SEAMAP Trawl Shrimp Data and Index Estimation Work Group Report

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Executive Summary

The SEAMAP (Southeast Area Monitoring and Assessment Program) Trawl Shrimp Data and Index Estimation Work Group (SEAMAP WG) was tasked with providing best practice recommendations for the abundance indices calculated from the SEAMAP Summer Groundfish Survey and the SEAMAP Fall Groundfish Survey for brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and pink shrimp (*F. duorarum*) in the Gulf of Mexico (GOM). For the purpose of this report, the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey are collectively referred to as the SEAMAP Groundfish Survey when discussing certain topics. Both of these surveys are identical in survey design and methodology, however, are considered separate time series in regards to the calculation of abundance indices and other analyses.

The first task of the SEAMAP WG was to review the history of the SEAMAP Groundfish Survey including survey design changes, survey expansion, timing of the survey in relation to shrimp migration patterns, and data collection methods. Particular attention was given to the change in survey design and expansion of the survey that occurred mid-year in 2008, since this could potentially lead to changes in catchability. This also included a review of the current abundance indices and how they are incorporated into the current stock assessments for the three shrimp species. The assessment overview included scenarios for each species where the indices were kept as a single time series or a split time series when the survey design was changed in 2008/2009 for the Fall Survey and Summer Survey, respectively.

The second task of the SEAMAP WG was to verify that the SEAMAP Groundfish Survey is operating across the same temporal and spatial scales as the commercial shrimp fisheries. From the review of the spatiotemporal extents of the survey, in combination with data from the NOAA Fisheries Service's Electronic Logbook (ELB) Program, the SEAMAP WG concluded that the SEAMAP surveys align pretty well with where the fishery is operating in most areas of the GOM, in the summer and fall months. Although, there were two areas where there was some divergence between the commercial shrimp fishery and the SEAMAP Groundfish Survey, the outer West Florida Shelf and the nearshore waters of Texas and Louisiana. For the area along the outer West Florida Shelf, it was determined that the SEAMAP Groundfish Survey extends further offshore than the commercial shrimp fishery. However, given the SEAMAP Groundfish Survey is a general biological survey, and not intended to replicate shrimp fishing effort precisely, general working group discussions concluded that (under spatiotemporal considerations) it is acceptable for the survey to stretch beyond the realized, biological distribution of the Penaeid shrimp stocks in the Gulf. The second divergence along the nearshore waters of Texas and Louisiana is due to the limitations of the survey vessel, but the SEAMAP WG agreed that the SEAMAP Groundfish Survey does a sufficient job tracking the spatial distribution of the adult brown and white shrimp stocks throughout the GOM. Therefore, the

SEAMAP WG agreed that overall the SEAMAP Groundfish Survey is representative of the fishery given it reliably tracks changes in stock abundance at the population level.

The SEAMAP WG was also tasked with exploring alternative analytical methods to calculate the indices of abundance. Vector autoregressive spatio-temporal model (VAST) and empirical dynamic modeling (EDM) approaches were reviewed and examples of abundance indices were presented. Both the VAST and EDM methods showed promise, but additional research is still needed prior to the adoption of these alternative methodologies for future assessments.

The final task of the SEAMAP WG was to provide best practice recommendations for the use of the data from the SEAMAP Summer and Fall Groundfish Surveys. Based on the consensus of the SEAMAP WG, it was recommended that the delta-lognormal model continue to be used to construct the abundance indices for the stock assessment. Additionally, it was recommended that the abundance indices be split for brown shrimp and white shrimp when the SEAMAP Groundfish Survey design was changed in 2008/2009. The split is recommended to account for unquantified differences in catchability between the survey designs. The primary areas of concern focus on the shift from towing perpendicular across depth contours requiring variable tow times (10 to ~165 minutes) to towing in random directions for a fixed tow time of 30 minutes. Additionally, with the change in survey design, there was a significant switch in the proportional allocation of stations between the shallow (5 – 20 fathoms) and deeper (20 – 60 fathoms) depth zones. Finally, by splitting the indices, it also allows for the inclusion of additional data off Florida that became available due to the expansion of the survey that accompanied the survey design change.

The SEAMAP WG also recommended that abundance indices from both the SEAMAP Summer Groundfish Survey and the SEAMAP Fall Groundfish Survey be used for brown and white shrimp as different portions of the populations were being targeted during the individual surveys. Specifically for brown shrimp, the SEAMAP WG recommended that the full extent of the survey area be used for the indices from the old design (1987-2008, shrimp statistical zones 11 – 21) and a selected area for the indices from the new design (2009-present, shrimp statistical zones 8 – 21). For white shrimp, the recommendation was to use an area from shrimp statistical zones 11 – 21 for both the old and new design indices, although it will be limited to those stations at less than 25 fathoms. For pink shrimp, the recommendation was to use the data from the summer survey since it has more complete spatial coverage in the eastern GOM when compared to the fall survey and both surveys seem to sample the same portion of the population. The SEAMAP WG recommends the continued use of the current spatial extent from shrimp statistical zones 2 – 11 for index estimation.

1. Introduction

With ongoing updates to the three Penaeid shrimp stock assessment models, including moving all three models into a research track process in 2022, the first step in the assessment model review process was to better understand data inputs and assumptions of the three Gulf of Mexico (GOM) Penaeid shrimp stock assessment models [brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and pink shrimp (*F. duorarum*)]. The Southeast Area Monitoring and Assessment Program (SEAMAP) Trawl Shrimp Data and Index Estimation Working Group (WG), here after referred to as the SEAMAP WG, was formed (as one of five special, technical shrimp data and estimation working groups) in 2020 with both internal (SEFSC) and external technical experts [e.g., Gulf of Mexico Fishery Management Council (GMFMC) Scientific and Statistical Committee (SSC) members and shrimp industry representatives].

1.1. Workgroup Meetings

The SEAMAP WG met during a series of seven webinars from September 2020 – March 2021 to examine the SEAMAP Groundfish Survey data and the associated relative abundance indices for brown, white, and pink shrimp in the northern GOM. The agendas for each webinar can be found in Appendix 1, while summaries of the topics discussed during the webinars can be found in Appendix 2.

1.2. Statement of Work

Listed below is the Statement of Work for the SEAMAP WG as approved by the GMFMC.

1. Review history of SEAMAP Groundfish Trawl Survey including survey design changes, survey expansion, timing of the survey in relation to shrimp migration patterns, and data collection methods.
2. Verify SEAMAP Groundfish Trawl Survey is operating across the same temporal and spatial scales as the commercial fisheries (brown, pink and white shrimp), to justify indices are representative of the fishery (e.g. GIS map of cELB data with overlaid SEAMAP samples locations).
3. Review current shrimp abundance indices including methodology, data exclusions, and survey area utilized.
4. Investigate alternative analytical methods (e.g. VAST, EDM) to generate shrimp abundance indices from SEAMAP Groundfish Trawl Survey data.
5. Provide best practice recommendations for developing shrimp abundance indices from the SEAMAP Groundfish Trawl Survey data and the use of fishery CPUE data.

1.3. Workgroup Members

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NMFS/SEFSC - National Marine Fisheries Service – Southeast Fisheries Science Center
NMFS/SWFSC - National Marine Fisheries Service – Southwest Fisheries Science Center
GMFMC SSC - Gulf of Mexico Fishery Management Council – Scientific and Statistical Committee
GSMFC - Gulf States Marine Fisheries Commission
GMFMC - Gulf of Mexico Fishery Management Council

2. SEAMAP Groundfish Survey

The Southeast Area Monitoring and Assessment Program is a collaborative effort between federal, state and university programs, designed to collect, manage, and distribute fishery independent data throughout the region. In the GOM, SEAMAP resource surveys include the Fall Shrimp/Groundfish Survey (, Spring Plankton Survey, Reef Fish Survey, Summer Shrimp/Groundfish Survey, Fall Plankton Survey and other plankton and environmental data surveys. Collectively, these surveys contribute to numerous stock assessments within the southeast region. For the purposes of this report, the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey are collectively referred to as the SEAMAP Groundfish Survey when discussing certain topics. Both of these surveys are identical in survey design and methodology, however, are considered separate time series in regards to the calculation of abundance indices and other analyses.

2.1. Survey History and Methodology

Standardized shrimp/groundfish (bottom trawling) surveys have been conducted annually in the northern GOM by the National Marine Fisheries Service (NMFS), SEFSC, Mississippi Laboratories (MSLABS) and/or SEAMAP since 1972. Data from these fishery-independent surveys are used to calculate indices of relative abundance and inform estimates of bycatch in the shrimp fishery for stock assessments of multiple species in the GOM. Although these data are often referred to as SEAMAP trawl data, the time series is a composite of the NMFS Shrimp/Bottomfish Trawl Survey (1972 – 1984), the SEAMAP Summer Groundfish Survey (1982 – present) and the SEAMAP Fall Groundfish Survey (1985 – present), with the common objective of quantifying the seasonal, spatial and interannual variations of groundfish resources.

The NMFS Shrimp/Bottomfish Trawl Survey was conducted from 1972 to 1984 with primary coverage in the north-central GOM between 88° W to 91°30′ W, with some additional sampling to the east and west (Figure 1). The survey was conducted mostly during October and November with up to three 10-minute tows at stations randomly selected from a block-grid system. Sampling occurred between 5 and 50 fathoms.

While the NMFS Shrimp/Bottomfish Trawl Survey was being conducted in the fall, a summer (primarily sampling during June and July) groundfish survey was added in 1982 under SEAMAP to address the effectiveness of the Texas Shrimp Season Closure. Sampling during the summer survey was conducted from sunset to sunrise using a stratified random design with strata defined by area and depth zone. This survey covered an area between Brownsville, TX and Mobile Bay, AL (Figure 2). It should be noted that shrimp statistical zone (SSZ) 10 was dropped from the survey universe in 1989 because of the increased number of hangs in the area as Alabama expanded their artificial reef permitting area.

The NMFS Shrimp/Bottomfish Trawl Survey was brought under the SEAMAP umbrella in 1985. The survey retained the block-grid survey design, but expanded the depth coverage out to 100 fathoms. Sampling intensity was reduced to a single 15-minute tow per grid to accommodate a westward expansion to include the Texas shelf (Figure 3). Sampling occurred during day and night. Even though this is officially a SEAMAP survey, it is typically treated as part of the NMFS Shrimp/Bottomfish Trawl Survey due to the use of the block-grid design. For a full description of all the surveys, additional background and time series rationale, see Nichols (2004). Beginning in 1987, the SEAMAP summer and fall groundfish surveys adopted a unified sample design.

Under the unified SEAMAP design, strata were still defined by area and depth zone, but with an additional stratum based on time of day (TOD) (day and night) incorporated into the design. Tow time was variable during the survey, ranging from 10 (min) to 55 (max) minutes, and was dependent on the time required to complete tow through a particular depth zone (e.g., 5 – 6 fathoms, Table 1). If the depth zone could not be covered in 55 minutes, multiple consecutive tows were made until the depth range constituting the strata was covered. The 55-minute limit for a single tow was mostly due to concerns over sea turtle bycatch.

Major changes in the sample design occurred between the 2008 summer and fall surveys. The TOD stratification was dropped, tow time was standardized to 30 minutes, and sampling effort allocated was proportional to the spatial area represented by each SSZ and depth zone combination; minor changes to depth zones were made during subsequent years (Table 1). The current design now utilizes two depth zones (5 – 20 fathoms and 20 – 60 fathoms), which have been consistent since 2013. With the shift from defined depth zones to generalized areas for station distribution there was a shift in the proportion of stations sampled (Figure 4 and Table 1). While the change in sample design occurred in 2008, it is important to note that some state partners (LA, MS, and AL) did not adopt the new sampling design until 2010. However, this only accounted for between 10-20% of stations sampled each season between 2008 and 2009.

The core spatial coverage of the SEAMAP Groundfish Survey initially ranged from Brownsville, TX to Mobile Bay, AL with sampling conducted by NMFS, Louisiana, Mississippi and Alabama state partners (Figure 3). In 2008, SEAMAP received supplemental funding that provided the opportunity to conduct experimental bottom trawl surveys on the West Florida Shelf. Based on the success of the experimental trawl surveys by the state of Florida, the surveys were expanded in 2010 to include the area from Mobile Bay, AL to Key West, FL.

In 2017, there was a change to the SEAMAP survey area. While the spatial extent of the survey remained unchanged (statistical zones 2 – 21), untrawlable areas within the statistical zones were removed and the area of each statistical zone/depth zone were recalculated (Figure 5). These changes were made to better reflect the available trawlable habitat within the survey area and to help avoid obstructions, which damage the gear, as well as sensitive live bottom areas.

Although, the NMFS Shrimp/Bottomfish and SEAMAP trawl surveys have utilized various survey designs over time, all programs have and continue to utilize the same trawl gear configuration. The survey gear consists of a 12.8-m (42 ft) semi-balloon shrimp trawl with a 12.8-m headrope and wooden doors that measure 2.4 m x 1 m. The trawls are towed at speeds between 2.5 and 3 knots. The wings, intermediate area, and codend of the net are composed of mesh sizes of 5.08 cm, 3.81 cm, and 4.13 cm, respectively. The trawl also does not contain a turtle excluder device (TED) or any bycatch reduction devices (BRD).

At the end of each tow, the catch was emptied onto the deck, where a total weight was taken. All commercial shrimp species (brown, pink and white shrimp) were removed from the catch and then counted and weighed. During the summer survey, up until 2018, 200 individual shrimp of each species were then measured (total length in mm), sexed, and weighed. Under the current protocols, up to 50 individual shrimp are measured, sexed, and weighed. This change was made in an effort to increase efficiency and allow for the completion of additional stations. Analysis showed no differences in the length distribution collected when measuring 50 versus 200 individuals. During the fall survey, up to 20 individual shrimp of each species were measured, with every fifth individual being weighed and sexed.

3. Current State of SEAMAP Shrimp Indices

3.1. Data

A total of 16,092 stations were sampled from 1987- 2018 with 8,350 and 7,742 stations (Tables 2 and 3) sampled during the summer and fall surveys, respectively (Figures 6 and 7). Trawl data from MSLABS were obtained from the MSLABS database and combined with data from the GSMFC database, which contains data collected by the Alabama, Florida, Louisiana, Mississippi and Texas SEAMAP state partners.

Data were filtered by several factors:

(1) No problems with tow (i.e., net torn, doors crossed, etc.)
(2) Depths between 5 and 60 fathoms
(3) Within SSZ 2 – 21

(4) Sampled with a 40 ft. shrimp trawl (Texas uses a 20 ft. shrimp trawl and data are not included in the analysis)
(5) Stations sampled between 1987 and 2018.

Data from the early NMFS Shrimp/Bottomfish Trawl Survey (1972-1981) and the early years of the SEAMAP survey (1982 -1986) were excluded from the analysis because of the limited spatial coverage and differences in the survey designs.

3.1.1. Temporal Scale

The general timing of the SEAMAP Summer and Fall Groundfish Surveys has remained largely unchanged during the period of 1987 – 2018. Typically, the summer survey occurs during the months of June and July (Figure 8), while the fall survey occurs during the months of October and November (Figure 9).

The timing of the summer survey, with regards to the opening of the Texas shrimp season (usually on or around July 15th), is important because the original intent of the survey was to sample the waters off of Texas prior to the start of commercial shrimping. In almost all years, the stations off Texas are completed prior to the opening of shrimp season (Figure 10). However, sampling occurs earlier in June during the later years of the survey compared to the 1980s and 1990s. In addition, the sampling in Texas waters is completed earlier (mid-June vs. July) in the later years due to the change in survey methodology, in particular, the expansion of spatial coverage to include Florida. Similarly, sampling coverage during the fall survey is typically completed by early November in the western GOM due to expansion of the survey into the eastern GOM.

For brown and white shrimp, the full survey time frame (1987 – 2018) was used in the construction of the abundance indices. The survey time frame for pink shrimp is limited to only years after the expansion of the survey into Florida waters in 2008, because pink shrimp mostly occurred in the eastern GOM, particularity in Florida waters (SSZ 2 - 8), and were in very low abundance in the western GOM. If the indices were calculated using the full time series, they would be limited to only the area off MS/AL and would not be comparable to any indices using the newer survey design that included the expanded survey coverage.

3.1.2. Spatial Scale

While the SEAMAP Groundfish Survey currently covers the area from Brownsville, TX to the Florida Keys, FL (Figure 5), spatial subsets of the sampling data are used when constructing the relative abundance indices for the three commercial shrimp species. For brown shrimp, indices constructed using the old survey data (1987 – 2008 for the summer survey or 1987 – 2007 for the fall survey) included the full time series from 1987 – 2018 and spatial extent from Brownsville, TX to Mobile Bay, AL (SSZ 11-21; Figure 11A). When using only the new survey data (2009 – 2018 for the summer survey and 2008 – 2018 for the fall survey), the data for brown shrimp are limited to the area from Brownsville, TX to Cape San Blas, FL (SSZ 8 – 21; Figure 11B). The addition of the areas off FL was done to match the current spatial extents of the fishery dependent data that are used in the stock assessment. It should be noted that the original intent was to include data from statistical zones 7 – 21 for the brown and white shrimp indices. However, this was not possible due to the extremely low or zero catches in statistical zone 7, which prevented model convergence. All the indices use the full depth range of the survey from 9 – 110 m.

White shrimp indices based on old survey data (1987 to 2008) data and the full time series (1987 to 2018) are limited to the area from Brownsville, TX to Mobile Bay, AL, similar to brown shrimp (SSZ 11-21; Figure 12A). However, the summer data are further limited to stations sampled in less than 25 fathoms because of the extremely low occurrence of white shrimp beyond this depth, which causes issues with model convergence. However, in the fall the full depth range of the survey is used (Figure 12B) because of the higher occurrence of more white shrimp in deeper offshore waters. For the indices using the newer data (2008 – 2018), the original intent was similar to brown shrimp, which was to include data from statistical zone 7, but the extremely low or zero catches in statistical zones 7 to 10, prevented their inclusion in the final model.

For pink shrimp, the data used for index construction extended from the mouth of the Mississippi River to the Florida Keys from 9 - 110 m (Figure 13). This limitation was originally implemented because of the predominance of the pink shrimp fishery in this area of the GOM.

3.1.3. Comparison with Commercial Fisheries

The starting location of SEAMAP Groundfish Survey and commercial shrimp fishery tows were compared in order to verify that the spatiotemporal distribution of the SEAMAP Groundfish Survey was representative of the Penaeid shrimp fishery (Figure 14 and 15). The commercial shrimp fishery data was obtained from NOAA Fisheries Service's Electronic Logbook (ELB) Program. The electronic logbook is a simple time-stamped global positioning system (GPS) unit that records and stores a vessel's location at 10-minute time intervals ("points"). An algorithm is then used to compute vessel speed between points and activity based on that speed. From 2013 through 2020, ELB data was retrieved remotely through transmission from a cellular connection to the device when the vessel was in (non-roaming) cellular range. Since 2013, a total of 605 federally permitted shrimp vessels have been selected by NOAA Fisheries Service to participate in the cellular ELB (cELB) program. As of January 01, 2021, there were 1,385 GOM shrimp permit holders. As of December 2020, data was being received from 397 of the ELB units.

In order to visualize overlapping point data (tow start locations), the data were summarized by a hexagonal grid. Each hexagon has an area of 259.8 sq. km. Each side of the hexagon is 10 km—based on the average minimum tow distance, as calculated from GOM Penaeid shrimp fishery observer data. In comparison, the average distance between the start and end of a tow for the SEAMAP Groundfish Survey is approximately 3 km under the new sample design. The number of tows and towing times were summarized for each cell in the grid, though the figures only show presence or absence of a tow in a cell in order to better facilitate the overlay of the data sets.

Comparison maps (Figures 14 and 15) were created with the commercial shrimp ELB data using the months that correspond with the SEAMAP Summer and Fall Groundfish Surveys (June- July and October-November, respectively), for the pre- and post-SEAMAP survey design change years (an explanation of the survey design changes and the associated years are provided in Section 2.1).

Figures 14 and 15 were used to guide working group considerations, as to whether the survey is operating along the same spatial and temporal scales as the fishery. When the survey tow start locations overlap with the shrimp fishery (ELB) tow start locations the coloring in the figures appears the darkest (Figure 14 and 15). Therefore, to assess acceptable ranges of spatial overlap of the shrimp fishery to the SEAMAP survey, the working group reviewed the dark shaded areas along statistical zones 1-21 in the GOM (Figures 14 and 15). To assess temporal overlap of the survey and the fishery, the SEAMAP WG considered tows occurring in the summer (Figure 14) and in the fall months (Figure 15). Overall, the working group agreed that the SEAMAP survey aligns pretty well with where the fishery is operating in most areas of the Gulf, in the summer and fall months. However, two distinct divergences stood out (Figures 14 and 15).

The first divergence in spatiotemporal overlap is along the western edge of the west Florida shelf (WFL), where the SEAMAP Groundfish Survey extends more westward along the shelf edge. Given the SEAMAP Groundfish Survey is a general biological survey, and not intended to replicate shrimp fishing effort precisely, general working group discussions concluded that (under spatiotemporal considerations) it is acceptable for the survey to stretch beyond the realized, biological distribution of the Penaeid shrimp stocks in the Gulf. In this situation, it would allow for flexibility of SEAMAP derived abundance indices to capture species range shifts.

The second divergence in spatial overlap between the shrimp fishery and the SEAMAP Groundfish Survey is inshore waters off Louisiana and Texas (Figure 14 and 15), as SEAMAP is unable to trawl in these shallower, inshore waters where the inshore shrimp fishery (smaller vessels) operates. Although the SEAMAP Groundfish Survey is not picking up the young of the year juveniles in the inshore Texas and Louisiana waters, the SEAMAP WG agreed that the SEAMAP Groundfish Survey does a sufficient job of tracking the spatial distribution of the adult brown and white shrimp stocks throughout the GOM. Therefore, the working group participants agreed that overall the SEAMAP Groundfish Survey is representative of the fishery given it reliably tracks changes in stock abundance at the population level.

3.2. Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for brown, pink and white shrimp (Pennington, 1983; Bradu and Mundlak, 1970). The main advantage of using this method is to allow 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 generalized linear models: a binomial (logistic) model that describes proportion of positive abundance values (i.e., presence/absence), and a lognormal model that 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 catch per unit of effort (CPUE) 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) $p = \dfrac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}}$,

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 as least-squares means 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 CPUE given presence. The two estimators are derived independently and have been shown not to covary for a given year (Mary Christman, MCC Statistical Consulting LLC, unpublished).

The submodels of the delta-lognormal model were built using a backward selection procedure based on Type III analyses with an inclusion level of significance of $\alpha = 0.05$. Binomial submodel performance was evaluated using Akaike information criterion (AIC), while the performance of the lognormal submodel was evaluated based on analyses of residual scatter and quantile-quantile (QQ) plots, in addition to AIC. Variables that could be included in the submodels were:

Submodel Variables (Brown and White Shrimp Indices for 1987 – 2018)

Year: 1987 – 2018
Depth Zone: 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-60 fm
SSZ: 11, 13, 14, 15, 16, 17, 18, 19, 20, 21
Time of Day: Day, Night
Survey: Old Design (1987-2008 (summer)), New Design (2008 (fall) - 2018)

Submodel Variables (Brown and White Shrimp Summer Indices for 1987 – 2008)

Year: 1987 – 2008
Depth Zone: 5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-22, 22-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-60 fm
Combined SSZ: 10-11, 13-15, 16-17, 18-19, 20-21
Time of Day: Day, Night

Submodel Variables (Brown and White Shrimp Summer Indices for 2009 – 2018)

Year: 2009 – 2018
Depth: 5-60 fm (continuous)
SSZ: 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21
Time of Day: Day, Night

Submodel Variables (Brown and White Shrimp Fall Indices for 1987 – 2007)

Year: 1987 – 2007
Depth Zone: 5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-22, 22-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-60 fm
Combined SSZ: 10-11, 13-15, 16-17, 18-19, 20-21
Time of Day: Day, Night

Submodel Variables (Brown and White Shrimp Fall Indices for 2008 – 2018)

Year: 2008 – 2018
Depth: 5 – 60 fm (continuous)
SSZ: 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21
Time of Day: Day, Night

Submodel Variables (Pink Shrimp Indices for 2008 – 2018)

Year: 2008 – 2018
Depth: 5 – 60 fm (continuous)
SSZ: 2, 3, 4, 5, 6. 7, 8, 9, 10, 11
Time of Day: Day, Night

3.3. Indices

3.3.1. Brown Shrimp

The distribution and abundance of brown shrimp captured during the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey are presented in Figures 16 and 17, respectively. The nominal CPUE for brown shrimp is presented in Figure 18A for the summer survey and Figure 18B for the fall survey. Brown shrimp length frequency distribution from the summer and fall surveys are presented Figures 19 and 20.

The final delta-lognormal SEAMAP Summer Groundfish Survey – Full Time Series index of brown shrimp abundance retained year, TOD, SSZ, and depth zone in the binomial submodel, while year, TOD, SSZ, depth zone, and survey were retained in the lognormal submodel. Annual abundance indices are presented in Table 4 and Figure 21A.

The final delta-lognormal SEAMAP Fall Groundfish Survey – Full Time Series index of brown shrimp abundance retained year, TOD, SSZ, and depth zone in the binomial submodel, while year, TOD, SSZ, depth zone, and survey were retained in the lognormal submodel. Annual abundance indices are presented in Table 5 and Figure 21B.

The final delta-lognormal SEAMAP Summer Groundfish Survey – 1987-2008 index of brown shrimp abundance retained year, TOD, combined SSZ, and depth zone in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 6 and Figure 21C.

The final delta-lognormal SEAMAP Fall Groundfish Survey – 1987-2007 index of brown shrimp abundance retained year, TOD, combined SSZ, and depth zone in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 7 and Figure 22A.

The final delta-lognormal SEAMAP Summer Groundfish Survey – 2009-2018 index of brown shrimp abundance retained year, TOD, SSZ, and depth in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 8 and Figure 22B.

The final delta-lognormal SEAMAP Fall Groundfish Survey – 2008-2018 index of brown shrimp abundance retained year, TOD, SSZ, and depth in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 9 and Figure 22C.

3.3.2. White Shrimp

The distribution and abundance of white shrimp captured during the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey are presented in Figures 23 and 24, respectively. The nominal CPUE for white shrimp is presented in Figure 25A for the summer survey and Figure 25B for the fall survey. White shrimp length frequency distribution from the summer and fall surveys are presented Figures 26 and 27.

For the summer survey indices, we decided to limit the model to all stations sampled at depths less than 25 fm. This was done because of the lack of consistent positive catches past 25 fm (45 white shrimp captured from 1987 – 2018). In the fall survey indices, the data were only limited by depth in the fall (2008-2018) survey because of issues with the model, i.e., large extra dispersion scale indicating a poor fit in the proportion positive model. For the other two fall indices, the full dataset was used.

Data for white shrimp in the summer survey were limited to all stations less than 25 fathoms. The final delta-lognormal SEAMAP Summer Groundfish Survey – Full Time Series index of white shrimp abundance retained year, TOD, SSZ, depth zone, and survey in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 10 and Figure 28A.

The final delta-lognormal SEAMAP Fall Groundfish Survey – Full Time Series index of white shrimp abundance retained year, TOD, SSZ, depth zone, and survey in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 11 and Figure 28B.

The final delta-lognormal SEAMAP Summer Groundfish Survey – 1987-2008 index of white shrimp abundance retained year, TOD, combined SSZ, and depth zone in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 12 and Figure 28C.

The final delta-lognormal SEAMAP Fall Groundfish Survey – 1987-2007 index of white shrimp abundance retained year, TOD, combined SSZ, and depth zone in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 13 and Figure 29A.

The final delta-lognormal SEAMAP Summer Groundfish Survey – 2009-2018 index of white shrimp abundance retained year and depth in the binomial submodel, while year, TOD, SSZ, and depth were retained in the lognormal submodel. Annual abundance indices are presented in Table 14 and Figure 29B.

The final delta-lognormal SEAMAP Fall Groundfish Survey – 2008-2018 index of white shrimp abundance retained year, TOD, SSZ, and depth in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 15 and Figure 29C.

3.3.3. Pink Shrimp

The distribution and abundance of pink shrimp captured during the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey are presented in Figures 30 and 31, respectively. The nominal CPUE for pink shrimp is presented in Figure 32A for the summer survey and Figure 32B for the fall survey. Pink shrimp length frequency distribution from the summer and fall surveys are presented Figure 33.

The final delta-lognormal SEAMAP Summer Groundfish Survey – 2009-2018 index of pink shrimp abundance retained year, TOD, SSZ, and depth in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 16 and Figure 34A.

The final delta-lognormal SEAMAP Fall Groundfish Survey – 2008-2018 index of pink shrimp abundance retained year, TOD, SSZ, and depth in both the binomial and lognormal submodels. Annual abundance indices are presented in Table 17 and Figure 34B.

3.4. Use in the stock assessment

In contrast to fishery dependent data (collected from the commercial fishery), the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey were developed to provide SEFSC stock assessments with long-term information on trends in abundance that is based on consistent sampling methodology. Although aspects of the sampling methods for the SEAMAP survey did change in 2008, the methods have been consistent from 2008 to present (and from 1987-2008). Further, since SEAMAP surveys are not influenced by fishery management (e.g., area closures or gear restrictions) and/or economics (e.g., changes in market price that lead to reductions in fishing effort), this data offers a less biased indicator of changes in stock abundance over time.

Historically, the brown shrimp, pink shrimp, and white shrimp stock assessment models have incorporated both the SEAMAP summer and fall indices (1987 to present) as separate but continuous indices (e.g., Figure 35), for both the summer and fall. However, recent analysis suggests that it may be more appropriate to split the summer and fall indices for all three shrimp species (brown shrimp, pink shrimp, and white shrimp) into a pre- and post-method change index (e.g., 1987-2007 & 2008-present eras) in order to account for substantial changes in survey design. By splitting the indices into pre- and post-method change eras, the trends in abundance over time differ slightly from the continuous time series version of the indices (e.g., Figure 36). However, the shrimp assessment models are conducted using the stock synthesis modeling software, which can readily support split indices. Future analysis (i.e., during future stock assessment model review workshops) should be done to understand the role of the summer and fall indices in capturing recruitment timing and/or seasonal variability in spatial range among all three GOM penaeid shrimp stocks.

4. Alternate Analytical Models

4.1. Vector Autoregressive Spatio-Temporal (VAST) Model

4.1.1. Background

Indices of abundance from fishery dependent and independent data utilizing spatio-temporal models for standardization are increasingly being adopted as inputs for stock assessment (Thorson, 2019). Potential advantages of these indices include: (1) improved prediction for data poor areas, (2) capacity to weight density/abundance by area, (3) the capacity to include estimation of age/length compositions and to weight predictions by catch to inform the composition of removals, (4) estimation of range expansion/contraction and distribution shifts, and (5) ability to combine data from multiple data sources/surveys (Thorson et al., 2020). Additionally, the inclusion of spatial and/or spatio-temporal effects may improve estimates by approximating unmeasured effects and processes inherent within survey data (Thorson and Ward, 2013: Shelton et al., 2014: Thorson, 2019). The generation of indices incorporating spatio-temporal effects has been greatly facilitated by the development of the vector autoregressive spatio-temporal model (VAST) (Thorson, 2019; Thorson and Barnett, 2017). The model incorporates spatio-temporal variation as Gaussian Markov random fields (Thorson et al., 2014) which implies that correlation in spatial variation decays as a function of distance (Tobler, 1970). VAST models are implemented via the package VAST (https://github.com/James-Thorson-NOAA/VAST) within the R statistical environment (R Core Team 2020).

The SEFSC MSLABS currently utilizes a delta-generalized linear modeling (delta-lognormal) approach to estimate indices of shrimp abundance from SEAMAP Groundfish Survey as described in Section 3.2. This approach is used to generate fourteen indices of abundance for 3 species of shrimp, from two groundfish surveys (summer and fall) and two primary sampling designs (old and new) or a combination of both (Pollack et al. 2018).

Like many survey programs, sampling effort during SEAMAP Groundfish Survey has been impacted due to severe weather, vessel breakdowns and/or time constraints, resulting in limited or lack of coverage for specific strata during a given survey. Due to the separation of data into the binomial and positive abundance components, the current delta-lognormal model does not account for missing observations nor the spatial weighting of strata within a given year. Instead, changes in catch by spatial area is approximated by modeling catch within 5 statistical zone groups and/or within 23 depth zones when analyzing data from the old sampling design; within 11 to 22 individual SSZ and/or across depth (continuous) when analyzing data from the new sampling design: and within 11 SSZ and/or within 9 depth zones when analyzing combined data from both survey designs.

Unlike our current model, VAST predicts variation in abundance across space, time and categories (e.g., species, size or age classes), and then predicts total abundance across a user-specified spatial domain by summing abundance estimates across the spatial domain while weighting abundance estimates by the area associated with each estimate (Thorson, 2019). The resulting total abundance estimate is then used as an index of abundance. In addition to estimates of total abundance, the VAST model is also capable of deriving estimates of the centroid of spatial abundance (center of gravity, COG) which examines spatial shifts in abundance (Thorson et al. 2016a), and effective area occupied (EAO) which examines range expansion based on the area required to contain the population at average abundance (Thorson et al. 2016b).

Given the VAST model structure's ability to generate indices of abundance that account for spatial weighting and provide predictions for data poor areas, we explored whether indices of abundance generated from VAST spatial delta-lognormal mixed models yield more precise indices of abundance when compared to our current delta-lognormal approach. Shrimp abundance from SEAMAP Summer Groundfish Survey was used as a case study. Models were developed for brown and white shrimp collected under SEAMAP old (1987 to 2008) and new (2009 to 2018) survey designs and pink shrimp collected under the new (2008 to 2018) survey design. Brown and white shrimp indices based on a combination of the new and old sampling design were not examined, as ongoing discussion regarding differences in catchability between the two survey designs suggests that shrimp indices should be based on the individual sampling designs until catchability is further evaluated.

4.1.2. Methodology

Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST DLN) and VAST spatial Delta-Lognormal (VAST S-T) standardized indices of abundance were generated for each species and time series from SEAMAP Summer Groundfish Survey. DLN indices of abundance were generated using methods outlined in Pollack et al. (2018). VAST DLN and VAST S-T models were implemented utilizing the package VAST within the R statistical environment (R Core Team, 2020). Spatial variation for the VAST DLN and VAST S-T models was approximated at 100 knots (spatial locations) using a stochastic partial differential approach (Lindgren et al., 2011). Spatial correlation among locations in VAST S-T models were configured to allow for geometric anisotropy. Spatial and spatio-temporal effects in VAST are estimated separately for the binomial and lognormal submodels. VAST S-T models were initially fit with both spatial and spatio-temporal components for each submodel enabled. In cases where model diagnostics indicated issues with spatial or spatio-temporal estimates hitting bounds or convergence issues, these components were turned off and the model refit. VAST DLN indices were intended to serve as a baseline for comparison between the current DLN approach and the VAST model structure and were run without geometric anisotropy or spatial and spatio-temporal components enabled in either submodel.

The submodels of the DLN approach were built using a backward selection procedure based on type 3 analyses with an inclusion level of significance of $\alpha = 0.05$. Effects (covariates) that were considered for in the submodels were the same as those listed above in Section 3.2 for the delta-lognormal model.

Once the final set of submodel covariates were determined for the DLN approach, the retained covariates were held constant between the DLN and VAST DLN submodels. The user defined spatial domain for each VAST DLN and VAST S-T models was set to match the spatial extent of the statistical zones and depth range included in their analogous DLN model. VAST model outputs do not provide p-values to examine significance of covariate terms. We approximated the significance of covariates from VAST models by examining whether their parameter estimates plus or minus two standard errors overlapped with zero. Factor effects were considered significant if any level within that factor did not show an overlap with zero. This was done as a check for similarity between the DLN and VAST DLN models. Residual plots for VAST DLN and VAST S-T models were also examined to ensure that extreme deviations from the delta-lognormal distribution did not occur when models were translated to the VAST modeling framework.

Annual index values from each model were standardized to a mean of one to account for differences in scaling between the current DLN and VAST models. Plots were then generated to examine annual trends and differences in coefficient of variation of the mean (CV, standard error / means) among the three models for each species and time series.

4.1.3. Results

Brown Shrimp Old Design 1987 to 2008 from 5 to 60 fm

The DLN modeling approach found TOD, combined SSZ and depth zone to have significant effects on brown shrimp catch rates for both the binomial and lognormal submodels. The covariates remained significant in each submodel when translated to the VAST DLN model. The VAST S-T model was successfully fitted with spatial and spatio-temporal terms estimated in both the binomial and lognormal submodels. Time of day was found to have a significant effect on catch rates in both VAST S-T submodels. No significant deviation was detected from the lognormal distribution for the VAST DLN model, but deviation from the distribution was detected for the VAST S-T model. The trends in standardized annual abundance were nearly identical among all three models (Figure 37A). Average annual CV was highest for the VAST

DLN (19.2%) model and lowest for the DLN (12.5%) model, but average annual CV was much closer between the DLN (12.5 %) and VAST S-T (13.8%) models (Figure 37B).

Brown Shrimp New Design 1987 to 2008 from 5 to 60 fm

The DLN modeling approach found TOD, SSZ, and depth to have significant effects on brown shrimp catch rates for both the binomial and lognormal submodels. The covariates remained significant in each submodel when translated to the VAST DLN model. The VAST S-T model was successfully fitted with spatial and spatio-temporal terms estimated in both the binomial and lognormal submodels. Time of day was found to have a significant effect on catch rates in both VAST S-T submodels. No significant deviation was detected from the lognormal distribution for the VAST DLN model, but slight deviation from the distribution was detected for the VAST S-T model. The trends in standardized annual abundance were identical between the DLN and VAST DLN models, with the overall trend from the VAST S-T very similar to the other models (Figure 38A). Average annual CV was highest for the VAST DLN (20.6%) model and lowest for the DLN (13.6%), but average annual CV was very similar between the DLN (13.6%) and VAST S-T (14.0%) models (Figure 38B).

White Shrimp Old Design 1987 to 2008 from 5 to 25 fm

The DLN modeling approach found TOD, combined SSZ, and depth zone to have significant effects on brown shrimp catch rates for both the binomial and lognormal submodels. The covariates remained significant in each submodel when translated to the VAST DLN model. The VAST S-T model was successfully fitted with spatial and spatio-temporal terms estimated in both the binomial and lognormal submodels. Time of day was found to have a significant effect on catch rates in both VAST S-T submodels. No significant deviation was detected from the lognormal distribution for both the VAST DLN and VAST S-T models. The trends in standardized annual abundance were nearly identical among all three models (Figure 39A). Average annual CV was highest for the VAST DLN (55.8%) model and lowest for the DLN (28.6%) model, but average annual CV was similar between the DLN (28.6%) and VAST S-T (29.4%) models (Figure 39B).

White Shrimp New Design 1987 to 2008 from 5 to 25 fm

The DLN modeling approach found TOD, combined SSZ, and depth have significant effects on brown shrimp catch rates for both the binomial and lognormal submodels. The covariates remained significant in each submodel when translated to the VAST DLN model. The VAST S-T model was successfully fitted with spatial and spatio-temporal terms estimated in both the binomial and lognormal submodels. Time of day was found to have a significant effect on catch rates in both VAST S-T submodels. No significant deviation was detected from the lognormal distribution for both the VAST DLN and VAST S-T models. The trends in standardized annual abundance were very similar among all three models (Figure 40A). Average annual CV was highest for the VAST DLN (53.1 %) model and lowest for the DLN (25.2%), but average annual CV was similar between the DLN (25.2%) and VAST S-T (26.0%) models (Figure 40B).

Pink Shrimp New Design 2008 to 2018 from 5 to 60 fm

The DLN modeling approach found TOD, SSZ, and depth to have significant effects on pink shrimp catch rates for both the binomial and lognormal submodels. The covariates remained significant in each submodel when translated to the VAST DLN model. The VAST S-T model was successfully fitted with spatial terms estimated in both the binomial and lognormal submodels and a spatio-temporal term in the lognormal submodel. However, the spatio-temporal term in the binomial submodel reached a zero boundary and the initial model was rerun without this parameter in the binomial model. Time of day was found to have a significant effect on catch rates in both VAST S-T submodels. No significant deviation was detected from the lognormal distribution for the VAST DLN and VAST S-T model. The trends in standardized annual abundance were similar among all three models (Figure 41A). Average annual CV was highest for the VAST DLN (36.7%) model and lowest for the VAST S-T (30.7%) with average annual CV of the VAST S-T (30.7%) approximately 2.6% lower than the DLN (33.3%) model (Figure 41B). However, when examining the time period from 2010 to 2018, average annual CV was considerably lower for the VAST S-T (28.3%) model than the DLN (33.1%) model.

4.1.4. Discussion

Overall, annual trends in the abundance of brown, white and pink shrimp based on VAST S-T models were nearly identical to those based on MSLABS' current DLN methodology. The average precision (CV) of the brown and white shrimp indices based on VAST S-T and DLN methods were also comparable, with average CVs over their respective time series typically within 0.4 to 1.3 percent of one another. In contrast, the average annual CV for pink shrimp in the eastern GOM was consistently lower by an average of 4.8% for the VAST S-T model than the DLN model for 9 out of 11 years of the time series.

Relative to the VAST S-T model, our initial results indicate that the current DLN methodology, which utilizes SSZ/combined SSZ and depth zones/depth to account for spatial effects, appears to capture average difference in abundance across the survey area reasonably well. However, the current DLN methodology still lacks the capability to allow for spatial weighting and to improve prediction for data poor strata/areas due to reduced sampling effort or missing samples. Given the nearly identical trends and the similar or increased precision associated with shrimp indices produced by the VAST S-T models, we suggest moving forward with the further development of VAST spatio-temporal indices of shrimp abundance, and outline specific areas of research in Section 6.

4.2. Empirical Dynamic Modeling (EDM)

4.2.1. Background

Empirical dynamic modeling (EDM) is a set of tools for 'equation-free' inference and prediction in incompletely observed nonlinear dynamical systems (Munch et al. 2020). EDM starts with the premise that the complete dynamics can be described in discrete time as

$$y_{t+1}=F(y_t)$$

where the state vector includes all relevant elements of the ecosystem (e.g., abundances of all interacting species and relevant environmental drivers). EDM is 'equation-free' as it attempts to estimate F from the observed time series using one of several nonparametric methods for function approximation, e.g., local linear regression (Sugihara 1994) or Gaussian process regression (Munch et al. 2017).

However, we rarely have data on all of the relevant state variables. In this case, EDM attempts to account for unobserved state variables using time lags of the observables. That is, if we divide y_t into the observed x_t (e.g., shrimp abundance, temperature, dissolved oxygen) and unobserved z_t state variables (e.g., everything else- including predators, competitors, food, etc.), we attempt to reconstruct the dynamics of the observables using a flexible model of the form $x_t=G(x_{t-1},\ldots x_{t-E})$ where the number of lags used, E, is referred to as the 'embedding dimension.' This approach has a strong justification in Takens (1981) theorem of time delay embedding. Takens' original proof applied to autonomous deterministic systems but has been extended by Stark (1999) and Stark et al. (1997, 1999) to forced and stochastic systems. The delay-embedding idea is illustrated in Figure 42

In each panel (Figure 42), the blue line indicates the time series while the black is its shadow on the horizontal axes. The colored points provide a visual reference for comparing plots; they are the same points in each coordinate system. In panel A (Figure 42), we have the attractor for a 3-species Rosenzweig MacArthur model in the native coordinate system where x is a producer, y is a grazer, and z is a predator. Panels B and D (Figure 42) show the attractor reconstructed using lags of just the producer or grazer, respectively. Panel C (Figure 42) is the attractor reconstructed by combining producer and grazer data. Each of the delay coordinate plots are different 1:1 representations of the attractor in A (Figure 42). Note that in all cases, the lines passing near each point tend to stay close together for a period of time. This is the essence of EDM – given a reconstructed attractor, we construct forecasts for a given point in the state space by finding nearby points in that space and using where they go to make a prediction. The various EDM algorithms differ primarily by the approximation scheme through which the predictions are constructed.

Although EDM has yet to become mainstream in ecological modeling, recent work has demonstrated its utility in a range of fisheries (e.g., Munch et al. 2018, Deyle et al. 2018, Ye et al. 2015, Glaser et al. 2014) and other ecological applications (e.g., Deyle and Sugihara 2011, Sugihara et al. 2012, Beninca et al. 2015, Deyle et al. 2016, Rogers and Munch 2020, Rogers et al. 2020)

In spatially extensive systems such as the GOM, we expect the observed fluctuations in abundance to reflect a combination of local population dynamics and movement. One way to account for this would be to treat the abundance in each location as a separate state variable (e.g., Parlitz and Merkwirth 2000, Johnson and Munch, *In press*). However, this approach dramatically increases the number of inputs to each F and consequently inflates the amount of data needed for fitting. At the other extreme, we could think of the abundance in each statistical zone as representing an independent dynamical system and estimate separate functions for each. This approach limits the input dimension, but uses the available data inefficiently when the dynamics are similar. A useful middle ground would be to model the abundance in each SSZ hierarchically, incorporating all of the available data while fitting models with a modest number of inputs and allowing some variability among sites (Johnson and Munch *In press*).

This hierarchical approach to EDM was introduced in Munch et al. (2017) and applied to blue crabs on the US East Coast by Rogers and Munch (2020). One of the advantages of this hierarchical approach is that it estimates a 'dynamic correlation' parameter, which measures the similarity among sites in their delay embedding maps. This will allow us to determine whether the dynamics in all SSZ are similar or whether we need to treat different regions of the Gulf differently. Dynamical similarity across neighboring sites that decays with distance may indicate the influence of movement or correlated environmental drivers.

4.2.2. Preliminary Shrimp EDM Methodology, Results and Discussion

The ultimate goal is to evaluate the predictability of abundance indices for brown, pink, and white shrimp. Here we present preliminary results for brown shrimp. In this application, we used a spatial/hierarchical version of EDM based on Gaussian process regression (Munch et al. 2017; Rogers and Munch 2020) implemented in R using TMB, hereafter referred to as GP-EDM. Using data from both seasonal SEAMAP surveys, we evaluated forecast accuracy for embedding dimensions from three up to eight. Embedding dimension is defined as the minimum number of lags needed to fully reconstruct the attractor. Figuratively, if you consider the attractor a ball of string, then any 1-d or 2-d shadow of the ball probably has many points where the string crosses itself. However, when we get to 3-d, it is no longer possible to follow the string from one end to the other without ambiguity. Operationally, is that the embedding dimension is the number of lags needed to optimize forecasting (or one plus that number of lags, if we are being cautious).

In the case of Brown Shrimp GP-EDM (Figure 43), an embedding dimension of t, t-2 and t-4 indicates the current, previous and two seasons before the current state, respectively. The Brown Shrimp GP-EDM uses CPUE at time t ($CPUE_t$) as a response variable, and $CPUE_{t-2}$ and $CPUE_{t-4}$ as explanatory variables. The bottom temperature at time t (T_t) is a third explanatory variable in the preliminary Brown Shrimp GP-EDM model. For the purposes of model fitting, only $CPUE_{t-2}$, $CPUE_{t-4}$ and T_t is used for predicting $CPUE_t$ to avoid overfitting.

A hierarchical model was used to integrate data from all SSZ and make zone-specific forecasts. After optimizing the model hyperparameters for within-zone forecasting, we averaged these to produce a Gulf-wide prediction for next year's abundance index (Figure 43). We found that the Gulf-wide abundance of brown shrimp is highly predictable; with an embedding dimension of five, we obtain forecast R^2 of 0.9. Here we have preliminarily concatenated seasonal CPUE across nine statistical (stat) zones and then combined (or averaged) zone-scale CPUE predictions into a cross-site CPUE index (Figure 44a) compared with predictions at each zone (Figure 44b). Preliminary results suggest that summer season GP-EDM forecasts always perform better than fall season forecasting, and that the best predictors for either summer or fall CPUE is $CPUE_{t-2}$ and $CPUE_{t-4}$ (i.e., the dynamic history of the summer and fall $CPUE_t$).

In addition, we computed the 'dynamic correlation' metric of Rogers and Munch (2020) to evaluate the similarity in dynamics among SSZ 11-21. The goal of this auxiliary work was to determine whether there are significant spatial gradients in the shrimp dynamics.

The dynamic correlation analysis suggests strong spatial structuring in the dynamics such that neighboring zones are more similar than distant zones. Most interestingly, there is a break between SSZ 11, 13, and the rest, such that the dynamics in 11 are nearly independent of all SSZ save 13, and SSZ 13 is weakly similar to neighboring zones.

5. Best Practices

After reviewing the current (delta-lognormal) and proposed (e.g., VAST and EDM) analytical methods to estimate (model) the relative abundance of brown, pink, and white shrimp, it is the recommendation of this SEAMAP WG that the delta-lognormal model continued to be used. Both the VAST and EDM methods showed promise, but additional research is still needed prior to the adoption of these alternative methodologies for future assessments. Overall, the SEAMAP WG believes the delta-lognormal model is doing a good job with the standardization of the abundance indices.

Specific to brown and white shrimp, the SEAMAP WG recommends that the indices be split when the survey methodology was changed in 2008. The split is recommended to account for unquantified differences in catchability between the survey designs. The primary areas of concern focus on the shift from towing perpendicular across depth contours requiring variable tow times (10 to ~165 minutes) to towing in random directions for a fixed tow time of 30 minutes. Additionally, with the change in survey design, there was a significant switch in the proportional allocation of stations between the shallow (5 – 20 fathoms) and deeper (20 – 60 fathoms) depth zones (Figure 4). The current Stock Synthesis model is capable of supporting the split indices. It is possible in the future, that it may be feasible to use the full time series, but that will depend on the results of future research (see Section 6).

Additional best practice recommendation are made for each species in the following sections.

5.1. Brown Shrimp

In addition to the recommendations listed above, the SEAMAP WG recommends that the spatial extent of the brown shrimp index should encompass shrimp statistical zones 8 – 21, for years when data are available. This allows the brown shrimp index to line up with the spatial extent of the commercial brown shrimp fishery (except for shrimp statistical zone 7, in which there were no landings in the SEAMAP data) and tracks the full extent of the stock (Appendix Tables 1 and 2). The SEAMAP WG also recommends retaining the brown shrimp indices from both the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey as each survey is tracking a separate life stage of brown shrimp. For reference, the SEAMAP Summer Groundfish Survey appears to be targeting the brown shrimp that have recruited to the offshore shrimp fishery, while the SEAMAP Fall Groundfish Survey is tracking the portion of the population of brown shrimp that is left after fishing. Finally, the SEAMAP WG recommends that a sensitivity run be done during the next stock assessment that examines the inclusion/exclusion of data from shrimp statistical zones 8 – 10.

5.2. White Shrimp

In addition to the recommendations listed above, the SEAMAMP WG recommends that the spatial extent of the white shrimp index should encompass shrimp statistical zones 11 – 21. Although the extent of the commercial fishery for white shrimp used in the stock assessment extends from shrimp statistical zones 7 – 21, there was relatively little to no catch in these zones in the SEAMAP data (Appendix Tables 3 and 4). Additionally, the SEAMAP WG recommends that the index abundance from the SEAMAP Summer Groundfish Survey only include survey data from depths less than 25 fathoms, similar to what is currently done for the SEAMAP Fall Groundfish Survey. This recommendation is based on the extremely low to zero occurrence of white shrimp from the deeper depths of the survey area. The SEAMAP WG also recommends retaining the white shrimp indices from both the SEAMAP Summer Groundfish Survey and SEAMAP Fall Groundfish Survey as each survey is tracking a separate life stage of the white shrimp. For reference, the SEAMAP Summer Groundfish Survey appears to be tracking the spawning white shrimp, while the SEAMAP Fall Groundfish Survey is tracking the portion of the population of white shrimp that recruited into the fishery. Finally, if in the future the full time series is used, the SEAMAP WG recommends removing the survey variable from the model.

5.3. Pink Shrimp

For pink shrimp, in addition to the recommendation to continue to use the delta-lognormal model, the SEAMAP WG recommends the continued use of the current spatial extent from shrimp statistical zones 2 – 11 for index estimation. While pink shrimp do occur outside of this area, the fishery is primarily located in the eastern GOM. Additionally, if pink shrimp are captured by the commercial fishery in the western GOM, they are typically lumped in with brown shrimp. Further, there is likely more misidentification in the western GOM, as brown and pink shrimp are extremely similar in appearance. From a temporal standpoint, the WG recommends that the abundance index from the SEAMAP Summer Groundfish Survey start in 2010 because of the limited sampling south of Tampa Bay in 2008 and 2009 (Appendix Figure 5). These two years were initially included when calculating the indices because of the short time frame of sampling in the eastern GOM, but now that sampling has been ongoing for at least 10 years, it is applicable to drop them. Similarly, for the SEAMAP Fall Groundfish Survey, a starting year of 2014 is recommended due to the lack of consistent sampling coverage in the early years (Appendix Figure 6). However, as it appears that both surveys sample relatively the same size of shrimp during the summer and fall season, only one abundance index may be necessary for inclusion in the stock assessment. Sensitivity runs should be pursued during the next shrimp assessment model updates to check if both the summer and fall SEAMAP indices are needed to inform the Pink Shrimp model. Should dropping an index be possible based on sensitivity results, the SEAMAP WG recommends that the SEAMAP Fall Groundfish Survey could be dropped given it is the shorter time series.

6. Research Recommendations

The following research recommendations were put forth by the SEAMAP WG in order to help further the use of the SEAMAP Summer and Fall Groundfish Survey data in future stock assessments.

- Examine the effect of the change in survey design and scaling issues to possibly use a continuous time series of abundance in future stock assessments.
- Explore the possibility of combining the SEAMAP Summer and Fall Groundfish Surveys together to put forth a single index for each species.
- Generate initial VAST spatial temporal indices for shrimp taken during SEAMAP fall groundfish survey.
    - Our current analyses focused solely on data from the SEAMAP summer groundfish survey. Analogous indices will need to be developed for the SEAMAP fall groundfish survey to determine if similar trends and comparable CVs are found between VAST spatio-temporal models and the current DLN methodology. An additional avenue to be explored may be the combination of data from both surveys into a single index of abundance.
- Examining the effects of spatial complexity.
    - The complexity of spatial variation for this analysis was modeled using 100 knots. This is a relatively low level, and was chosen to quickly facilitate model development. Increased spatial complexity within VAST is a balance of precision and computation efficiency. Increasing the number of knots, and consequently the spatial resolution, may account for additional spatial variance in the model. Therefore, a comparison of indices and index precision generated across a range of spatial complexity (knots) should be explored.
- Exploring alternate statistical distributions.
    - The models developed in this study focused on delta-lognormal statistical distributions to allow for a direct comparison among VAST and our current DLN methodology. The VAST package supports a wide range of common statistical distributions to model encounter, count and catch per unit data, which may yield better fits.
- Identify and explore additional catchability and habitat covariates that affect shrimp abundance.
    - VAST allows the user to distinguish between catchability and habitat covariates (Thorson, 2019). In essence, catchability effects are those that affect the sampling process such as gear types and weather, and habitat/density covariates are those that affect the distribution of catch independently of sampling such as preferred habitat (depth, sediment type etc.). The VAST model utilizes these covariates in two different ways. Catchability covariates are used when calculating and index by removing their estimated effect. In contrast, density/habitat covariates are used to improve interpolated/extrapolated predictions of density. The determination of what is catchability or a habitat is left to the analyst. The VAST S-T models presented here incorporate only time of day (Day or Night) as a catchability covariate. Additional catchability and/or habitat variables should be

identified and evaluated. For example, increasing the resolution to time of day to hourly.

- Leveraging VAST's capability to examine spatial shifts via center of gravity and effective area occupied metrics
    - The VAST S-T indices presented here focus on trends in abundance and their associated precision. The same models are capable of deriving estimates of the centroid of spatial abundance (center of gravity) and effective area occupied. These metrics should be generated and examined to determine if spatial shifts in abundance and expansion/contraction of shrimp abundance has occurred over their respective time series.
- Using the EDM framework laid out above, produce Gulf-wide forecasts for white and pink shrimp.
- Work relevant environmental drivers into the EDM forecasts for all three shrimp species.
- Using the resulting models (from EDM) to identify management targets for each species [Brias and Munch (*In press*)]

7. References

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8. Tables

Table 1. Summary of depth zones by survey year.

Survey Years	Minimum Depth (fm)	Maximum Depth (fm)	Depth Zones (fm)
1982 – 1985	5	50	5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14,14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-21, 21-22, 22-23, 23-24, 24-25, 25-27.5, 27.5-30, 30-35, 35-40, 40-45, 45-50
1986	5	50	5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-21, 21-22, 22-23, 23-24, 24-25, 25-26, 26-27, 27-28, 28-29, 29-30, 30-35, 35-40, 40-45, 45-50
1987 – 1988	5	60	5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-21, 21-22, 22-23, 23-24, 24-25, 25-26, 26-27, 27-28, 28-29, 29-30, 30-35, 35-40, 40-45, 45-50, 50-55, 55-60
1989	5	60	5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-22, 22-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-55, 55-60
1990 – 2008 (Summer)	5	60	5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-22, 22-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-60
2008 (Fall)	5	60	5-10, 10-20, 20-30, 30-40, 40-60
2009 – 2012	5	60	5-60 (single depth zone)
2013 – 2016	2 (SSZ 1-17) 5 (SSZ 18-21)	60	2-20, 20-60 5-20, 20-60
2017 – present	5	60	5-20, 20-60

Table 2. Number of stations sampled by shrimp statistical zone for the SEAMAP Summer Groundfish Survey.

	Shrimp Statistical Zone																				
Year	1	2	3	4	5	6	7	8	9	10	11	13	14	15	16	17	18	19	20	21	Total
1987										29	59	6	20	19	25	20	16	25	28	19	*266*
1988										17	46	5	4	3	19	24	14	25	28	23	*208*
1989										21	30		3	18	25	7	15	20	29	24	*192*
1990											65	11	20	15	23	16	20	23	24	20	*237*
1991											44	12	24	13	23	22	24	18	23	26	*229*
1992										1	44	2	20	24	20	25	12	31	26	20	*225*
1993											44	10	19	17	24	19	14	29	24	22	*222*
1994											60	6	17	22	25	17	20	22	26	22	*237*
1995											42	10	16	18	22	23	13	27	26	21	*218*
1996											46	14	12	19	22	18	17	21	26	25	*220*
1997											42		12	16	22	23	10	28	26	26	*205*
1998											34	2	14	21	25	18	14	22	36	17	*203*
1999											43	7	20	19	20	23	13	25	32	20	*222*
2000											43	2	19	15	19	27	8	29	31	21	*214*
2001											34	7	18	18	13	3	10	9	17	21	*150*
2002											44	11	14	21	27	19	15	25	29	22	*227*
2003											42	9	10	8	2	17	20	22	26	23	*179*
2004											38	11	18	17	20	25	21	19	25	21	*215*
2005											31	10	9	11	16	21	5	28	22	27	*180*
2006											45	11	21	12	20	23	17	23	31	18	*221*
2007											40		6	15	22	23	7	29	32	21	*195*
2008				1	8	11	6	11	8	11	42	24	19	26	23	21	16	24	21	28	*300*
2009				36	21	29	14	16	18	24	66	25	20	36	39	46	50	33	29	23	*525*
2010			31	26	20	24	10	12	14	13	21	5	19	16	21	33	34	27	27	19	*372*
2011		11	24	22	20	29	2	15	11	8	16	7	14	17	23	29	29	18	21	13	*329*
2012		12	39	33	29	30	19	16	16	13	16	7	14	18	25	30	27	20	20	15	*399*
2013		9	27	28	23	19	8	11	8	7	14	5	12	14	22	21	22	16	17	12	*295*
2014		15	31	23	24	30	17	14	9	7	15	6	15	18	22	28	23	18	18	14	*347*
2015	1	9	32	29	22	27	21	17	10	8	16	7	15	18	21	28	27	19	20	13	*360*
2016		9	25	29	25	22	15	15	10	8	15	6	16	16	21	30	23	19	17	14	*335*
2017		10	28	19	28	14	15	14	6	10	17	7	13	13	23	26	24	19	21	14	*321*
2018		8	30	28	24	23	16	12	5	7	14	7	12	14	21	26	19	11	11	14	*302*
Total	*1*	*83*	*267*	*274*	*244*	*258*	*143*	*153*	*115*	*184*	*1168*	*252*	*485*	*547*	*695*	*731*	*599*	*724*	*789*	*638*	*8350*

Table 3. Number of stations sampled by shrimp statistical zone for the SEAMAP Fall Groundfish Survey.

	Shrimp Statistical Zone																				
Year	1	2	3	4	5	6	7	8	9	10	11	13	14	15	16	17	18	19	20	21	Total
1987										16	26	15	14	16	17	15	15	15	18	3	*170*
1988										8	27	7	22	17	18	26	19	21	31	20	*216*
1989											43	12	19	17	22	20	17	22	25	26	*223*
1990											52	14	12	23	22	19	18	22	19	27	*228*
1991											45	6	24	14	20	25	24	19	25	22	*224*
1992											32	7	23	14	25	18	17	27	30	18	*211*
1993											70	10	19	17	26	18	16	25	28	18	*247*
1994											49	9	16	21	25	20	21	23	24	20	*228*
1995											39	10	17	18	24	19	14	26	30	19	*216*
1996											43	9	18	19	17	28	13	25	29	24	*225*
1997											43	10	17	20	26	19	18	23	22	24	*222*
1998											43	10	22	14	34	11	15	24	29	22	*224*
1999											42	9	17	18	29	18	12	28	29	22	*224*
2000											42	10	14	22	20	26	12	30	25	21	*222*
2001											43	10	17	19	26	20	14	27	28	23	*227*
2002										1	49	10	13	22	22	23	14	26	30	21	*231*
2003										1	74	9	16	21	24	22	20	23	25	23	*258*
2004											43		11	18	17	27	14	24	30	21	*205*
2005											43	11	20	16	33	18	14	23	24	27	*229*
2006										1	45	7	22	14	18	28	13	23	32	19	*222*
2007											31	9	20	17	18	28	17	20	18	26	*204*
2008					15	14	4	4	3	4	34	16	28	34	42	46	44	19	36	20	*363*
2009				20	21	25	11	21	13	12	47	12	23	23	30	49	47	31	36	22	*443*
2010				9	25	27	17	16	11	14	15	7	15	18	26	30	29	18	19	14	*310*
2011								9	11	6	15	6	15	16	27	31	28	21	18	15	*218*
2012			2	3	6	6	17	10	7	5	12	5	11	13	19	23	22	13	15	11	*200*
2013		4	14	9	9	11	10	10	6	5	10	5	11	9	3	12	16	12	14	9	*179*
2014	1	8	31	25	22	23	13	12	7	7	16	5	13	14	21	27	22	15	17	12	*311*
2015	1	10	28	25	25	21	13	11	9	11	16	6	13	13	19	27	21	16	17	12	*314*
2016	1	5	4	8	11	9	6	13	5	4	8	4	12	10	18	22	17	13	13	8	*191*
2017		9	19	27	19	18	8	12	7	7	15	6	9	12	22	25	22	15	18	14	*284*
2018		9	29	21	14	10	7	13	8	7	13	5	12	15	21	25	22	13	15	14	*273*
Total	*3*	*45*	*127*	*147*	*167*	*164*	*106*	*131*	*87*	*109*	*1125*	*271*	*535*	*554*	*731*	*765*	*627*	*682*	*769*	*597*	*7742*

Table 4. Brown shrimp abundance index for the SEAMAP Summer Groundfish Survey, 1987-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.76371	237	138.881	0.57110	0.14790	0.42554	0.76645
1988	0.67539	191	73.226	0.30111	0.16795	0.21571	0.42033
1989	0.76023	171	179.605	0.73856	0.16614	0.53095	1.02735
1990	0.73840	237	172.125	0.70780	0.14950	0.52574	0.95290
1991	0.74672	229	267.361	1.09942	0.15101	0.81421	1.48454
1992	0.72321	224	70.035	0.28799	0.15493	0.21165	0.39188
1993	0.70270	222	130.187	0.53535	0.15680	0.39198	0.73115
1994	0.76793	237	129.302	0.53171	0.14802	0.39610	0.71374
1995	0.76606	218	276.855	1.13846	0.15218	0.84119	1.54078
1996	0.75909	220	105.748	0.43485	0.15201	0.32141	0.58833
1997	0.80000	205	130.802	0.53787	0.15298	0.39680	0.72911
1998	0.87685	203	173.355	0.71286	0.14839	0.53066	0.95761
1999	0.83784	222	270.115	1.11075	0.14639	0.83010	1.48627
2000	0.85514	214	362.459	1.49048	0.14711	1.11233	1.99718
2001	0.79333	150	202.864	0.83420	0.16997	0.59523	1.16912
2002	0.84141	227	212.030	0.87189	0.14498	0.65341	1.16343
2003	0.89385	179	278.564	1.14549	0.15289	0.84519	1.55248
2004	0.81395	215	306.007	1.25834	0.14929	0.93506	1.69339
2005	0.78333	180	218.010	0.89649	0.16038	0.65181	1.23300
2006	0.86878	221	725.418	2.98301	0.14454	2.23747	3.97697
2007	0.83590	195	354.388	1.45729	0.15288	1.07529	1.97499
2008	0.76230	244	295.155	1.21372	0.14681	0.90631	1.62539
2009	0.89646	367	368.374	1.51480	0.17525	1.06975	2.14501
2010	0.87838	222	296.212	1.21806	0.21397	0.79781	1.85970
2011	0.89305	187	303.815	1.24933	0.21863	0.81094	1.92471
2012	0.95313	192	391.106	1.60828	0.21554	1.05018	2.46296
2013	0.90968	155	208.240	0.85631	0.22479	0.54927	1.33498
2014	0.88701	177	140.002	0.57570	0.22101	0.37198	0.89102
2015	0.94022	184	326.099	1.34096	0.21773	0.87194	2.06228
2016	0.84746	177	198.836	0.81764	0.22289	0.52639	1.27004
2017	0.96045	177	253.422	1.04210	0.21805	0.67718	1.60366
2018	0.89933	149	223.265	0.91809	0.22671	0.58672	1.43662

Table 5. Brown shrimp abundance index for the SEAMAP Fall Groundfish Survey, 1987-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.75974	154	58.178	0.54042	0.14055	0.40855	0.71485
1988	0.65385	208	36.067	0.33503	0.13506	0.25603	0.43839
1989	0.79372	223	86.497	0.80347	0.11895	0.63389	1.01841
1990	0.76754	228	95.637	0.88837	0.11968	0.69985	1.12766
1991	0.82143	224	98.287	0.91299	0.11728	0.72267	1.15342
1992	0.86256	211	92.546	0.85966	0.11766	0.67996	1.08685
1993	0.78138	247	80.792	0.75048	0.11517	0.59652	0.94416
1994	0.78947	228	98.269	0.91282	0.11842	0.72091	1.15581
1995	0.87037	216	109.340	1.01565	0.11609	0.80585	1.28009
1996	0.87111	225	83.672	0.77723	0.11440	0.61873	0.97632
1997	0.84234	222	85.930	0.79820	0.11641	0.63290	1.00667
1998	0.86607	224	96.244	0.89401	0.11477	0.71119	1.12383
1999	0.79464	224	104.992	0.97527	0.11921	0.76904	1.23680
2000	0.81532	222	122.444	1.13738	0.11814	0.89877	1.43933
2001	0.79295	227	99.140	0.92091	0.11856	0.72710	1.16638
2002	0.85217	230	118.537	1.10109	0.11431	0.87672	1.38288
2003	0.81323	257	92.019	0.85477	0.11185	0.68391	1.06831
2004	0.81951	205	101.314	0.94110	0.12143	0.73884	1.19873
2005	0.84279	229	105.447	0.97950	0.11518	0.77855	1.23231
2006	0.88235	221	192.223	1.78555	0.11442	1.42137	2.24304
2007	0.83824	204	110.890	1.03005	0.12028	0.81052	1.30904
2008	0.90282	319	121.367	1.12738	0.14268	0.84872	1.49753
2009	0.86875	320	168.552	1.56568	0.12957	1.20956	2.02665
2010	0.91099	191	147.986	1.37464	0.16431	0.99180	1.90526
2011	0.94792	192	102.405	0.95124	0.16279	0.68837	1.31450
2012	0.93750	144	125.232	1.16327	0.17314	0.82491	1.64043
2013	0.87129	101	88.593	0.82294	0.19322	0.56114	1.20688
2014	0.91975	162	138.924	1.29046	0.16952	0.92160	1.80696
2015	0.93750	160	153.969	1.43021	0.16937	1.02171	2.00204
2016	0.84800	125	111.170	1.03266	0.18368	0.71735	1.48655
2017	0.90506	158	111.156	1.03253	0.17101	0.73524	1.45002
2018	0.89677	155	107.124	0.99507	0.17215	0.70699	1.40054

Table 6. Brown shrimp abundance index for the SEAMAP Summer Groundfish Survey, 1987-2008. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.70301	266	90.302	0.52897	0.11933	0.41701	0.67098
1988	0.62981	208	45.314	0.26544	0.14545	0.19874	0.35452
1989	0.68750	192	111.613	0.65380	0.14228	0.49259	0.86778
1990	0.73840	237	122.808	0.71938	0.12218	0.56393	0.91768
1991	0.74672	229	192.501	1.12762	0.12428	0.88030	1.44443
1992	0.72000	225	51.572	0.30209	0.12848	0.23389	0.39019
1993	0.70270	222	94.471	0.55339	0.13134	0.42602	0.71882
1994	0.76793	237	92.559	0.54219	0.11994	0.42691	0.68858
1995	0.76606	218	205.500	1.20377	0.12514	0.93815	1.54459
1996	0.75909	220	76.518	0.44822	0.12522	0.34926	0.57522
1997	0.80000	205	95.831	0.56135	0.12536	0.43730	0.72060
1998	0.87685	203	133.839	0.78399	0.11885	0.61865	0.99353
1999	0.83784	222	206.660	1.21056	0.11714	0.95849	1.52893
2000	0.85514	214	281.035	1.64623	0.11777	1.30180	2.08179
2001	0.79333	150	140.056	0.82041	0.14634	0.61319	1.09766
2002	0.84141	227	164.493	0.96356	0.11564	0.76519	1.21335
2003	0.89385	179	207.998	1.21840	0.12500	0.94981	1.56295
2004	0.81395	215	227.173	1.33072	0.12111	1.04538	1.69395
2005	0.78333	180	166.848	0.97735	0.13438	0.74791	1.27718
2006	0.86878	221	565.170	3.31062	0.11480	2.63342	4.16197
2007	0.83590	195	269.657	1.57958	0.12482	1.23181	2.02552
2008	0.73359	259	213.794	1.25235	0.11812	0.98966	1.58477

Table 7. Brown shrimp abundance index for the SEAMAP Summer Groundfish Survey, 2009-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2009	0.79059	425	445.066	1.30537	0.10132	1.06649	1.59776
2010	0.75096	261	364.951	1.07039	0.13363	0.82033	1.39669
2011	0.76923	221	391.866	1.14933	0.13910	0.87137	1.51597
2012	0.77637	237	485.869	1.42504	0.13062	1.09864	1.84842
2013	0.78453	181	247.839	0.72691	0.15106	0.53828	0.98163
2014	0.77778	207	177.485	0.52056	0.14363	0.39115	0.69278
2015	0.80365	219	417.267	1.22384	0.13252	0.93997	1.59342
2016	0.74286	210	229.500	0.67312	0.14994	0.49955	0.90700
2017	0.85507	207	344.289	1.00979	0.12909	0.78086	1.30585
2018	0.80925	173	305.369	0.89564	0.14814	0.66705	1.20257

Table 8. Brown shrimp abundance index for the SEAMAP Fall Groundfish Survey, 1987-2007. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.70588	170	40.352	0.50926	0.13032	0.39285	0.66018
1988	0.62963	216	24.737	0.31219	0.12759	0.24212	0.40253
1989	0.79372	223	68.197	0.86069	0.10478	0.69837	1.06073
1990	0.76754	228	76.854	0.96994	0.10570	0.78557	1.19757
1991	0.82143	224	79.256	1.00025	0.10202	0.81606	1.22601
1992	0.86256	211	75.778	0.95636	0.10212	0.78010	1.17243
1993	0.78138	247	64.989	0.82020	0.09987	0.67203	1.00102
1994	0.78947	228	78.401	0.98946	0.10368	0.80460	1.21679
1995	0.87037	216	90.389	1.14076	0.10019	0.93408	1.39316
1996	0.87111	225	68.488	0.86435	0.09816	0.71061	1.05136
1997	0.84234	222	69.455	0.87656	0.10084	0.71683	1.07188
1998	0.86607	224	80.181	1.01193	0.09868	0.83109	1.23211
1999	0.79464	224	84.738	1.06944	0.10458	0.86809	1.31749
2000	0.81532	222	99.130	1.25107	0.10309	1.01853	1.53671
2001	0.79295	227	79.514	1.00351	0.10401	0.81551	1.23486
2002	0.85281	231	99.660	1.25776	0.09811	1.03416	1.52971
2003	0.81395	258	74.790	0.94388	0.09550	0.78012	1.14203
2004	0.81951	205	80.864	1.02054	0.10638	0.82544	1.26175
2005	0.84279	229	83.704	1.05639	0.09954	0.86612	1.28845
2006	0.88288	222	155.764	1.96582	0.09785	1.61717	2.38964
2007	0.83824	204	88.717	1.11965	0.10540	0.90737	1.38159

Table 9. Brown shrimp abundance index for the SEAMAP Fall Groundfish Survey, 2008-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2008	0.87273	330	140.838	0.94861	0.09883	0.77885	1.15538
2009	0.77049	366	196.342	1.32246	0.09766	1.08833	1.60696
2010	0.76293	232	170.253	1.14674	0.11704	0.90813	1.44804
2011	0.84862	218	129.921	0.87509	0.11144	0.70074	1.09281
2012	0.83133	166	163.341	1.10018	0.12689	0.85446	1.41658
2013	0.73770	122	85.477	0.57573	0.17795	0.40444	0.81956
2014	0.81383	188	177.504	1.19558	0.12222	0.93716	1.52526
2015	0.81152	191	195.255	1.31514	0.11940	1.03664	1.66847
2016	0.74150	147	116.513	0.78478	0.15438	0.57735	1.06672
2017	0.79348	184	129.304	0.87093	0.12719	0.67600	1.12207
2018	0.80328	183	128.388	0.86476	0.12660	0.67200	1.11282

Table 10. White shrimp abundance index for the SEAMAP Summer Groundfish Survey, 1987-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.16749	203	1.6291	0.09426	0.38105	0.04513	0.19685
1988	0.12025	158	0.5394	0.03121	0.46583	0.01286	0.07572
1989	0.20779	154	1.8800	0.10877	0.39220	0.05105	0.23178
1990	0.12766	188	0.7267	0.04204	0.42746	0.01853	0.09540
1991	0.29651	172	2.7363	0.15832	0.33545	0.08240	0.30421
1992	0.14201	169	1.2735	0.07368	0.42953	0.03236	0.16780
1993	0.17751	169	1.4989	0.08673	0.40048	0.04010	0.18757
1994	0.16000	175	0.8946	0.05176	0.40632	0.02369	0.11312
1995	0.19880	166	2.2901	0.13250	0.38613	0.06287	0.27928
1996	0.17470	166	0.8795	0.05089	0.40287	0.02343	0.11053
1997	0.18421	152	0.8108	0.04692	0.40975	0.02134	0.10316
1998	0.28289	152	2.0071	0.11613	0.35406	0.05840	0.23091
1999	0.33533	167	3.8397	0.22216	0.32583	0.11770	0.41935
2000	0.18750	160	0.8826	0.05107	0.39862	0.02369	0.11008
2001	0.21849	119	0.8241	0.04768	0.41575	0.02146	0.10597
2002	0.26036	169	2.8094	0.16255	0.35181	0.08209	0.32188
2003	0.24286	140	2.1732	0.12574	0.38017	0.06030	0.26218
2004	0.24242	165	2.2046	0.12756	0.36393	0.06301	0.25824
2005	0.32468	154	4.1538	0.24034	0.33787	0.12452	0.46387
2006	0.39181	171	5.7007	0.32984	0.30549	0.18149	0.59944
2007	0.38411	151	8.7239	0.50476	0.31887	0.27089	0.94053
2008	0.29500	200	4.1886	0.24235	0.32272	0.12913	0.45482
2009	0.43056	288	39.1846	2.26720	0.21179	1.49124	3.44692
2010	0.48148	162	98.4206	5.69456	0.28113	3.28022	9.88594
2011	0.41844	141	57.8887	3.34941	0.30335	1.85036	6.06289
2012	0.36220	127	45.1520	2.61247	0.33467	1.36157	5.01259
2013	0.37383	107	24.7418	1.43155	0.34326	0.73438	2.79057
2014	0.32000	125	20.2870	1.17379	0.36178	0.58206	2.36710
2015	0.49219	128	81.0634	4.69028	0.28515	2.68128	8.20457
2016	0.40000	115	22.4047	1.29632	0.33486	0.67539	2.48813
2017	0.45082	122	88.5322	5.12242	0.30525	2.81982	9.30530
2018	0.28302	106	22.7225	1.31471	0.38404	0.62612	2.76059

Table 11. White shrimp abundance index for the SEAMAP Fall Groundfish Survey, 1987-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.32468	154	2.9791	0.45583	0.34202	0.23437	0.88654
1988	0.34615	208	5.9799	0.91498	0.28579	0.52244	1.60246
1989	0.26906	223	5.7996	0.88740	0.30722	0.48670	1.61797
1990	0.26754	228	3.0699	0.46973	0.30785	0.25732	0.85746
1991	0.28125	224	3.7450	0.57302	0.30034	0.31835	1.03140
1992	0.36493	211	8.6675	1.32621	0.28743	0.75490	2.32989
1993	0.39271	247	10.2300	1.56529	0.25382	0.94964	2.58005
1994	0.32895	228	5.0498	0.77267	0.28603	0.44098	1.35384
1995	0.32407	216	11.4258	1.74826	0.29717	0.97708	3.12813
1996	0.28889	225	6.3257	0.96790	0.29817	0.53993	1.73509
1997	0.30180	222	5.6634	0.86656	0.29810	0.48346	1.55322
1998	0.42411	224	26.4982	4.05449	0.25818	2.43943	6.73882
1999	0.34375	224	4.0071	0.61313	0.28302	0.35192	1.06821
2000	0.38739	222	10.7885	1.65075	0.27078	0.96968	2.81017
2001	0.40529	227	10.4773	1.60314	0.26191	0.95772	2.68349
2002	0.42609	230	14.1384	2.16331	0.25332	1.31372	3.56233
2003	0.28016	257	3.6980	0.56583	0.28391	0.32423	0.98748
2004	0.30244	205	5.2417	0.80204	0.30104	0.44500	1.44553
2005	0.36681	229	9.9438	1.52150	0.27361	0.88898	2.60407
2006	0.36199	221	10.7985	1.65227	0.27774	0.95787	2.85008
2007	0.37255	204	7.0701	1.08180	0.28197	0.62216	1.88103
2008	0.35737	319	4.9265	0.75380	0.25214	0.45879	1.23850
2009	0.41250	320	7.4339	1.13746	0.24463	0.70231	1.84223
2010	0.31937	191	3.9107	0.59838	0.33845	0.30970	1.15616
2011	0.29167	192	2.3165	0.35445	0.34156	0.18240	0.68879
2012	0.24306	144	1.0313	0.15780	0.41185	0.07150	0.34827
2013	0.28713	101	4.1174	0.63000	0.44171	0.27079	1.46570
2014	0.21605	162	0.5960	0.09120	0.40291	0.04198	0.19809
2015	0.31250	160	2.9421	0.45017	0.37031	0.21979	0.92203
2016	0.29600	125	1.0459	0.16004	0.40078	0.07396	0.34630
2017	0.27215	158	2.2407	0.34286	0.38194	0.16390	0.71719
2018	0.36774	155	6.9783	1.06775	0.35648	0.53462	2.13249

Table 12. White shrimp abundance index for the SEAMAP Summer Groundfish Survey, 1987-2008. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.16749	203	5.1796	0.67640	0.29305	0.38097	1.20092
1988	0.12025	158	1.8529	0.24196	0.38749	0.11452	0.51123
1989	0.20779	154	5.7927	0.75646	0.29864	0.42161	1.35726
1990	0.12766	188	2.6860	0.35075	0.34544	0.17921	0.68648
1991	0.29651	172	9.5026	1.24093	0.23695	0.77757	1.98041
1992	0.14201	169	3.8747	0.50599	0.34721	0.25769	0.99354
1993	0.17751	169	5.0351	0.65753	0.31173	0.35761	1.20900
1994	0.16000	175	3.4169	0.44621	0.32121	0.23843	0.83505
1995	0.19880	166	7.7166	1.00769	0.29564	0.56480	1.79787
1996	0.17470	166	3.0805	0.40228	0.31484	0.21752	0.74398
1997	0.18421	152	2.5614	0.33448	0.32114	0.17875	0.62589
1998	0.28289	152	6.4549	0.84294	0.25597	0.50931	1.39511
1999	0.33533	167	11.1558	1.45681	0.22440	0.93514	2.26950
2000	0.18750	160	2.9405	0.38400	0.30937	0.20976	0.70295
2001	0.21849	119	2.7459	0.35858	0.32944	0.18870	0.68138
2002	0.26036	169	9.0046	1.17589	0.25651	0.70975	1.94818
2003	0.24286	140	7.0689	0.92311	0.29055	0.52237	1.63128
2004	0.24242	165	7.4222	0.96925	0.26880	0.57150	1.64381
2005	0.32468	154	13.4545	1.75700	0.23919	1.09623	2.81607
2006	0.39181	171	17.8086	2.32560	0.20387	1.55331	3.48186
2007	0.38411	151	26.2714	3.43073	0.21718	2.23316	5.27054
2008	0.29208	202	13.4423	1.75540	0.22471	1.12615	2.73626

Table 13. White shrimp abundance index for the SEAMAP Summer Groundfish Survey, 2009-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2009	0.46617	266	36.3141	1.05518	0.17360	0.74758	1.48936
2010	0.50980	153	72.5574	2.10831	0.20714	1.39927	3.17662
2011	0.44030	134	41.3146	1.20048	0.23316	0.75772	1.90196
2012	0.38793	116	29.9142	0.86922	0.27408	0.50741	1.48901
2013	0.39216	102	16.2172	0.47123	0.28224	0.27087	0.81979
2014	0.33613	119	12.7285	0.36985	0.29624	0.20707	0.66062
2015	0.52066	121	53.4009	1.55168	0.21788	1.00865	2.38704
2016	0.41818	110	14.7811	0.42950	0.26669	0.25426	0.72550
2017	0.47826	115	52.8197	1.53479	0.23835	0.95912	2.45598
2018	0.30000	100	14.1023	0.40977	0.32918	0.21574	0.77830

Table 14. White shrimp abundance index for the SEAMAP Fall Groundfish Survey, 1987-2007. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
1987	0.30000	170	8.9768	0.48513	0.26075	0.29046	0.81027
1988	0.33333	216	11.5333	0.62329	0.21851	0.40467	0.96001
1989	0.26906	223	15.9967	0.86451	0.24226	0.53621	1.39381
1990	0.26754	228	9.0952	0.49153	0.24017	0.30610	0.78930
1991	0.28125	224	9.5608	0.51669	0.23449	0.32529	0.82071
1992	0.36493	211	18.7752	1.01466	0.20840	0.67178	1.53256
1993	0.39271	247	22.6716	1.22524	0.18471	0.84943	1.76731
1994	0.32895	228	12.4598	0.67336	0.21385	0.44114	1.02784
1995	0.32407	216	30.7319	1.66084	0.22133	1.07245	2.57204
1996	0.28889	225	14.5151	0.78443	0.23125	0.49694	1.23825
1997	0.30180	222	15.4379	0.83431	0.22800	0.53185	1.30877
1998	0.42411	224	56.4143	3.04878	0.18313	2.12016	4.38414
1999	0.34375	224	9.7137	0.52496	0.20947	0.34684	0.79454
2000	0.38739	222	21.6050	1.16759	0.19610	0.79171	1.72194
2001	0.40529	227	21.8652	1.18166	0.18788	0.81417	1.71501
2002	0.42424	231	26.4473	1.42929	0.18140	0.99731	2.04837
2003	0.27907	258	9.5438	0.51577	0.21977	0.33405	0.79635
2004	0.30244	205	11.3402	0.61285	0.23354	0.38654	0.97167
2005	0.36681	229	22.7994	1.23214	0.20066	0.82810	1.83331
2006	0.36036	222	24.8006	1.34029	0.20693	0.88991	2.01861
2007	0.37255	204	14.2974	0.77267	0.21360	0.50644	1.17886

Table 15. White shrimp abundance index for the SEAMAP Fall Groundfish Survey, 2008-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2008	0.54369	206	41.0562	1.32909	0.15685	0.97307	1.81536
2009	0.54936	233	52.5957	1.70265	0.16074	1.23709	2.34341
2010	0.50000	122	41.5249	1.34426	0.23721	0.84190	2.14638
2011	0.44444	126	22.4088	0.72543	0.24310	0.44922	1.17145
2012	0.34343	99	11.5830	0.37497	0.35675	0.18766	0.74926
2013	0.45763	59	45.8720	1.48498	0.34330	0.76173	2.89496
2014	0.28926	121	5.3146	0.17205	0.36252	0.08520	0.34743
2015	0.43119	109	26.3998	0.85462	0.30308	0.47237	1.54619
2016	0.43529	85	10.3994	0.33665	0.33106	0.17663	0.64165
2017	0.39252	107	24.4571	0.79173	0.31297	0.42960	1.45914
2018	0.55446	101	58.1849	1.88358	0.25612	1.13774	3.11835

Table 16. Pink shrimp abundance index for the SEAMAP Summer Groundfish Survey, 2008-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2008	0.33673	98	35.2943	2.26717	0.39665	1.05552	4.86971
2009	0.31250	224	16.5577	1.06361	0.29028	0.60219	1.87858
2010	0.24561	171	17.2132	1.10571	0.34174	0.56882	2.14938
2011	0.25949	158	8.4591	0.54338	0.35437	0.27312	1.08106
2012	0.26906	223	10.3031	0.66183	0.29794	0.36935	1.18592
2013	0.26623	154	15.9404	1.02395	0.34029	0.52816	1.98516
2014	0.24865	185	10.6029	0.68109	0.33581	0.35423	1.30956
2015	0.22513	191	4.9910	0.32060	0.34894	0.16276	0.63153
2016	0.27168	173	15.1619	0.97395	0.31587	0.52562	1.80468
2017	0.31056	161	26.2622	1.68699	0.29885	0.93987	3.02800
2018	0.24551	167	10.4569	0.67172	0.34440	0.34387	1.31215

Table 17. Pink shrimp abundance index for the SEAMAP Fall Groundfish Survey, 2008-2018. The nominal frequency of occurrence, the number of samples (N), the delta-lognormal index (LoIndex) (number per trawl-hour), the delta-lognormal index scaled to a mean of one for the time series (ScaledLoIndex), the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	NominalFrequency	N	LoIndex	ScaledLoIndex	CV	LCL	UCL
2008	0.25641	78	15.2715	1.53938	0.40754	0.70286	3.37151
2009	0.29412	170	10.1091	1.01900	0.29474	0.57211	1.81497
2010	0.15672	134	1.4978	0.15098	0.41807	0.06766	0.33692
2011	0.12195	41	5.5898	0.56346	0.74974	0.14817	2.14269
2012	0.44118	68	24.3826	2.45777	0.35193	1.24091	4.86794
2013	0.27273	88	3.2367	0.32626	0.40033	0.15090	0.70543
2014	0.22561	164	4.9429	0.49825	0.32610	0.26383	0.94094
2015	0.28402	169	4.2431	0.42771	0.29464	0.24018	0.76167
2016	0.31507	73	4.8678	0.49068	0.39656	0.22848	1.05377
2017	0.39007	141	14.1258	1.42388	0.26292	0.84900	2.38804
2018	0.39695	131	20.8593	2.10263	0.26442	1.25014	3.53645

9. Figures

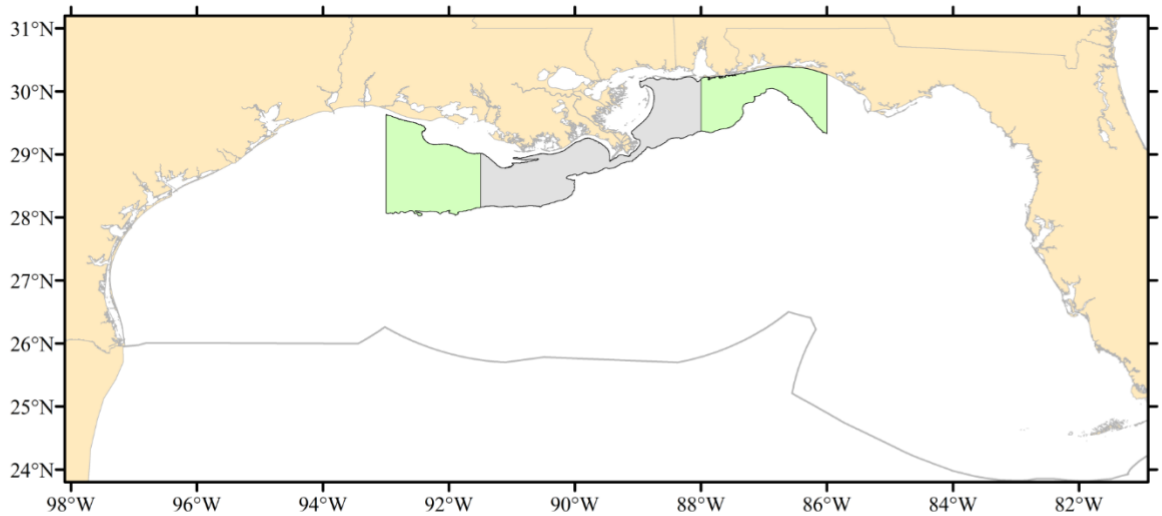


Figure 1. Primary area (gray) and secondary areas (green) covered by the NMFS Shrimp / Bottomfish Survey between 1972 and 1984 conducted during the fall.

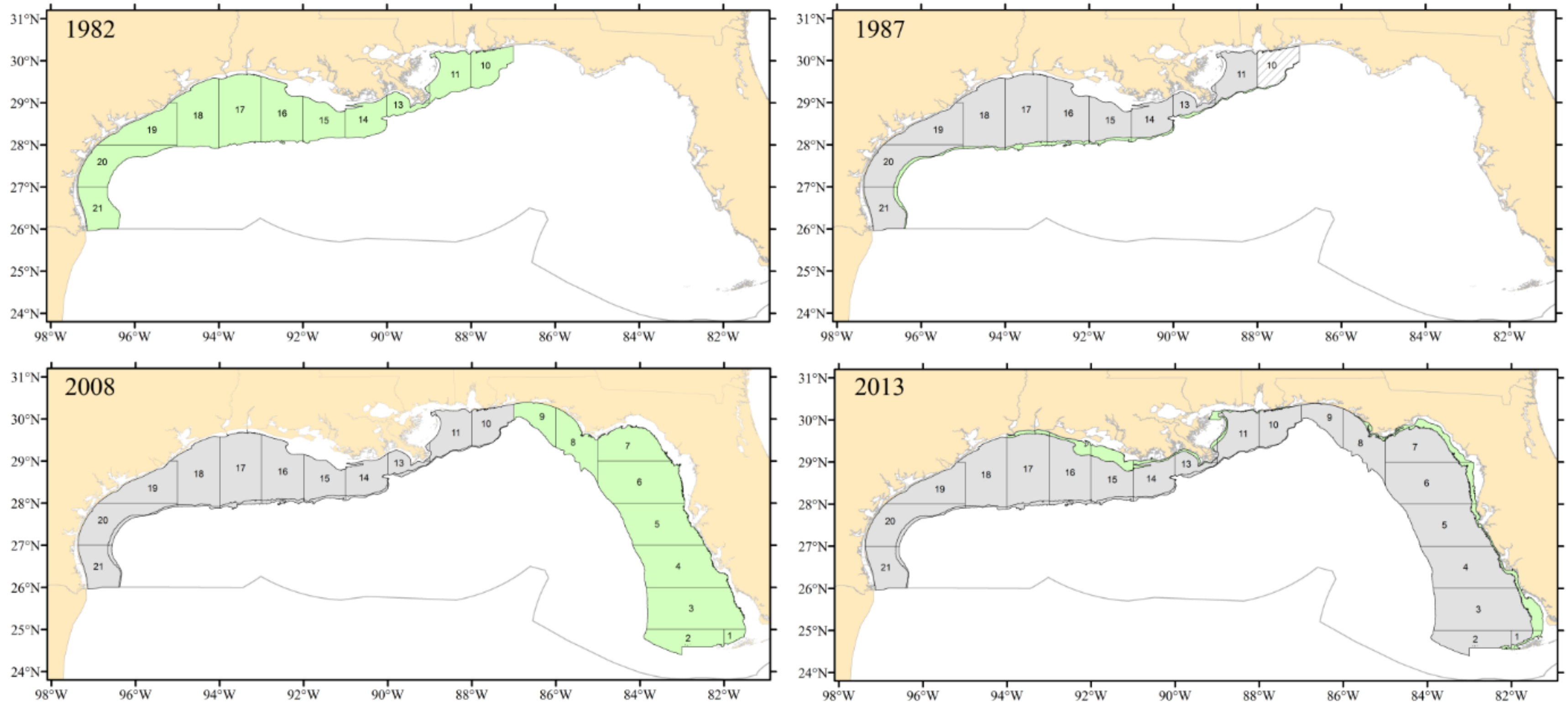


Figure 2. Changes in the spatial extent of the SEAMAP Summer Groundfish survey since its inception in 1982. Green shaded areas represent survey expansion in their respective years, while the striped area was dropped from sampling in 1989. Gray shaded areas represent the previous extent of the survey.

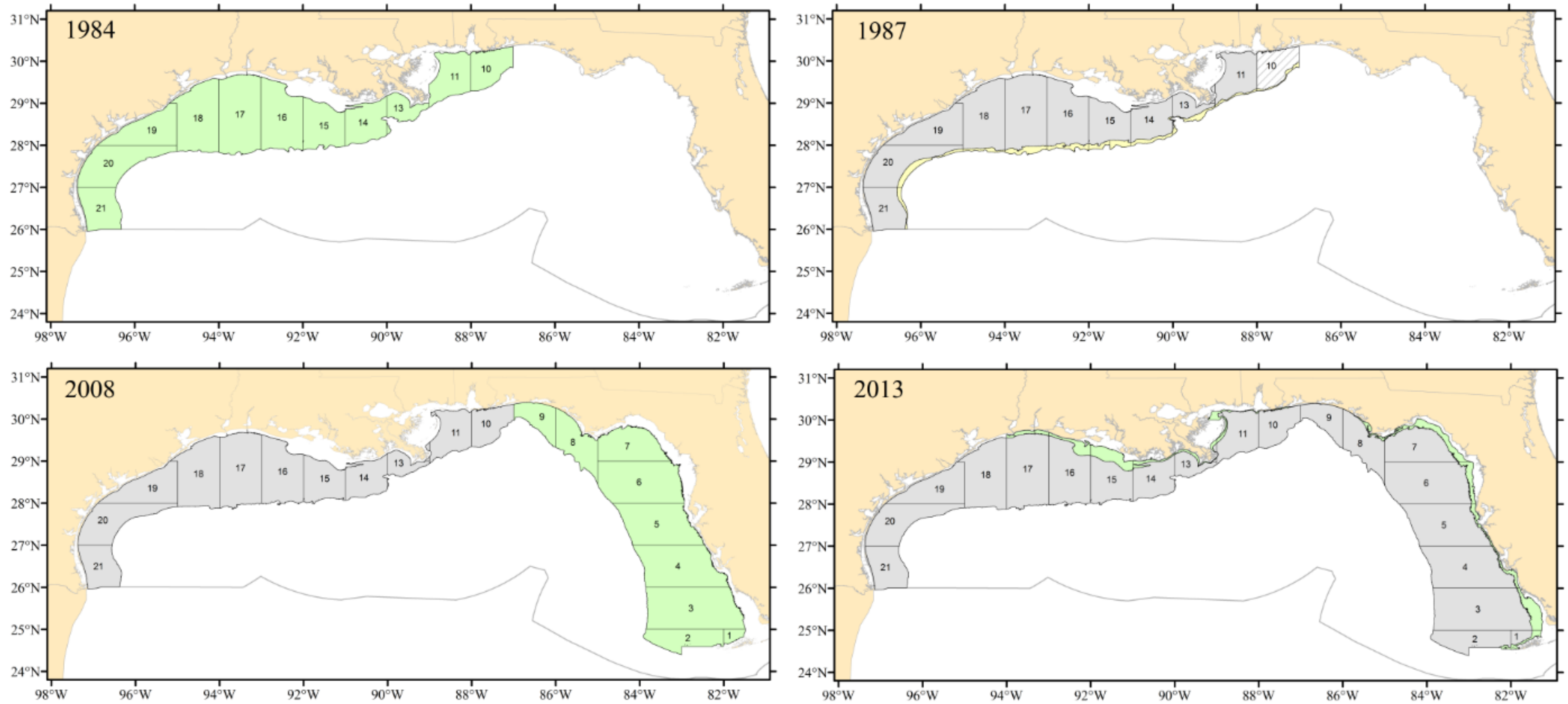
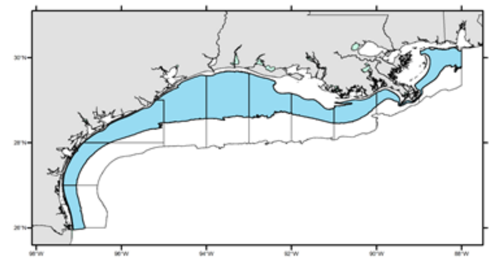


Figure 3. Changes in the spatial extent of the SEAMAP Fall Groundfish survey since its inception in 1984. Green shaded areas represent survey expansion in their respective years, while the yellow shaded area was only sampled in 1985 and 1986 and the striped area was dropped from sampling in 1989. Gray shaded areas represent the previous extent of the survey.

5 – 20 Fathom Breakdown

Stat Zones	Old Design	Current Design
11	0.13	0.04
13-15	0.13	0.09
16-17	0.13	0.17
18-19	0.13	0.16
20-21	0.13	0.07



Overall Strata Proportions

Stat Zones	Old Design	Current Design
11	0.2	0.08
13-15	0.2	0.19
16-17	0.2	0.29
18-19	0.2	0.24
20-21	0.2	0.19

20 – 60 Fathom Breakdown

Stat Zones	Old Design	Current Design
11	0.07	0.04
13-15	0.07	0.10
16-17	0.07	0.12
18-19	0.07	0.08
20-21	0.07	0.12

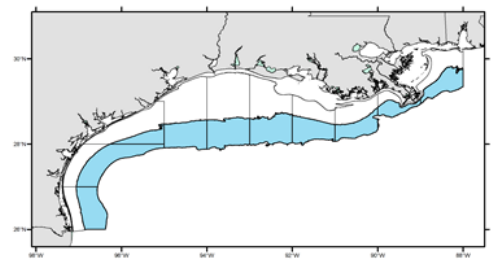


Figure 4. Change in proportional allocation of samples between old and new designs of the SEAMAP Summer and Fall Groundfish Surveys.

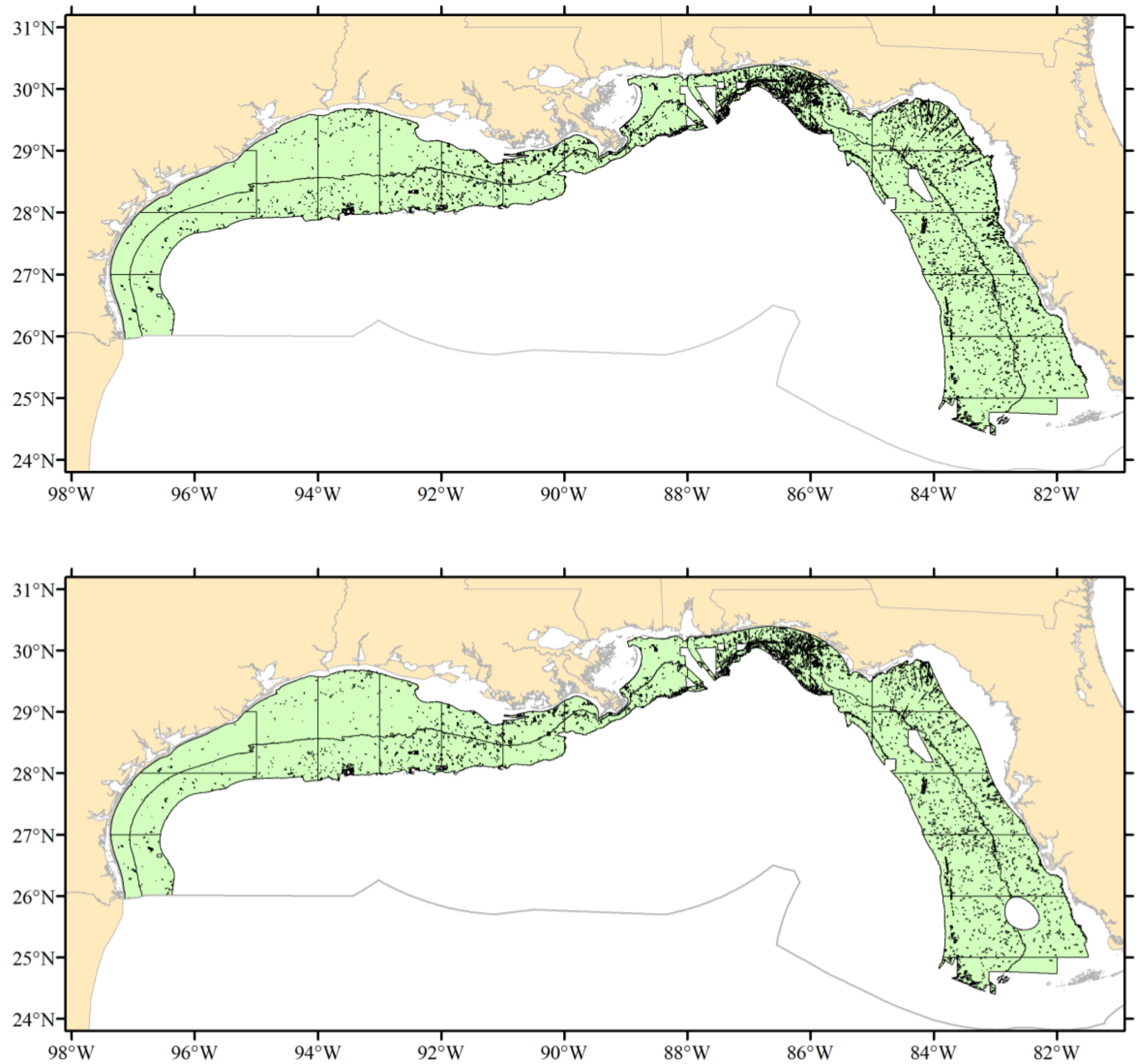


Figure 5. Refinement of SEAMAP sampling universe in 2017 (top) and 2020 (bottom).

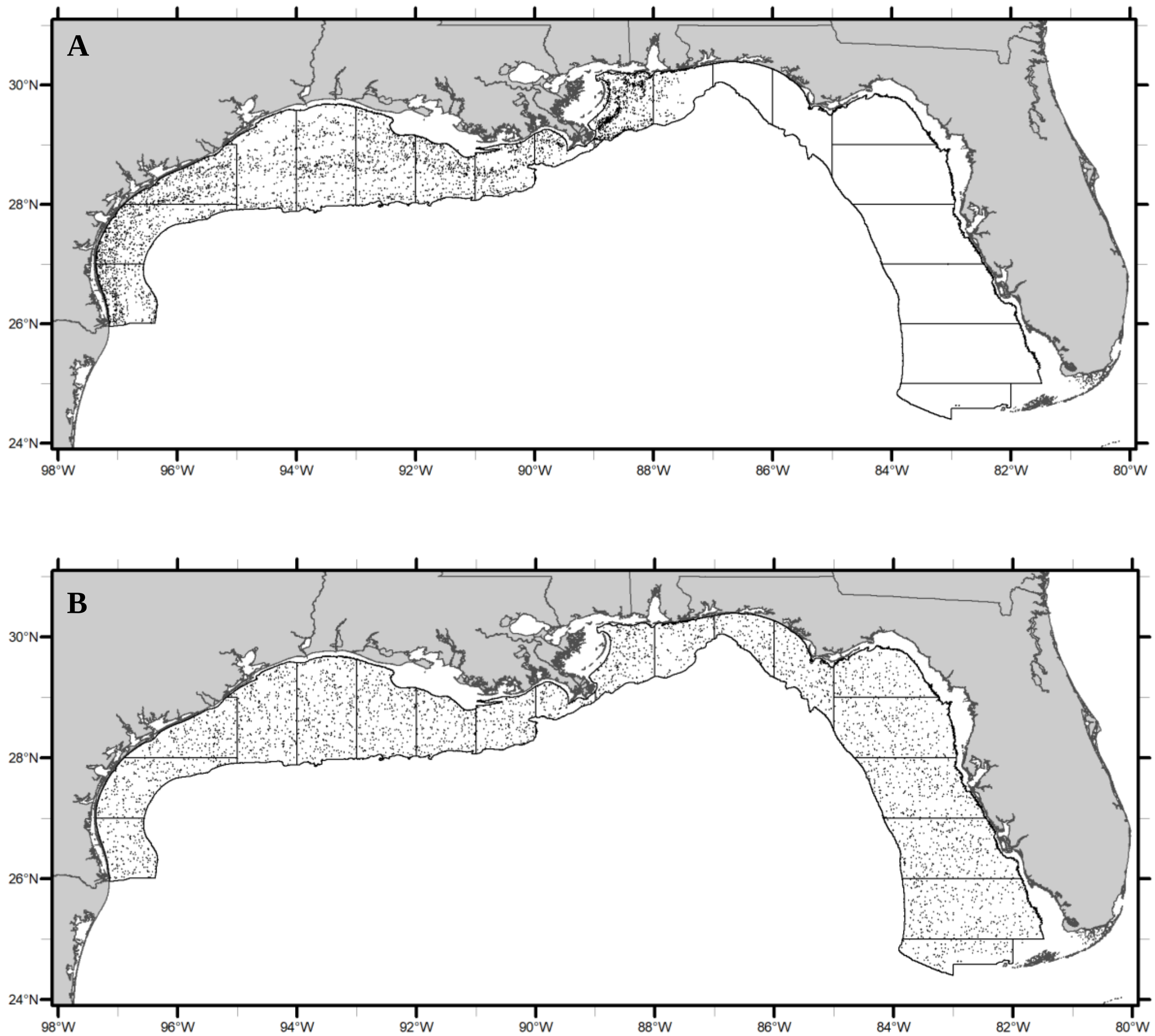


Figure 6. Distribution of stations sampled during the SEAMAP Summer Groundfish Survey from A. 1987 – 2008 (old design) and B. 2009 – 2018 (new design).

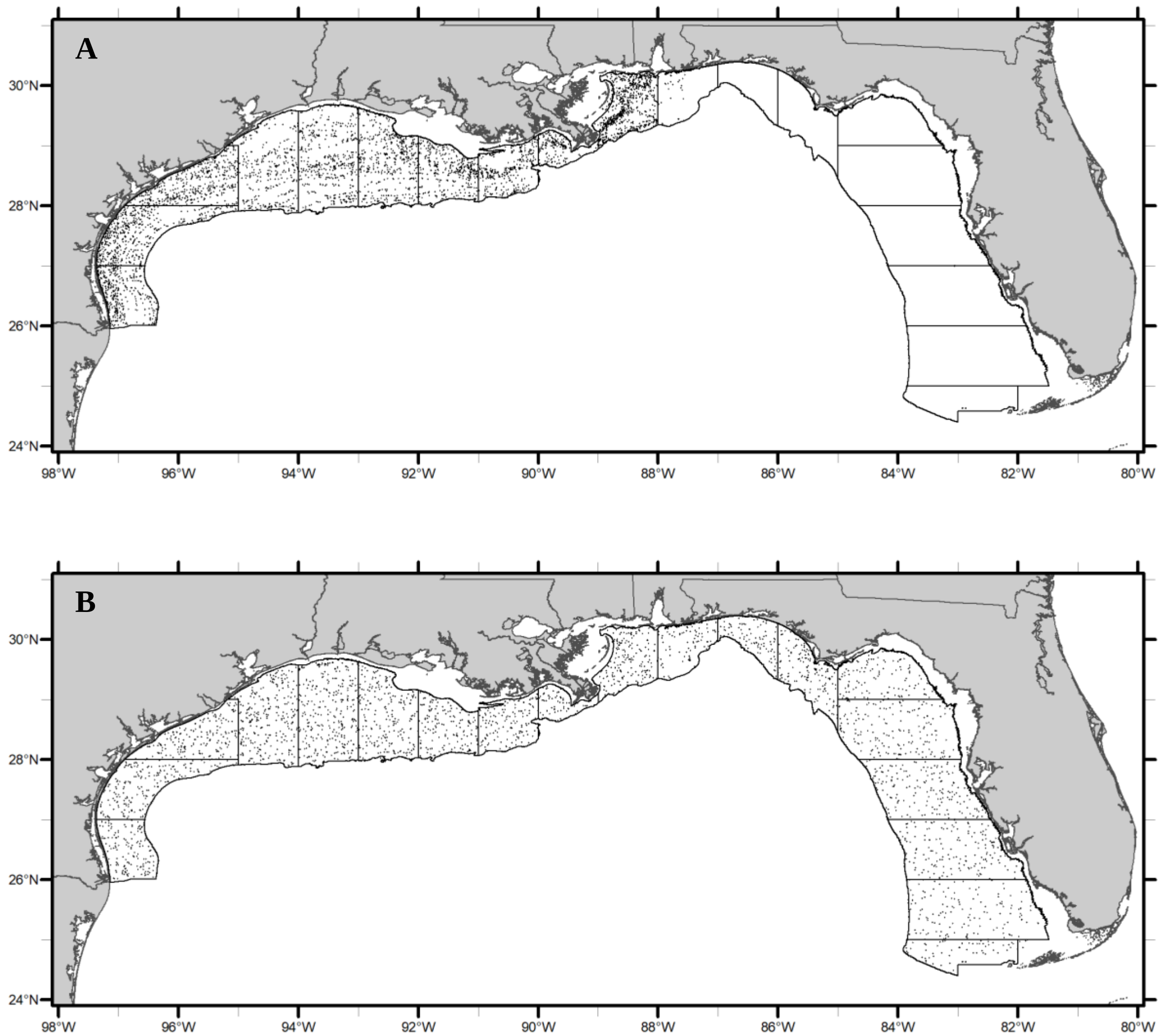


Figure 7. Distribution of stations sampled during the SEAMAP Fall Groundfish Survey from A. 1987 – 2007 (old design) and B. 2008 – 2018 (new design).

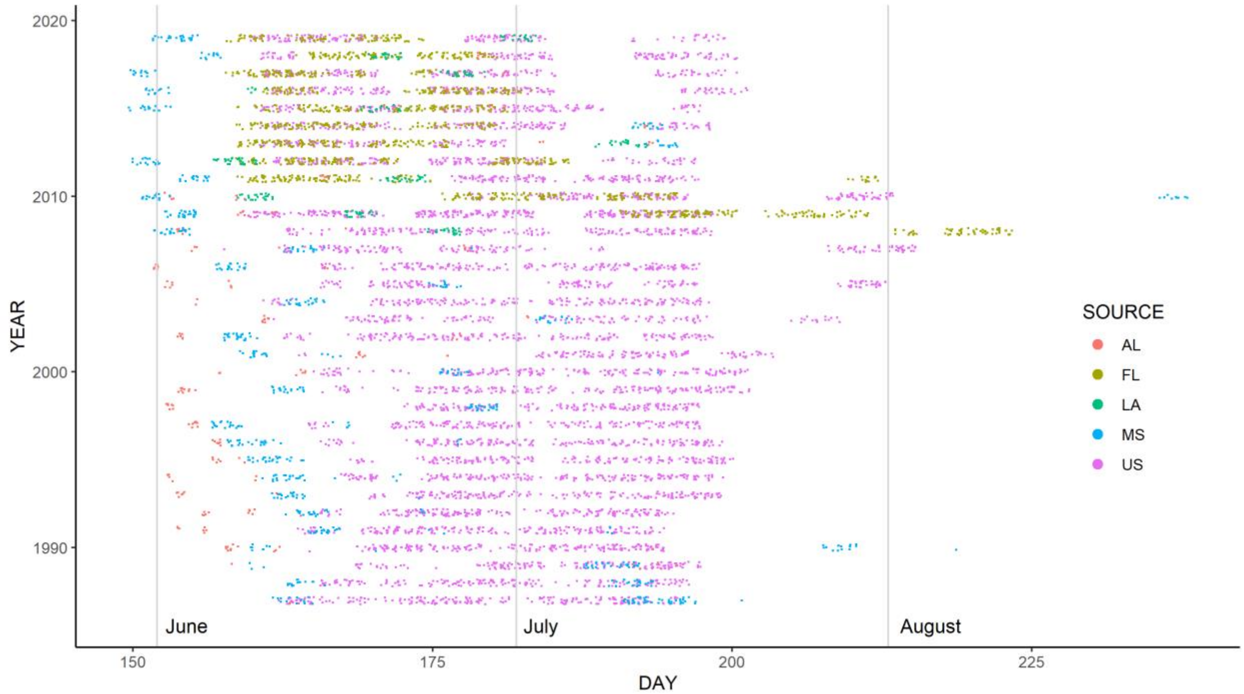


Figure 8. Timing of the SEAMAP Summer Groundfish Survey.

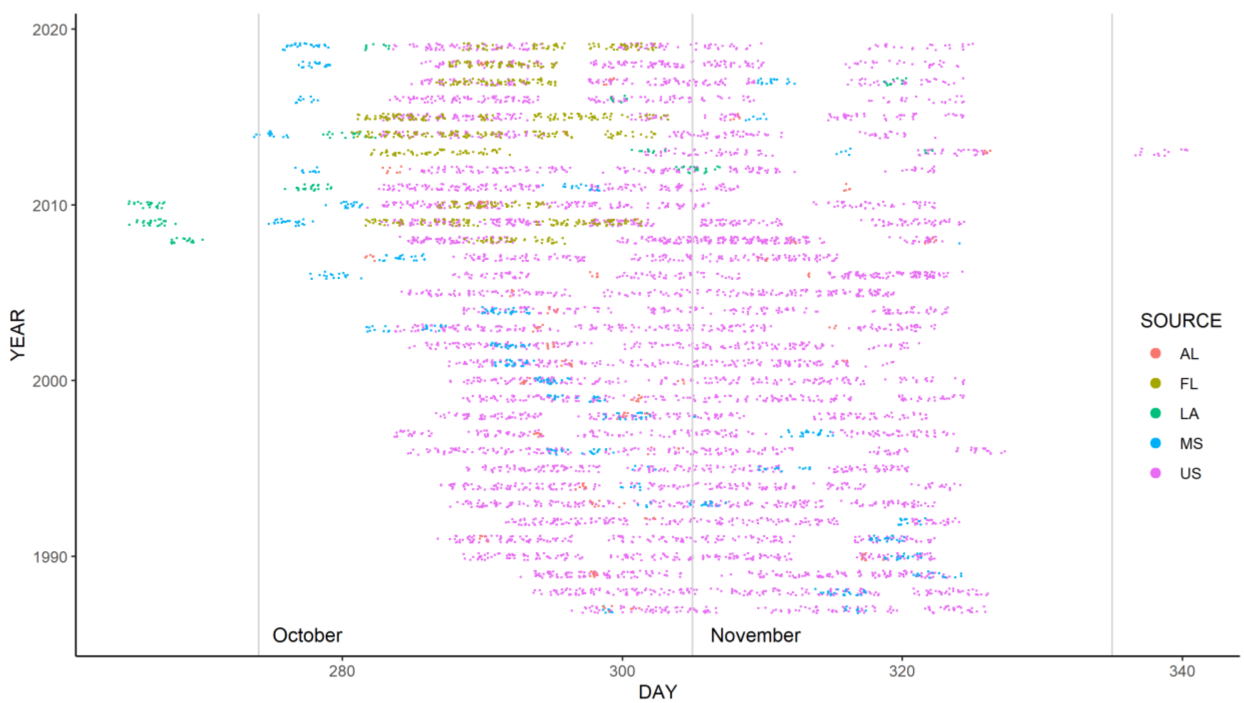


Figure 9. Timing of the SEAMAP Fall Groundfish Survey.

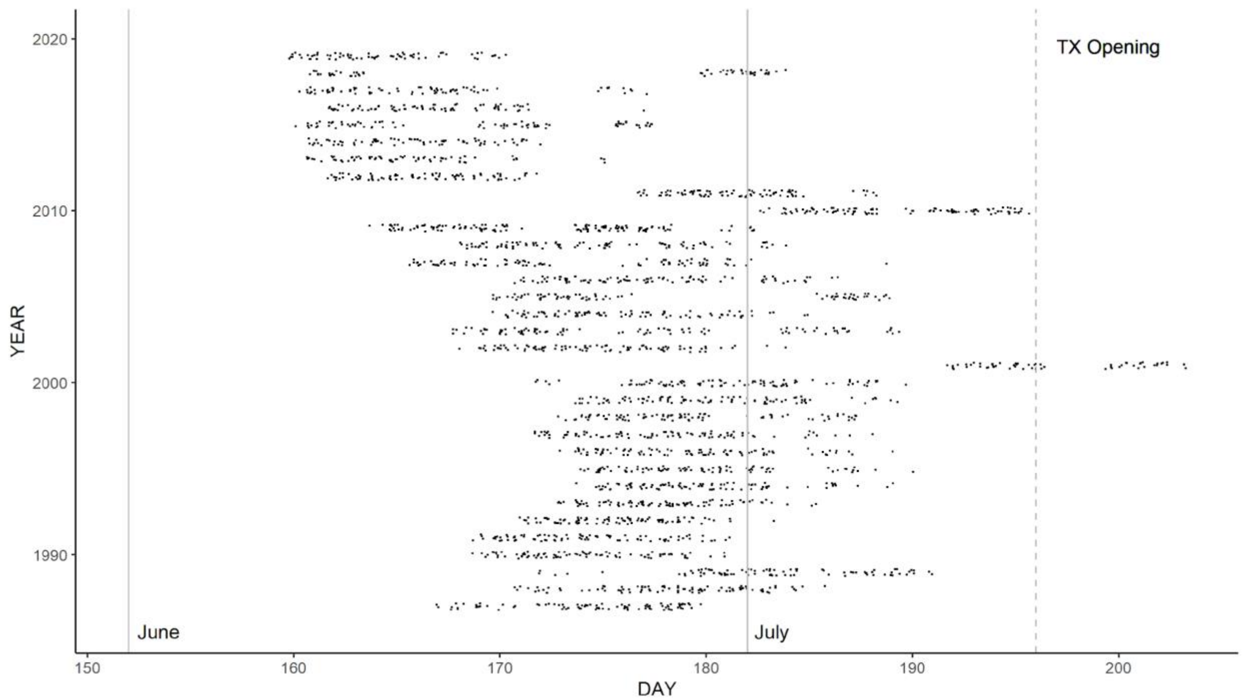


Figure 10. Timing of the Summer Survey with respect to the Texas (TX) opening of commercial shrimping. Note that the TX opening usually occurs on or around July 15th, but may differ slightly year to year.

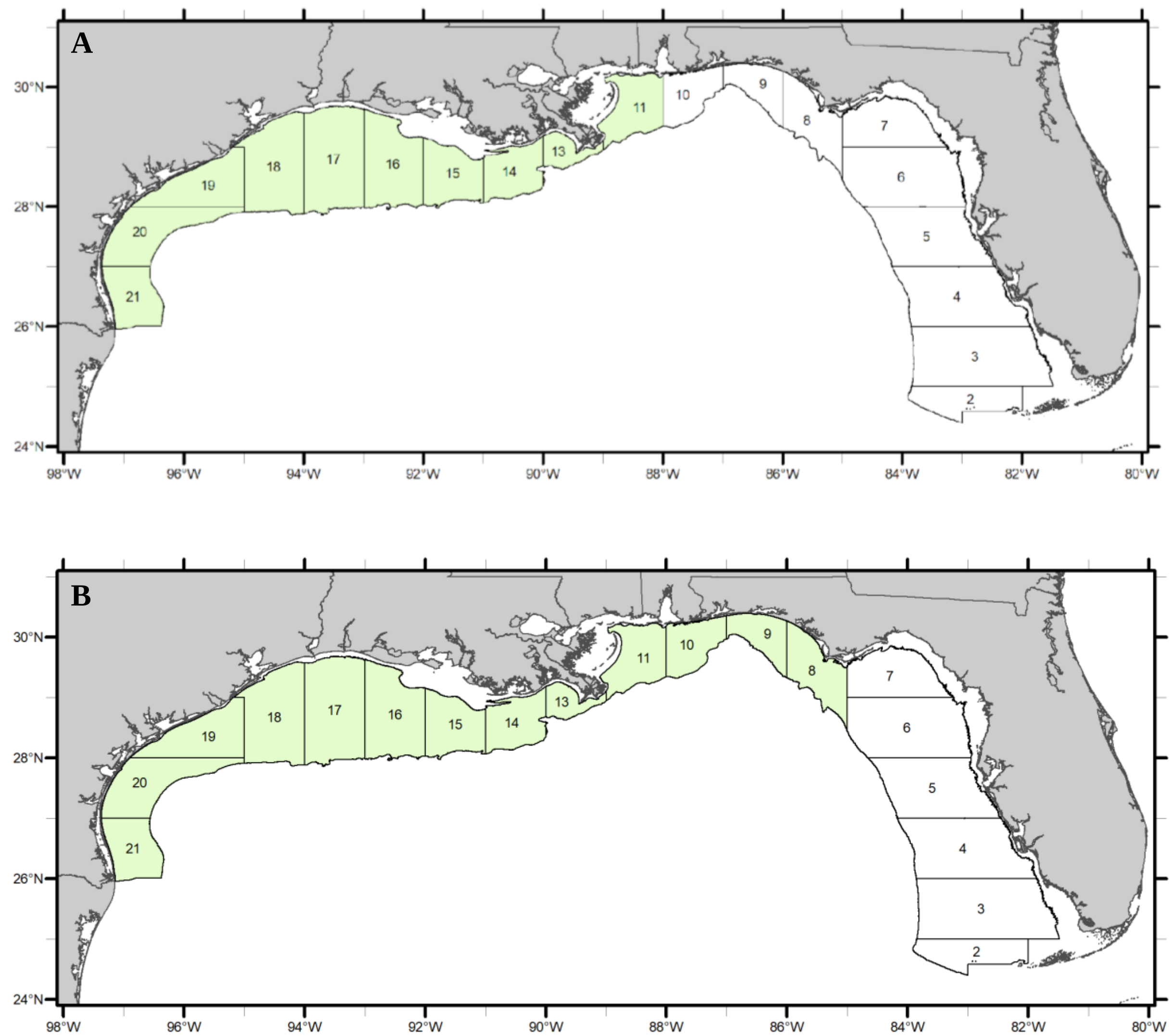


Figure 11. Spatial coverage of the SEAMAP Groundfish Survey for brown shrimp A. full time series, old survey design, B. new design.

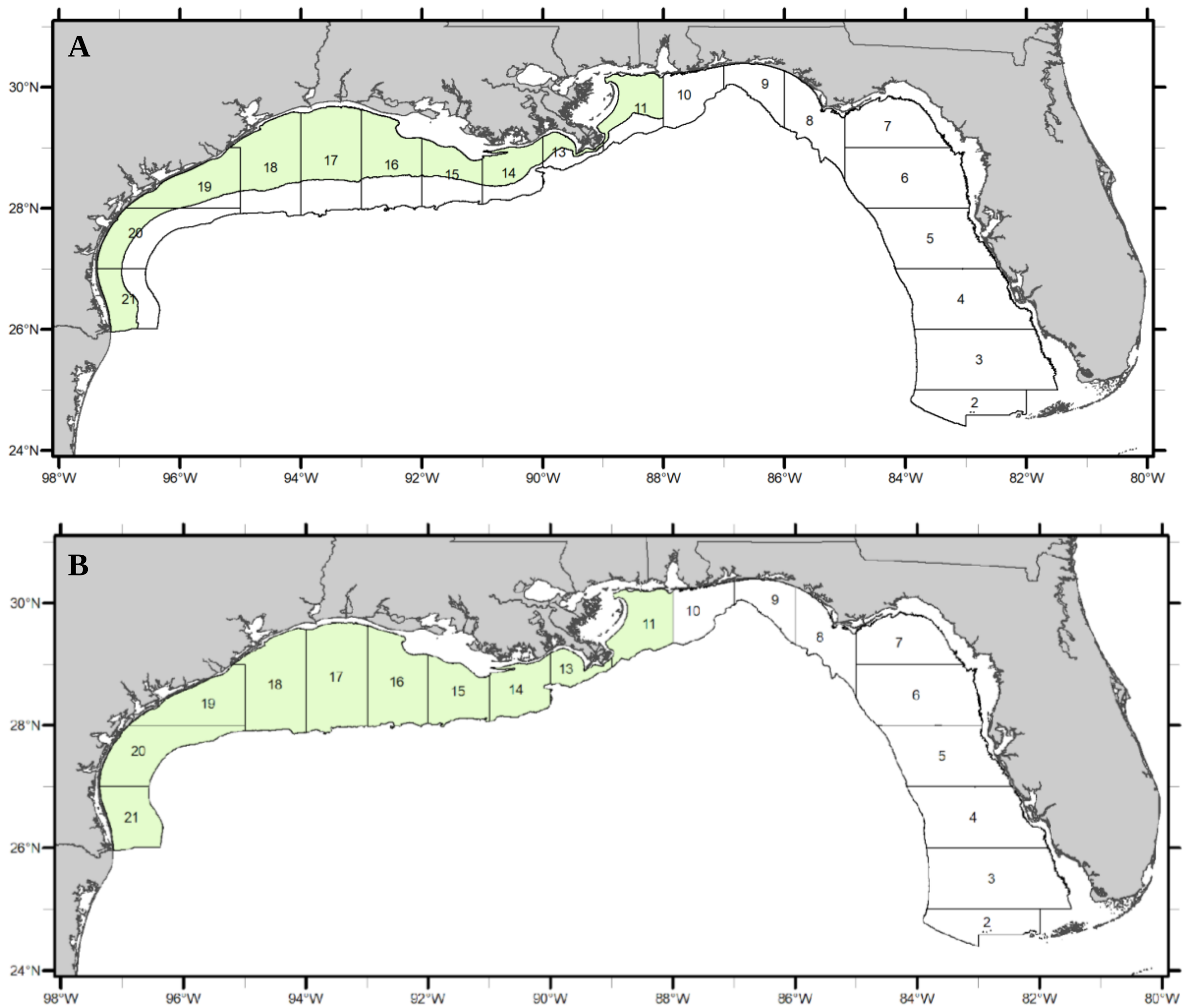


Figure 12. Spatial coverage of the SEAMAP Groundfish Survey for white shrimp A. full time series, old survey design, B. new design.

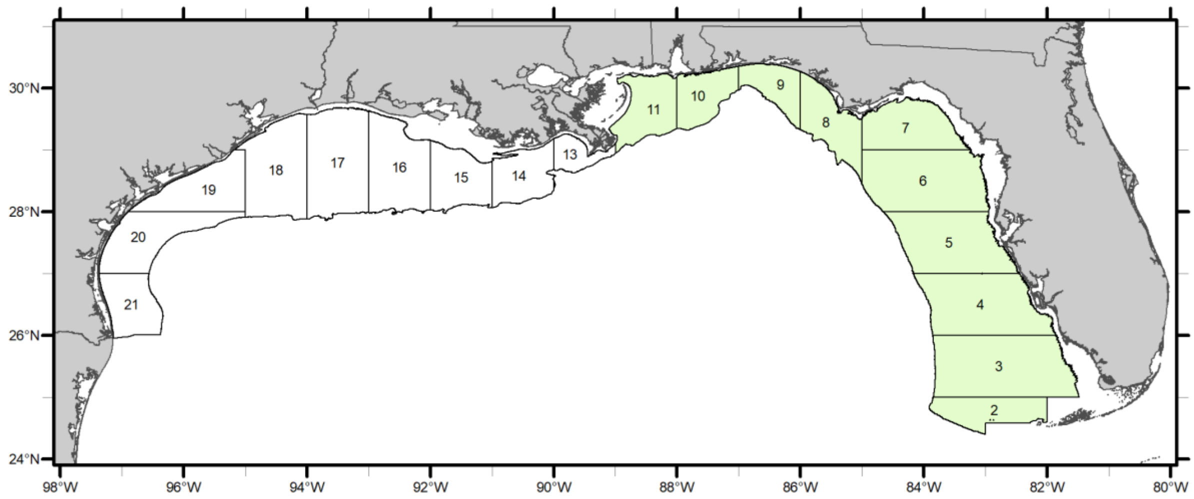


Figure 13. Spatial coverage of the SEAMAP Groundfish Survey for pink shrimp.

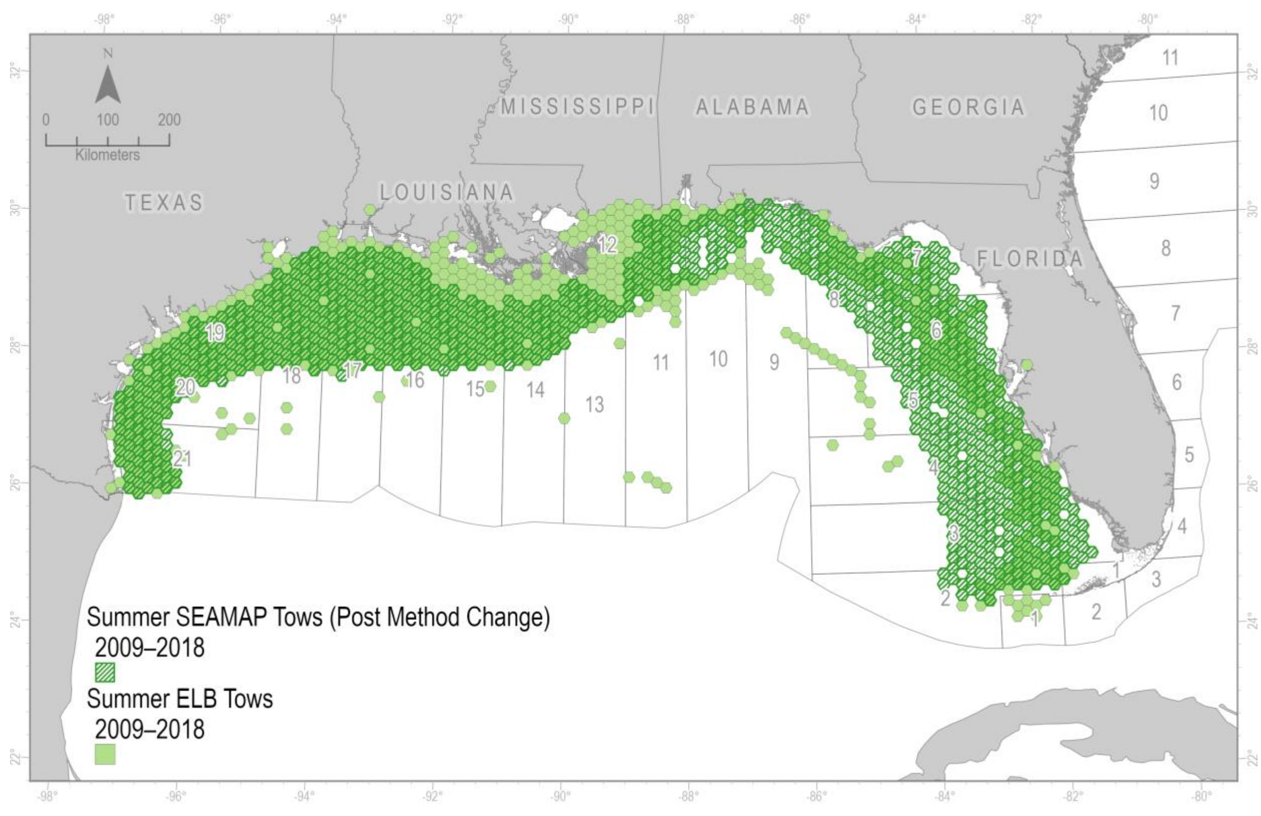


Figure 14. Summer comparison (showing tow presence), for post-method change years of the SEAMAP survey (2009-2018). Light colors represent ELB tows, warm colors represent SEAMAP tows

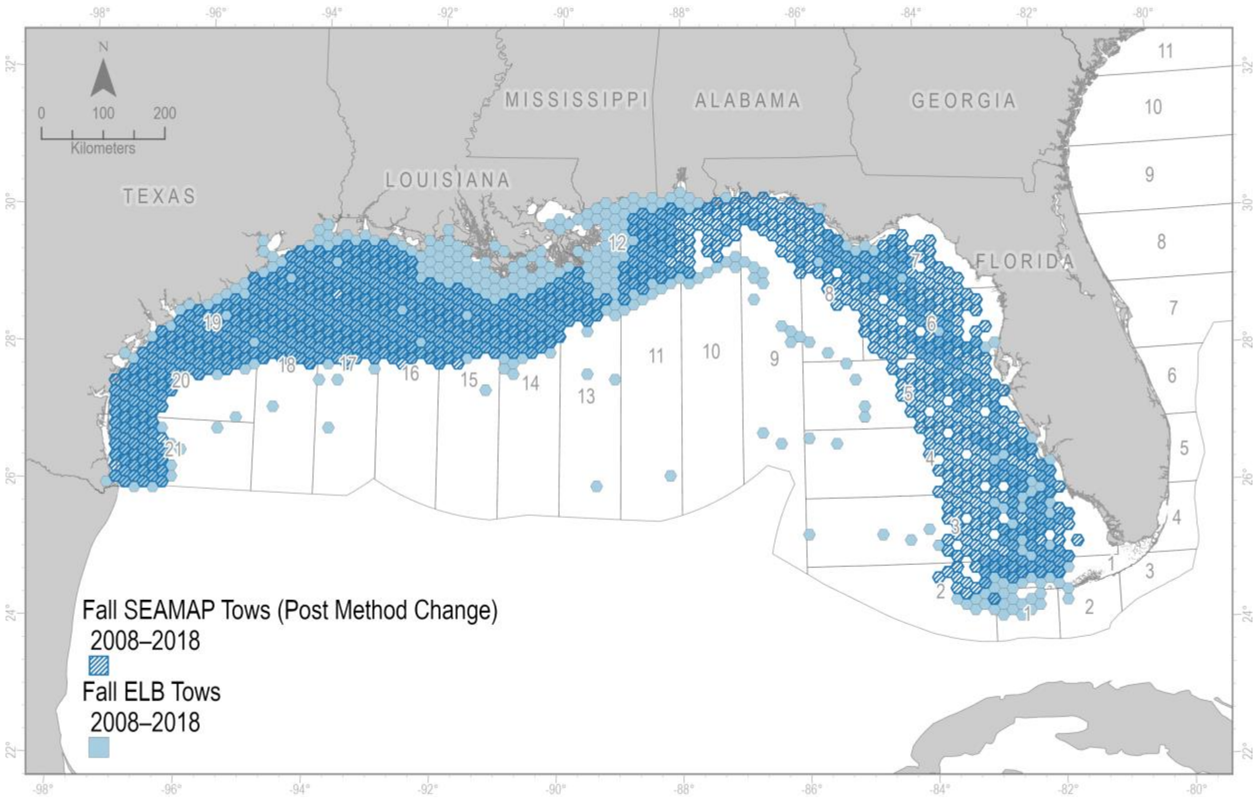


Figure 15. Fall comparison (showing tow presence), for post-method change years of the SEAMAP survey (2008-2018). Light colors represent ELB tows, warm colors represent SEAMAP tows

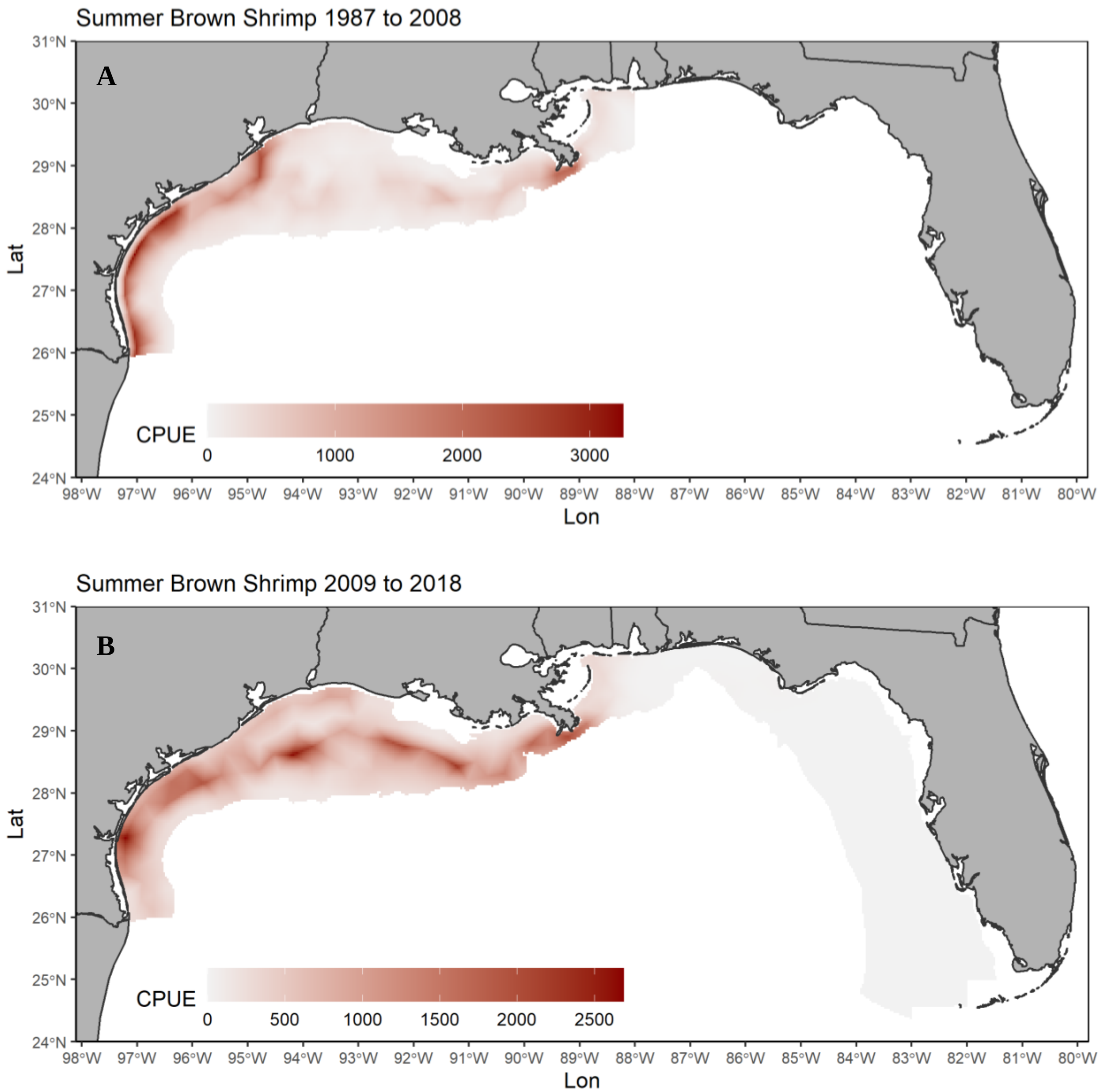


Figure 16. Distribution of brown shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Summer Groundfish Survey from A. 1987 – 2008 (old design) and B. 2009 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is implemented utilizing the package VAST within the R statistical environment.

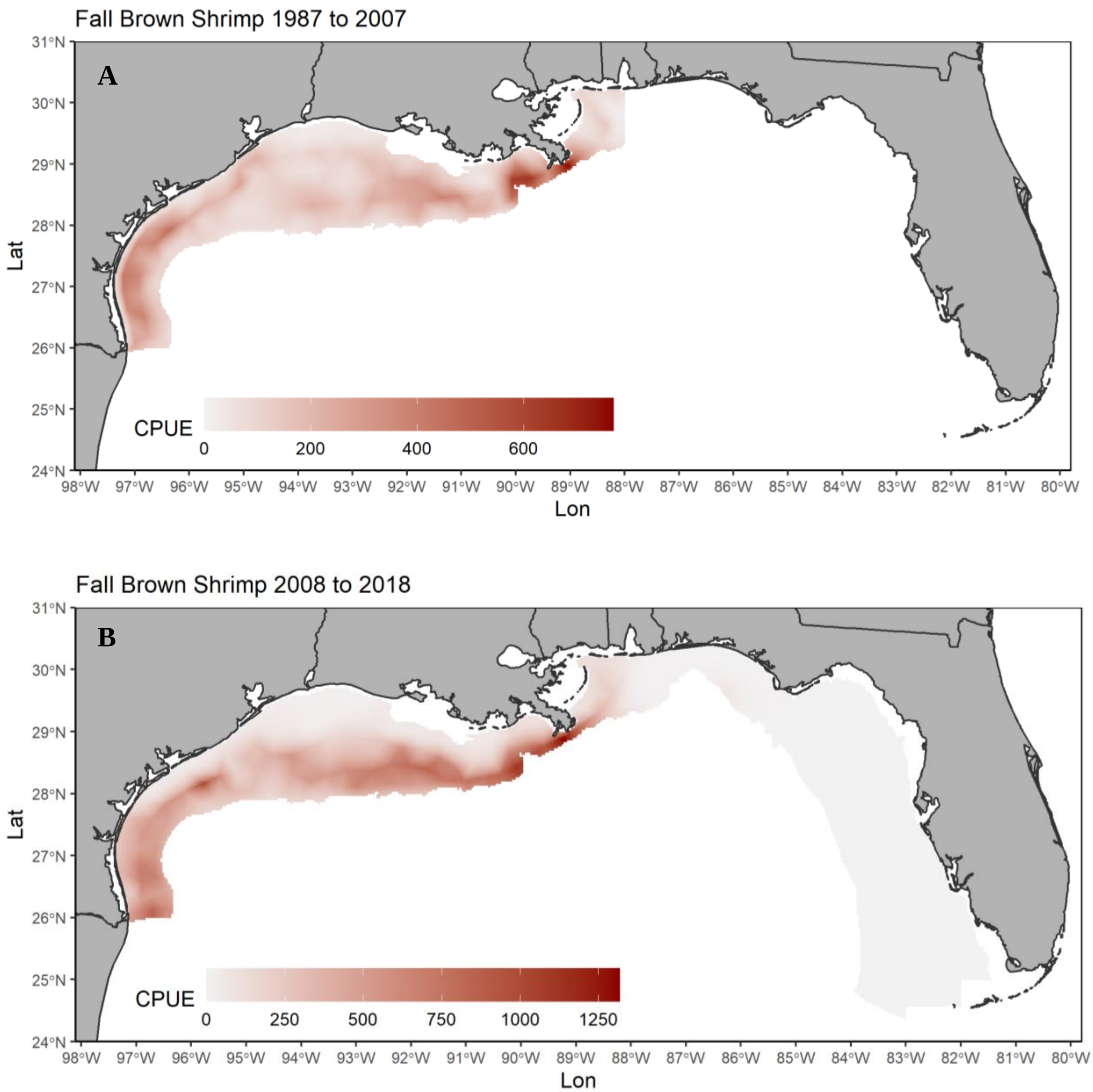


Figure 17. Distribution of brown shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Fall Groundfish Survey from A. 1987 – 2007 (old design) and B. 2008 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is implemented utilizing the package VAST within the R statistical environment.

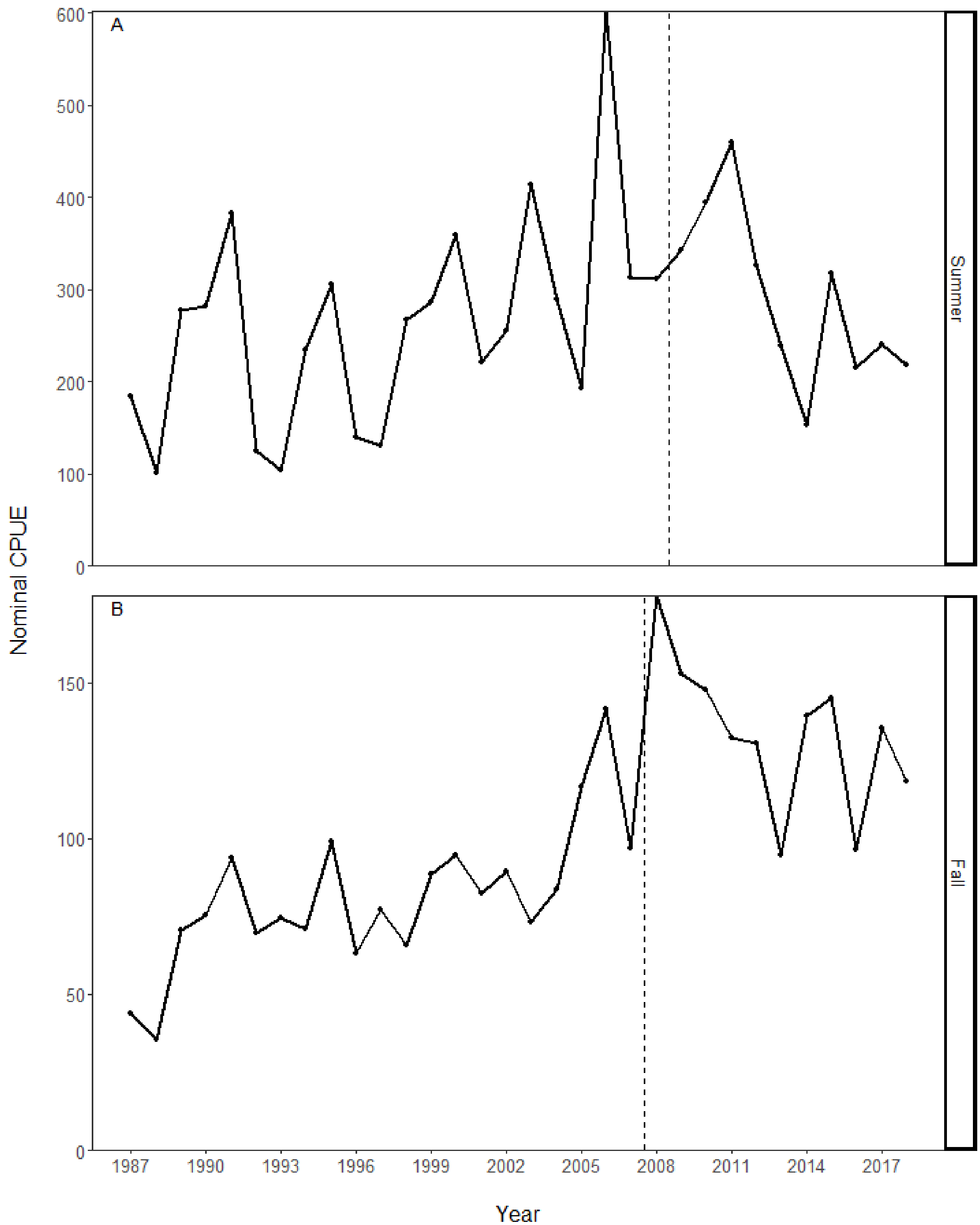


Figure 18. Nominal catch per unit effort (CPUE) of brown shrimp from the A. SEAMAP Summer Groundfish Survey and B. SEAMAP Fall Groundfish Survey. The dotted line denotes when the change in survey design was implemented for each survey.

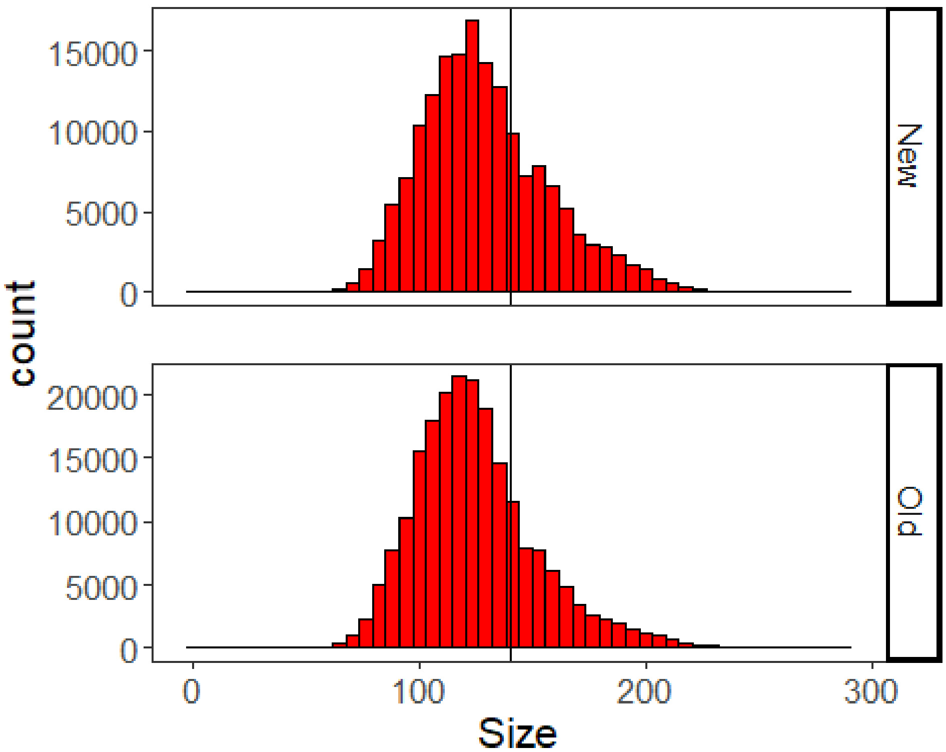


Figure 19. Length distribution of brown shrimp captured during the SEAMAP Summer Groundfish Survey under the old survey design (1987-2008) and the new survey design (2009-2018).

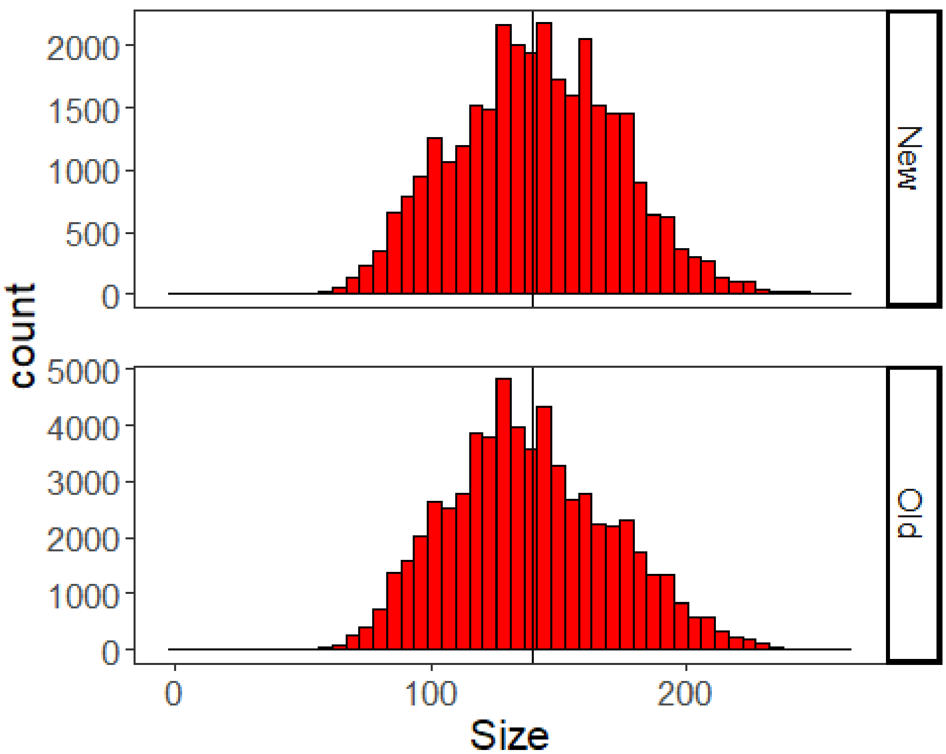


Figure 20. Length distribution of brown shrimp captured during the SEAMAP Fall Groundfish Survey under the old survey design (1987-2007) and the new survey design (2008-2018).

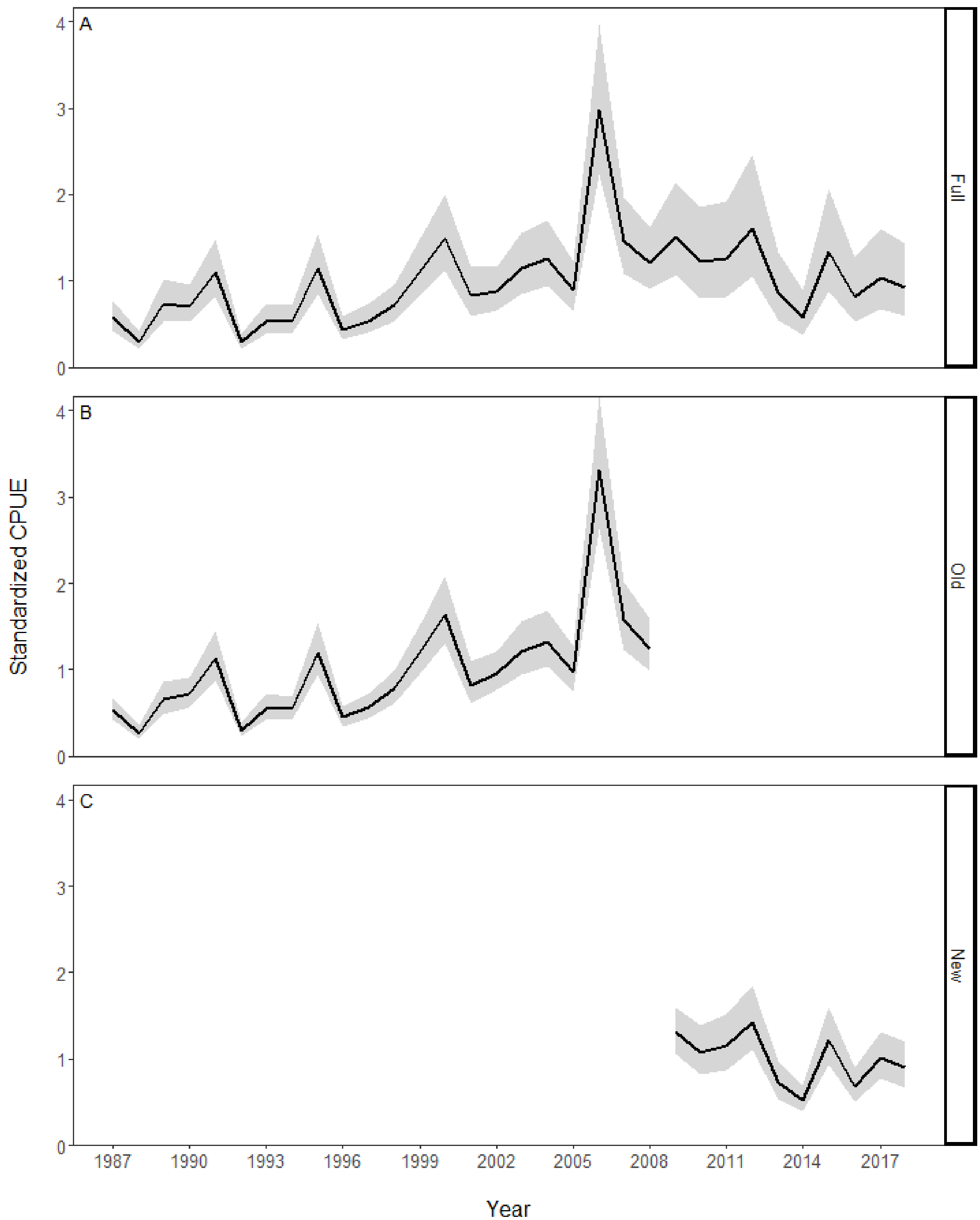


Figure 21. Annual index of abundance for brown shrimp from the SEAMAP Summer Groundfish Survey from A. 1987 – 2018 (full time series). B. 1987 – 2008 (old design), and C. 2009 – 2018 (new design).

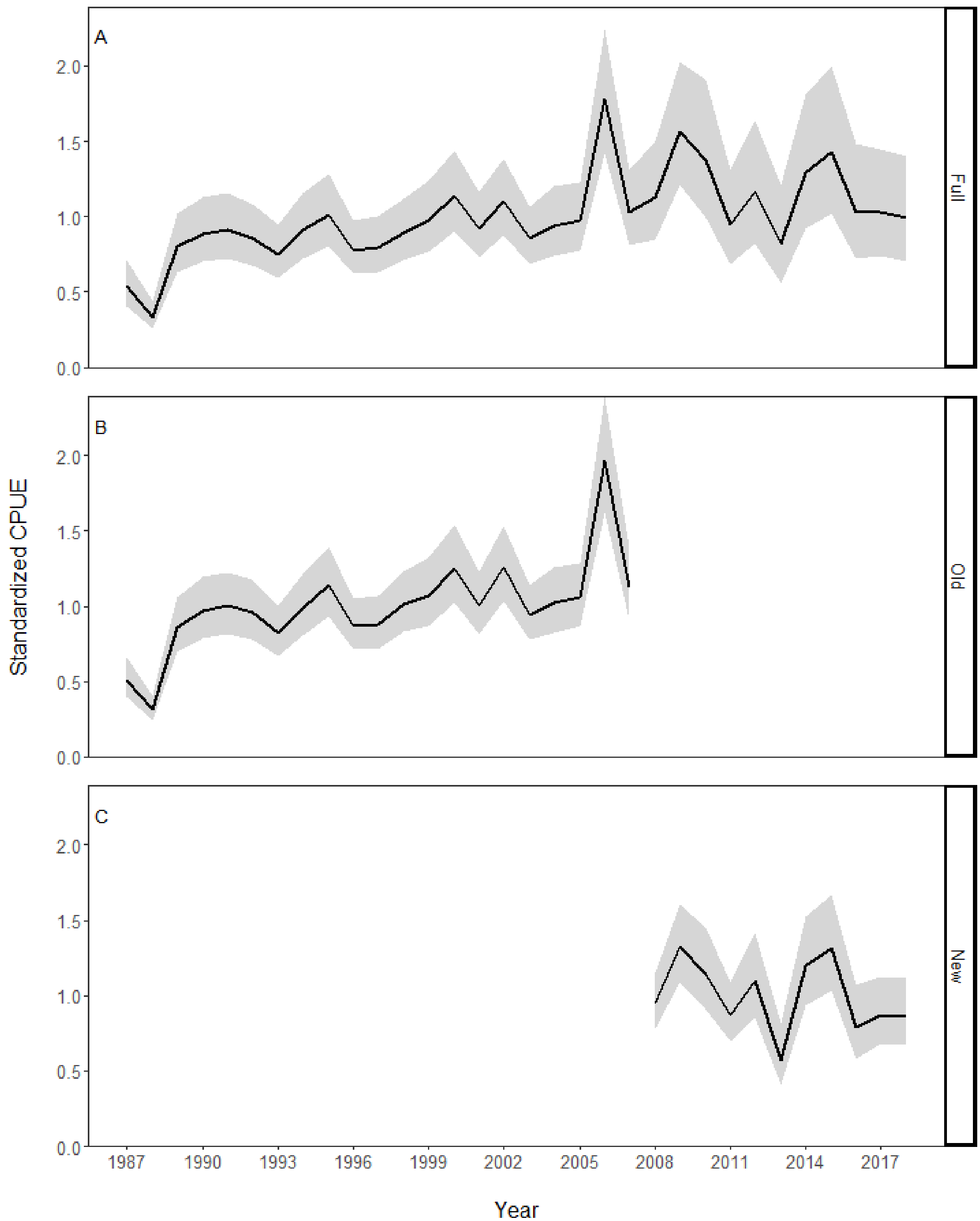


Figure 22. Annual index of abundance for brown shrimp from the SEAMAP Fall Groundfish Survey from A. 1987 – 2018 (full time series). B. 1987 – 2007 (old design), and C. 2008 – 2018 (new design).

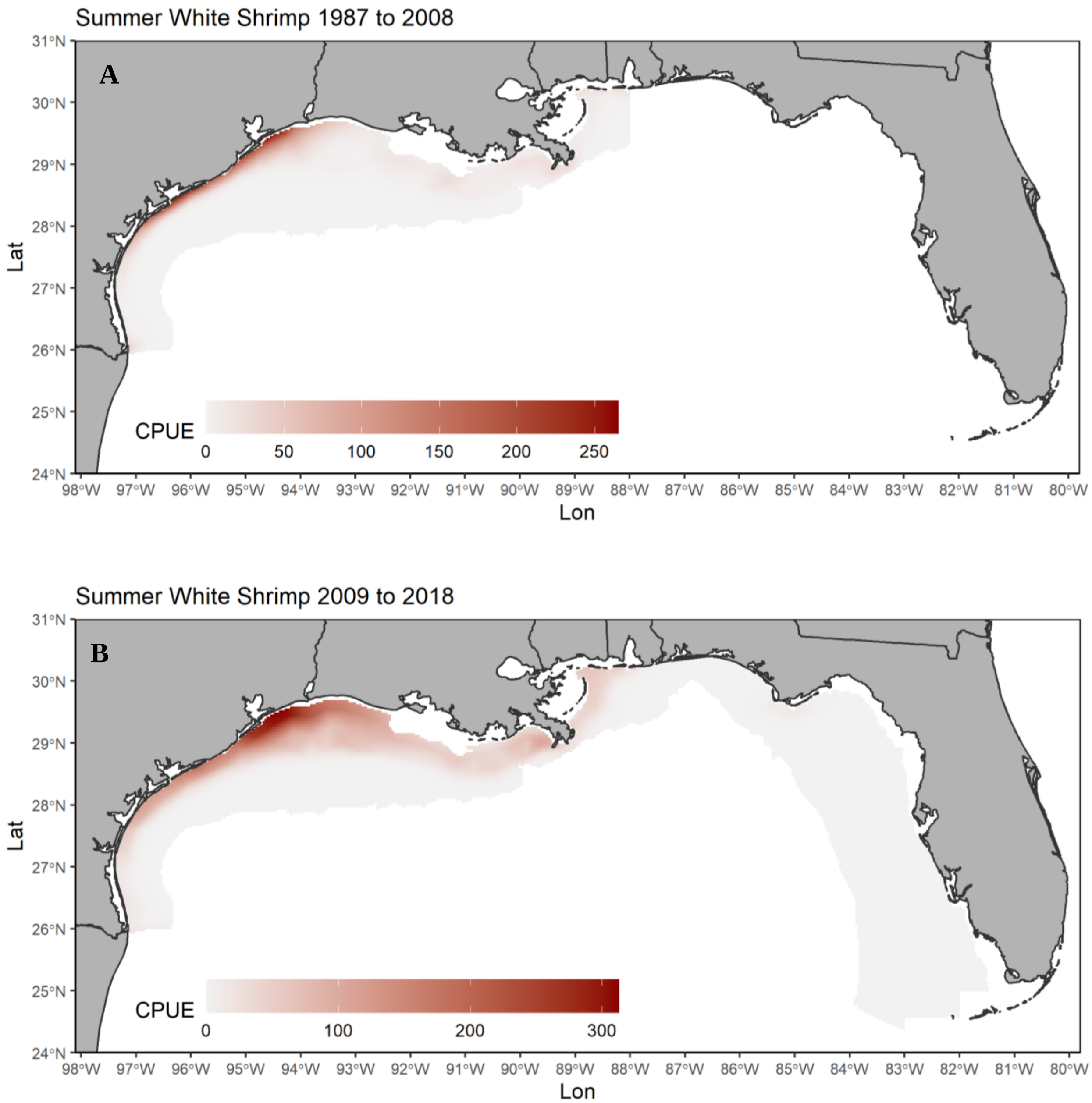


Figure 23. Distribution of white shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Summer Groundfish Survey from A. 1987 – 2008 (old design) and B. 2009 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is implemented utilizing the package VAST within the R statistical environment.

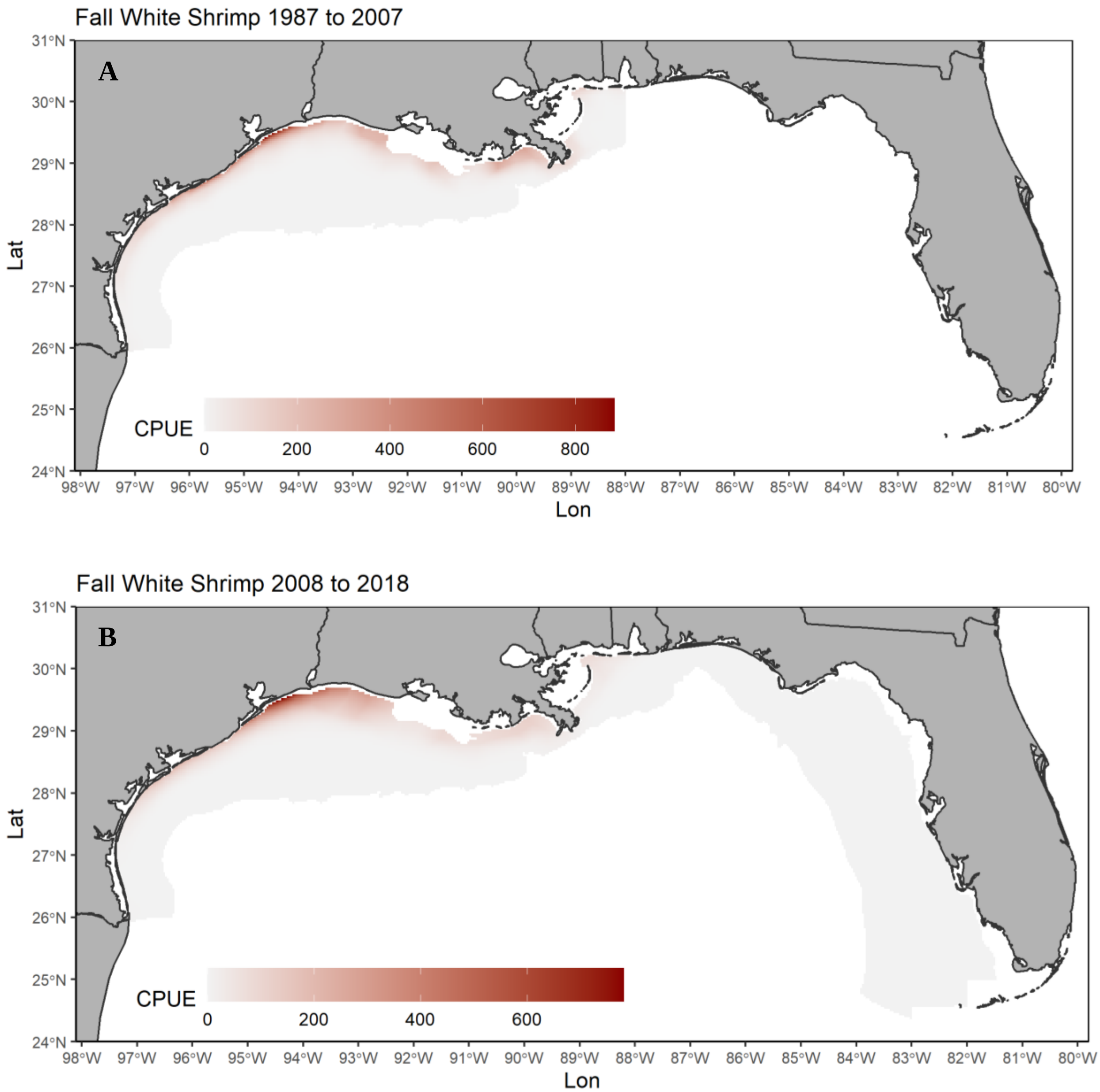


Figure 24. Distribution of white shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Fall Groundfish Survey from A. 1987 – 2007 (old design) and B. 2008 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is implemented utilizing the package VAST within the R statistical environment.

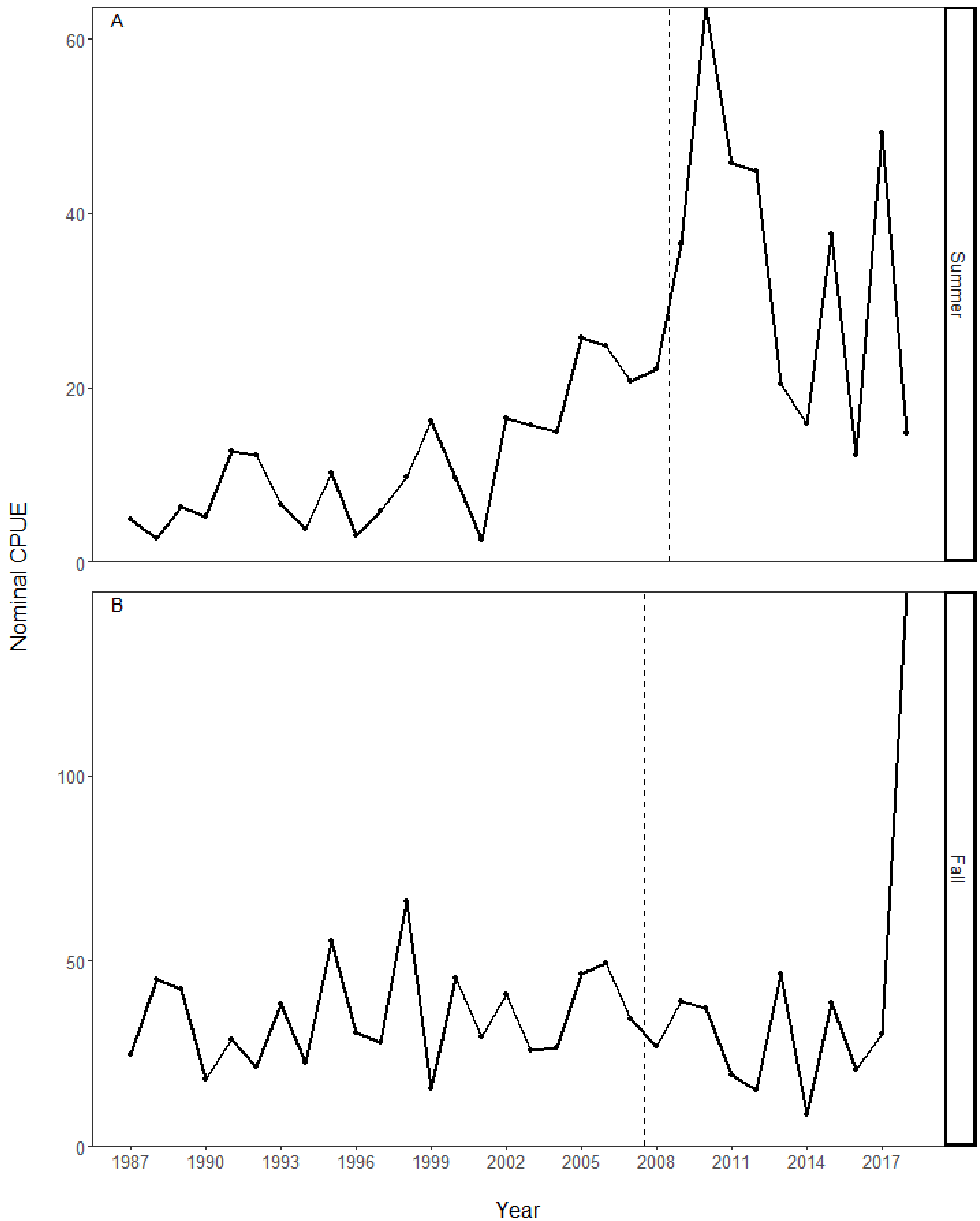


Figure 25. Nominal catch per unit effort (CPUE) of white shrimp from the A. SEAMAP Summer Groundfish Survey and B. SEAMAP Fall Groundfish Survey. The dotted line denotes when the change in survey design was implemented for each survey.

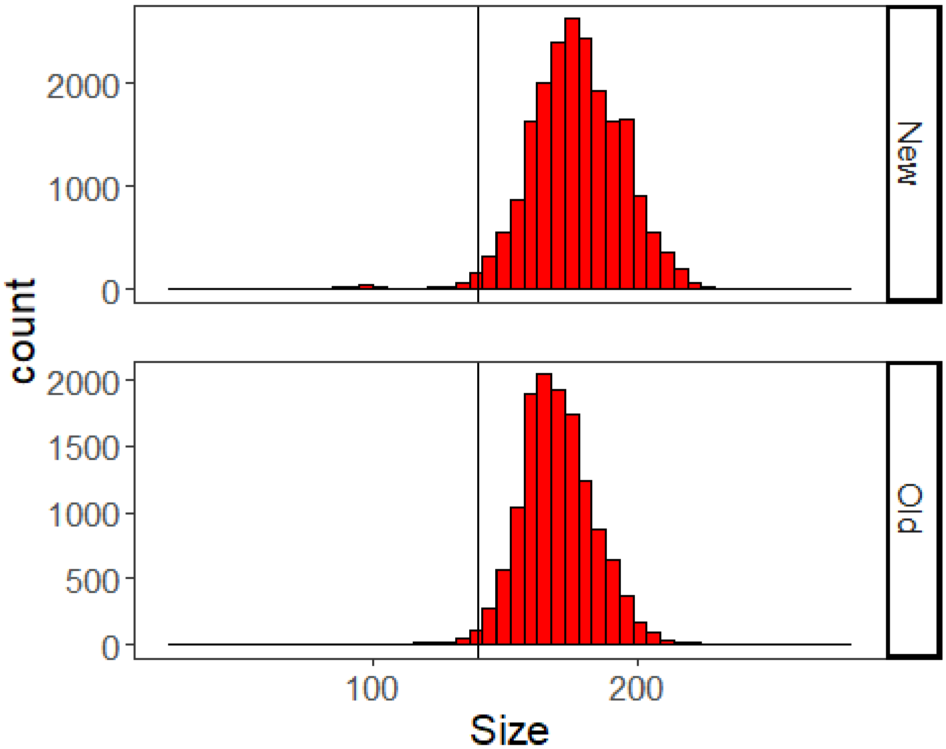


Figure 26. Length distribution of white shrimp captured during the SEAMAP Summer Groundfish Survey under the old survey design (1987-2008) and the new survey design (2009-2018).

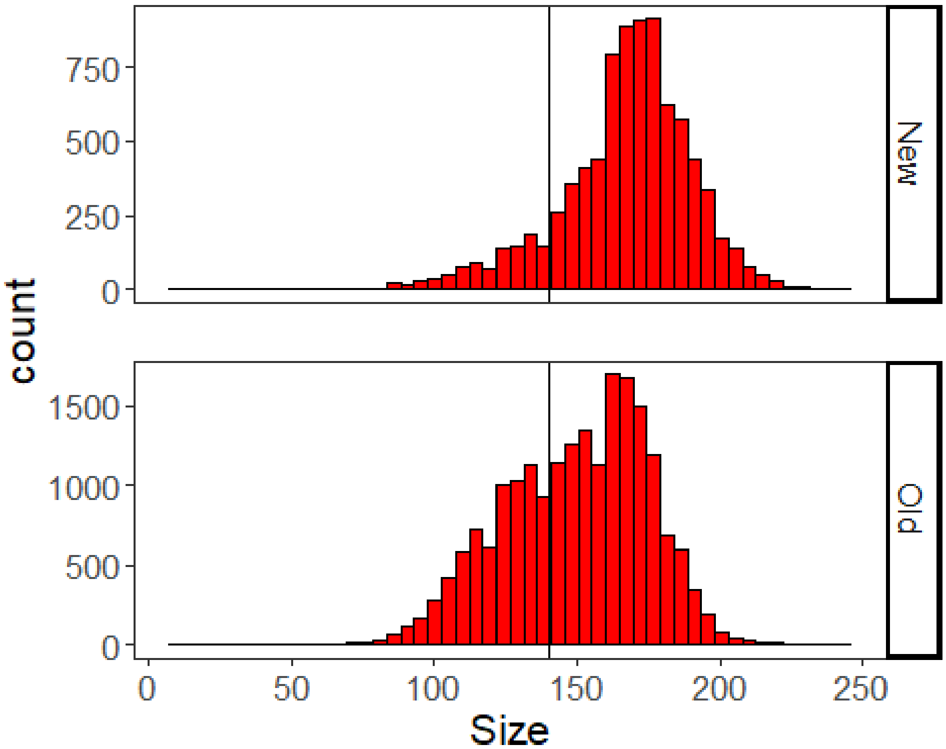


Figure 27. Length distribution of white shrimp captured during the SEAMAP Fall Groundfish Survey under the old survey design (1987-2007) and the new survey design (2008-2018).

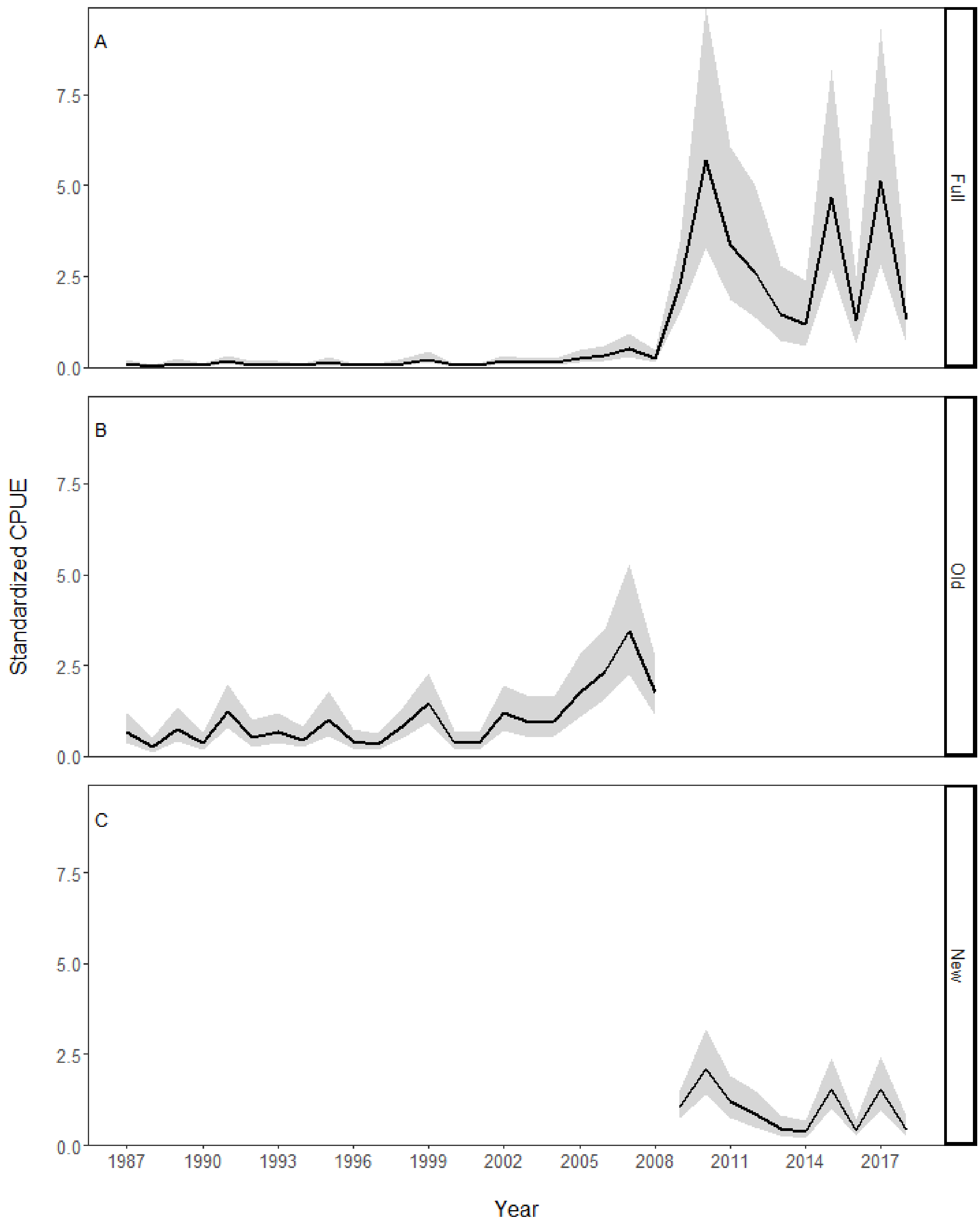


Figure 28. Annual index of abundance for white shrimp from the SEAMAP Summer Groundfish Survey from A. 1987 – 2018 (full time series). B. 1987 – 2008 (old design), and C. 2009 – 2018 (new design).

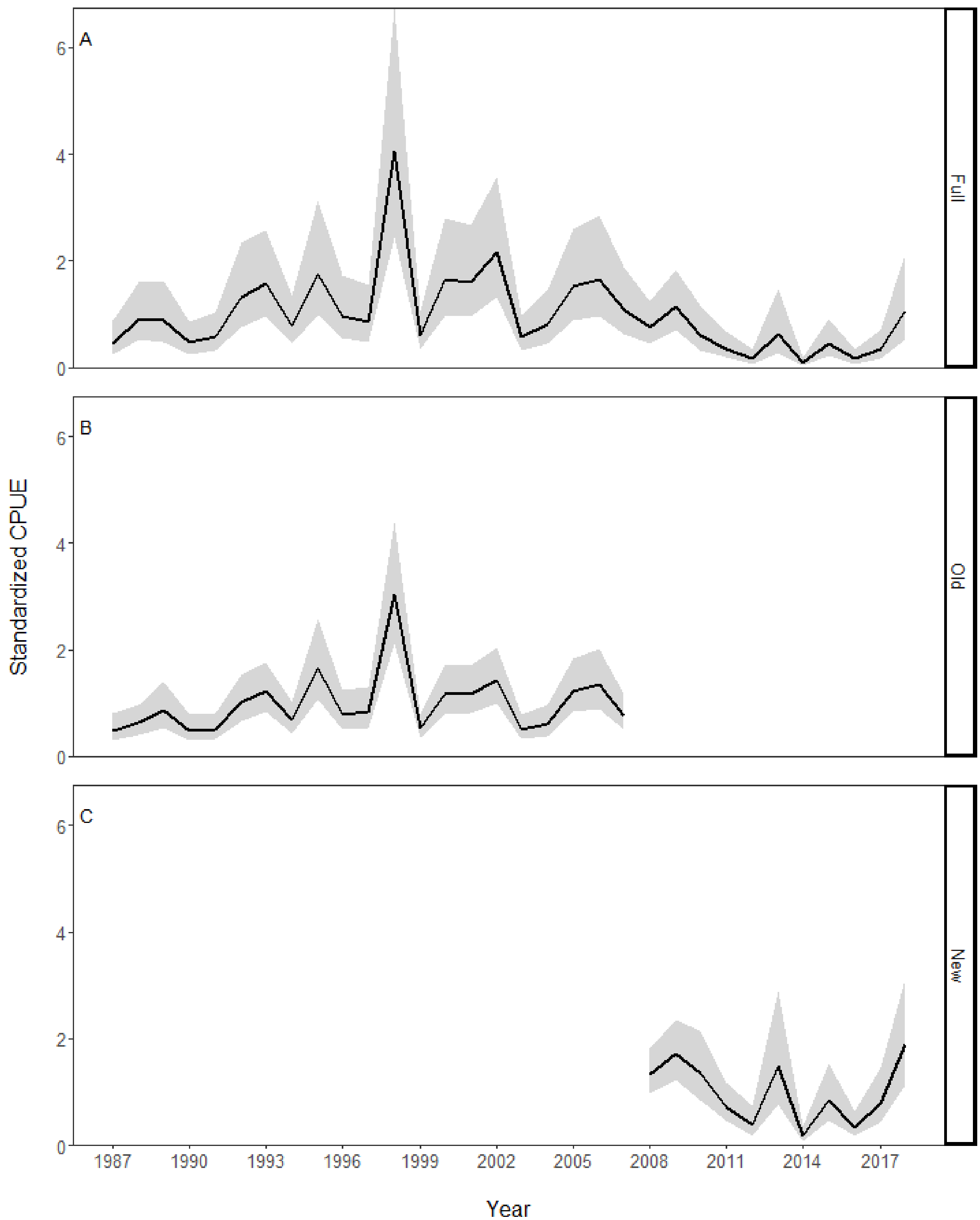


Figure 29. Annual index of abundance for white shrimp from the SEAMAP Fall Groundfish Survey from A. 1987 – 2018 (full time series). B. 1987 – 2007 (old design), and C. 2008 – 2018 (new design).

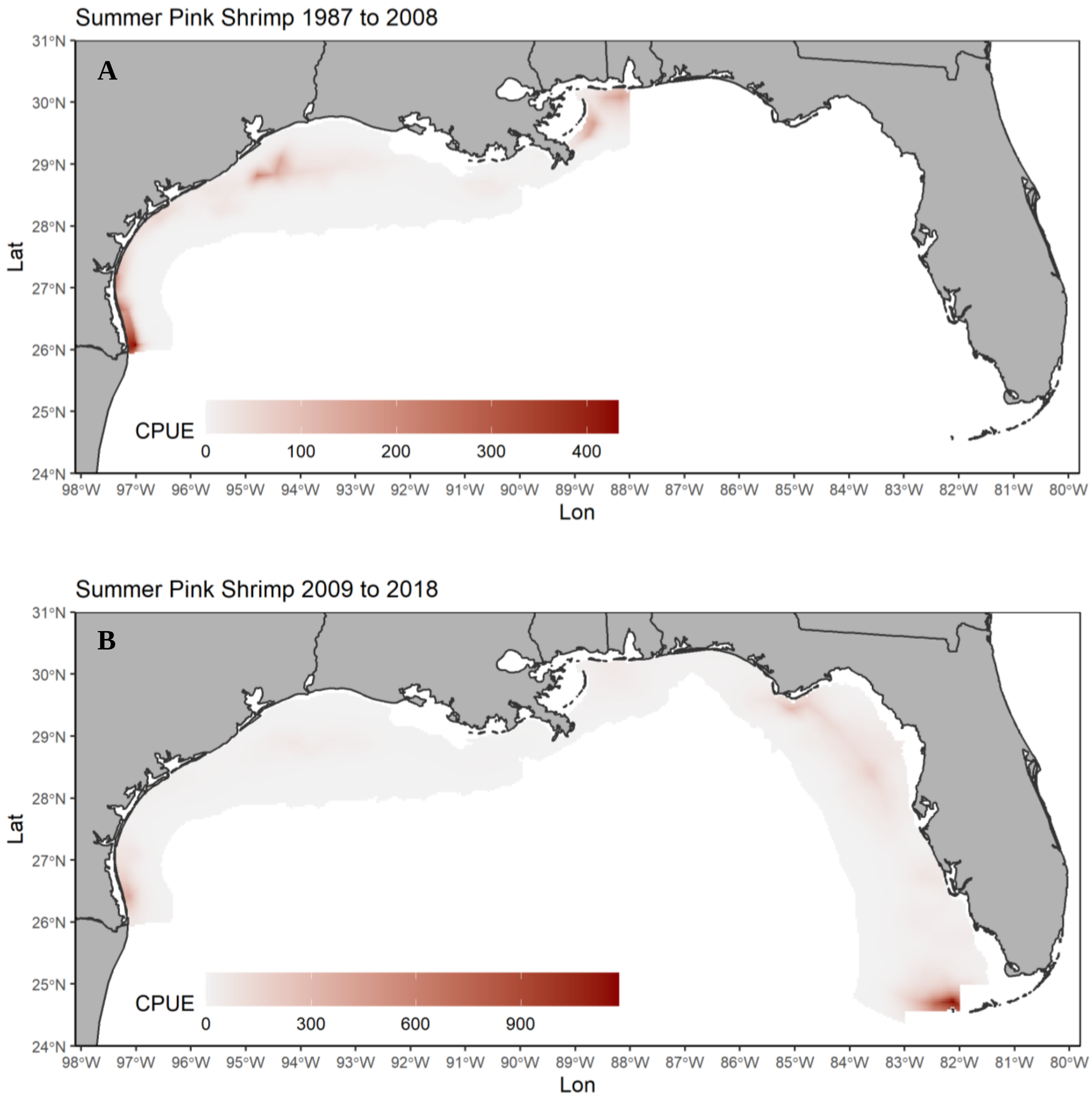


Figure 30. Distribution of pink shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Summer Groundfish Survey from A. 1987 – 2008 (old design) and B. 2009 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is mplemented utilizing the package VAST within the R statistical environment.

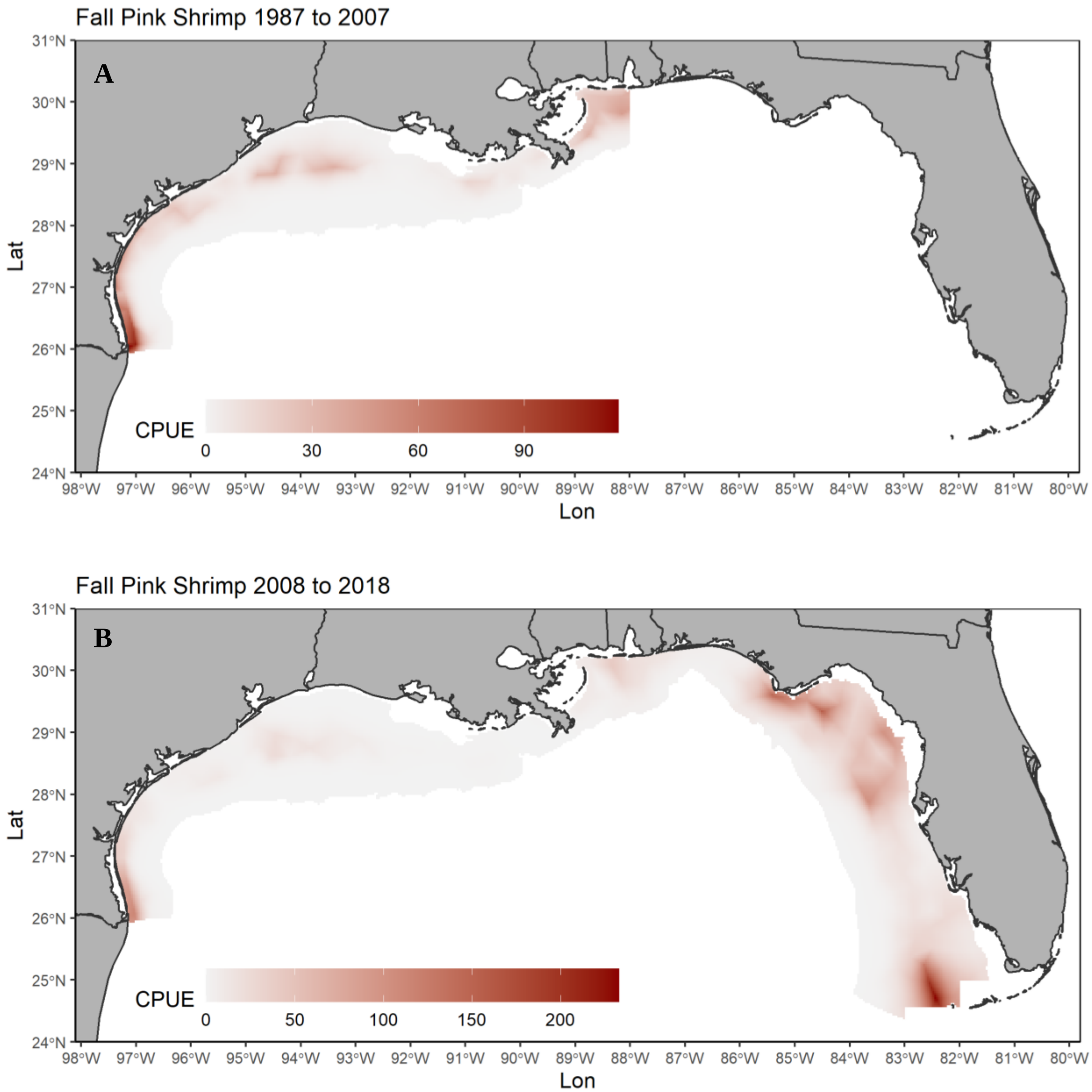


Figure 31. Distribution of pink shrimp relative catch per unit effort (CPUE) in numbers caught per one-hour tow taken during the SEAMAP Fall Groundfish Survey from A. 1987 – 2007 (old design) and B. 2008 – 2018 (new design). The distribution of CPUE is estimated utilizing a delta-lognormal spatial generalized linear mixed model. The model is implemented utilizing the package VAST within the R statistical environment.

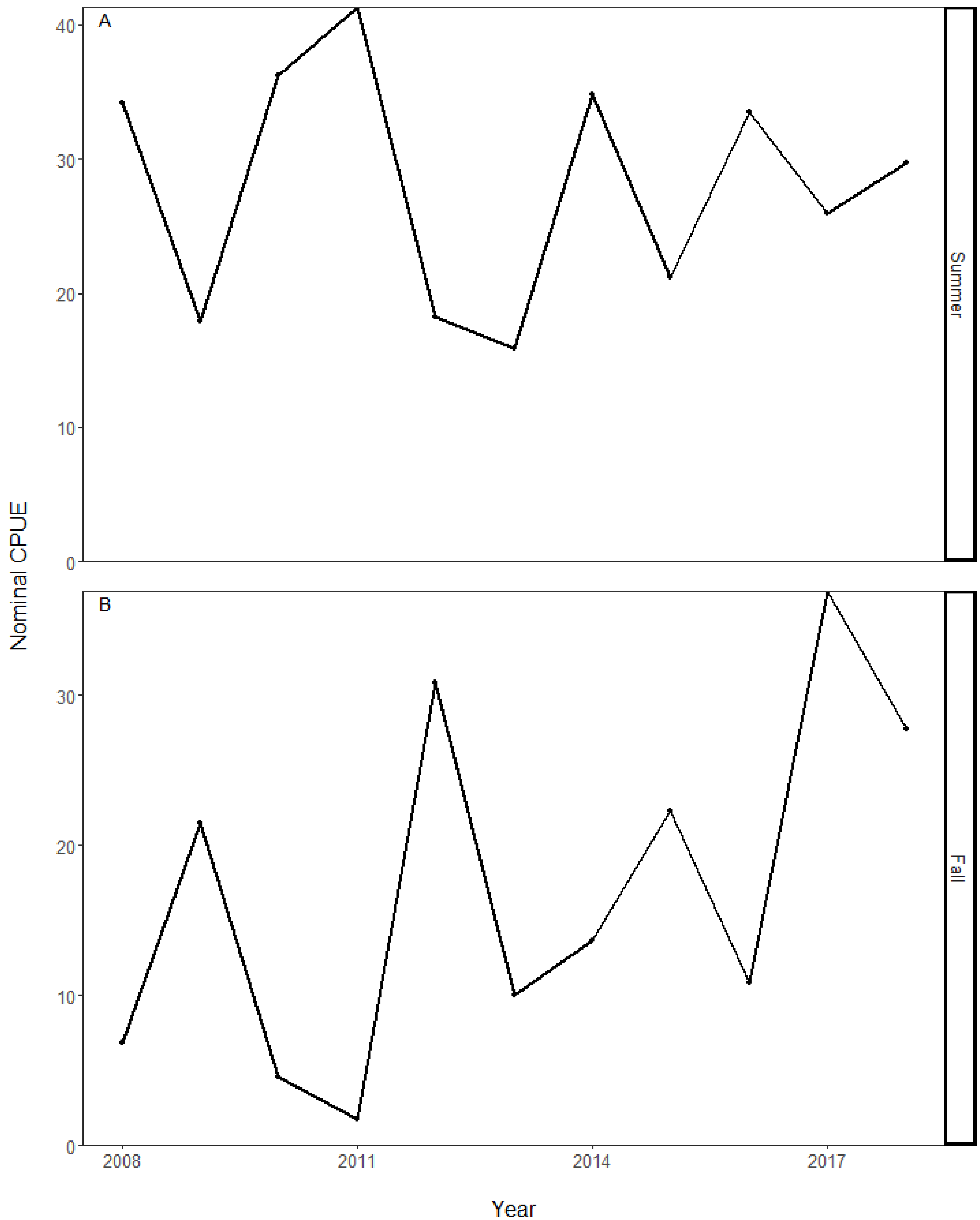


Figure 32. Nominal catch per unit effort (CPUE) of pink shrimp from the A. SEAMAP Summer Groundfish Survey and B. SEAMAP Fall Groundfish Survey.

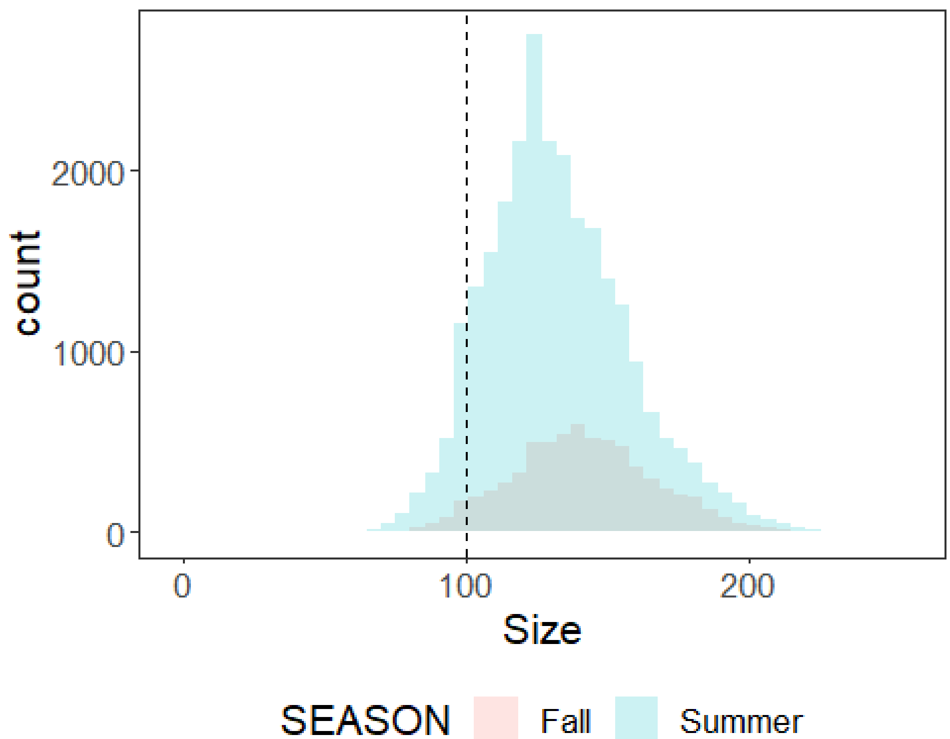


Figure 33. Length distribution of pink shrimp captured during the SEAMAP Summer and Fall Groundfish Surveys from 2009-2018.

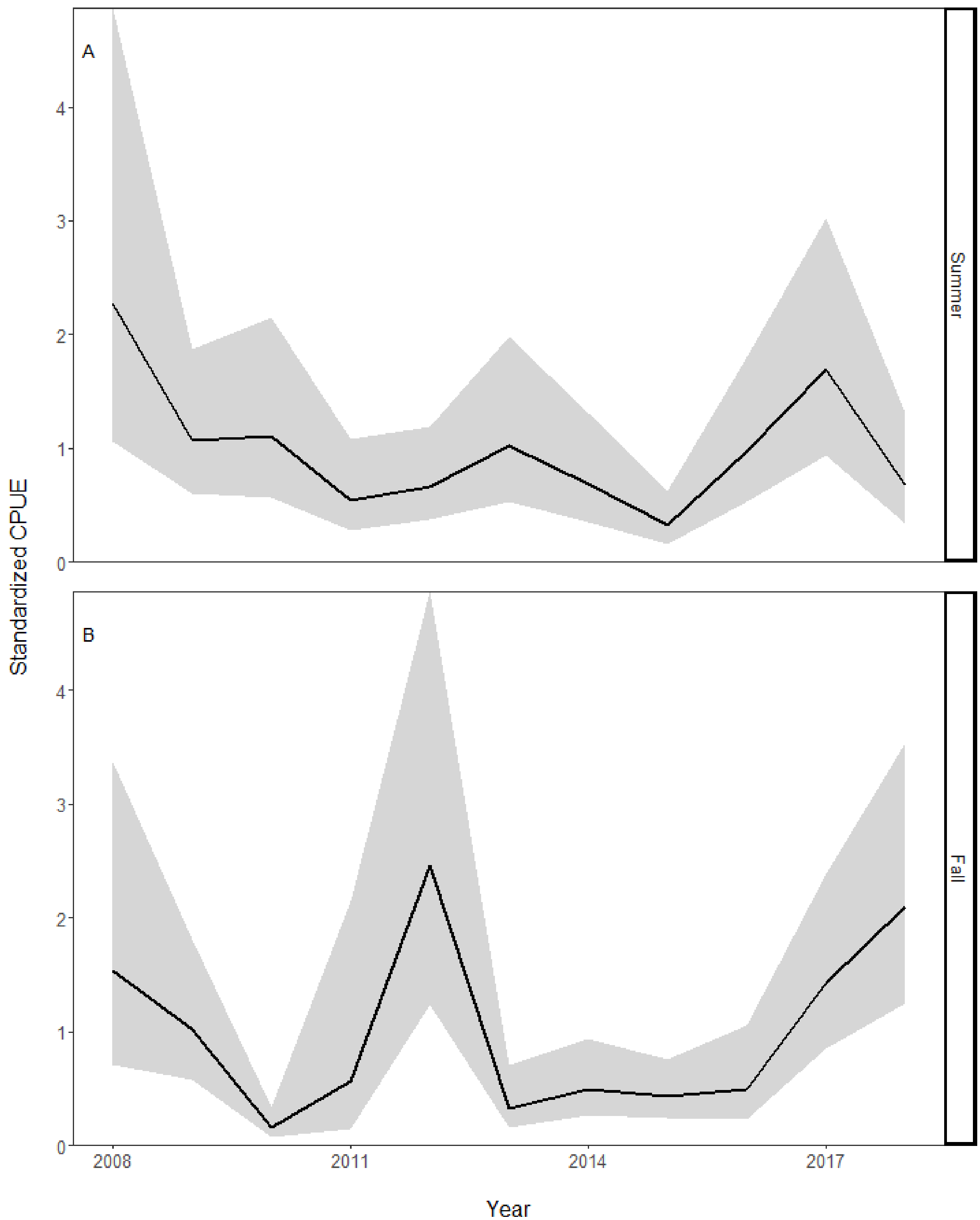


Figure 34 Annual index of abundance for pink shrimp from the A. SEAMAP Summer Groundfish Survey and B. SEAMAP Fall Groundfish Survey.

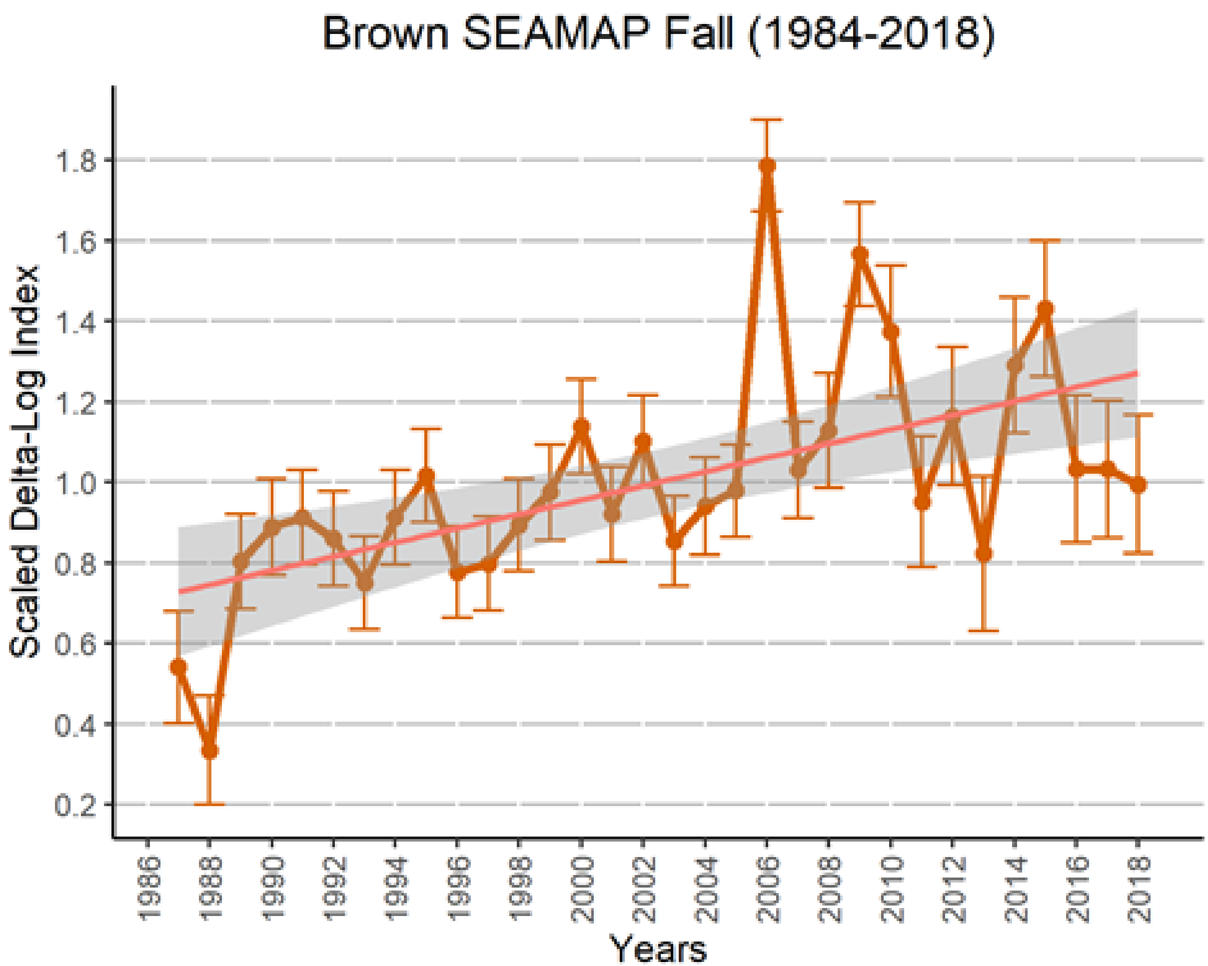


Figure 35. Historical use of the Brown Shrimp SEAMAP Fall Index of Abundance in the Gulf of Mexico's Brown Shrimp stock assessment model - a continuous model (no split for pre- and post-method change years)

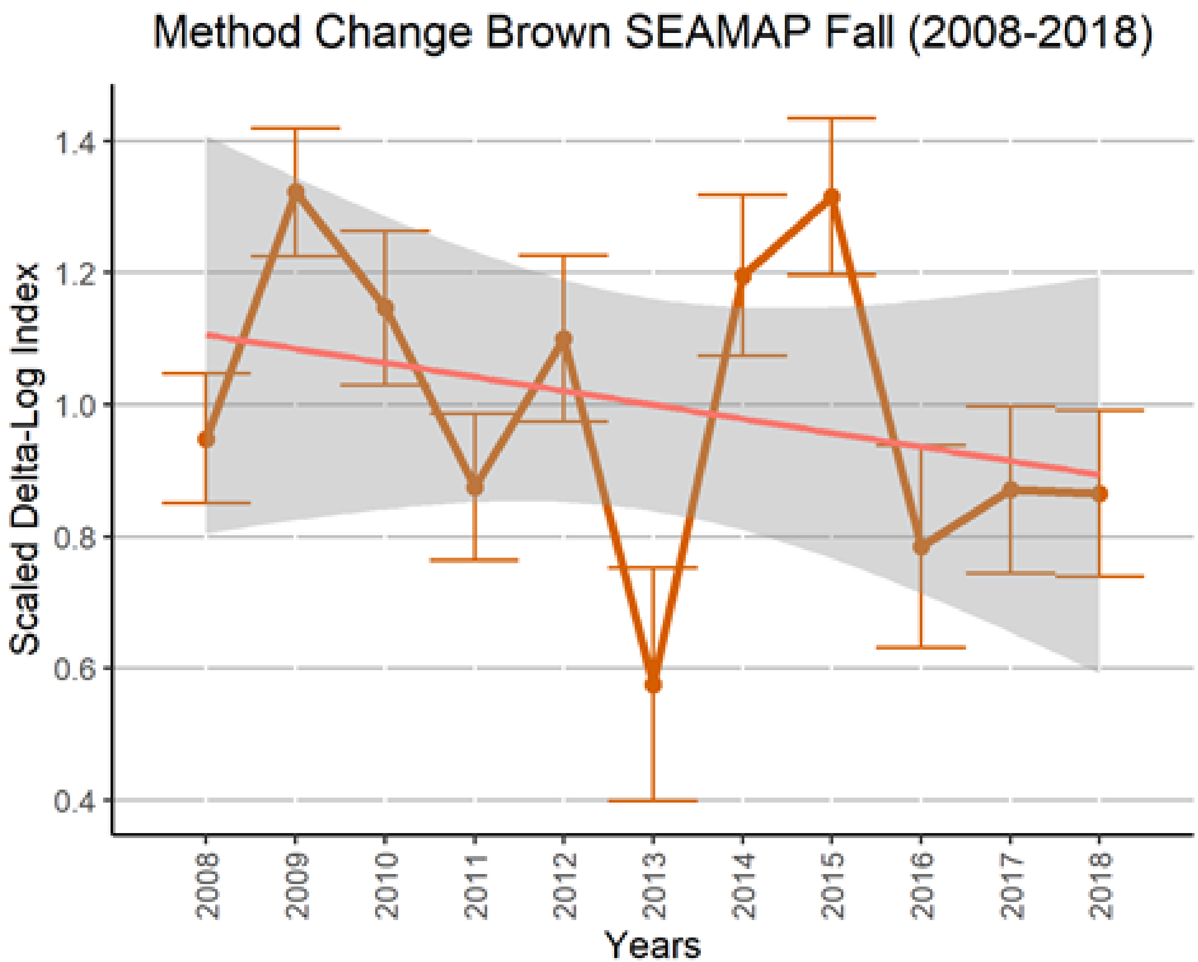


Figure 36. Post-method change era (2008-2018) Brown Shrimp SEAMAP Fall Index of Abundance

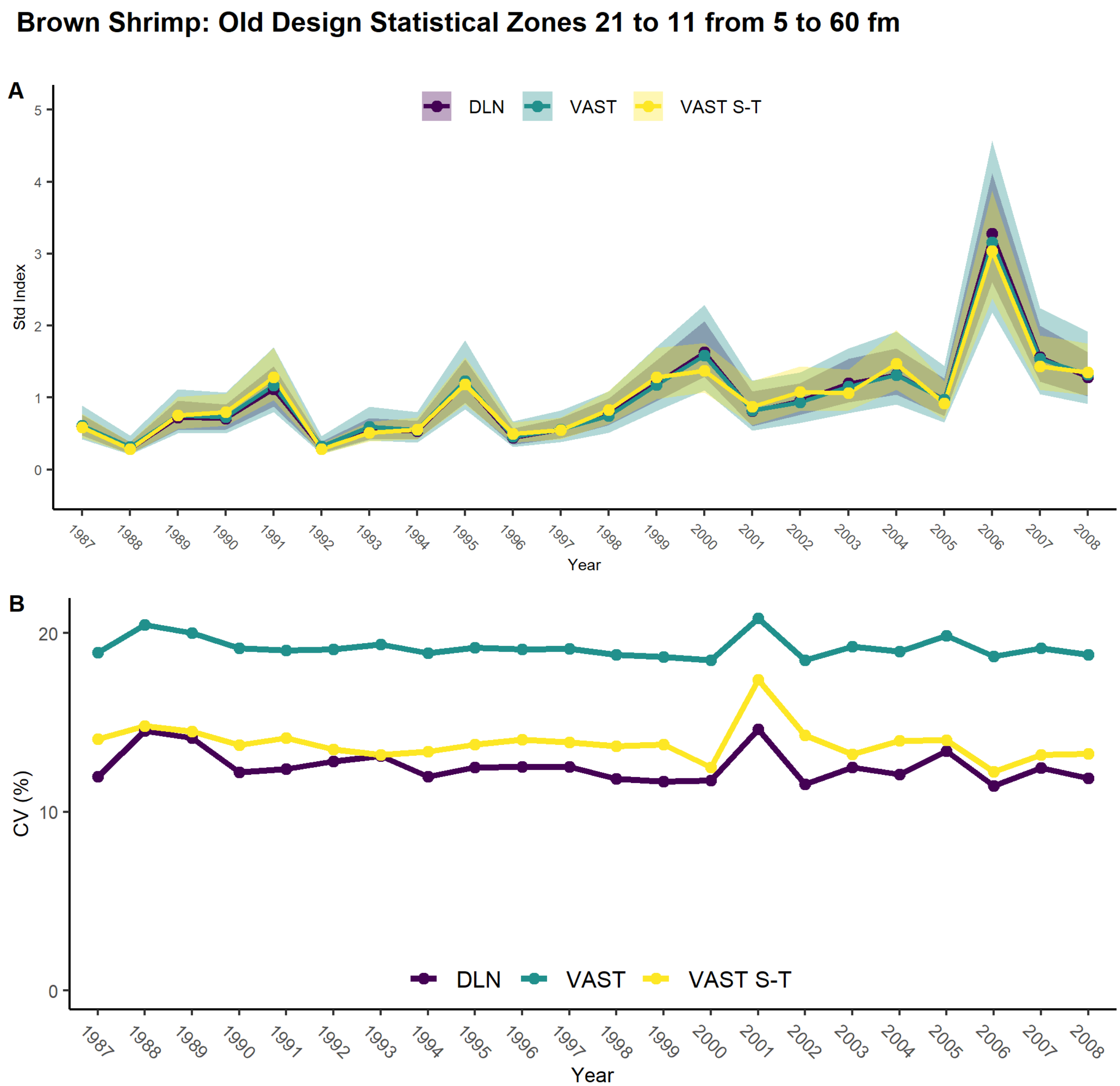


Figure 37. Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST) and VAST spatio-temporal Delta-Lognormal (VAST S-T) indices of relative abundance (A) and percent coefficient of variation (B) of brown shrimp from SEAMAP summer groundfish surveys from 1987 to 2008. Relative abundance is scaled to a mean of one for each index.

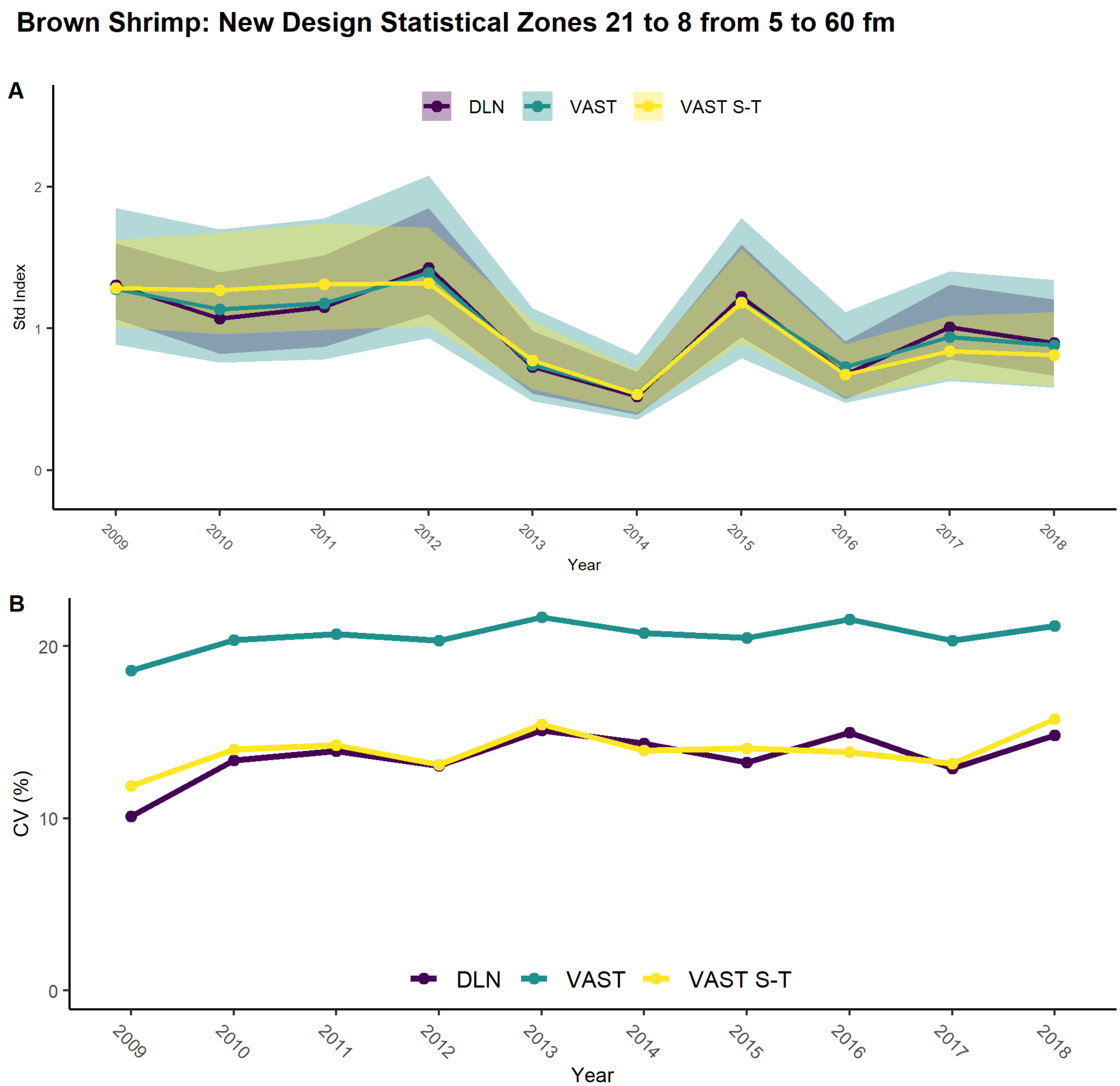


Figure 38. Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST) and VAST spatio-temporal Delta-lognormal (VAST S-T) indices of relative abundance (A) and percent coefficient of variation (B) of brown shrimp from SEAMAP summer groundfish surveys from 2009 to 2018. Relative abundance is scaled to a mean of one for each index.

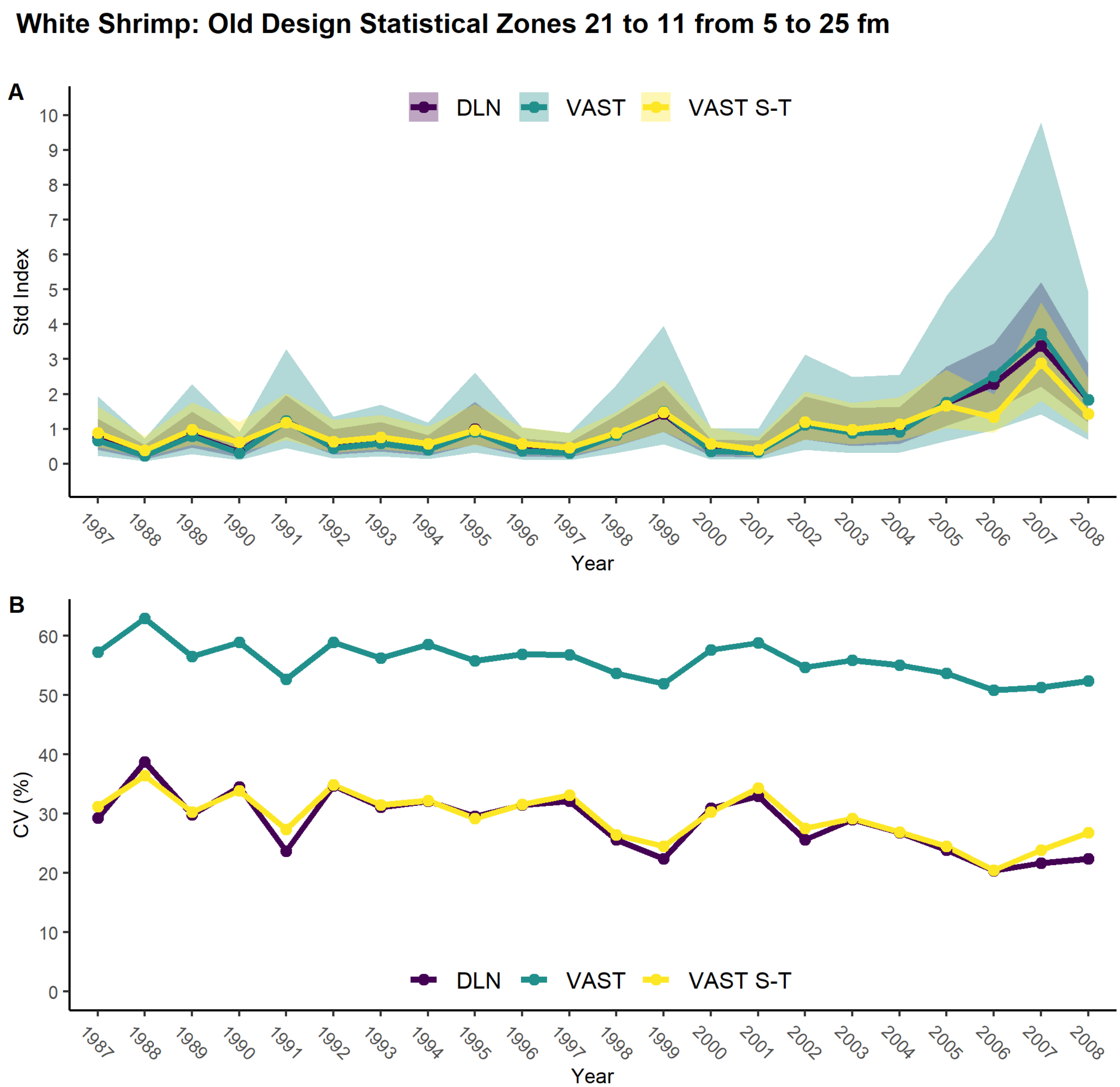


Figure 39. Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST) and VAST spatio-temporal Delta-lognormal (VAST S-T) indices of relative abundance (A) and percent coefficient of variation (B) of white shrimp from SEAMAP summer groundfish surveys from 1987 to 2008. Relative abundance is scaled to a mean of one for each index.

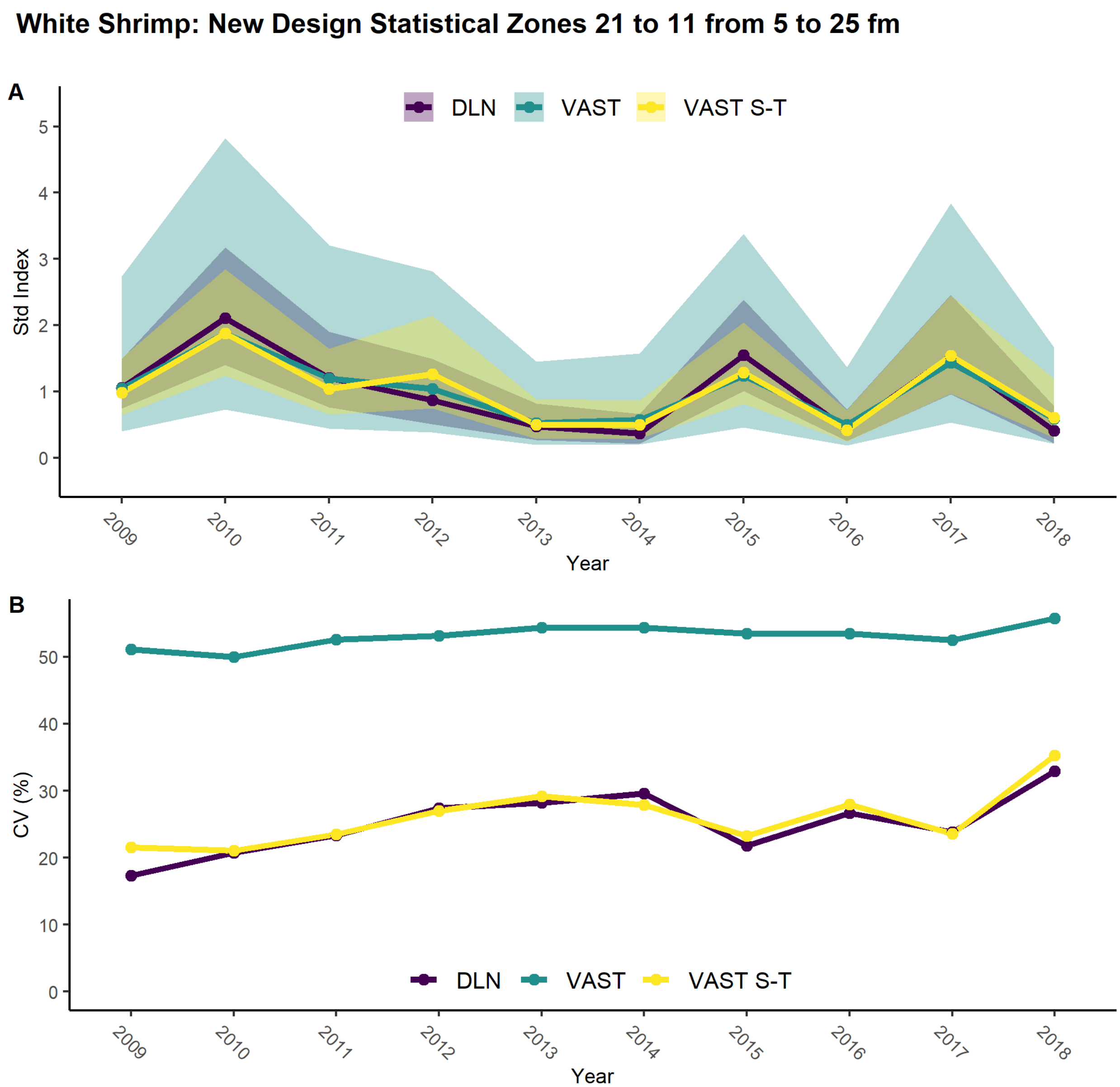


Figure 40. Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST) and VAST spatio-temporal Delta-Lognormal (VAST S-T) indices of relative abundance (A) and percent coefficient of variation (B) of white shrimp from SEAMAP summer groundfish surveys from 2009 to 2018. Relative abundance is scaled to a mean of one for each index.

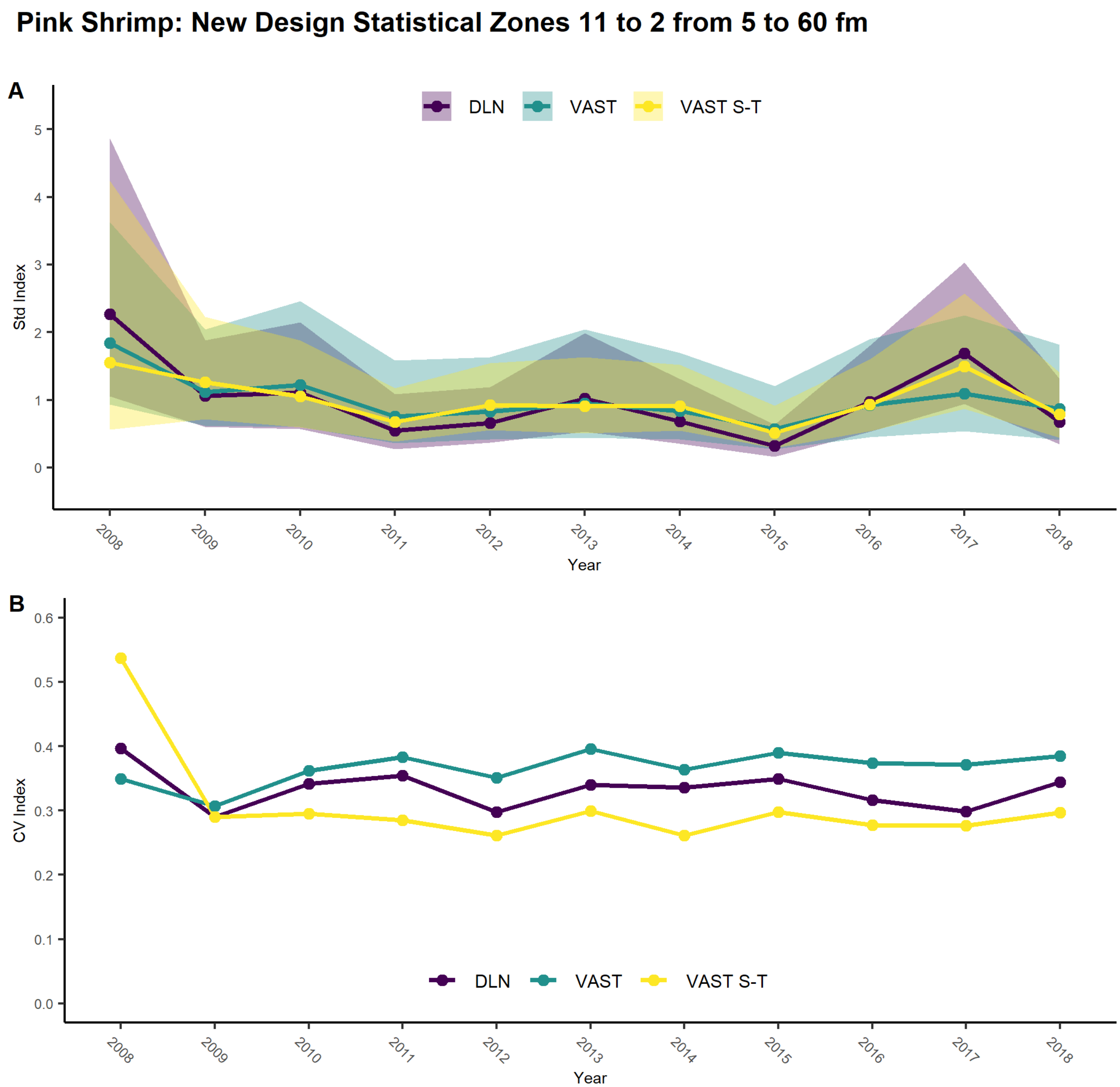


Figure 41. Delta-Lognormal (DLN), VAST Delta-Lognormal (VAST) and VAST spatio-temporal Delta-lognormal (VAST S-T) indices of relative abundance (A) and percent coefficient of variation (B) of pink shrimp from SEAMAP summer groundfish surveys from 2008 to 2018. Relative abundance is scaled to a mean of one for each index.

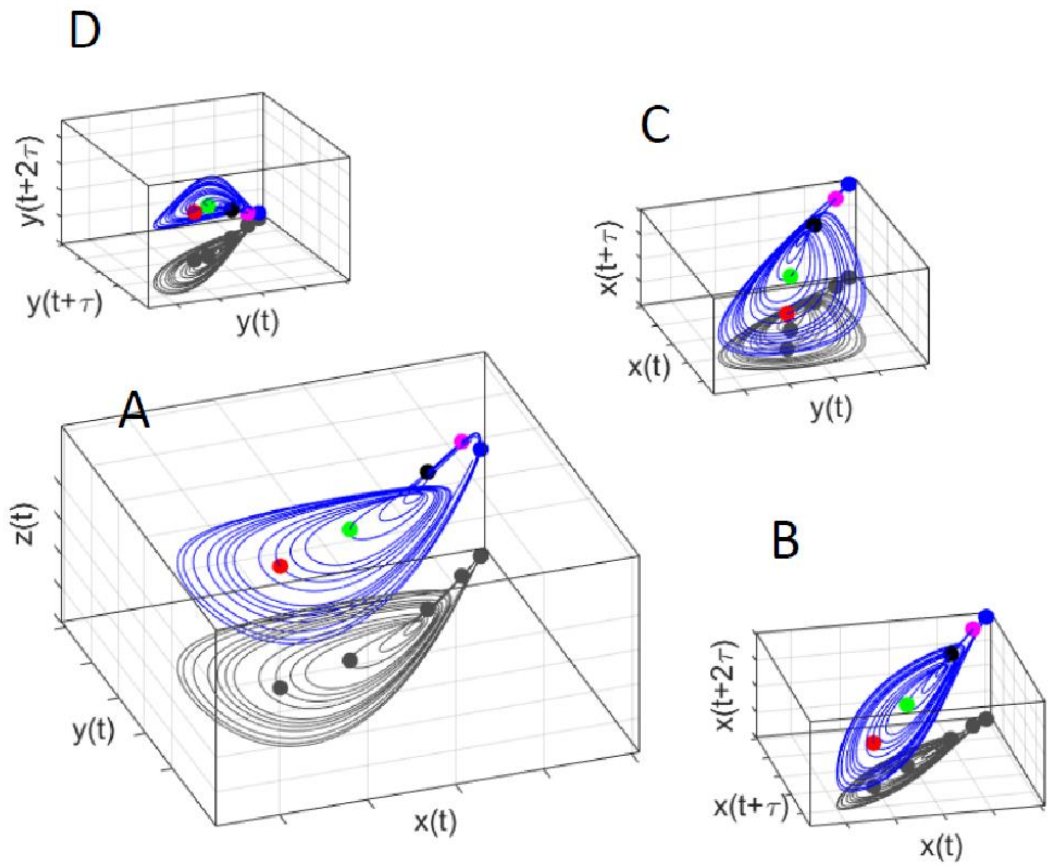


Figure 42. Delay embedding illustrated.

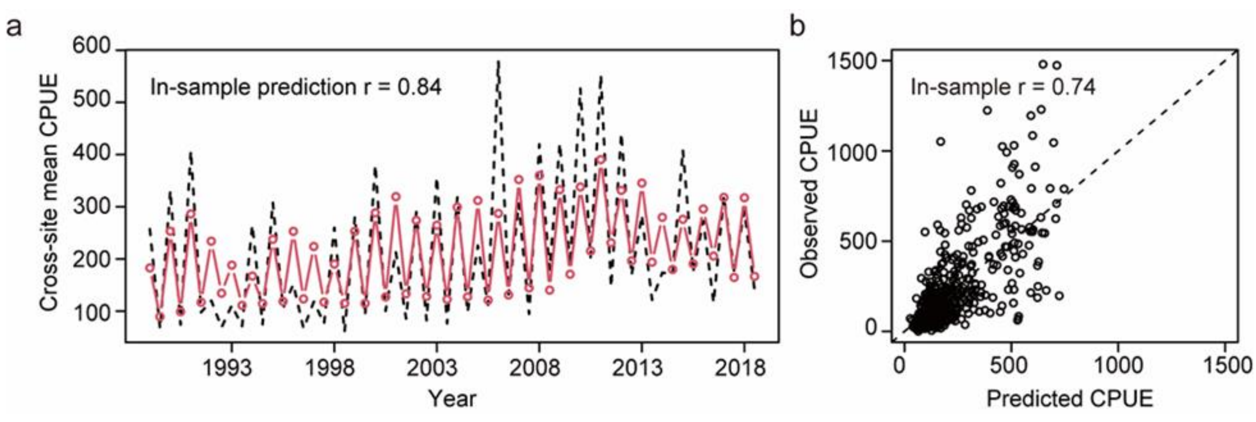


Figure 43. Predicted and observed seasonal abundance dynamics of brown shrimps in the Gulf of Mexico. (a) The gulf-scale CPUE time series averaged over operation zones. Dashed and solid line represents the observed and GPEDM-predicted time series, respectively. (b) The predictive power of GPEDM on zone-scale abundance time series. Diagonal dashed line represents the 1:1 relationship.

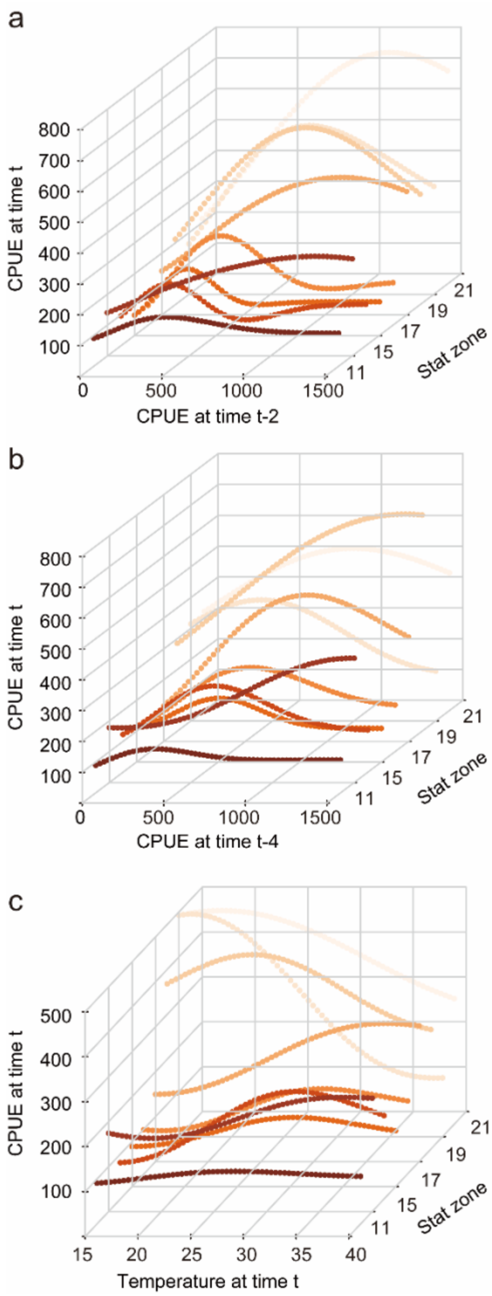


Figure 44. (a) cross-shrimp statistical zone averaged GP-EDM predictions, (b) GP-EDM prediction by shrimp statistical zone, and (c) Temperature at time t (T_t) as the third explanatory variable in the GP-EDM model.

10. Appendix

Appendix 1. Meeting dates and agenda

<u>Meeting 1 - September 10, 2020</u>

- WG participant introductions
- Review Statement of Work
- Presentation: History of the SEAMAP Groundfish Survey (Adam)
- Assignment of tasks

Post-meeting 1: Assignment of Initial Tasks

- GIS work - Michelle, Jo
- Presentation to review VAST as alternative abundance index: David, Adam
- Presentation to review EDM as alternative abundance index: Steve, , Adam(?)
- Presentation on direct effort: Benny Gallaway
- Other indices - David, Adam

<u>Meeting 2 - September 28, 2020</u>

- Index development methods presentation (Adam)
- Review of methods, data, coverage for fishery directed-species CPUE abundance indices (Benny Gallaway)
- Discussion of presentations
- Brief update on progress of GIS mapping task; requesting input from participants
- Assignment of tasks

Post-meeting 2: Assignment of Initial Tasks

- Presentation: VAST (David)
- Presentation: EDM (Steve)
- Presentation: review of shrimp migration patterns (Jen Leo SEFSC)
- Presentation: Uses of the abundance indices in the assessment (Michelle)

<u>Meeting 3 - October 16, 2020</u>

- Alternative indices: VAST (David) & EDM (Steve)
- Presentation on timing of survey in relation to shrimp migration patterns (Michelle Masi - shrimp migration and Adam Pollack - timing of survey)
- Update on GIS mapping (Jo Williams and Michelle Masi)

<u>Meeting 4 - November 4, 2020</u>

- Any remaining alternative indices - EDM (Steve)?
- Update on GIS mapping (Jo Williams and Michelle Masi)
- Presentation on how indices are used in SS, including discrepancies in index trajectories between full survey (all years) and only indices using the method change years (Michelle Masi)

- Summary/review of topics covered
- Best practice recommendations for developing shrimp abundance indices from SEAMAP groundfish trawl survey and the use of fishery CPUE data
- Develop/discuss potential WG report sections and assignment of those sections

Meeting 5 - November 18, 2020

- Q&A with Steve Bosarge (local shrimper)

Meeting 6 - December 7, 2020

- WG report discussions, follow-ups and conclusions

Meeting 7 - March 9, 2021

- WG report discussions, best practice recommendations

Appendix 2. Summary of Meeting Notes

The SEAMAP Trawl Shrimp Data and Index Estimation Working Group (WG) convened its first meeting on September 10, 2020. The WG reviewed the statement of work, which included reviewing a history of the SEAMAP Groundfish Trawl Survey, current shrimp abundance indices and investigating alternative analytical methods to generate abundance indices, among other charges. The WG included members from NMFS/SEFSC, the Gulf SSC, GSMFC, and the Gulf Council.

SEAMAP sampling officially began in 1982. Variations in sampling methods and areas have changed over time; however, gear-type has remained constant. Major changes occurred to sampling methods in 1987 and 2008. From 1987 to 2008, data from Louisiana and Texas were excluded from the SEAMAP survey due to differences in methodologies and gear used. Sampling across all Gulf partners was "officially" standardized in 2010. Sampling has been consistent across years until the summer survey was canceled in 2020 due to the COVID-19 pandemic. The WG discussed whether multiple vessels have been used for sampling and if gear type across vessels has been consistent. Discussion also centered around temporal sampling and differences between the summer and fall survey. Over the course of the survey, sampling has shifted based on consideration of bottom-type, species assemblages in different depth zones, total number of stations and adequate representation of rare-event species. The question was also asked if cELB data have been used to determine trawlable vs. un-trawlable areas and that a comparison of these data types may be useful.

The WG reviewed current SEAMAP indices. Summer and fall survey data are analyzed separately and indices for certain shrimp species are limited to select zones. The WG discussed whether the model accounts for time of day effects; shrimp behavior differs among species and some species are more susceptible to capture based on when the fishery is active. There were also concerns about data gaps and whether anomalies in data are a result of a lack of data in a particular area or reflective of fishery behavior and/or a natural event such as a major hurricane. Presentations were given on estimation of directed effort using ELBs vs. cELBs and mapping efforts. Evaluation of how dependent and independent data are used is necessary as both are provided for assessment purposes; however, both have biases and limitations.

A WG member provided information on alternatives models for shrimp indices using VAST (Vector Autoregressive Spatio-Temporal). The WG discussed an alternative method to calculate abundance indices for shrimp using brown shrimp from the summer survey as an example. Comparisons were made of day/night catch rates between the old and new survey designs as there have been changes in proportion of stations sampled by depth and in station allocation by SSZ. The model run in VAST showed slight shifts in abundance to the east and north within the survey area over the time series and increases in the effective area occupied. The base model showed similar trends to the delta model but with higher CVs. More work is underway to explore the model including change in the overall output based on an increase or decrease in knots and whether depth and SSZ may be confounding factors. It may also be useful to investigate results from flipping the old and new survey design variables in the model input. A presentation was also given on shrimp migration patterns among brown, white and pink shrimp. All three species spawn offshore but peak settlement and emigration vary by species. WG Members noted that brown shrimp abundance has decreased with decreasing marsh edge and that time of day shrimpers target certain species and when emigration occurs can affect estimates of true abundance.

Besides VAST, Empirical Dynamic Modeling (EDM) may be a useful alternative analytical method to generate shrimp abundance indices from SEAMAP Groundfish Trawl Survey data as it is a useful framework for modeling nonlinear dynamic ecosystems. For example, an observed variable, such as shrimp abundance, can be predicted given there is a long enough history of that variable to approximate past values of unobserved variables. A Ph.D student is currently attempting to use EDM as a preliminary analysis of brown, pink and white shrimp to predict abundance in each SSZ using data from previous years. The EDM model has performed well for predicting brown shrimp gulf-wide catch per unit effort (CPUE) for the upcoming year; however, it has not been as successful for white and pink shrimp. The next step will be to incorporate environmental variables; estimate MSY and combine data across the summer and fall surveys.

An update was given on GIS mapping. There seem to be some issues with data access but overall, there appears to be a good overlay between the shrimp fishery and the SEAMAP survey. Use of the Stock Synthesis (SS) model was also discussed at one of the meetings. Number of indices differs among the three shrimp species. All showed increases in spawning stock biomass (SSB) around 2006, driven by the fishery CPUE, which is calculated using a simple ratio estimator. WG members expressed concern over reductions in shrimping effort affecting fleet dynamics and if the model can adequately account for the change in the survey design.

At the following meeting, Mr. Steve Bosarge provided insight on the commercial shrimp industry, especially in Mississippi. He answered questions regarding shrimp behavior and life history, commercial fishery practices, gear types and history of the commercial shrimp fishery. Group members also discussed differences between the commercial shrimp fishery and the SEAMAP trawl survey as well as mitigation of bycatch. PSEA Windplot tracks (start and end points of trawling) may give a good representation of where the fishery is operating as the SEAMAP survey may not be indicative of where the shrimp fishery is operating as it is an ecosystem survey and does not specifically target shrimp. It may also be useful to post-stratify the survey data for bycatch estimation and weight the SEAMAP survey to get a better sense of fringe vs high-density shrimp habitat. Discussion also centered on the major changes made to the SEAMAP survey design in 2008 including changes to depth zones and removal of day/night stations. Ultimately, post-2008 survey design resulted in increased survey efficiency.

The sixth meeting allowed WG members to address any final questions and provide alternative index updates. The group discussed outstanding issues related to data gaps and discrepancies. The final report will provide best practice recommendations for developing shrimp abundance indices from the SEAMAP Groundfish Trawl Survey data and the use of fishery CPUE data.

The final meeting allowed WG members to discuss best practice recommendations.

Appendix Table 1. Nominal CPUE (number per trawl-hour) for brown shrimp by shrimp statistical zone for the SEAMAP Summer Groundfish Survey.

Year	Shrimp Statistical Zone														Total
	7	8	9	10	11	13	14	15	16	17	18	19	20	21	
1987				1.22	49.48	137.73	62.62	32.63	70.03	49.51	55.04	353.60	178.17	1360.36	*184.03*
1988				0.30	11.34	54.55	27.69	73.82	42.86	24.51	44.04	174.86	181.83	364.86	*100.99*
1989				0.59	95.47		4.61	30.71	76.96	46.54	294.64	495.64	575.60	692.65	*277.82*
1990					39.73	87.82	51.85	80.75	51.78	23.25	98.27	820.82	584.53	1229.20	*281.93*
1991					54.90	176.25	167.48	178.00	67.79	69.79	97.05	563.95	993.08	1473.84	*382.53*
1992				0.00	14.84	39.23	30.68	21.52	43.84	13.66	15.52	186.89	652.01	101.62	*124.64*
1993					15.84	107.55	82.04	95.96	13.09	55.61	79.45	108.11	180.06	371.26	*103.92*
1994					38.11	26.62	29.78	66.30	36.83	29.46	182.77	270.15	506.82	1224.43	*234.37*
1995					60.66	121.31	105.82	136.89	59.30	90.65	145.67	702.17	682.08	788.98	*304.87*
1996					24.19	164.49	151.74	46.49	73.00	28.55	173.32	565.51	68.48	231.16	*139.19*
1997					42.59		18.20	55.94	20.77	17.79	68.78	249.45	156.71	432.31	*130.51*
1998					68.14	6.52	86.89	41.11	84.18	27.18	278.23	600.10	559.31	593.61	*267.62*
1999					159.24	36.76	135.41	97.25	57.94	60.03	185.45	689.81	566.35	576.79	*286.11*
2000					127.84	21.11	441.68	183.08	126.96	61.76	471.94	364.57	729.54	911.78	*359.20*
2001					157.17	99.80	88.43	63.81	57.83	53.04	157.97	476.96	157.04	708.18	*220.72*
2002					90.79	35.00	51.08	94.00	35.66	80.36	690.41	714.92	219.70	631.53	*255.74*
2003					275.13	375.59	337.87	276.74	0.86	70.87	109.72	1084.91	670.69	384.94	*413.91*
2004					83.65	128.33	193.70	109.24	77.64	110.54	366.75	669.81	322.69	926.31	*289.29*
2005					43.85	283.49	119.35	162.29	206.32	253.89	629.59	226.81	191.74	196.85	*192.88*
2006					551.27	844.62	373.33	545.33	380.95	333.06	635.79	1030.29	781.04	585.20	*601.86*
2007					181.11		281.68	61.11	117.67	202.22	339.52	485.37	428.65	654.86	*312.88*
2008	0.00	0.18	1.46	0.97	127.53	96.58	80.11	311.62	102.67	384.96	1024.11	791.68	408.80	545.77	*310.79*
2009	0.00	13.88	4.56	0.08	78.48	331.57	194.02	293.64	329.74	627.60	695.19	791.48	231.40	552.59	*342.26*
2010	0.00	0.00	4.57	0.00	129.64	364.00	1051.80	415.40	397.01	258.41	201.51	553.50	534.85	1195.56	*395.04*
2011	0.00	24.13	0.00	0.25	105.18	326.10	438.17	158.89	204.88	677.27	415.94	1479.97	870.53	624.84	*460.20*
2012	0.10	0.00	0.00	1.83	230.38	708.29	717.32	370.00	412.00	192.12	469.82	258.09	908.10	410.63	*326.58*
2013	0.00	0.00	0.00	0.29	330.46	589.89	213.72	130.95	114.06	99.13	342.06	1045.60	214.94	62.28	*239.28*
2014	0.00	0.00	31.78	0.00	105.07	525.87	68.06	169.79	238.42	130.51	187.68	266.05	360.58	37.16	*152.28*
2015	0.00	0.47	0.00	0.00	150.50	321.73	560.17	425.40	236.00	590.57	371.29	544.07	469.91	327.87	*317.68*
2016	0.53	2.66	0.80	0.50	91.73	198.66	214.88	288.20	311.31	222.38	213.31	541.35	447.00	121.95	*215.04*
2017	1.06	0.00	1.99	10.17	229.92	155.94	425.87	242.10	208.84	264.79	232.40	214.59	468.30	595.64	*240.22*
2018	0.00	2.82	95.02	2.29	133.74	472.71	312.29	259.71	134.67	174.13	356.66	681.06	491.12	83.72	*218.45*
Total	*0.18*	*4.36*	*8.16*	*1.17*	*108.67*	*241.83*	*229.30*	*170.54*	*144.78*	*200.81*	*318.55*	*544.65*	*466.17*	*617.05*	275.27

Appendix Table 2. Nominal CPUE (number per trawl-hour) for brown shrimp by shrimp statistical zone for the SEAMAP Fall Groundfish Survey.

	Shrimp Statistical Zone														
Year	7	8	9	10	11	13	14	15	16	17	18	19	20	21	Total
1987				0.84	17.29	67.68	121.94	68.13	64.97	29.25	32.86	41.55	28.49	0.00	*43.81*
1988				0.00	15.55	67.60	58.33	77.07	21.42	9.98	25.23	35.05	52.76	32.21	*35.31*
1989					100.26	92.49	49.99	89.94	64.63	71.32	31.46	66.76	70.41	47.11	*70.57*
1990					43.22	138.35	42.37	96.69	130.98	38.74	69.73	90.51	90.90	63.76	*75.57*
1991					63.24	51.34	121.45	83.75	91.41	72.21	88.00	144.80	170.12	44.23	*93.59*
1992					63.41	83.60	72.64	105.90	105.35	44.54	39.89	53.91	78.35	54.47	*69.52*
1993					66.94	136.10	18.88	203.66	57.21	40.45	21.61	81.65	121.61	28.80	*74.47*
1994					31.28	70.87	43.65	94.62	87.12	79.17	48.37	134.13	95.98	58.51	*71.02*
1995					42.03	70.25	73.89	234.14	187.28	36.07	48.98	106.65	70.32	150.56	*99.17*
1996					24.40	108.20	127.95	105.89	90.49	33.81	16.54	32.97	65.83	101.94	*63.19*
1997					65.89	68.92	21.62	123.75	85.81	22.22	51.75	97.36	113.98	102.78	*77.31*
1998					43.71	155.40	35.82	48.01	59.31	46.53	64.98	89.65	93.11	66.22	*65.65*
1999					84.67	90.46	314.46	60.73	102.64	55.02	41.00	67.63	50.48	54.22	*88.47*
2000					33.83	98.00	150.41	79.04	90.20	27.75	30.71	107.95	137.40	246.40	*94.54*
2001					51.04	89.93	150.14	47.55	78.16	56.50	87.04	76.25	103.05	121.91	*82.29*
2002				559.25	106.91	140.98	123.82	101.69	40.66	101.75	44.26	82.31	75.12	65.76	*89.54*
2003				5.73	58.22	63.11	71.14	80.26	83.64	32.02	60.90	70.63	125.11	106.07	*72.97*
2004					23.60		220.89	107.16	41.54	72.01	76.48	64.97	86.68	186.09	*83.72*
2005					68.16	301.13	245.75	89.01	77.90	59.71	98.68	108.44	149.07	111.21	*116.52*
2006				30.77	86.97	465.30	221.42	62.44	71.97	96.30	114.23	105.34	183.64	245.05	*141.35*
2007					112.64	72.67	142.12	69.66	36.22	84.74	47.95	71.03	151.27	136.89	*96.64*
2008	0.00	0.00	0.00	0.00	48.13	530.42	479.19	207.04	142.74	154.31	90.86	146.01	124.84	225.03	*177.97*
2009	0.00	0.00	39.23	0.65	207.84	103.86	150.83	129.53	115.54	152.77	133.88	186.91	233.54	374.45	*152.96*
2010	0.00	0.00	3.27	0.29	224.13	103.70	83.63	122.95	250.37	196.25	101.25	205.60	227.76	416.09	*147.72*
2011		0.00	9.06	0.00	80.40	301.09	148.28	188.82	198.87	65.69	167.40	159.53	164.02	141.52	*132.46*
2012	0.00	2.99	0.00	5.60	184.23	42.80	44.00	136.53	173.99	158.12	181.07	113.91	235.96	291.91	*130.60*
2013	0.00	0.00	38.27	0.40	155.04	162.40	65.52	89.32	76.95	77.93	68.32	147.04	126.81	287.89	*94.76*
2014	0.00	6.64	17.43	0.86	99.13	244.37	200.60	160.38	191.57	186.67	155.47	121.56	163.81	257.48	*139.55*
2015	0.00	5.27	3.54	0.00	88.91	675.61	245.83	170.37	105.93	130.33	158.13	229.76	126.34	324.10	*144.81*
2016	0.00	6.28	8.78	0.00	21.00	142.81	230.46	182.34	111.61	109.17	104.17	58.24	109.84	116.87	*96.44*
2017	0.00	0.83	0.00	0.00	120.93	128.00	120.95	409.43	152.96	65.16	179.86	66.70	182.73	295.05	*135.23*
2018	0.00	7.98	3.75	8.84	151.88	585.98	203.87	113.63	124.96	65.29	76.30	188.72	133.89	204.83	*118.50*
Total	*0.00*	*2.77*	*12.68*	*6.60*	*71.73*	*170.03*	*142.60*	*121.72*	*106.77*	*85.78*	*88.56*	*102.00*	*119.99*	*144.02*	*101.52*

Appendix Table 3. Nominal CPUE (number per trawl-hour) for white shrimp by shrimp statistical zone for the SEAMAP Summer Groundfish Survey.

	Shrimp Statistical Zone														
Year	7	8	9	10	11	13	14	15	16	17	18	19	20	21	Total
1987				0.00	3.78	0.91	4.41	0.79	3.36	6.16	15.33	5.12	0.13	0.58	*3.49*
1988				0.00	0.79	0.00	0.00	0.00	2.84	5.95	2.31	5.26	0.19	0.00	*1.94*
1989				0.00	4.47		0.00	4.95	2.86	1.96	13.41	5.09	8.69	0.52	*4.56*
1990					0.54	5.00	0.00	2.11	0.48	1.81	2.97	27.74	4.91	0.60	*4.17*
1991					1.33	5.50	0.30	3.46	2.17	11.25	20.58	34.90	23.64	3.50	*9.74*
1992				0.00	0.64	18.46	2.54	0.07	0.39	0.31	0.89	32.87	2.66	42.00	*9.21*
1993					0.02	1.10	1.32	4.35	0.00	5.60	3.54	13.68	18.68	1.96	*5.20*
1994					0.45	2.11	0.54	2.85	2.70	11.16	5.74	8.45	1.04	0.00	*2.94*
1995					1.00	0.46	2.23	14.99	1.26	1.62	28.80	8.87	17.73	10.13	*7.82*
1996					0.45	6.80	1.43	0.48	0.35	0.00	8.85	5.12	3.24	0.24	*2.26*
1997					0.19		0.54	0.15	0.60	0.04	0.12	20.31	8.04	3.23	*4.36*
1998					0.82	2.61	4.28	0.71	1.34	5.00	26.62	32.50	3.45	2.80	*7.34*
1999					1.98	0.95	0.84	6.21	4.30	0.11	41.45	52.13	12.88	8.87	*12.37*
2000					2.68	0.00	3.48	0.00	2.26	0.69	148.77	1.95	1.91	0.67	*7.30*
2001					0.92	0.86	0.51	4.45	1.30	5.45	0.56	1.88	7.28	0.35	*2.09*
2002					2.77	1.16	1.69	2.78	0.74	0.07	26.42	30.97	39.33	10.13	*12.21*
2003					6.98	7.47	29.36	1.64	0.00	0.00	9.30	34.89	22.20	0.00	*12.28*
2004					0.53	7.64	0.36	2.85	2.36	0.31	76.60	18.69	8.54	4.22	*11.53*
2005					9.95	29.72	22.21	22.85	6.38	4.05	1.59	90.68	2.55	4.76	*22.09*
2006					16.55	36.72	8.74	10.89	21.24	5.71	86.11	26.12	5.31	1.61	*19.35*
2007					9.18		15.53	13.85	6.87	31.97	91.62	26.65	5.15	0.00	*16.07*
2008	0.00	0.00	0.00	0.00	7.93	13.85	1.86	11.22	5.42	1.29	0.33	121.97	3.44	1.39	*14.96*
2009	0.00	4.50	0.00	0.00	27.42	51.02	37.61	12.72	10.87	29.29	53.90	27.89	3.07	0.09	*22.42*
2010	0.00	0.00	0.00	0.00	8.43	188.00	22.00	27.57	20.10	21.86	104.62	90.46	13.31	13.72	*35.94*
2011	0.00	0.00	0.00	0.00	3.25	30.00	18.76	18.65	22.22	22.52	39.72	50.20	99.64	2.90	*27.76*
2012	0.00	0.00	0.00	0.15	1.75	25.71	7.29	1.78	33.64	22.43	50.64	82.86	16.35	0.00	*20.35*
2013	0.00	0.73	0.00	0.00	3.71	28.60	11.59	1.13	2.54	18.10	55.87	3.36	0.12	0.17	*11.01*
2014	0.00	0.00	0.00	0.00	1.33	4.66	0.53	5.66	3.36	24.69	30.11	2.11	12.51	0.00	*8.39*
2015	0.00	5.88	0.00	0.00	1.88	10.86	18.13	20.08	13.38	41.97	73.98	16.13	2.40	0.00	*19.36*
2016	0.00	0.00	0.00	0.00	12.40	0.67	11.07	5.33	7.57	4.04	18.68	7.82	2.10	0.42	*6.01*
2017	0.00	0.00	0.00	0.00	36.47	26.00	54.92	5.54	73.89	38.48	36.82	17.12	7.77	0.57	*25.53*
2018	0.00	0.00	0.00	0.00	1.86	2.57	3.00	6.43	2.55	13.91	15.47	51.58	5.61	0.14	*7.99*
Total	*0.00*	*1.18*	*0.00*	*0.01*	*5.19*	*18.09*	*8.47*	*6.93*	*8.58*	*12.50*	*37.47*	*30.85*	*11.07*	*3.74*	12.42

Appendix Table 4. Nominal CPUE (number per trawl-hour) for white shrimp by shrimp statistical zone for the SEAMAP Fall Groundfish Survey.

	Shrimp Statistical Zone														
Year	7	8	9	10	11	13	14	15	16	17	18	19	20	21	Total
1987				0.09	6.53	29.27	5.56	31.94	3.17	0.59	0.84	52.61	52.95	12.57	*17.97*
1988				0.00	3.08	55.77	24.43	12.44	30.74	11.66	224.78	26.26	4.59	4.44	*33.02*
1989					13.16	43.23	124.60	0.56	20.00	39.68	56.85	56.73	10.84	0.26	*32.23*
1990					4.51	57.50	68.14	1.00	19.85	3.19	21.90	10.73	12.08	0.44	*14.25*
1991					21.95	95.00	48.04	33.22	33.97	8.85	28.11	7.26	5.15	0.25	*22.43*
1992					28.62	97.61	17.95	15.26	14.19	3.50	1.41	30.88	12.68	2.89	*18.64*
1993					12.38	134.51	41.67	60.89	16.56	1.33	17.15	46.77	55.99	4.28	*30.69*
1994					5.02	82.92	10.16	9.50	23.46	17.87	29.47	20.29	16.12	7.06	*17.16*
1995					4.52	172.74	35.84	31.56	89.18	0.00	0.00	45.83	86.96	12.55	*42.87*
1996					0.97	64.21	7.73	29.18	12.54	5.00	57.63	90.34	18.21	5.55	*23.71*
1997					11.44	41.59	7.23	12.95	17.08	0.63	14.29	60.21	57.91	5.95	*21.64*
1998					61.39	140.58	60.19	28.61	35.03	0.00	41.40	108.30	49.76	2.59	*52.15*
1999					1.96	52.83	8.02	8.13	9.85	1.01	22.14	20.04	18.92	3.94	*11.64*
2000					91.02	109.58	17.60	35.29	22.42	34.74	0.00	20.95	7.49	14.75	*37.92*
2001					3.81	35.78	5.57	29.41	43.63	6.88	70.12	30.15	27.02	1.74	*22.20*
2002				0.00	19.09	46.23	36.97	59.00	40.84	5.85	61.49	58.05	13.57	7.07	*30.89*
2003				0.00	4.85	50.45	39.52	7.18	45.32	0.44	5.67	75.77	21.94	4.06	*20.12*
2004					3.06		4.74	27.08	32.59	22.87	72.01	36.14	11.24	0.10	*19.79*
2005					43.30	121.09	36.45	15.79	21.63	33.29	110.14	39.64	4.04	0.99	*35.22*
2006				0.00	7.74	300.22	49.56	22.06	56.34	29.67	19.15	91.34	14.70	0.73	*38.42*
2007					11.13	114.41	9.12	17.53	17.33	6.18	75.87	102.57	2.40	0.86	*28.17*
2008	0.00	0.00	0.00	0.00	11.41	38.00	17.97	7.70	10.81	17.36	22.56	60.48	11.02	1.77	*16.73*
2009	0.00	0.00	0.00	0.00	20.65	53.38	19.04	15.22	27.79	52.47	48.78	29.35	3.84	0.00	*24.26*
2010	0.00	0.00	0.00	0.00	0.40	36.50	43.93	17.88	29.95	49.31	28.33	10.74	2.52	0.29	*18.34*
2011		0.00	0.00	0.00	5.20	9.33	26.40	2.75	7.65	22.29	14.95	21.39	4.48	0.53	*11.14*
2012	0.00	0.00	0.00	0.00	2.31	57.20	20.73	0.15	14.58	4.63	23.33	8.13	3.42	0.00	*8.73*
2013	0.00	0.00	0.00	0.00	44.00	68.00	8.00	9.31	35.32	77.78	39.90	7.76	2.84	0.00	*20.93*
2014	0.00	0.00	0.00	0.00	2.25	22.40	7.23	11.13	5.24	13.33	2.36	5.33	0.94	0.00	*5.05*
2015	0.00	0.00	0.00	0.00	38.76	60.18	0.76	9.38	46.14	50.07	28.36	15.20	7.40	0.00	*21.11*
2016	0.00	0.00	0.00	0.00	0.00	8.50	58.83	0.20	9.07	7.43	20.07	25.66	1.22	0.00	*11.50*
2017	0.00	0.00	0.00	0.00	5.47	76.00	101.11	22.03	8.23	12.65	11.32	46.92	3.42	0.00	*16.79*
2018	0.00	0.00	0.00	0.00	10.59	80.94	13.95	35.34	31.14	318.46	166.68	134.77	4.25	0.00	*80.73*
Total	*0.00*	*0.00*	*0.00*	*0.01*	*16.23*	*75.60*	*30.58*	*19.61*	*25.46*	*28.94*	*41.08*	*44.08*	*18.66*	*2.99*	*25.20*

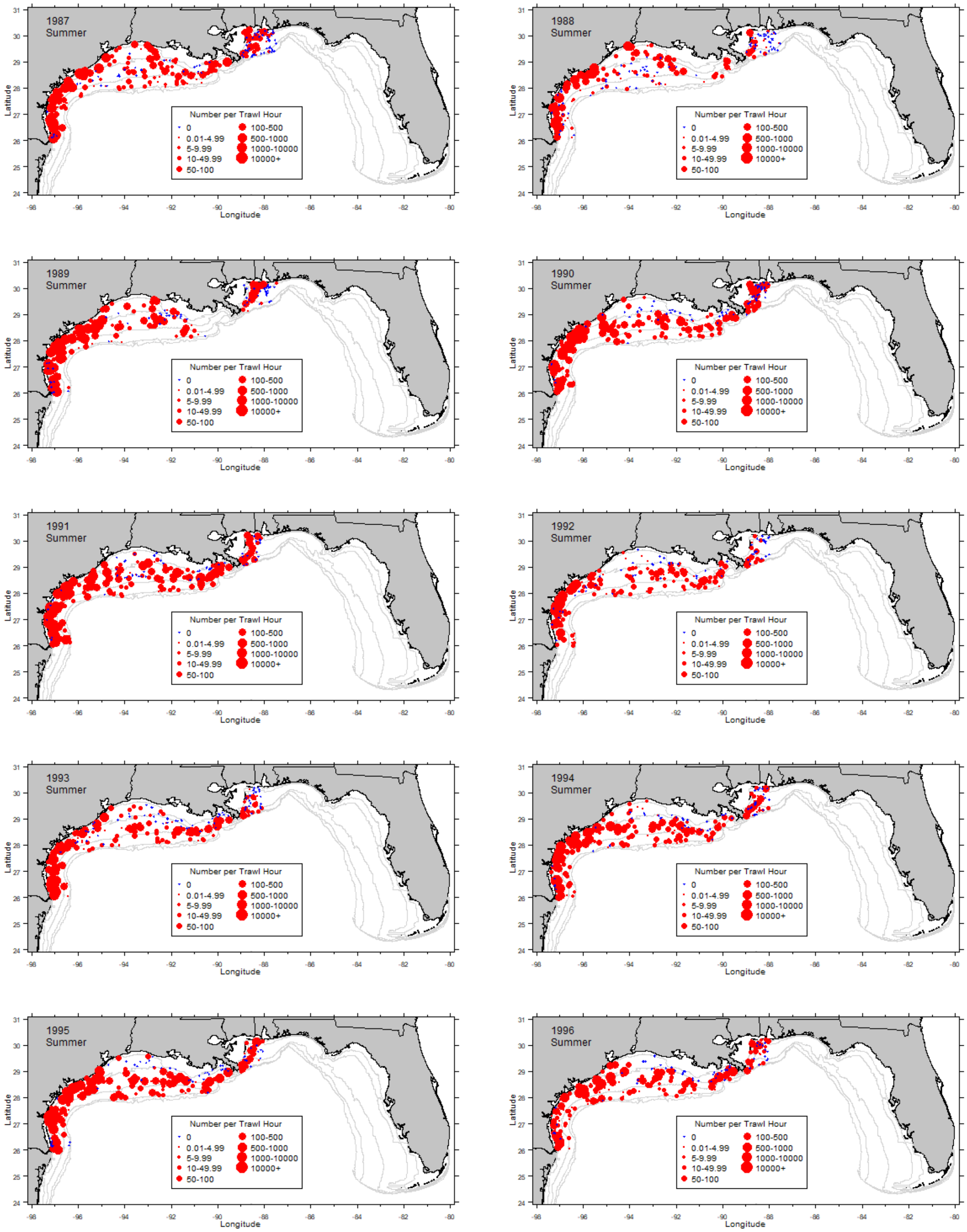
Appendix Table 5. Nominal CPUE (number per trawl-hour) for pink shrimp by shrimp statistical zone for the SEAMAP Summer Groundfish Survey.

	Shrimp Statistical Zone										
Year	2	3	4	5	6	7	8	9	10	11	Total
1987									9.91	6.91	*7.90*
1988									5.23	28.09	*21.92*
1989									26.12	0.58	*11.10*
1990										20.05	*20.05*
1991										31.77	*31.77*
1992									4.44	34.07	*33.41*
1993										8.93	*8.93*
1994										28.38	*28.38*
1995										61.07	*61.07*
1996										32.00	*32.00*
1997										13.30	*13.30*
1998										30.04	*30.04*
1999										11.03	*11.03*
2000										40.17	*40.17*
2001										26.08	*26.08*
2002										21.18	*21.18*
2003										20.42	*20.42*
2004										5.97	*5.97*
2005										12.87	*12.87*
2006										17.52	*17.52*
2007										22.74	*22.74*
2008			0.00	0.00	0.73	1.67	23.64	0.25	34.70	63.98	*34.17*
2009			26.39	1.62	19.72	27.57	70.38	12.86	2.66	9.83	*17.91*
2010		23.61	6.07	81.46	45.58	237.80	3.79	0.71	1.95	5.79	*36.22*
2011	428.55	15.16	3.27	28.50	20.36	0.00	0.00	16.00	0.50	2.22	*41.30*
2012	8.33	18.63	4.54	5.83	46.68	28.52	31.71	0.88	14.91	15.88	*18.19*
2013	0.22	25.26	7.79	2.70	24.42	42.75	58.73	0.75	2.00	0.43	*15.86*
2014	234.52	6.82	26.09	8.17	24.75	51.87	1.00	1.11	0.00	17.20	*34.76*
2015	196.00	26.75	2.90	7.18	30.46	8.05	11.29	0.00	0.25	1.50	*21.32*
2016	401.78	5.68	4.62	10.72	16.27	28.17	40.86	1.40	2.49	13.20	*33.44*
2017	173.60	4.57	8.21	21.07	29.29	57.65	12.20	1.32	0.60	6.35	*25.95*
2018	156.75	26.93	4.14	10.58	68.96	20.50	48.13	0.40	0.00	2.71	*29.72*
Total	*201.25*	*17.41*	*9.63*	*16.11*	*31.19*	*44.23*	*27.14*	*4.12*	*8.91*	*21.58*	*25.53*

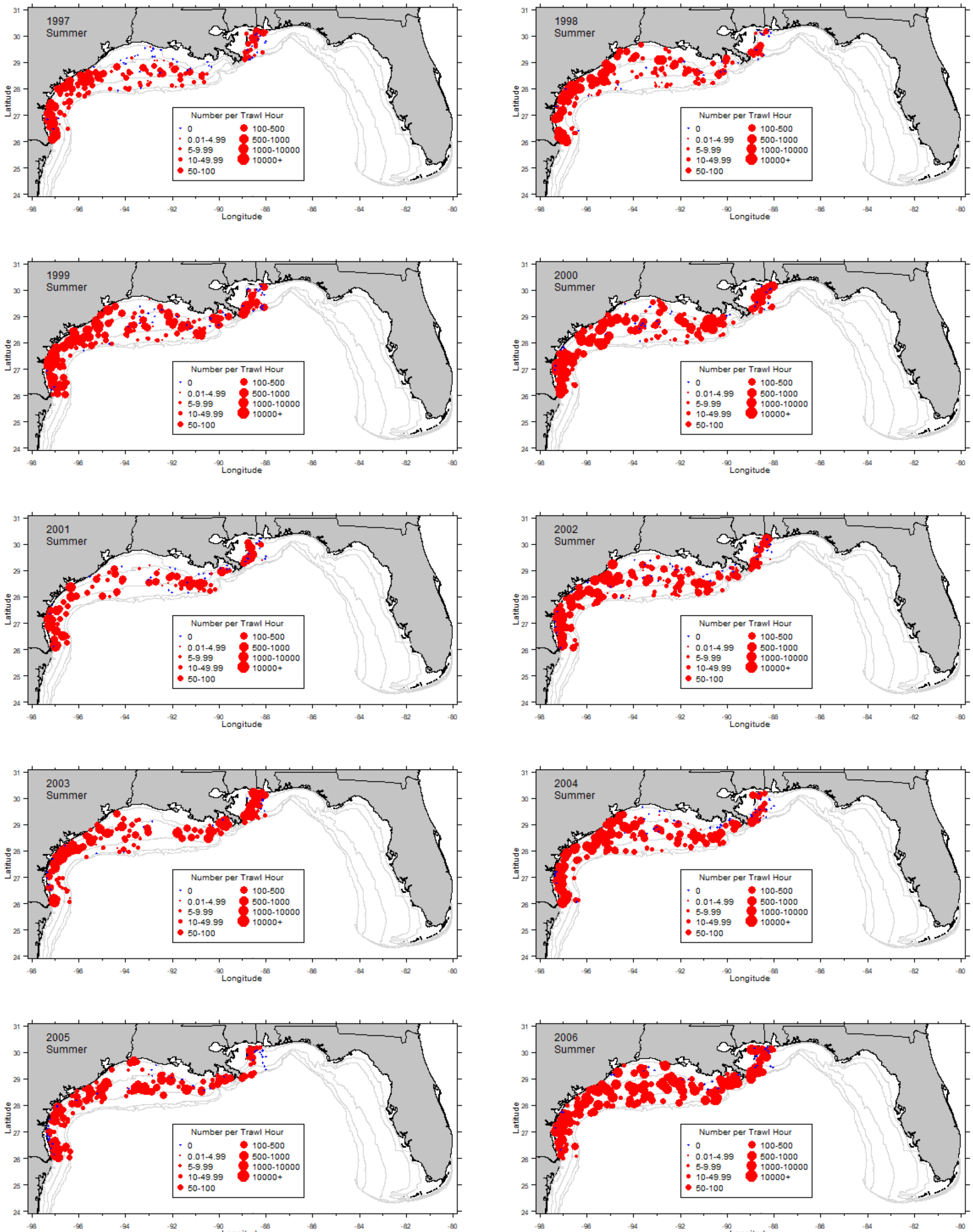
Appendix Table 6. Nominal CPUE (number per trawl-hour) for pink shrimp by shrimp statistical zone for the SEAMAP Fall Groundfish Survey.

	Shrimp Statistical Zone										
Year	2	3	4	5	6	7	8	9	10	11	Total
1987									7.80	14.20	*11.76*
1988									1.50	18.94	*14.95*
1989										13.77	*13.77*
1990										14.00	*14.00*
1991										10.05	*10.05*
1992										8.05	*8.05*
1993										10.91	*10.91*
1994										4.06	*4.06*
1995										19.96	*19.96*
1996										3.01	*3.01*
1997										8.01	*8.01*
1998										27.67	*27.67*
1999										0.39	*0.39*
2000										5.28	*5.28*
2001										4.88	*4.88*
2002									14.05	13.11	*13.13*
2003									0.00	9.73	*9.60*
2004										10.48	*10.48*
2005										3.45	*3.45*
2006									0.00	10.63	*10.40*
2007										8.90	*8.90*
2008				5.03	0.86	24.88	1.50	0.00	0.50	10.00	*6.86*
2009			8.70	14.57	41.84	94.00	31.71	1.07	5.26	7.38	*21.47*
2010			25.06	0.48	3.61	12.07	0.00	0.18	1.00	3.47	*4.54*
2011							6.83	0.36	0.00	0.27	*1.69*
2012		55.81	29.21	1.66	74.71	59.70	34.86	5.70	4.00	1.50	*30.87*
2013	129.00	8.11	10.22	0.44	1.09	10.60	3.00	0.33	0.00	0.80	*10.04*
2014	0.50	15.35	0.80	4.18	29.62	19.69	58.28	0.00	0.00	1.50	*13.74*
2015	147.00	5.57	0.40	0.64	4.84	47.24	60.36	1.11	8.18	2.49	*18.77*
2016	15.48	0.50	4.98	9.61	31.42	11.94	16.86	0.40	0.00	0.50	*11.02*
2017	132.67	113.89	5.93	35.77	19.04	52.39	19.10	0.56	0.00	1.20	*36.95*
2018	128.67	15.17	2.00	23.35	36.53	58.26	45.54	0.00	1.14	22.95	*27.77*
Total	*98.21*	*27.27*	*5.79*	*9.75*	*20.67*	*39.89*	*26.84*	*0.89*	*3.19*	*9.45*	*14.74*

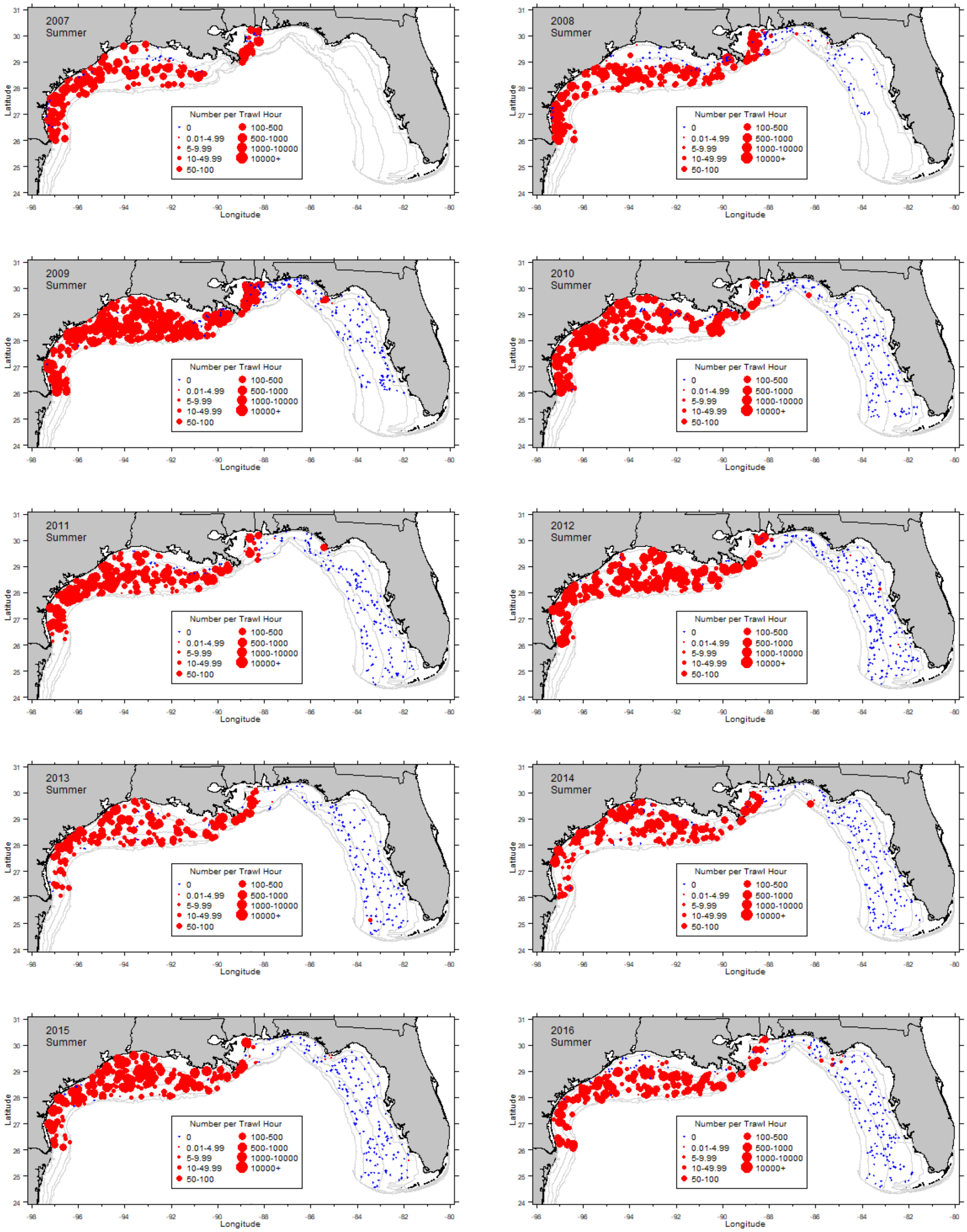
Appendix Figure 1. Distribution and abundance of brown shrimp (*Farfantepenaeus aztecus*) captured during the SEAMAP Summer Groundfish Survey from 1987 – 2018.



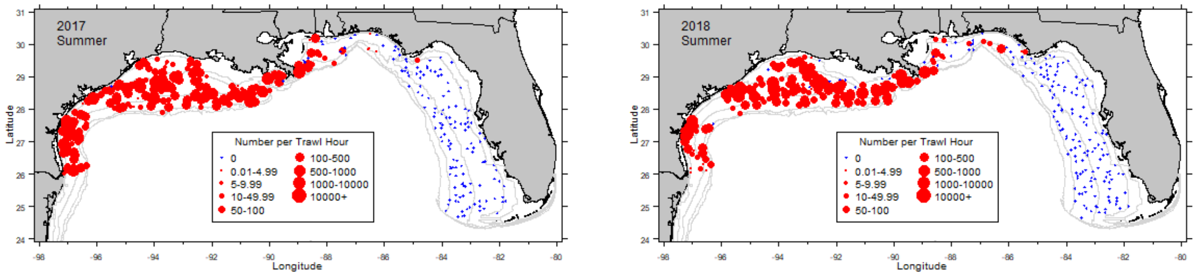
Appendix Figure 1 (continued).



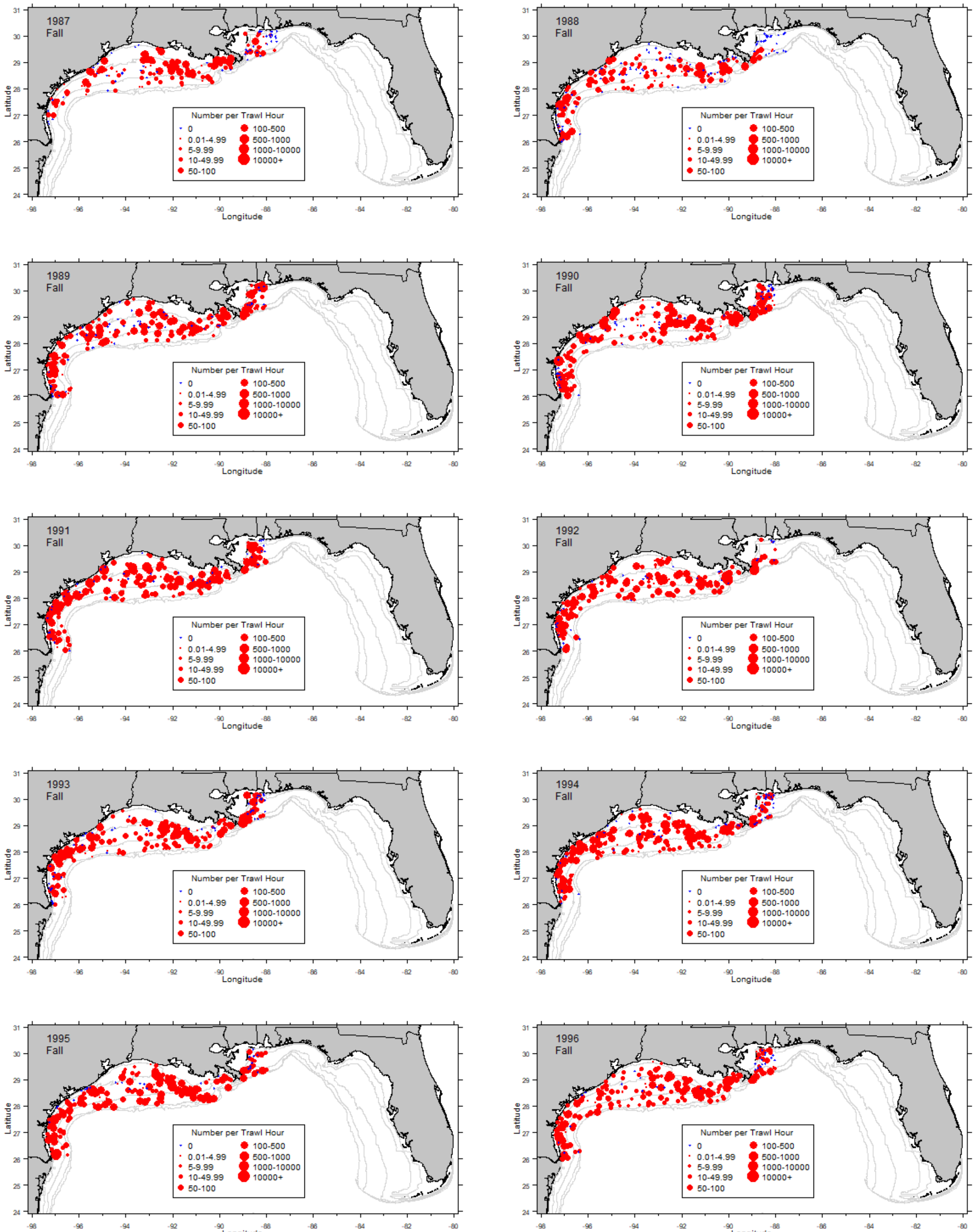
Appendix Figure 1 (continued).



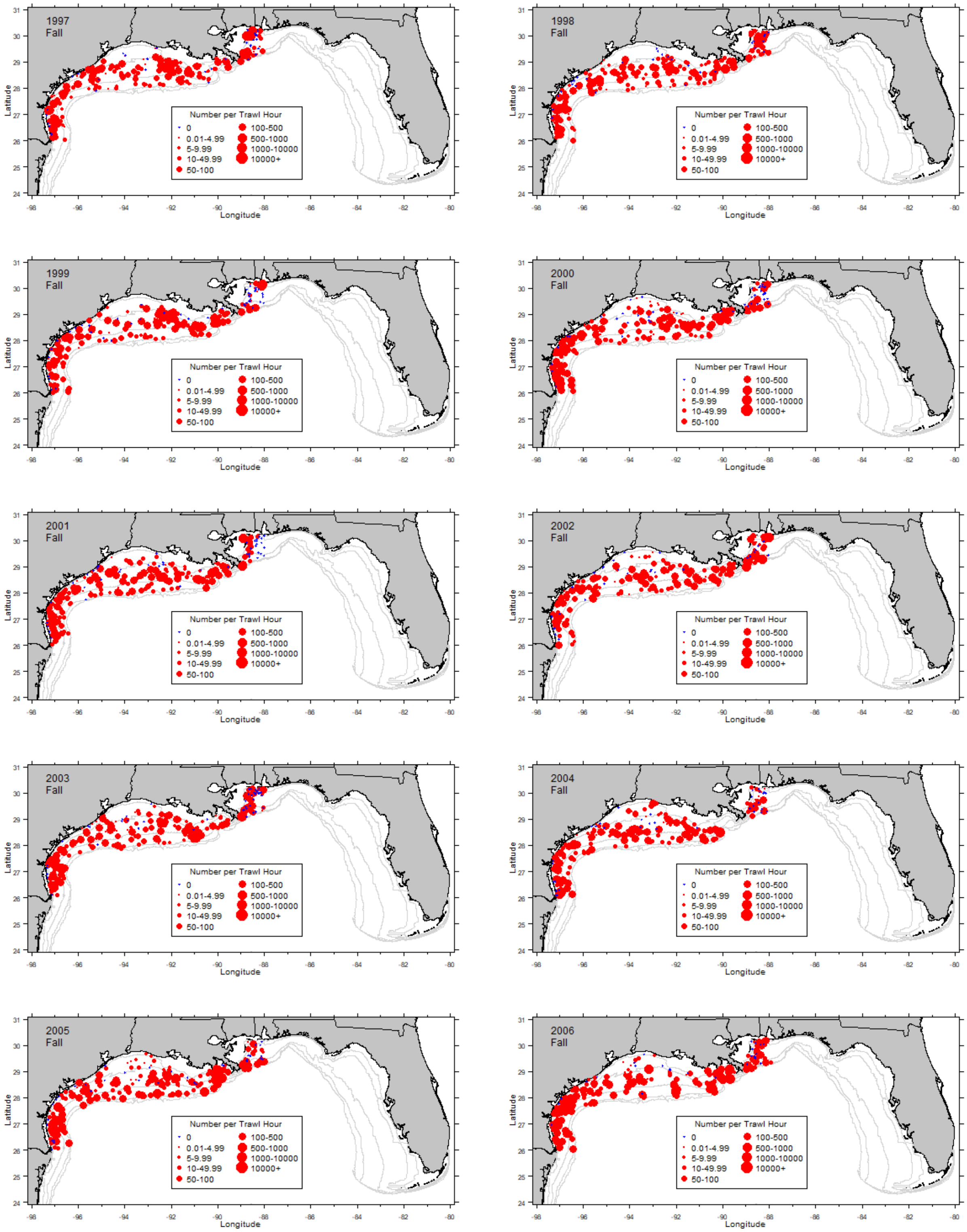
Appendix Figure 1 (continued).



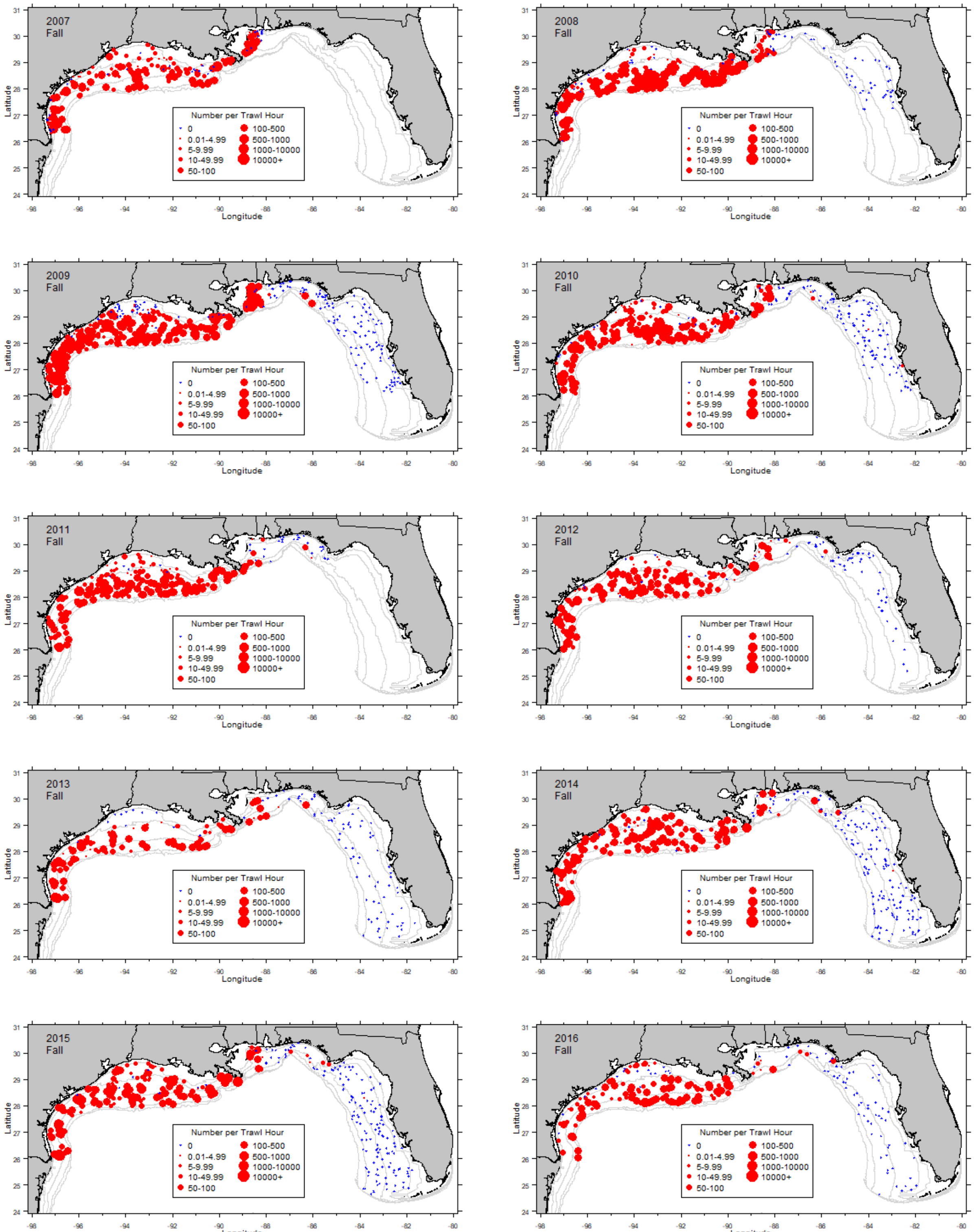
Appendix Figure 2. Distribution and abundance of brown shrimp (*Farfantepenaeus aztecus*) captured during the SEAMAP Fall Groundfish Survey from 1987 – 2018.



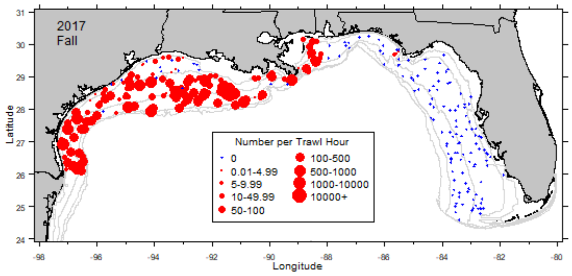
Appendix Figure 2 (continued).

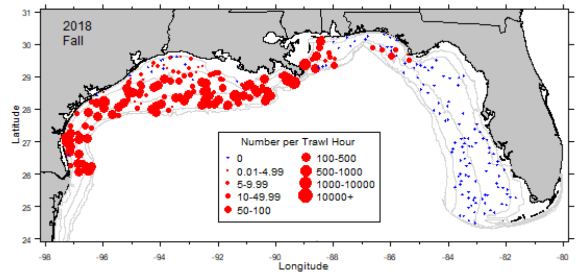


Appendix Figure 2 (continued).

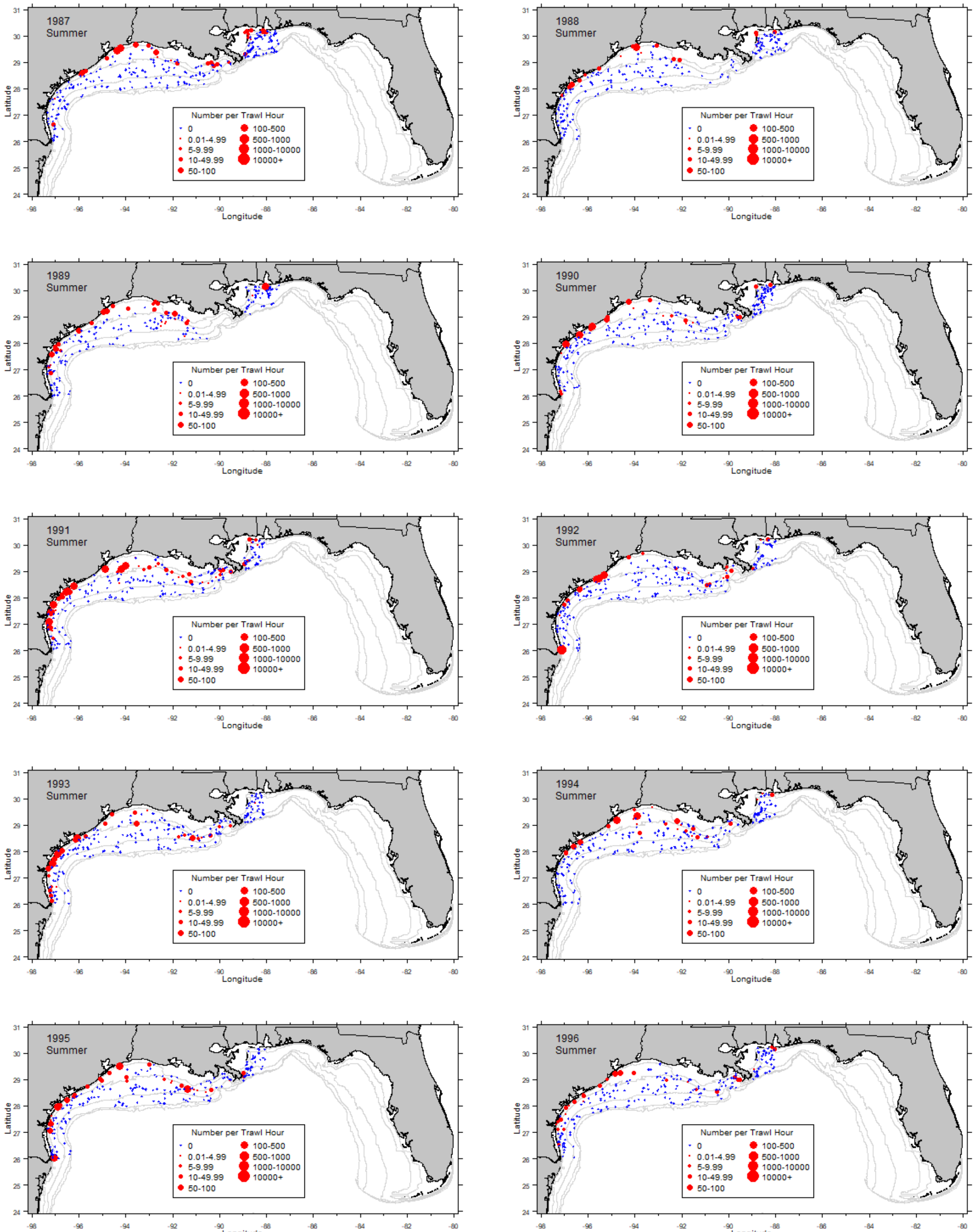


Appendix Figure 2 (continued).

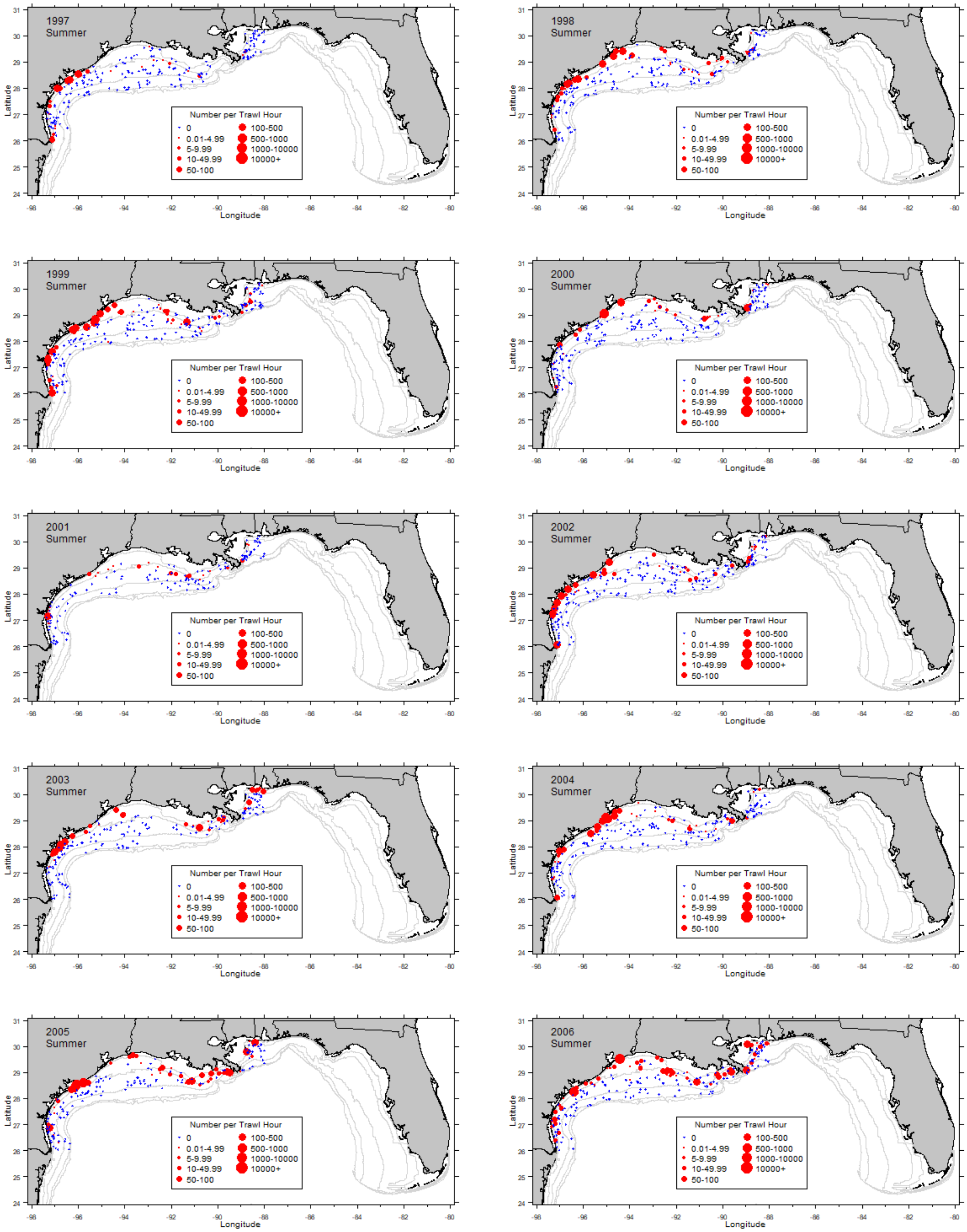




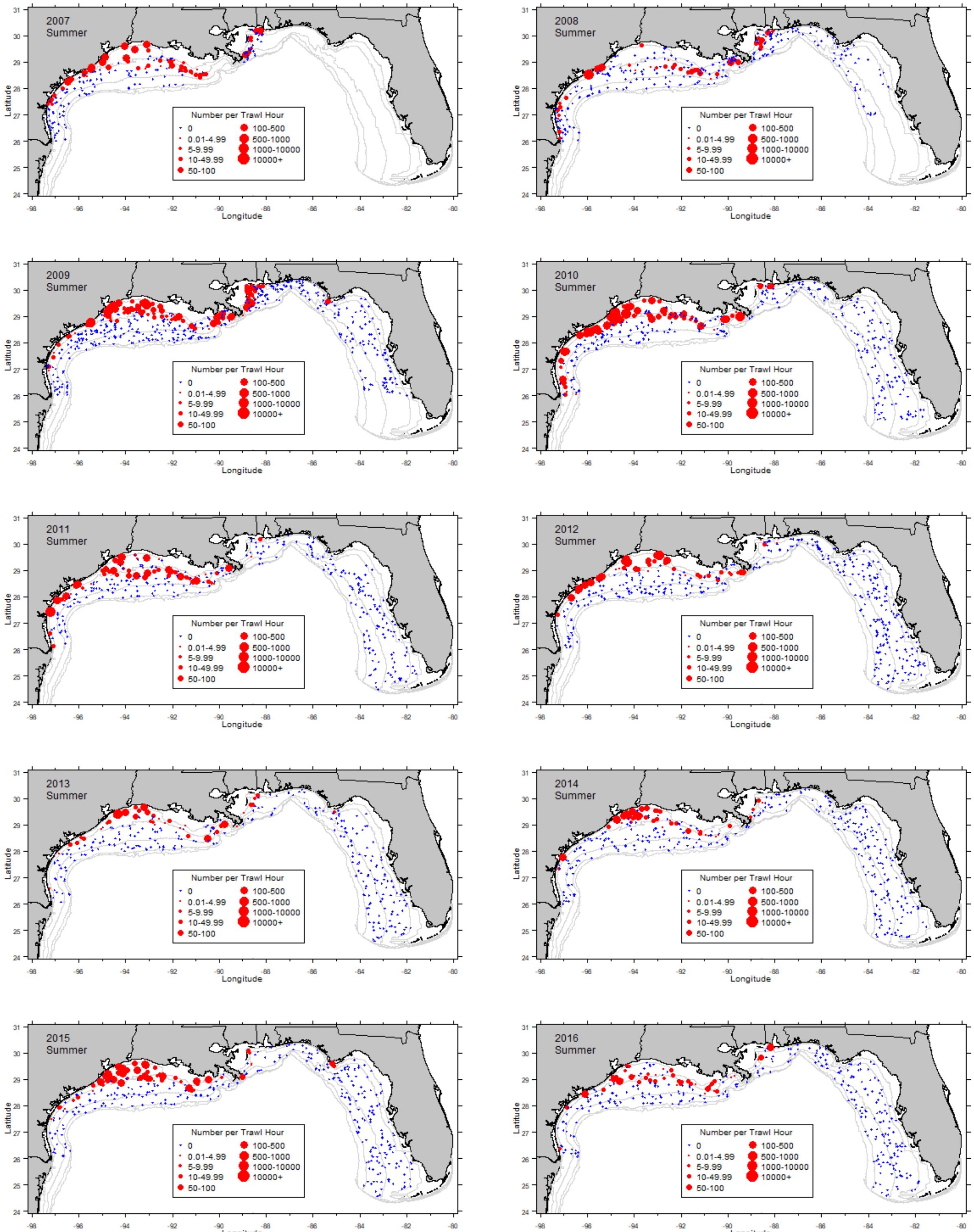
Appendix Figure 3. Distribution and abundance of white shrimp (*Litopenaeus setiferus*) captured during the SEAMAP Summer Groundfish Survey from 1987 – 2018.



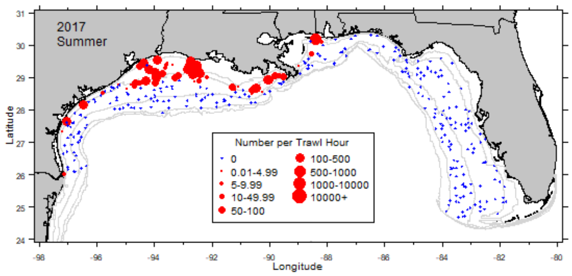
Appendix Figure 3 (continued).

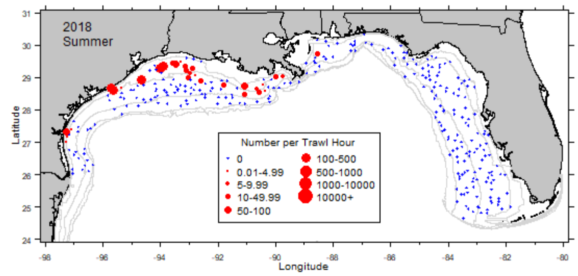


Appendix Figure 3 (continued).

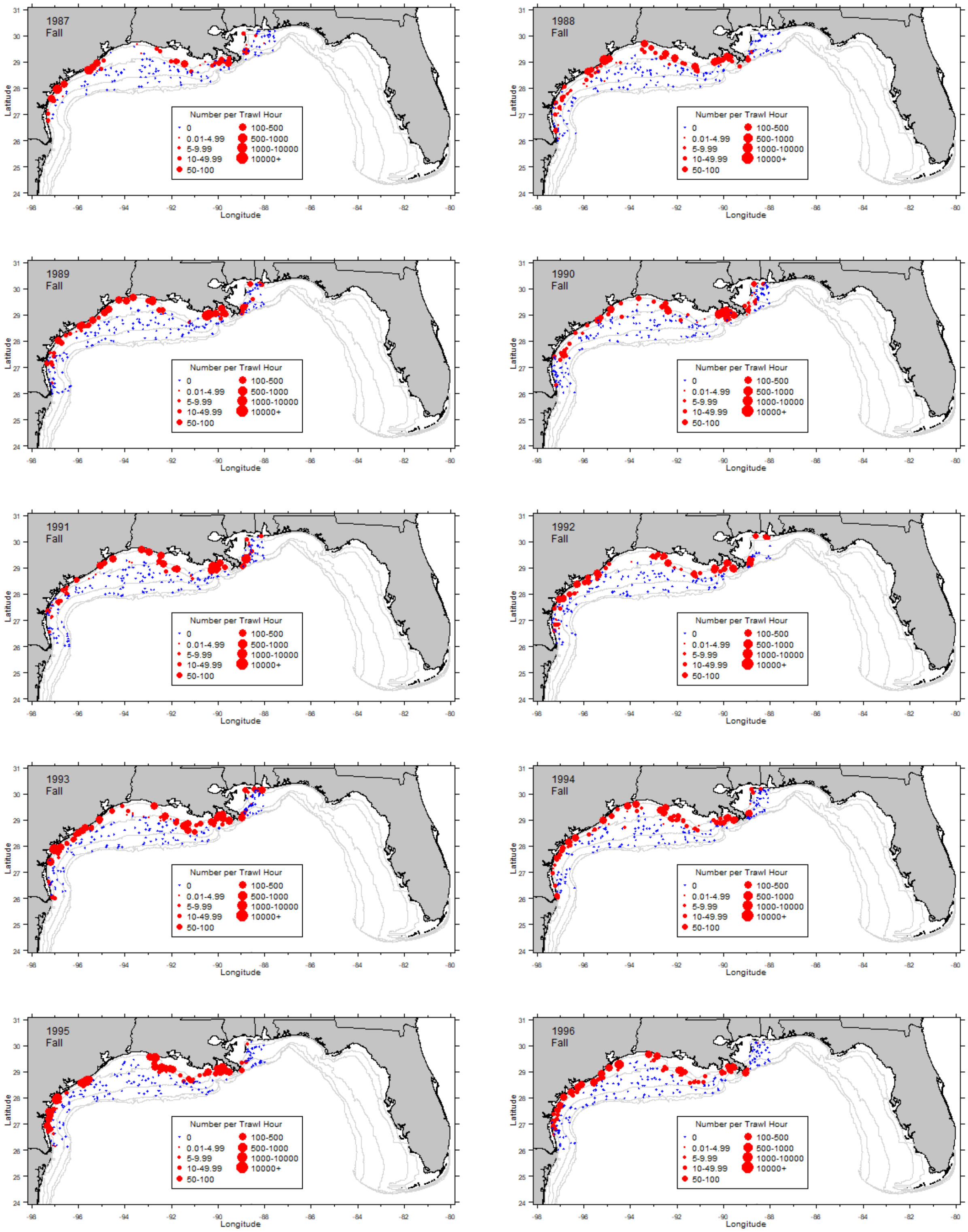


Appendix Figure 3 (continued).

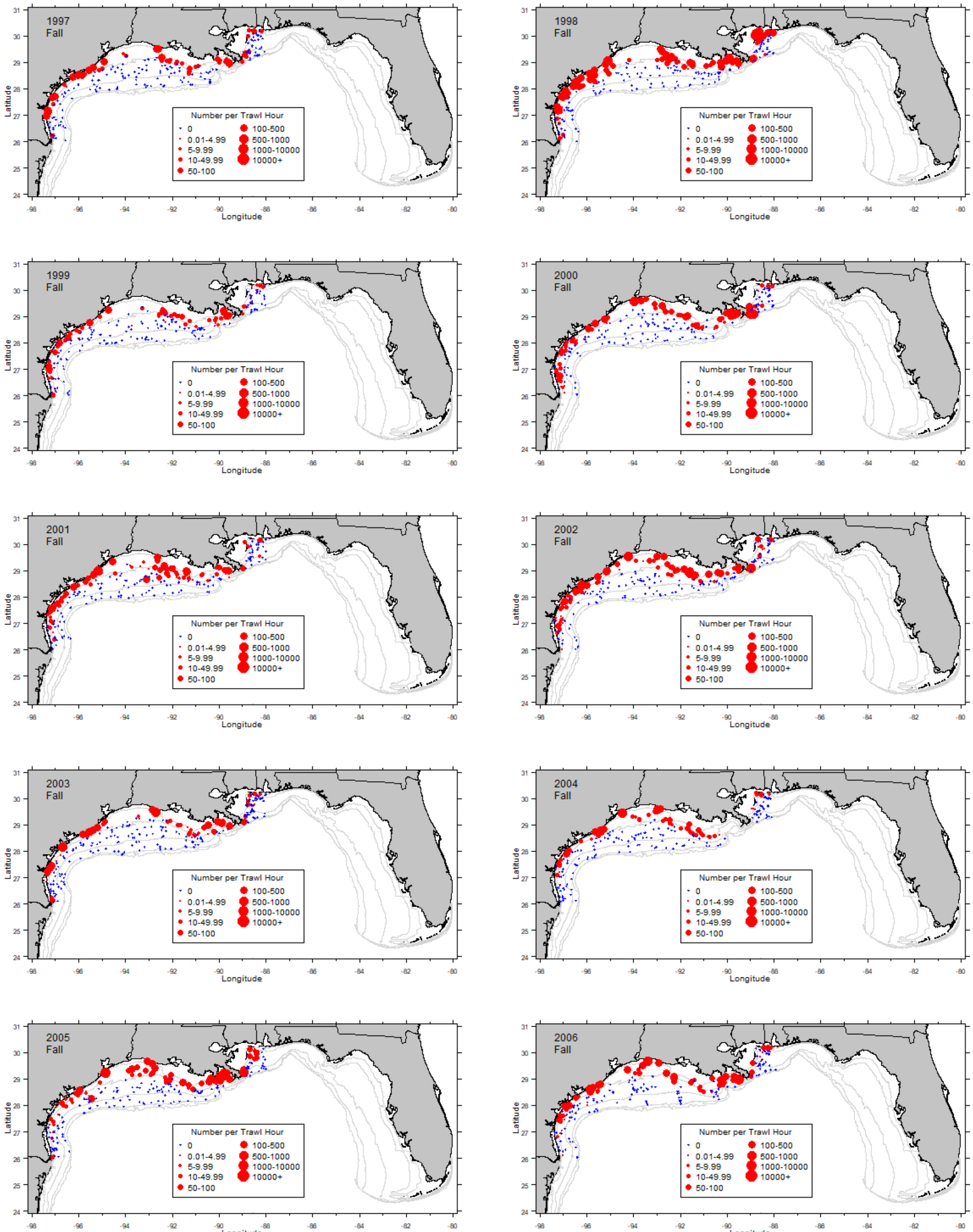




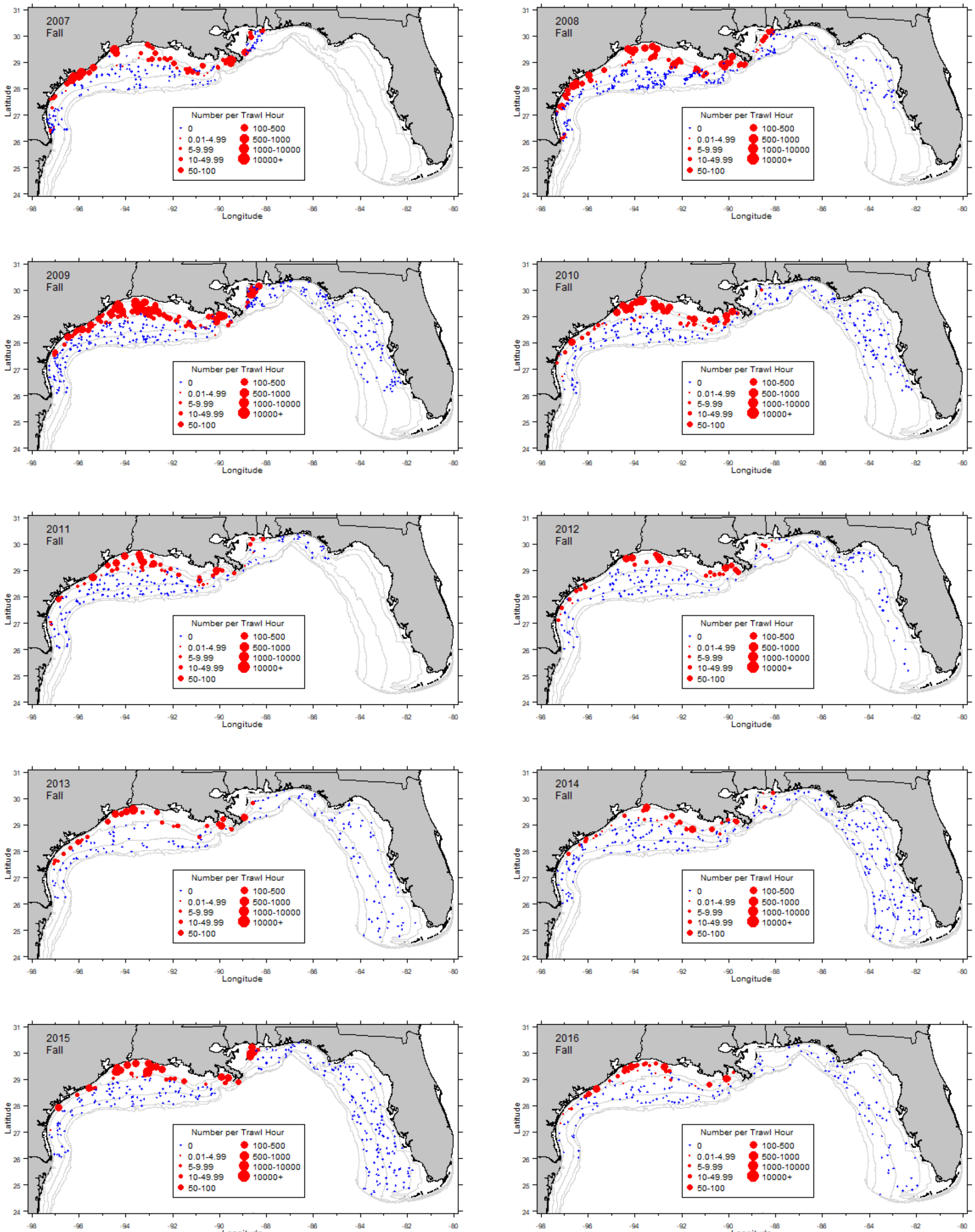
Appendix Figure 4. Distribution and abundance of white shrimp (*Litopenaeus setiferus*) captured during the SEAMAP Summer Groundfish Survey from 1987 – 2018.



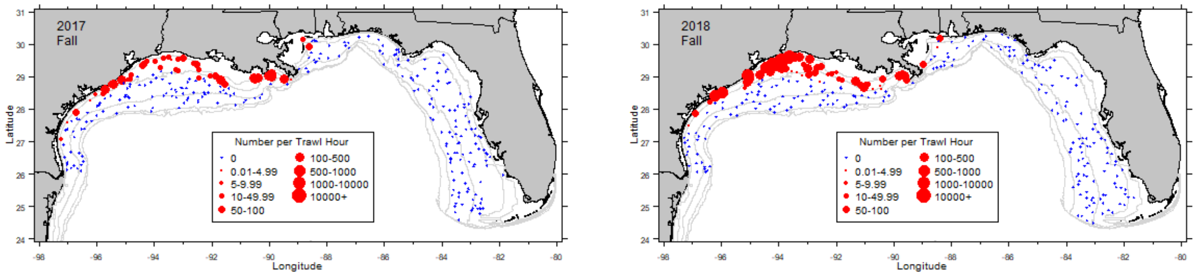
Appendix Figure 4 (continued).



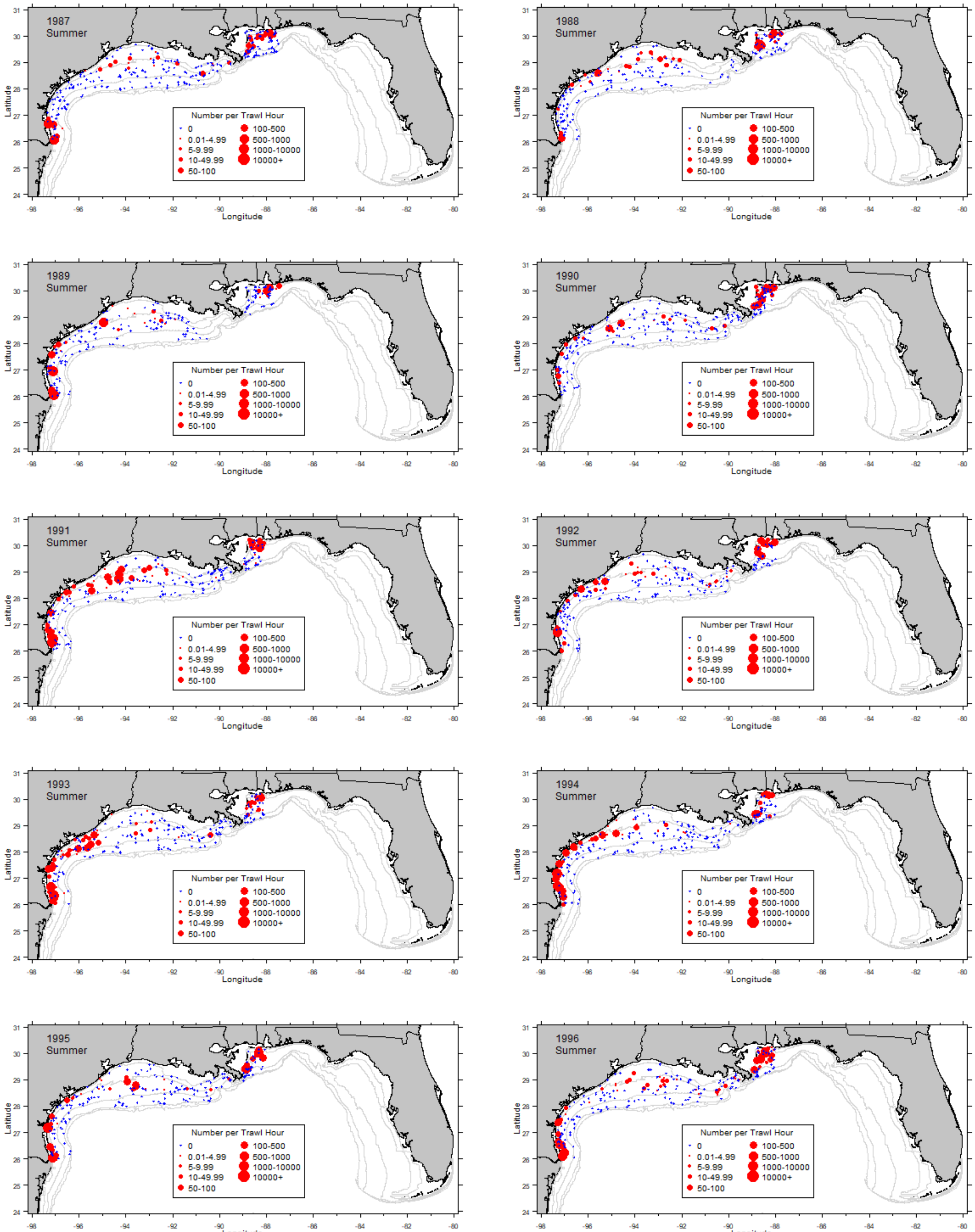
Appendix Figure 4 (continued).



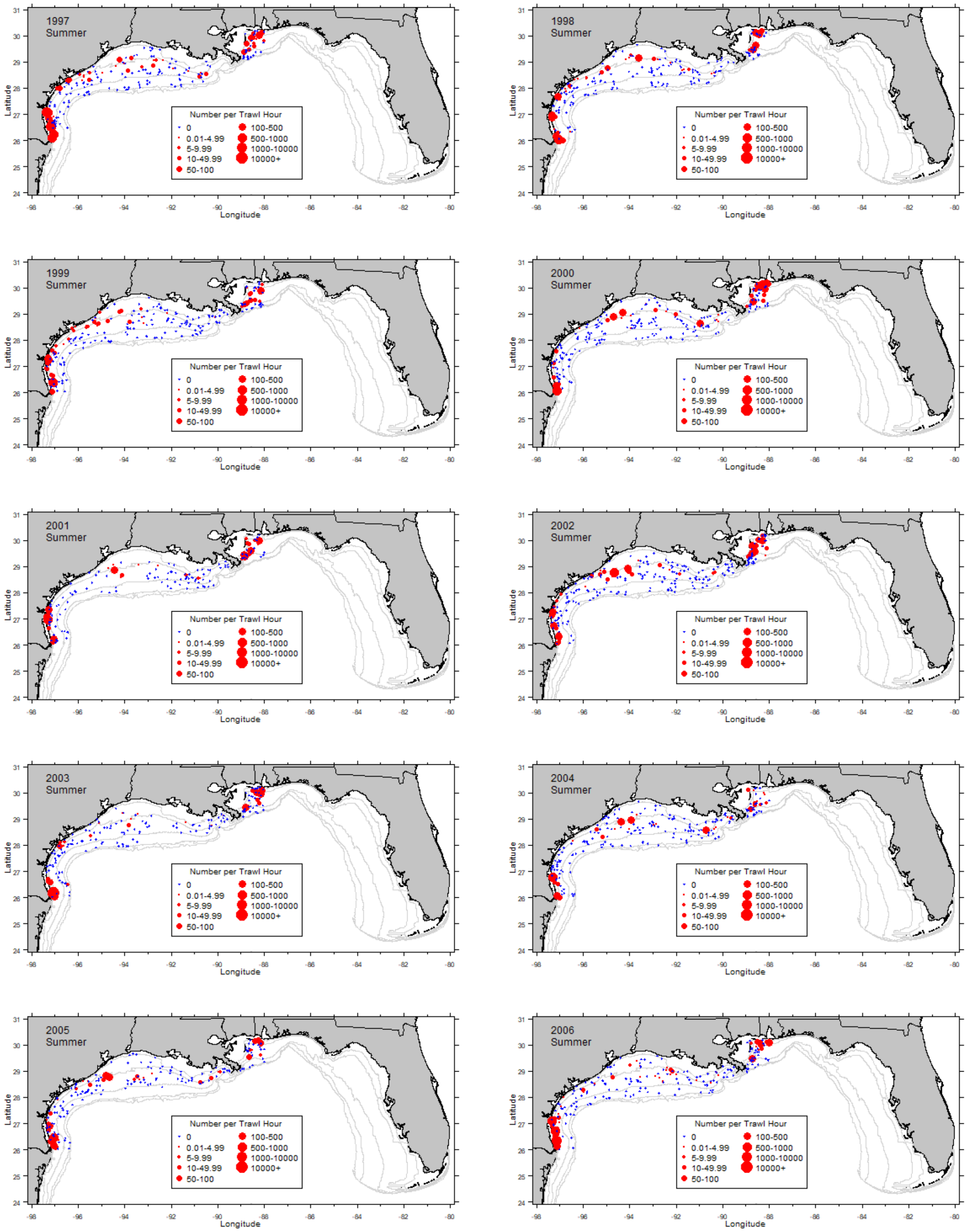
Appendix Figure 4 (continued).



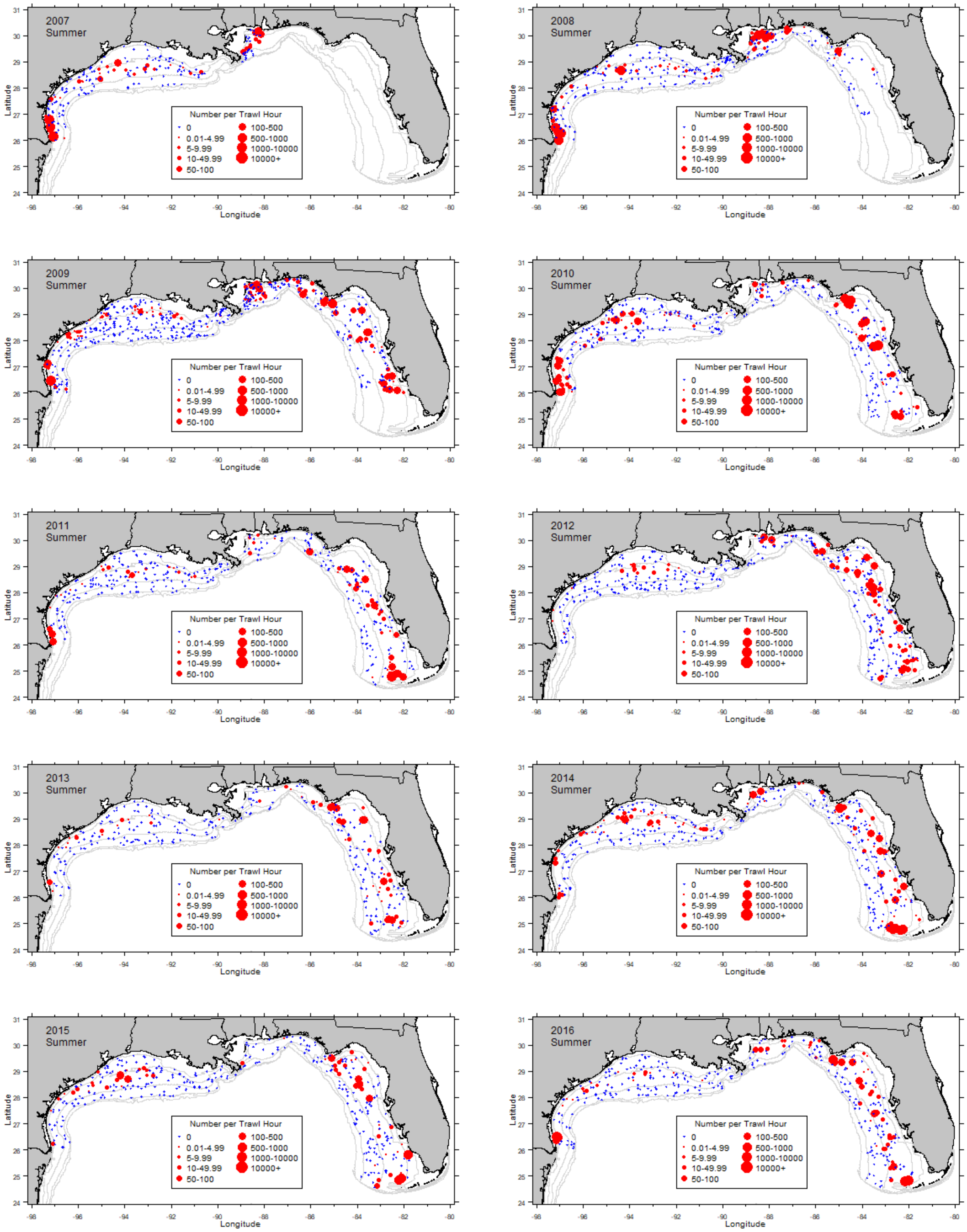
Appendix Figure 5. Distribution and abundance of pink shrimp (*Farfantepenaeus duorarum*) captured during the SEAMAP Summer Groundfish Survey from 1987 – 2018.



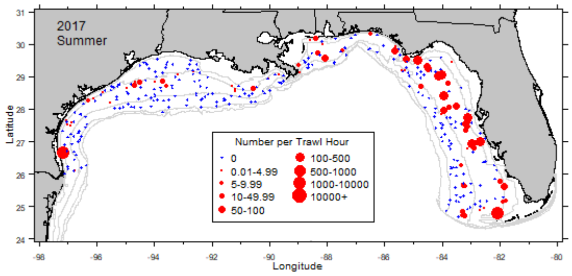
Appendix Figure 5 (continued).

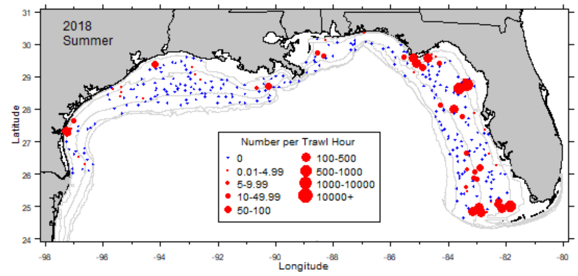


Appendix Figure 5 (continued).

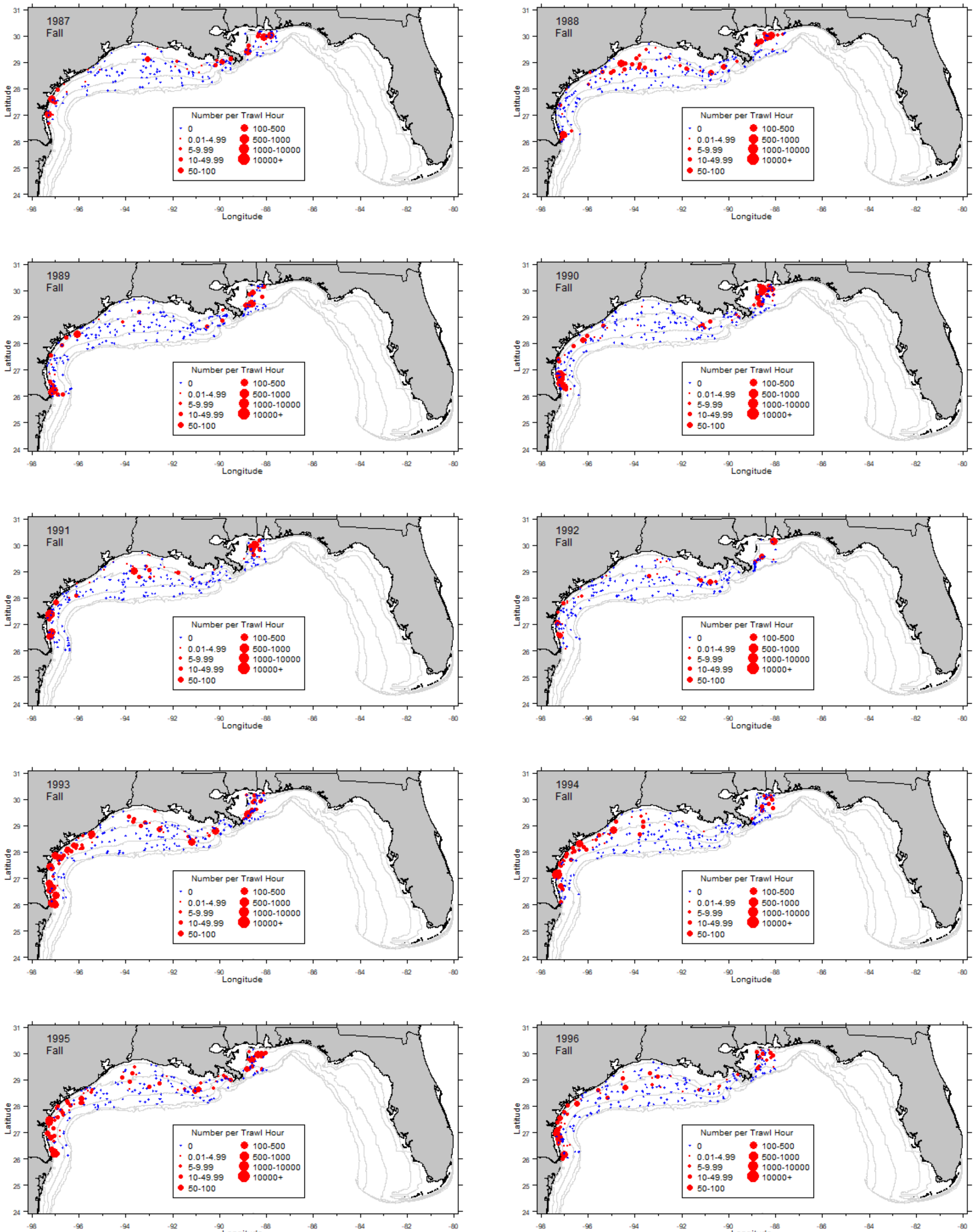


Appendix Figure 5 (continued).

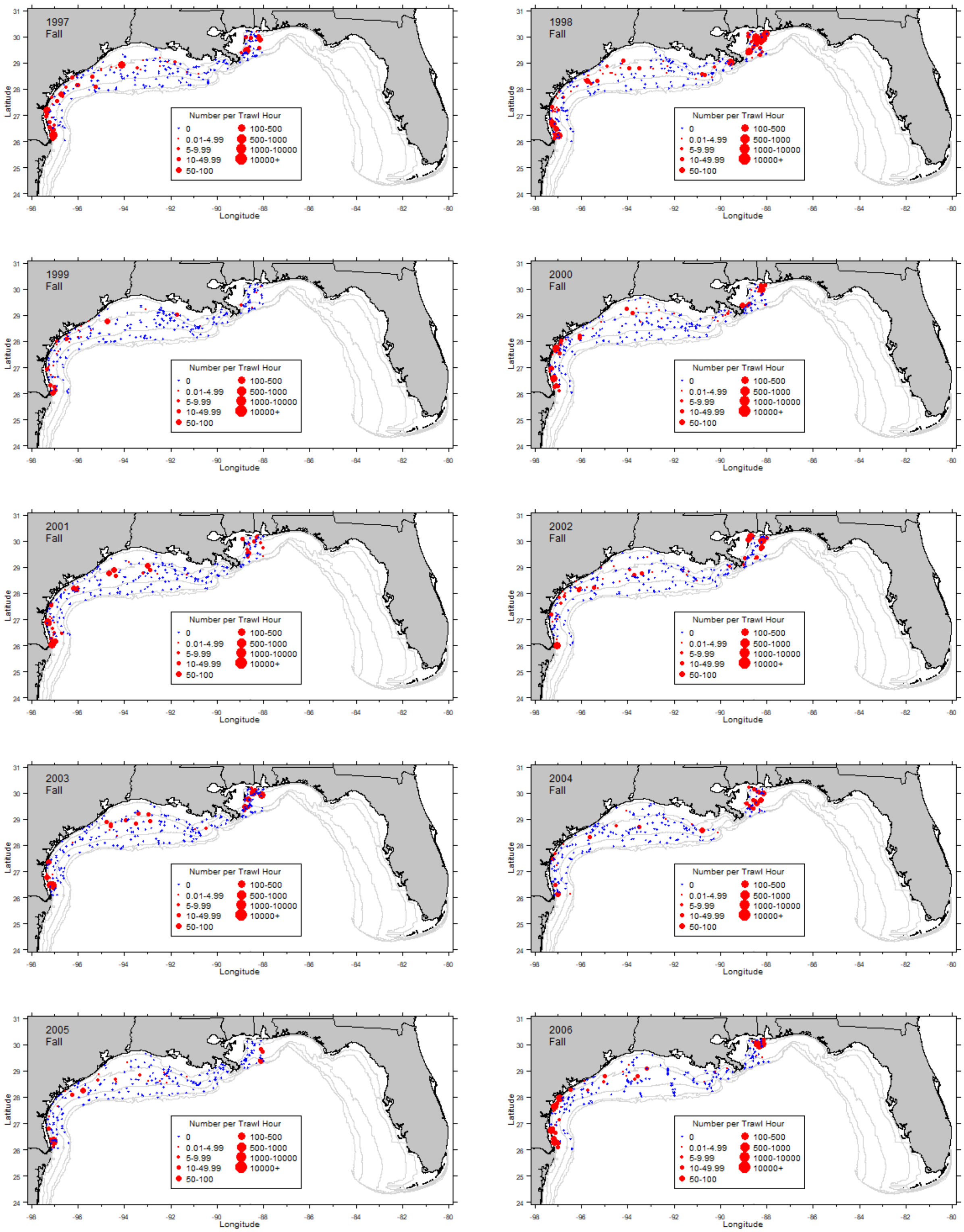




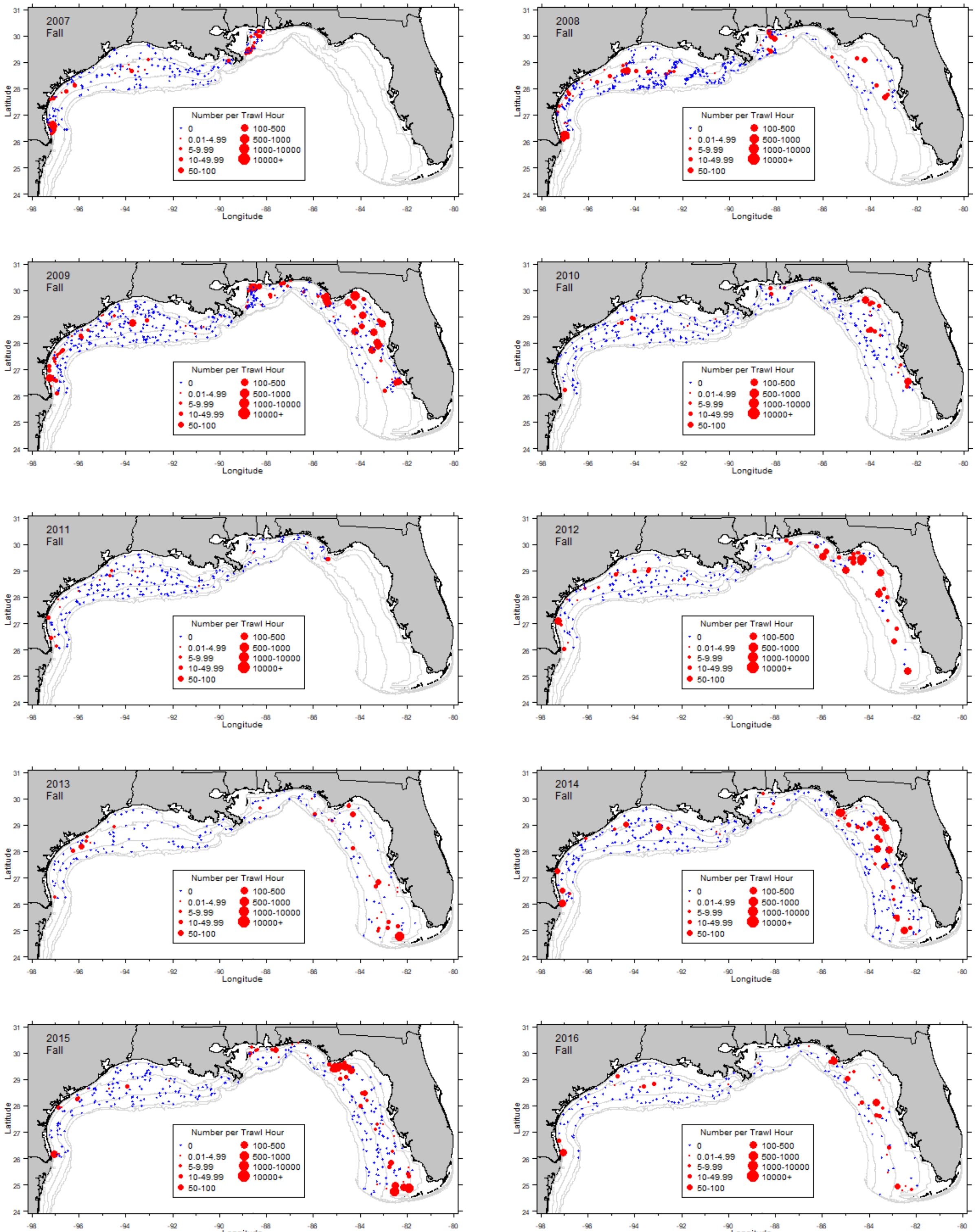
Appendix Figure 6. Distribution and abundance of pink shrimp (*Farfantepenaeus duorarum*) captured during the SEAMAP Fall Groundfish Survey from 1987 – 2018.



Appendix Figure 6 (continued).



Appendix Figure 6 (continued).



Appendix Figure 6 (continued).