Average Relative Density of Fish Species and Functional Groups in the Newfoundland and Labrador Shelves Bioregion from 1981-2017

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ABSTRACT

Wells, N.J., Pretty, C., Warren, M., Novaczek, E. and Koen-Alonso, M. 2021. Average Relative Density of Fish Species and Functional Groups in the Newfoundland and Labrador Shelves Bioregion from 1981-2017. Can. Tech. Rep. Fish. Aquat. Sci. 3427: viii + 76 p.

The Fisheries and Oceans Canada (DFO) multispecies research vessel (RV) survey dataset represents the longest time series of species data in the Newfoundland and Labrador (NL) region, making it ideal for mapping average relative densities (ARD) over time. ARD maps are interpolated densities of biomass data that represent persistent areas of relatively high and low densities for a specific species or functional group over a time series, independent of season.

Maps depicting the ARD of eight fish functional groups and 40 individual species were developed for the Engel (1981-1995) and Campelen (1995-2017) time series. These maps are well suited for use as decision support tools related to conservation areas and marine spatial planning. These maps can also inform other processes that require information on areas important to marine fish, such as environmental assessments.

RÉSUMÉ

Wells, N.J., Pretty, C., Warren, M., Novaczek, E. and Koen-Alonso, M. 2021. Average Relative Density of Fish Species and Functional Groups in the Newfoundland and Labrador Shelves Bioregion from 1981-2017. Can. Tech. Rep. Fish. Aquat. Sci. 3427: viii + 76 p.

L'ensemble de données du relevé des navires de recherche plurispécifiques de Pêches et Océans Canada (MPO) représente la plus longue série chronologique de données sur les espèces dans la région de Terre-Neuve-et-Labrador (T.-N.-L), ce qui en fait un outil idéal pour cartographier les densités relatives moyennes (DRM) au fil du temps. Les cartes DRM sont des densités interpolées de données de biomasse qui représentent des zones persistantes de densités relativement élevées et faibles pour une espèce ou un groupe fonctionnel spécifique sur une série chronologique, indépendamment de la saison.

Des cartes illustrant la DRM de huit groupes fonctionnels de poissons et de 43 espèces individuelles ont été élaborées pour les séries chronologiques Engel (1981-1995) et Campelen (1995-2017). Ces cartes sont bien adaptées pour servir comme outils de soutien aux décisions liées aux aires de conservation et à la planification spatiale marine. Ces cartes peuvent également éclairer d'autres processus qui nécessitent des informations sur les zones importantes pour les poissons marins, comme les évaluations environnementales..

INTRODUCTION

The Science Branch of Fisheries and Oceans Canada (DFO) in the Newfoundland and Labrador (NL) region has been conducting multispecies research vessel (RV) surveys using a random stratified survey design since the early 1970s. While these data represent a critical component of most science-based stock assessments (Rideout and Ings 2020), they have been used for a multitude of purposes, including the identification of Ecologically and Biologically Significant Areas (Wells et al. 2017), identification of spawning and juvenile areas (Ollerhead et al. 2004) and spatial analysis of demersal species (Kulka et al. 2003). This dataset represents the longest time series of species data in the NL region, making it ideal for mapping average relative densities of species over time. These maps can help to identify areas that are important to various species and functional groups, which can then be used as decision support tools for various jurisdictions with mandates and responsibilities related to protected areas and other spatial conservation measures (e.g. Marine Conservation Area network planning). These maps can also inform other processes that require information on areas important to marine fish, such as marine spatial planning and environmental assessments.

METHODOLOGY

Data Source

Data from spring, fall, and winter DFO multispecies research vessel (RV) bottom trawl surveys (hereafter referred to as the 'DFO RV surveys') between 1981 and 2017, inclusive, were used for the analysis. The coverage of the DFO RV surveys has been relatively consistent since 1981; however, there was some modification of the timing of surveys in 3Ps in the early 1990s. Winter surveys were conducted in the offshore areas of Div. 3Ps from 1972-1993. Due to concerns about the degree of mixing of cod in Div. 3Ps with those from Div. 3Pn4RS during winter months, surveys since 1992 (both winter and spring surveys were conducted in 1993) have been conducted in the spring (typically April-June) (Worcester et al. 2009). The number of successful sets for each survey per year, season, and NAFO division can be found in Table 1 and Table 2.

The survey area is stratified by depth range with survey sets (i.e. standardized fishing hauls at a randomly selected sampling unit) randomly distributed using a proportional-allocation scheme, whereby the number of sets allocated for a given stratum is proportional to the stratum area. Additional details regarding survey design can be found in Rideout and Ings (2020).

While multiple gear types have been used to conduct surveys throughout the history of the DFO RV survey, this analysis focuses on two that have been the most consistently used: the Engel 145 Hi-Lift Otter Trawl that was used to conduct surveys from 1979 until spring 1995 and the Campelen 1800 shrimp trawl that has been in use since fall 1995 (McCallum and Walsh 1997). The mesh size of the Engel gear ranged from 180 mm in the upper and lower wing and square, to 150 mm in the first and second bellies, and

130 mm in the third belly, extension, and codend. The trawl was towed at 3.5 knots for 30 minutes. The Campelen gear had a mesh size ranging from 80 mm in the wings to 60 mm in the square and first bellies, and 40 mm in the remaining bellies and codend. Unlike the Engel trawl, the Campelen trawl was towed at 3.0 knots for only 15 minutes. Because of the differences in the characteristics of these two gear types (i.e. catchability) and because conversion factors only exist for a small group of commercial species, Engel data cannot be scaled to comparable Campelen catches and so they are treated as two separate datasets. Additionally, the design of the DFO RV survey has changed over time. Prior to 1995, during the Engel time series, the survey covered NAFO Divisions 2J3KLNOP; however, with the adoption of the Campelen trawl, the survey was expanded to include Division 2H (Brodie and Stansbury 2007). Therefore, the two datasets have different spatial extents.

Fish Functional Groups

A functional group is a collection of species of similar size, diet and role in the ecosystem. Eight fish functional groups were identified based on the DFO RV survey dataset: small benthivores, medium benthivores, large benthivores, piscivores, plank-piscivores, planktivores, shrimp, and forage fish (see Appendix A). Species in the forage fish group overlap with other functional groups, however this additional grouping was included to illustrate the relative densities of three ecologically important forage fish species throughout the bioregion: Capelin (*Mallotus villosus*), Sand Lance (*Ammodytes dubius*), and Arctic Cod (*Boreogadus saida*). It should be noted that pelagic species are generally not well sampled by the RV survey trawl and therefore these data are not used to estimate their abundance (Mowbray et al. 2019). However, DFO RV survey data are still routinely used to describe species distributions (e.g. center of mass for the capelin stock; see Mowbray et al. 2019). For this reason, available data for the above-mentioned pelagic species were included in this analysis.

Two other important forage species are present in the region but not included in this layer. Atlantic Herring (*Clupea harengus*) are not well sampled in the RV survey trawl, mainly because of their inshore distribution (Bourne et al. 2018). Shrimp are a highly abundant forage species; their inclusion would dominate the layer and thereby mask the relative density of other forage fish species. Therefore, the two main shrimp species in the bioregion were mapped together, while the individual species were mapped as the dominant (*Pandalus borealis*) and non-dominant (*P. montaguii*) species.

The identification and classification of some species caught in the DFO RV survey trawl is less reliable when compared with more common, often commercial, species. To overcome this issue, we categorized some species to ‘operational species’ (i.e. the lowest taxonomic level of reliable and consistent identification). For example, several species of seasnails, including two genera (*Paraliparis* sp. and *Liparis* sp.), are captured in the trawl survey but they are unreliably identified to the species level at sea. When identified to species, the most commonly occurring species is the gelatinous seasnail (*Liparis fabricii*). However, the majority of records in the survey database are identified at the Liparidae level. Therefore, all records of seasnails, whether identified at the species, genus or family level, are grouped under Liparidae. The operational species that were used in each functional group are listed in Appendix A. Similarly, three species of redfish occur in Newfoundland and Labrador waters: *Sebastes mentella, S. fasciatus*, and *S. marinus*. *S. marinus* has distinguishing characteristics, however, *S. mentella* is visually indistinguishable from *S. fasciatus* and at-sea identification of these species is very challenging. For the purpose of this report, maps labelled as redfish or *S. mentella* (as a dominant plank-piscivore; see Appendix A) include *S. mentella* and *S. fasciatus*. *S. marinus* is a non-dominant plank-piscivore.

Identification of Dominant Fish Species

For fish, the number of species in each functional group is very high (see Appendix A). The relative densities displayed in data layers created for each functional group are largely driven by the dominant species (i.e. top 90% of biomass) in that group. To show the influence of these species on the average relative density of the functional group as a whole, the dominant species from each functional group were mapped separately from the non-dominant species to illustrate the relative distribution of the functional group when the dominant species are removed. Species in the top 90% were identified by calculating the average weight per tow (kg/tow) for each species in a functional group per year over the Campelen time series only. The averages were summed and the proportion of the total for each species was calculated and then ordered from largest to smallest. A cumulative proportion was then calculated and the species that fell into the top 90% of cumulative biomass were selected (Table 3) and maps were created for each species in each time series (with exceptions; see below). As this was done using the dataset selected for this analysis, the species that fall into the top 90% may vary slightly if the dataset is filtered using different parameters (e.g. seasons, NAFO Divisions, strata, species).

Species in the forage fish group are also included in other functional groups; Capelin and Sand Lance in the Planktivores group and Arctic Cod in the Plank-piscivores group. Capelin and Sand Lance are considered dominant species within their functional group. However, Arctic Cod is not a dominant species in the Plank-piscivores group. Nevertheless, we produced individual data layers for all three forage fish species to illustrate the spatial patterns for these important species in the bioregion.

At-risk Fish Species

At-risk fish species are species recognized by COSEWIC as endangered, threatened or of special concern. A subset of these species is also protected under *SARA* (*Species at Risk Act* 2002). The species considered at risk, and for which there were enough data to generate a data layer, can be found in Table 4. While it is recognized that the Designatable Units for some species are at a smaller spatial scale than the NL bioregion, the entire range of data available was used to map species average relative densities. For some species that are endangered, threatened, or of special concern under COSEWIC, there were not enough data to generate a surface. These species are listed in Table 5.

In addition, fish stocks that were considered to be depleted by DFO or NAFO (but are not considered at-risk by COSEWIC) at the time that these analyses were performed were also mapped (Table 6). For the purpose of this analysis, these were cases where estimates of stock size were near or below biomass limit reference points, where survey indices suggested that stocks were at low levels, or the fishery is under moratorium (see references in Table 6).

Data Processing

The data processing and analysis workflow can be found in Figure 1. Weight per tow (kg/tow; standardized for tow length for each gear type) data for fish, shrimp, and crab species from 1981-2017 were extracted from the database. The data were filtered prior to use so that only core strata (areas consistently sampled across years) in NAFO Div. 2J3KLNOP (Engel) and Div. 2HJ3KLNOP (Campelen) were included (Figure 2). This meant that most deep water and inshore sets were not included in this analysis. Only successful sets from regular multispecies survey trawls were used (see Table 1 and Table 2).

To identify the average relative density of the functional groups and species regardless of season, the spring, fall, and winter survey sets for Engel (1981-1995) and Campelen (1995-2017) were compiled into two composite datasets in R (v.3.5.0) using a log transformation ($\log(x+1)$) on the biomass (kg/tow), which was then standardized ($(x-\bar{x})/(s.d.)+3$) across each functional group. The +3 was added to the end of the standardizing equation to ensure that the range of all standardized values reflected in the resulting maps were positive. Absences (0 kg/tow catch values) were included. The same method was used for individual species (i.e., dominant species within each functional group and at-risk species). All datasets were exported as CSVs and were projected in ArcMap (version 10.4.1) as point layers using the custom WGS 1984 UTM Zone 21.5 N projection.

Kriging

Smoothed, continuous raster surfaces were generated from the output point data described in the section above through kriging, a common geostatistical interpolation technique. Kriging uses the statistical properties of the measured data to inform interpolated values. In this case, a semivariogram is used to quantify the strength of spatial autocorrelation within the dataset and, through this estimate, the distance-dependent influence of measured data points on each interpolated value.

Kriging the RV survey data required a multi-step process, all of which was completed using ArcMap (version 10.4.1). To smooth the variability of the standardized biomass point data (e.g. outliers, inter-annual variability) without excluding values from the dataset, the Mean Centre tool was used with an 8 km x 8 km fishnet grid to calculate the mean geographic centre and mean standardized biomass value of all points falling into a given grid cell for each point layer. On average, this 8 km x 8 km grid captured 8 neighbouring points. The resulting point dataset effectively had less points but also less attribute variability. This smoothed point dataset was then used in a kriging interpolation with ordinary kriging and a spherical semivariogram. A variable search radius was used to find the 8 nearest sample points over a maximum distance of 37 km. This maximum distance value was the maximum distance required to find 8 neighbours in the original point layer. The output cell size was set to 4 km. The output raster was then clipped to a mask that corresponded to the extent of the data points for each gear type (i.e. Engel or Campelen) with an 8 km buffer applied so that the data were not extrapolated past the distance of one grid cell used to generate the mean centres.

Finally, due to the standardization of biomass values (including zeros), the zero catches were no longer represented by actual zeros; each layer had its own 'zero' value based on the mean and standard deviation of the biomass in each functional group or species. To clean up the layers, the standardized zero was set to null from each layer and thus removed.

The results of this process are raster layers (exported as ESRI grids and geoTIFFs) showing the average relative density of fish functional groups and selected individual species during both the Engel (1981-1995) and Campelen (1995-2017) time series.

Map Production

The Engel and Campelen data are two separate datasets, so two sets of maps were produced for most functional groups and species. Engel maps were based on spring, fall, and winter data collected from spring 1981 to spring 1995 in NAFO Divisions 2J3KLNOP. Campelen maps were based on spring and fall data collected from fall 1995 to fall 2017 in NAFO Divisions 2HJ3KLNOP. However, due to catchability issues with the Engel trawl, and because some species/taxa were not specifically recorded when the Engel trawl was used, only Campelen maps were produced for some functional groups (planktivores, shrimp, and small benthivores) and their associated species.

The maps are displayed using a percent clip (min: 0.5, max: 0.5) stretched symbology along a red-yellow-blue colour ramp. Due to the processing of the data, the original units are no longer relevant (e.g. kg/tow) and the cell values are not comparable between species. The data are displayed as a range of average relative densities from low (blue) to high (red).

RESULTS

In total, 34 maps were produced for functional groups (Figures 3-14) and 65 maps were produced for individual species (Figures 15-52; see Table 7). Two sets of three maps were generated for each functional group to capture all species (left panel), dominant species (middle panel), and non-dominant species (right panel) for each time series (Engel and Campelen; see exceptions listed above). The forage fish functional group contains three species that are also found in other functional groups, and these species are also mapped individually; therefore, this functional group was not split into dominant and non-dominant species. The first set of maps for each functional group is generally based on Engel survey data (NAFO Divisions 2J3KLNOP, 1981-1995) and the second set uses Campelen survey data (NAFO Divisions 2HJ3KLNOP, 1995-2017). For some functional groups (i.e. small benthivores, planktivores, and shrimp), map sets were generated for Campelen data only (see Figures 3, 12, and 13, respectively).

The species maps (Figures 15-52) are ordered from the most dominant species (i.e. highest mean kg/tow from Campelen survey sets, all seasons and NAFO divisions combined) to the least dominant species within a functional group, including any non-dominant at-risk species for that group. Northern Shrimp and Striped Shrimp maps can be found in the set of maps for the shrimp functional group, as this group contains only these two species and Northern Shrimp is considered the dominant species (Figure 13). A list of all individual species mapped from each functional group, including at-risk (non-dominant) species, can be found in Table 3. The proportion of the summed average weight per tow (based on Campelen data only) is also provided for each species.

DISCUSSION

The average relative densities of eight fish functional groups and 40 individual species were mapped for two time periods: 1981-1995 and 1995-2017. Functional groups were split into dominant and non-dominant species to show the influence of dominant species on the relative density of the full functional group. The average relative densities of 15 at-risk species were also mapped to illustrate important areas for these vulnerable species.

For all functional groups, the influence of dominant species was evident, as illustrated by the similarity of maps containing all species in a functional group (left panel) and maps containing only the dominant species (middle panel). Spatial patterns of average relative density of non-dominant species are generally very different from those of dominant species. However, it is noted that some of these differences are more predominant in the southern or northern portion of the bioregion. For example, from the Campelen survey, the relative density of non-dominant large benthivores compared to all large benthivores is somewhat similar in the north (i.e. NAFO Divisions 2HJ3K) but patterns between these two groups differ drastically in the south (i.e. NAFO Divisions 3LNOP; Figure 7). Examining the individual species maps provides some clues as to why this is. American Plaice (*Hippoglossoides platessoides*; Figure 35) and Thorny Skate (*Raja radiate*; Figure 36) are the two most dominant species in this functional group and they are found in high densities in the southern portion of the bioregion. The highest densities of non-dominant species are found in deeper waters on the edge and slope of the continental shelf and in deep troughs and channels, similar to the distributions of dominant species like Roughhead Grenadier (*Macrourus berglax*; Figure 37) and haddock (*Melanogrammus aeglefinus*; Figure 38).

Other noteworthy spatial patterns can be found in the planktivores (Figure 12), plank-piscivores (Figure 10, Figure 11), and forage fish (Figure 14) functional groups. Planktivores are dominated by Sand Lance (Figure 50) and Capelin (Figure 51). These two species have little overlap in their distributions, however given that Capelin are better sampled by acoustic survey equipment than the survey trawl used in this process, it is difficult to make any concrete conclusions on important areas for this species. Nevertheless, it is interesting to note that the three forage fish species are generally separated in their distributions: Arctic Cod (Figure 49) has the highest densities in the northern portion of the bioregion, Capelin in the middle (i.e. NAFO Divisions 3KL) and Sand Lance in the south. Argentine (*Argentina silus*) and Atlantic Herring (*Clupea harengus*) drive the distribution of non-dominant planktivores. These species are found in highest densities along the south coast of Newfoundland, an area where other forage fish appear to be found in relatively low densities.

In comparing the relative densities between functional groups, it is interesting to note the spatial overlap (or lack thereof) between them. The waters south of Newfoundland (i.e. NAFO Division 3P) show high relative densities of all functional groups except shrimp (Figure 13), with the Laurentian Channel being important to all groups, with the exception of planktivores (Figure 12). Depth and latitudinal gradients at the species and functional group levels are evident in the data. For example, the southern Grand Bank (i.e. NAFO Divisions 3NO) is dominated by medium (Figure 4, Figure 5) and large benthivores (Figure 6, Figure 7) and the northern portion of the bank (i.e. NAFO Division 3L) consists mainly of small benthivores (Figure 3) and planktivores, with shrimp also being found in relatively high densities in the northern portion of this area. The northern Newfoundland shelf (i.e. NAFO Divisions 2J3K) has high densities of shrimp, piscivores (Figure 8, Figure 9), planktivores, and small benthivores. The most northern portion of the bioregion (i.e. NAFO Division 2H) is dominated by small benthivores, piscivores, plank-piscivores (Figure 10, Figure 11), and shrimp. Finally, deeper waters found at the continental shelf edge and slope are dominated by small, medium, and large benthivores, piscivores, and plank-piscivores. When comparing the distribution of high density areas for each functional group, some groups appear to have restricted ranges (e.g. medium benthivores, plank-piscivores, shrimp), while other groups are found throughout the bioregion but appear to be associated with specific habitat features. For example, small benthivores appear to be most highly associated with banks and shelf edges, while piscivores appear to have highest densities in deeper channels and troughs. Planktivores appear to be associated with relatively shallower depths; this has been observed in previous studies in other countries and is linked, at least in part, to food availability (Maravelias 1999, Bonanno et al. 2014).

The Campelen time series data used in these analyses has better temporal coverage (22,735 sets over 23 years, 1995-2017) than the Engel time series (13,561 sets over 15 years, 1981-1995). The depth distribution and frequency at which depths were surveyed differ between the two time series (see Appendix B). During the Engel time series, the minimum mean depth recorded for a set was 36 m and the maximum was 1,239 m. The average mean depth of the Engel time series was approximately 219 m. Meanwhile, during the Campelen time series, the minimum mean depth recorded for a set was similar at 34 m, but the maximum was 1,494 m. The average mean depth of the Campelen time series was deeper at approximately 263 m. The Campelen time series surveyed deeper areas of the bioregion, but also sampled all depth classes with more frequency, especially the shallowest (i.e. <100 m) and the deeper (i.e. >500 m) depth classes. While the proportion of sets in the shallowest depth class is virtually the same for both Engel (29.43%, 3,991 sets) and Campelen (29.91%, 6,800 sets), the proportion of sets in the deeper depth classes is more than twice as large during Campelen years (10.79%, 2,452 sets) as compared to Engel years (4.51%, 611 sets). Depths beyond

1,000 m are not well surveyed in either period; during Engel, there were only 3 sets (0.02%) greater than 1,000 m, while during Campelen, there were 656 sets (2.89%). The Engel time series had a higher proportion of sets than the Campelen time series in the 101-200 m (23.70% vs. 21.25%), 201-300 m (20.48% vs. 16.80%), and 301-400 m (14.39% vs. 12.07%) depth classes.

The Engel and Campelen surveys represent separate time series with important differences in catchability, depth distribution, and spatial distribution (Engel data are not available for NAFO Division 2H). However, because these maps represent a relative density calculated in separate processing routines, general comparisons may be made within the spatial overlap (i.e., NAFO divisions 2J3KLNOP) regarding the general distribution of species and functional groups in the two time periods. This is particularly true for commercial species, which were sampled effectively by both gear types. When making any comparison, it is important to consider that differences between Engel and Campelen may be due to changes in distribution of biomass over time, catchability, or a combination of these factors.

At-risk Species

For the 13 COSEWIC and *SARA* at-risk fish species, overall changes in distribution between the Engel and Campelen time series are noted below.

Distribution of Redfish (*Sebastes mentella* and *S. fasciatus*; Figure 48) is consistent across both survey periods, with high relative density found along the continental shelf edge and slope. However, there are more records in shallower waters during the Campelen period.

American Plaice (*Hippoglossoides platessoides*; Figure 35) were distributed widely throughout the bioregion from NAFO Division 2J south to 3P during the Engel survey period. The more recent Campelen survey indicates that the highest relative densities occur on the southern portion of the Grand Bank, with some high catches on the northeast edge of the Grand Bank.

Atlantic Cod (*Gadus morhua*; Figure 43), a species well sampled by both surveys, were found throughout most of the bioregion during the Engel survey years, which roughly corresponds to the pre-collapse period. During Campelen years, NAFO Divisions 2J3K have the highest relative densities, with high densities also occurring in 3P and along the southwest portion of the Grand Bank.

In general, similar areas appear to be important for each wolffish species across the two time series. However, the importance of northern regions (i.e. NAFO Divisions 2HJ) to Atlantic Wolffish (*Anarhichas lupus*; Figure 39) is more evident in the Campelen data. It is also important to note that complex, rocky habitats preferred by this species are not well sampled by the survey trawls, and therefore these data may provide an incomplete picture of their distribution and important habitat. Similarly, the importance of deeper areas along the slope of the continental shelf for Northern Wolffish (*A. denticulatus*; Figure 41) is more evident in the Campelen data, which is likely a result of deeper survey sets carried out during Campelen years. For all species, the lack of NAFO Division 2H data in the Engel time series prevents direct comparison of northern distributions, which is an area of high relative density particularly for Spotted Wolffish (*A. minor*; Figure 40) observed in the Campelen survey.

Parts of NAFO Division 3P have been important for the Common Lumpfish (*Cyclopterus lumpus*; Figure 31) throughout both survey periods. However, northern areas (i.e. NAFO Divisions 2J3K) appear more important for this species in the recent Campelen years.

Distribution patterns of Roundnose Grenadier (*Coryphaenoides rupestris*; Figure 33) are generally similar in both time series. Campelen data also show that this species occurs in deeper waters than were sampled during Engel years.

Distribution of high relative density areas for Smooth Skate (*Malacoraja senta*; Figure 34) are quite different across the two time series, and most of the areas that appear as important in the Engel time series appear to have low relative densities in the Campelen time series. This may be due, in part, to the higher catches in more northern (i.e. NAFO Division 2H) and southern (i.e. NAFO Divisions 3NP) areas that were not sufficiently sampled in Engel years. However, the Funk Island Deep stock of Smooth Skate, where high relative densities were recorded during the Engel survey, has been assessed as endangered and a decrease in overall abundance (DFO 2017) has also contributed to shifts of important areas over time.

Relative densities of Thorny Skate (*Amblyraja radiate*; Figure 36) on the northeast side of the Grand Bank are much lower during Campelen years than during the Engel years, as it appears that the southern portion of the Grand Bank has recently become a more important area for this species.

The Laurentian Channel and southwest slope of the Grand Bank are important areas for White Hake (*Urophycis tenuis*; Figure 47) in both time periods. However, low density areas emerge in the more northern areas throughout the bioregion (i.e. NAFO Divisions 2J3KL) in the Campelen time series, potentially indicating a range shift for White Hake.

There are very few records of Winter Skate (*Leucoraja ocellata*; Figure 42) in the RV survey data. The area just south of Saint Pierre and Miquelon seems to be the most important area for this species in both time periods, however observations appear in more northern areas of the bioregion (as far north as NAFO Division 2H) during the Campelen years.

Data Limitations and Other Considerations

These maps represent the average relative density based on kilograms per tow in DFO multispecies survey trawls over the entire duration of the survey. They are broken into two time periods due to a change in gear (from Engel to Campelen) that took place after the spring 1995 survey. The Campelen trawl has a smaller mesh size than the Engel trawl and is towed at a slower speed for a shorter duration, making the catchability of the trawls very different and not directly comparable. The Campelen trawl catches smaller species of fish, as well as smaller-sized fish (i.e. juveniles) of species that were caught with the Engel trawl. Still, data from the Campelen trawl are biased towards maturing and adult fish and most likely do not fully represent the distribution and relative abundance of young-of-the-year fish and most juveniles. Furthermore, the catchability of the surveys may vary slightly between seasons and vessels but this issue was addressed by log transforming the data across each time series and by standardizing the data by species or functional group.

There was no attempt to quantify variability or uncertainty in these maps. Small-scale changes in the distribution of species over time (i.e. seasons and years) are not detectable as the data were aggregated over the entire time series. Also, there was no consideration of the scale at which these species associate with their habitats or with competitors or predators. In other words, these maps allow for the identification of general areas where high or low densities occur on average, but should not be used to make management decisions on issues that require consideration of seasonality, changes in distribution within the survey time period, or fine-scale habitat associations.

Additionally, these maps could benefit from further analyses such as a sensitivity analysis, which could involve removing some of the data (e.g. at the set, species, survey, or NAFO division scale) and re-running the analysis to determine the effect of those data on the trends seen in the resulting maps. As well, where these maps were produced using the geostatistical method kriging, it is possible to measure the accuracy or certainty of the interpolation. However, measures of accuracy or certainty were not recorded for this analysis. It is recommended that future iterations of this work include some determination of accuracy or certainty (e.g. cross-validation).

Bottom trawl surveys are not the ideal way to survey pelagic species (e.g. Capelin, herring, some shark species, etc.). Acoustic surveys, for example, provide better estimates of biomass and spatial occupancy for schooling pelagic species. Furthermore, in DFO’s RV surveys, there has been a bias for increased catches of Capelin (Figure 51) since 1995 not only due to a change in sampling gear but also due to a change in habitat use of Capelin (Mowbray 2002). Capelin have been observed deeper in the water column and closer to the bottom since the 1990s. This change in behavior may be in response to a decline in the risk of groundfish (e.g. Atlantic Cod) predation that would normally drive Capelin into the pelagic zone. Bottom trawl data can provide information on presence/absence of Capelin across its distribution range but are not useful for determining absolute abundance or biomass information.

Further to acoustics data for pelagic species, other datasets exist that could contribute to our understanding of spatio-temporal patterns in species distributions. For example, DFO conducts regular single-species surveys for some commercial species, while others are surveyed occasionally based on stock status, or industry or management requests. Additionally, effort based data, such as fisheries observer data, could be used to supplement our knowledge of the distribution of some species (commercial and bycatch).

Furthermore, while the change from Engel to Campelen gear was accompanied by an expansion of the survey into areas deeper than 1,000 m (Brodie and Stansbury 2007), depths greater than 700 m are generally still not well surveyed, as they account for only 1.23% (167 of 13,561) of Engel sets and 4.60% (1,046 of 22,734) of Campelen sets in the core strata. Planned sets in deep water are sometimes cancelled due to vessel breakdowns, weather, and other factors (Brodie and Stansbury 2007). Some species may be found at these or deeper depths (e.g. Northern Wolffish, Roundnose Grenadier) and thus are not always well-sampled by the RV surveys.

If further application or mapping of these data layers requires a classification, we recommend Jenks natural breaks (which attempts to reduce the variance within classes and maximize the variance between classes) with 5 classes. All numeric values should be removed from the labels and legend as they do not represent absolute values and are not comparable between groups or species. Instead, label the highest average relative density class as “high” and the lowest average relative density class as “low.”

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Tables

Table 1: Number of successful DFO RV survey sets in core strata. All data were collected using an Engel trawl and are arranged by year, season, and NAFO Division.

	Spring						Fall						Winter			Grand Total
Year	**3L**	**3N**	**3O**	**3Ps**	**3Pn**	**Total**	**2J**	**3K**	**3L**	**3N**	**3O**	**Total**	**3Ps**	**3Pn**	**Total**	
1981	81	55	22	-	-	158	103	121	99	73	-	396	-	-	-	554
1982	103	61	77	92	-	333	157	146	121	-	-	424	-	-	-	757
1983	-	-	-	171	16	187	130	126	126	-	-	382	-	-	-	569
1984	37	61	56	95	-	249	99	153	209	-	-	461	-	-	-	710
1985	221	85	93	112	-	511	131	167	232	-	-	530	-	-	-	1041
1986	211	101	102	145	9	568	109	96	142	-	-	347	-	-	-	915
1987	181	91	100	86	9	467	131	144	165	-	-	440	49	-	49	956
1988	154	77	84	-	-	315	110	116	189	-	-	415	152	13	165	895
1989	205	94	101	-	-	400	145	163	195	-	-	503	157	14	171	1074
1990	156	85	93	-	-	334	145	161	188	80	91	665	109	12	121	1120
1991	143	93	116	-	-	352	136	182	219	67	84	688	164	17	181	1221
1992	178	94	91	-	-	363	139	174	215	34	54	616	147	8	155	1134
1993	181	85	81	138	11	496	105	155	154	70	75	559	-	-	-	1055
1994	152	71	77	156	12	468	103	146	200	75	75	599	-	-	-	1067
1995	151	89	85	153	15	493	-	-	-	-	-	-	-	-	-	493
Total	**2154**	**1142**	**1178**	**1148**	**72**	**5694**	**1743**	**2050**	**2454**	**399**	**379**	**7025**	**778**	**64**	**842**	**13561**

Table 2: Number of successful DFO RV survey sets in core strata. All data were collected using a Campelen trawl and are arranged by year, season, and NAFO Division.

	Spring						Fall							Grand Total
Year	**3L**	**3N**	**3O**	**3Ps**	**3Pn**	**Total**	**2H**	**2J**	**3K**	**3L**	**3N**	**3O**	**Total**	
1995	-	-	-	-	-	-	-	84	122	164	96	83	549	549
1996	195	82	86	143	13	519	-	117	142	149	83	61	552	1071
1997	158	71	82	128	13	452	70	117	142	141	100	81	651	1103
1998	155	88	93	166	15	517	68	118	142	140	101	84	653	1170
1999	145	82	86	144	15	472	4	115	142	142	68	75	546	1018
2000	134	88	84	143	15	464	-	117	126	113	70	76	502	966
2001	142	82	85	143	15	467	57	120	136	141	70	75	599	1066
2002	142	86	80	146	14	468	-	117	142	142	70	75	546	1014
2003	142	84	79	145	15	465	-	116	140	141	70	75	542	1007
2004	139	79	79	147	15	459	87	115	118	113	69	76	578	1037
2005	133	78	79	213	15	518	-	117	136	169	83	75	580	1098
2006	141	22	32	24	9	228	81	117	122	142	70	74	606	834
2007	137	79	79	147	15	457	-	115	119	138	69	75	516	973
2008	122	71	80	137	-	410	69	99	94	126	64	66	518	928
2009	142	78	79	144	15	458	-	108	129	127	64	76	504	962
2010	130	78	80	146	15	449	70	113	142	141	68	75	609	1058
2011	140	79	78	145	15	457	79	99	120	116	70	75	559	1016
2012	132	78	79	146	15	450	84	115	136	142	70	75	622	1072
2013	134	79	79	148	15	455	83	116	123	142	70	75	609	1064
2014	135	60	59	125	-	379	66	110	142	140	3	-	461	840
2015	56	72	74	144	-	346	53	114	139	142	69	75	592	938
2016	140	78	75	127	-	420	77	115	130	138	70	74	604	1024
2017	32	68	71	148	-	319	68	114	142	141	70	73	608	927
Total	**2926**	**1662**	**1698**	**3099**	**244**	**9629**	**1016**	**2588**	**3026**	**3190**	**1637**	**1649**	**13106**	**22735**

Table 3: List of dominant (top 90% biomass) and at-risk (non-dominant) species in each functional group with associated figure number. Species are ordered from high to low within each functional group based on their proportion of the summed average kg/tow.

Functional Group	Common Name	Scientific Name	Proportion of summed avg. kg/tow per functional group	Figure Number
Small benthivores	Mailed Sculpin	*Triglops sp.*	0.346	15
	Common Grenadier	*Nezumia bairdi*	0.133	16
	Daubed Shanny	*Lumpenus maculatus*	0.098	17
	Northern Alligatorfish	*Agonus decagonus*	0.085	18
	Seasnails	Liparidae	0.042	19
	Lumpsuckers	*Eumicrotremus sp.*	0.038	20
	Threebeard Rockling	*Gaidropsarus sp.*	0.038	21
	Hookear Sculpin	*Artediellus sp.*	0.036	22
	Spatulate Sculpin	*Icelus spatula*	0.030	23
	Fourline Snakeblenny	*Eumesogrammus praecisus*	0.027	24
	Common Alligatorfish	*Aspidophoroides monopterygius*	0.016	25
	Goitre Blacksmelt	*Bathylagus euryops*	0.011	26
	Fourbeard Rockling	*Enchelyopus cimbrius*	0.009	27
Medium benthivores	Yellowtail Flounder	*Limanda ferruginea*	0.806	28
	Witch Flounder[a]	*Glyptocephalus cynoglossus*	0.037	29
	Blue Hake	*Antimora rostrate*	0.022	30
	Common Lumpfish[a]	*Cyclopterus lumpus*	0.020	31
	Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	0.015	32
	Roundnose Grenadier[ab]	*Coryphaenoides rupestris*	0.015	33
	Smooth Skate[ab]	*Malacoraja senta*	0.003	34
Large benthivores	American Plaice[a]	*Hippoglossoides platessoides*	0.483	35
	Thorny Skate[a]	*Raja radiate*	0.295	36
	Roughhead Grenadier	*Macrourus berglax*	0.050	37
	Haddock	*Melanogrammus aeglefinus*	0.040	38
	Atlantic Wolffish[a]	*Anarhichas lupus*	0.033	39
	Spotted Wolffish[ab]	*Anarhichas minor*	0.021	40
	Northern Wolffish[ab]	*Anarhichas denticulatus*	0.020	41
	Winter Skate[ab]	*Leucoraja ocellata*	0.003	42
Piscivores	Atlantic Cod[a]	*Gadus morhua*	0.353	43
	Greenland Halibut (Turbot)	*Reinhardtius hippoglossoides*	0.291	44
	Greenland Shark	*Somniosus microcephalus*	0.193	45
	Silver Hake	*Merluccius bilinearis*	0.055	46
	White Hake[a]	*Urophycis tenuis*	0.029	47
Plank-piscivores	Redfish[a]	*Sebastes mentella*	0.926	48
	Arctic Cod[bc]	*Boreogadus saida*	0.051	49
Planktivores	Sand Lance[c]	*Ammodytes dubius*	0.539	50
	Capelin[ac]	*Mallotus villosus*	0.417	51
Shrimps	Northern Shrimp[a]	*Pandalus borealis*	N/A	13

Shrimps, cont.	Striped Shrimp[b]	*Pandalus montaguii*	N/A	13
-	Snow Crab	*Chionoecetes opilio*	N/A	52

[a]At-risk species.
[b]Non-dominant species in functional group.
[c]Species also included in forage fish functional group.

Table 4: At-risk species for which average relative densities were mapped, including COSEWIC and SARA status for each population/stock at the time of publication.

Common Name	**Scientific Name**	**Population/Stock**	**COSEWIC Status**	**SARA Status**
Acadian Redfish[ab]	*Sebastes fasciatus*	Atlantic	Threatened	No Status
American Plaice[b]	*Hippoglossoides platessoides*	Newfoundland and Labrador	Threatened	No Status
Atlantic Cod[b]	*Gadus morhua*	Newfoundland and Labrador/Laurentian North	Endangered	No Status
Atlantic Wolffish	*Anarhichas lupus*	-	Special Concern	Special Concern
Deepwater Redfish[ab]	*Sebastes mentella*	Gulf of St. Lawrence-Laurentian Channel/ Northern Population	Endangered/ Threatened	No Status
(Common) Lumpfish	*Cyclopterus lumpus*	-	Threatened	No Status
Northern Wolffish	*Anarhichas denticulatus*	-	Threatened	Threatened
Roundnose Grenadier	*Coryphaenoides rupestris*	-	Endangered	No Status
Smooth Skate	*Malacoraja senta*	Funk Island Deep	Endangered	No Status
Spotted Wolffish	*Anarhichas minor*	-	Threatened	Threatened
Thorny Skate	*Amblyraja radiate*	-	Special Concern	No Status
White Hake	*Urophycis tenuis*	Atlantic and Northern Gulf of St. Lawrence	Threatened	No Status
Winter Skate[c]	*Leucoraja ocellata*	Eastern Scotian Shelf-Newfoundland	Endangered	No Status

[a]Data for Deepwater and Acadian Redfish species combined to generate one layer for these species.
[b]Species also considered depleted by DFO and/or NAFO.
[c]Data only available from spring Campelen time series.

Table 5: At-risk species for which sufficient data were not available to produce average relative density maps.

Common Name	**Scientific Name**	**Population/Stock**	**COSEWIC Status**	**SARA Status**
Atlantic Bluefin Tuna	*Thunnus thynnus*	-	Endangered	No Status
Atlantic Salmon	*Salmo salar*	South Newfoundland	Threatened	No Status
Basking Shark	*Cetorhinus maximus*	Atlantic	Special Concern	No Status
Cusk	*Brosme brosme*	-	Endangered	No Status
Porbeagle	*Lamna nasus*	-	Endangered	No Status
Shortfin Mako	*Isurus oxyrinchus*	Atlantic	Special Concern	No Status
Spiny Dogfish	*Squalus acanthias*	Atlantic	Special Concern	No Status
White Shark	*Carcharodon carcharias*	Atlantic	Endangered	Endangered

Table 6: List of species considered depleted by DFO and/or NAFO.

Common Name	Scientific Name	Population/Stock	DFO Status	NAFO Status	Reference	Figure Number
Acadian Redfish[ab]	*Sebastes fasciatus*	Unit 1/ Unit 2/ 2+3K	Depleted/ -/ Depleted	-	DFO 2016a, 2020ab	48
American Plaice[a]	*Hippoglossoides platessoides*	SA2 + Div. 3K/ 3LNO/ 3Ps	Depleted/ -/ Depleted	-/ Depleted/ -	DFO 2012/ NAFO Summary Sheet/ DFO 2020c	35
Atlantic Cod[b]	*Gadus morhua*	2J3KL/ 3NO/ 3Ps	Depleted/ -/ Depleted	-/ Depleted/ -	DFO 2016b/ NAFO Summary Sheet/ DFO 2020d	43
Capelin	*Mallotus villosus*	3NO	-	Depleted	NAFO Summary Sheet	51
Deepwater Redfish[ab]	*Sebastes mentella*	Unit 1/ Unit 2/ 2+3K	-/ -/ Depleted	-	DFO 2016a, 2020ab	48
Northern Shrimp	*Pandalus borealis*	SFA 6/ 3LNO	Depleted/ -	-/ Depleted	DFO 2018a NAFO Summary Sheet	13
Witch Flounder	*Glyptocephalus cynoglossus*	2J+3KL/ 3NO	Depleted/ -	-/ Depleted	DFO 2018b, NAFO Summary Sheet/ NAFO Summary Sheet	29

[a]COSEWIC Status: Threatened
[b]COSEWIC Status: Endangered

Table 7: Number of data layers (maps) for each time series, functional group, and species.

	Number of Layers	
	Engel (1981-1995)	**Campelen (1995-2017)**
Functional Groups	12	22
Species	24	41

Figures

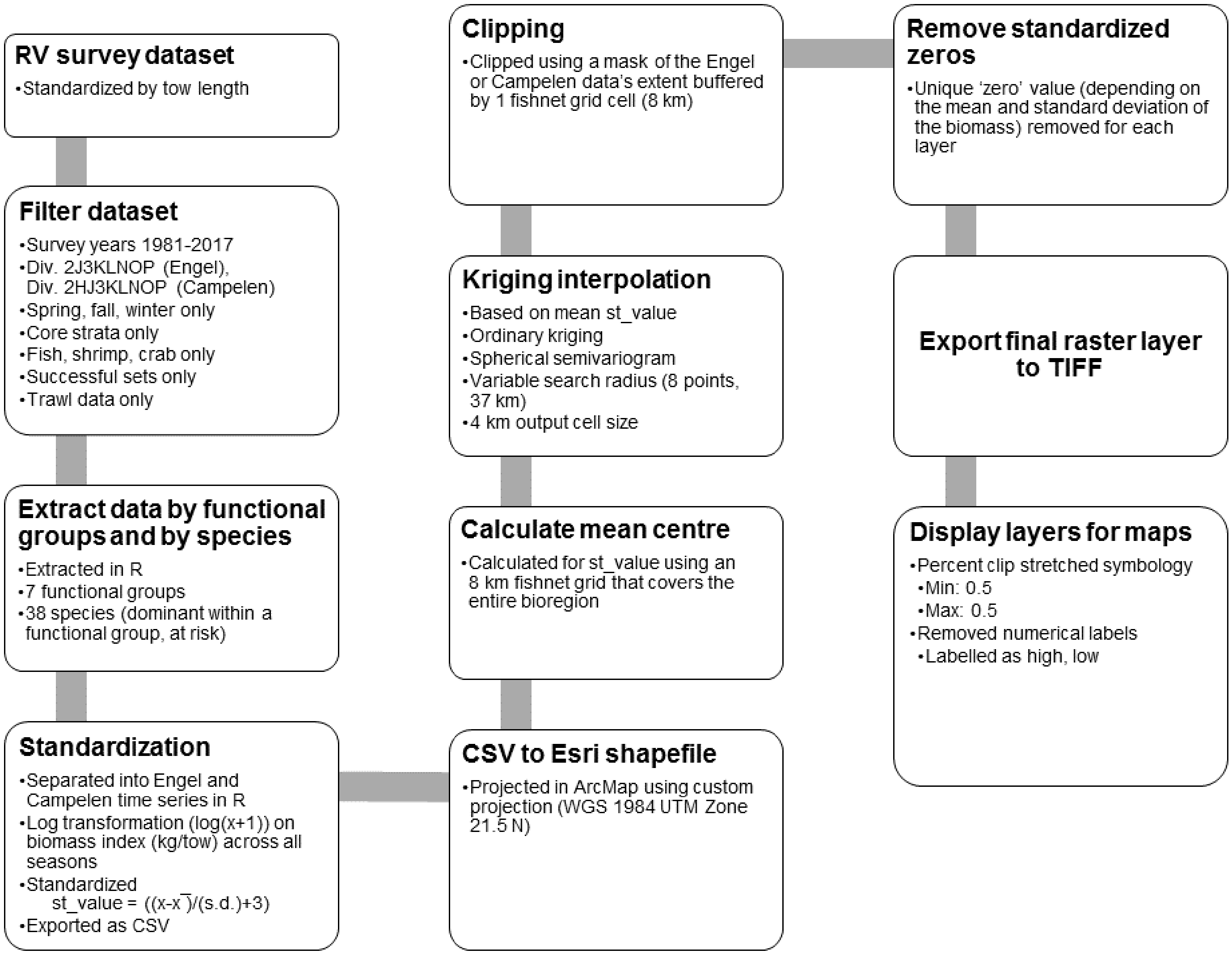


Figure 1: Data processing and analysis workflow.

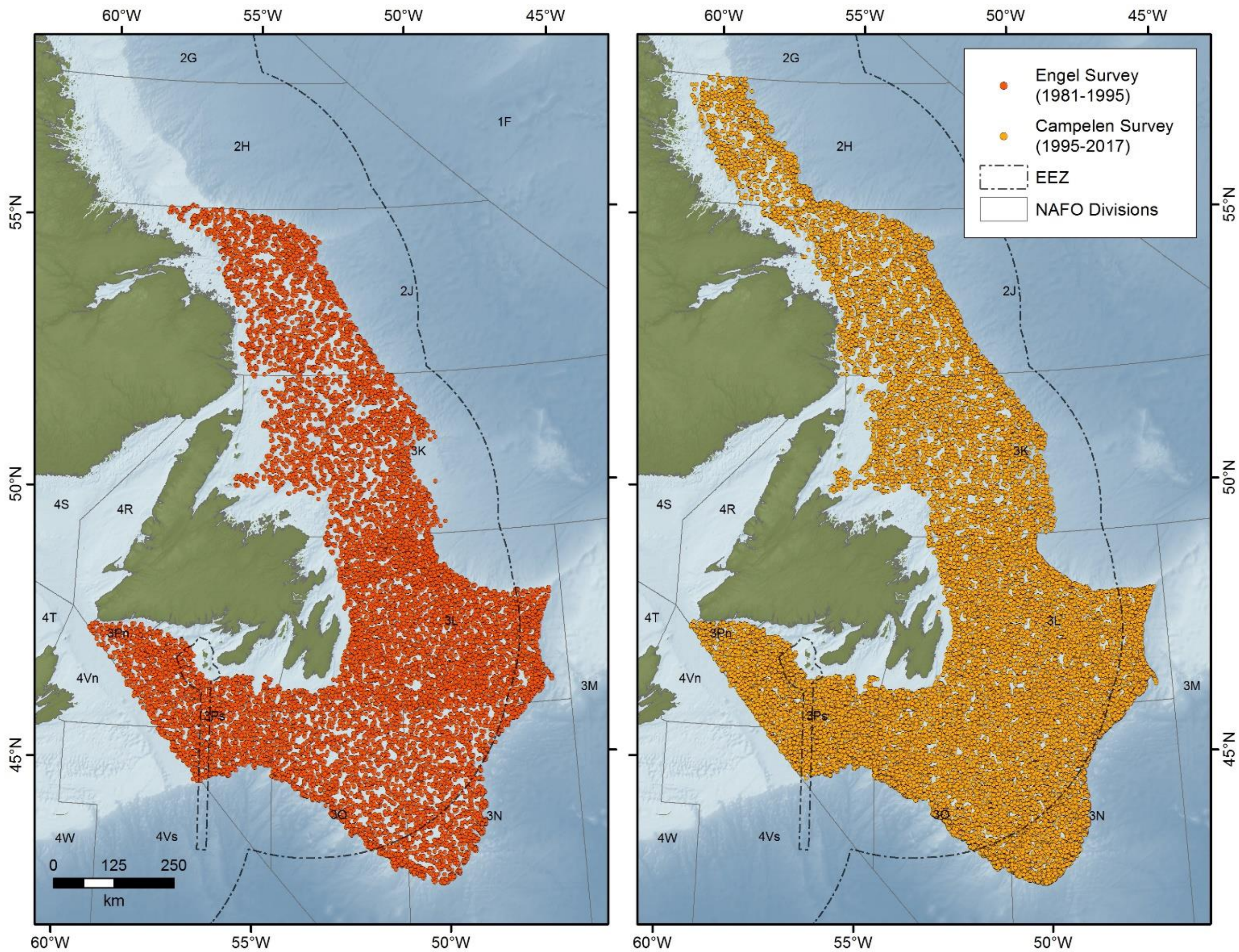


Figure 2: Set locations for trawls conducted in core strata using Engel gear (1981-1995, left panel) and Campelen gear (1995-2017, right panel).

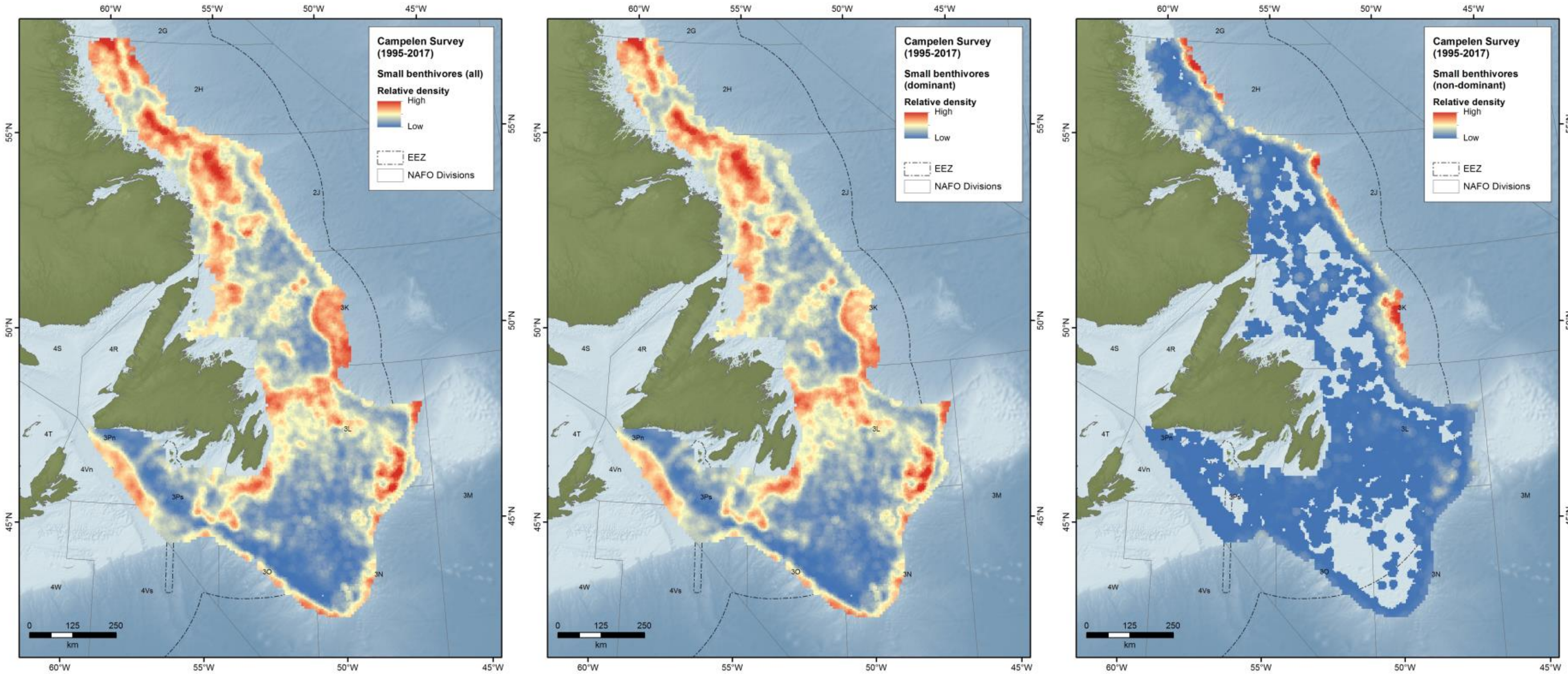


Figure 3: Average relative density of small benthivores from 1995-2017 (Campelen), showing all small benthivores (left), dominant small benthivores (middle), and non-dominant small benthivores (right).

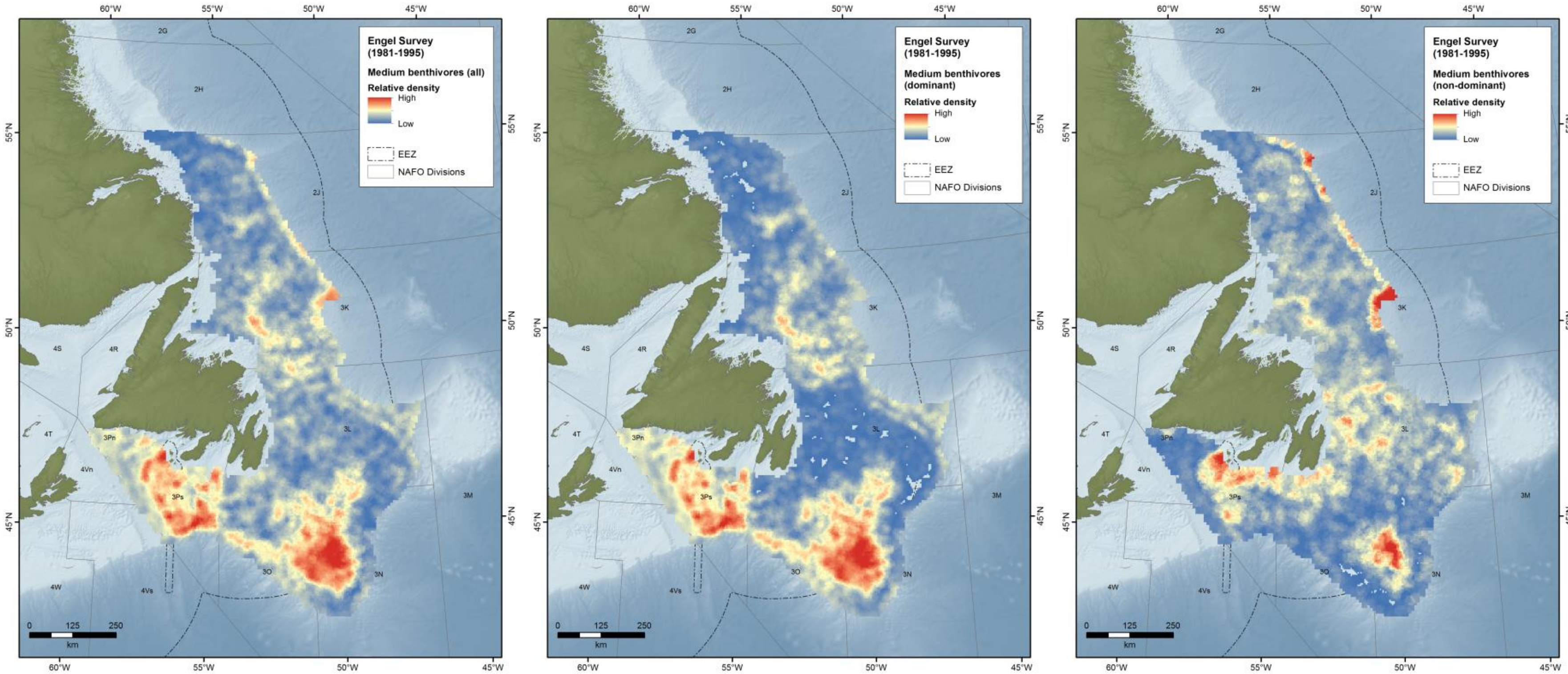


Figure 4: Average relative density of medium benthivores from 1981-1995 (Engel), showing all medium benthivores (left), dominant medium benthivores (middle), and non-dominant medium benthivores (right).

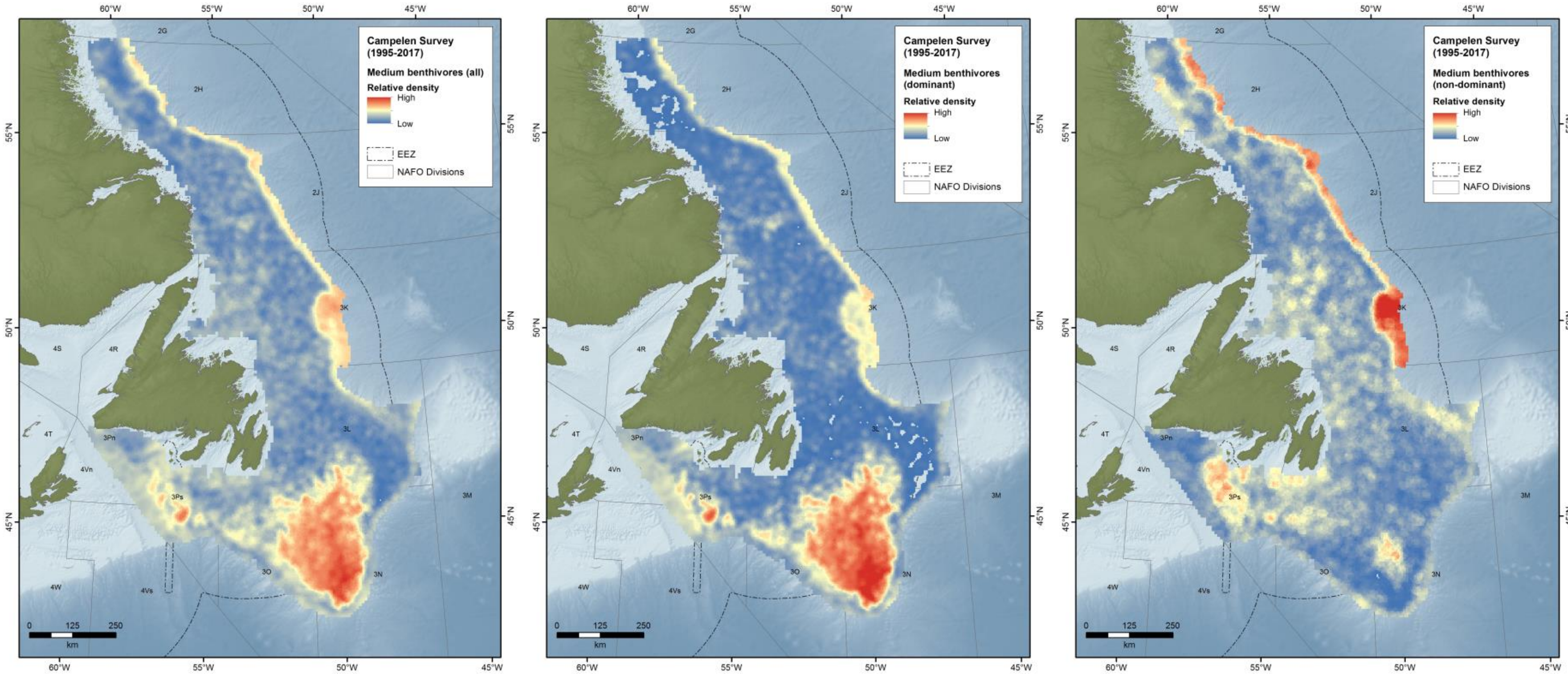


Figure 5: Average relative density of medium benthivores from 1995-2017, showing all medium benthivores (left), dominant medium benthivores (middle), and non-dominant medium benthivores (right).

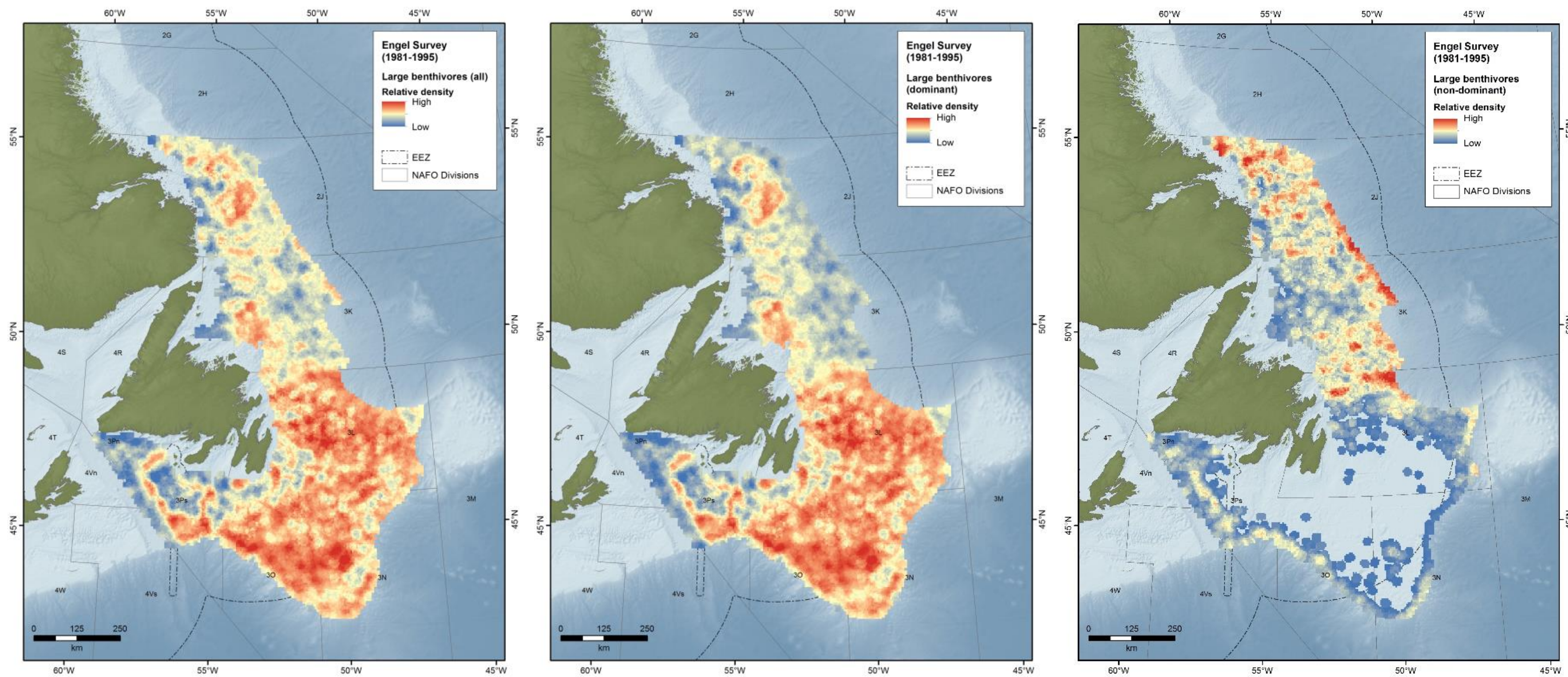


Figure 6: Average relative density of large benthivores from 1981-1995, showing all large benthivores (left), dominant large benthivores (middle), and non-dominant large benthivores (right).

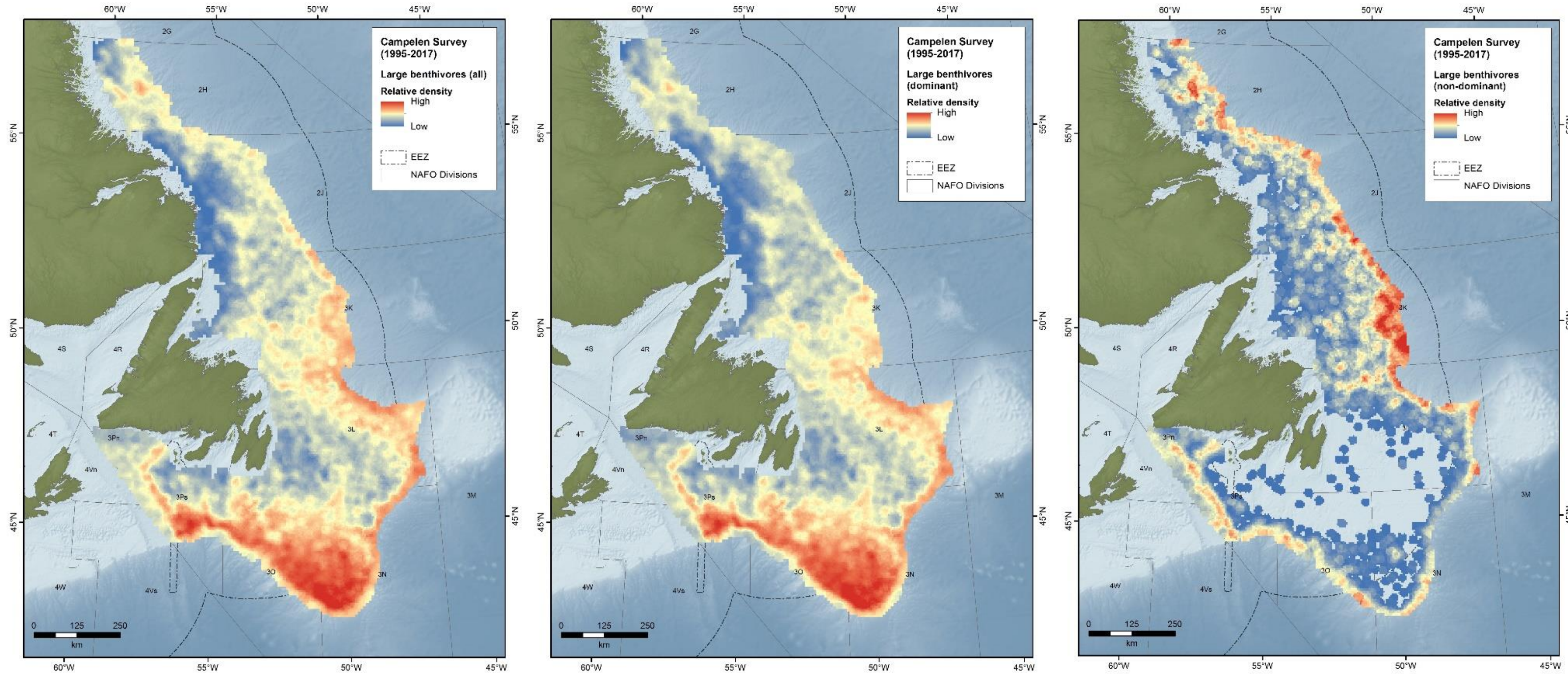


Figure 7: Average relative density of large benthivores from 1995-2017, showing all large benthivores (left), dominant large benthivores (middle), and non-dominant large benthivores (right).

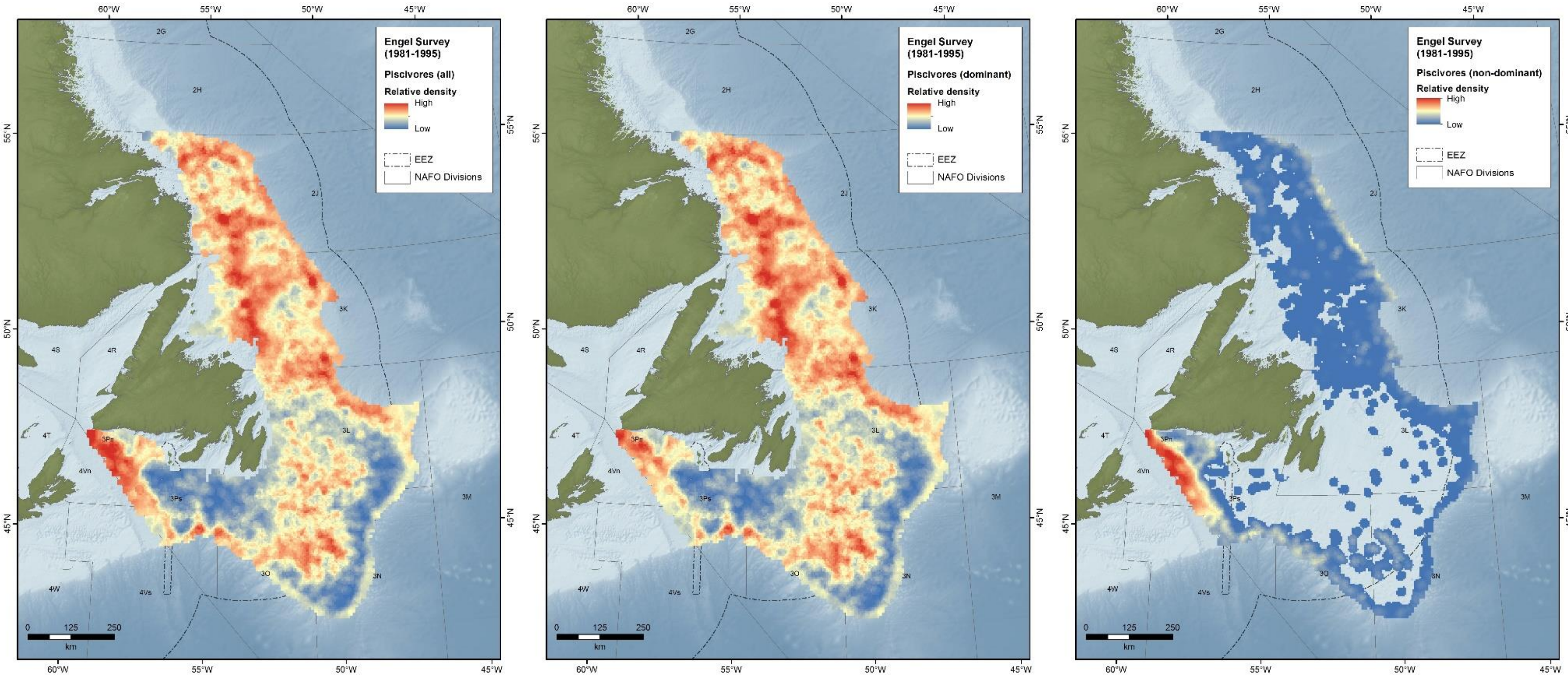


Figure 8: Average relative density of piscivores from 1981-1995, showing all piscivores (left), dominant piscivores (middle), and non-dominant piscivores (right).

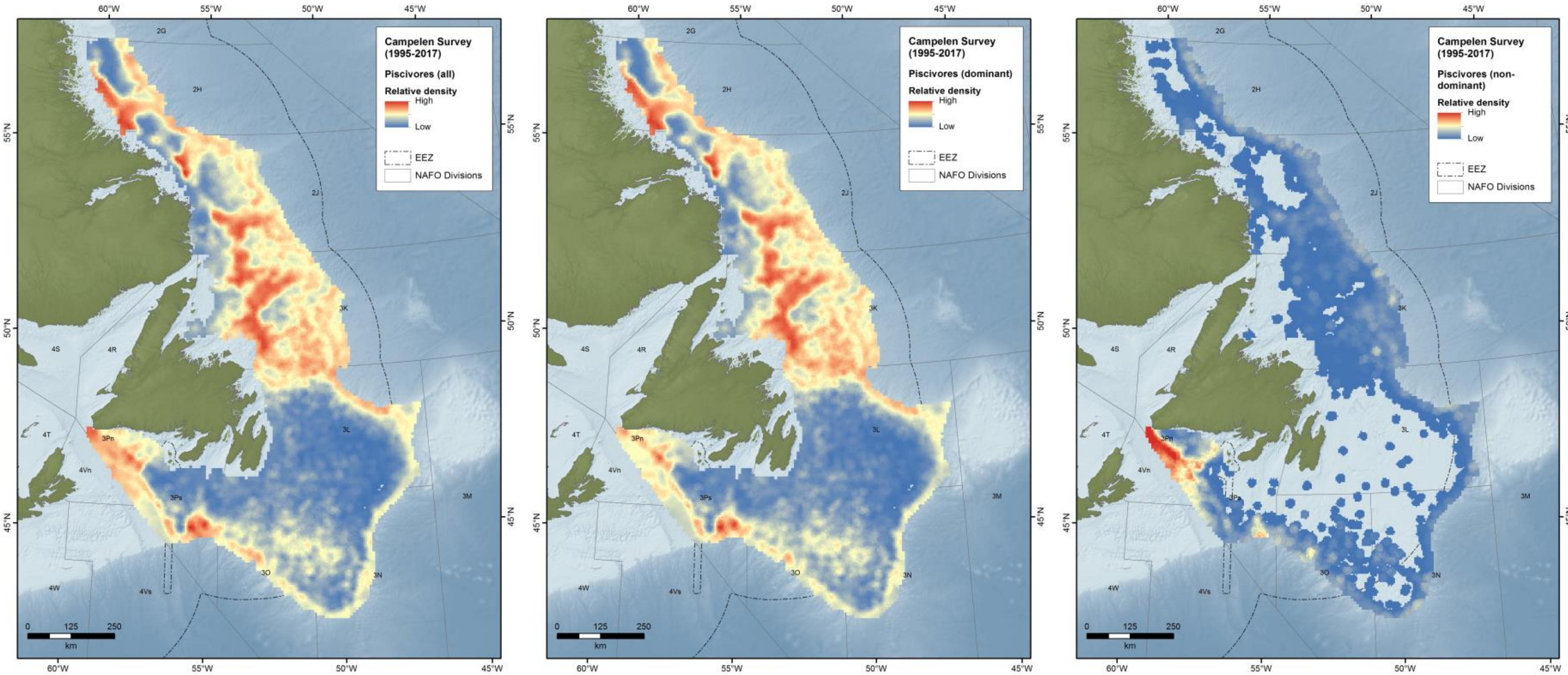


Figure 9: Average relative density of piscivores from 1995-2017, showing all piscivores (left), dominant piscivores (middle), and non-dominant piscivores (right).

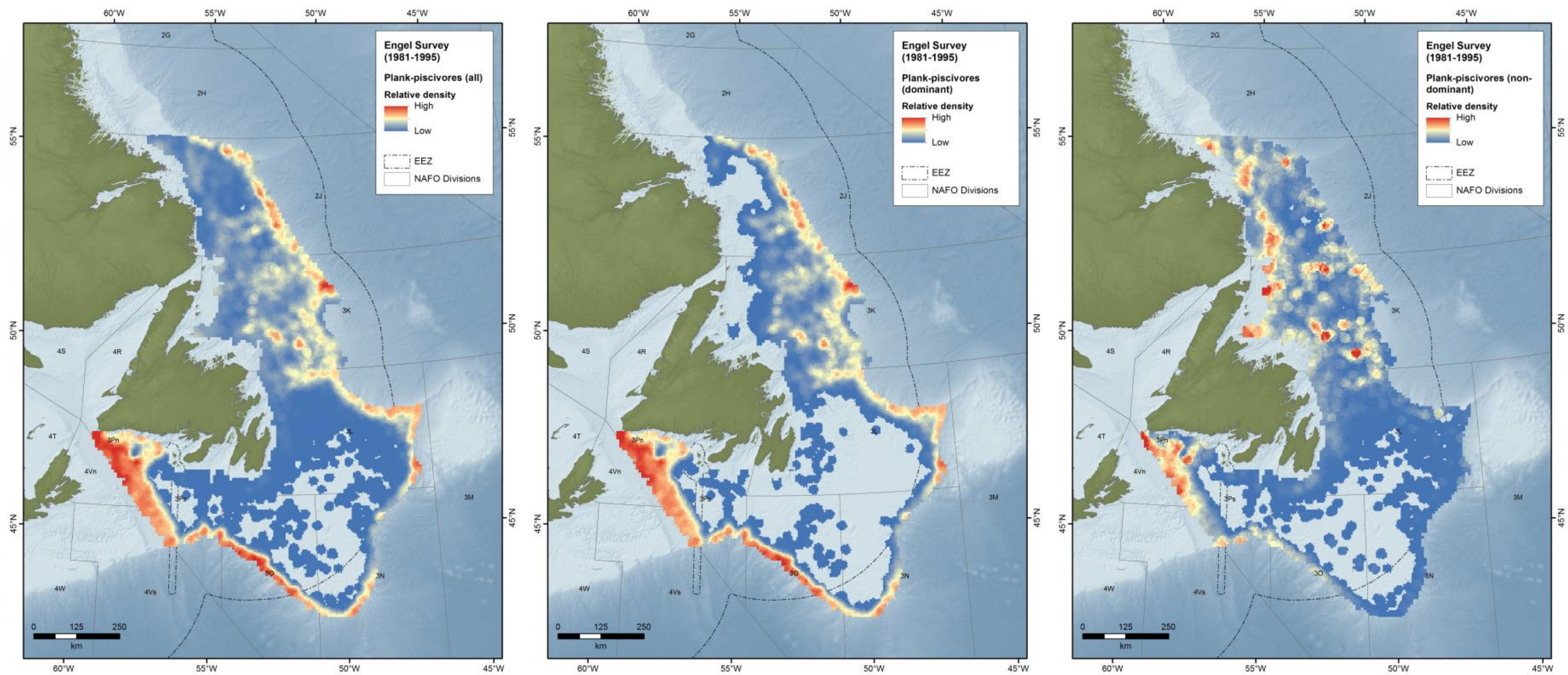


Figure 10: Average relative density of plank-piscivores from 1981-1995, showing all plank-piscivores (left), dominant plank-piscivores (middle), and non-dominant plank-piscivores (right).

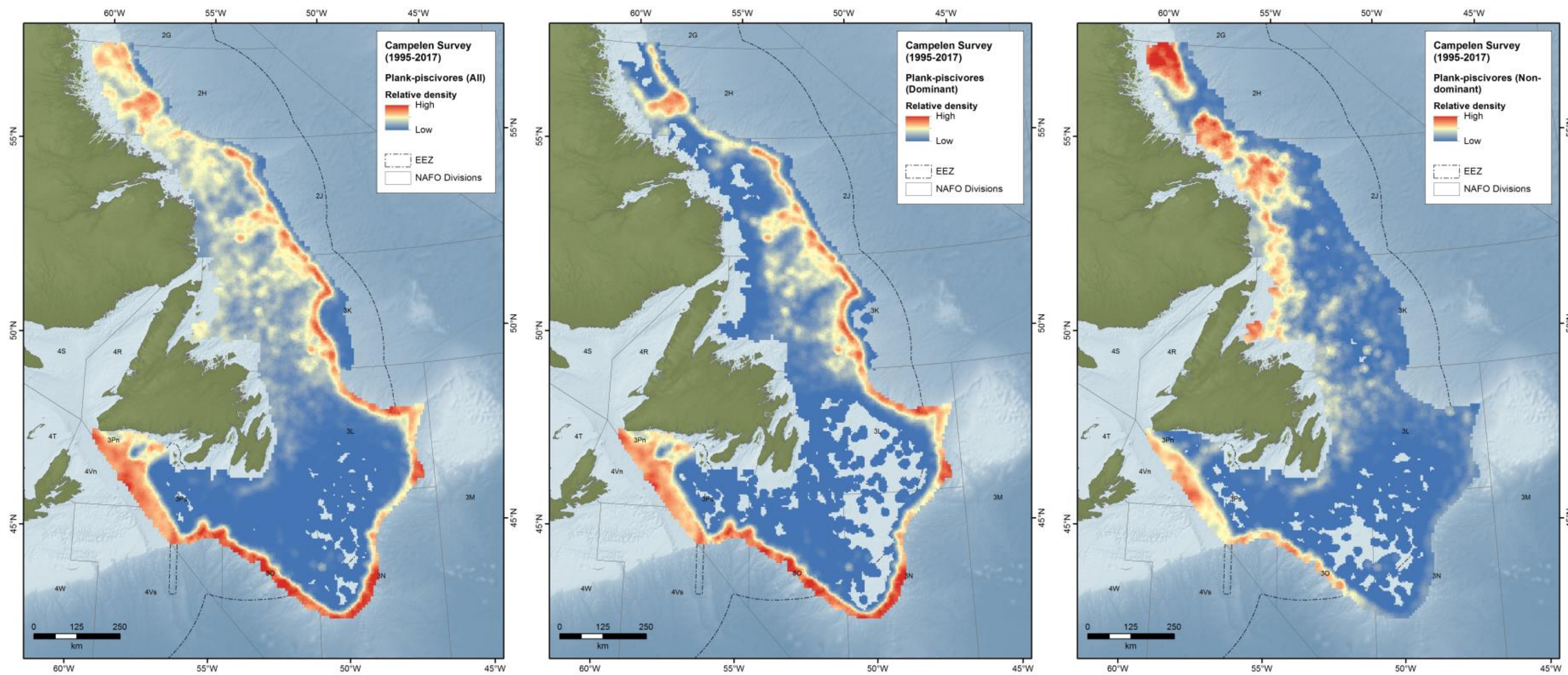


Figure 11: Average relative density of plank-piscivores from 1995-2017, showing all plank-piscivores (left), dominant plank-piscivores (middle), and non-dominant plank-piscivores (right).

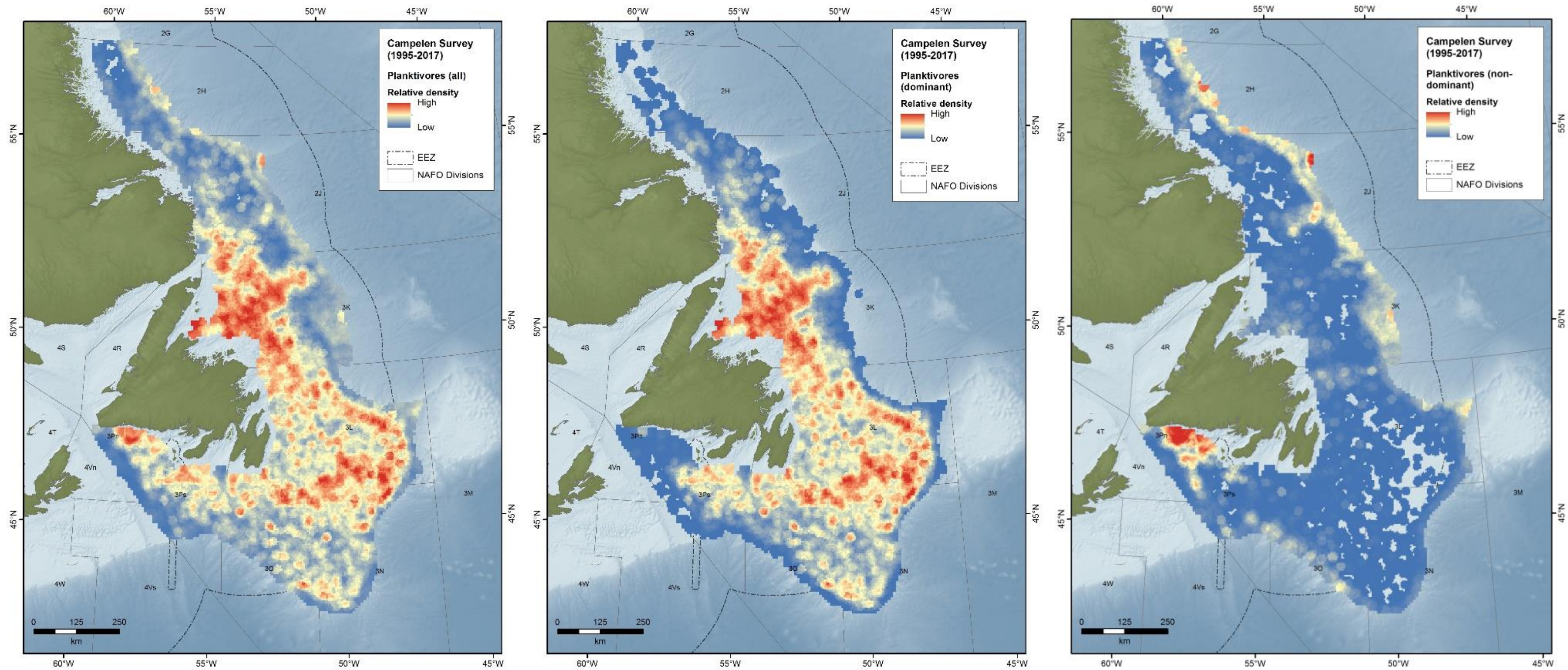


Figure 12: Average relative density of planktivores from 1995-2017, showing all planktivores (left), dominant planktivores (middle), and non-dominant planktivores (right).

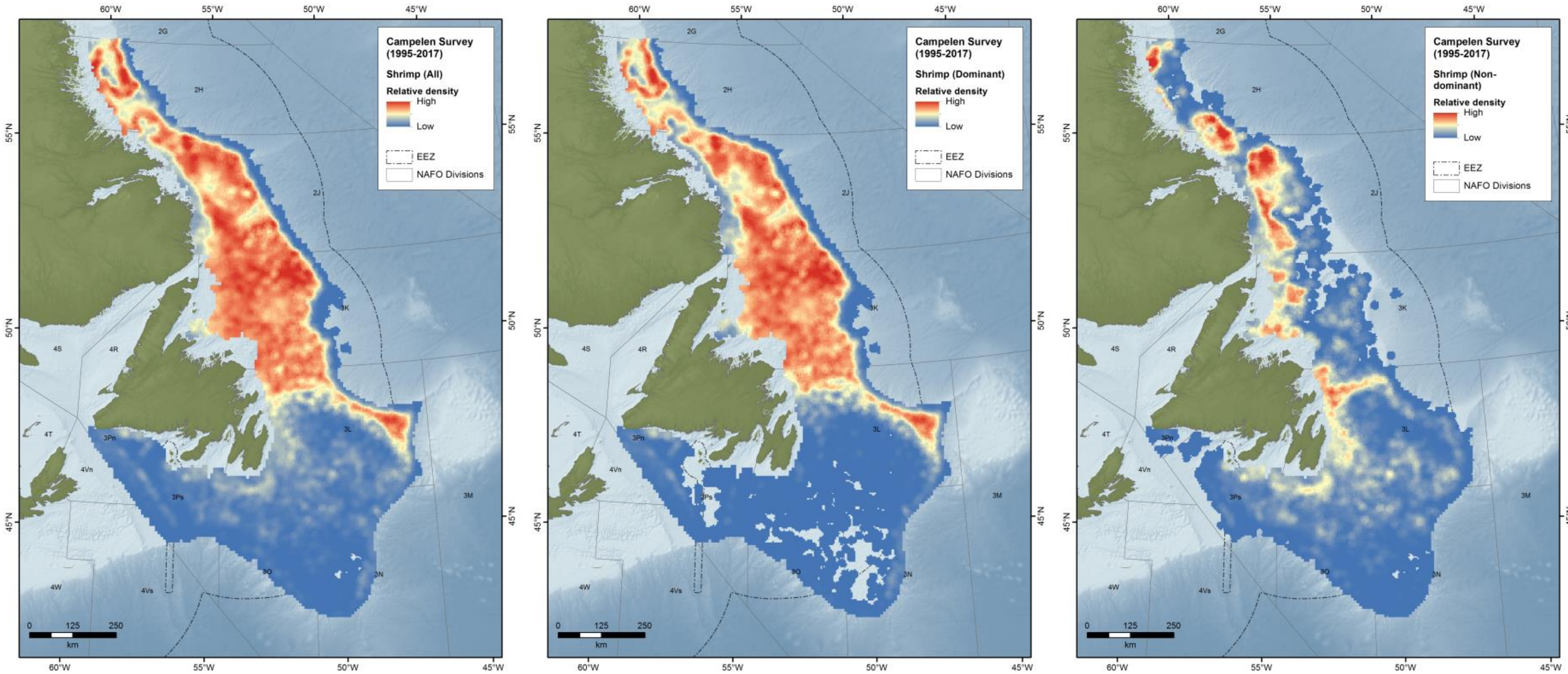


Figure 13: Average relative density of shrimp from 1995-2017, showing all shrimp (left), Northern Shrimp (middle), and Striped Shrimp (right).

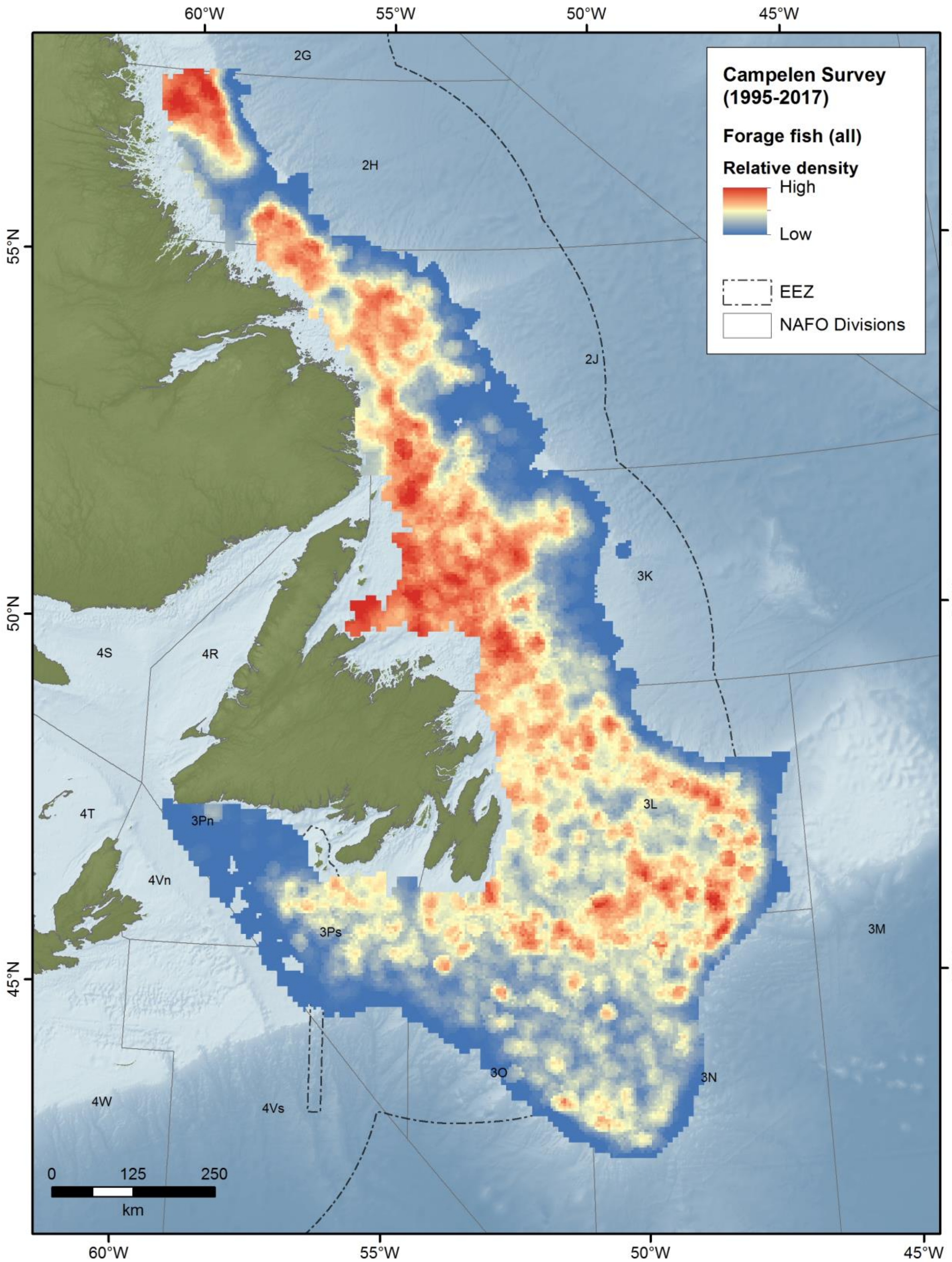


Figure 14: Average relative density of forage fish from 1995-2017.

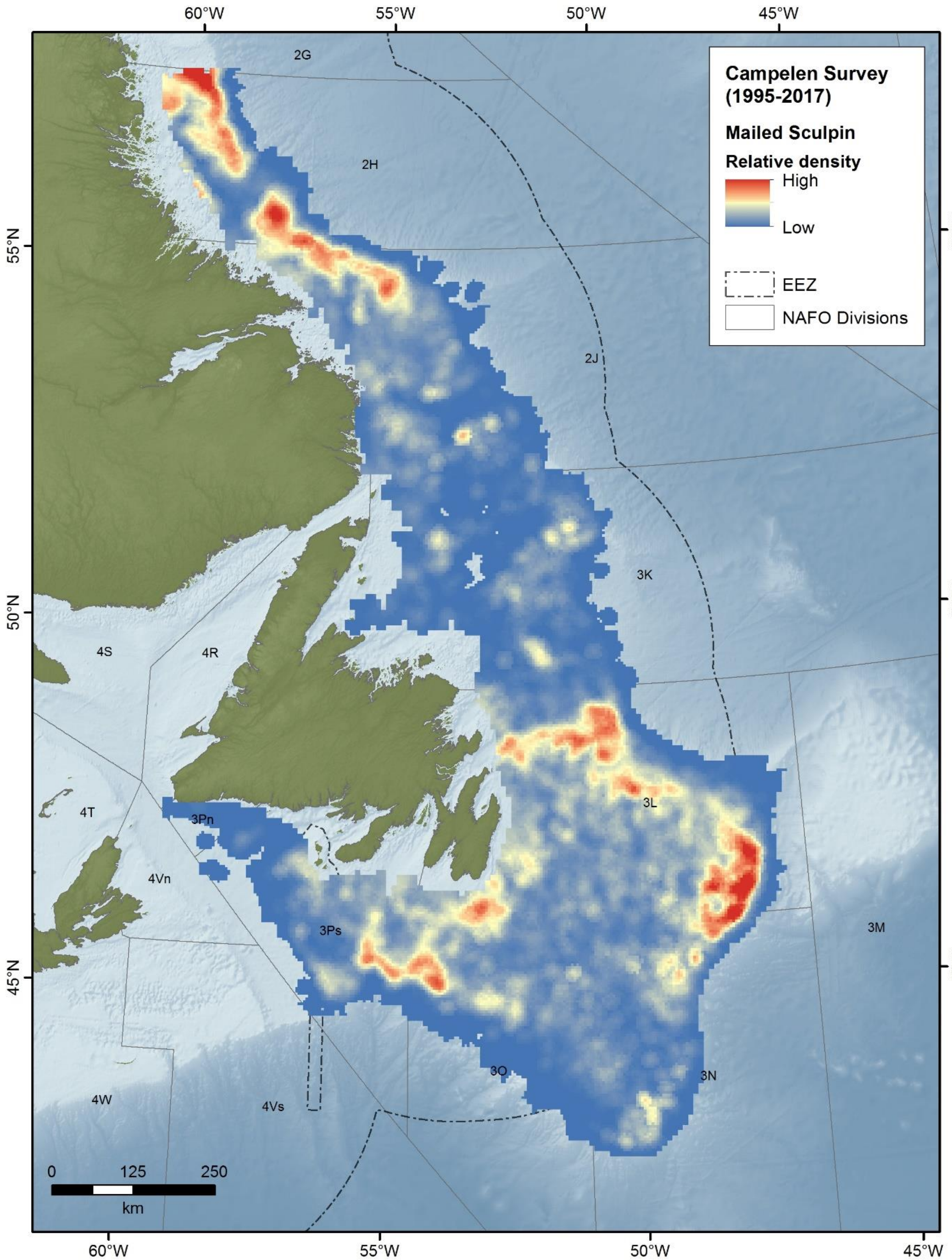


Figure 15: Average relative density of Mailed Sculpin from 1995-2017.

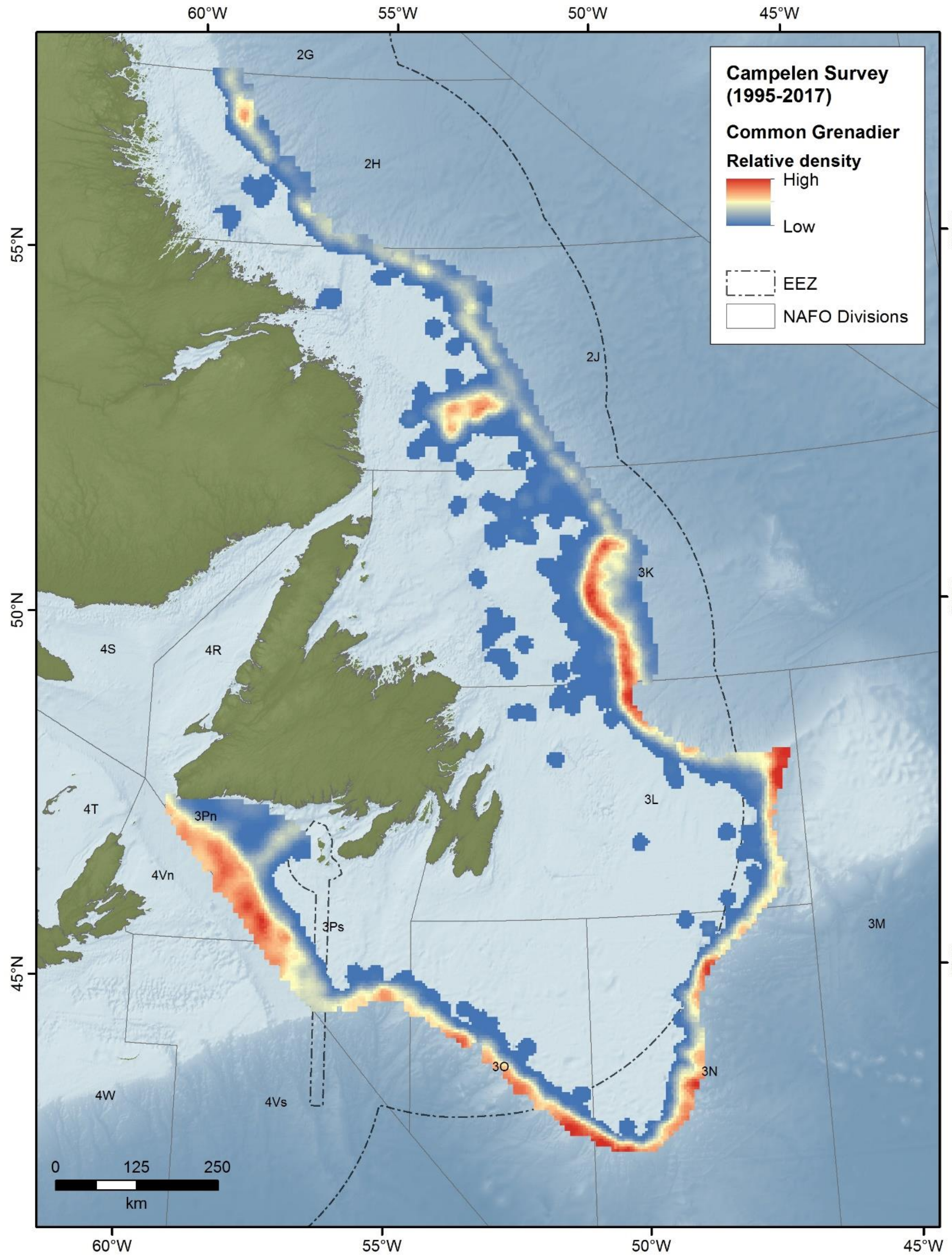


Figure 16: Average relative density of Common Grenadier from 1995-2017.

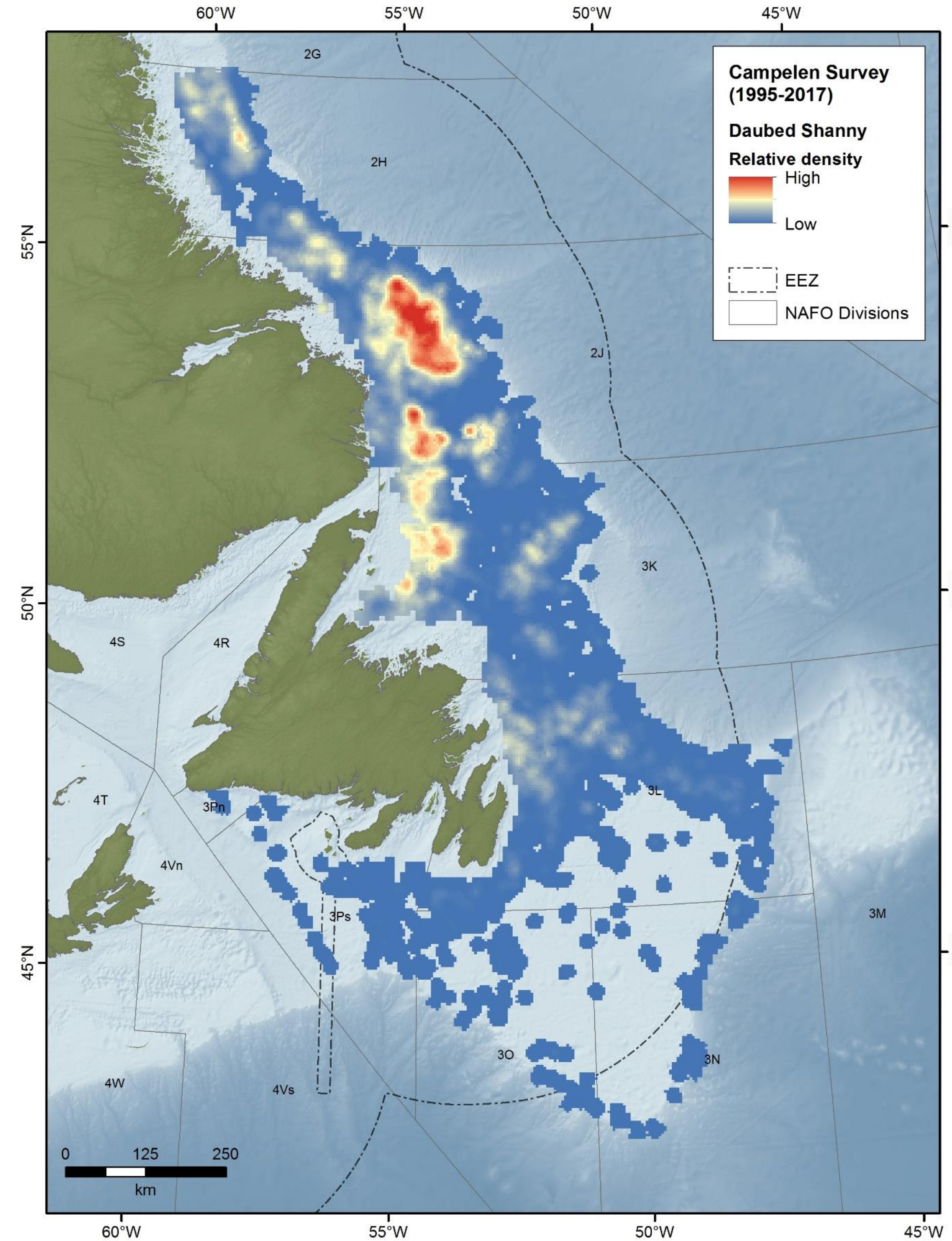


Figure 17: Average relative density of Daubed Shanny from 1995-2017.

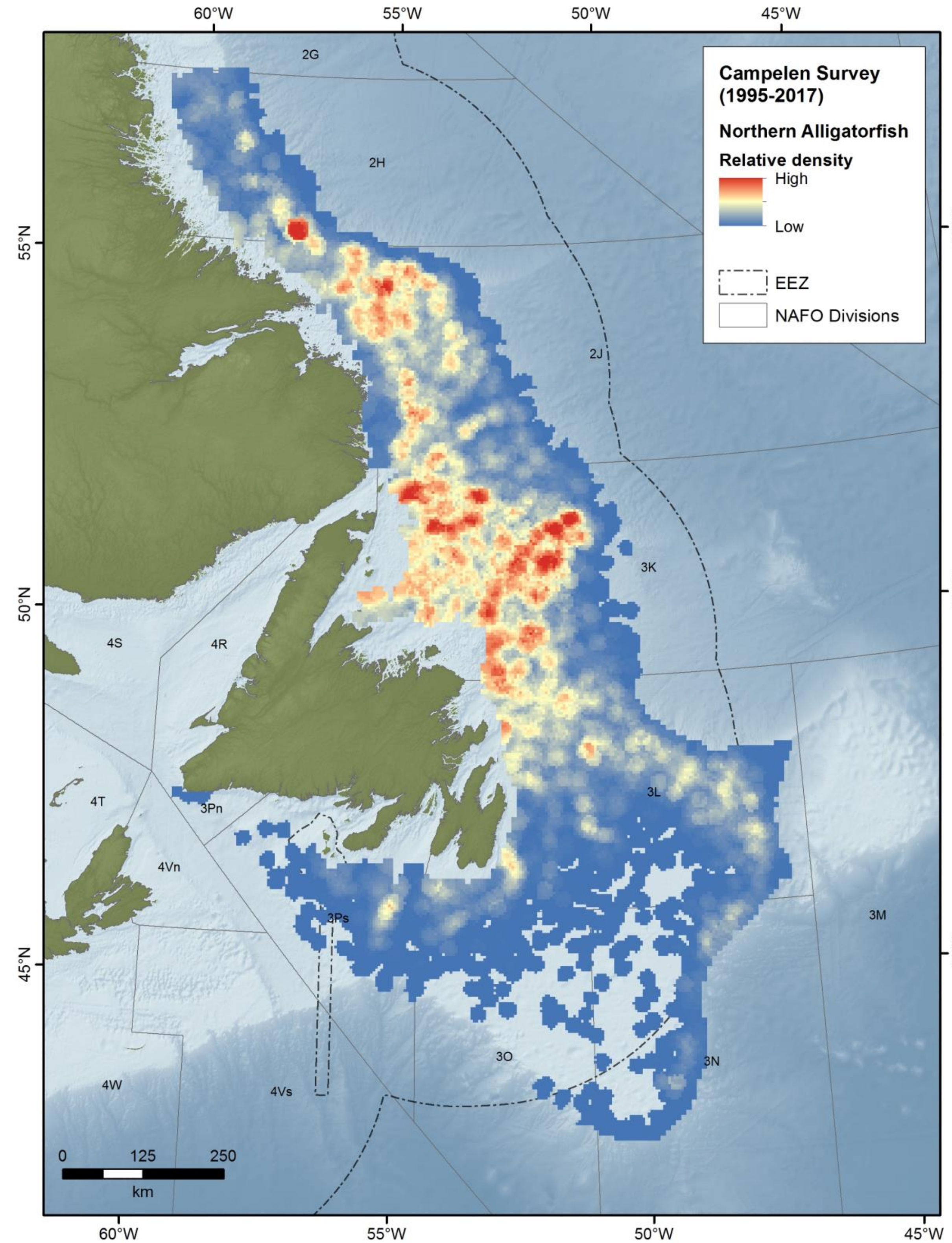


Figure 18: Average relative density of Northern Alligatorfish from 1995-2017.

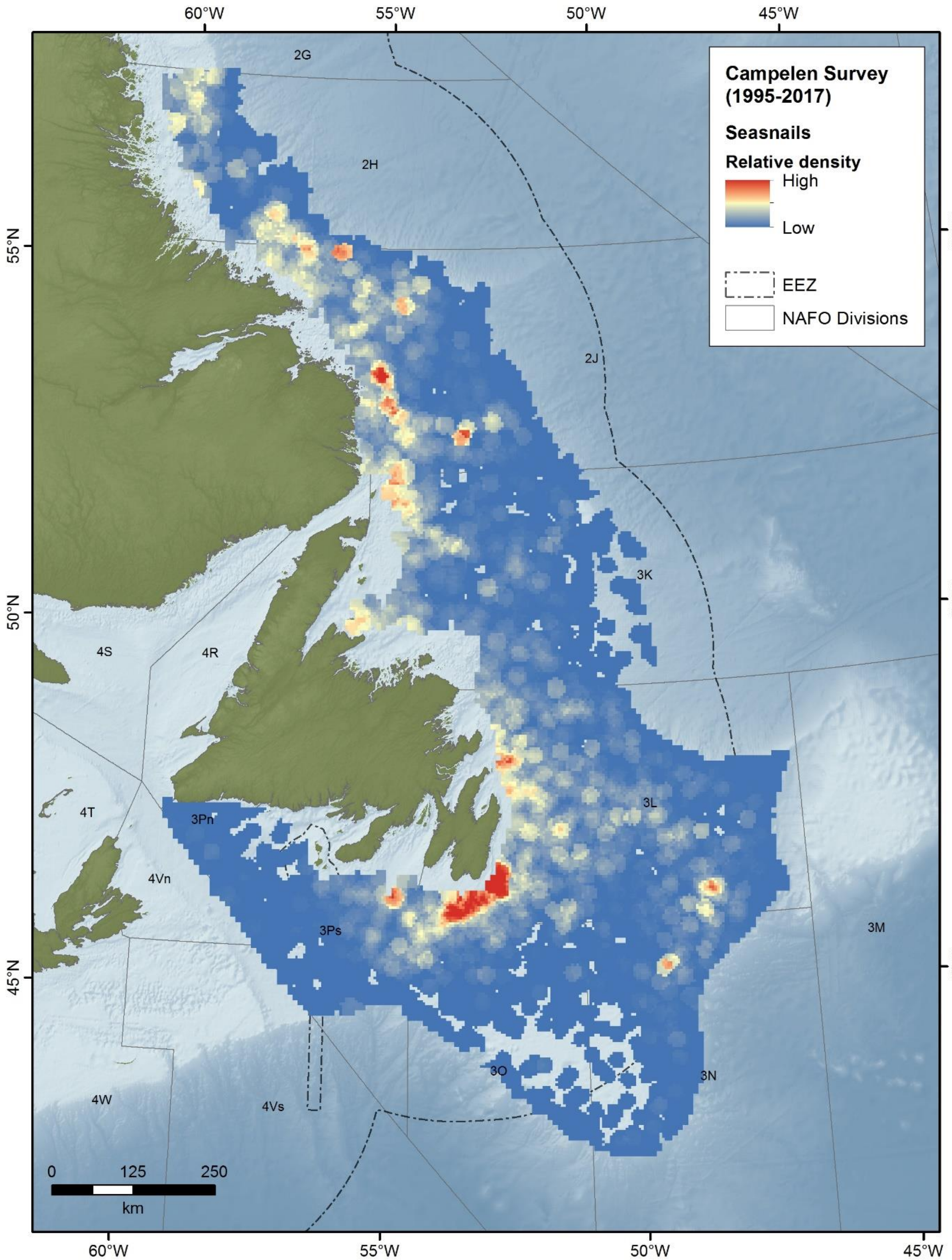


Figure 19: Average relative density of Seasnails from 1995-2017.

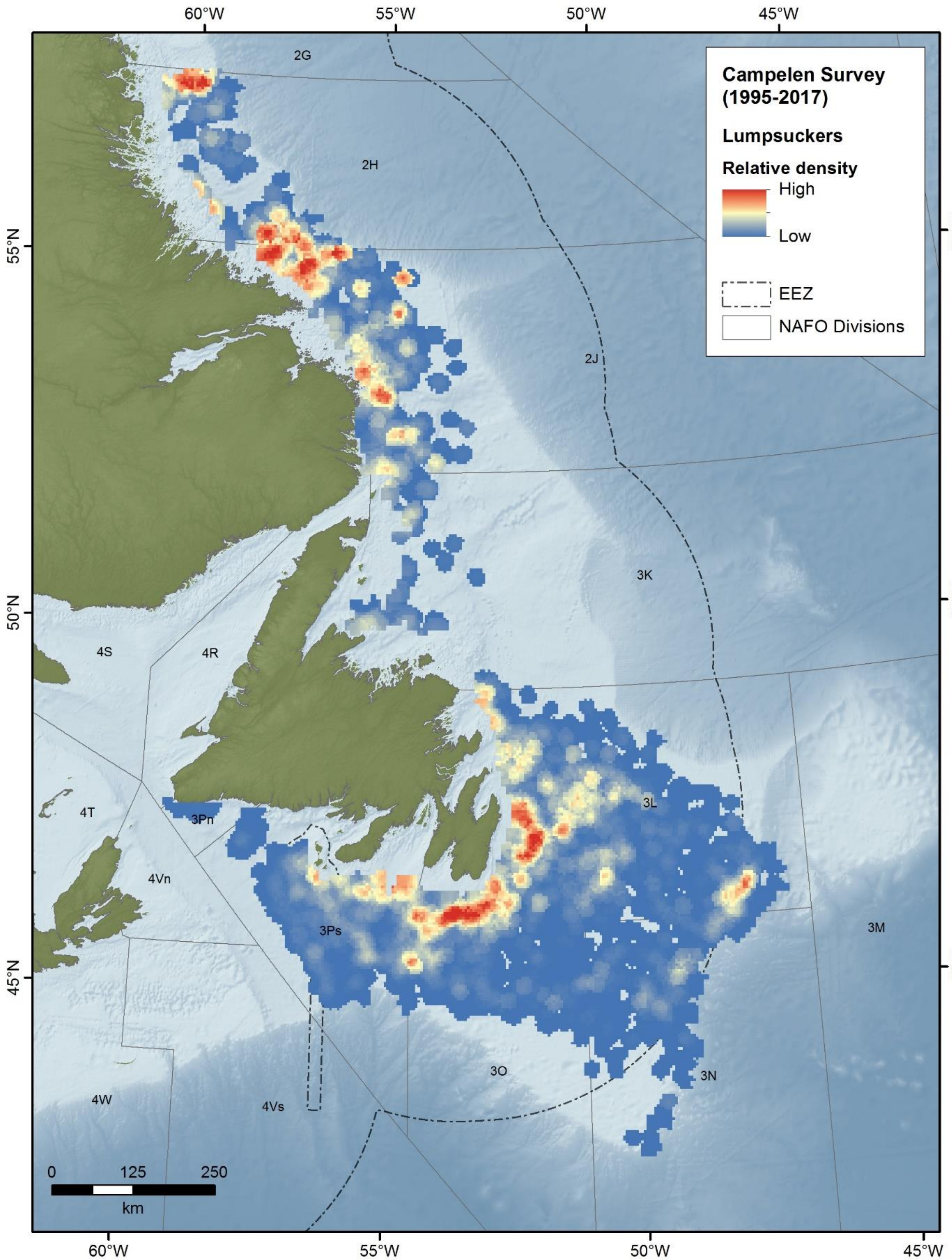


Figure 20: Average relative density of Lumpsuckers from 1995-2017.

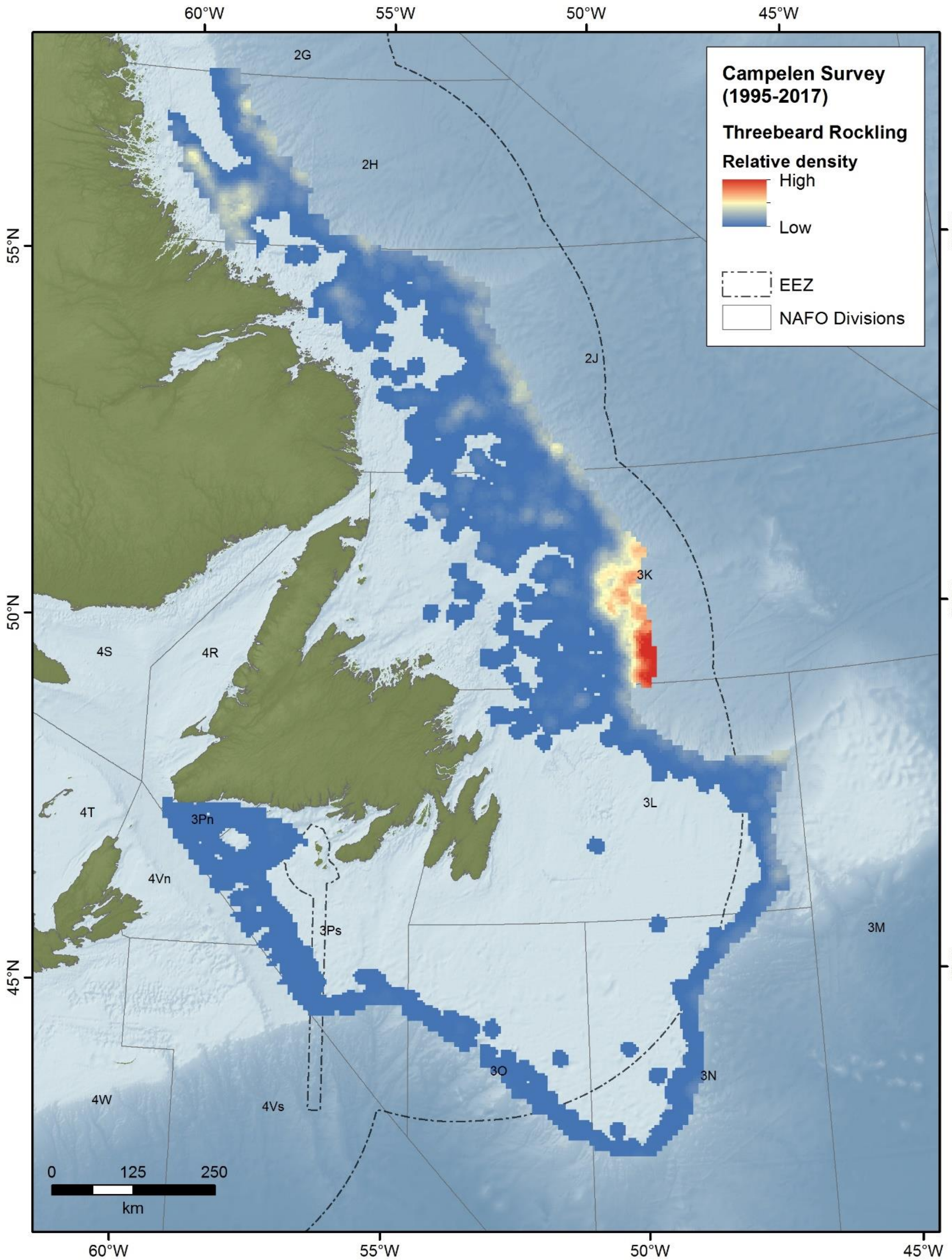


Figure 21: Average relative density of Threebeard Rockling from 1995-2017.

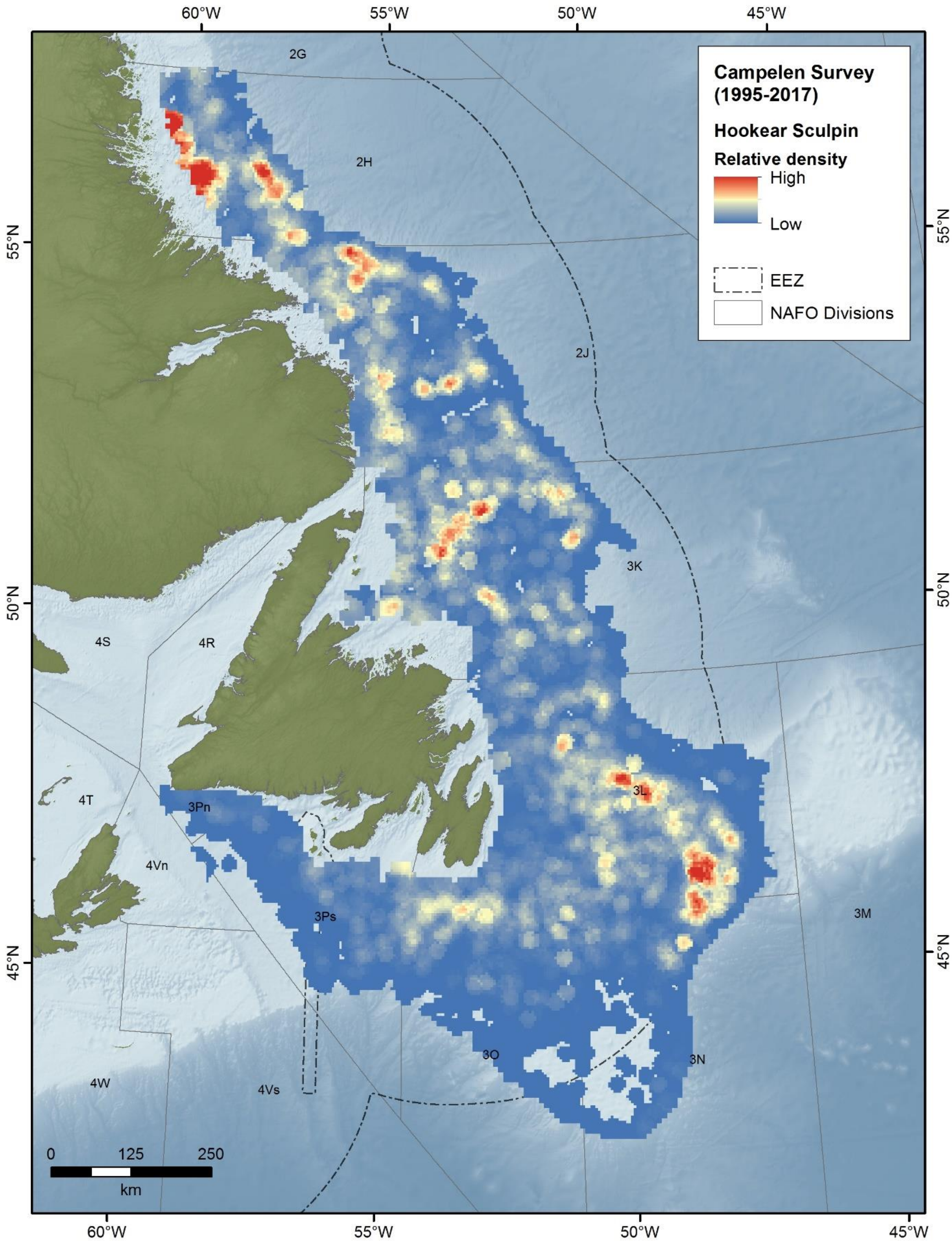


Figure 22: Average relative density of Hookear Sculpin from 1995-2017.

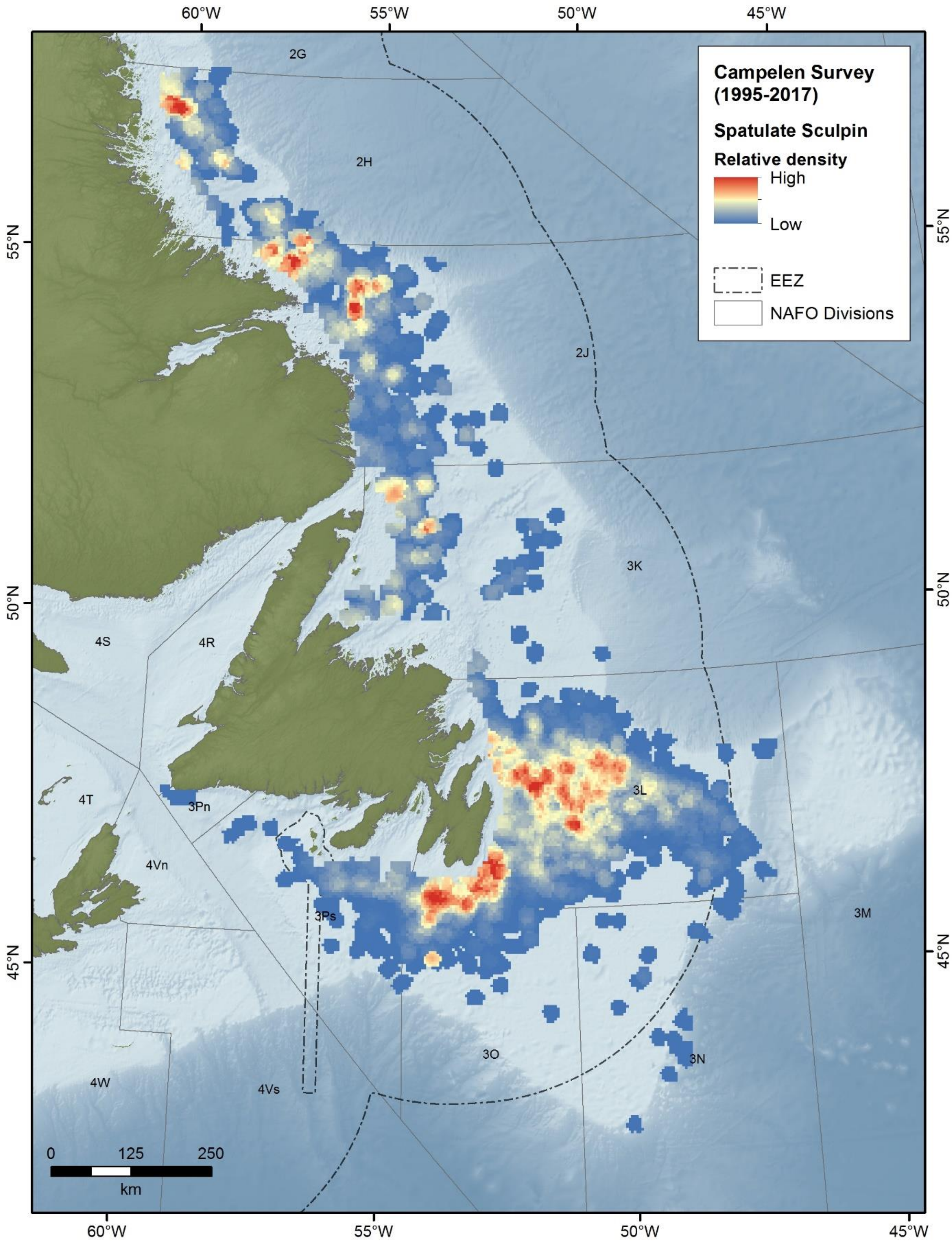


Figure 23: Average relative density of Spatulate Sculpin from 1995-2017.

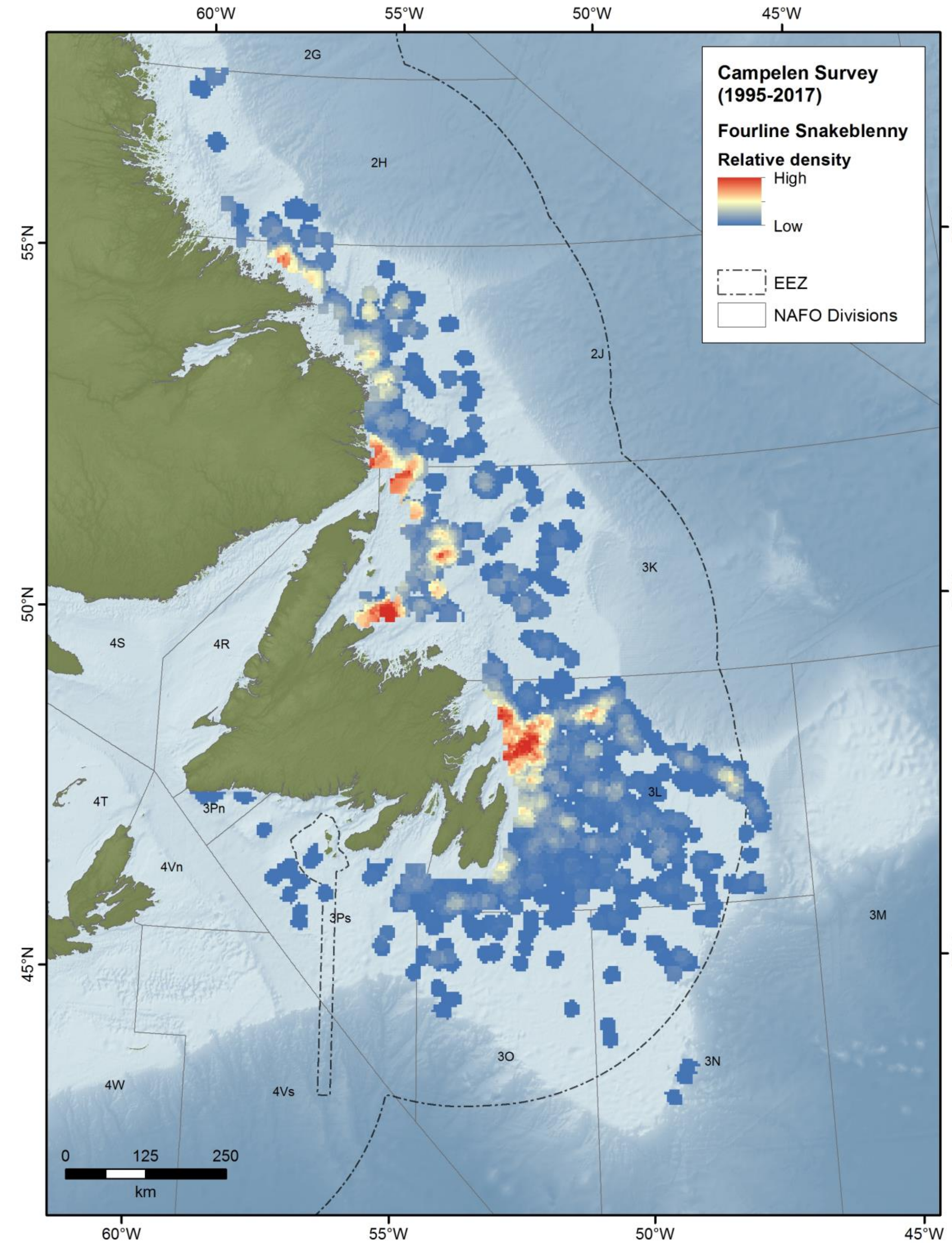


Figure 24: Average relative density of Fourline Snakeblenny from 1995-2017.

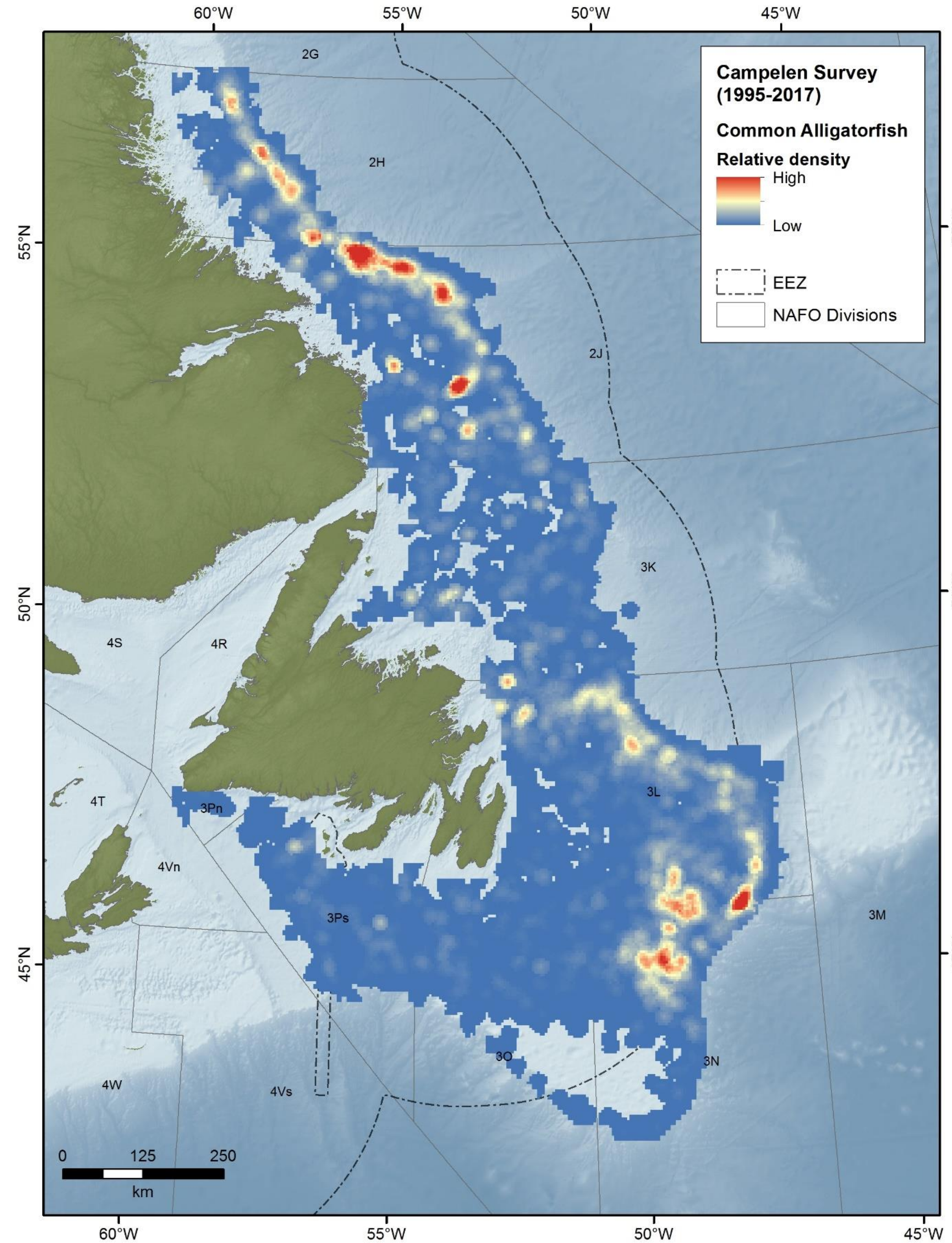


Figure 25: Average relative density of Common Alligatorfish from 1995-2017.

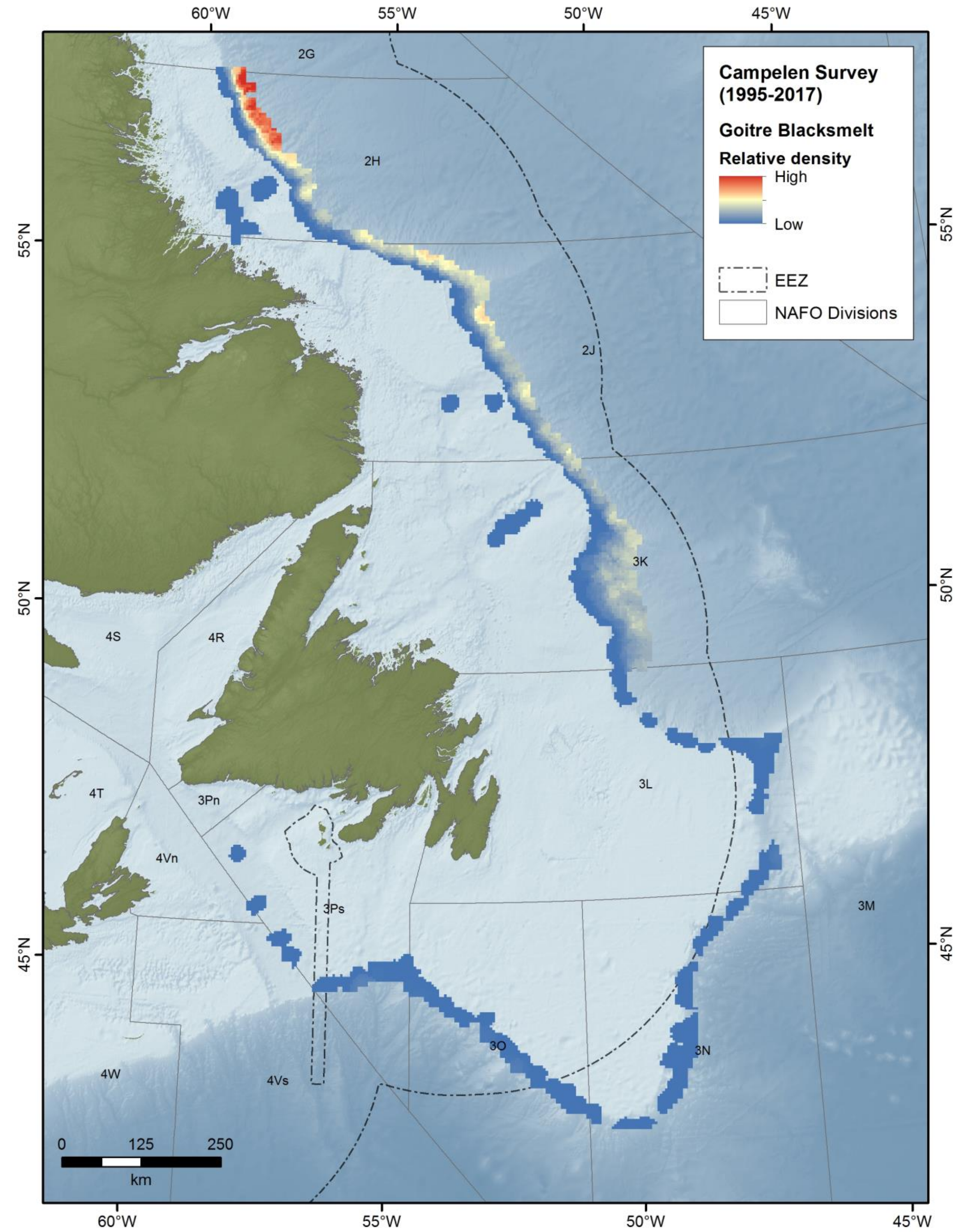


Figure 26: Average relative density of Goitre Blacksmelt from 1995-2017.

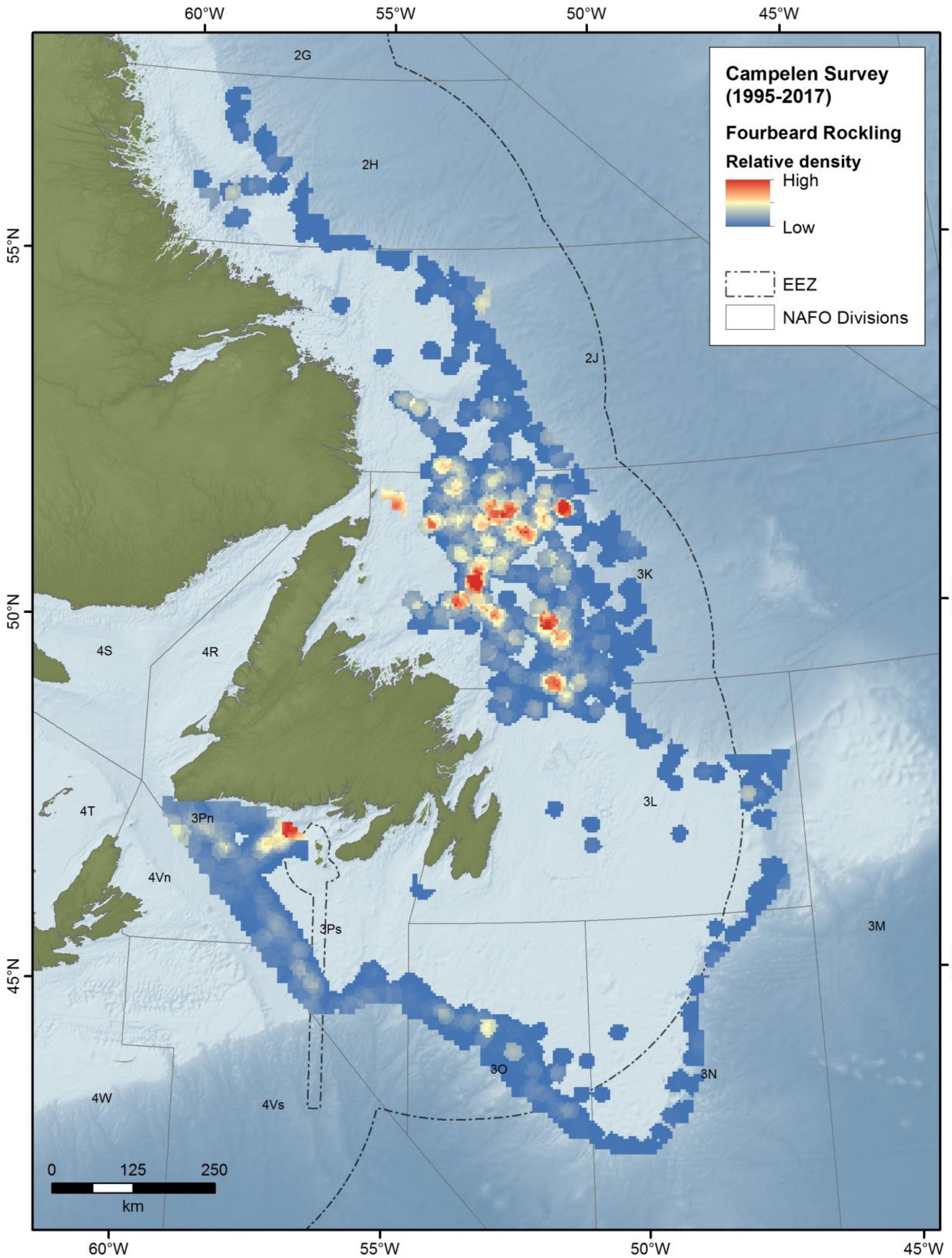


Figure 27: Average relative density of Fourbeard Rockling from 1995-2017.

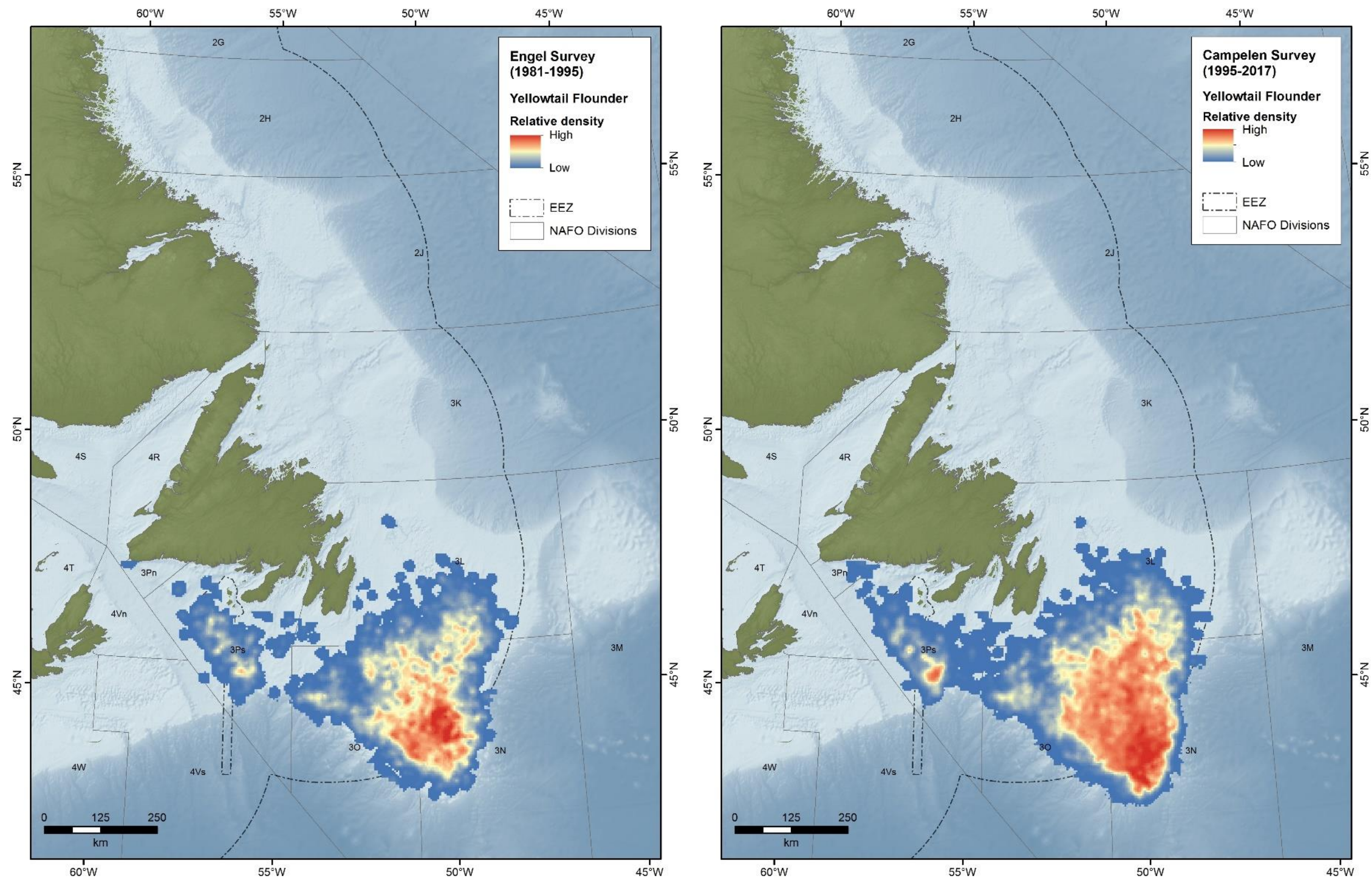


Figure 28: Average relative density of Yellowtail Flounder from 1981-1995 (left) and 1995-2017 (right).

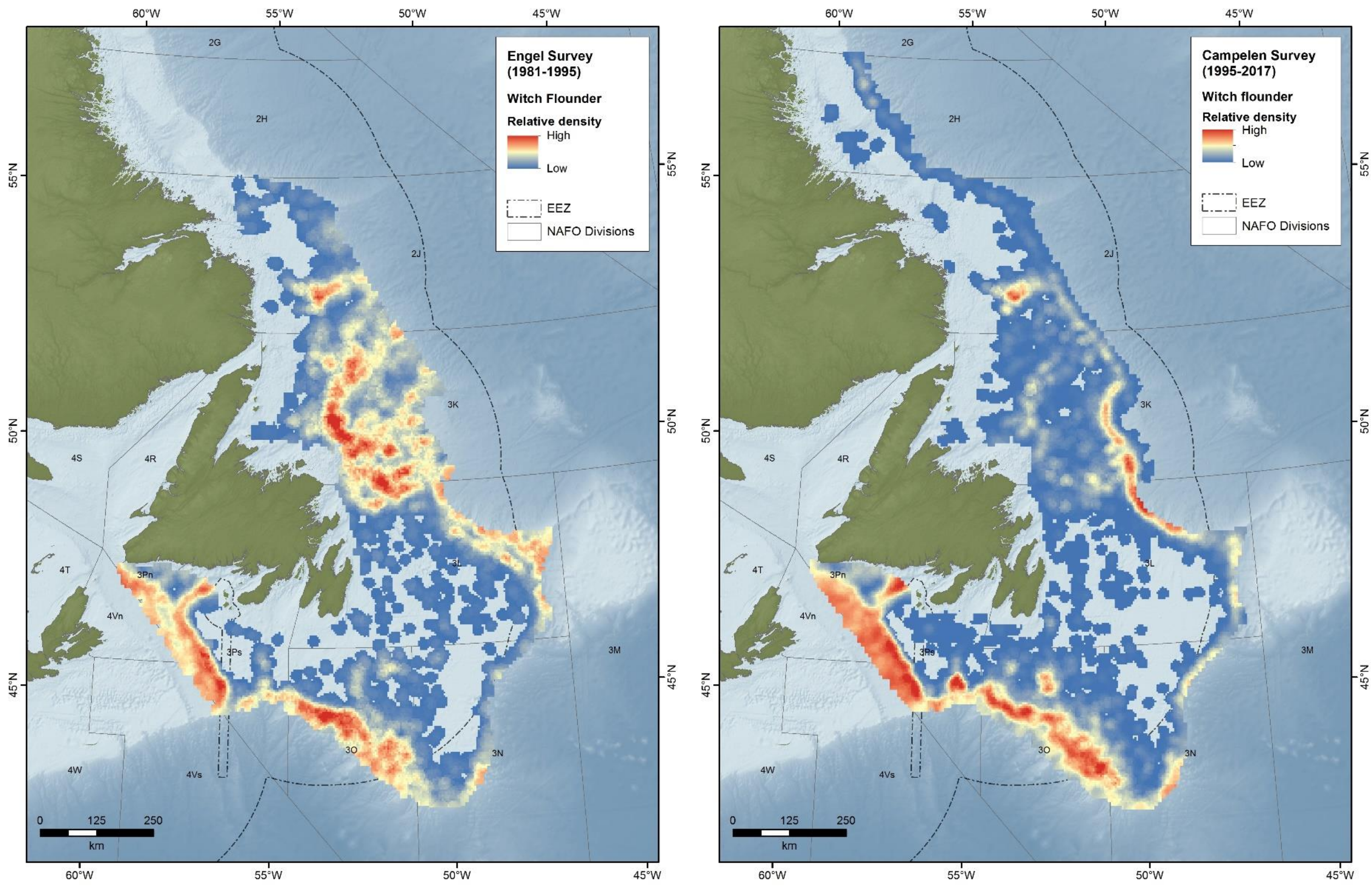
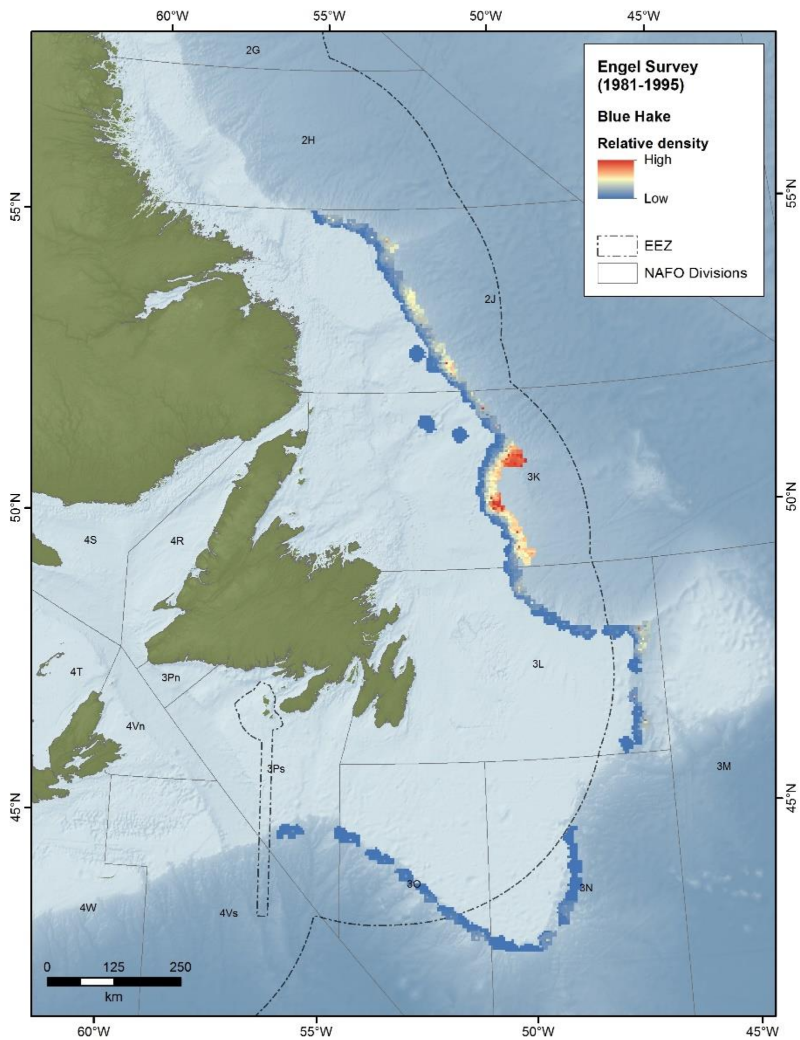


Figure 29: Average relative density of Witch Flounder from 1981-1995 (left) and 1995-2017 (right).



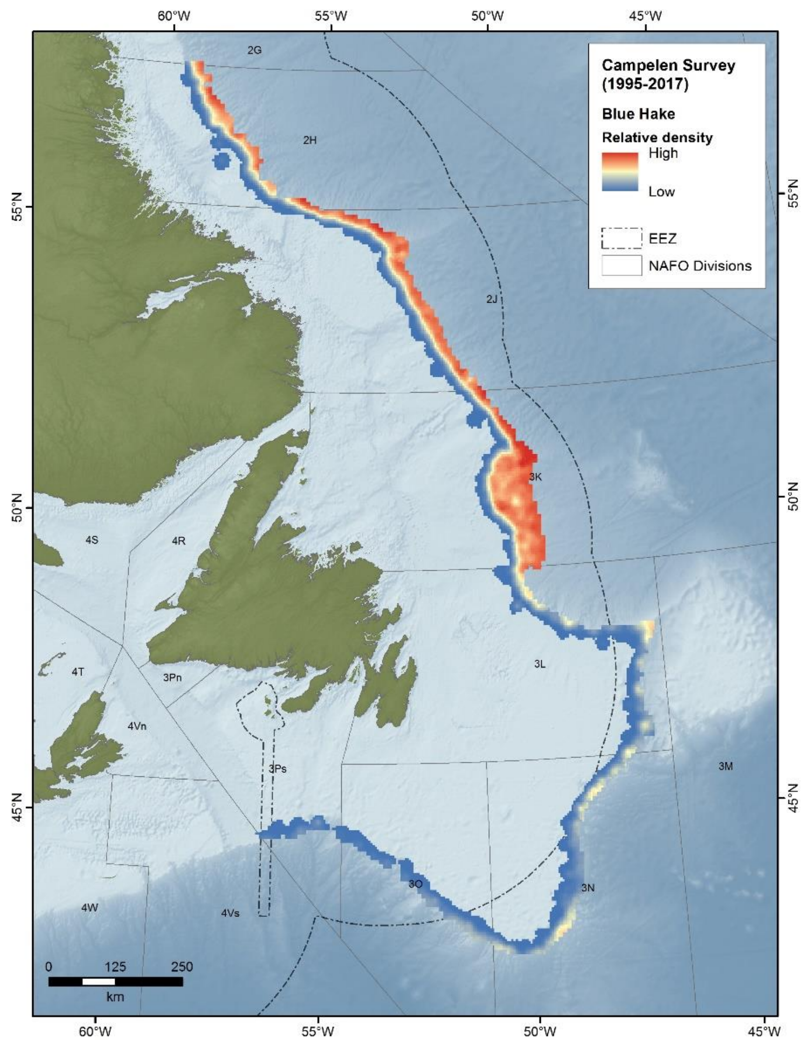


Figure 30: Average relative density of Blue Hake from 1981-1995 (left) and 1995-2017 (right).

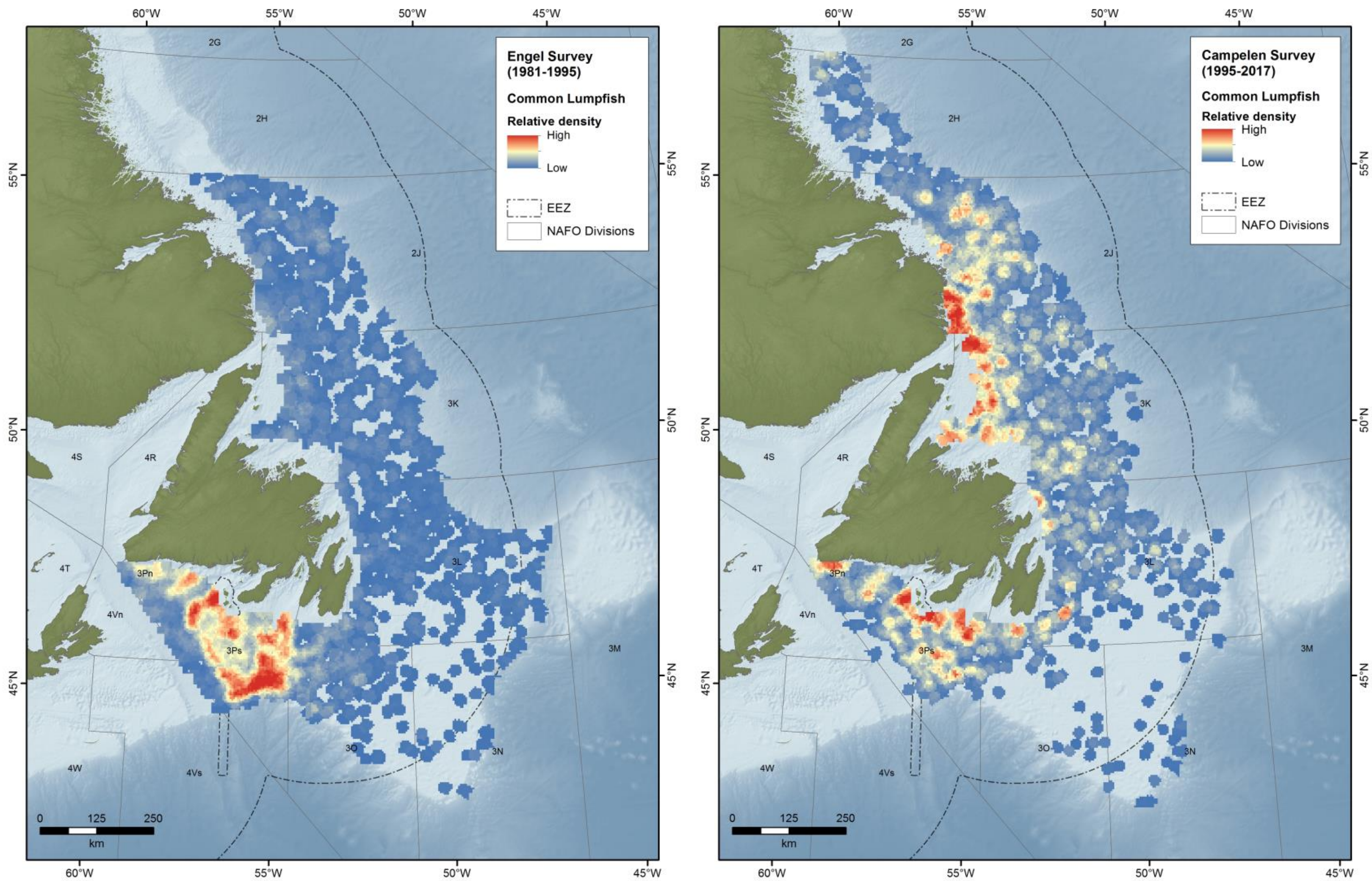


Figure 31: Average relative density of Common Lumpfish from 1981-1995 (left) and 1995-2017 (right).

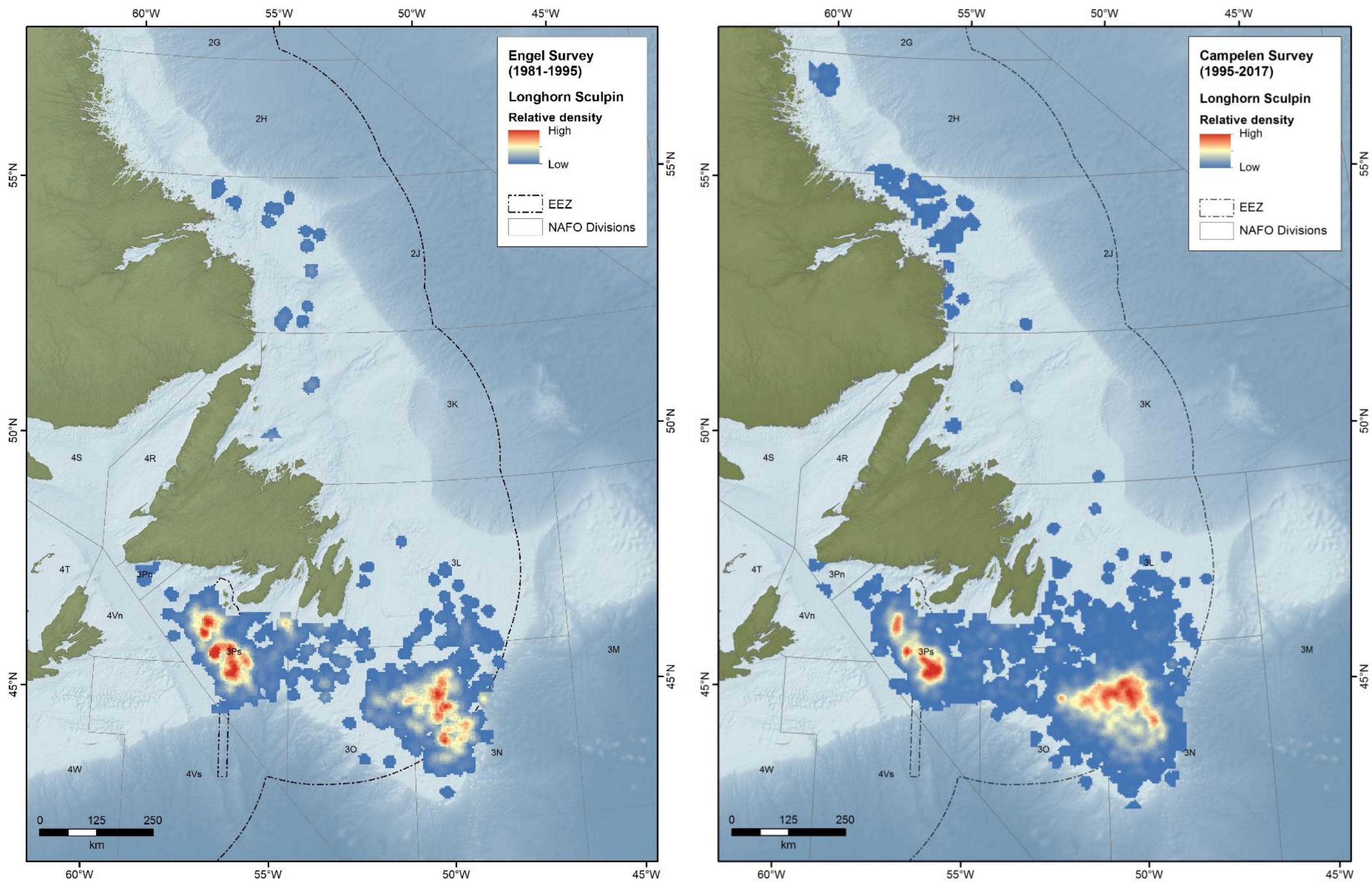


Figure 32: Average relative density of Longhorn Sculpin from 1981-1995 (left) and 1995-2017 (right).

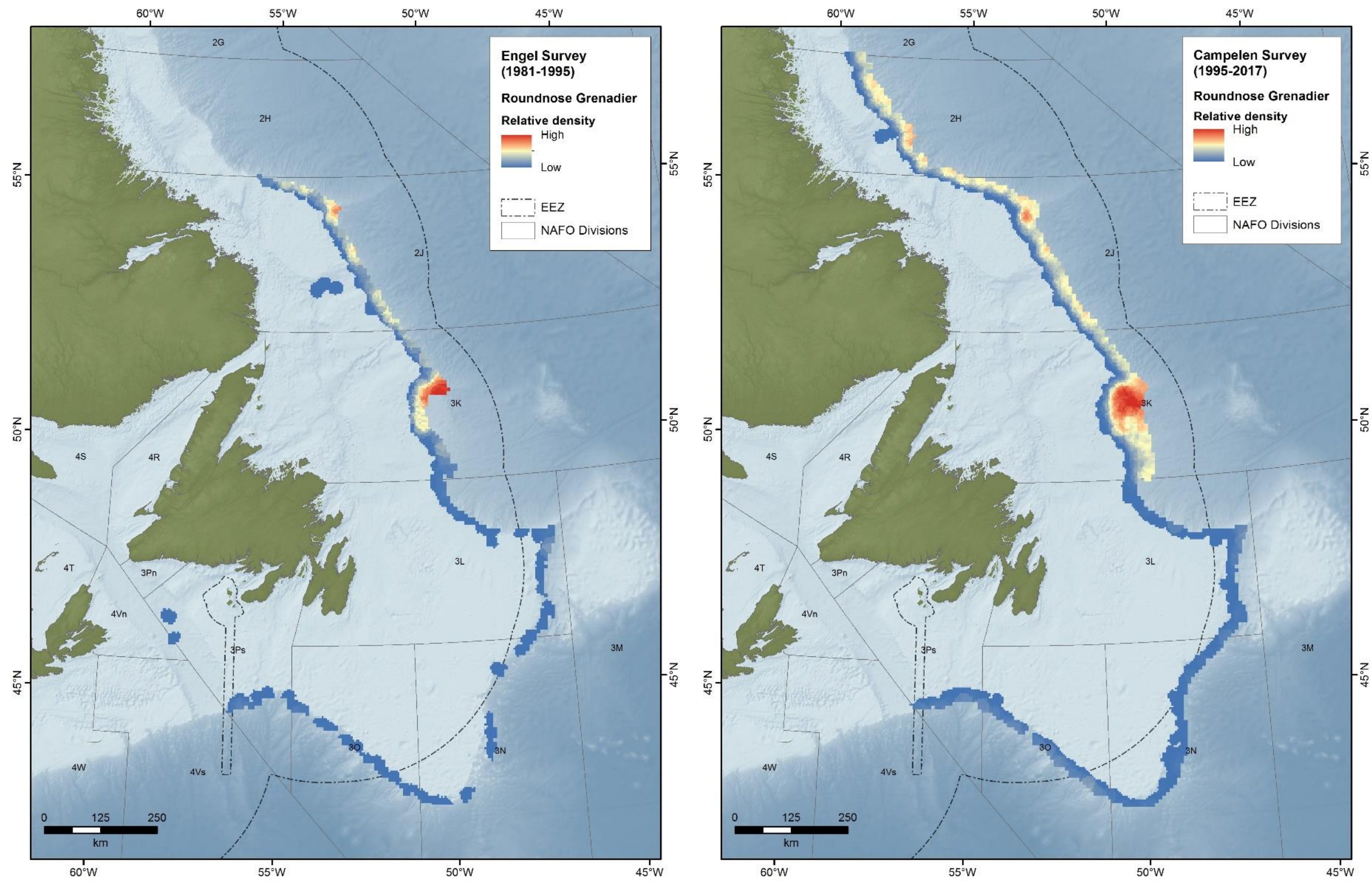


Figure 33: Average relative density of Roundnose Grenadier from 1981-1995 (left) and 1995-2017 (right).

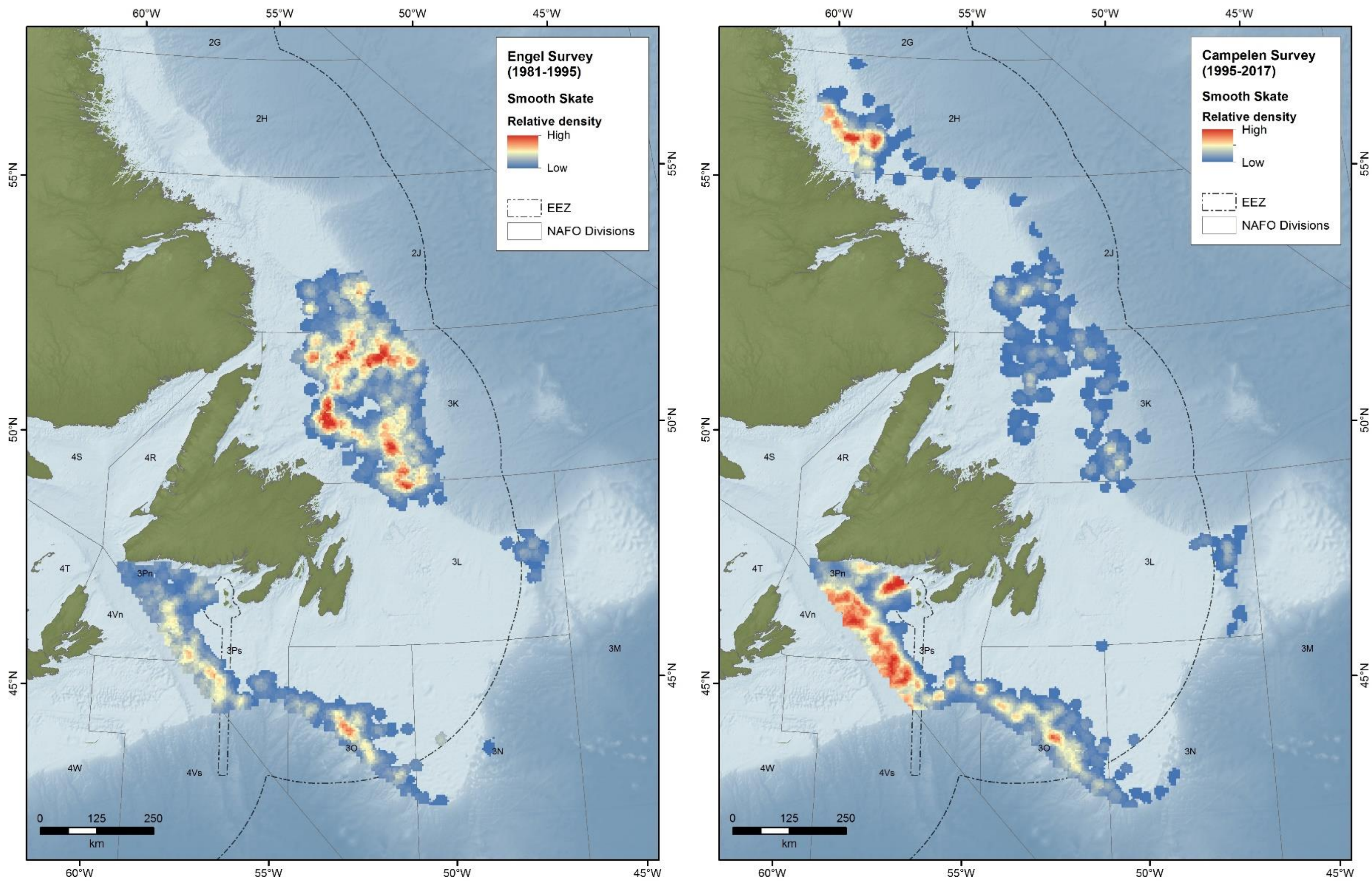


Figure 34: Average relative density of Smooth Skate from 1981-1995 (left) and 1995-2017 (right).

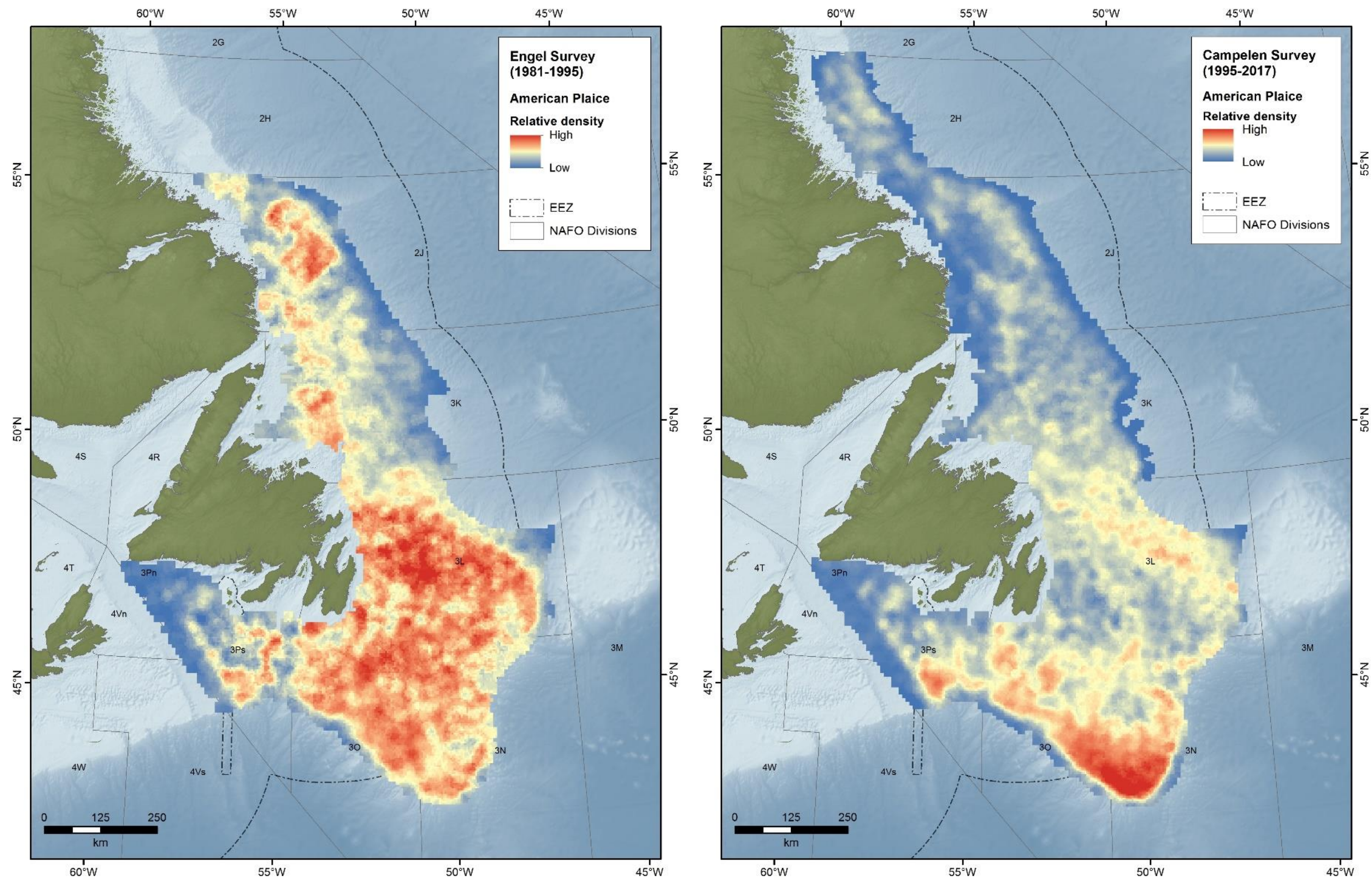


Figure 35: Average relative density of American Plaice from 1981-1995 (left) and 1995-2017 (right).

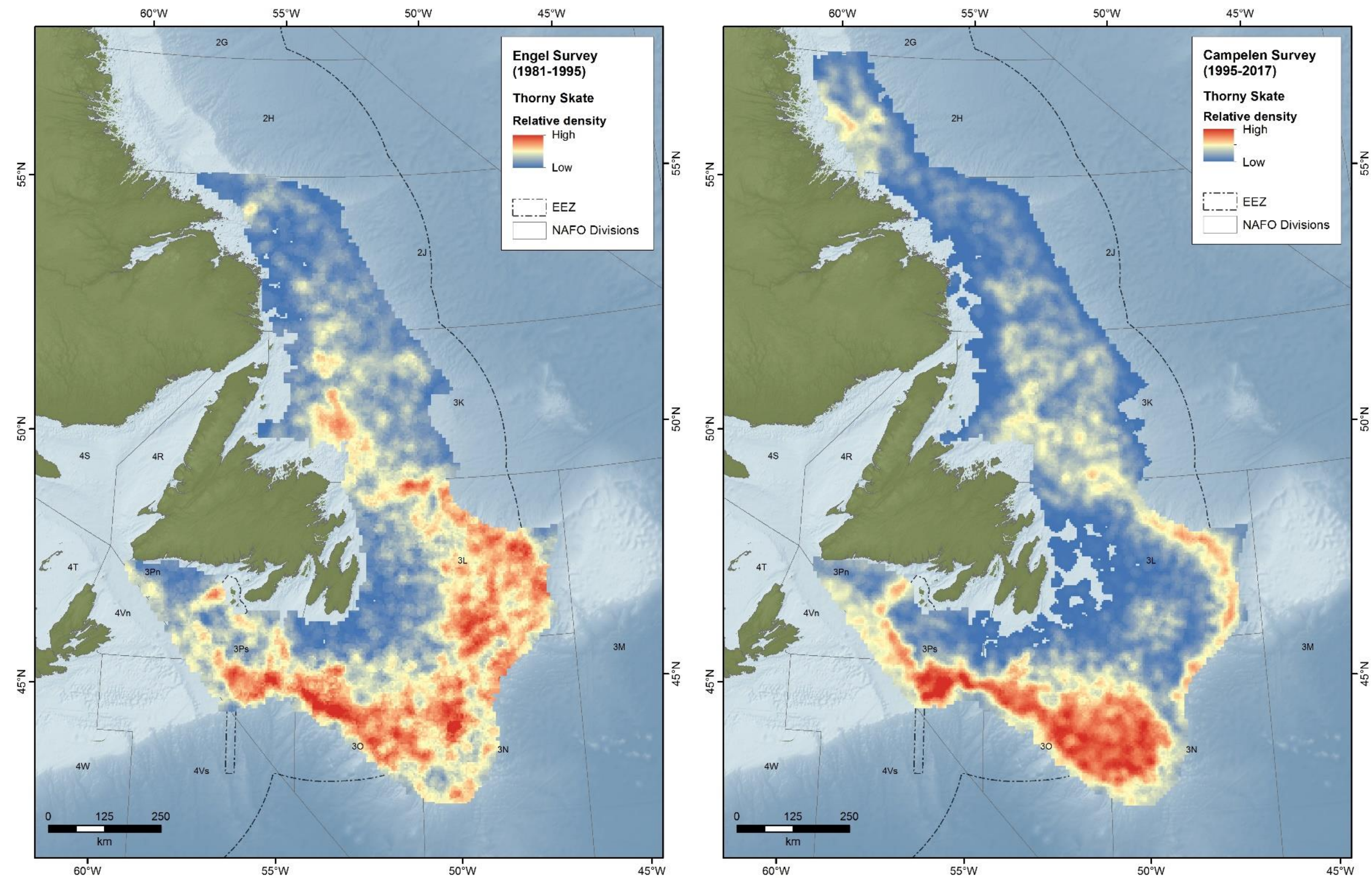


Figure 36: Average relative density of Thorny Skate from 1981-1995 (left) and 1995-2017 (right).

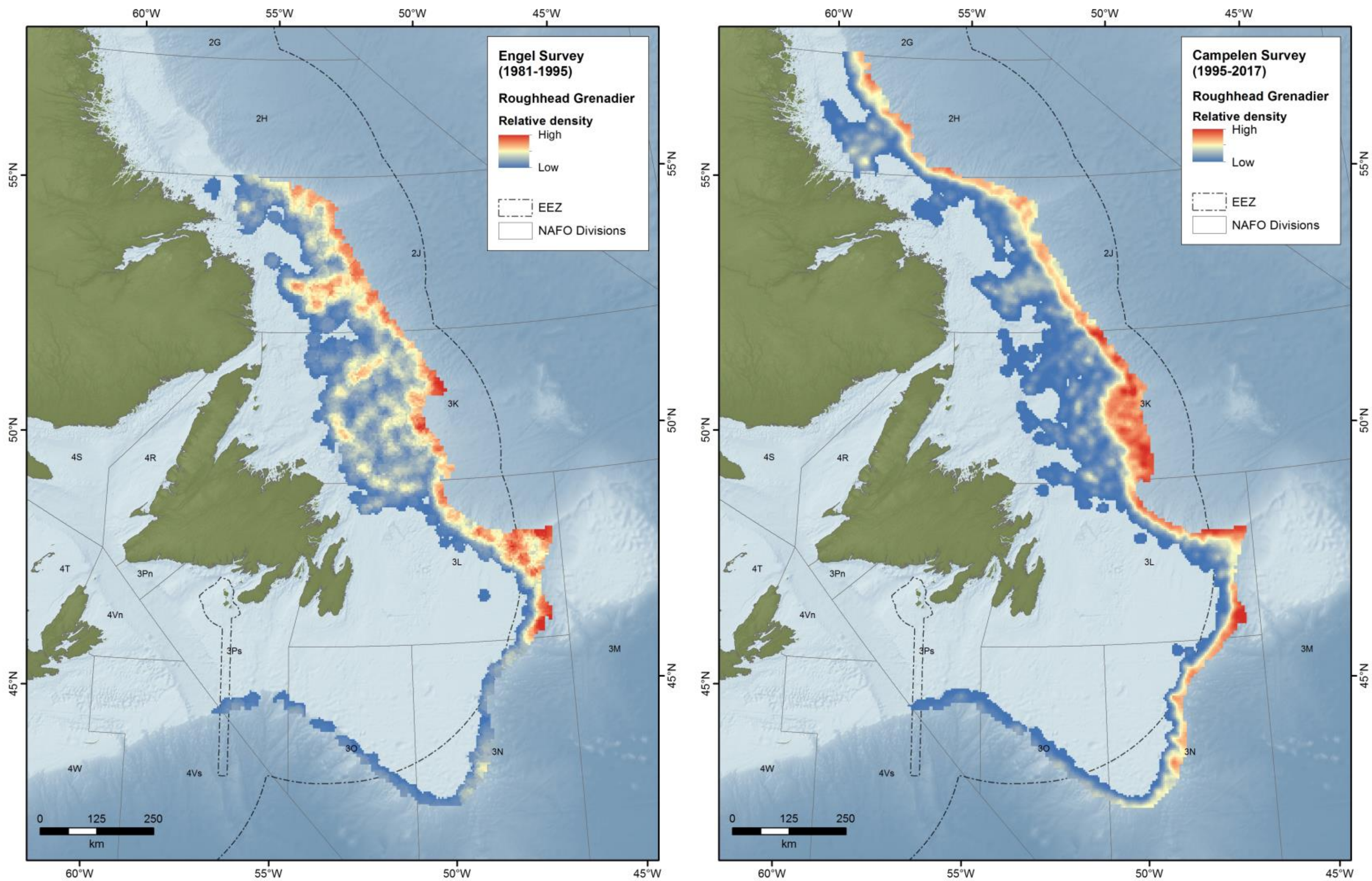


Figure 37: Average relative density of Roughhead Grenadier from 1981-1995 (left) and 1995-2017 (right).

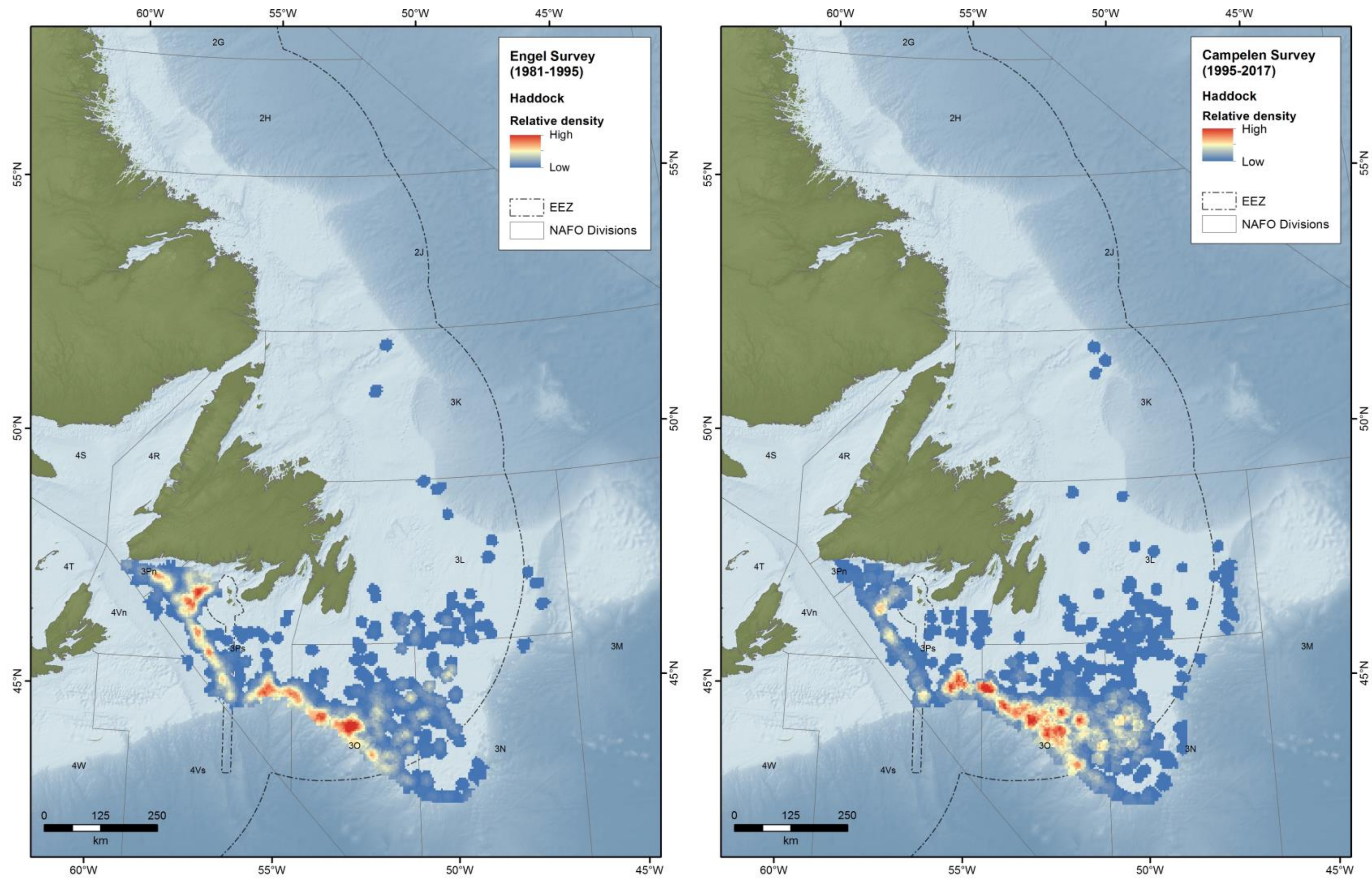


Figure 38: Average relative density of Haddock from 1981-1995 (left) and 1995-2017 (right).

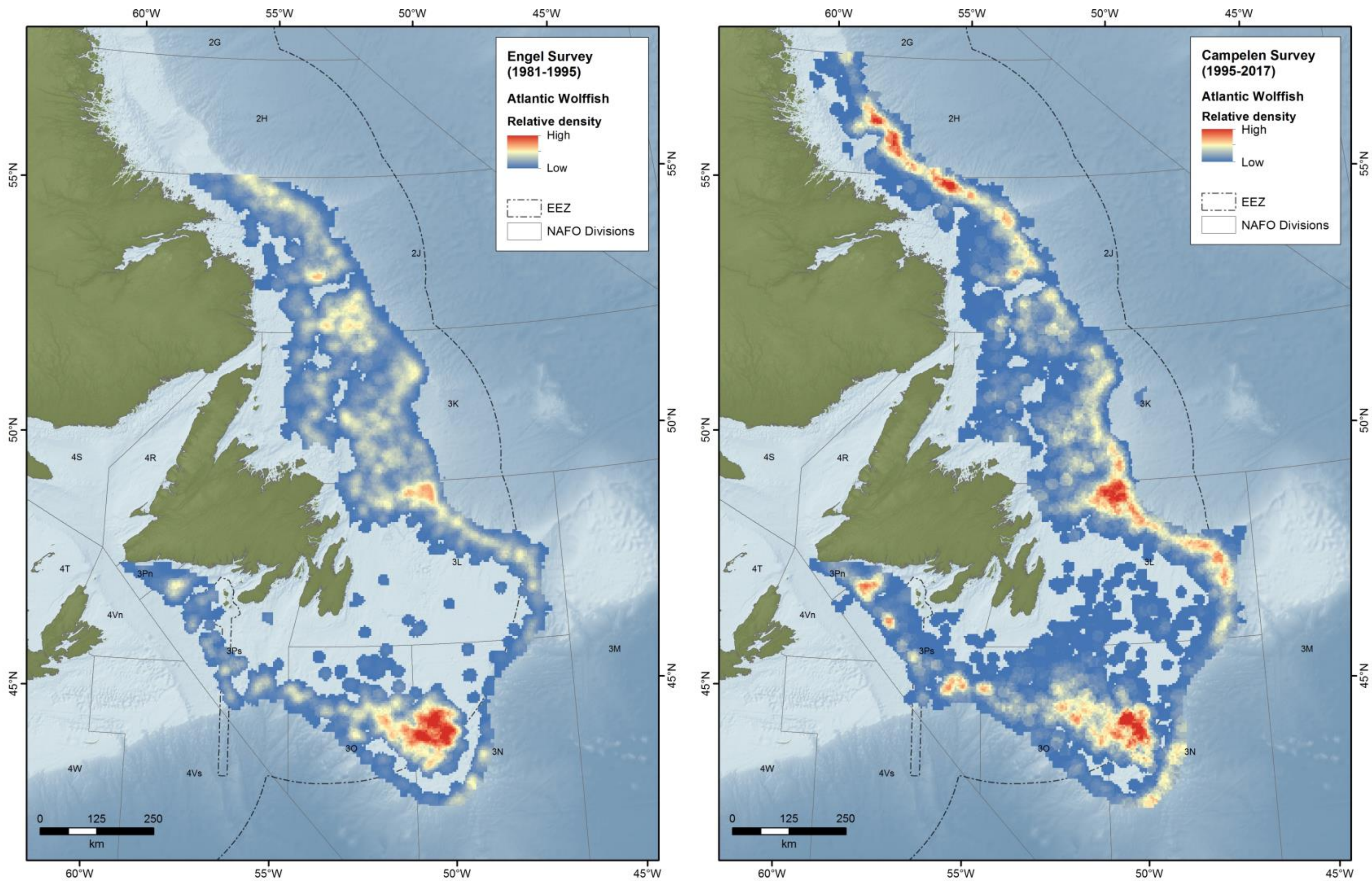


Figure 39: Average relative density of Atlantic Wolffish from 1981-1995 (left) and 1995-2017 (right).

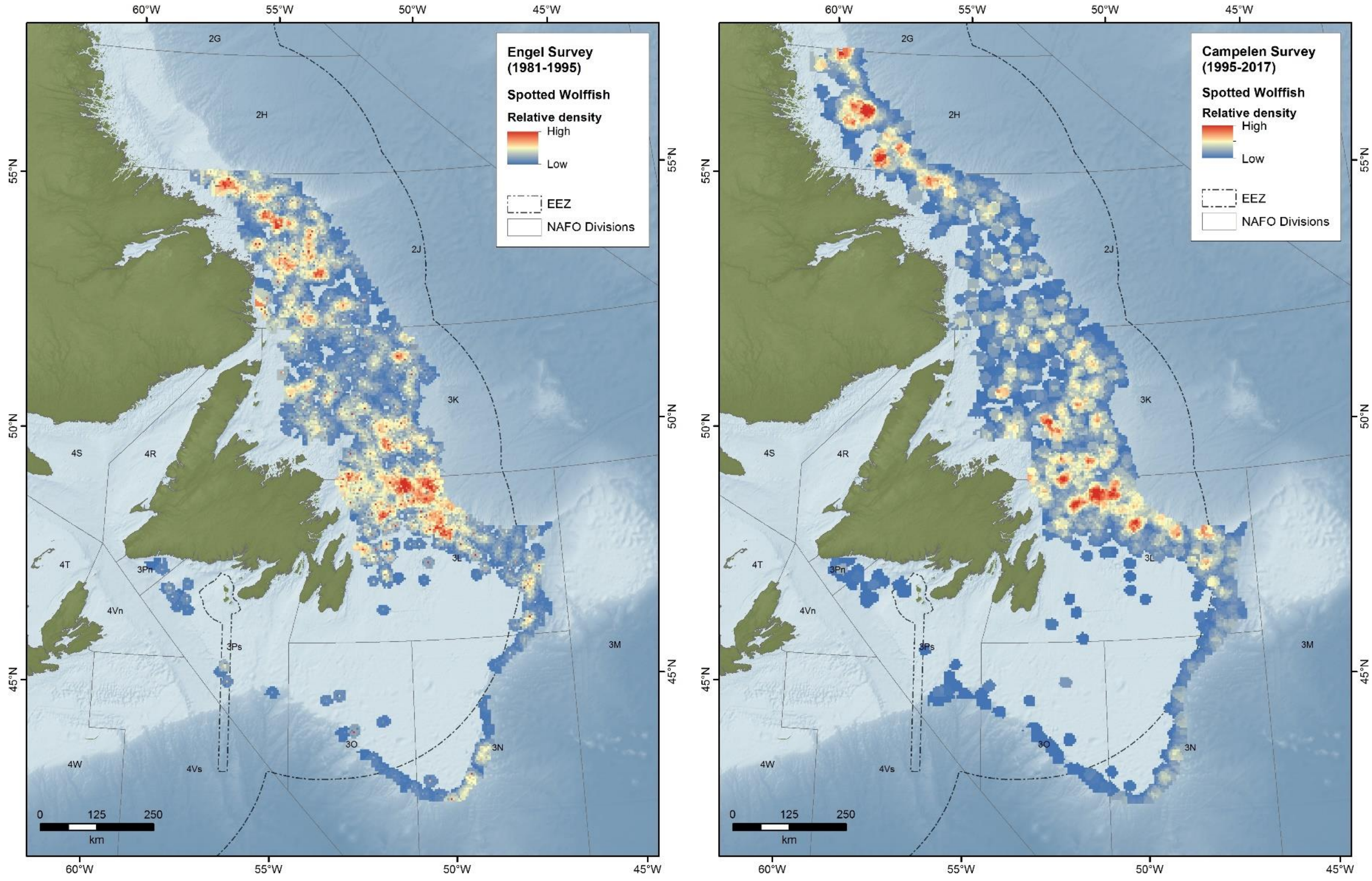


Figure 40: Average relative density of Spotted Wolffish from 1981-1995 (left) and 1995-2017 (right).

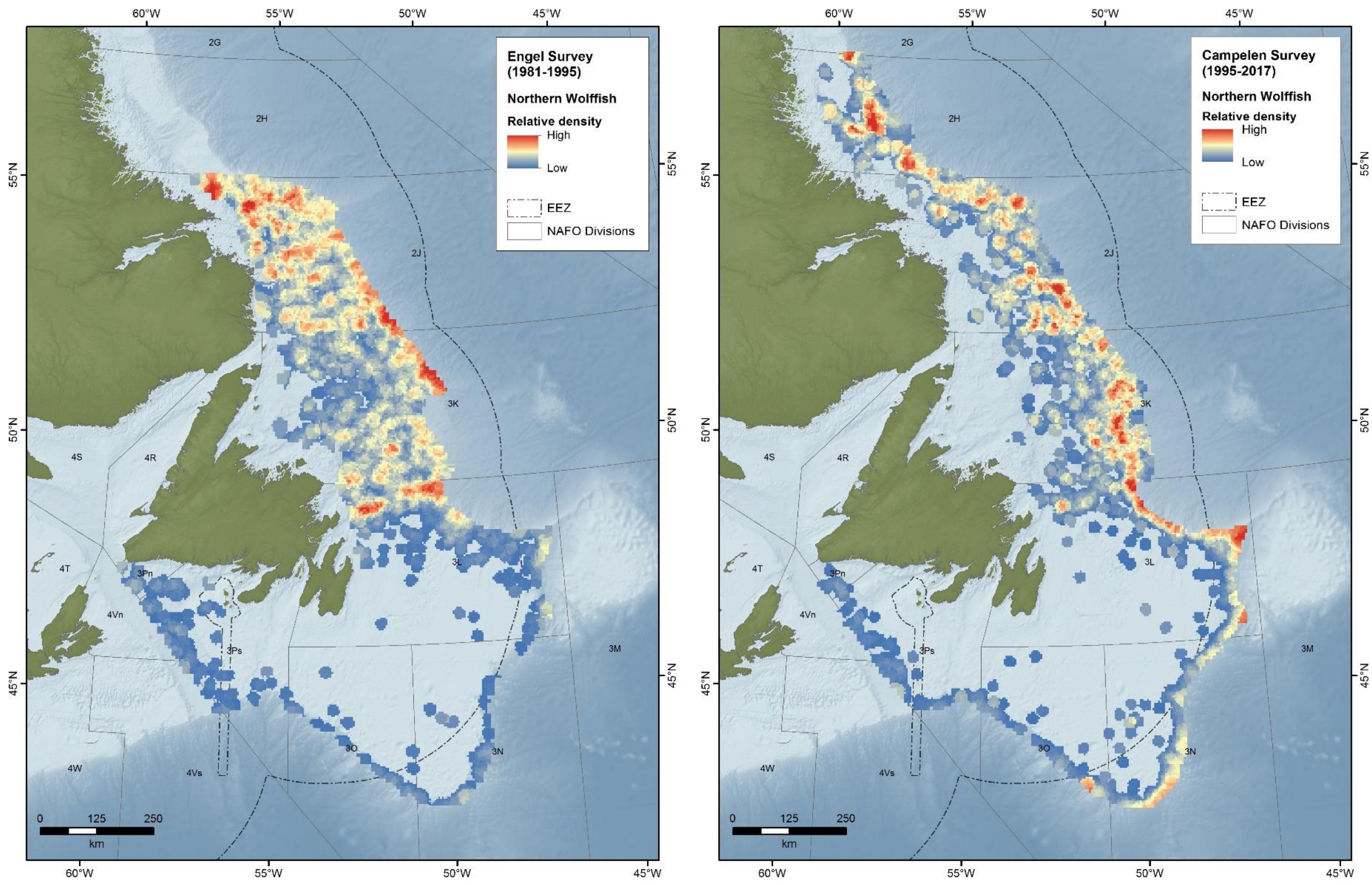


Figure 41: Average relative density of Northern Wolffish from 1981-1995 (left) and 1995-2017 (right).

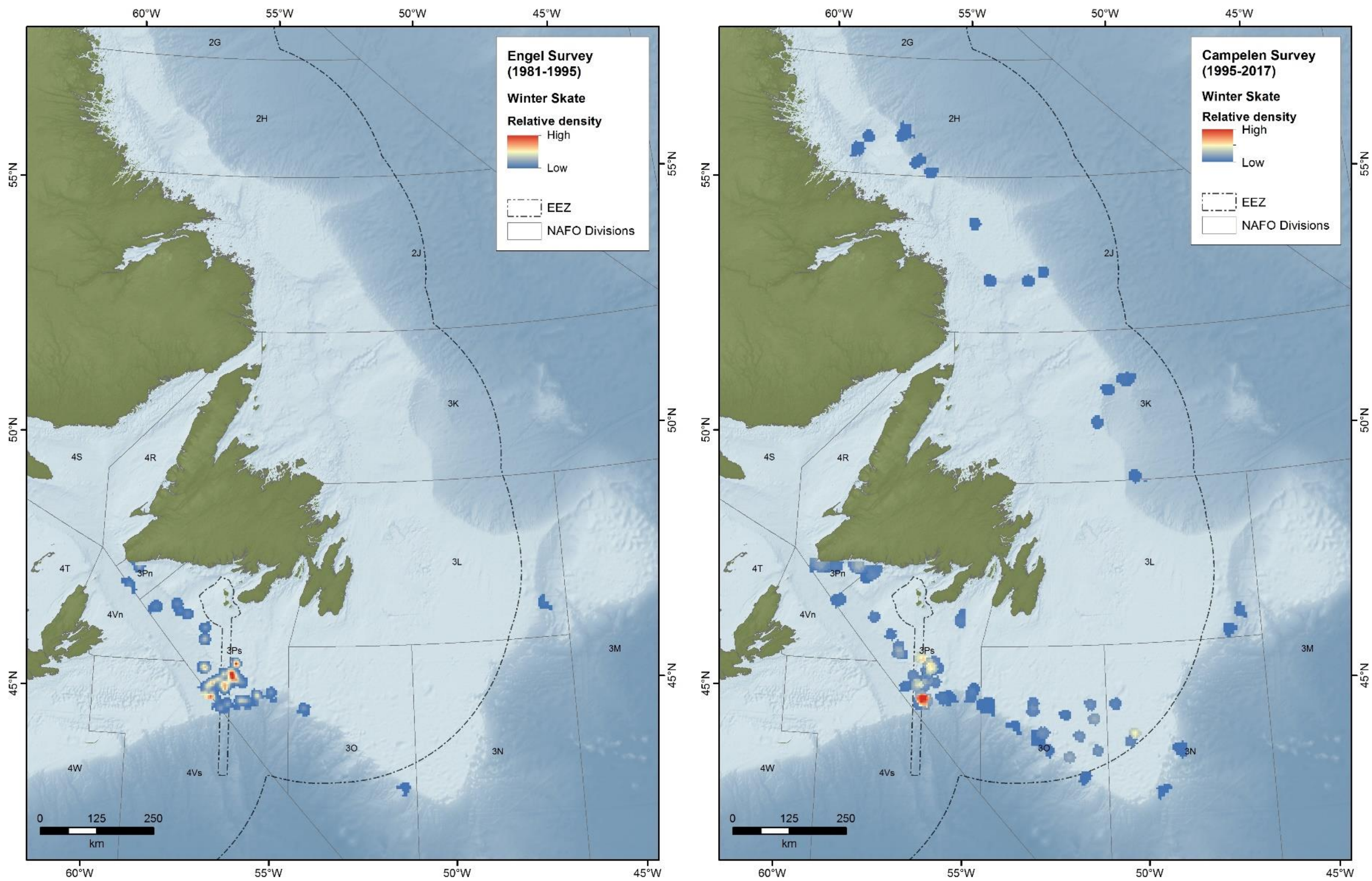


Figure 42: Average relative density of Winter Skate from 1981-1995 (left) and 1995-2017 (right).

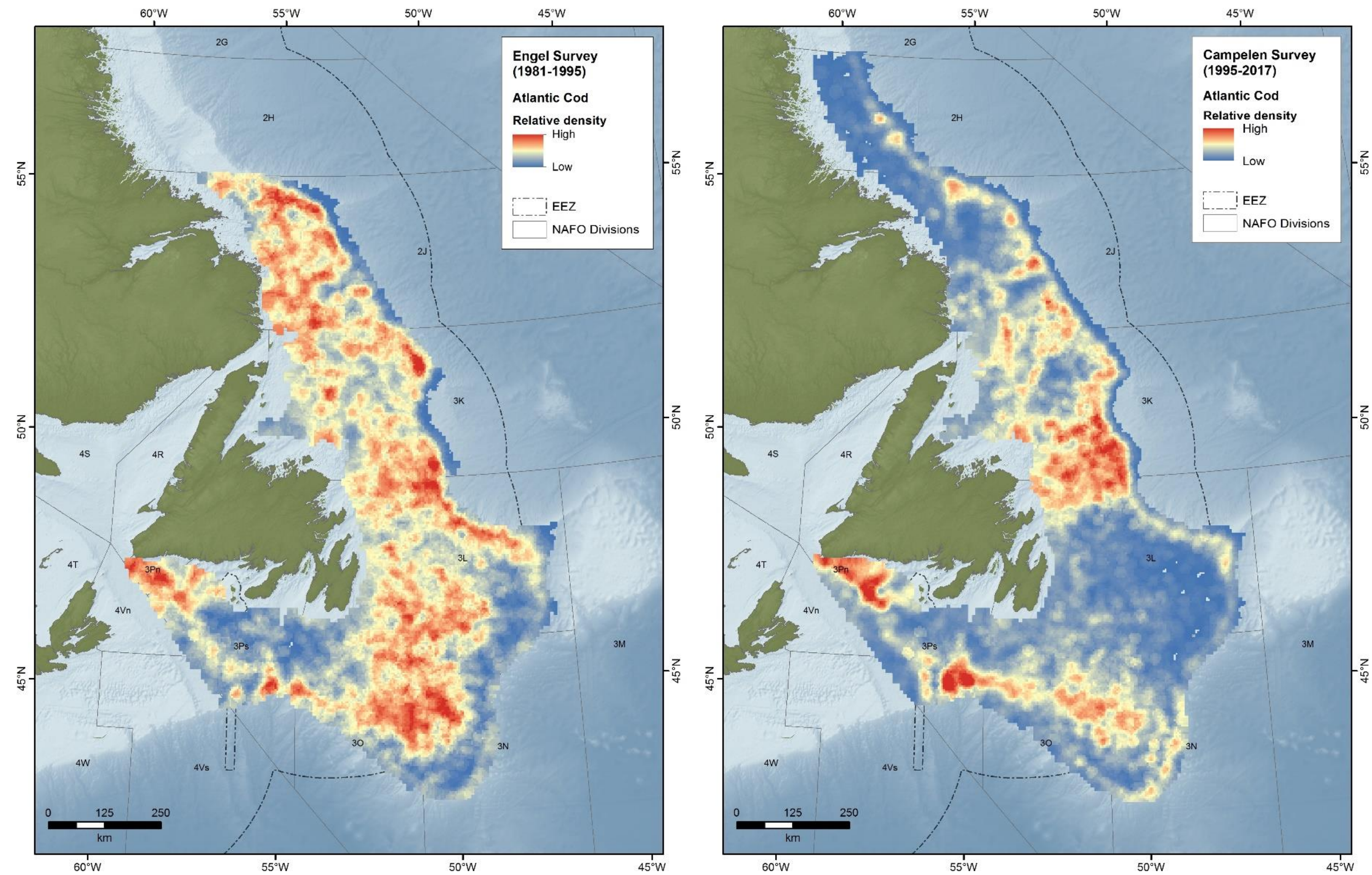


Figure 43: Average relative density of Atlantic Cod from 1981-1995 (left) and 1995-2017 (right).

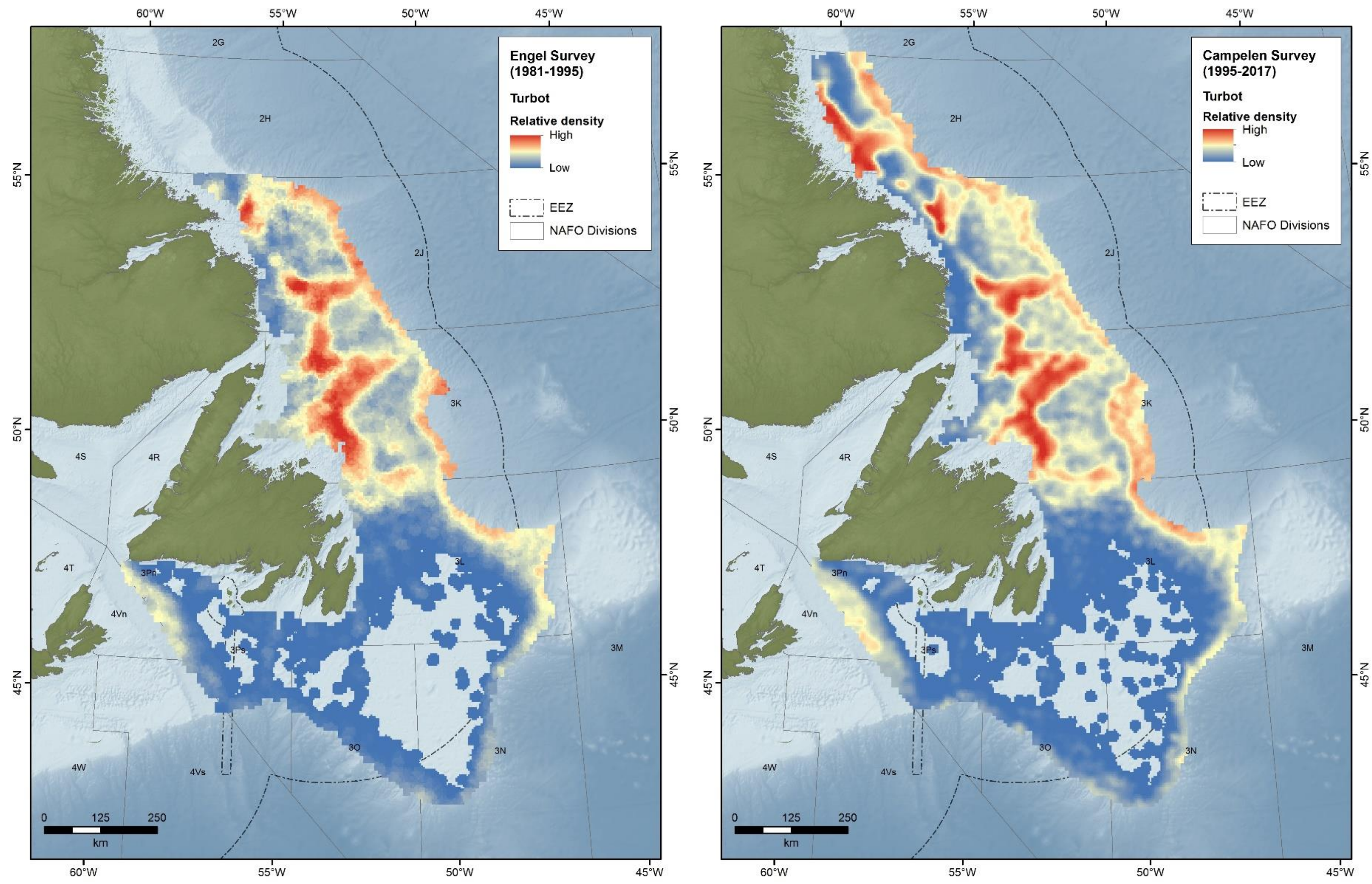


Figure 44: Average relative density of Greenland Halibut (Turbot) from 1981-1995 (left) and 1995-2017 (right).

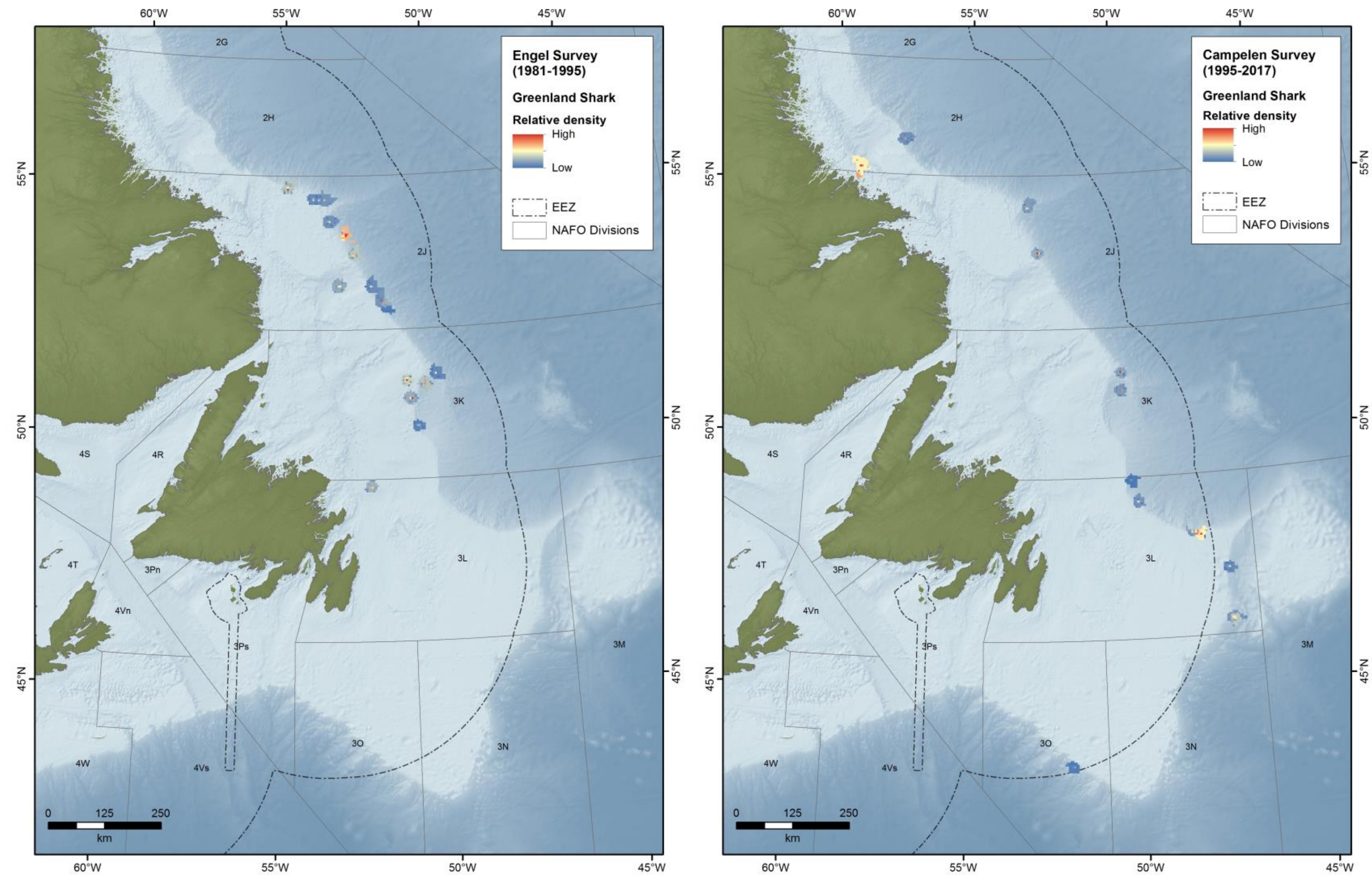


Figure 45: Average relative density of Greenland Shark from 1981-1995 (left) and 1995-2017 (right).

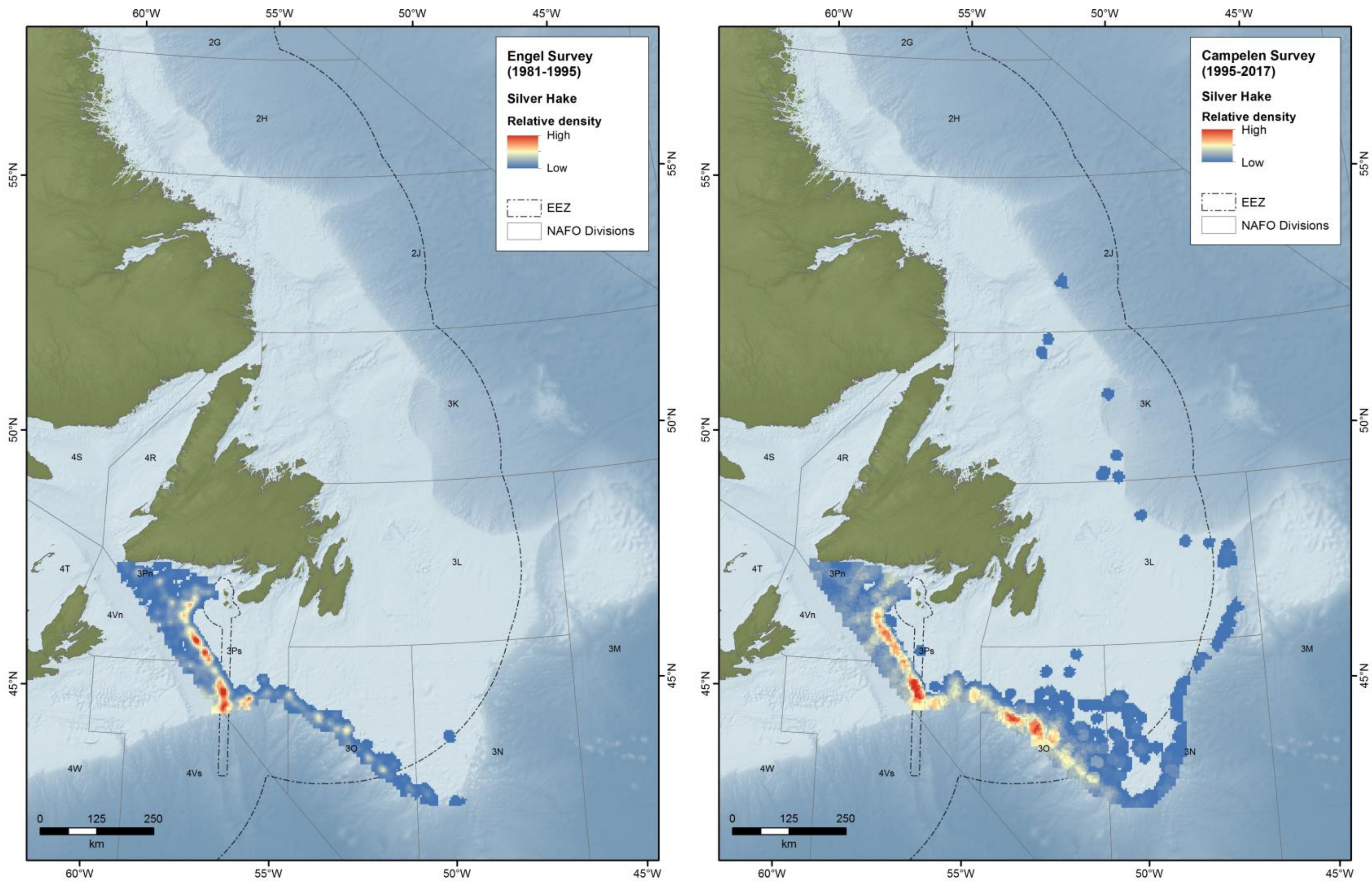


Figure 46: Average relative density of Silver Hake from 1981-1995 (left) and 1995-2017 (right).

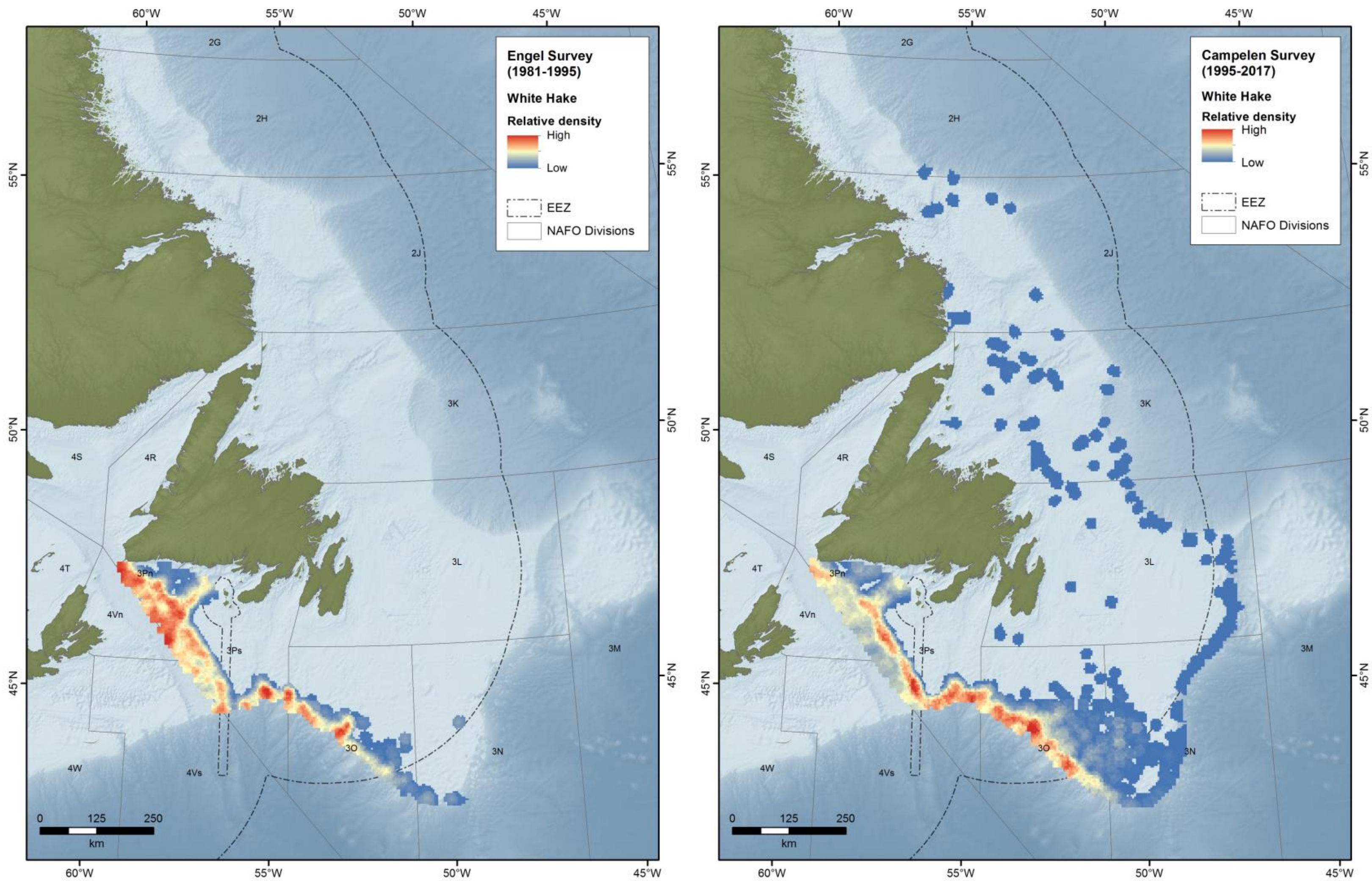


Figure 47: Average relative density of White Hake from 1981-1995 (left) and 1995-2017 (right).

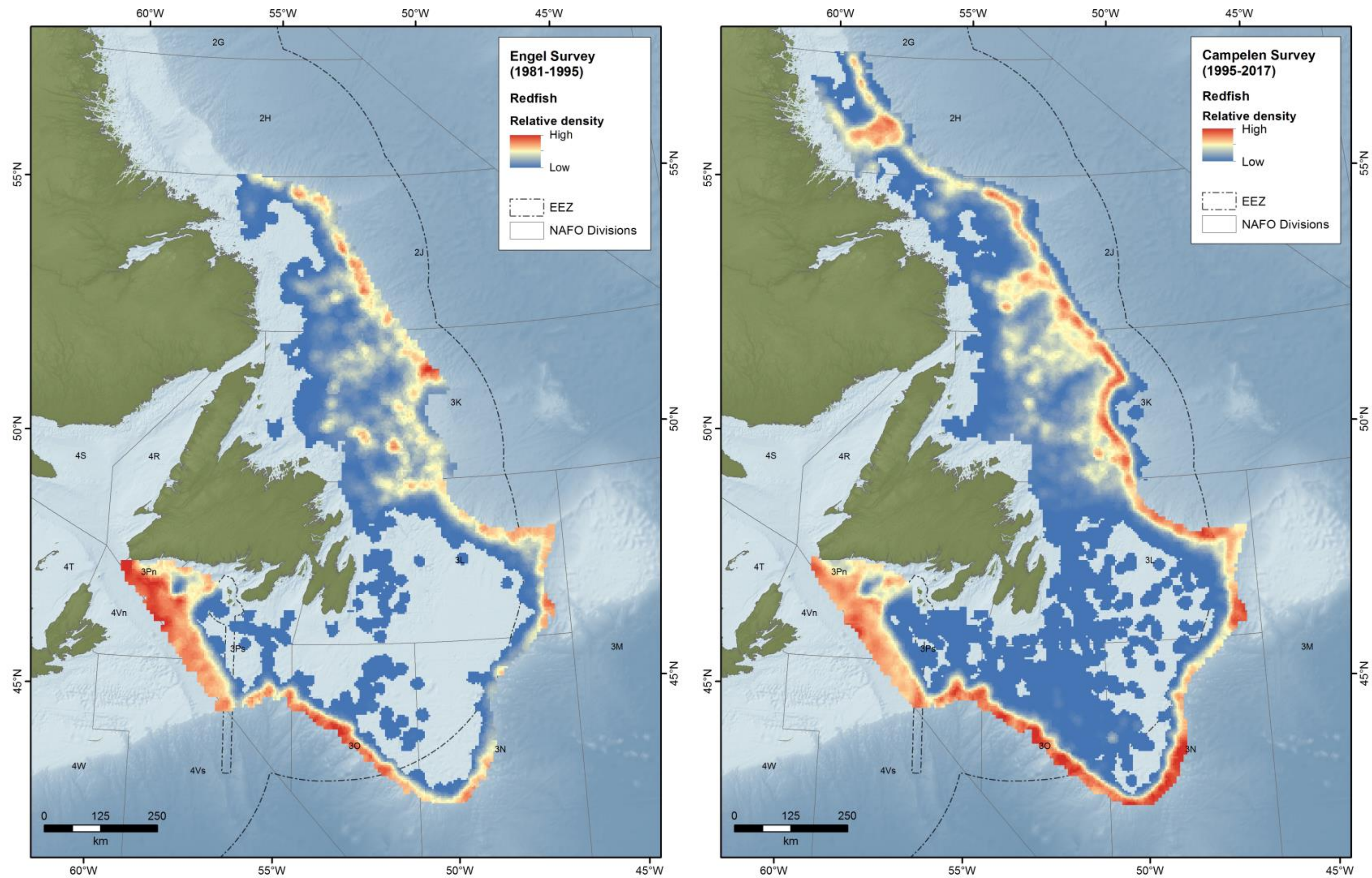


Figure 48: Average relative density of Redfish from 1981-1995 (left) and 1995-2017 (right).

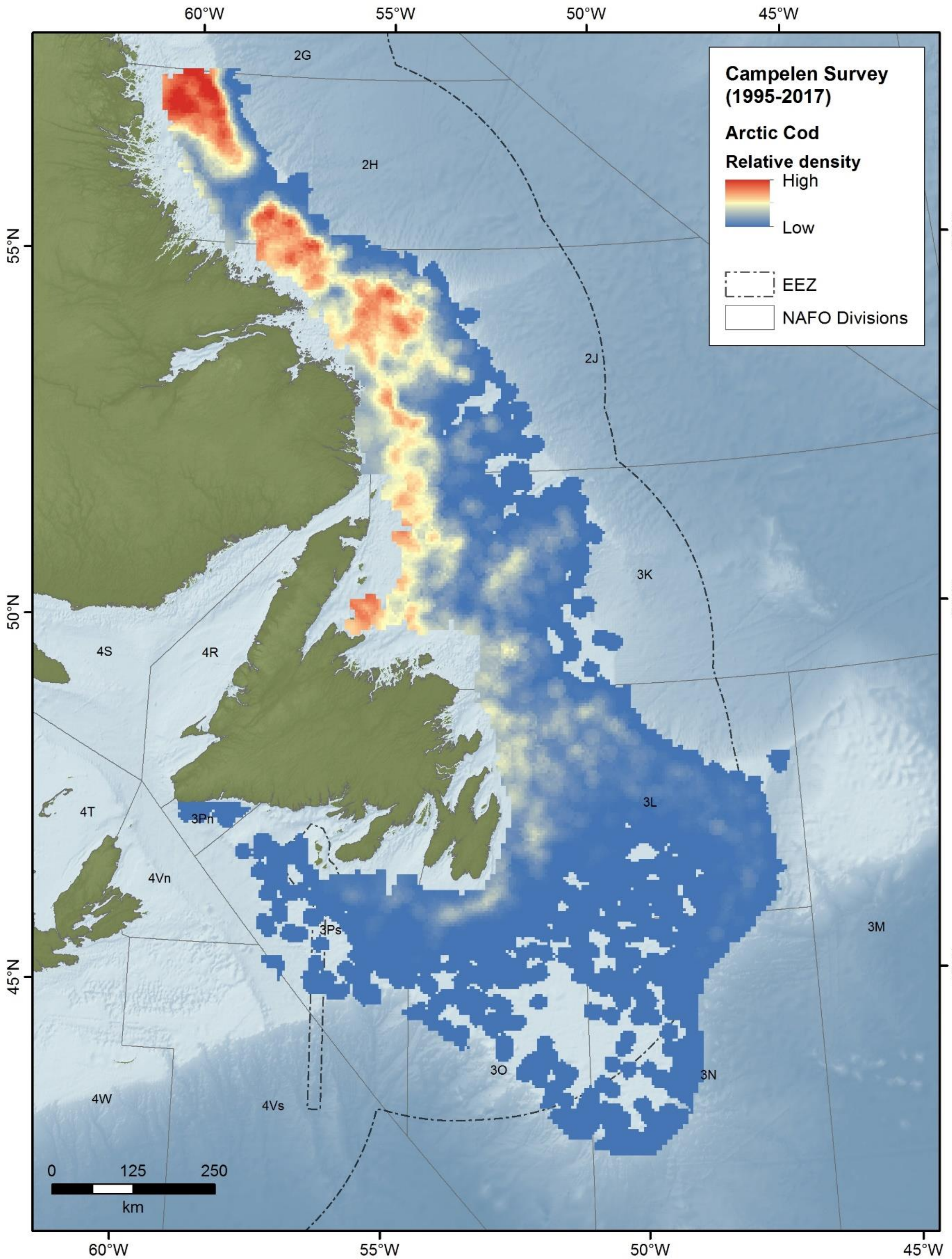


Figure 49: Average relative density of Arctic Cod from 1995-2017.

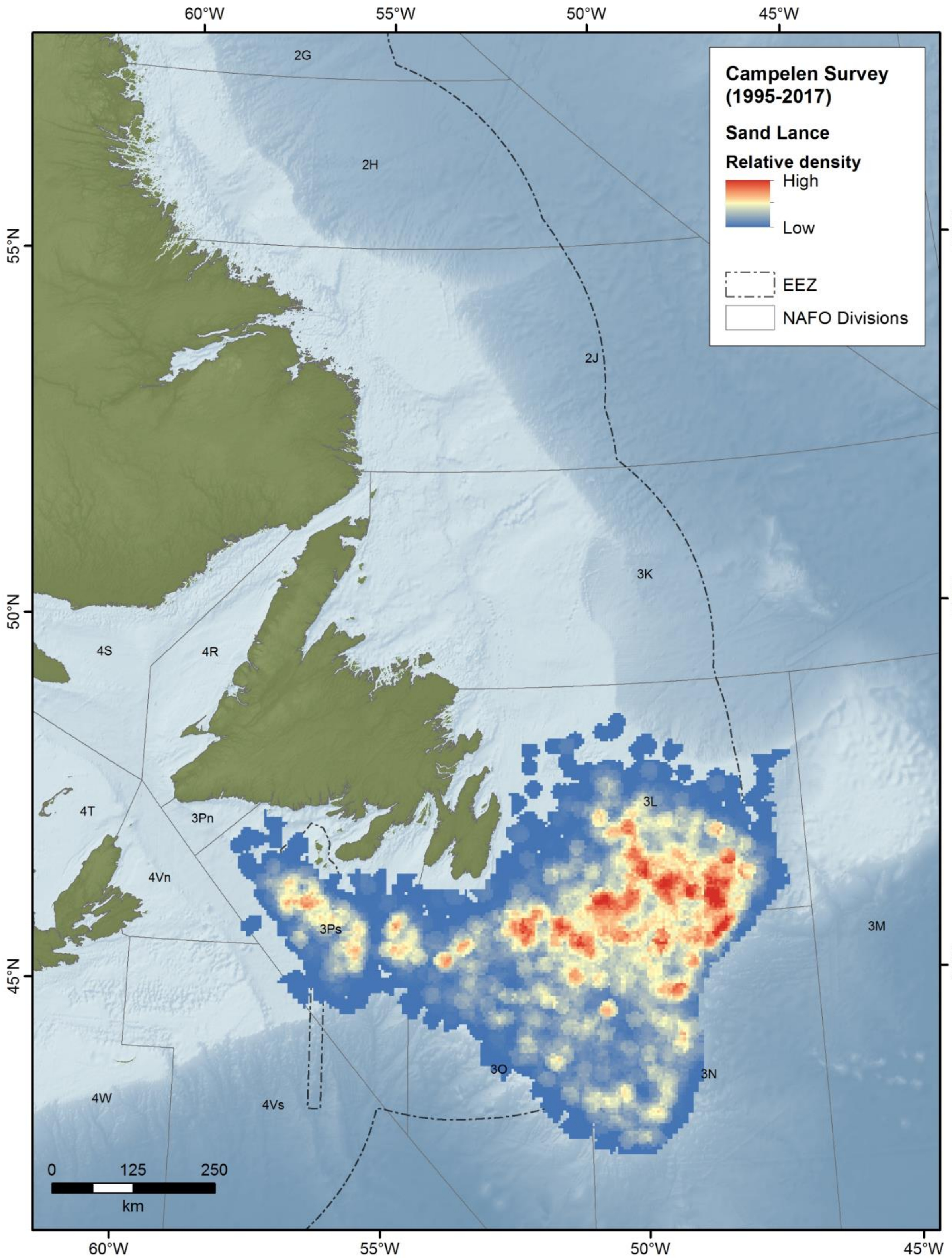


Figure 50: Average relative density of Sand Lance from 1995-2017.

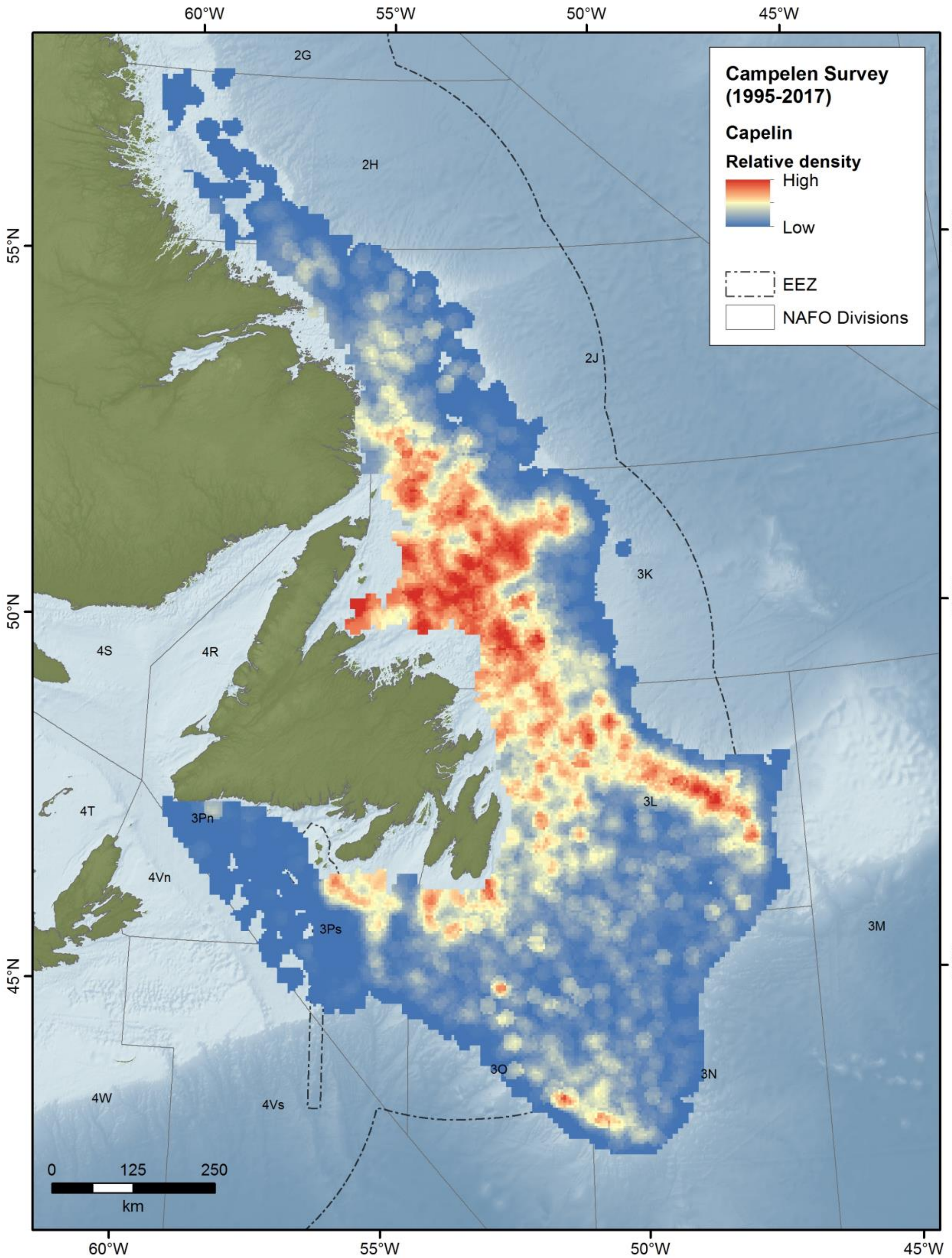


Figure 51: Average relative density of Capelin from 1995-2017.

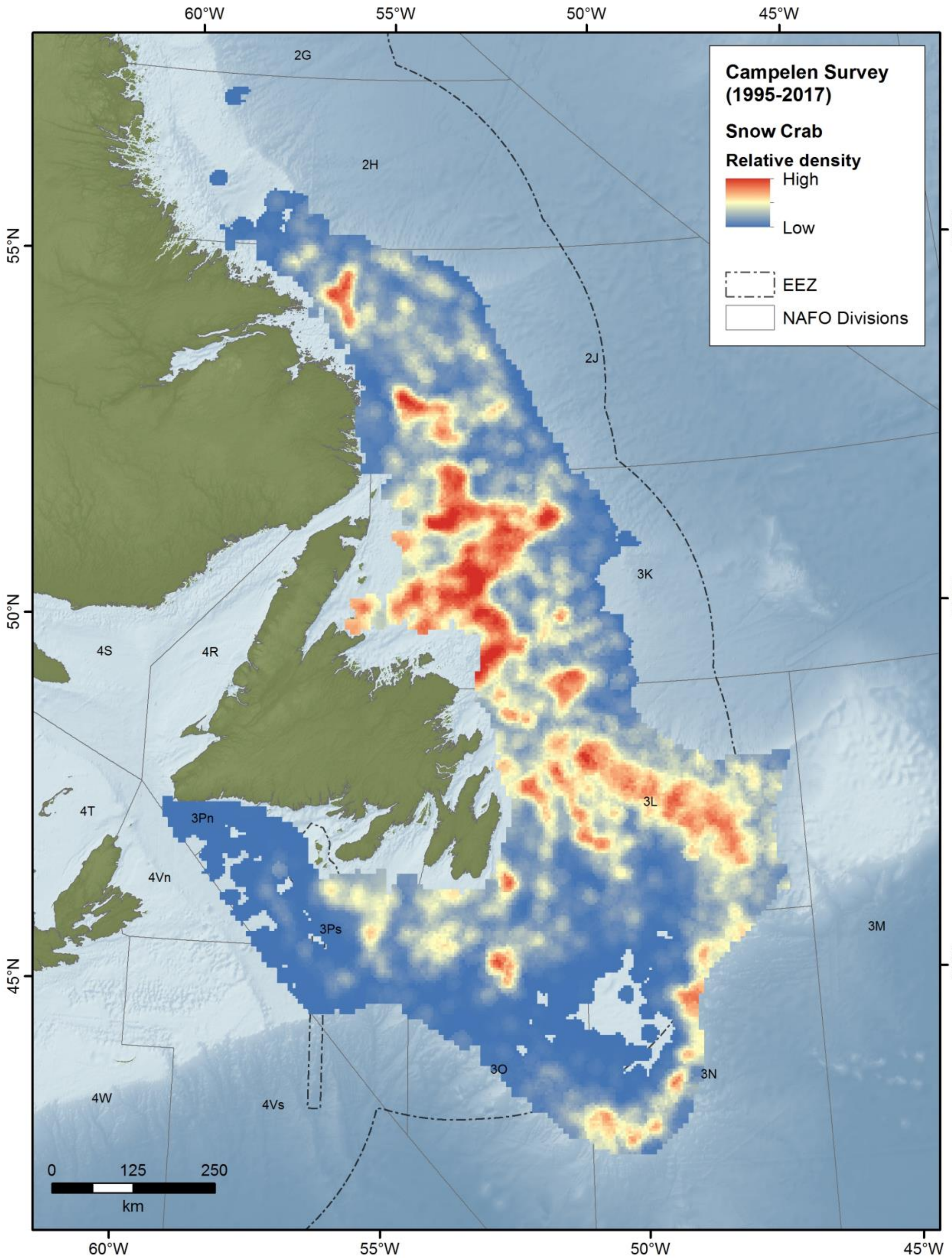


Figure 52: Average relative density of Snow Crab from 1995-2017.

Appendix A

Table A1: List of species in the Small Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
ALFONSINO (NCN) CAU.LON.	*Caulolepis longidens*		
ALLIGATORFISH (NS)	*Agonidae*		
ALLIGATORFISH,ARCTIC	*Aspidophoroides olriki*		
ALLIGATORFISH,COMMON	*Aspidophoroides monopterygius*	Y	
ALLIGATORFISH,NORTHERN	*Agonus decagonus*	Y	
ANGLEMOUTHS (NS)	*Cyclothone sp.*		
ANGLEMOUTHS (NS)	*Gonostoma sp.*		
ARGENTINE,LARGE EYED	*Nansenia groenlandica*		
ATLANTIC GYMNAST	*Xenodermichthys (aleposomus) copei*		
BATFISH,ATLANTIC	*Dibranchus atlanticus*		
BIGSCALEFISHES, RIDGEHEADS	*Melamphaidae*		
BLACK SWALLOWER	*Chiasmodon niger*		
BLACKSMELT,GOITRE	*Bathylagus euryops*	Y	
BLACKSMELTS (NS)	*Bathylagus sp.*		
BUTTERFISH (NS)	*Stromateidae*		
CARDINALFISH,SHERBORN'S	*Rhectogramma sherborni*		
DEEPSEA SCULPIN,PALLID	*Cottunculus thompsoni*		
DEEPSEA SCULPIN,POLAR	*Cottunculus microps*		
EELPOUT,SOFT	*Melanostigma atlanticum*		
FANGTOOTH (Ogrefish) Ana	*Anoplogaster cornuta*		
FEELERFISH,NOTCH	*Bathypterois dubius*		
FOURBEARD ROCKLING	*Enchelyopus cimbrius*	Y	
FOURLINE SNAKEBLENNY	*Eumesogrammus praecisus*	Y	
GRENADIER,COMMON (MARLIN)	*Nezumia bairdi*	Y	
GRENADIER,ROUGHNOSE	*Trachyrhynchus murrayi*		
GRENADIERS (NS)	*Macrouridae*		
GRUBBY	*Myoxocephalus aeneus*		
GUNNELS (NS)	*Pholidae*		
HATCHETFISHES (NS)	*Sternoptychidae*		
HOOKEAR SCULPIN (NS)	*Artediellus sp.*	Y	
LEPIDION (NCN)	*Lepidion (haloporphyrus) eques*		
LIGHTFISHES (NS)	*Gonostomidae*		
LOOSEJAW	*Malacosteus niger*		
LUMPFISH (NS) EUM.SP.	*Eumicrotremus sp.*	Y	
MAILED SCULPINS (NS)	*Triglops sp.*	Y	
MANEFISH, ATLANTIC	*Caristius groenlandicus*		
PLATYTROCTES APUS	*Platytroctes apus*		
SCULPIN, ARCTIC	*Myoxocephalus scorpioides*		
SCULPIN,ARCTIC STAGHORN	*Gymnocanthus tricuspis*		
SCULPIN,SPATULATE	*Icelus spatula*	Y	
SCULPINS (NS)	*Cottidae*		
SEA DEVIL, WARTED	*Cryptosaras couesi*		
SEASNAILS (NS)	*Liparidae*	Y	
SHANNY,DAUBED	*Lumpenus maculatus*	Y	
SLIMEHEAD	*Hoplostethus sp.*		
SMELTS, DEEPSEA (NS)	*Bathylagidae*		
SPINYFIN	*Diretmus argenteus*		
TAPIRFISH, SHORTSPINE	*Macdonaldia rostrata*		
THREEBEARD ROCKLING (NS)	*Gaidropsarus sp.*	Y	
TWOHORN SCULPIN (NS)	*Icelus sp.*		
WOLF EEL (NS)	*Lycenchelys sp.*		

Table A2: List of species in the Medium Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
BIGEYES (NS)	*Priacanthidae*		
BLENNIES (NS)	*Lumpenus sp.*		
DUCKBILL EEL	*Nessorhamphus ingolfianus*		
EELPOUT (NS)	*Lycodes sp.*		
EELPOUT,ARCTIC	*Lycodes reticulatus*		
EELPOUT,ESMARK'S	*Lycodes esmarki*		
EELPOUT,VAHL'S	*Lycodes vahlii*		
FISH DOCTOR (GREEN OCEAN)	*Gymnelis viridis*		
FLOUNDER,WINTER	*Pseudoplueronectes americanus*		
GRENADIER,LONGNOSE	*Coelorhynchus carminatus*		
GRENADIER,ROUNDNOSE	*Coryphaenoides rupestris*		Y
HAKE,BLUE	*Antimora rostrata*	Y	
HAKE,RED (SQUIRREL)	*Urophycis chuss*		
HALOSAURUS (NS)	*Halosauridae*		
LIPOGENYS	*Lipogenys gillii*		
LONGNOSE EEL	*Synaphobranchus kaupi*		
LUMPFISH,COMMON	*Cyclopterus lumpus*	Y	Y
MORA (NCN) HAL.AFF.	*Halargyreus affinis*		
MORA (NCN) HAL.JOH.	*Halargyreus johnsonii*		
MORAS	*Moridae*		
SCULPIN, RIBBED (HORNED)	*Myoxocephalus sp.*		
SCULPIN,FOURHORN	*Myoxocephalus quadricornis*		
SCULPIN,LONGHORN	*Myoxocephalus octodecemspinosus*	Y	
SCULPIN,SHORTHORN	*Myoxocephalus scorpius*		
SEA RAVEN	*Hemitripterus americanus*		
SHARK,DEEPSEA CAT	*Apristurus profundorum*		
SKATE,DEEPWATER (ROUND)	*Raja fyllae*		
SKATE,LITTLE	*Raja erinacea*		
SKATE,SOFT	*Raja mollis*		
SMOOTH SKATE	*Malacoraja senta*		Y
SNAKE BLENNY	*Lumpenus lumpretaeformis*		
SNIPE EEL (NCN)	*Serrivomer brevidentatus*		
SNIPE EEL,SHORTNOSE	*Serrivomer beani*		
SNUBNOSE EEL	*Simenchelys parasiticus*		
WHITING,BLUE	*Micromesistius poutassou*		
WITCH FLOUNDER	*Glyptocephalus cynoglossus*	Y	Y
YELLOWTAIL FLOUNDER	*Limanda ferruginea*	Y	

Table A3: List of species in the Large Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
AMERICAN PLAICE	*Hippoglossoides platessoides*	Y	Y
ANGLER,COMMON(MONKFISH)	*Lophius americanus*		
CHIMAERA,DEEPWATER	*Hydrolagus affinis*		
CHIMAERA,KNIFENOSE	*Rhinochimaera atlantica*		
CHIMAERA,LONGNOSE	*Harriotta raleighana*		
CHIMAERAS (NS)	*Chimaeriformes (holocephali) (order)*		
CUSK	*Brosme brosme*		Y
DEEPSEA ANGLER,BIG	*Ceratius holboelli*		
GRENADIER,ROUGHHEAD	*Macrourus berglax*	Y	
HADDOCK	*Melanogrammus aeglefinus*	Y	
HAGFISH, ATLANTIC	*Myxine glutinosa*		
POUT,OCEAN (COMMON)	*Macrozoarces americanus*		
SEA DEVILS (NS)	*Ceratiidae*		
SKATE,ABYSSAL	*Raja bathyphila*		
SKATE,ARCTIC	*Raja hyperborea*		
SKATE,BARNDOOR	*Raja laevis*		
SKATE,JENSEN'S	*Raja jenseni*		
SKATE,SPINYTAIL	*Raja (bathyraja) spinicauda*		
SKATE,THORNY	*Raja radiata*	Y	Y
SKATE,WHITE	*Raja lintea*		
SKATE,WINTER (SPOTTED)	*Leucoraja ocellata*		Y
SKATES (NS) RAJA SP.	*Raja sp.*		
SMOOTHHEADS (NS)	*Alepocephalidae*		
SNIPE EEL,ATLANTIC	*Nemichthys scolopaceus*		
SPINY EELS (NS)	*Notacanthidae*		
STURGEON,ATLANTIC	*Acipenser oxyrhynchus*		Y
TAPIRFISH,LARGE SCALE	*Notacanthus nasus*		
WOLFFISH,ATLANTIC (STRIPED)	*Anarchichas lupus*	Y	Y
WOLFFISH,NORTHERN (BROADHEAD)	*Anarhichas denticulatus*		Y
WOLFFISH,SPOTTED	*Anarhichas minor*		Y
WOLFFISHES (NS)	*Anarhichadidae*		
WRYMOUTH	*Cryptacanthodes maculatus*		

Table A4: List of species in the Piscivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
ANGLERS	*Lophiformes (pediculati) (order)*		
BARRACUDINAS (NS)	*Paralepididae*		
COD,ATLANTIC	*Gadus morhua*	Y	Y
COD,GREENLAND (ROCK)	*Gadus ogac*		
COD,POLAR	*Arctogadus glacialis*		
CODS,HAKES,ETC.	*Gadiformes (anacanthini) (order)*		
DAGGERTOOTH	*Anotopterus pharao*		
DOGFISH SHARKS (NS)	*Squalidae*		
DOGFISH,BLACK	*Centroscyllium fabricii*		
DOGFISH,SPINY	*Squalus acanthias*		
DRAGONFISH,BOA	*Stomias boa ferox*		
DRAGONFISHES,SCALED (NS)	*Stomiatidae*		
FROSTFISH	*Benthodesmus simonyi*		
GADOIDS (NS)	*Gadidae*		
GREENEYE,LONGNOSE	*Parasudis truculentus*		
GULPER (NCN) SAC.AMP.	*Saccopharynx ampullaceus*		
HAKE (NS) MER.SP.	*Merluccius sp.*		
HAKE,OFFSHORE SILVER	*Merluccius albidus*		
HAKE,SILVER	*Merluccius bilinearis*	Y	
HAKE,WHITE (COMMON)	*Urophycis tenuis*	Y	Y
HALIBUT (ATLANTIC)	*Hippoglossus hippoglossus*		
LAMPREY, SEA	*Petromyzon marinus*		
LANCETFISH, SHORTNOSED	*Alepisaurus brevirostis*		
LANCETFISH,LONGNOSE	*Alepisaurus ferox*		
LANCETFISHES (NS)	*Alepisauridae (plagyodontidae)*		
LING,BLUE	*Molva brykelange*		
MAKO,SHORTFIN	*Isurus oxyrinchus*		
POLLOCK	*Pollachius virens*		
PORBEAGLE	*Lamna nasus*		
SCABBARDFISH,BLACK	*Aphanopus carbo*		
SHARK,BASKING	*Cetorhinus maximus*		
SHARK,GREENLAND	*Somniosus microcephalus*	Y	
SHARK,PORTUGUESE	*Centroscymnus coelolepis*		
SHARKS,MACKEREL (NS)	*Lamnidae*		
TURBOT (GREENLAND HALIBUT)	*Reinhardtius hippoglossoides*	Y	
VIPERFISH	*Chauliodus sloani*		

Table A5: List of species in the Plank-Piscivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
BEARDFISHES (NS)	*Polymixiidae*		
COD,ARCTIC	*Boreogadus saida*		
GULPER,PELICAN	*Eurypharynx pelecanoides*		
HAKE,LONGFIN	*Urophycis chesteri*		
REDFISH, DEEP WATER	*Sebastes mentella*	Y	Y
REDFISH,ACADIAN	*Sebastes fasciatus*		Y
REDFISH,GOLDEN(MARINUS)	*Sebastes marinus*		
ROCKFISHES (NS)	*Scorpaenidae*		
SCOPELOSAURUS (NS)	*Scopelosauridae*		
SEASNAIL (NS) CAR.SP.	*Careproctus sp.*		

Table A6: List of species in the Planktivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
ALEWIFE (GASPERAUX)	*Alosa pseudoharengus*		
ARGENTINE,ATLANTIC	*Argentina silus*		
ARGENTINE,STRIATED	*Argentina striata*		
ARGENTINES (NS)	*Argentinidae*		
BILLFISH	*Scomberesox saurus*		
CAPELIN	*Mallotus villosus*	Y	Y
HERRING,ATLANTIC	*Clupea harengus*		
HERRING,BLACK	*Bathytroctes sp.*		
LANTERNFISHES (NS)	*Myctophidae*		
MACKEREL,ATLANTIC	*Scomber scombrus*		
MENHADEN, ATLANTIC	*Brevoortia tyrannus*		
RONDELETIIDAE	*Whalefishes, redmouth*		
SAND LANCE,OFFSHORE	*Ammodytes dubius*	Y	
SHAD, AMERICAN	*Alosa sapidissima*		
SHANNY,RADIATED	*Ulvaria subbifurcata*		
STICKLEBACK,FOURSPINE	*Apeltes quadracus*		
STICKLEBACK,THREESPINE	*Gasterosteus aculateus*		
STICKLEBACKS (NS)	*Gasterosteiformes (order)*		

Table A7: List of species in the Shrimp Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name	Dominant Species	At-risk Species
SHRIMP,NORTHERN	*Pandalus borealis*	Y	Y
SHRIMP,MONTAGUI	*Pandalus montagui*		

Table A8: List of species in the Forage Fish Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
SAND LANCE,OFFSHORE	*Ammodytes dubius*
COD,ARCTIC	*Boreogadus saida*
CAPELIN	*Mallotus villosus*

Appendix B

Table B1: Number and percentage of sets per depth class based on Engel (1981-1995) and Campelen (1995-2017) trawl data.

Depth Class (m)	# sets Engel	% sets Engel	# sets Campelen	% sets Campelen
0-100	3991	29.430%	6800	29.910%
101-200	3214	23.700%	4830	21.245%
201-300	2777	20.478%	3820	16.802%
301-400	1951	14.389%	2743	12.065%
401-500	1017	7.499%	2090	9.193%
501-600	221	1.630%	617	2.714%
601-700	223	1.644%	789	3.470%
701-800	62	0.457%	98	0.431%
801-900	76	0.560%	187	0.823%
901-1000	26	0.192%	105	0.462%
1001-1100	1	0.007%	131	0.576%
1101-1200	1	0.007%	170	0.748%
1201-1300	1	0.007%	86	0.378%
1301-1400	0	0.0%	204	0.897%
1401-1500	0	0.0%	65	0.286%
Total	**13561**		**22735**	

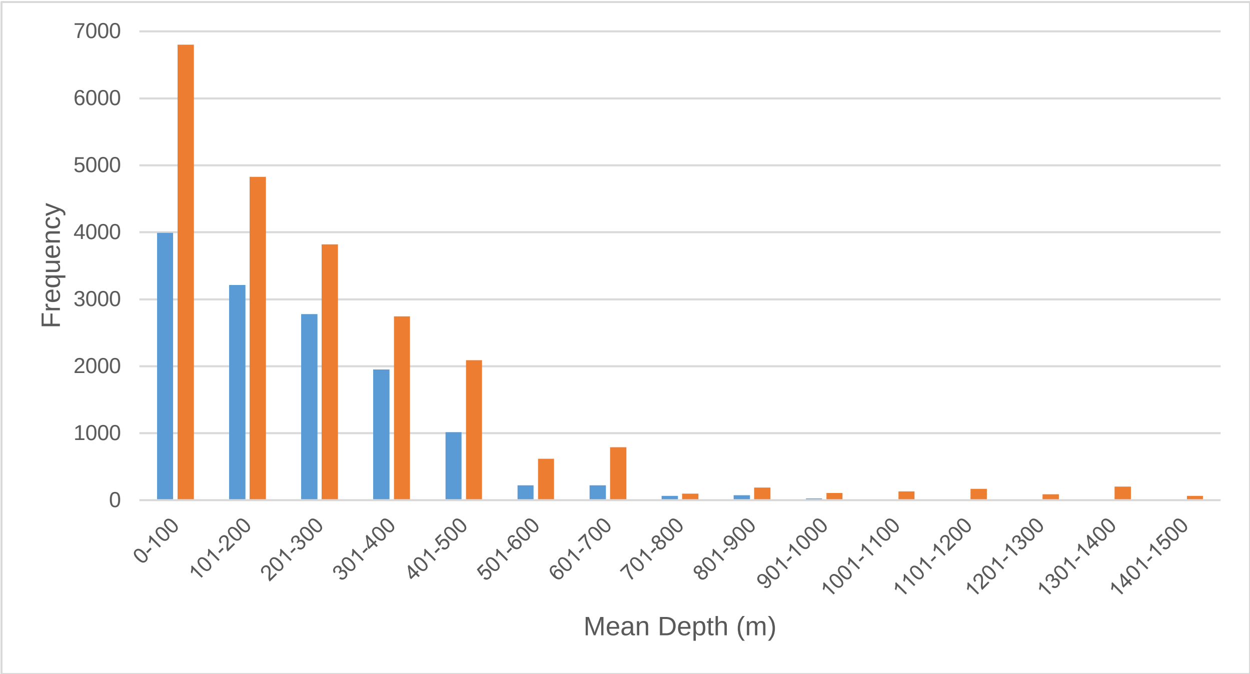


Figure B1: Frequency distribution of sets by mean depth class for Engel (blue) and Campelen (orange) data.