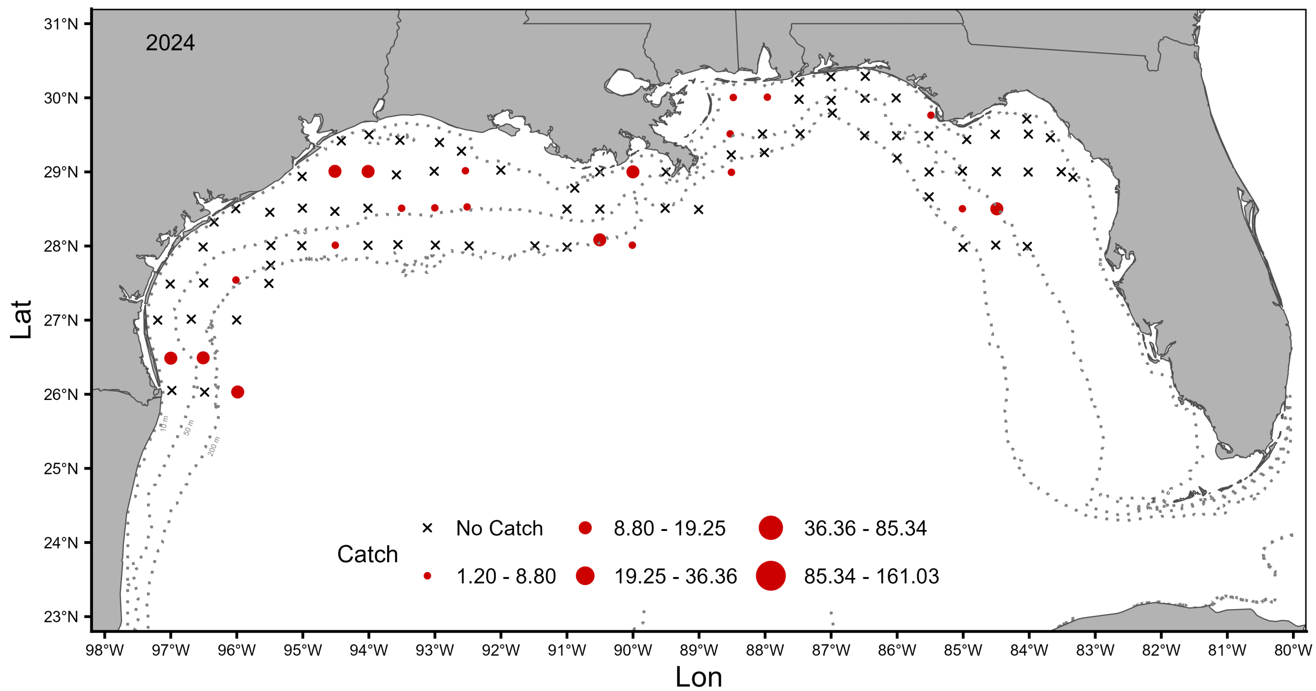

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