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Mapping Biodiversity on the Scotian Shelf and in the Bay of Fundy

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The purpose of this report is to provide Science advice on the Convention on Biological Diversity (CBD) criteria (vii); that is, to identify areas of high biological diversity for the identification of Ecologically or Biologically Significant Areas (EBSAs) in Canada's Scotian Shelf marine bioregion (i.e., Scotian Shelf and Bay of Fundy). Biological diversity (biodiversity) is defined by the CBD to mean "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

Here, three species based biodiversity indices were estimated from the Fisheries and Oceans Canada (DFO) Research Vessel (RV) survey data: species richness, the exponential of Shannon-Wiener Index (ESW) and Heip's Evenness Index. The main conclusions are that:

- Areas with high values of ESW and Heip's Evenness Index often occur in the same or similar locations.
- Areas of high species richness usually occur in different areas from high values of ESW and Heip's Evenness Index.
- The size and location of the hotspots for these biodiversity indicators change over time.
- There is no consistent relationship between any of these indicators and areas of high abundance of key species; there does appear to be a strong relationship between fish species richness and ecosystem functioning, as represented by fish biomass, and there is some evidence of a relationship between invertebrate diversity and ecosystem functioning, which needs to be further explored.
- The Bay of Fundy was consistently identified as an area with high biodiversity, across indices and across time.

For the current purposes of EBSA identification, and as a first step only, it is recommended that areas consistently high in biodiversity through time, regardless of time period or index used, should be considered essential ecosystem features that would provide integrity and resilience to the ecosystem in the face of disturbance and change and likely provide high functional value. This initial exploration of different measures of biodiversity on the Scotian Shelf and in the Bay of Fundy, however, underscores the need for greater research in this area. In addition, it is further recommended that for EBSA identification purposes, further research is required to explore the implications of functional diversity, both within trophic guilds or trophic levels, and across them.

Cartographier la biodiversité pour le plateau néo-écossais et la baie de Fundy

RÉSUMÉ

L'objectif du présent rapport est de fournir des avis scientifiques sur les critères vii) de la Convention sur la diversité biologique (CDB); c'est-à-dire de cerner les zones présentant une diversité biologique élevée pour déterminer les zones d'importance écologique et biologique (ZIEB) dans la biorégion marine du plateau néo-écossais du Canada (c.-à-d. le plateau néo-écossais et la baie de Fundy). La diversité biologique (biodiversité) est définie dans la CDB comme étant la « variabilité des organismes vivants de toute origine y compris, entre autres, les écosystèmes terrestres, marins et autres écosystèmes aquatiques ainsi que les complexes écologiques dont ils font partie; cela comprend la diversité au sein des espèces et entre espèces ainsi que celle des écosystèmes ».

Dans le présent rapport, trois indices de biodiversité des espèces ont été estimés à partir du relevé par navire de recherche (NR) de Pêches et Océans Canada (MPO) : la richesse en espèces, l'indice de diversité de Shannon-Wiener et l'indice d'équitabilité de Heip. Les principales conclusions sont les suivantes :

- Les zones pour lesquelles l'indice de diversité de Shannon-Wiener et l'indice d'équitabilité de Heip sont élevés se trouvent souvent dans des endroits semblables ou similaires.
- Les zones ayant une richesse d'espèces élevée se trouvent habituellement dans différentes zones que celles où l'indice de diversité de Shannon-Wiener et l'indice d'équitabilité de Heip sont élevés.
- La taille et l'emplacement des zones sensibles pour ces indicateurs de biodiversité changent au fil du temps.
- Il n'y a aucune cohérence dans le lien entre l'un ou l'autre de ces indicateurs et les zones de forte abondance en espèces clés.
- Il semble y avoir une forte relation entre la richesse en espèces de poissons et le fonctionnement de l'écosystème; il est représenté par la biomasse du poisson, et il existe un lien entre la diversité des invertébrés et le fonctionnement de l'écosystème, qui devra être examiné plus en profondeur.
- La baie de Fundy a constamment été désignée comme une zone comportant une grande biodiversité, et ce, pour l'ensemble des indices et au fil du temps.

Pour les fins actuelles de désignation des ZIEB, et en tant que première étape seulement, il est recommandé que les zones présentant constamment une forte biodiversité au fil du temps, peu importe la période ou l'indice utilisé, soient considérées comme étant des caractéristiques essentielles à l'intégrité et à la résilience de l'écosystème face au changement et aux perturbations et elles offriront vraisemblablement une grande valeur fonctionnelle. L'exploration préliminaire des différentes mesures de la biodiversité du plateau néo-écossais et de la baie de Fundy fait toutefois état du besoin d'effectuer plus de recherches dans cette zone. En outre, il est de plus recommandé aux fins de désignation des ZIEB d'effectuer plus de recherches afin d'explorer les répercussions sur la diversité fonctionnelle, à la fois pour les guildes trophiques ou les niveaux trophiques et entre ces derniers.

INTRODUCTION

The Government of Canada has committed to creating a network of Marine Protected Areas (MPAs); the *Oceans Act* assigns responsibility to the Minister of Fisheries and Oceans Canada (DFO) to lead and coordinate development and implementation of a national system (or network) of MPAs on behalf of the Government of Canada, within the context of integrated management of estuarine, coastal and marine environments (Government of Canada 2011). Further, Canada has committed to the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) global target of "at least... 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services...conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures…integrated into the wider landscape and seascape" by 2020 (Government of Canada 2011; see also CBD's Aichi Biodiversity Targets).

In the design of the global network of MPAs, the COP to the CBD recommended that designated protected areas include ecologically and biologically significant areas (EBSAs), which provide important services to other populations, species or to the ecosystem as a whole (CBD 2008). As defined by the CBD, EBSAs are areas with:

i) Unique or rare species;
ii) Special importance for different life-history stages;
iii) Threatened, vulnerable or declining species;
iv) Vulnerable, fragile, sensitive or slow to recover species;
v) High biological productivity;
vi) Naturalness; and
vii) High biological diversity (CBD 2008).

Fisheries and Oceans Canada defined EBSA criteria in 2004 (DFO 2004), prior to the availability of CBD criteria. The two sets of criteria, however, are comparable to each other (see: Table 1 in King et al. 2016). That said, the DFO criterion "aggregation" subsumes four of the CBD criteria, including "biological diversity". In the DFO Maritimes Region, development of a MPA network plan for the Scotian Shelf marine bioregion (i.e., Scotian Shelf and Bay of Fundy) has been led by the DFO Oceans and Coastal Management Division (OCMD) (Figure 1). The OCMD has used DFO EBSA criteria as the primary basis for identifying EBSAs, but has also considered the CBD criteria, since the EBSAs may also be used by other government departments that draw upon the more specific CBD criteria (e.g., Parks Canada and Environment Canada).

The purpose of this report is to provide science advice on CBD criteria (vii); that is, to identify areas of high biological diversity for the identification of EBSAs on the Scotian Shelf and in the Bay of Fundy. Biological diversity (biodiversity) is defined by the CBD to mean "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems[1]".

There has already been a significant body of work conducted by DFO scientists on the attributes of biodiversity in the Scotian Shelf marine bioregion (Table 1). These investigations have been largely based on the fisheries independent DFO Research Vessel (RV) survey data, which provides in part information on the spatial-temporal patterns of marine species on the Scotian Shelf and in the Bay of Fundy. Although obtaining a precise estimate of diversity in a large

[1] For more information, visit CBD's Article 2. Use of Terms page. (Accessed on 09 September 2015).

marine ecosystem such as the Scotian Shelf marine bioregion is a challenge (Shackell and Frank 2003), many patterns of diversity have been brought to light. For example, spatial biodiversity patterns, as described by number of species per tow, have been used in combination with an array of other criteria to analyse a network of MPAs for the bioregion (Horsman et al. 2011). Fisher et al. (2011) examined the potential influence of scope for growth (energy available for growth and reproduction) and natural disturbance (local characteristic of seafloor) on species distribution, community composition and diversity on the Scotian Shelf and in the Bay of Fundy, as measured by species richness and evenness. As well, distribution patterns of the biomass of key species have been used to identify important areas for key species on the Scotian Shelf and in the Bay of Fundy (Horsman and Shackell 2009). Cook and Bundy (2012) used the stomach contents of the fish caught in the DFO RV survey to improve descriptions of species richness. Additionally, spatial distributions of ichthyoplankton and larval fish have been described on the Scotian Shelf (O'Boyle et al. 1984; Shackell and Frank 2000). All of these studies demonstrate the complexity of patterns in habitat preference between species, with some showing that preferred areas change through time. Despite these dynamic patterns, a few areas have come up time and again as being important: Bay of Fundy; the Gully; the slopes; Western Bank; and the Northeastern Shelf (Shackell and Frank 2003; Horsman et al. 2011; Cook and Bundy 2012).

Recently, some concerns have been raised regarding the simplicity of classic biodiversity indices and whether they capture the complexities of ecosystems and their structure and functioning (Kenchington and Kenchington 2013). Some of these concerns will be explored in this report, with respect to the use of indicators of biodiversity for mapping purposes and to provide science advice for the identification of EBSAs. Notably, the three indicators recommended by Kenchington and Kenchington (2013) have been selected as being useful for communicating science advice for monitoring and mapping biodiversity on the Scotian Shelf and in the Bay of Fundy: species richness; the exponential of the Shannon-Weiner Index (ESW); and Heip's Evenness Index. The ESW is an ecological diversity metric that uses each species relative abundance to provide a value of the effective numbers of species in a community (Jost 2006). Heip's Evenness Index, estimated using both ESW and species richness, describes how evenly the abundance of species in a community are distributed (Heip 1974). Kenchington and Kenchington (2013) recommend "retention of ecological diversity *sensu stricto,* but also that, whenever possible, it be accompanied by measures of species richness and evenness" (Kenchington and Kenchington 2013:10). The data needed to estimate these biodiversity indicators, including relative abundance of each species, are readily available and some, such as species richness and evenness, have been linked to ecosystem function, efficiency, integrity and resilience in ocean ecosystems (Danovaro et al. 2008). Given the primary goal of a network of MPAs in the Scotian Shelf marine bioregion is to protect and restore biodiversity, it seems appropriate to explore the utility of these indices.

This report is a preliminary study of these three biodiversity indices and their possible relationship to ecosystem functioning and their utility for oceans management on the Scotian Shelf and in the Bay of Fundy. Specifically, using fisheries independent trawl survey data.We:

i) Map the three biodiversity indices for fish and invertebrates, creating additional biodiversity layers;
ii) Summarize the spatial distribution patterns of these new layers, compare hotspots identified for the biodiversity indices to high abundance areas for key species, high biomass areas and other biodiversity indicators; and
iii) Provide some initial recommendations for the use of biodiversity indices with respect to the identification of EBSAs.

METHODS

DATA

Fisheries and Oceans Canada has conducted standardised, fishery independent bottom trawl research surveys on the Scotian Shelf and in the Bay of Fundy each summer since 1970. The survey has a stratified random design, with 48 strata (strata 470-495) defined by depth range and geographic locations (for further details see Doubleday 1981; Simon and Comeau 1994), and are in the North Atlantic Fishery Organisation (NAFO) Divisions 4Vn, 4Vs, 4W and 4X (Figure 2). The RV and trawl gear changed in 1983 from the *AT Cameron* vessel fishing with a Yankee 36 trawl to the *Alfred Needler* fishing with a Western IIA trawl. Catch rates for a limited number of species were adjusted to account for these changes based on the conversion factors estimated by Fanning (1985). The net is towed for approximately 30 minutes, from touchdown on the bottom to lift off. All catch rates were standardised to a tow distance of 1.75 nautical miles. For invertebrates, abundance and biomass have been collected and recorded since 1999 (Tremblay et al. 2007); however, they have only been identified in a reliable manner since 2007 (D. Clark, DFO, pers. comm.). For finfish, the sampling protocols were more rigorous throughout the survey's duration, and within each set the total number and weight of all finfish species were measured, as well as the individual length and weights of a sample of each species (up to approximately 300 individuals). Therefore, in this analysis, 7 years of invertebrate data (2007-2013) and 44 years of fish data were used (1970-2013).

Prior to analysis, the data were examined to remove records with insufficient taxonomic resolution, rare occurrences (which may be misidentified, or due to entry-error), or both. Therefore, where possible, only survey data resolved to the species level were used, and data for higher taxonomic levels excluded. In cases with no species records, but with a higher taxonomic record (e.g., genus or family), these were retained, only if there were one or no species records. Data were then extracted from this dataset where species were observed in more than five survey sets or were recorded in two or more years. This dataset was then separated into invertebrates and fish. For invertebrates, records collected before 2007 were discarded. For fish, the data were split into the four fishing eras defined by Horsman and Shackell (2009): that is, 1970-1977 (era 1; when foreign fleets fished Canadian waters), 1978–1985 (era 2; domestic stock recovery following 200 mile Exclusive Economic Zone implementation and prior to domestic fishery being fully developed), 1986-1993 (era 3; fully established domestic fleets with cold eastern Scotian Shelf waters, fish stocks decline in growth and some collapse) and 1994-2013 (era 4; several groundfish species collapse and show signs of non-recovery), as well as the complete fish dataset ("complete"), (Table 2). Note that era 4 was extended to 2013, since Horsman and Shackell's (2009) descriptors of era 4 still basically apply. In total, 116 fish and 100 invertebrate species were used in the following analysis. See Appendix A (Tables A1 and A2) for additional details in species selection and for a complete list of species included.

In addition to the analysis of DFO RV survey data described above, a preliminary investigation of the species biodiversity patterns in surveyed strata from deeper waters along the Shelf edge (Edge sets and Deep sets) was also conducted. The Edge strata, 496-498 (Figure 2), have been sampled since 1995, with another five exploratory Deep strata (501-505) being sampled since 2010 (Clark and Emberly 2011). In contrast to the Shelf sets, in the Deep sets the net was towed for 20 to 60 minutes, from touchdown on the bottom to lift off. All catch rates were standardised to a tow distance of 1.75 nautical miles. For this analysis, species were selected using the method described above. See Appendix A (Tables A3 and A4) for a list of included species.

BIODIVERSITY INDICES

The following three biodiversity indices suggested by Kenchington and Kenchington (2013) were used for this analysis:

(i) Species richness, S, the count of species present;

(ii) The exponential of the Shannon-Wiener Index, H', which measures species richness and evenness,

$$ESW = eH'$$

$$\text{where, } H' = -\sum p_i ln\, p_i$$

and p_i is the relative abundance of species i; and

(iii) Heip's Evenness Index, E', which is a value from 0-1 that is calculated using S and H',

$$E' = \frac{e^{H'} - 1}{S - 1}$$

Essentially, species richness is a simple count of the number of species per set in terms of presence or absence. Heip's Evenness Index measures how equally those species contribute to the total abundance, and ESW is a combination of both richness and evenness; that is, a measure of ecological diversity, *sensu stricto* (Kenchington and Kenchington 2013). For the Shelf strata and the Edge strata, the three biodiversity indices were calculated in R (version 3.0.2), using the vegan package for the Shannon-Wiener Index (Okansen et al. 2013), for each set in each year of the four fishing eras and for the whole time period for fish, and from 2007-2013 for invertebrates. For the Deep strata, only species richness was calculated, since there are too little data to usefully examine relative abundance, which is required for the other two indices. See Tables 3 and 4 for a summary of each data set.

MAPPING PROCEDURE

Biodiversity

A similar mapping procedure was followed to that described in Horsman and Shackell (2009), which used inverse distance weighting (IDW) interpolation. This method of interpolation provides an exact interpolation using a weighted distance average that is constrained by the maximum and minimum values set by the data. The interpolation was performed in ArcGIS® (version 10.1) Spatial Analyst. To create the interpolated surface, the IDW settings used by Horsman and Shackell (2009) were used with a cell size of 0.026177, a power of 0.5 (specified by OCMD for consistency between other data layers), and a fixed search with radius of 0.15 degrees (approximately 14-15 km for the study area) that constrains the interpolation to the areas with data.

To visualize and gain information on the geographical patterns in each biodiversity index, data were grouped into five equal-area classes (quantiles) following Horsman and Shackell (2009); except that the Slice tool in Spatial Analyst (ArcGIS® version 10.1) was used rather than the Reclassify tool, since it provided more evenly distributed results across the classified percentiles for these data (i.e., in the five classes of the classification).

To explore areas of high or low diversity for more than one indicator, the classified raster layers (from above) were combined, by adding multiple layers, using Raster Calculator in Spatial Analyst (ArcGIS® version 10.1; see schematic in Figure 3). Species richness was combined with ESW and with Heip's Evenness Index, and ESW with Heip's Evenness Index, and all three combined. The complete time period was used for fish, and 2007-2013 for invertebrates. In this way, cells that have high values for all the individual layers will be ranked high when the layers are combined.

Next, the spatial distribution of the highest values (i.e., by classes) was explored for each invertebrate and fish biodiversity index in each time period, and from multiple biodiversity indices over time and/or indices. High values were extracted using the Raster Calculator tool (Spatial Analyst, ArcGIS® version 10.1). For each of the biodiversity indices in each time period, the top class was extracted and represents 20% by area. For the analyses of multiple indices and/or time periods, the following data layers were combined:

- i) Each of the three fish biodiversity indices across the four fishing eras;
- ii) The three biodiversity indices within each fishing era;
- iii) All biodiversity indices across all years for fish and invertebrates separately; and
- iv) All biodiversity indices for fish and invertebrates combined, for the most recent time period (i.e., era 4 for fish and for all invertebrates).

In each case, the classified raster layers from above were combined, and then the top classes extracted (one class per combined layer; i.e., when three layers were combined the top three classes were extracted). This information identifies the areas that are consistently high across all biodiversity indices or fishing eras regardless of area covered.

Last, the Edge strata and Deep strata were treated separately from the Shelf strata since there were data limitations (i.e., sparse data collected along a line over a more limited time period) that precluded the possibility of a meaningful interpolation. Therefore, the relative values of the biodiversity indices were simply mapped using a colour-ramp to display sets of high and low biodiversity: species richness, ESW and Heip's Evenness Index for the Edge sets, and only species richness for the Deep sets.

Comparison of biodiversity indices with ecosystem functioning

Several studies have linked biodiversity to ecosystem functioning (e.g., Duffy et el. 2007; Danovaro et al. 2008; Fisher et al. 2010). One of many potential indicators of ecosystem functioning is production. The distribution patterns used were:

- i) The abundance of key species as described in Horsman and Shackell (2009); and
- ii) Total biomass[2] of invertebrates and fish, as proxies for production and compared these to each biodiversity index.

Key species abundance data for 5 invertebrate (2007-2013) and 22 fish species (1970-2012, Table 5) were extracted from the Shelf analysis (described above). Abundance and total biomass data were interpolated using IDW and classified following the same methods as described above for the Shelf analysis (i.e., in five classes; except that the Reclassify tool was used for the abundance data rather than Slice because the data were highly skewed). The classified layers were then combined with each classified biodiversity index layer, and the top two classes were extracted to identify the area of overlap between high abundance or biomass and high biodiversity. For visualization, the classified abundance and biomass data are shown with the top 20% by area of each biodiversity index.

Comparison with other biodiversity indices

The fish and invertebrate biodiversity indices were also compared to the species richness of small fish and small invertebrates derived from fish food habits data (Cook and Bundy 2012), to

[2] Fish biomass data were obtained from the DFO Oceans and Coastal Management Division (A. Serdynska, unpublished data) and represent slightly different data than the Shelf analysis due to differences in the years included (1970-2012) and species selection process. These differences, however, are minor.

evaluate how the understanding of diversity changes with the data source used. In this analysis, areas of high and low small fish and small invertebrates species richness were overlaid with the top 20% by area of species richness, ESW and Heip's Evenness Index.

RESULTS

MAP INTERPRETATION

In the multi-coloured maps (Figures 4-8), red represents the area with the highest biodiversity values and blue shows the lowest. In the red-coloured maps (Figures 9-11), only the areas with the top classes are shown, where the number of classes is equal to the number of layers combined. In the Deep strata maps (Figures 12-13), point colours represent relative biodiversity, where red is high and blue is low. In the key species and biomass maps (i.e., Figures 14-41) the highest abundance of each key species and total biomass is shown in black (Table 6 shows the area of overlap between high diversity and high abundance of the key species and biomass). In the Food Habits maps (i.e., Figure 42), from Cook and Bundy (2012), black shows areas with higher species richness than expected. In the key species, biomass and Food Habits maps (Figures 14-42), pink areas show the top 20% by area of each biodiversity index.

BIODIVERSITY INDICES

Invertebrates

There were clear patterns on the Scotian Shelf and in the Bay of Fundy in invertebrate species biodiversity for the period of 2007-2013. The areas with highest species richness were generally found in the Bay of Fundy and the mid-Scotian Shelf (NAFO Division 4W, Figure 4a), whereas most areas with high values of ESW and Heip's Evenness Index were located on the eastern Scotian Shelf, with a few high spots on the western Scotian Shelf and, in the case of ESW, in the Bay of Fundy (Figures 4b, c).

The combined plots of species richness with ESW (Figure 4d) and species richness with Heip's Evenness Index (Figure 4e) showed similar patterns with each other, although there was a greater area of overlap between species richness and ESW than species richness and Heip's Evenness Index. The top two classes for these combined indices covered 9.9% and 2.2% of the total area of the Scotian Shelf, respectively (Layers: InRiEsw and InHpRi in Appendix B). High values of these combined indicators were located in the Bay of Fundy, along the shelf edge of the Laurentian Channel, at the head of the Gully and on Western Bank, around The Cow Pen, the 4WX Division line off Halifax (and to the east) and Browns Bank in 4X. The combined plot of ESW and Heip's Evenness Index (Figure 4f), on the other hand, illustrates the similarities between these two indices. The top two classes of these indices combined covered 22.4% of the study area (Layer: InEswHp in Appendix B). As described above, areas of high diversity were mostly located on banks of the eastern Scotian Shelf.

In Figure 4g, the three indices were combined to represent overall invertebrate biodiversity. Interestingly, the overall pattern is very similar to the plot of species richness and ESW, although there are fewer high diversity areas in the Bay of Fundy. The top three classes covered 7.5% of the study area (Layer: InRiEswHp in Appendix B). Note that although species richness was quite high, in the the mid-Scotian Shelf areas (on either side of the 4WX NAFO Division line), overall invertebrate diversity, as measured by the RV survey, was very low.

Fish

In the early-1970s (era 1), areas of highest species richness (Figure 5a) occurred in the Bay of Fundy, off southwest Nova Scotia and across many other areas of the Scotian Shelf; although, other than along the edge of the Laurentian Channel, species richness was mainly low on the eastern Scotian Shelf (NAFO Division 4V). However, with successive fishing eras, contiguous areas with both low and high species richness shifted location and increased in size (Figures 5c-d). By the 2000s, highest species richness had moved northwest, from being spread across the Scotian Shelf, to a greater concentration in the Bay of Fundy and northwards to more coastal waters of mixed depths. When combined across all years (Figure 5e), species richness was similar to era 4: it was highest in the Bay of Fundy, and in waters of mixed depths, 50-100 m along the inner Scotian Shelf and in the middle of 4VsW centred on The Cow Pen, at the head of the Gully, and along the Shelf edge at 4Vn.

For the ESW, high areas were generally found throughout the Scotian Shelf for all fishing eras (Figure 6), although it was low in the NAFO Division 4Vn in eras 1 and 2, prior to the mid-1980s, then increased in eras 3 and 4. Conversely, much of the Bay of Fundy had high ESW in eras 1 and 2, but this was much reduced in eras 3 and 4. As with species richness, there was some enlargement of contiguous high and low areas with successive fishing eras. When combined across all years (Figure 6e), highest values of ESW were located on the eastern Scotian Shelf and throughout the Bay of Fundy. Notably, there were areas of high diversity along the southern Shelf edge, although diversity was low along the edge of the Laurentian Channel. Over successive eras, an area of low ESW appeared in the general area, and to the west of LaHave Basin, the 4VW NAFO Division line.

High values of Heip's Evenness Index were located throughout the Bay of Fundy and across the Scotian Shelf in fishing era 1 and 2 (Figures 7a, b) , but not along the edge of the Laurentian Channel. However, by fishing eras 3 and 4 (Figures 7c, d), high values of Heip's Evenness Index shifted to the east, and by era 4, most high values were located to the north and east of NAFO Division 4VW. Also, as for ESW, an area of low values of Heip's Evenness Index appeared in the general area of LaHave Basin to the west of the 4WX NAFO division line. In all eras, Heip's Evenness Index was low across the Shelf edge along the Laurentian Channel. When the data were combined across years (Figure 7e), evenness was low in the Bay of Fundy and generally high on the eastern Scotian Shelf. There are broad similarities between the results for ESW and Heip's Evenness Index.

When all three of the biodiversity indices were combined using data for the whole time period (Figure 8a), small areas of high diversity were scattered throughout the Bay of Fundy and its approaches, including the deeper waters of the Northeast Channel, pockets of high diversity along the shelf edge and along the inner limits of the survey area, approximately 12 miles offshore, and some larger areas mainly located in the northern parts of 4VW (See Appendix C for a magnification of this area). Notably, there is a consistent area of high diversity where the NAFO Divisions 4Vn, 4Vs and 4W intersect off of southern Cape Breton: three fingers of high diversity radiate to the east and south from Chedabucto Bay, tracing the deeper waters between the banks. This was also observed for the other combinations of biodiversity indicators in Figures 8b-d. In addition, one of the only areas of high fish diversity in 4Vn is off Mira Bay, which is consistent across all combinations of biodiversity indices. When combined, the top three classes covered 12.3% of the study area (Layer: FiEswHpRi in Appendix B).

Similar to the results for the invertebrates, ESW with Heip's Evenness Index (Figure 8b) were most similar to each other, and the top two classes combined covered 20.2% of the study area (Layer: FiEswHpp in Appendix B). As noted for the invertebrates, there are broad similarities between the combined plots of species richness with Heip's Evenness Index and species richness with ESW (Figures 8c, d), top two classes covering 13.9% and 3.5%, respectively (Layers: FiESWRi and FiRiHp in Appendix B). The main differences were in the Bay of Fundy and 4VW. As noted for the individual indicators of fish diversity, there was a large area of low fish diversity in NAFO Division 4X centred on LaHave Basin, but extending well beyond it. Other low fish diversity areas included the upper reaches of the Bay of Fundy, Shelf edge along the

Laurentian Channel and in 4Vs. Generally speaking, the large basins of the Scotian shelf were low in fish diversity.

Changes in biodiversity indices through time

The top 20% area from each fishing era are plotted together in Figures 9a-c, for species richness, ESW and Heip's Evenness Index. The areas with consistently high values of each index in each time period are shown in Figures 9d-f. There are four clear messages from these plots:

i) There are some key areas of high fish diversity through time;
ii) The exact location of these areas varies over time;
iii) Not all areas of high diversity persist through time; and
iv) The pattern of consistent species richness on the Scotian Shelf and in the Bay of Fundy is generally different from the pattern of either ESW or Heip's Evenness Index, which show some broad similarities.

The most prominent area exhibiting consistently high values of species richness was the Bay of Fundy. Other areas were Scotian Shelf mid-depth strata to the south of the 12 mile line in 4WX, in the area of The Cow Pen, at the head of the Gully and off northern Cape Breton in 4Vn (Figure 9d). These areas covered 14.6% of the study area (Layer: FiRiSumYr17+ in Appendix B).

The ESW was consistently high across all four fishing eras in only isolated areas of the Bay of Fundy, the Scotian Shelf slope edge to the south, the southern parts of Western and Sable Banks, the head and mouth of the Gully, in the mid-depth waters to the northwest of Western Bank, in the mixed depth waters of the Misaine Bank (Figure 2) (strata 444, Figure 2) and off the top of northern Cape Breton in 4Vn (Figure 9e). Only 8.4% of the study area had high (top four classes) ESW in all four fishing eras (Layer: FiEswSumYr17+ in Appendix B).

High values of Heip's Evenness Index occurred on the Scotian Shelf and in the Bay of Fundy in all time periods (Figure 9c), but only 11% of the study area was consistently high in all four fishing areas (Layer: FiHpSumYr17+ in Appendix B; Figure 9f). Almost all of these areas were on the eastern Scotian Shelf, located along the Shelf edge and mainly in NAFO Division 4V, in some of the same locations as ESW.

Comparison across biodiversity indices

The areas of overlap of the three biodiversity indicators in each fishing era are plotted in Figures 10a-d. Areas of overlap of the three indicators were highest in the first two eras (16.5% and 16.9%, respectively; Layers: FiE1Met13+ and FiE2Met13+, Appendix B), with concentrations in the Bay of Fundy and off southwestern Nova Scotia, prior to the collapse of Atlantic Cod (*Gadus morhua)* and severe reductions of other groundfish stocks. Since the mid-1980s, co-occurrence of the three indicators has shifted more to the east, primarily on Misaine Bank (Figures 2, 10c), with reduced occurrence in the Bay of Fundy or western Scotian Shelf, with area of overlap decreasing slightly to 12.6% and 13.9%, respectively (Layers: FiE3Met13+ and FiE4Met13+ in Appendix B). In the most recent time period, most of the areas of high fish diversity are located in the Bay of Fundy, NAFO Division 4V and along the Shelf edge, with a few in NAFO Division 4W.

When the three biodiversity indicators were compared for the invertebrates, high values across all three indicators covered only 7.5% of the study area (Figure 11a; Layer InRiEswHp13+ in Appendix B). There were concentrated areas in the deep water approaches to the Bay of Fundy, on Western Bank, to the north of the Gully, around The Cow Pen, as well as along the edge of the Laurentian Channel and off the coast of northern Cape Breton in 4Vn.

For fish, across all years (1970-2013), co-location of the three biodiversity indices occurred in 12.3% of cells (Figure 11b, Layer: FiHpRiEsw13+ in Appendix B), mainly in the Bay of Fundy, the deeper southwestern waters of 4X, the Northeast Channel, across Misaine Bank (Figure 2), the head of the Gully, along the Shelf edge and off northern Cape Breton in 4Vn.

Finally, when the three biodiversity indices were combined for fish and invertebrates together for the most recent time period (i.e., era 4 for fish, 2007-2013 for invertebrates; Figure 11c), concentrated areas of high biodiversity, for all investigated species in the summer DFO RV survey, were found in the approaches to and middle areas of the Bay of Fundy, the Northeast Channel, Western Bank, the head of the Gully, along the shelf edge and off northern Cape Breton in 4Vn.

Deeper strata

There are much less data for the deeper strata (i.e., Deep strata and Edge strata) along the shelf edge than on the Scotian Shelf itself. Table 4 provides a summary of the Edge strata and Deep strata data, Figure 12 shows the relative point values of the three biodiversity indices for invertebrates and fish for the Edge strata, and Figure 13 the results for species richness for the Deep strata. Initial analysis of these data indicates that invertebrate species richness may be lower in these deeper strata compared to on the Scotian Shelf. On the Scotian Shelf, there was an average of 9.2 invertebrate species per set (Table 3), whereas in the deeper strata the average was 6.7 and 6.4 species per set for the Edge strata and Deep strata, respectively (Table 4). However, fish diversity was higher in the deeper strata than on the Scotian Shelf; 12.5-24.2 mean species richness in the Edge and Deep strata, respectively (Table 4), compared to 9.5 on the Scotian Shelf (Table 3).

For invertebrates, there were no clear along-shelf patterns in biodiversity for any of the three indices. For fish, although there were no obvious patterns in species richness along the shelf edge, ESW and Heip's Evenness Index were both higher on the western shelf edge compared to the eastern shelf edge. Although there is a very limited number of data points from the deeper 500-series sets (Figure 13), for which only species richness was calculated, the highest species richness values for both invertebrates and fish were all in the sets to the west.

COMPARISON WITH ECOSYSTEM FUNCTIONING

Comparing biodiversity indices with high abundance of key species

Figures 14-40 show the top 20% by area class for:

i) Species richness;
ii) ESW; and
iii) Heip's Evenness Index, plotted together with the abundance map for 5 invertebrate species (2007-2013) and 22 fish species (1970-2013) (Table 6, Appendix D).

Overall, there was a mixture of patterns between areas of high abundance and the three metrics of biodiversity.

For invertebrates, high abundance of key commercial invertebrate species, including *Cucumaria frondosa* (Sea Cucumber; Figure 14), *Chionoecetes opilio* (Snow Crab; Figure 15), *Pandalus borealis* (Shrimp; Figure 16) and *Strongylocentrotus droebachiensis* (Sea Urchin; Figure 17), were mainly located on the eastern Scotian Shelf, in different areas from the top 20% quantile of invertebrate species richness, but often adjacent or overlapping areas of high ESW and Heip's Evenness Index. For *Illex illecebrosus* (Short-fin Squid; Figure 18), which had high abundance along the middle of the Shelf and along the Shelf edge, there was little overlap with high invertebrate species richness, ESW or Heip's Evenness Index.

Atlantic Cod were distributed across the Scotian Shelf, with concentrated areas of high abundance on the eastern Shelf in 4Vn, 4Vs, and in eastern 4W on Middle, Western and Sable banks over the period from 1970-2013 (Figure 19). There were also some areas of mid-level abundance in the Bay of Fundy, where there was some association with high fish species richness, and to ESW and Heip's Evenness Index. The areas of highest Cod abundance on the eastern Scotian Shelf were mostly located adjacent to areas of high ESW and Heip's Evenness Index (along the Northeastern Shelf and Misaine Bank), although there was little correspondence with the top 20% quantile for species richness outside of the Bay of Fundy. Overall, the spatial overlap of the top classes of Cod abundance was highest with Heip's Evenness Index (9.5%, and lowest with species richness (5.5%), Table 6).

High Haddock (*Melanogrammus aeglefinus*) abundance was spread across the banks of the Scotian Shelf in 4WX (Figure 20), and there was some overlap between high Haddock abundance and the top 20% quantile for species richness in the outer reaches and middle of the Bay of Fundy, with an overall spatial overlap of 10% (Table 6). Areas of high Haddock abundance overlapped with high values of ESW in 4W and to some extent in the Bay of Fundy, with an overall spatial overlap of 10% (Table 6), whereas they overlapped with high values of Heip's Evenness Index along the shelf edge in 4W, with an overall spatial overlap of 6.5% (Table 6).

High abundances of White Hake (*Urophycis tenuis)* was mainly in the Bay of Fundy (Figure 21), although high abundance of both White Hake and Redfish (*Sebastes* spp) were generally located in the deeper waters along the Shelf edges, especially the Northeastern Shelf edge, the Gully, and also in mid-depth waters along the inshore western Shelf (Figures 21-22). There was a fair degree of overlap between species richness and high White Hake abundance in these areas (overall spatial overlap of 18.8% (Table 6), and along the inshore of along the western Shelf for Redfish. There was little overlap between these species and ESW or Heip's Evenness Index.

Red Hake (*Urophycis chuss, S*ilver Hake (*Merluccius bilinearis)* and Atlantic Mackerel (*Scomber scombrus)* abundance was highest in some isolated areas in the Bay of Fundy, as well as on the western Shelf (Figures 23-25). For all three species, the Bay of Fundy concentrations coincided with high species richness, whereas only the most inshore concentrations of Silver Hake and Red Hake coincided with high species richness on the Scotian Shelf. For all three species, there was little overlap with ESW or Heip's Evenness Index on the eastern Scotian Shelf. For Red Hake, there were some high abundance areas along the Scotian Shelf edge, which corresponded with areas of high Heip's Evenness Index (Figure 23). Overall, there was greatest overlap between high abundance of Red Hake and species richness (12.3%, Table 6).

Pollock (*Pollachius virens)* abundance was mainly distributed in NAFO Divisions 4WX of the Scotian Shelf, with high abundances concentrated in the deeper waters in the approaches to the Bay of Fundy, around the Lahave Basin area and along the Shelf edge (Figure 26). There was some overlap with high species richness in the Bay of Fundy and along the inshore middle Shelf. There was little overlap with areas of high ESW, with exceptions in the Gully and the mouth of the Bay of Fundy. Areas with high Heip's Evenness Index were largely adjacent to areas with high Pollock abundance. Overall, there was greatest overlap between high abundance and species richness and ESW (8.8%, 6.6%, Table 6).

Spiny Dogfish (*Squalus acanthias)* abundance was highest in the deeper waters in the approaches to the Bay of Fundy and off southwest Nova Scotia, and a few areas of the Bay of Fundy (Figure 27). High Spiny Dogfish abundance in the Bay of Fundy and southwestern areas of the Scotian Shelf often coincided with areas of high species richness and were adjacent to areas of high ESW, but were not close to areas of high Heip's Evenness Index. Overall, there was greatest overlap between high abundance and species richness (7.7%, Table 6).

High abundance of Longhorn Sculpin (*Myoxocephalus octodecemspinosus)* in the Bay of Fundy co-occurred with high species richness, whereas their eastern populations on Western Bank overlapped with areas of high Heip's Evenness Index (Figure 28). There was little overlap with ESW, although these areas were often adjacent. Overall, there was greatest overlap between high abundance and species richness (7.2%, Table 6).

Relatively high abundance areas of Atlantic Halibut (*Hippoglossus hippoglossus*) occurred on Browns Bank and German Bank, and along the Shelf edge and the Gully (Figure 29). There was considerable overlap between Halibut abundance and the top 20% quantile for species richness around the southern tip of Nova Scotia, especially on German Bank, although the spatial overlap across the whole shelf was only 5.5% (Table 6). High Halibut abundance was also adjacent to many areas with high values of ESW and Heip's Evenness Index, notably along the Shelf edge and the Bay of Fundy, but again, over the whole shelf, the overlap was low. Notably, all indices overlapped with high abundance of Atlantic Halibut at the head of the Gully.

American Plaice and Witch Flounder abundance was high in many areas of the Scotian Shelf, but were mostly concentrated in NAFO Division 4V on the eastern Shelf (Figures 30-31). Both species also had some areas of higher abundance in the Bay of Fundy. The Bay of Fundy and inshore western Shelf concentrations corresponded with high species richness, whereas the western Scotian Shelf populations corresponded with high ESW, and, to a lesser extent, Heip's Evenness Index. The overall area of overlap were relatively high for both species with all the indices (range: 6.6-16.2, average = 12%, Table 6).

Smooth Skate (*Malacoraja senta)* abundance was highest in the deep waters of the Bay of Fundy, off Browns Bank in the southwestern part of the study area, the eastern Shelf edge, and along the Northeastern Shelf (Figure 32). Roseway Bank also had an area of higher smooth skate abundance. The Bay of Fundy and inshore Shelf areas had some overlap with species richness, whereas the high concentration areas on the western Scotian Shelf tended to be adjacent to areas with high ESW and Heip's Evenness Index. The overall area of overlap were relatively high for all of the indices (range: 8.3-13.4, average = 11%, Table 6).

Winter Skate abundance was highest at the head of the Bay of Fundy, around Browns Bank, the Gully, and along Banquereau (Figure 33). There was very little overlap between high Winter Skate abundance and any of the biodiversity indicators, except with species richness at the head of the Bay of Fundy, and with ESW and Heip's Evenness Index on the eastern Scotian shelf outer banks. The overall area of overlap was relatively low for all the indices (range: 1.9-4.0, average: 3%, Table 6).

Cusk sampled by the DFO RV survey mainly occurred on the western Scotian Shelf, particularly in the outer reaches and mouth of the Bay of Fundy and around the southwestern tip of Nova Scotia, as well as along the Shelf edge (Figure 34). In the southwestern parts, there is good overlap with the top 20% quantile for species richness and ESW, with an overall spatial overlap of 9.5% and 7% respectively (Table 6). The majority of areas with high Heip's Evenness Index did not overlap with areas of high Cusk abundance (area of overlap=4.3%).

Patterns differed across three Wolffish populations. Atlantic Wolffish (*Anarhichas lupus*) abundance was high on the eastern Scotian Shelf (4V), as well as in the western Scotian Shelf, in the area of Roseway, LaHave and Browns Banks (Figure 35) and in the Bay of Fundy. Across these areas, there was a consistent 7-8% overlap between high abundance and the three biodiversity indices (Table 6). In contrast, there was very little overlap between the three metrics of biodiversity and high abundance of Northern Wolffish (*Anarhichas denticulatus)* or Spotted Wolffish (*Anarhichas minor*) except for a couple areas of ESW and Heip's Evenness Index along the Shelf edge (Figures 36 and 37). The overall area of overlap for these two species ranged from 0.2-0.3% (Table 6).

High abundance of Capelin (*Mallotus villosus)* was restricted to the eastern Scotian Shelf on the Northeastern Shelf and Misaine Bank (Figure 38). The areas of high abundance had little overlap with any of the three biodiversity metrics, although they were adjacent to high ESW and Heip's Evenness Index areas. The overall area of overlap across the three biodiversity indices ranged from 0.5-0.8% (Table 6).

Highest abundances of Northern Sand Lance (*Ammodytes dubius*) occurred on the eastern Scotian Shelf (Figure 39). There was no overlap of high Sand Lance abundance with the top 20% quantile for species richness (0.05%, Table 6). High values of ESW and Heip's Evenness Index on the eastern Scotian Shelf were often immediately adjacent to areas with high Sand Lance abundance, but the total percentage areas of overlap were less than 4% (Table 6).

Highest abundance areas of Atlantic Herring (*Clupea harengus)* were located in the Bay of Fundy and the inshore side of the western Shelf, and were closely associated with high species richness in both areas (Figure 40). However, there was very little association with areas of high ESW or Heip's Evenness Index values anywhere on the Scotian Shelf. Tellingly, there was a 9% overlap between the top classes of Cod abundance and species richness across the whole shelf; but less than 1% overlap for either ESW or Heip's Evenness Index (Table 6).

Comparison of biodiversity indices with areas of high biomass

In Figure 41, total biomass of invertebrates and fish is shown with the top 20% by area for each of the three biodiversity indices. Areas of high invertebrate biomass (Figures 41a, c, e) were located largely on the eastern Scotian Shelf, whereas areas of high invertebrate species richness were mainly located in the Bay of Fundy (i.e., they had opposite distributions). However, areas of high invertebrate biomass did co-occur with all three measures of species diversity to some extent: there was a 12.3% overlap with high invertebrate Heip's Evenness Index, 9.8% with ESW and 8.7% with species richness (Table 6b).

High fish biomass, was located in the Bay of Fundy, inshore western Scotian Shelf, Western Bank, eastern Shelf edge and the edge of the Laurentian Channel (Figures 41b, d, f). Overall, there is a high overlap between high fish biomass and fish species richness (19%) and much of this is located in the Bay of Fundy and western inshore Shelf. There is also some overlap between high fish biomass as ESW, again mostly in the Bay of Fundy (8.3%), but overall there is little overlap area with Heip's Evenness Index (Table 6b).

Comparing biodiversity indices with species richness of juvenile fish and small invertebrates

In Figure 42, the highest 20% by area of the three biodiversity indices from the DFO RV survey data were mapped with expected species richness of small invertebrates and fish sampled by the food habits data (Cook and Bundy 2012). For invertebrates, areas with highest species richness of small invertebrates did not always correspond with the DFO RV surveyed invertebrate species richness, ESW or Heip's Evenness Index, but there were some co-occurrences between small invertebrate species richness and DFO RV surveyed invertebrate species richness in the Bay of Fundy. For fish, the top 20% class of species richness from the DFO RV survey data co-occur with some of the higher areas of juvenile species richness, identified from fish food habits data; however, the pattern is less clear for ESW and Heip's Evenness Index since these data are more dispersed, although some of the top 20% quantile of these indicators does co-occur with areas of high juvenile abundance. Generally, most areas of high juvenile fish abundance do not co-occur with high values of the biodiversity indices.

DISCUSSION

The objective of this analysis was to explore biodiversity on the Scotian Shelf and in the Bay of Fundy to provide science advice for the identification of EBSAs in the Scotian Shelf marine bioregion. In this report, biodiversity was estimated from DFO RV survey data and represented using three indices: species richness, ESW and Heip's Evenness Index. The main conclusions of this analysis are:

i) ESW and Heip's Index often occur in the same or similar locations;
ii) Areas of high species richness usually occur in different areas from high values of ESW and Heip's Evenness Index;
iii) The size and location of the hotspots for these biodiversity indicators change over time;
iv) There is no consistent relationship between any of these indicators and areas of high abundance of key species; and
v) There does appear to be a strong relationship between fish species richness and ecosystem functioning, as represented by fish biomass, and some relationship between invertebrate diversity and ecosystem functioning, which need to be explored further. Last, the Bay of Fundy was consistently identified as an area with high biodiversity, across indices and across time.

Many of the previous studies of biodiversity on the Scotian Shelf and in the Bay of Fundy have used only species richness as a measure of biodiversity (Table 1). This study was expanded to include two additional measures, the exponential of Shannon-Wiener Index and Heip's Evenness Index, which explore different aspects of biodiversity and account for the relative number of individuals of different species. Incorporating these additional indicators of biodiversity expands the area of ecological diversity under consideration for inclusion in the identification of EBSAs, since the three indicators often occur in different locations. The results support the findings of other recent studies, which show opposing trends for species richness and evenness. For example, Stuart-Smith et al. (2013) demonstrated that while the concept of species richness increasing with decreasing latitude is familiar, the reverse is true of species evenness (i.e., it increases with increasing latitude). Combined, the results demonstrate that areas of high species richness and high species evenness do not co-occur, highlighting the importance of using different biodiversity measures when defining EBSAs.

One criterion for incorporating ecological diversity using these three biodiversity indices into the identification of EBSAs could be to identify those areas where high values for all three indicators co-occur. In such areas, both species richness and species evenness would be high, indicating that these areas may be more resilient to change given they are likely to have redundancy among many species. Protecting these areas may enhance the integrity and resiliency of the ecosystems more broadly and, thus, enhance the sustainability of Canada's aquatic ecosystems; one of the core mandates of DFO.

Following this logic, for invertebrates (Figure 11a), many areas on the western Scotian Shelf, as well as the area around the Gully, Middle Bank and the Northeastern Shelf, would fit this criterion. For fish (Figure 11b), when using the whole time period, much of the Bay of Fundy would be under consideration, as well as the Scotian Shelf edges, some inshore areas across the Scotian Shelf and areas across Misaine Bank on the Northeastern Shelf.

For fish, the extent of these areas varied with the time period under examination (Figure 10). Four time periods were explored, representing different fishing eras, consistent with the approach used by Horsman and Shackell (2009). In the latter era (i.e., post-groundfish collapse), the areas where all indicators occurred together were almost all located on the eastern Scotian Shelf, whereas in the 1970s and 1980s (eras 1 and 2), most of the overlap was in the Bay of Fundy. These changes represent changes in the relative abundance, and perhaps distribution of fish species on the Scotian Shelf. To some extent, it also reflects differences in species richness, which increased across these eras, in some cases representing increase in species richness, but in others, changes in survey protocol (Shackell and Frank 2003). These changes through time raise the question of which time period should be used as input for the identification of EBSAs. Shackell et al. (2005) examined range contraction and hotspots of key species on the Scotian Shelf and concluded that areas occupied when species are depleted, and range has contracted, may not represent historical arrays of subpopulations. For depleted species they recommended that only data from periods prior to significant population presence be used for analysis since “these areas represent those with the potential to support higher densities and multiple populations, regardless of distribution at minimal population sizes, density-dependent geographic shifts, and possible effects of fishing on declining populations” (Shackell et al. 2005: 1448). However, Shackell et al.. (2005) were considering single species, whereas ecosystem level indicators of diversity are being considered here, which incorporate both species that have declined, or are depleted and, in some case, species at risk, and species that have increased. The Scotian Shelf ecosystem has changed considerably since the first two eras, and has been described as going through a regime shift (Bundy 2005; Frank et al. 2005). Therefore, the question of which time period to use as the basis for defining high diversity areas is related to the overall conservation objectives for the EBSA or the intended MPA network.

Preliminary results for the Edge and Deep survey strata indicate differences between fish and invertebrate diversity on the shelf and in the deeper strata. However, it was not possible to determine clear patterns along the shelf edge. This is an under-sampled and under-studied area that requires greater attention, especially since a large swath of the shelf edge is being considered as a potential EBSA (Doherty and Horsman 2007; King et al. 2016).

A second objective of this work was to explore how these measures of ecological diversity may be related to ecosystem functioning. In a preliminary analysis, invertebrate and fish abundance were used for a few key species as a proxy for production at the individual species level. Results indicated that there is great variation in the relationship between the three indicators of ecological diversity and the key species examined. In general, species with a westerly distribution had higher overlap with species richness than species with an easterly distribution. In a few cases, the areas defined by the top 20% quantile of the biodiversity indices captured areas of high species abundance. For example, the area of overlap between White Hake high abundance and species richness was 19%, areas of American Plaice high abundance and areas of high Heip’s Evenness Index had an overlap of 16%, and there was a 13% overlap between areas of high abundance of Smooth Skate and Witch Flounder with species richness (Table 6a). However, in many other cases, there was very little overlap indicating that in most cases, these biodiversity indices do not reflect important areas for individual species. Interestingly, areas of high abundance were frequently located adjacent to areas with high values of ESW or Heip's Evenness Index, indicating that areas of lower abundance were located together with high values of these indices. Since ESW or Heip's Evenness Index both measure evenness, they provide information about areas that are not dominated by a few species, therefore, it would not expect to find them co-located with high species abundance.

In a second analysis, total fish or invertebrate biomass was used as a proxy for ecosystem production, and compared to top classes of the biodiversity indices. Other studies have shown a connection between diversity and biomass (Duffy et al. 2007), and the preliminary analysis presented here offers partial support for this: for fish, biomass and species richness often co-occurred, particularly in the Bay of Fundy; invertebrate biomass and species evenness and diversity have similar easterly distributions and were often co-located, especially on the eastern Scotian Shelf. This analysis was conducted using biomass-per-tow for the whole time period. Further research could include exploring whether this relationship is robust on a finer time scale, such as the fishing eras used here.

For the current purposes of EBSA planning, and as a first step only, it is recommended that areas that were consistently high in biodiversity, regardless of time period or index used, should be considered essential ecosystem features that would provide integrity and resilience to the ecosystem in the face of disturbance and change (ICES 2012) and likely provide high functional value (DFO 2004). These areas are identified in Figures 8-11, and include areas such as the Bay of Fundy, the Northeast Channel, the Shelf slopes, Western Bank, the Gully, The Cow Pen (newly identified in this study) and areas along the Laurentian Channel, especially off the tip of northern Cape Breton. These are generally consistent with areas identified in earlier studies (Shackell and Frank 2003; Horsman et al. 2011; Cook and Bundy 2012), and should be considered important. One of these areas, the Gully, is already an MPA: given its location on the shelf's edge, with steep slopes and rapidly changing habitat, this result confirms expectations that it would expect to see high species diversity, evenness and richness.

Different measures of biodiversity and different data sources can produce different patterns of biodiversity and underscores the need for exploring multiple measures of biodiversity, using different sources of data, in the identification of EBSAs. For example, it was found that there was little coherence between the indicators when comparing fish and invertebrate biodiversity indices from the DFO RV survey to juvenile fish and small invertebrate species richness estimated from a different data source (such as food habits). Further, the area of low fish and invertebrate diversity identified in the middle of the shelf from DFO RV survey data was less evident, especially for juvenile fish. This result underscores a problem in that the DFO RV survey captures only a part of the biological diversity on the Scotian Shelf and in the Bay of Fundy, and that the understanding of diversity needs to come from multiple data sources and measures of diversity. Recent assessments of biodiversity have moved beyond simple species diversity to the diversity of functional traits, such as body size, or feeding types, or a combination of several function traits (Cadotte 2011; Fisher et al. 2010, 2011; Shackell and Frank 2007, 2012; Stuart-Smith et al. 2013). A study on the Scotian Shelf for example, has shown clear patterns in distribution of fish by body-size, with larger fish at age located to the west (Shackell and Frank 2007). One recently used method shows great promise to measure functional diversity using Rao's Q (Stuart-Smith et al. 2013; Botta-Dukát 2005). It is recommended that for EBSA identification purposes, further research is required to explore the implications of functional diversity, both within trophic guilds or trophic levels, as well as across them (Duffy et al. 2007).

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TABLES

Table 1. Biodiversity indices used on the Scotian Shelf and in the literature.

Biodiversity Index Used	Reference	Location	Purpose	EBSA Mentioned
Species richness	Cook and Bundy 2012	Scotian Shelf	Biodiversity and ecosystem function	yes
Species richness	Fisher et al. 2011	Scotian Shelf	Linking richness and evenness to SG and ND	no
Species richness	Horsman et al. 2011	Scotian Shelf	Define biodiversity hotspots and MPA	yes
Species richness	Shackell and Frank 2003	Scotian Shelf	Linking area and depth to species richness	no
Species richness	Frank and Shackell 2001	Scotian Shelf	Describing area effect of fish diversity	no
Species distribution	Cook and Bundy 2012	Scotian Shelf	Biodiversity and ecosystem function	yes
Simpson index (1-SI)	Fisher et al. 2011	Scotian Shelf	Linking richness and evenness to SG and ND	no
Shannon’s entropy index	Shackell and Frank 2000	Scotian Shelf	Spatial and temporal distributions of larval fish	no
Pielou’s evenness (J′)	Shackell et al. 2012	Scotian Shelf	Linking spatial similarity with community stability	no
IUCN richness	Horsman et al. 2011	Scotian Shelf	Define biodiversity hotspots and MPA	yes
Genus richness	Shackell and Frank 2000	Scotian Shelf	Spatial and temporal distributions of larval fish	no
Fish body size	Shackell et al. 2012	Scotian Shelf	Linking spatial similarity with community stability	No
Endemic richness	Horsman et al. 2011	Scotian Shelf	Define biodiversity hotspots and MPA	Yes
Density	O'Boyle et al, 1984	Scotian Shelf	Icthyoplankton distribution	No
Density	Shackell and Frank 2000	Scotian Shelf	Spatial and temporal distributions of larval fish	No
Bray Curtis’s Index of Similarity	Shackell and Frank 2003	Scotian Shelf	Linking area and depth to species richness	No
Biomass	Horsman et al. 2011	Scotian Shelf	Define biodiversity hotspots and MPA	Yes
Biomass	O'Boyle et al, 1984	Scotian Shelf	Zooplankton distribution	no
Biomass	Shackell et al. 2012	Scotian Shelf	Linking spatial similarity with community stability	no
Total records in OBIS	Williams et al. 2010	Global	Describing global biodiversity for EBSA identification	yes
Species richness	Bos et al. 2011	Dutch Continental Shelf	Biodiversity hotspots	no
Species richness	Narayanaswamy et al. 2013	European Seas	Synthesis of biodiversity	yes
Species richness	Fisher et al. 2010	Global	Linking fish body size, biodiversity and ecosystem function	no
Species richness	Selig et al. 2014	Global	Prioritizing global biodiversity conservation	yes
Species richness	Williams et al. 2010	Global	Describing global biodiversity for EBSA	yes

Biodiversity Index Used	Reference	Location	Purpose	EBSA Mentioned
			identification	
Species richness	Worm et al. 2006	Global	Impacts of biodiversity loss	no
Species richness	Danovaro et al. 2008	Global: deep-sea	Linking biodiversity to ecosystem function	no
Species richness	Mouillot et al. 2011	Mediterranean	Congruence of MPA with biodiversity	no
Species richness	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Species richness	Olsgard et al. 2013	Norweigan Coast	Linking polychaete richness to total species richness	no
Species richness	Fraser et al. 2008	North Sea	Diversity differences using different metrics	no
Species evenness	Stuart-Smith et al. 2013	Global	Diversity hotspots	no
Species density	Stuart-Smith et al. 2013	Global	Diversity hotspots	no
Simpson index (1-SI)	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Simpson index (1-SI)	Fraser et al. 2008	North Sea	Diversity differences using different metrics	no
Shannon's index	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Shannon-Weiner index	Bos et al. 2011	Dutch Continental Shelf	Biodiversity hotspots	no
Shannon-Weiner diversity index	Danovaro et al. 2008	Global: deep-sea	Linking biodiversity to ecosystem function	no
Shannon index	Williams et al. 2010	Global	Describing global biodiversity for EBSA identification	yes
Range rarity	Selig et al. 2014	Global	Prioritizing global biodiversity conservation	yes
Proportional range rarity	Selig et al. 2014	Global	Prioritizing global biodiversity conservation	yes
Predator species richness	Danovaro et al. 2008	Global: deep-sea	Linking biodiversity to ecosystem function	no
Polychaete richness	Olsgard et al. 2013	Norweigan Coast	Linking polychaete richness to total species richness	no
Pielou's evenness (J′)	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Margalef diversity index	Danovaro et al. 2008	Global: deep-sea	Linking biodiversity to ecosystem function	no
Margalef diversity index	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Hurlbert's index	Williams et al. 2010	Global	Describing global biodiversity for EBSA identification	yes
Functional group richness	Stuart-Smith et al. 2013	Global	Diversity hotspots	no
Functional diversity	Stuart-Smith et al. 2013	Global	Diversity hotspots	no
Fished taxa richness	Worm et al. 2006	Global	Impacts of biodiversity loss	no
Fish body size	Bos et al. 2011	Dutch Continental Shelf	Biodiversity hotspots	no

Biodiversity Index Used	Reference	Location	Purpose	EBSA Mentioned
Fish body size	Fisher et al. 2010	Global	Linking fish body size, biodiversity and ecosystem function	no
Exponential of Shannon-Wiener index	Fraser et a. 2008	North Sea	Diversity differences using different metrics	no
Density	Bos et al. 2011	Dutch Continental Shelf	Biodiversity hotspots	no
Density	Ellis et al. 2011	North Sea	Spatial patterns in benthos	no
Biomass	Bos et al. 2011	Dutch Continental Shelf	Biodiversity hotspots	no
Biomass	Narayanaswamy et al. 2013	European Seas	Synthesis of biodiversity	yes

Table 2. Summary of time periods of data layers created in this study.

Time period (by fishing era)	**Fish (1970-2013)**	**Invertebrates (2007-2013)**
Era 1: 1970-1977	Yes	No
Era 2: 1978-1985	Yes	No
Era 3: 1986-1993	Yes	No
Era 4: 1994-2013	Yes	Yes
Complete	Yes	No

Table 3. Summary of data used in this study. Note 'n/a' refers to 'not applicable'.

Dataset	Years	No. sets	No. species	Max species	No. sets with zero species	No. sets with one species	Mean species richness	Mean ESW	Mean Heip's Evenness Index
Invertebrates	2007-2013	1395	100	21	0	11	9.2	2.9	0.35
Fish All	Complete	7767	116	24	5	24	9.5	3.3	0.29
Fish Era 1	1970-1977	1099	n/a	19	1	2	8.5	3.4	0.34
Fish Era 2	1978-1985	1174	n/a	20	2	6	9.1	3.5	0.32
Fish Era 3	1986-1993	1491	n/a	22	0	6	9.1	3.2	0.31
Fish Era 4	1994-2013	4003	n/a	24	2	10	10.1	3.2	0.26

Table 4. Summary of data used in deep-set analysis. Note 'n/a' refers to 'not applicable'.

Dataset	Years	No. sets	No. species	Max species	No. sets with zero species	No. sets with one species	Mean species richness	Mean ESW	Mean Heip's Evenness Index
Invertebrates All strata	2007-2013	65	73	14	0	1	6.6	3.3	0.43
Fish All strata	1995-2013	145	107	31	0	0	14.6	5.0	0.27
Invertebrates Strata 496-498	2007-2013	39	n/a	14	0	1	6.7	3.5	0.48
Fish Strata 496-498	1995-2013	119	n/a	23	0	0	12.5	3.9	0.25
Invertebrates Strata 501-505	2010, 2011, 2013	26	n/a	12	0	0	6.4	n/a	n/a
Fish Strata 501-505	2010, 2011, 2014	26	n/a	31	0	0	24.2	n/a	n/a

Table 5. List of key species used in the comparison of biodiversity with ecosystem function.

Species	Name	Latin name	Group
6600/6611	Sea Cucumbers	*Cucumaria frondosa*	Commercial
2526	Snow Crab (Queen)	*Chionoecetes opilio*	Commercial
2211	Shrimp commercial	*Pandalus borealis*	Commercial
6411	Sea Urchin	*Strongylocentrotus droebachiensis*	Commercial
4511	Short-fin Squid	*Illex illecebrosus*	Forage
10	Atlantic Cod	*Gadus morhua*	influential predator, depleted species
60	Atlantic Herring	*Clupea harengus*	Forage
610	Northern Sand Lance	*Ammodytes dubius*	Forage
30	Atlantic Halibut	*Hippoglossus hippoglossus*	influential predator
11	Haddock influential	*Melanogrammus aeglefinus*	influential predator
15	Cusk depleted	*Brosme brosme*	Depleted
50	Striped Atlantic Wolffish	*Anarhichas lupus*	Depleted
52	Northern Wolffish	*Anarhichas denticulatus*	Depleted
51	Spotted Wolffish	*Anarhichas minor*	Depleted
204	Winter Skate	*Leucoraja ocellata*	influential predator, depleted species
202	Smooth Skate	*Malacoraja senta*	influential predator
220	Spiny Dogfish	*Squalus acanthisa*	influential predator
14	Silver Hake	*Merluccius bilinearis*	influential predator
70	Atlantic Mackerel	*Scomber scombrus*	forage
13	Red Hake	*Urophycis chuss*	influential predator
64	Capelin forage	*Mallotus villosus*	forage
40	American Plaice	*Hippoglossoides platessoides*	influential predator
41	Witch Flounder	*Glyptocephalus cynoglossus*	forage
12	White Hake	*Urophycis tenuis*	influential predator
23	Redfish unseparated	*Sebastes spp.*	influential predator
300	Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	influential predator
16	Pollock influential	*Pollachius virens*	influential predator

Table 6. Percent overlap of top classes for each biodiversity index for (a) key species and (b) total invertebrate or fish biomass.

(a) Key species:

Species	**Species richness**	**ESW**	**Heip's Evenness Index**
Sea Cucumbers	0.03	2.64	4.33
Snow Crab	1.15	6.21	9.71
Shrimp (2211)	0.63	0.40	1.59
Sea Urchin	0.19	4.99	8.35
Short-fin Squid	6.97	3.70	3.50
Cod	5.53	8.33	9.52
Haddock	9.71	9.15	6.40
White Hake	18.77	9.21	3.52
Redfish	4.98	1.05	0.89
Red Hake	12.26	7.40	4.13
Silver Hake	8.11	3.23	1.85
Mackerel	3.33	2.66	1.65
Pollock	8.80	6.62	3.79
Dogfish	7.74	2.53	0.19
Longhorn Sculpin	7.22	4.62	4.69
Atlantic Halibut	5.48	5.30	3.92
American Plaice	6.58	12.21	16.24
Witch Flounder	13.40	13.34	9.98
Smooth Skate	13.42	11.79	8.34
Winter Skate	4.04	1.89	2.15
Cusk	9.52	7.13	4.32
Atlantic Wolffish	7.26	7.73	7.46
Spotted Wolffish	0.32	0.29	0.21
Northern Wolffish	0.34	0.24	0.34
Atlantic Herring	8.92	0.88	0.11
Sand Lance	0.05	1.42	3.99
Capelin	0.54	0.78	0.75

(b) Total invertebrate or fish biomass:

Biomass	**Species richness**	**ESW**	**Heip's Evenness Index**
Invertebrate	8.66	9.76	12.31
Fish	18.82	2.84	8.26

FIGURES

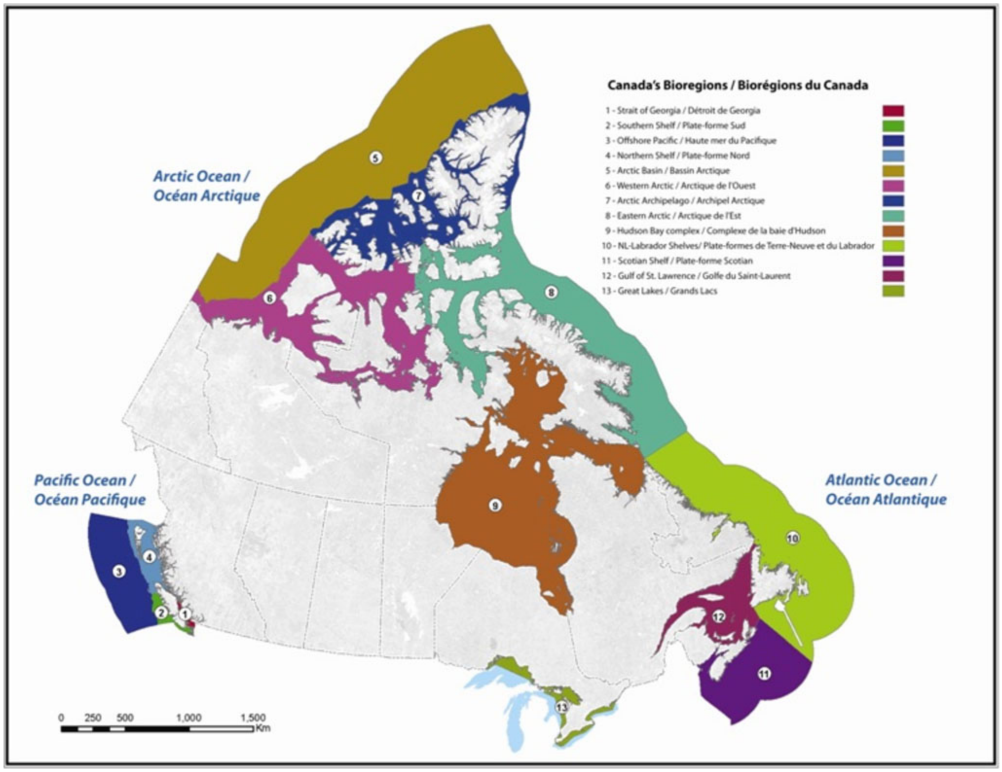
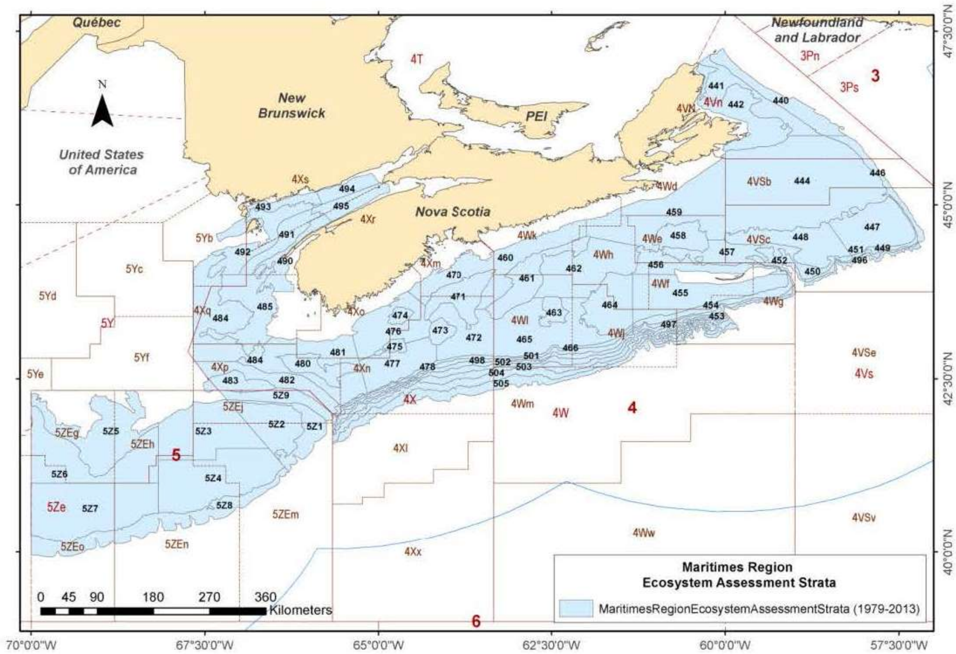


Figure 1. Canada's marine bioregion. The Scotian Shelf marine bioregion (No. 11) encompasses the Scotian Shelf and Bay of Fundy, including the offshore within Canada's exclusive economic zone. The analysis presented here is limited to the Scotian Shelf and Bay of Fundy consistent with DFO RV survey locations (see: Figure 2).



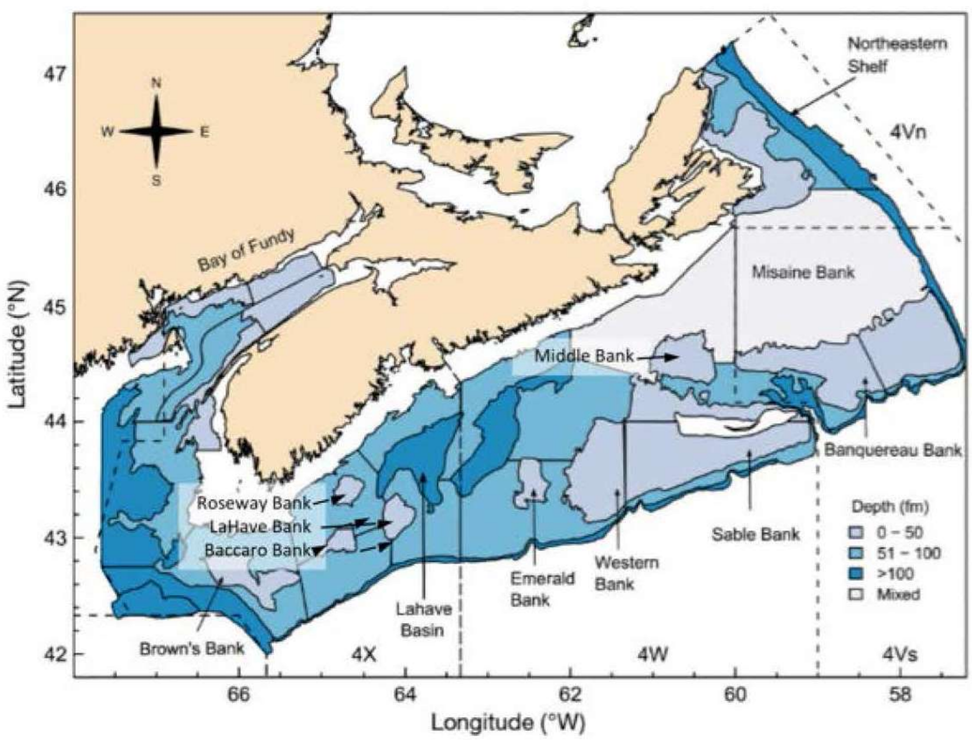


Figure 2. Upper panel shows DFO RV survey strata in study area (map provided by Michele Greenlaw, DFO Science). Lower panel is a map of the Scotian Shelf marine bioregion, showing the location of the major banks and the North Atlantic Fishery Organisation (NAFO) Divisions 4Vn, 4Vs, 4W and 4X.

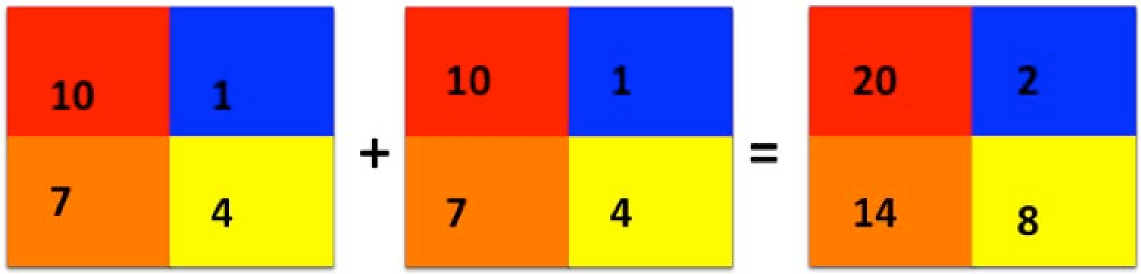


Figure 3. Schematic outlining the addition of raster layers using the 'Raster Calculator' tool to identify areas with high biodiversity across multiple layers (i.e., species richness, exponential of the Shannon-Wiener Index, Heip's Evenness Index, or across multiple fishing eras).

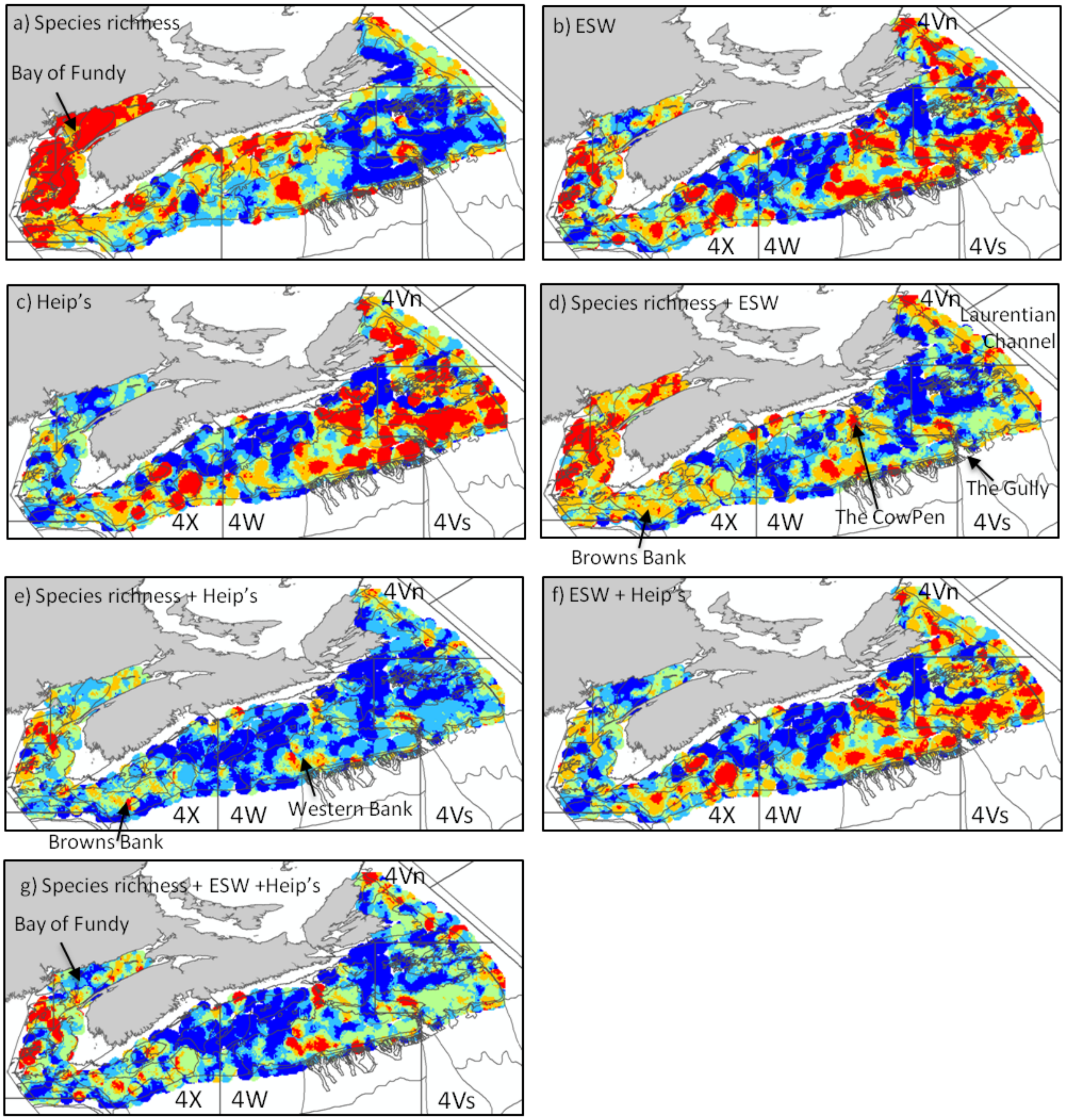


Figure 4. IDW interpolation for invertebrates reclassified into 20% by area quantiles for each of three biodiversity metrics, including their combination. Red = top 20%, blue = bottom 20%.

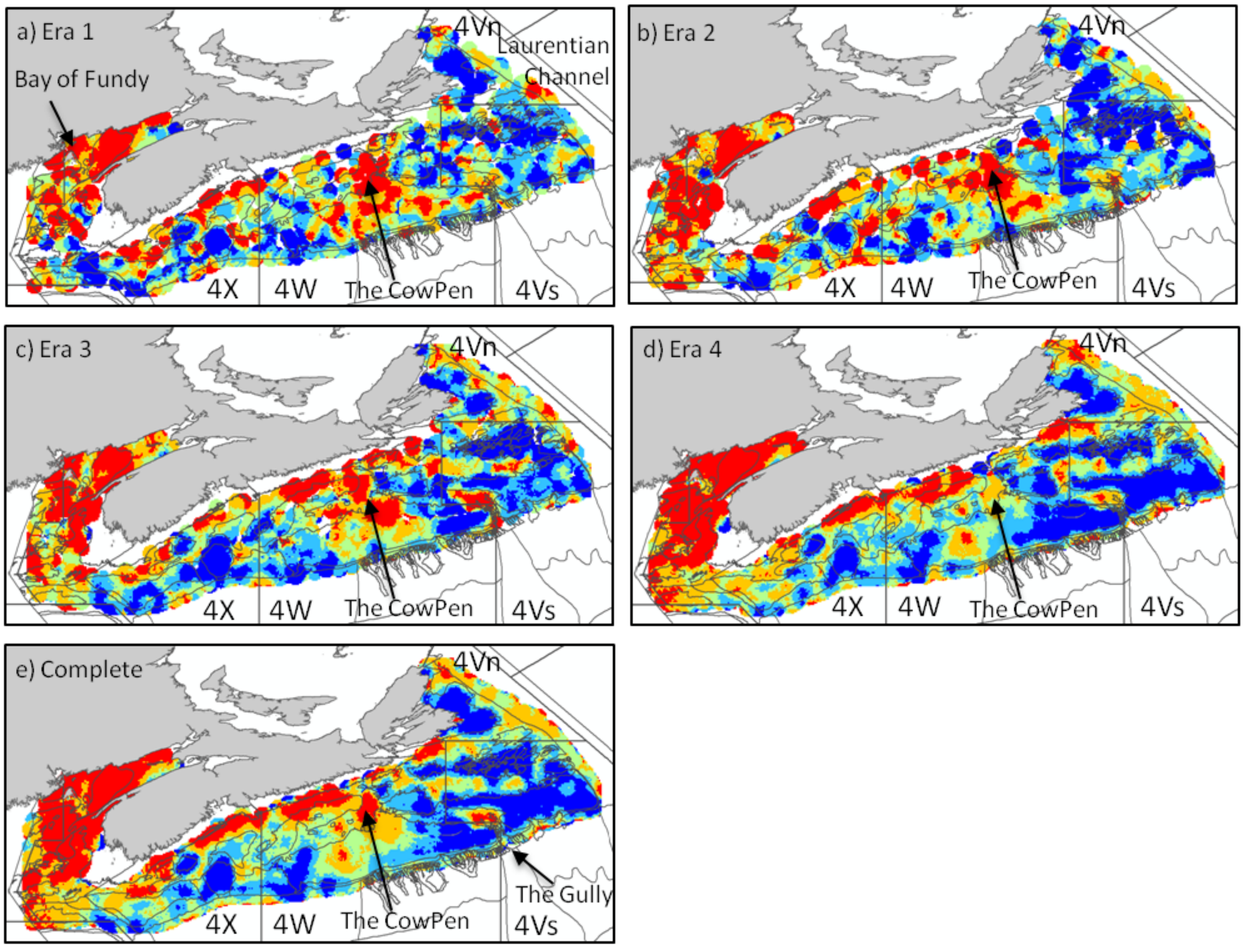


Figure 5. IDW interpolation for fish reclassified into 20% by area quantiles for Species richness in each of the four fishing eras, including across the whole time series. Red = top 20%, blue = bottom 20%.

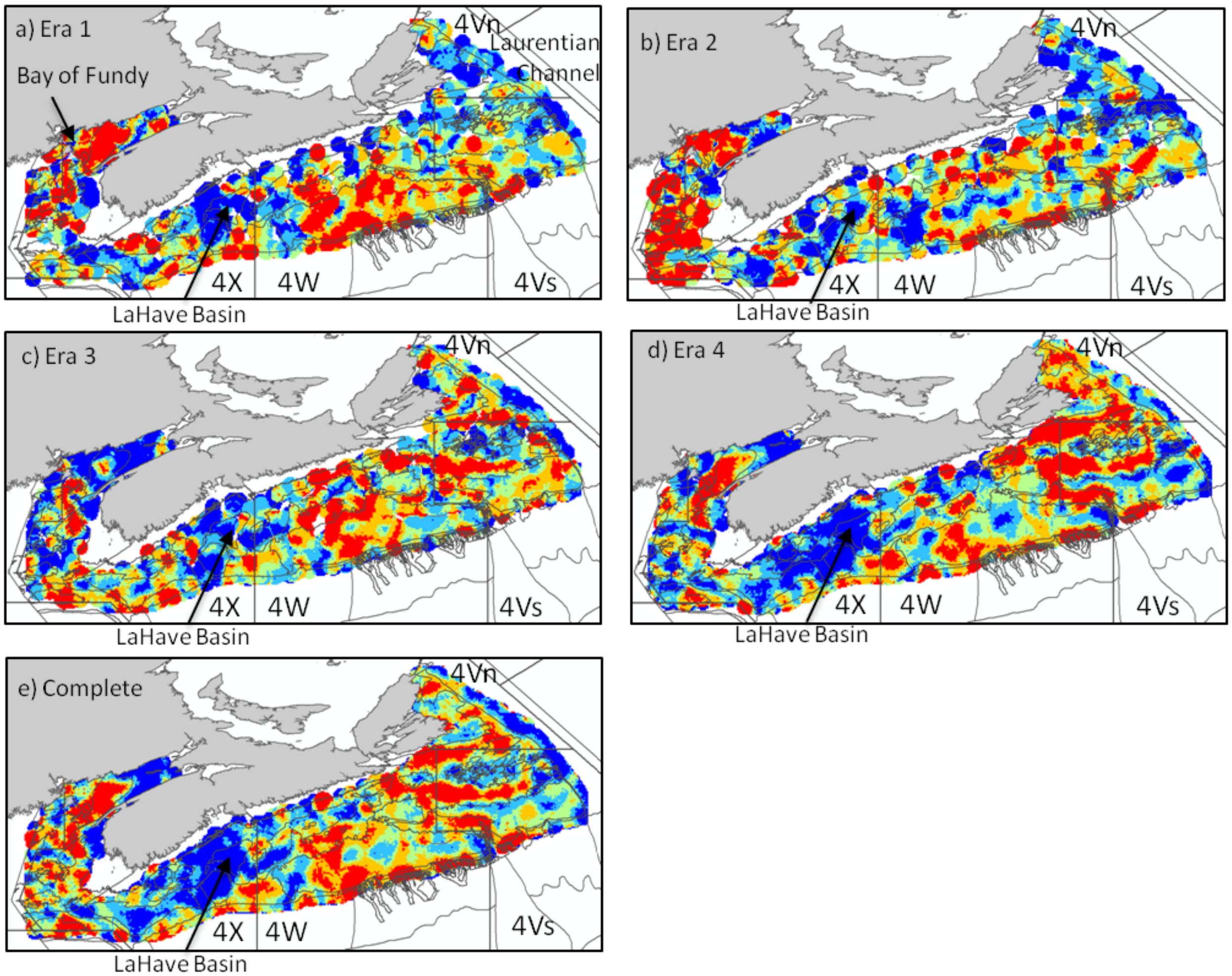


Figure 6. IDW interpolation for fish reclassified into 20% quantiles for the exponential of the Shannon-Wiener Index (ESW) in each of the four fishing eras including across the whole time series. Red = top 20%, blue = bottom 20%.

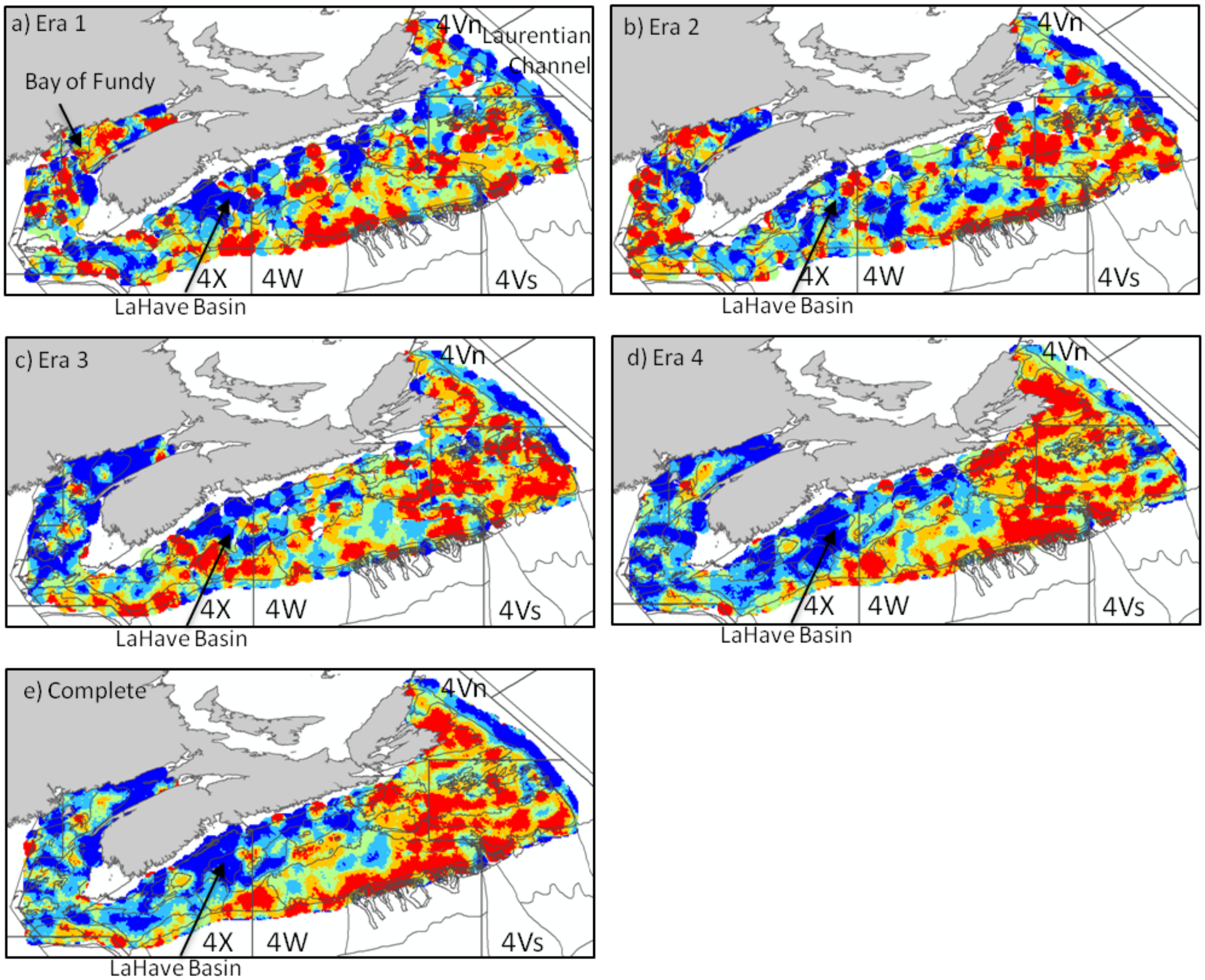


Figure 7. IDW interpolation for fish reclassified into 20% by area quantiles for Heip's Evenness Index in each of the four fishing eras, including across the whole time series. Red = top 20%, blue = bottom 20%.

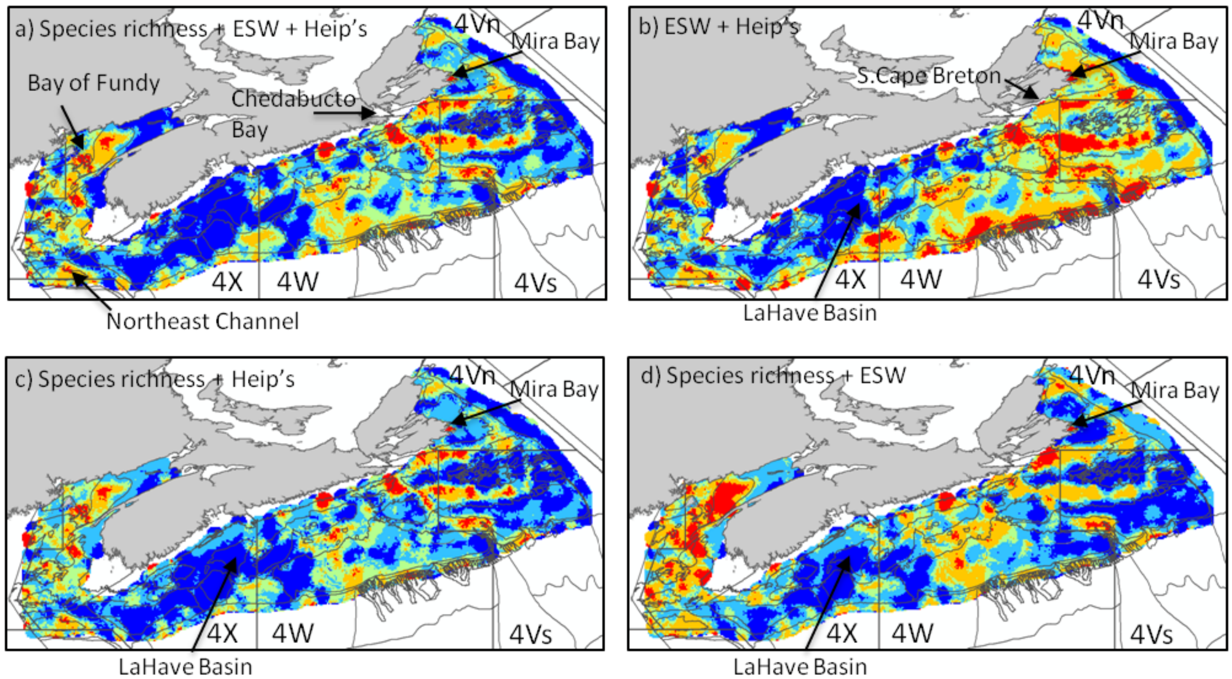


Figure 8. Combined reclassified layers for fish across the whole time series (i.e., addition of complete layers in Figures 5e, 6e, 7e) for Species richness, exponential of the Shannon-Wiener Index and Heip's Evenness Index. Red = high across all metrics, blue = low across all metrics.

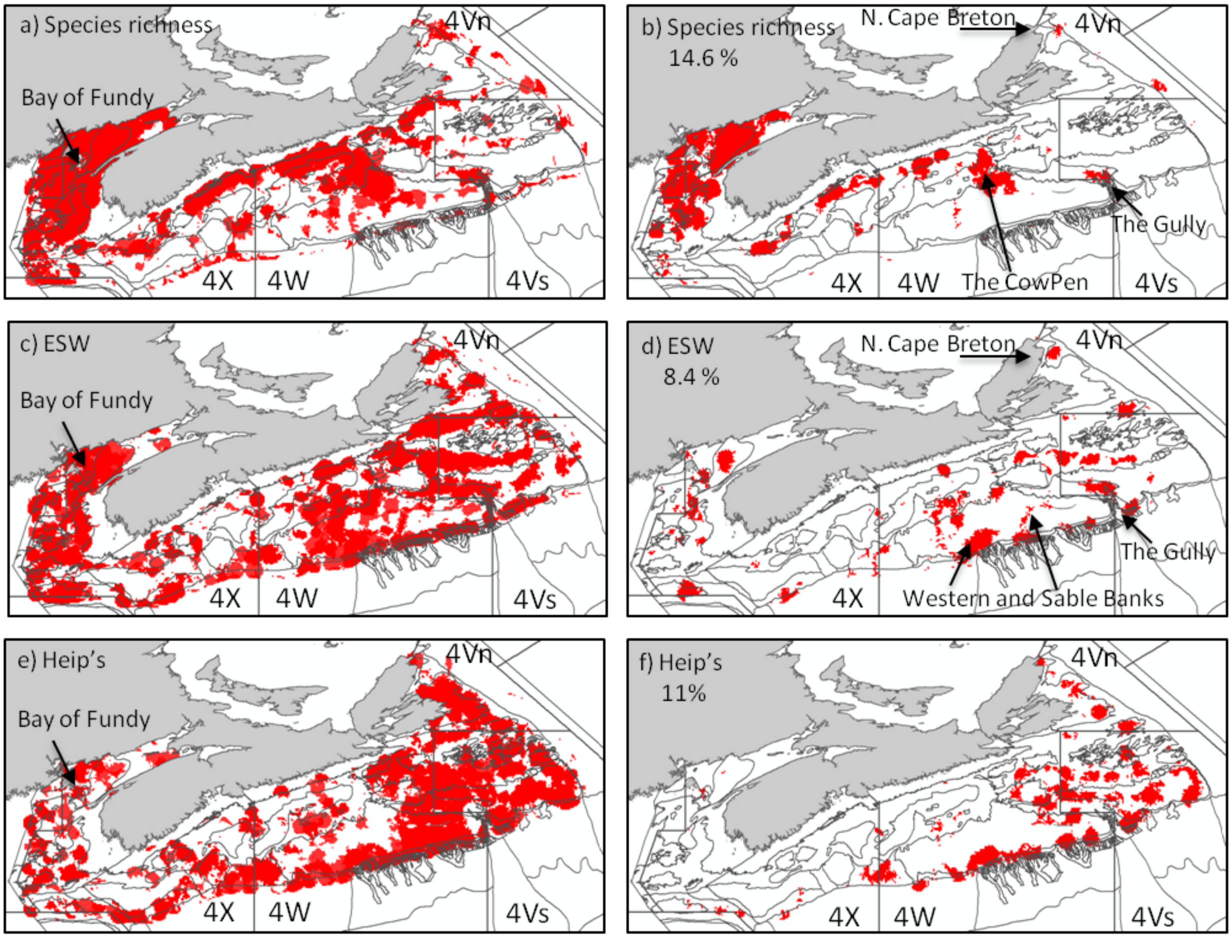


Figure 9. Top four classes for fish across fishing eras (i.e., in any of the 4 eras). Panels 'a', 'c', and 'e' show the combination of each era simultaneously for each biodiversity metric. Panels 'b' ,'d' and 'f' show the areas of overlap across the four fishing eras, indicating areas with consistently high values of the diversity index. Percentages indicate the percentage area covered by the top four classes of the combined indicators.

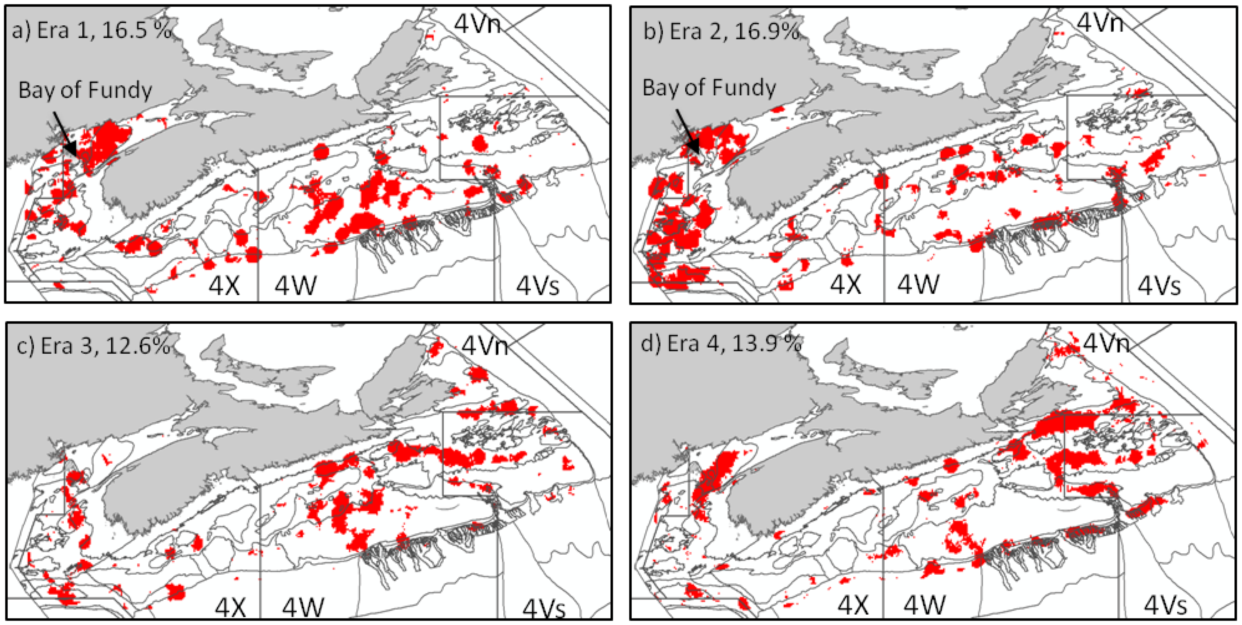


Figure 10. Fish biodiversity within each fishing era where all three biodiversity metrics were combined and top three classes shown. Percentages indicate the percentage area covered by the top three classes of the combined indicators.

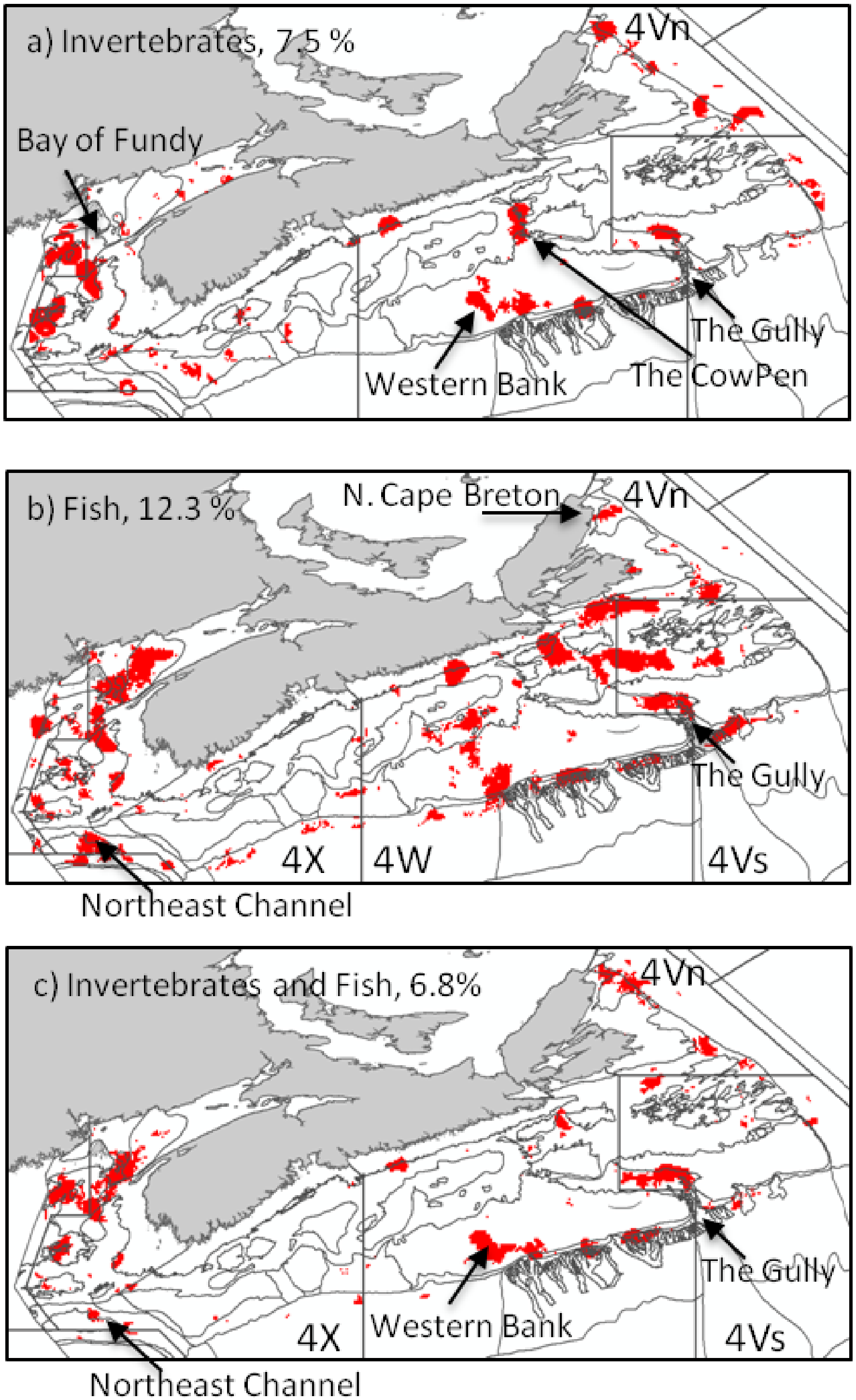


Figure 11. Areas of high biodiversity across all three biodiversity metrics and across all years: a) invertebrates (2007-2013); b) fish (1970-2013); and c) invertebrates (2007-2013) and fish (fishing era 4, 1995-2013). The three classified biodiversity metrics were added and the top three classes shown. Percentages indicate the percentage area covered by the top three classes of the combined indicators.

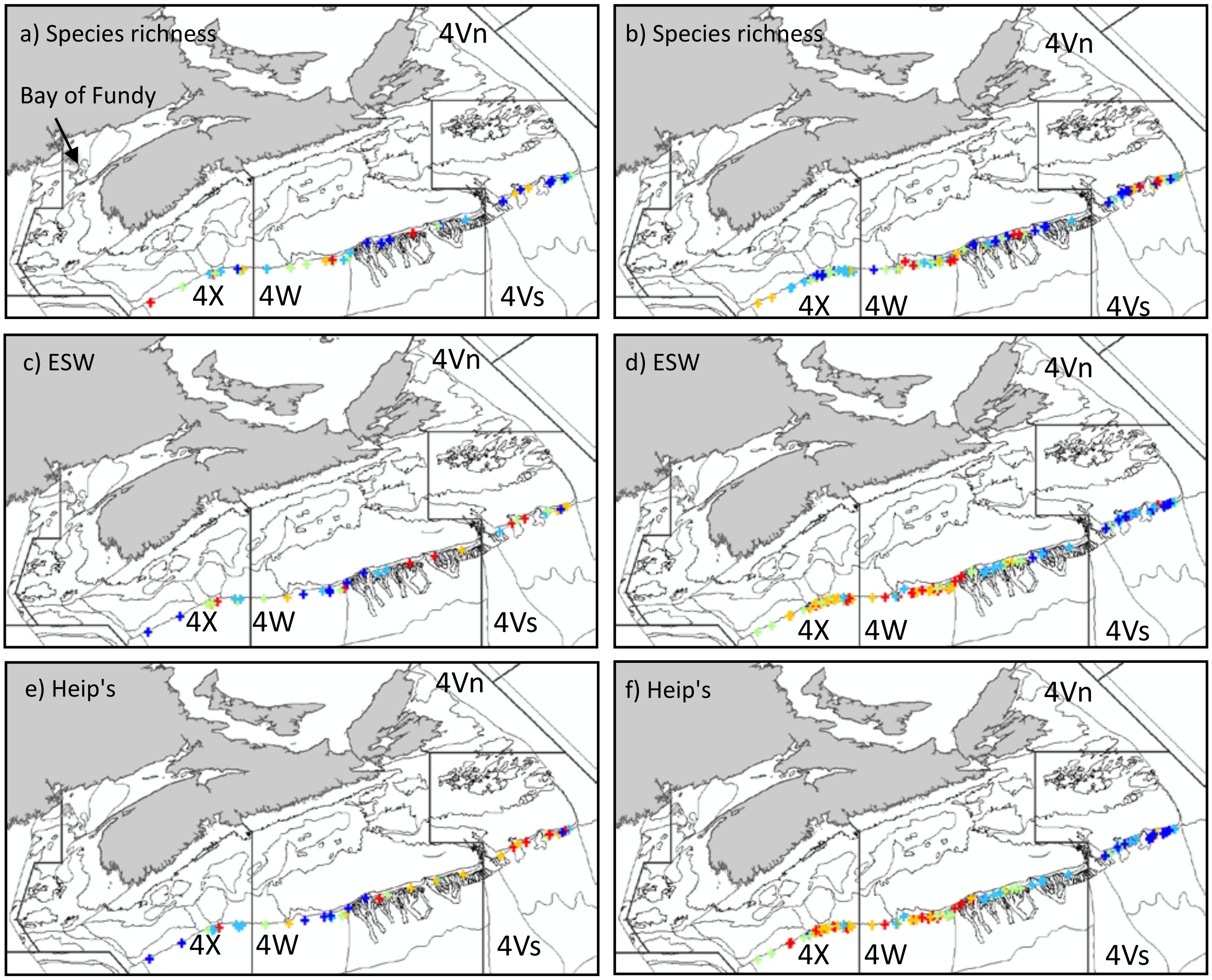


Figure 12. Biodiversity in the Edge sets, 400 series strata, Panels 'a', 'c', and 'e' are for invertebrates and panels 'b', 'd', and 'f' for fish. Blue is low biodiversity and red is high biodiversity.

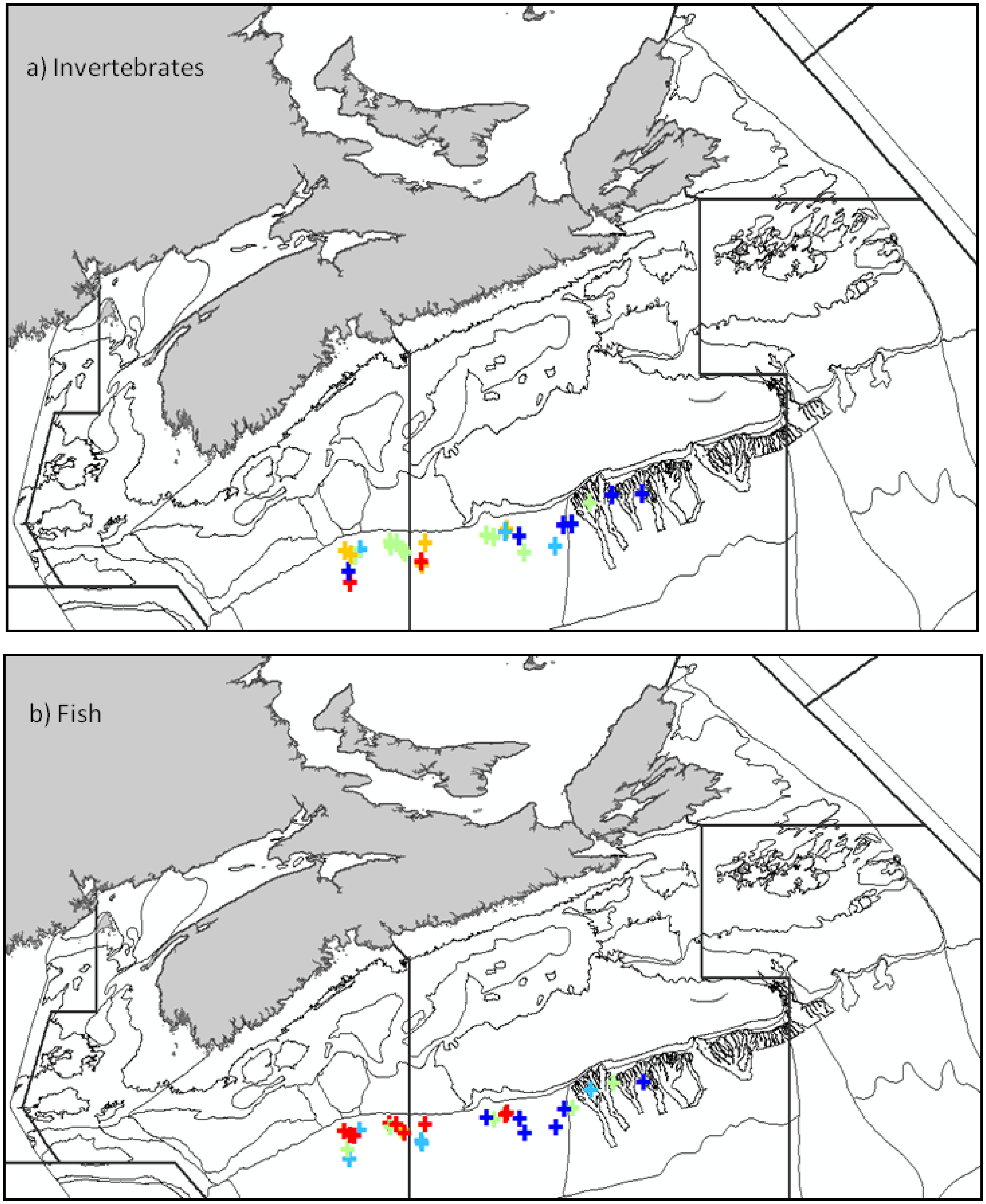


Figure 13. Species richness in the Deep sets, 500 series strata for: a) invertebrates; and b) fish. Blue is low species richness and red is high species richness.

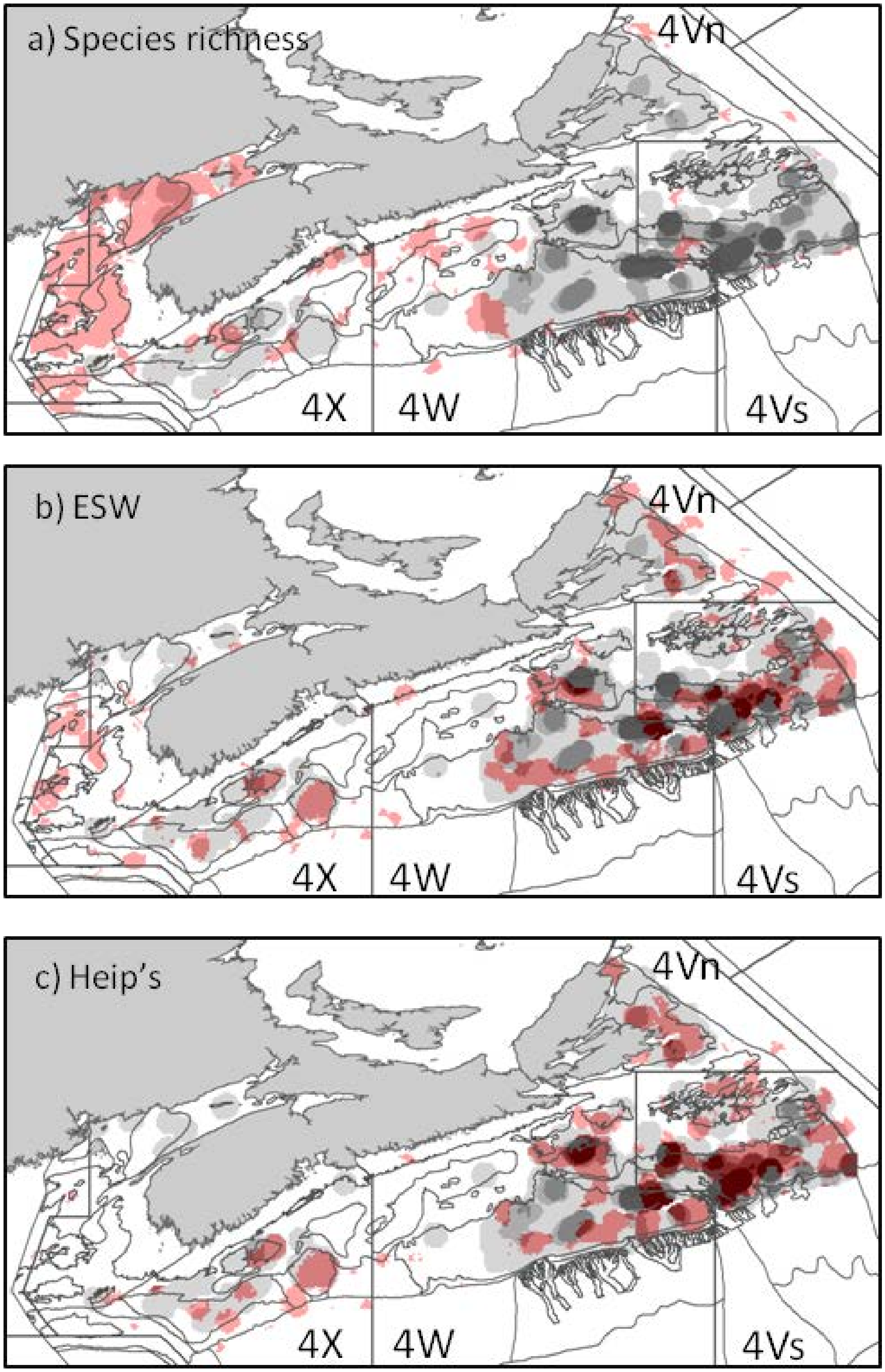


Figure 14. Invertebrate biodiversity and abundance of Sea Cucumbers (Cucumaria frondosa) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

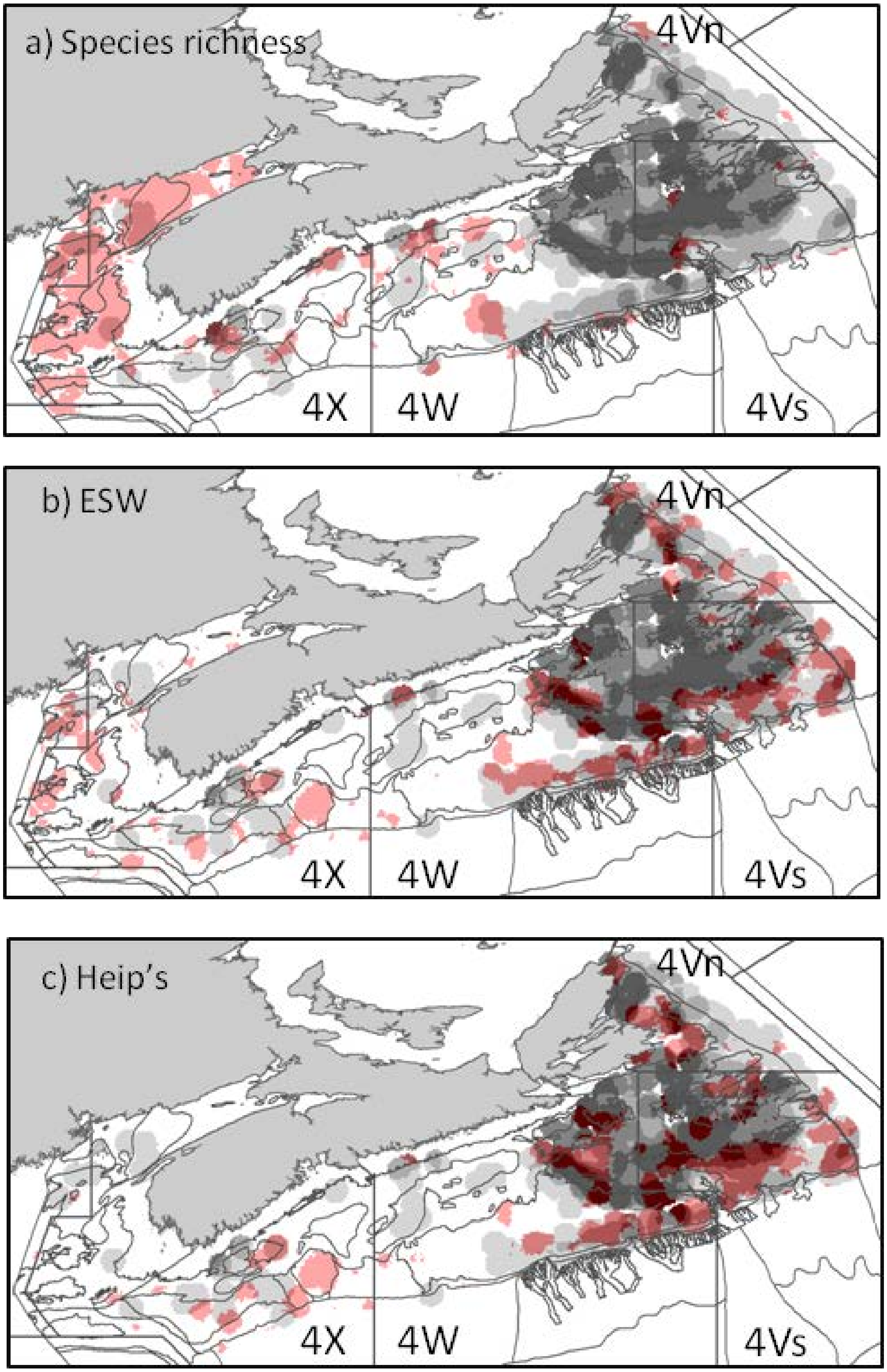


Figure 15. Invertebrate biodiversity and abundance of Snow Crab (Chionoecetes opilio) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

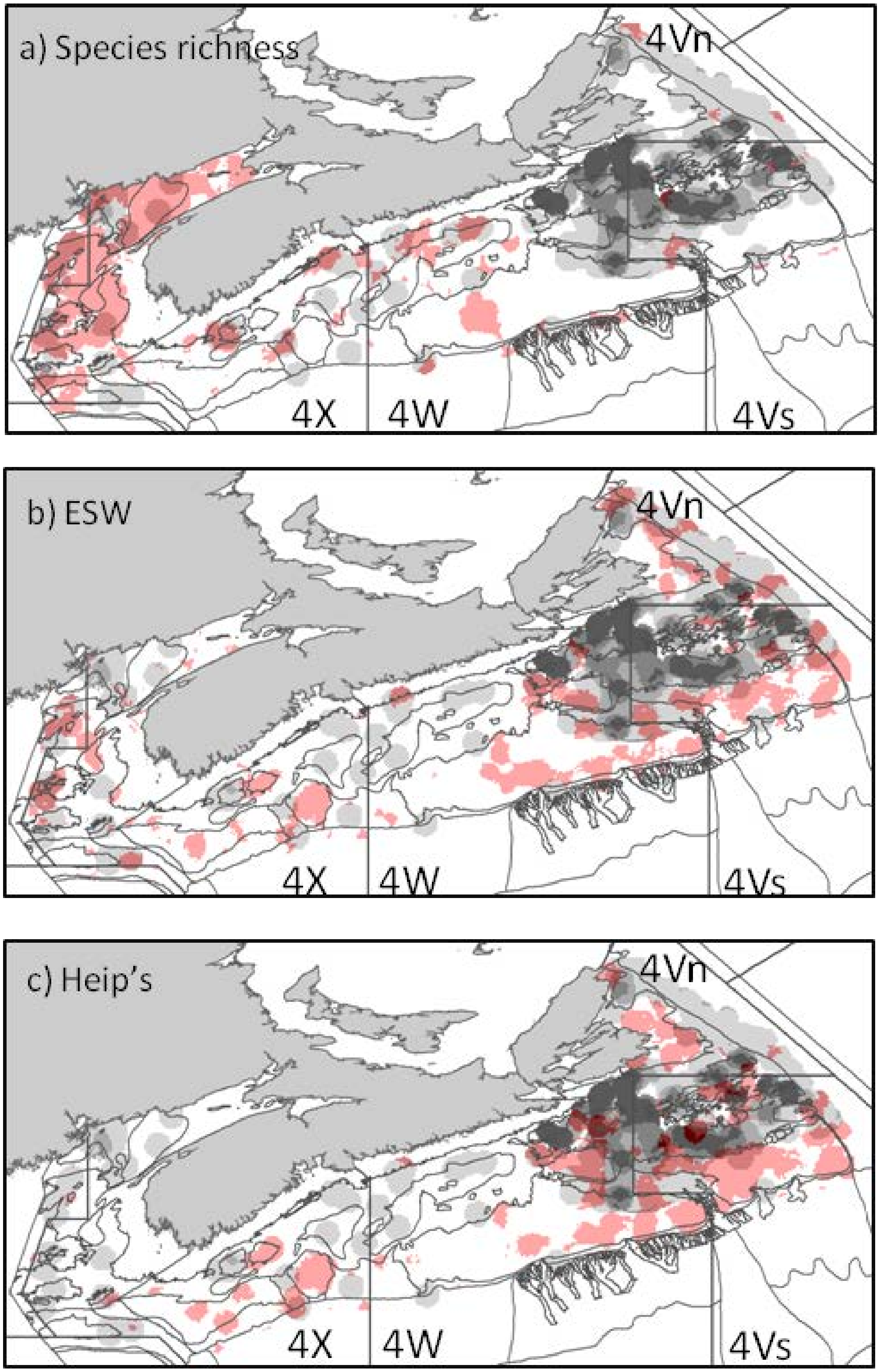


Figure 16. Invertebrate biodiversity and abundance of Northern Shrimp (Pandalus borealis) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

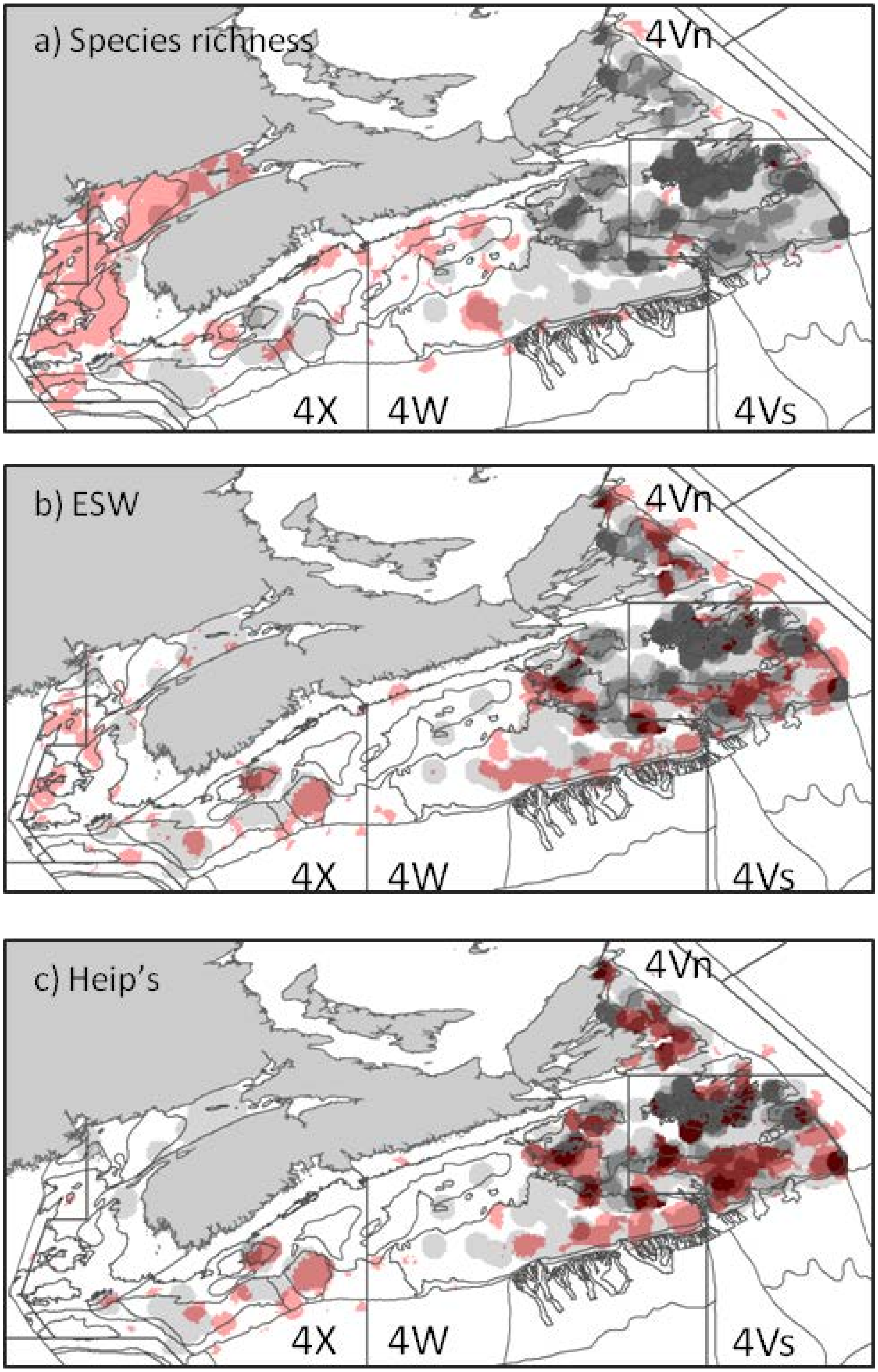


Figure 17. Invertebrate biodiversity and abundance of Sea Urchin (Strongylocentrotus droebachiensis) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

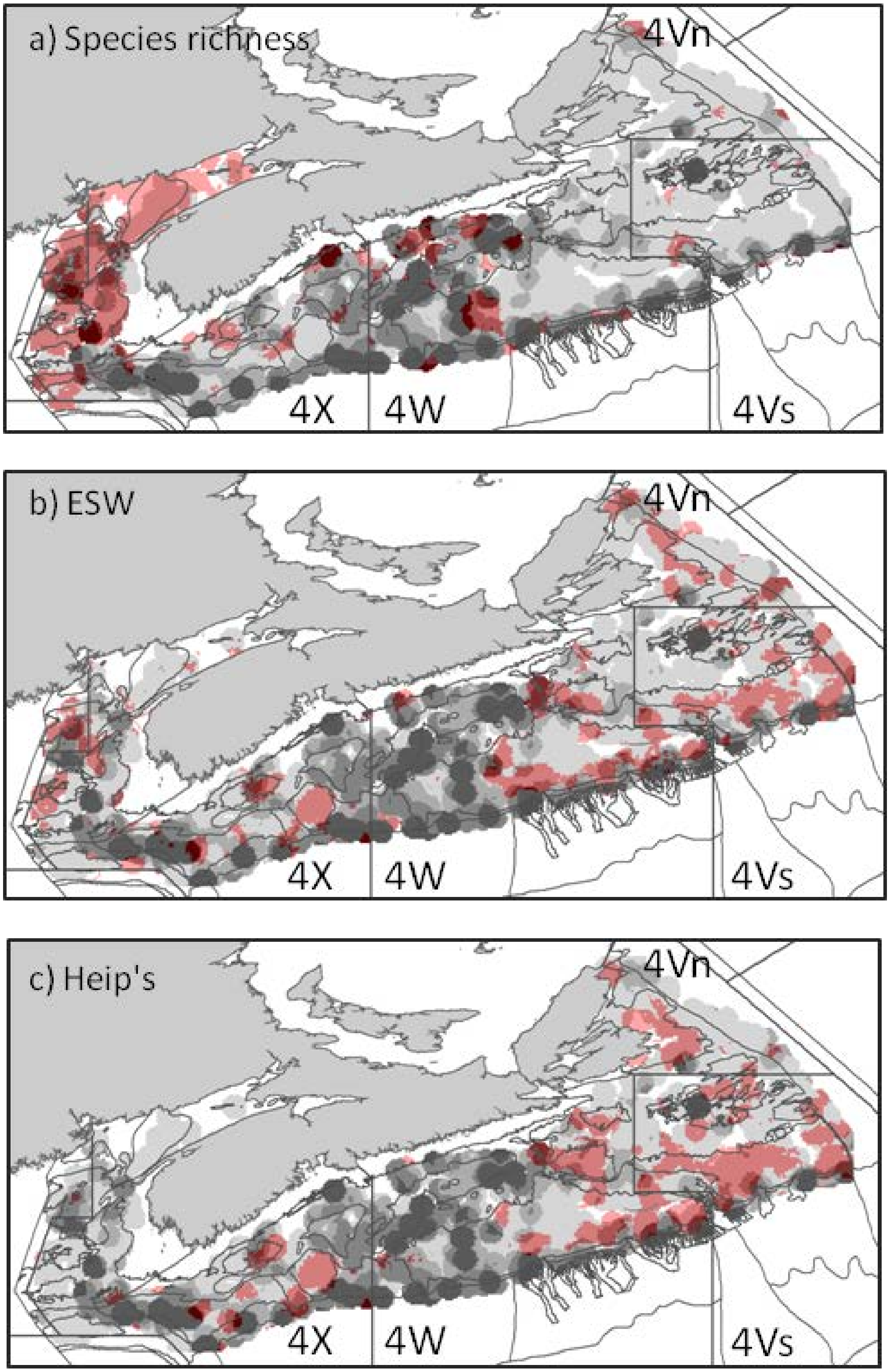


Figure 18. Invertebrate biodiversity and abundance of Short-fin Squid (Illex illecebrosus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

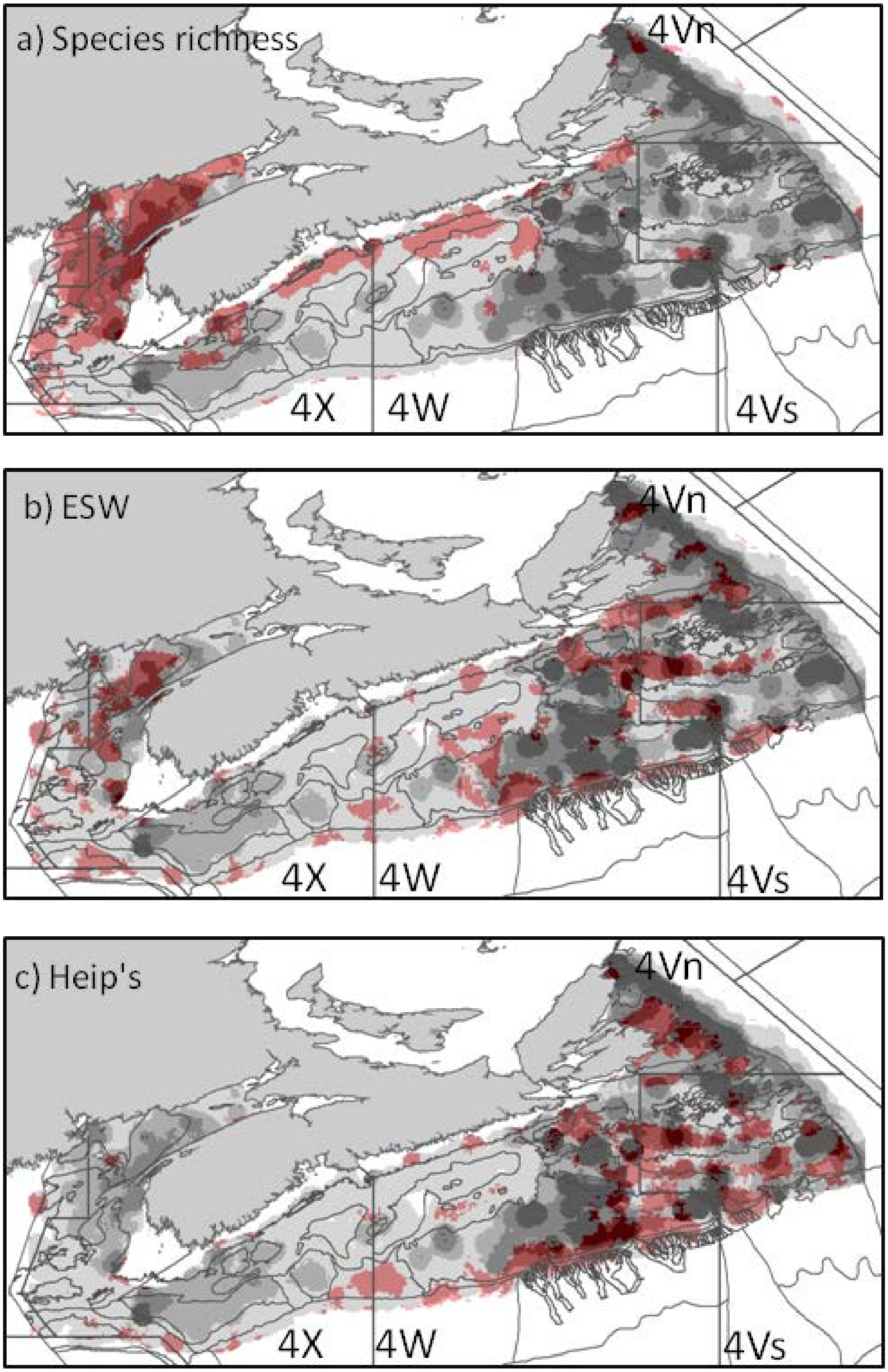


Figure 19. Fish biodiversity and abundance of Atlantic Cod (Gadus morhua) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

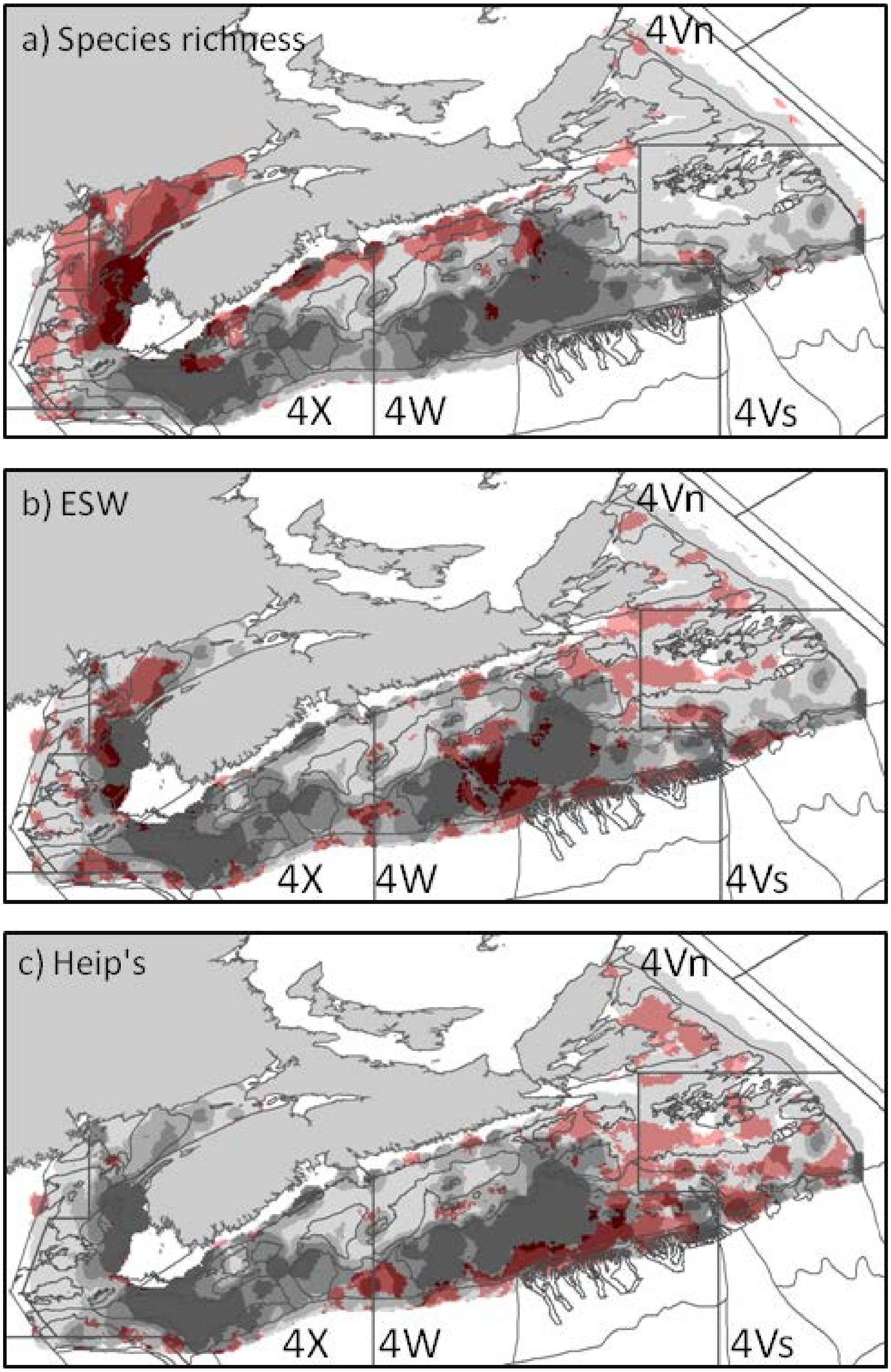


Figure 20. Fish biodiversity and abundance of Haddock (Melanogrammus aeglefinus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

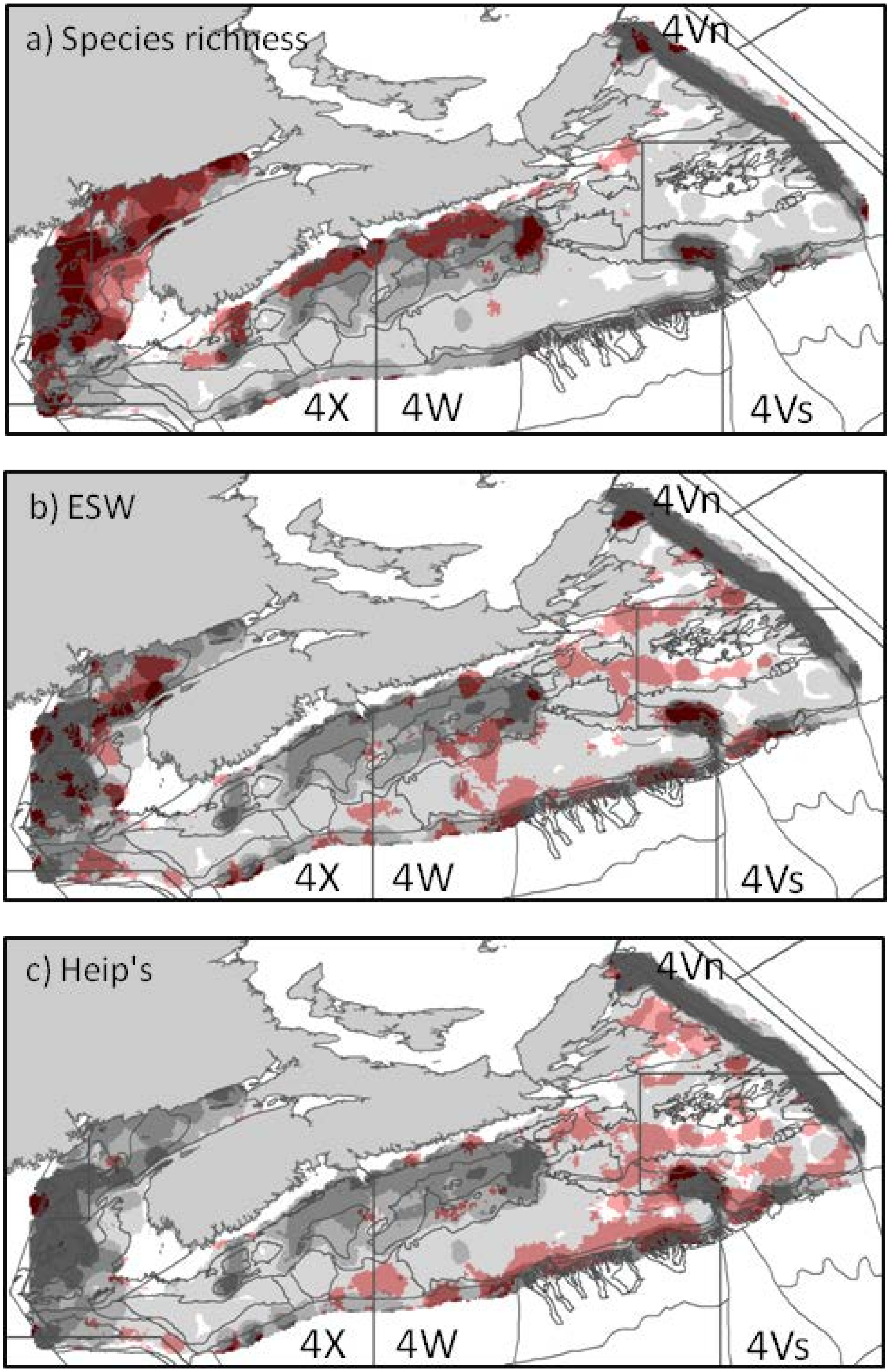


Figure 21. Fish biodiversity and abundance of White Hake (Urophycis tenuis) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

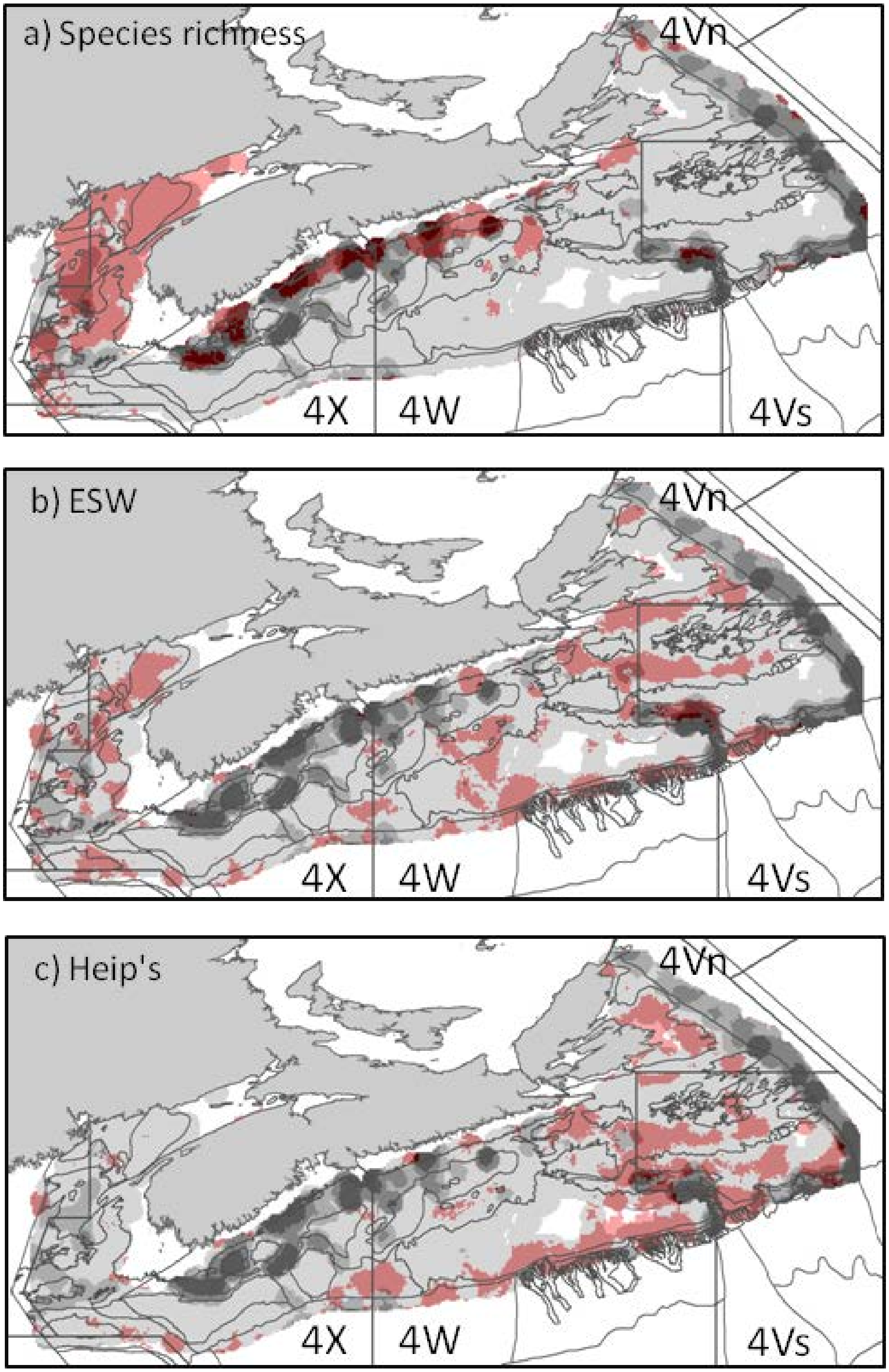


Figure 22. Fish biodiversity and abundance of Redfish (Sebastes spp.) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

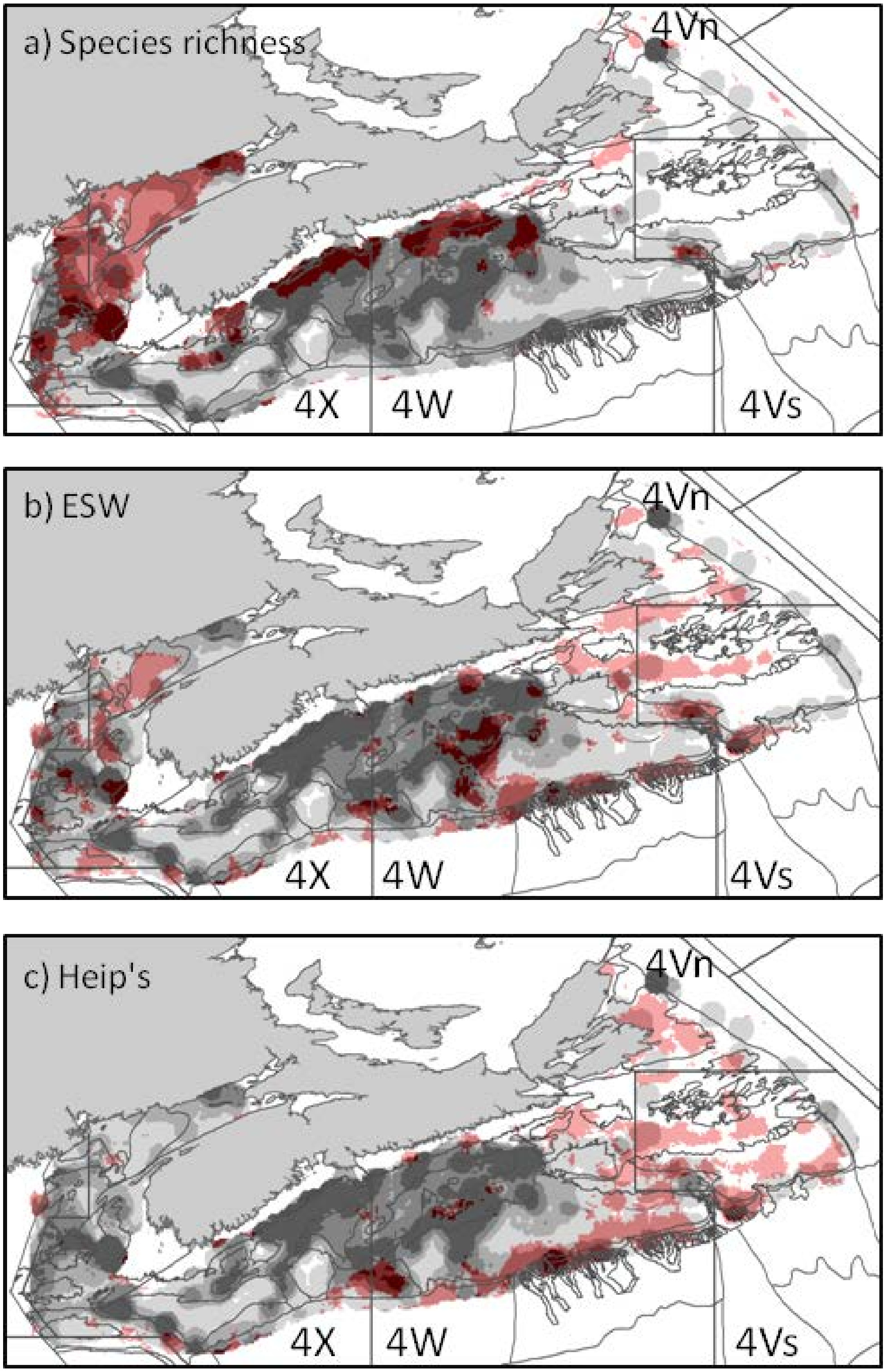


Figure 23. Fish biodiversity and abundance of Red Hake (Urophycis chuss) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

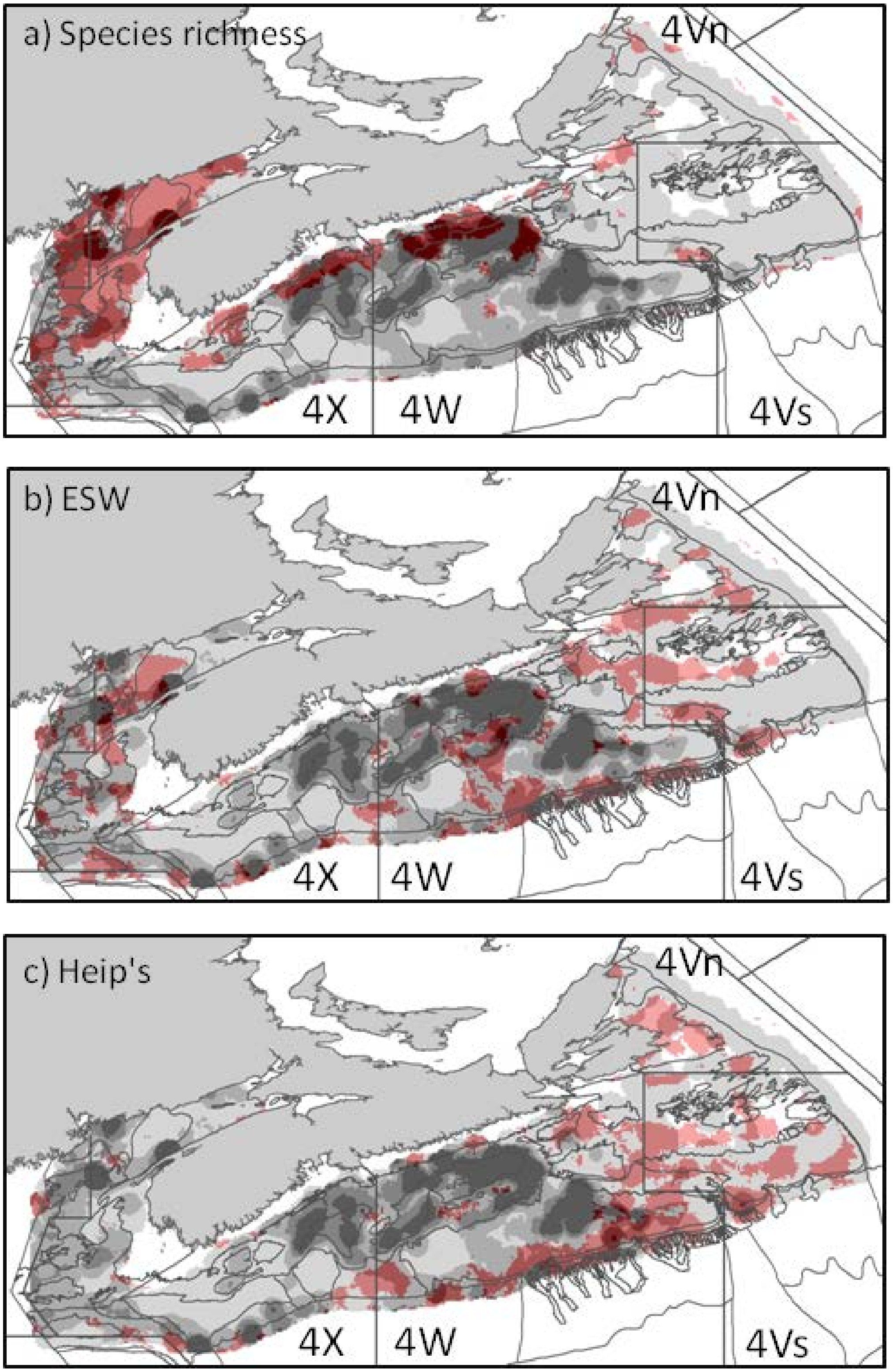


Figure 24. Fish biodiversity and abundance of Silver Hake (Merluccius bilinearis) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

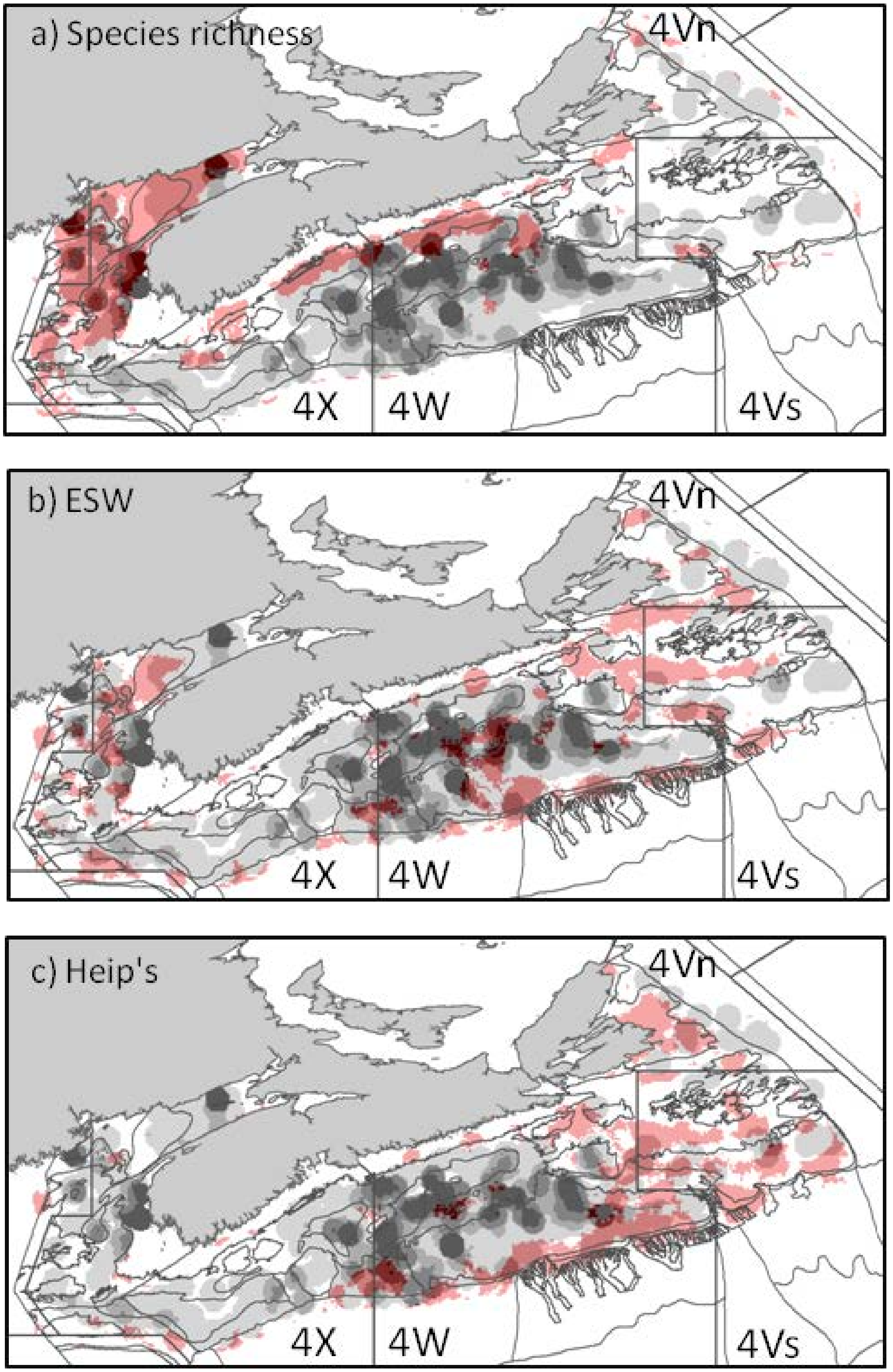


Figure 25. Fish biodiversity and abundance of Atlantic Mackerel (Scomber scombrus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

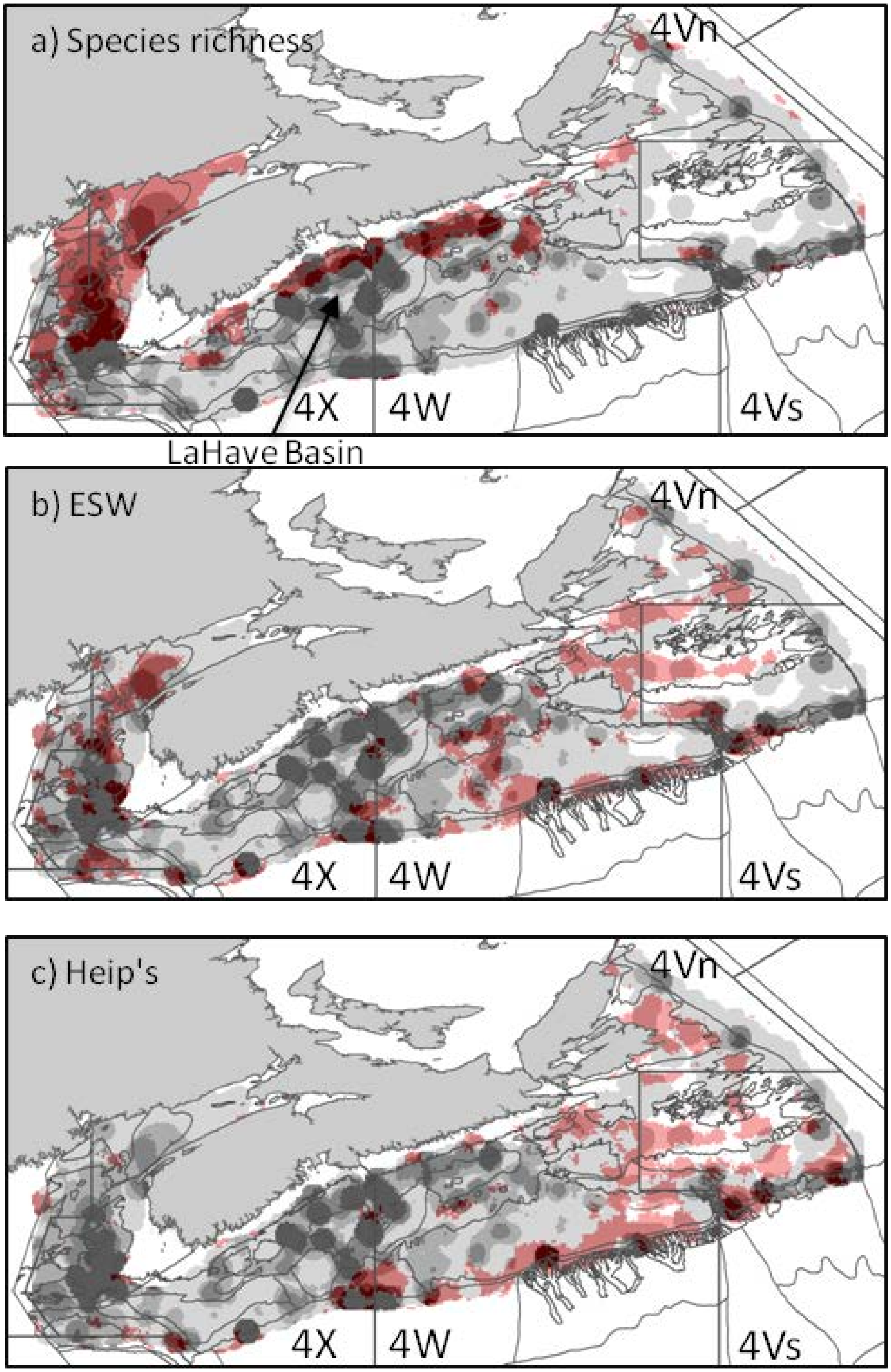


Figure 26. Fish biodiversity and abundance of Pollock (Pollachius virens) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

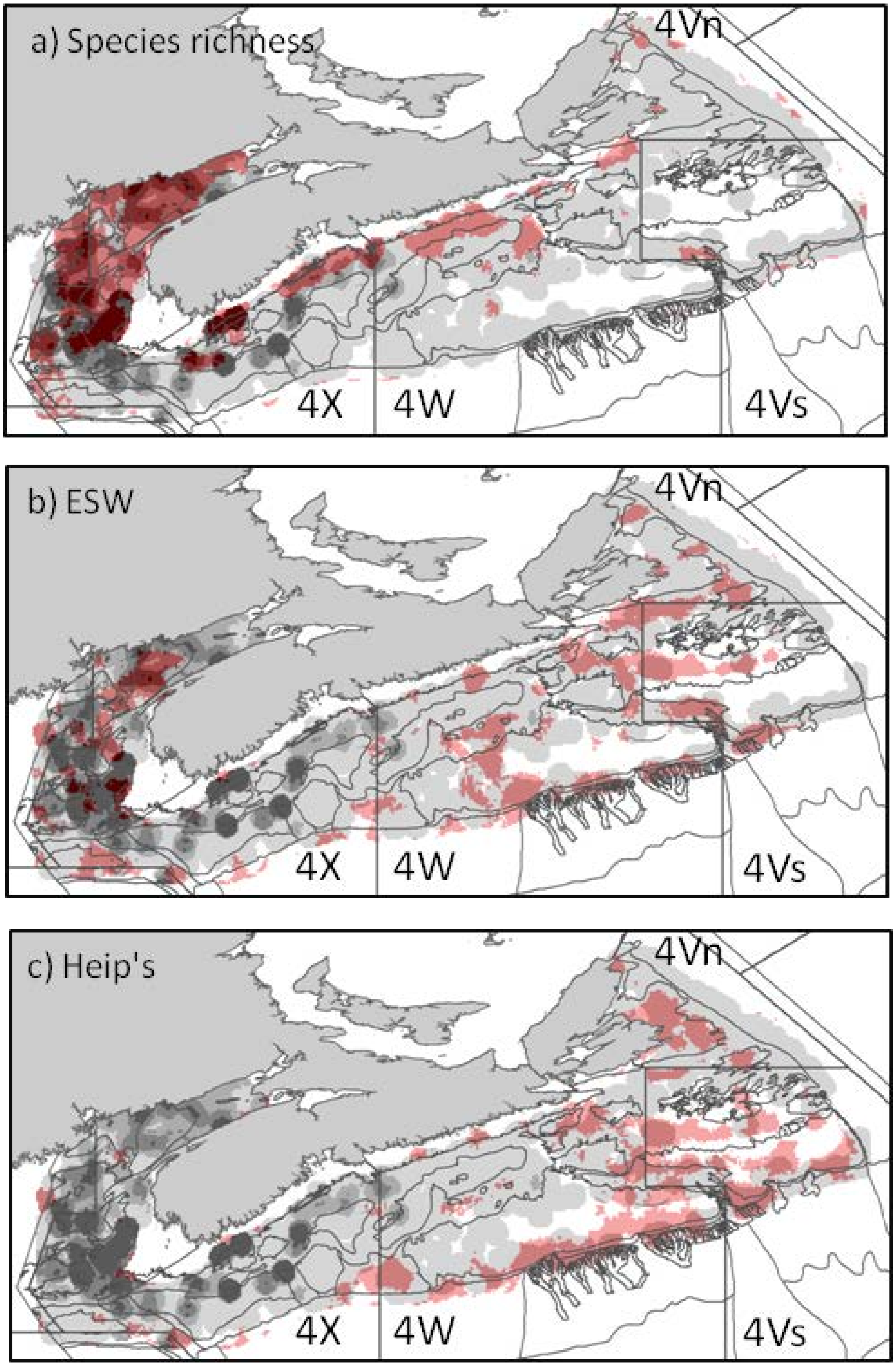


Figure 27. Fish biodiversity and abundance of Spiny Dogfish (Squalus acanthias) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

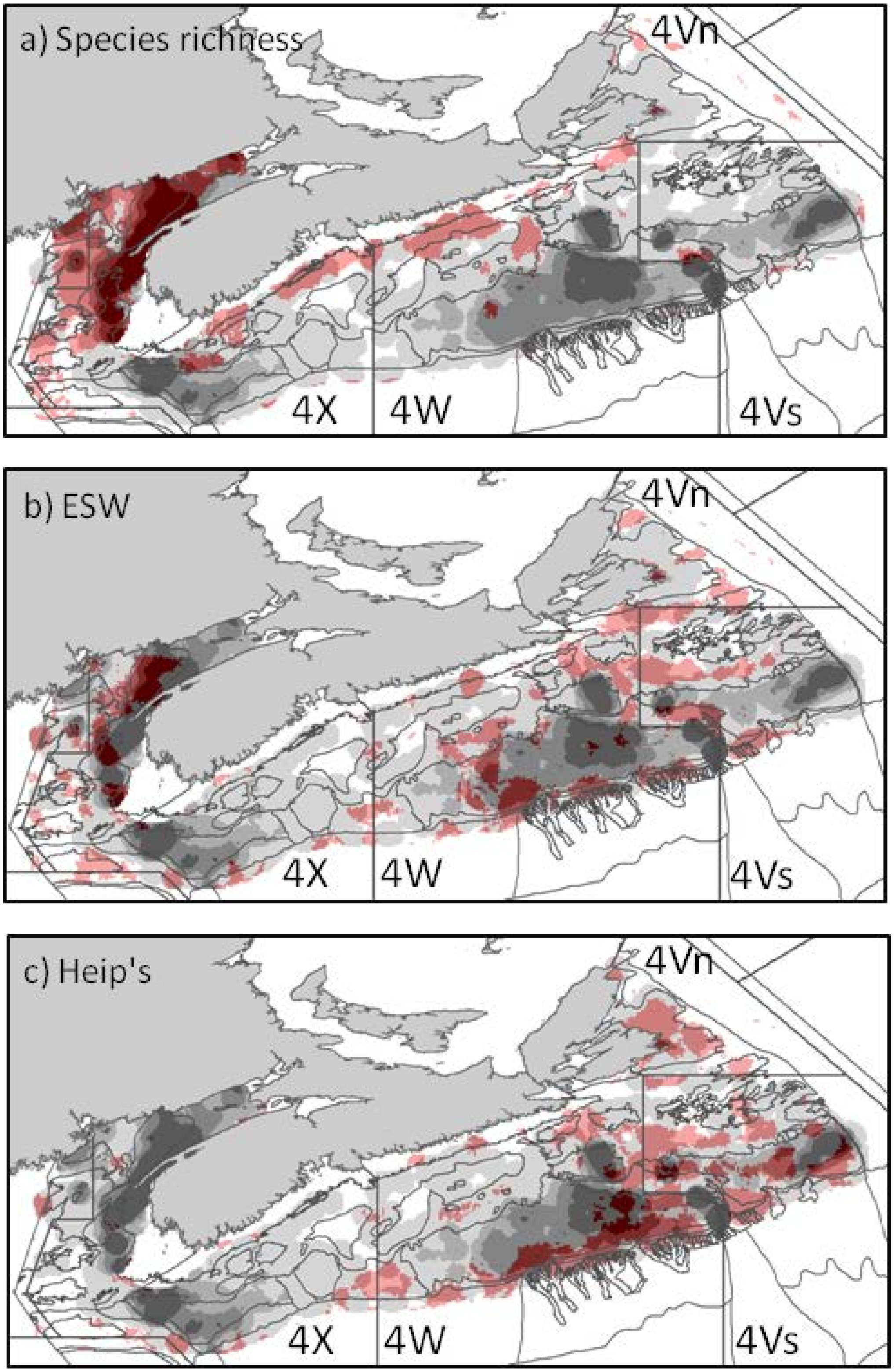


Figure 28. Fish biodiversity and abundance of Longhorn Sculpin (Myoxocephalus octodecemspinosus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

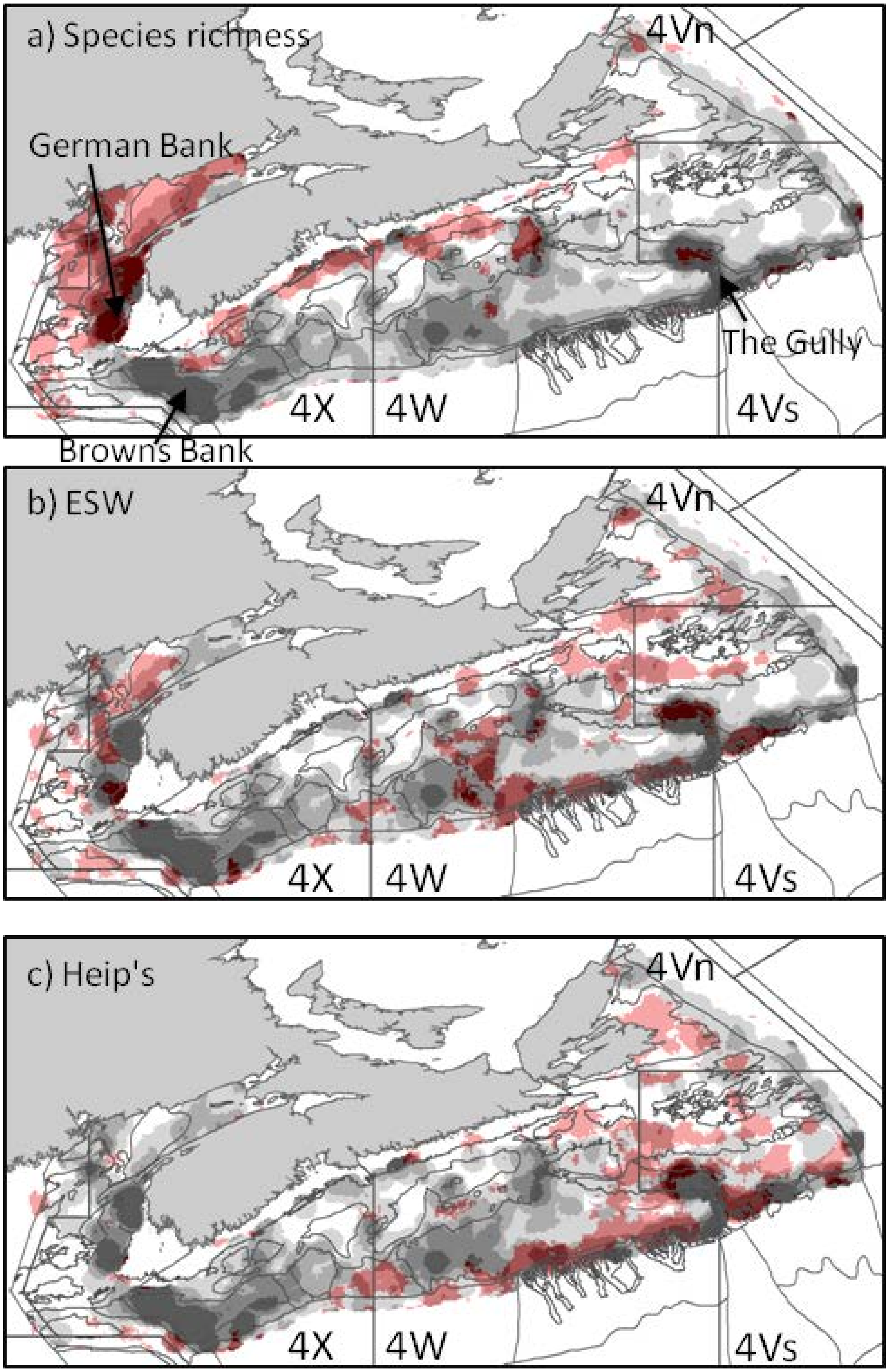


Figure 29. Fish biodiversity and abundance of Atlantic Halibut (Hippoglossus hippoglossus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

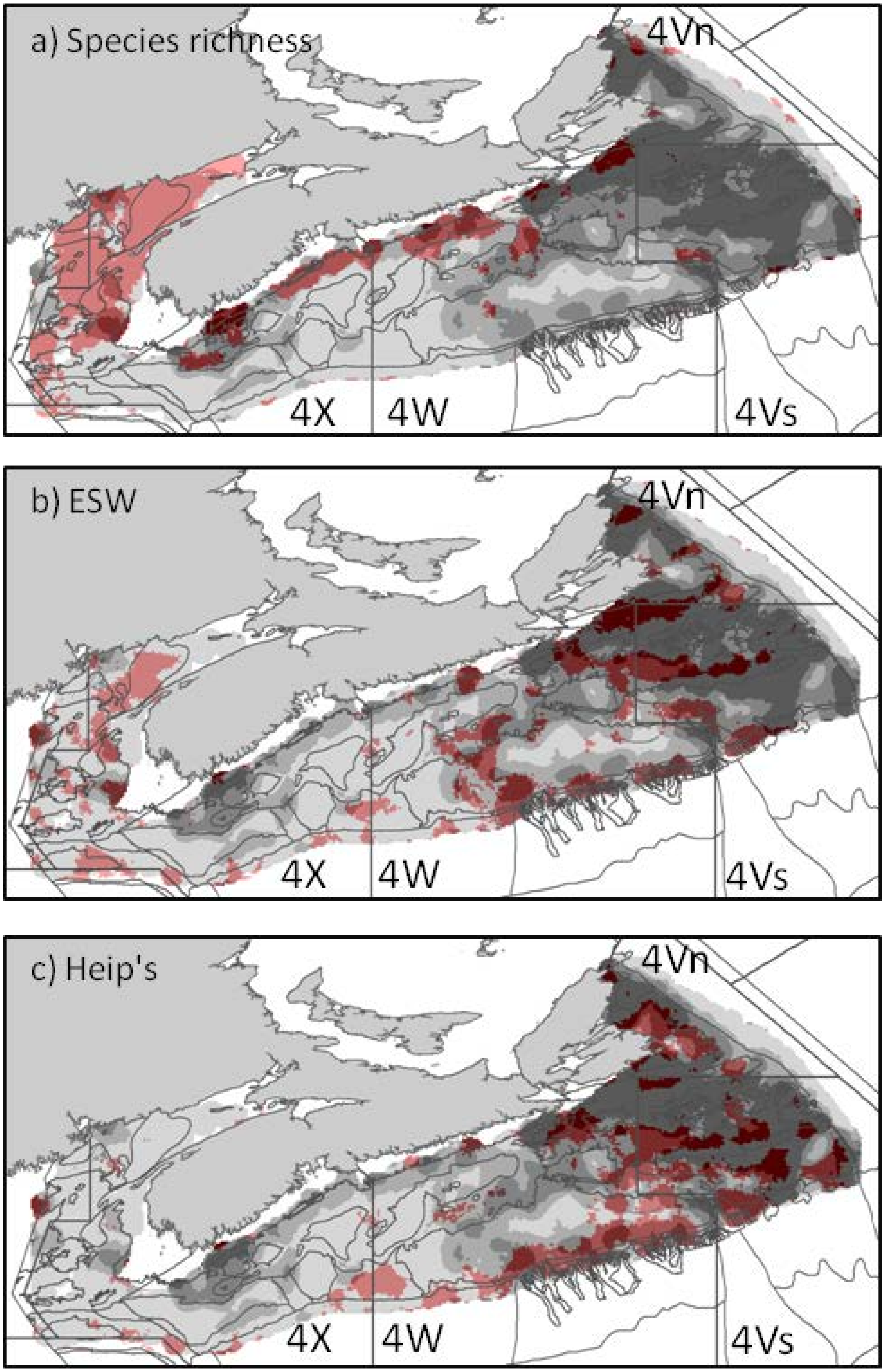


Figure 30. Fish biodiversity and abundance of American Plaice (Hippoglossoides platessoides) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

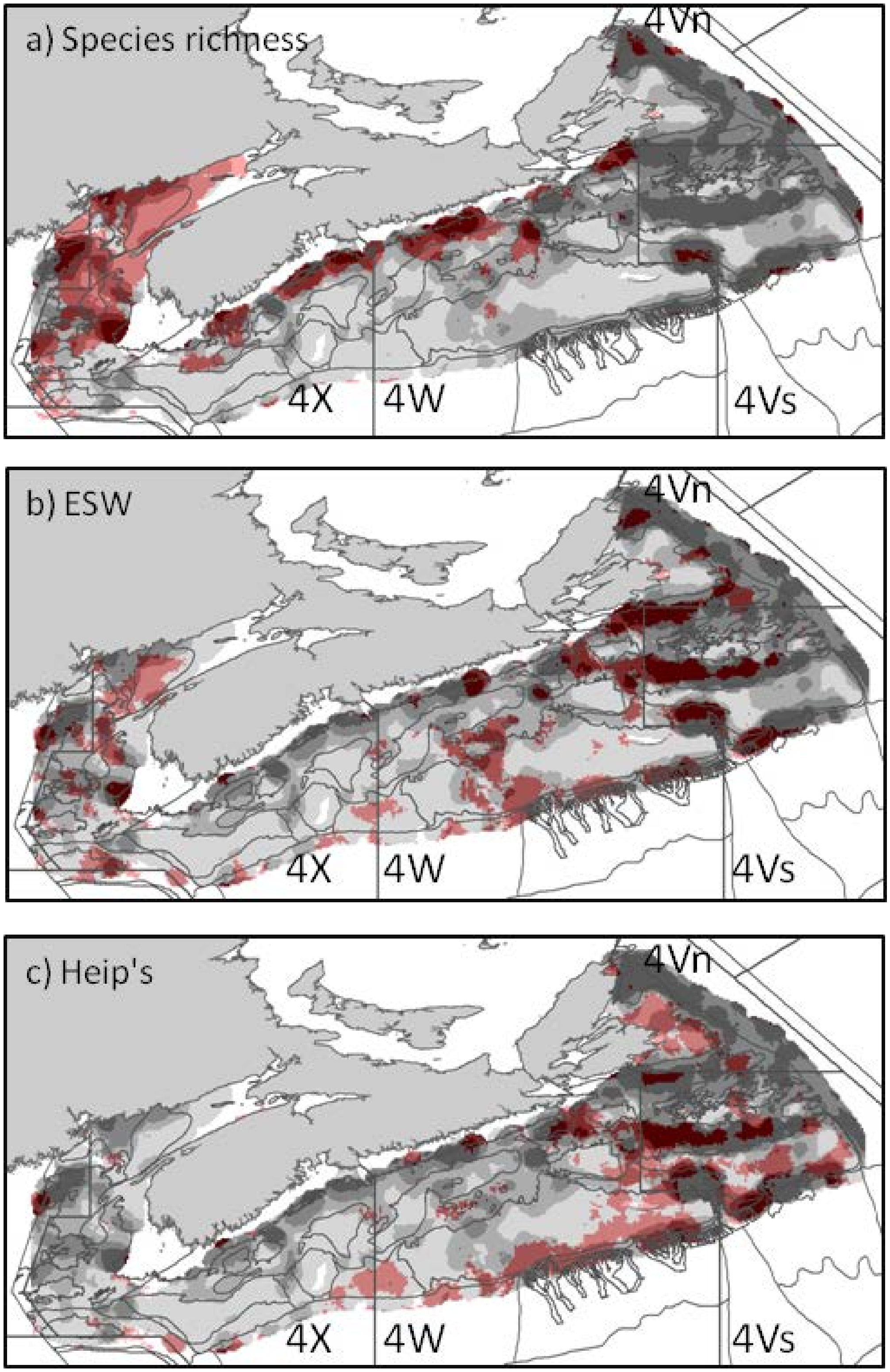


Figure 31. Fish biodiversity and abundance of Witch Flounder (Glyptocephalus cynoglossus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

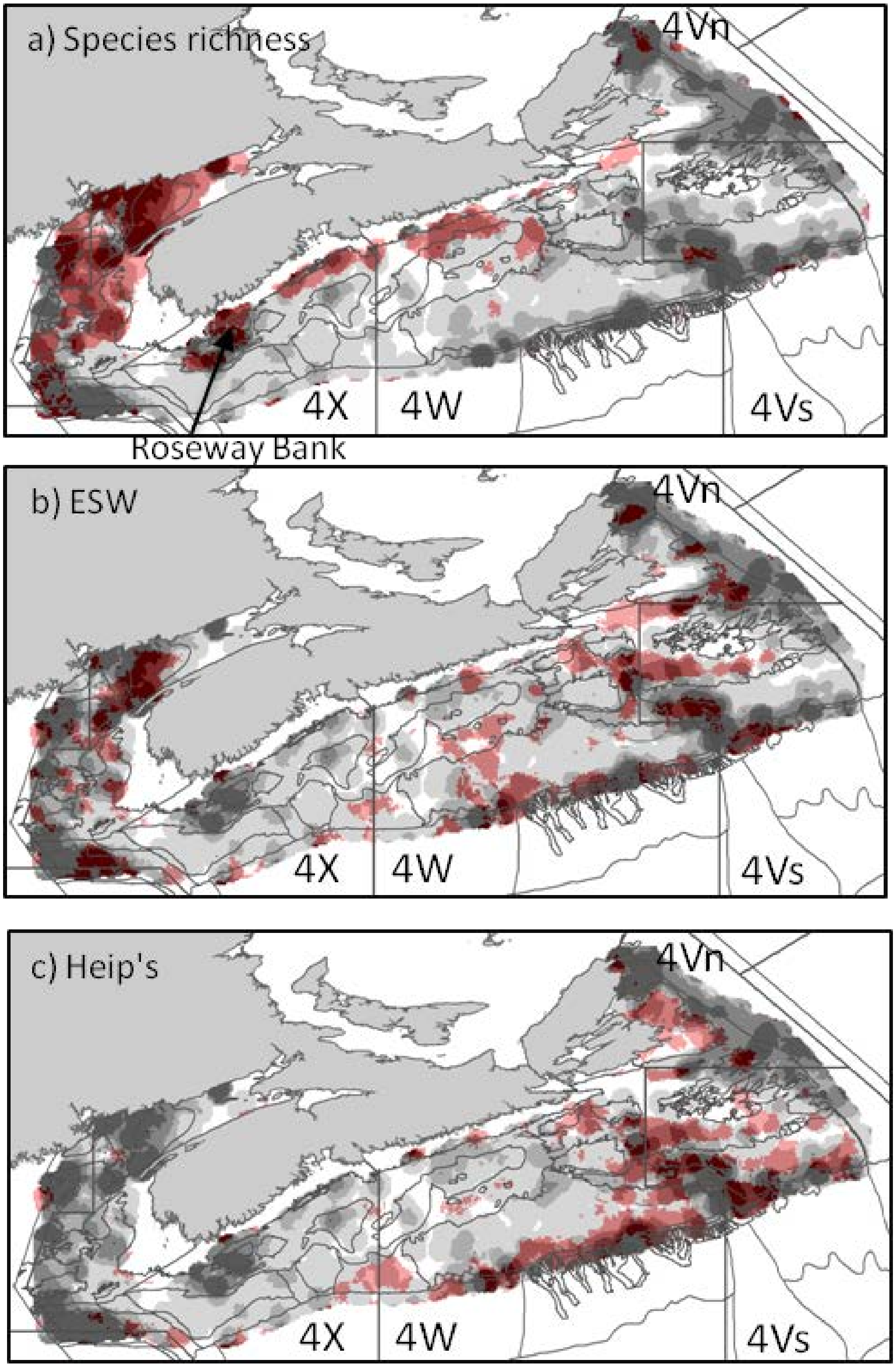


Figure 32. Fish biodiversity and abundance of Smooth Skate (Malacoraja senta) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

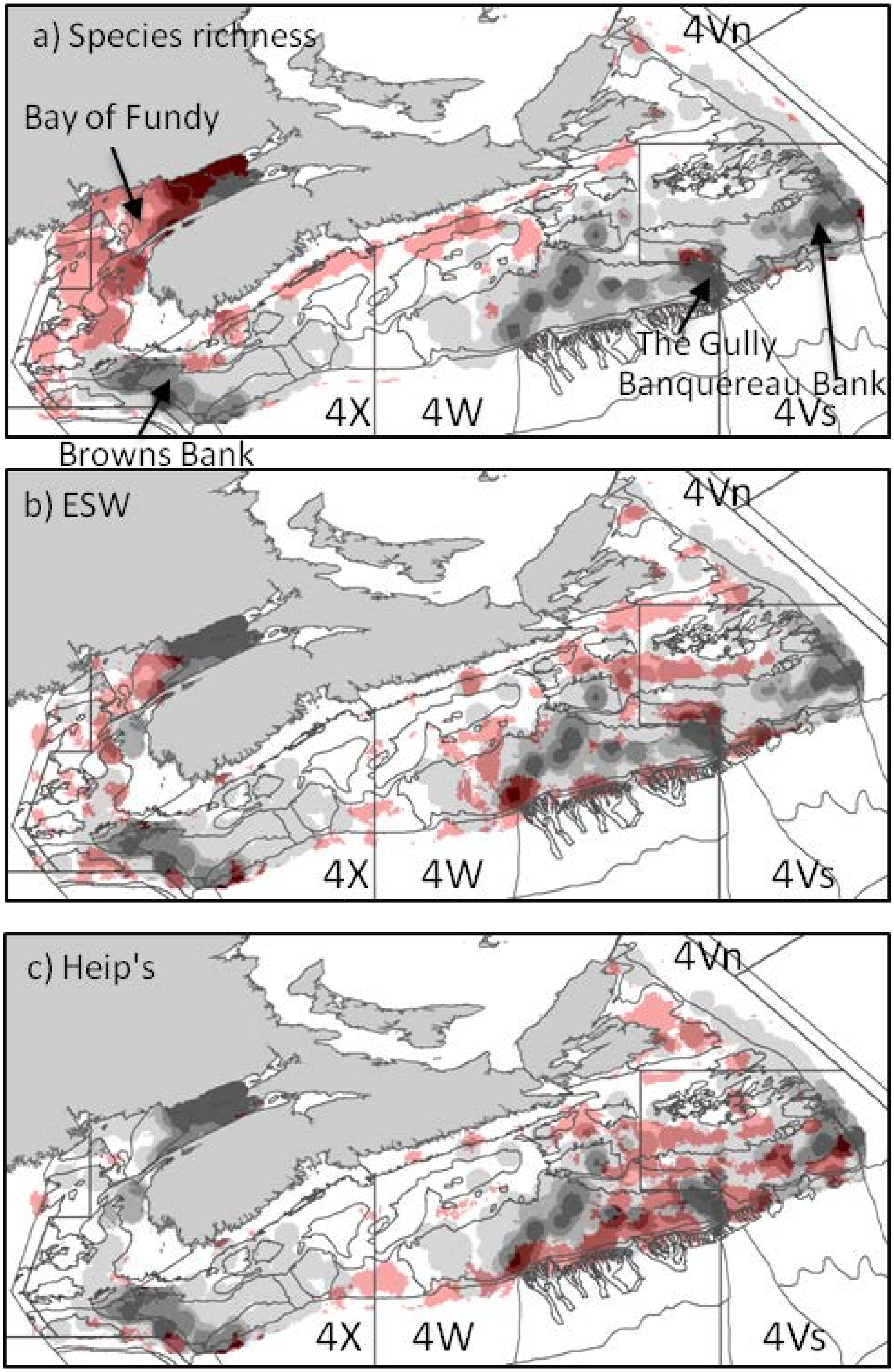


Figure 33. Fish biodiversity and abundance of Winter Skate (Leucoraja ocellata) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

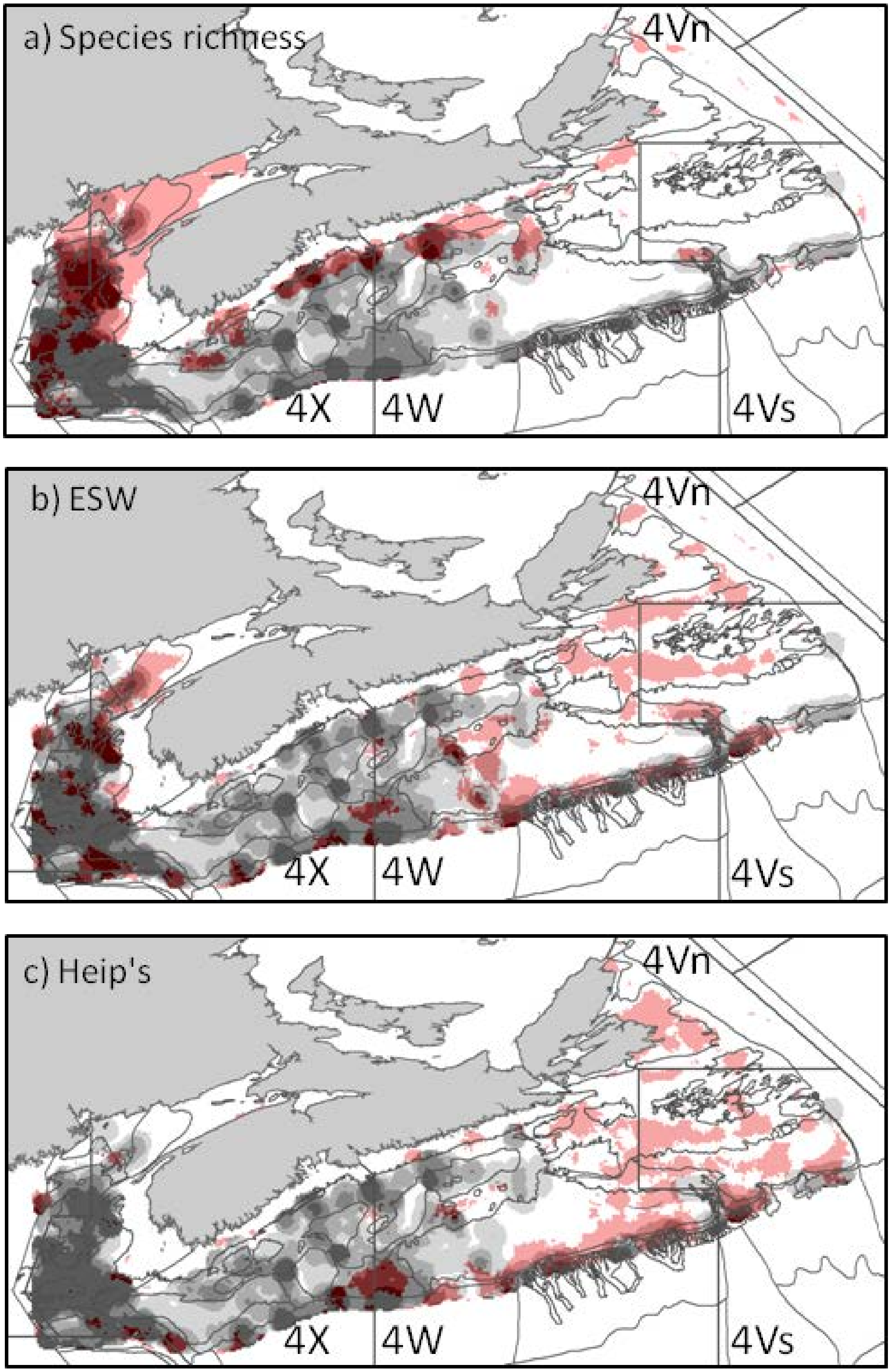


Figure 34. Fish biodiversity and abundance of Cusk (Brosme brosme) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

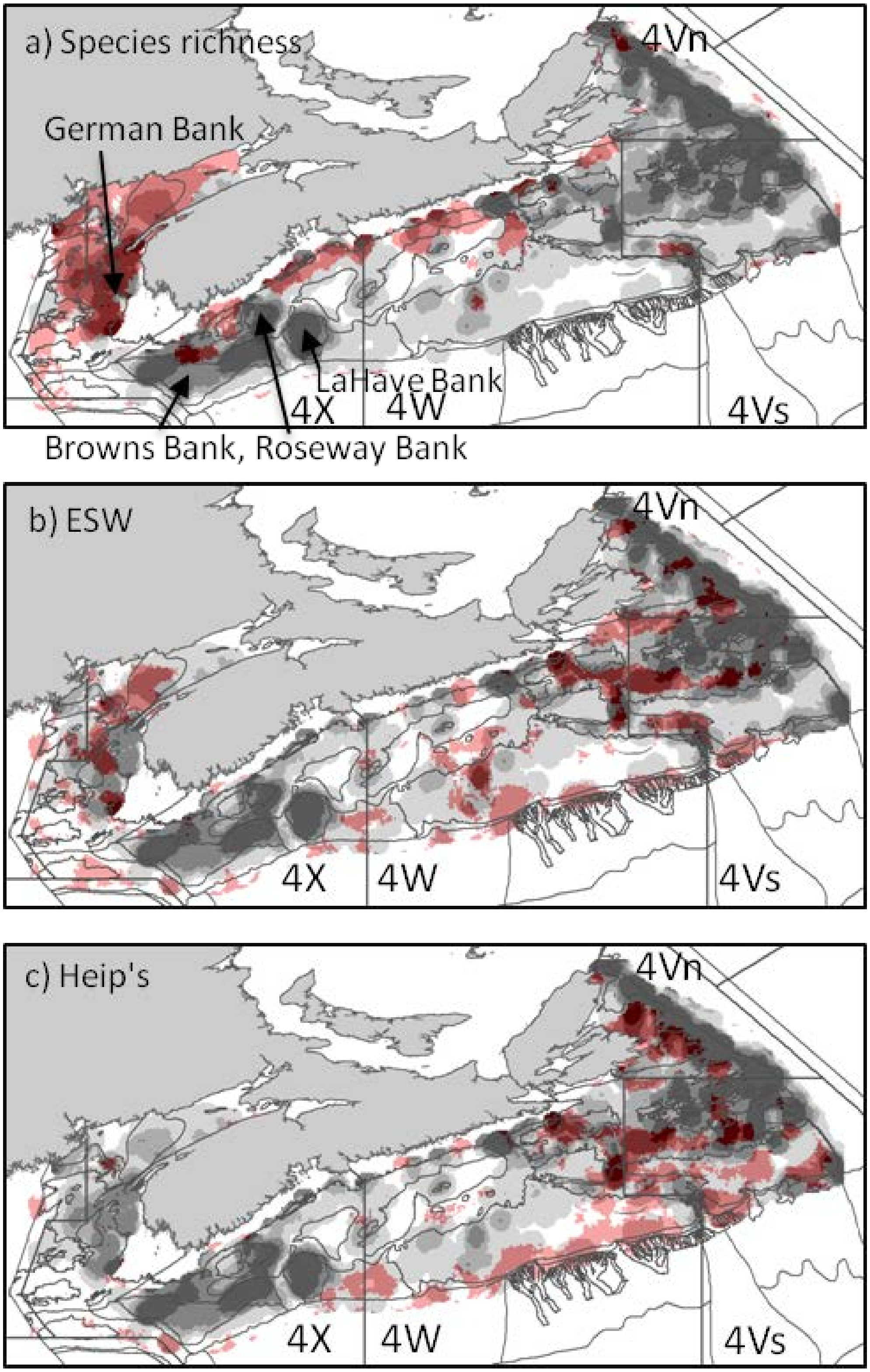


Figure 35. Fish biodiversity and abundance of Atlantic Wolffish (Anarhichas lupus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

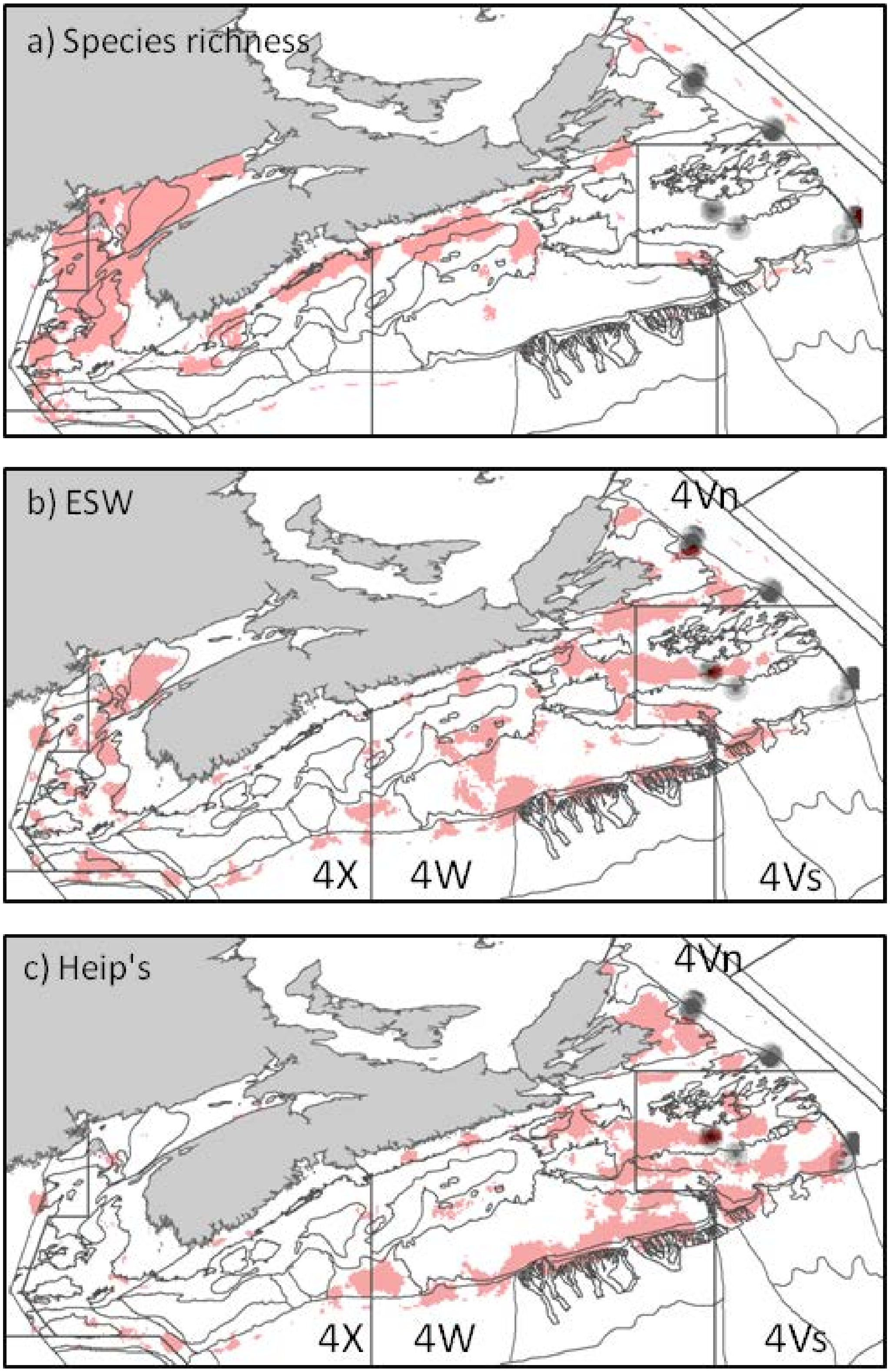


Figure 36. Fish biodiversity and abundance of Spotted Wolffish (Anarhichas minor) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

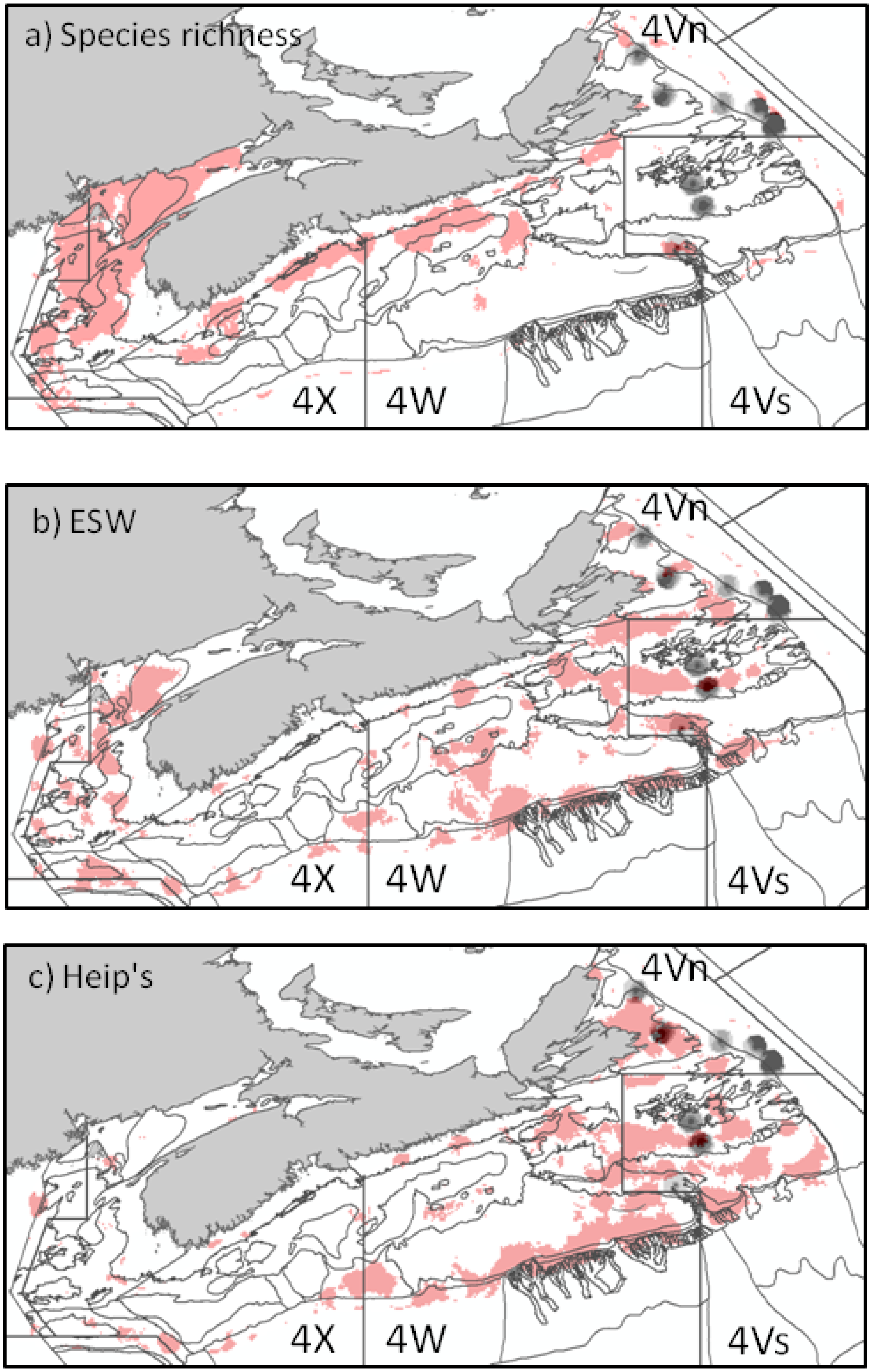


Figure 37. Fish biodiversity and abundance of Northern Wolffish (Anarhichas denticulatus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

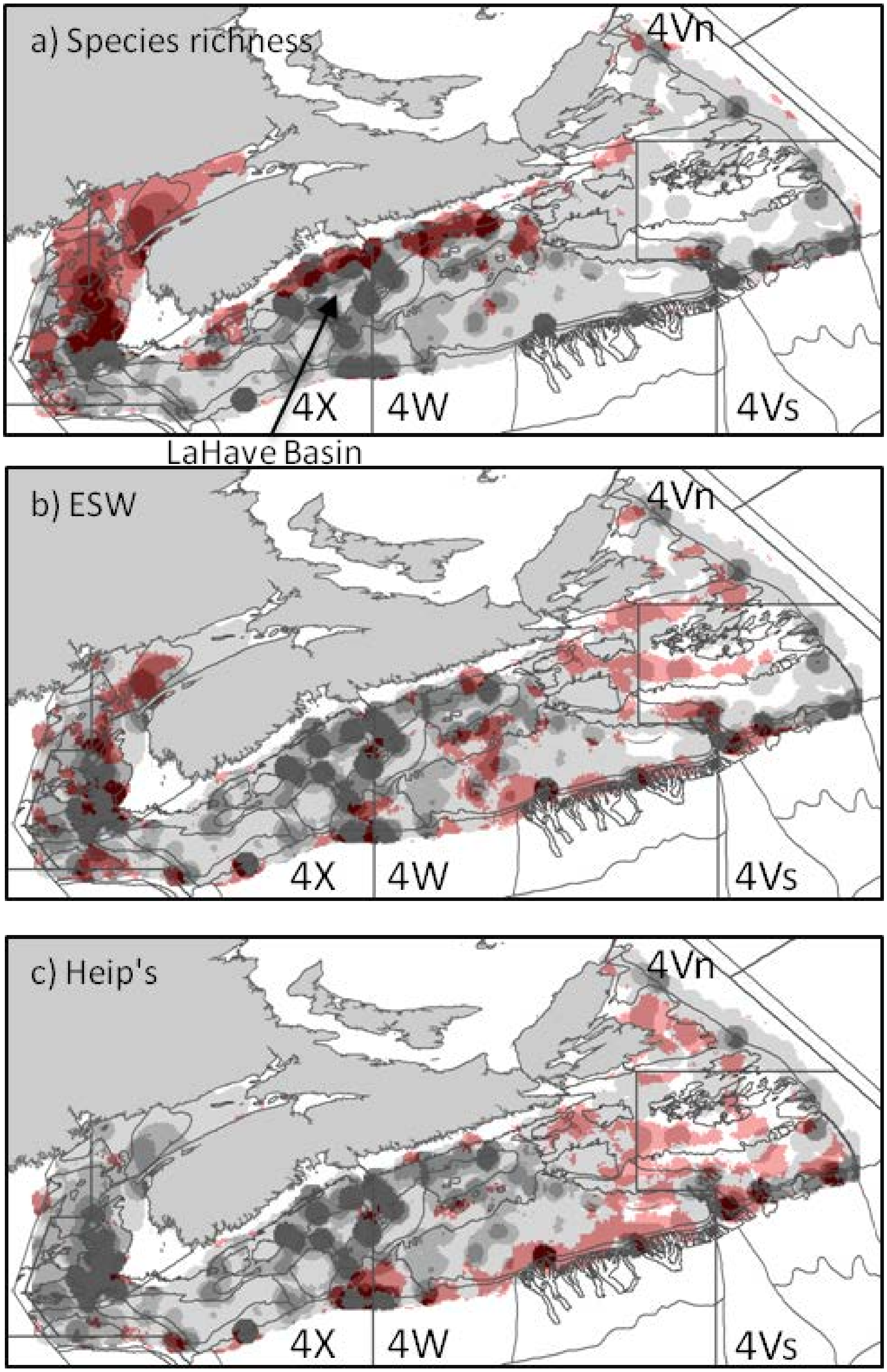


Figure 38. Fish biodiversity and abundance of Capelin (Mallotus villosus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

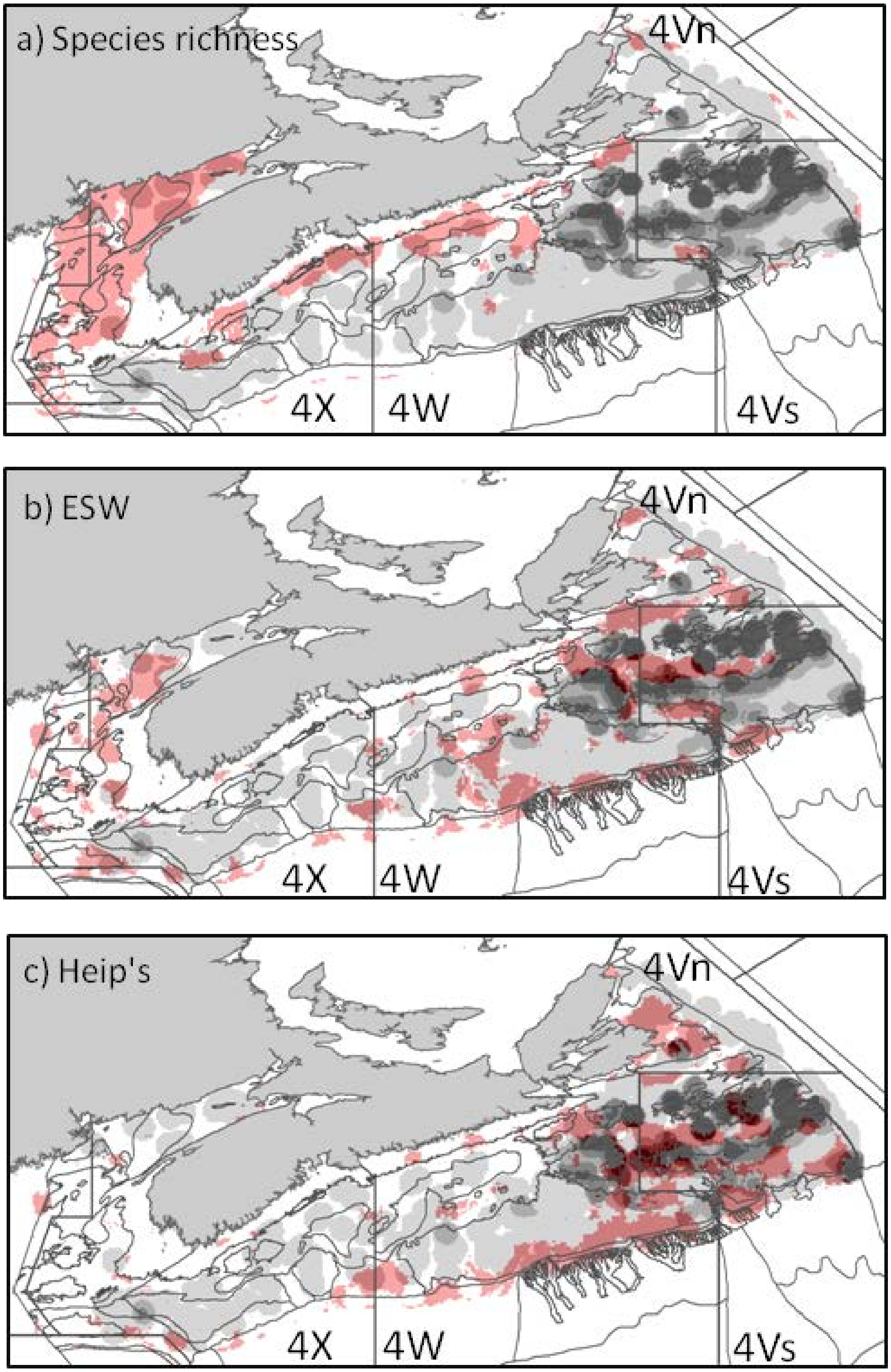


Figure 39. Fish biodiversity and abundance of Northern Sand Lance (Ammodytes dubius) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

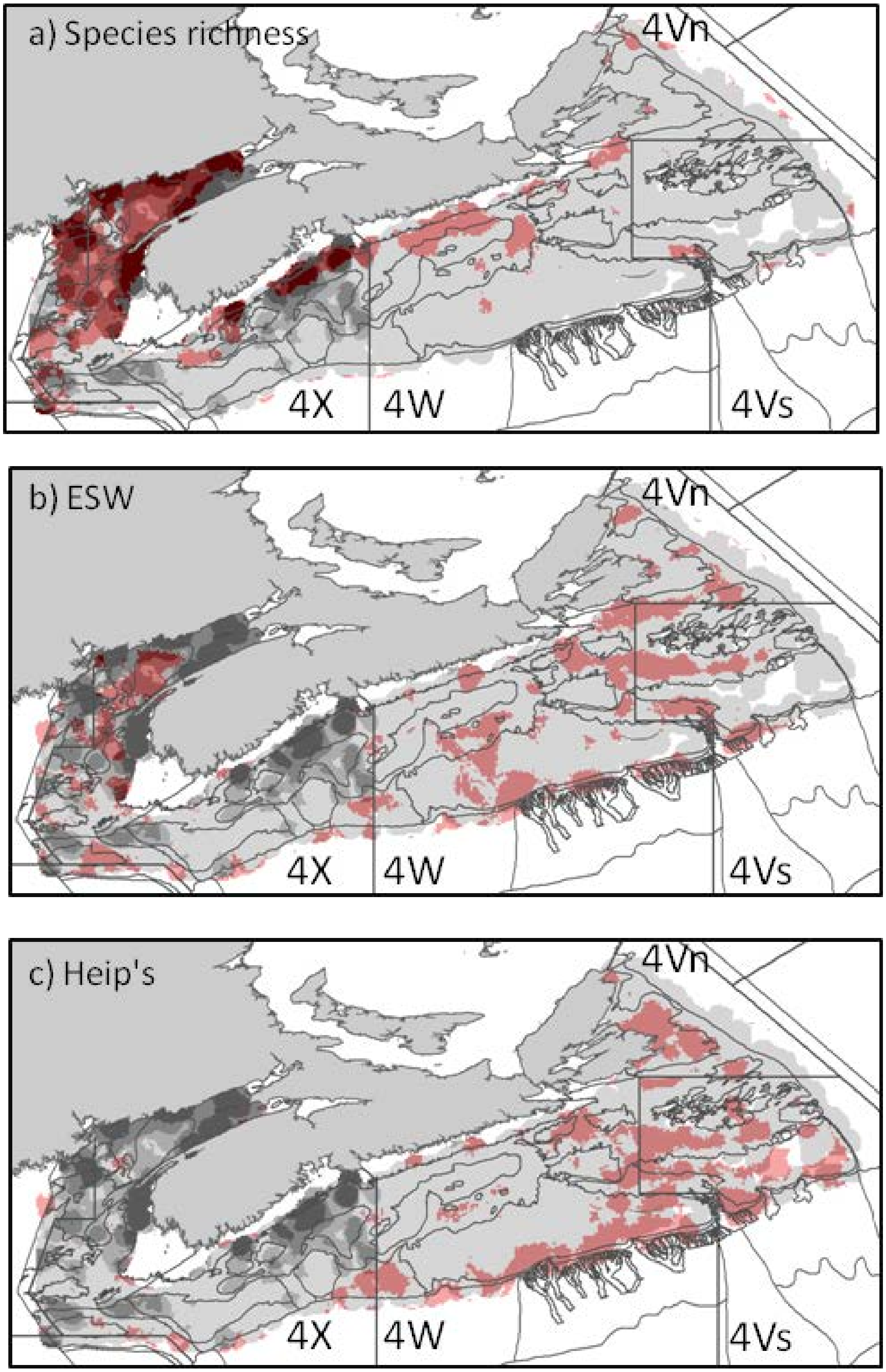


Figure 40. Fish biodiversity and abundance of Atlantic Herring (Clupea harengus) by: a) species richness; b) ESW; and c) Heip's Evenness Index. Areas of high biodiversity (top 20%) area shown in red, areas of high abundance are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

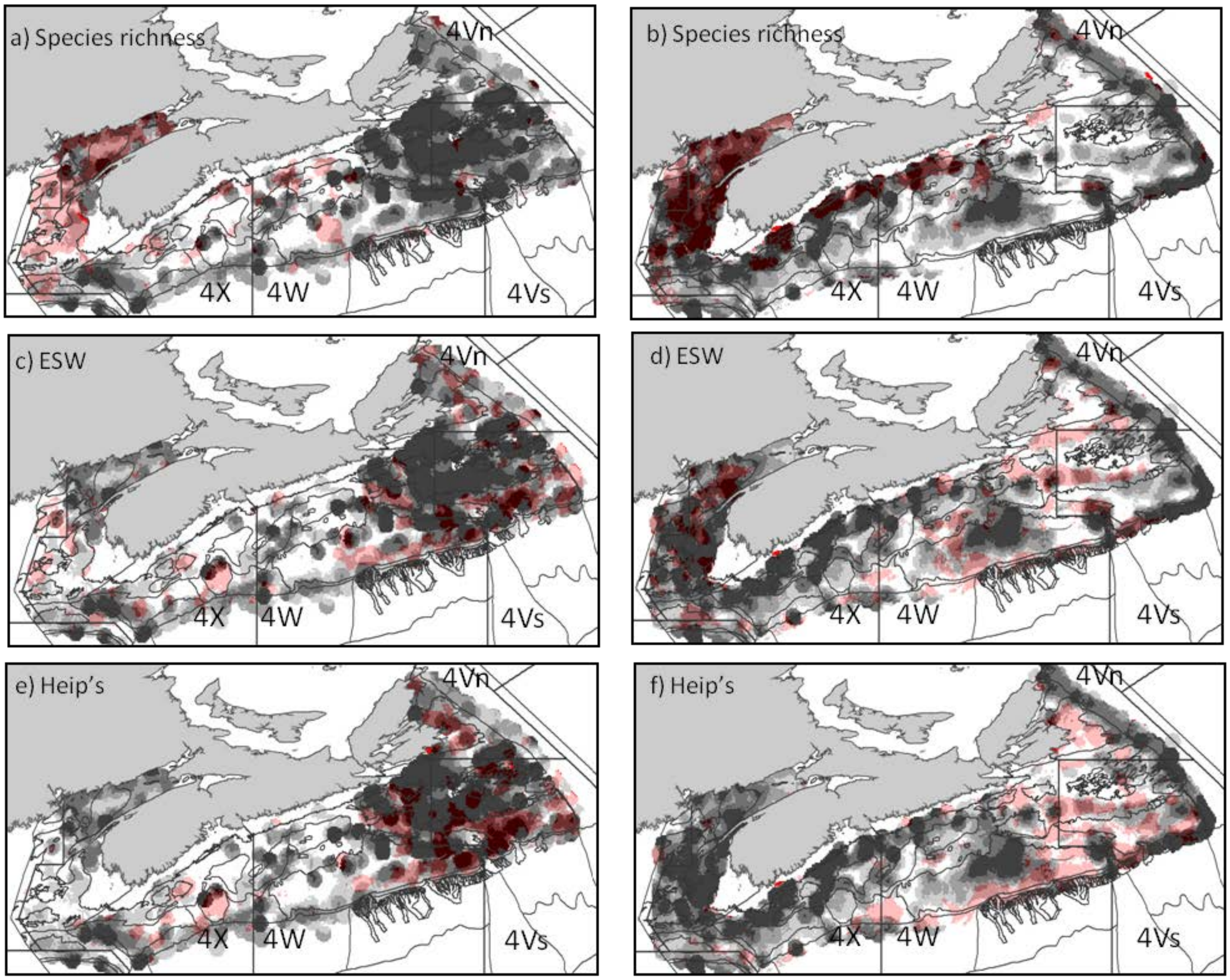


Figure 41. Areas of high biodiversity (in red) shown with biomass for invertebrates (1999-2012) in panels 'a', 'c', and 'e' and for fish (1970-2012) in panels 'b', 'd', and 'f, in kilograms per tow. Areas of high biomass are shown in shades of grey (darkest=top 20%, lightest = lowest 20%).

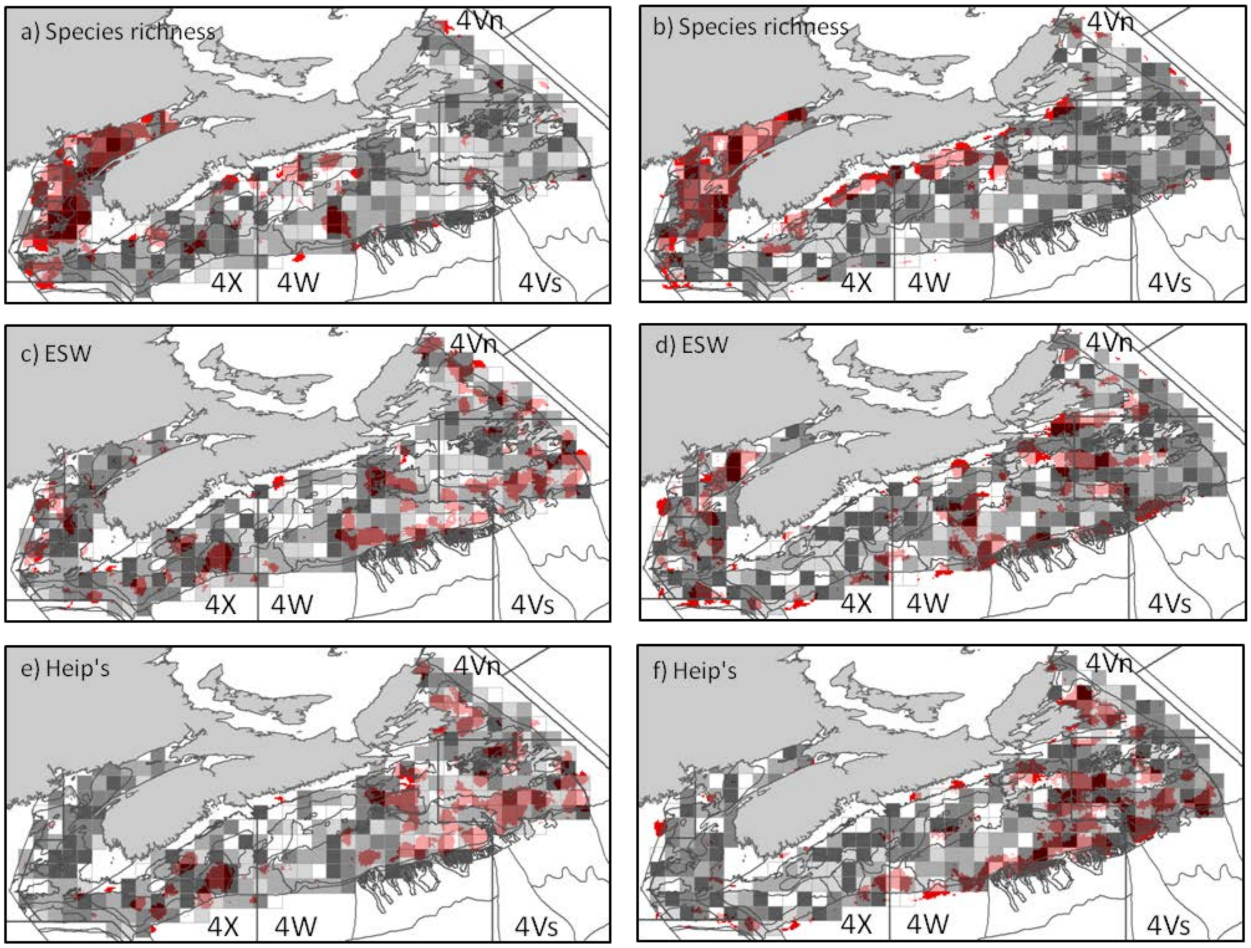


Figure 42. Invertebrate and fish biodiversity (top 20% shown in red), with diversity of invertebrates in panels 'a', 'c', and 'e' and for fish in panels 'b', 'd', and 'f', from the Food Habits dataset. Black cells are areas with higher than expected species richness.

APPENDICES

APPENDIX A

Species inclusion lists and additional details

Additional treatment of species for Scotian Shelf dataset

In addition to the method outlined in the main paper, the generic classification of “polychaetes” (3100) was also excluded because other polychaetes were identified to species/family/genus level.

Species codes 4380 (*Anomia simplex*) and 4381 (*Anomia* spp.) were treated as one category because they never occurred in the same year and most probably represent a change in protocol for identification.

The species codes for Sea Cucumber (*Cucumaria frondosa*) appear to have changed over time. Species code 6600 (Holothuroidea) was used until around 2009, and since then species code 6611 (*Cucumaria frondosa)* has been mostly used. This most probably represents a change in protocol for identification.

Table A1. Invertebrate species included for the Scotian Shelf biodiversity analysis.

Species	Name	Latin Name
1823	SEA POTATO	*Boltenia sp.*
1826	SEA GRAPES	*Molgula manhattensis*
1827	SEA PEACH	*Halocynthia pyriformis*
1900	BRYOZOANS P.	*Bryozoans p.*
2211	PANDALUS BOREALIS	*Pandalus borealis*
2212	PANDALUS MONTAGUI	*Pandalus montagui*
2213	PANDALUS PROPINQUUS	*Pandalus propinquus*
2221	P. MULTIDENTATA	*Pasiphaea multidentata*
2240	PALAEMONIDAE F.	*Palaemonidae f.*
2312	LEBBEUS POLARIS	*Lebbeus polaris*
2313	S. LILJEBORGII	*Spirontocaris liljeborgii*
2316	S. SPINUS	*Spirontocaris spinus*
2319	L. GROENLANDICUS	*Lebbeus groenlandicus*
2331	EUALUS MACILENTUS	*Eualus macilentus*
2332	EUALUS FABRICII	*Eualus fabricii*
2333	EUALUS GAIMARDII	*Eualus gaimardii*
2411	ARGIS DENTATA	*Argis dentata*
2414	S. BOREAS	*Sclerocrangon boreas*
2415	P. NORVEGICUS	*Pontophilus norvegicus*
2417	C. SEPTEMSPINOSA	*Crangon septemspinosa*
2420	SABINEA SP.	*Sabinea sp.*
2421	S. SEPTEMCARINATA	*Sabinea septemcarinata*
2511	JONAH CRAB	*Cancer borealis*
2513	ATL ROCK CRAB	*Cancer irroratus*
2519	SPIDER CRAB (NS)	*Majidae f.*
2521	HYAS COARCTATUS	*Hyas coarctatus*
2523	NORTHERN STONE CRAB	*Lithodes maja*
2525	SPINY CRAB	*Lithodes/neolithodes*
2526	SNOW CRAB (QUEEN)	*Chionoecetes opilio*
2527	TOAD CRAB	*Hyas araneus*
2528	SPINY SPIDER CRAB	*Neolithodes grimaldi*
2532	DEEP SEA RED CRAB	*Geryon quinquedens*
2541	AXIUS SERRATUS	*Axius serratus*
2550	AMERICAN LOBSTER	*Homarus americanus*
2555	MUNIDA IRIS	*Munida iris*
2559	HERMIT CRABS	*Paguridae f.*
2611	M. NORVEGICA	*Meganyctiphanes norvegica*
2811	GAMMARIDAE F.	*Gammaridae f.*
2995	BALANIDAE F.	*Balanidae f.*
3138	SABELLIDAE F.	*Sabellidae f.*
3200	SEA MOUSE	*Aphrodita hastata*
3501	L. SQUAMATUS	*Lepidonotus squamatus*
4211	WAVE WHELK,COMMON EDIBLE	*Buccinum undatum*
4212	SILKY BUCCINUM	*Buccinum scalariforme*
4221	MOONSHELL	*Lunatia heros*
4227	NEW ENGLAND NEPTUNE	*Neptunea decemcostata*
4228	SPINDLE SHELL	*Colus sp.*
4304	OCEAN QUAHAUG	*Arctica islandica*
4312	BANK CLAM	*Cyrtodaria siliqua*
4314	MORRHUA VENUSNA	*Pitar morrhuana*
4317	BAR,SURF CLAM	*Spisula solidissima*
4321	SEA SCALLOP	*Placopecten magellanicus*
4322	ICELAND SCALLOP	*Chlamys islandicus*
4331	COMMON MUSSELS	*Mytilus edulis*

Species	Name	Latin Name
4332	HORSE MUSSELS	*Modiolus modiolus*
4511	SHORT-FIN SQUID	*Illex illecebrosus*
4512	LONG-FINNED SQUID	*Loligo pealei*
4536	SEPIOLIDAE F.	*Sepiolodae f.*
5100	SEA SPIDER	*Pycnogonida s.p.*
6101	CEREMASTERNAGRANULARIS	*Ceremasternagranularis*
6102	PORANIA PULVILIS	*Porania pulvilis*
6109	ASTERIAS FORBESI	*Asterias forbesi*
6111	PURPLE STARFISH	*Asterias vulgaris*
6113	L. POLARIS	*Leptasterias polaris*
6114	LEPTASTERIAS SP.	*Leptasterias sp.*
6115	MUD STAR	*Ctenodiscus crispatus*
6116	PSEUDARCHASTER SP	*Pseudarchaster sp*
6117	H. PHRYGIANA	*Hippasteria phrygiana*
6119	BLOOD STAR	*Henricia sanguinolenta*
6121	PURPLE SUNSTAR	*Solaster endeca*
6123	SUN STAR	*Solaster papposus*
6125	PTERASTER MILITARIS	*Pteraster militaris*
6129	P. HISPIDA	*Poraniomorpha hispida*
6131	D. MULTIPES	*Diplopteraster multipes*
6201	OPHIACANTHANAABYSSICOLA	*Ophiacanthanaabyssicola*
6211	DAISY	*Ophiopholis aculeata*
6213	OPHIURA SARSI	*Ophiura sarsi*
6411	S. DROEBACHIENSIS	*Strongylocentrotus droebachiensis*
6413	HEART URCHIN	*Brisaster fragilis*
6421	PURPLE SEA URCHIN	*Arabacia punctulata*
6511	E. PARMA	*Echinarachnius parma*
8311	METRIDIUM SENILE	*Metridium senile*
8315	TEALIA FELINA	*Tealia felina*
8322	P. RESEDAEFORMIS	*Primnoa resedaeformis*
8323	PARAGORGIA ARBOREA	*Paragorgia arborea*
8324	SEA CAULIFLOWER	*Duva multiflora*
8325	GOLD-BANDED/BAMBOONACORAL	*Keratoisisnaornata*
8326	ACANTHOGORGIANAARMATA	*Acanthogorgianaarmata*
8329	ACANELLANAARBUSCULA	*Acanellanaarbuscula*
8330	RADICIPESNAGRACILIS	*Radicipesnagracilis*
8335	CUPNACORAL	*Flabellumnasp*
8336	DEAD MANS FINGERS	*Alcyonium digitatum*
8346	PSEUDARCHASTERNAPARELII	*Pseudarchasternaparelii*
8347	PSILASTERNAANDROMEDA	*Psilasternaandromeda*
8356	SPONGE	*Rhizaxinella sp.*
8364	GEODIA SPP.	*Geodia spp.*
8520	JELLYFISH	*Pelagia noctiluca*
8601	RUSSIANNAHATS	*Vazellanapourtalesi*
4380_4381	ANOMIA SIMPLEX + ANOMIA SP.	*Anomia simplex + anomia sp.*
6611_6600	SEA CUCUMBERS + CUCUMARIA FRONDOSA	*Holothuroidea c. + cucumaria frondosa*

Table A2. Fish species included for the Scotian Shelf biodiversity analysis.

Species	Name	Latin Name
10	COD(ATLANTIC)	*Gadus morhua*
11	HADDOCK	*Melanogrammus aeglefinus*
12	WHITE HAKE	*Urophycis tenuis*
13	SQUIRREL OR RED HAKE	*Urophycis chuss*
14	SILVER HAKE	*Merluccius bilinearis*
15	CUSK	*Brosme brosme*
16	POLLOCK	*Pollachius virens*
17	TOMCOD(ATLANTIC)	*Microgadus tomcod*
19	OFF-SHORE HAKE	*Merluccius albidus*
23	REDFISH UNSEPARATED	*Sebastes sp.*
30	HALIBUT(ATLANTIC)	*Hippoglossus hippoglossus*
31	TURBOT,GREENLAND HALIBUT	*Reinhardtius hippoglossoides*
40	AMERICAN PLAICE	*Hippoglossoides platessoides*
41	WITCH FLOUNDER	*Glyptocephalus cynoglossus*
42	YELLOWTAIL FLOUNDER	*Limanda ferruginea*
43	WINTER FLOUNDER	*Pseudopleuronectes americanus*
44	GULF STREAM FLOUNDER	*Citharichthys arctifrons*
50	STRIPED ATL WOLFFISH	*Anarhichas lupus*
51	SPOTTED WOLFFISH	*Anarhichas minor*
52	NORTHERN WOLFFISH	*Anarhichas denticulatus*
60	HERRING(ATLANTIC)	*Clupea harengus*
61	SHAD AMERICAN	*Alosa sapidissima*
62	ALEWIFE	*Alosa pseudoharengus*
63	RAINBOW SMELT	*Osmerus mordax mordax*
64	CAPELIN	*Mallotus villosus*
70	MACKEREL(ATLANTIC)	*Scomber scombrus*
111	SPOTTED HAKE	*Urophycis regia*
112	LONGFIN HAKE	*Phycis chesteri*
114	FOURBEARD ROCKLING	*Enchelyopus cimbrius*
115	THREEBEARD ROCKLING	*Gaidropsarus ensis*
118	GREENLAND COD	*Gadus ogac*
122	CUNNER	*Tautogolabrus adspersus*
123	ROSEFISH(BLACK BELLY)	*Helicolenus dactylopterus*
141	SUMMER FLOUNDER	*Paralichthys dentatus*
142	FOURSPOT FLOUNDER	*Paralichthys oblongus*
143	BRILL/WINDOWPANE	*Scophthalmus aquosus*
149	LONGNOSE GREENEYE	*Parasudis truculenta*
156	SHORT-NOSE GREENEYE	*Chlorophthalmus agassizi*
158	MULLER'S PEARLSIDES	*Maurolicus muelleri*
159	BOA DRAGONFISH	*Stomias boa ferox*
160	ARGENTINE (ATL)	*Argentina silus*
163	LANTERNFISH,HORNED	*Ceratoscopelus maderensis*
165	BLUEBACK HERRING	*Alosa aestivalis*
169	VIPERFISH	*Chauliodus sloani*
200	BARNDOOR SKATE	*Dipturus laevis*
201	THORNY SKATE	*Amblyraja radiata*
202	SMOOTH SKATE	*Malacoraja senta*
203	LITTLE SKATE	*Leucoraja erinacea*
204	WINTER SKATE	*Leucoraja ocellata*
216	ATLANTIC TORPEDO	*Torpedo nobiliana*
220	SPINY DOGFISH	*Squalus acanthias*
221	BLACK DOGFISH	*Centroscyllium fabricii*
240	SEA LAMPREY	*Petromyzon marinus*

Species	Name	Latin Name
241	ATLANTIC HAGFISH	*Myxine glutinosa*
300	LONGHORN SCULPIN	*Myoxocephalus octodecemspinosus*
301	SHORTHORN SCULPIN	*Myoxocephalus scorpius*
302	ARCTIC STAGHORN SCULPIN	*Gymnocanthus tricuspis*
303	GRUBBY(LITTLE)	*Myoxocephalus aeneus*
304	MOUSTACHE (MAILED) SCULPIN	*Triglops murrayi*
306	ARCTIC HOOKEAR SCULPIN	*Artediellus uncinatus*
307	POLAR SCULPIN	*Cottunculus microps*
308	PALLID SCULPIN	*Cottunculus thompsoni*
313	TWOHORN SCULPIN	*Icelus bicornis*
314	SPATULATE SCULPIN	*Icelus spatula*
316	ARCTIC SCULPIN	*Myoxocephalus scorpioides*
317	RIBBED SCULPIN	*Triglops pingeli*
320	SEA RAVEN	*Hemitripterus americanus*
331	ARMORED SEA ROBIN	*Peristedion miniatum*
340	ALLIGATORFISH	*Aspidophoroides monopterygius*
341	ARCTIC ALLIGATORFISH	*Uleina olrikii*
350	ATL SEA POACHER	*Leptagonus decagonus*
400	MONKFISH,GOOSEFISH,ANGLER	*Lophius americanus*
409	AMER STRAPTAIL GRENADIER	*Malacocephalus occidentalis*
410	MARLIN-SPIKE GRENADIER	*Nezumia bairdii*
411	ROUGHHEAD GRENADIER	*Macrourus berglax*
412	ROUGHNOSE GRENADIER	*Trachyrhynchus murrayi*
414	ROCK GRENADIER(ROUNDNOSE)	*Coryphaenoides rupestris*
501	LUMPFISH	*Cyclopterus lumpus*
502	ATL SPINY LUMPSUCKER	*Eumicrotremus spinosus*
503	ATLANTIC SEASNAIL	*Liparis atlanticus*
505	SEASNAIL,GELATINOUS	*Liparis fabricii*
508	INQUILINE SEASNAIL	*Liparis inquilinus*
512	SEASNAIL,DUSKY	*Liparis gibbus*
520	SEA TADPOLE	*Careproctus reinhardi*
595	RED DORY	*Cyttus roseus*
602	GRAY'S CUTTHROAT EEL	*Synaphobranchus kaupi*
603	WOLF EELPOUT	*Lycenchelys verrilli*
604	SLENDER SNIPE EEL	*Nemichthys scolopaceus*
610	NORTHERN SAND LANCE	*Ammodytes dubius*
616	FISH DOCTOR	*Gymnelis viridis*
617	COMMON WOLF EEL	*Lycenchelys paxillus*
620	LAVAL`S EELPOUT	*Lycodes lavalaei*
621	ROCK GUNNEL(EEL)	*Pholis gunnellus*
622	SNAKEBLENNY	*Lumpenus lumpretaeformis*
623	DAUBED SHANNY	*Leptoclinus maculatus*
625	RADIATED SHANNY	*Ulvaria subbifurcata*
626	4-LINE SNAKE BLENNY	*Eumesogrammus praecisus*
630	WRYMOUTH	*Cryptacanthodes maculatus*
631	SLENDER EELBLENNY	*Lumpenus fabricii*
637	SPOTFIN DRAGONET	*Callionymus agassizi*
640	OCEAN POUT(COMMON)	*Zoarces americanus*
641	ARCTIC EELPOUT	*Lycodes reticulatus*
646	ATL SOFT POUT	*Melanostigma atlanticum*
647	CHECKER EELPOUT(VAHL)	*Lycodes vahlii*
701	BUTTERFISH	*Peprilus triacanthus*
704	AMER. JOHN DORY	*Zenopsis ocellata*
711	SHORT BARRACUDINA	*Paralepis atlantica*
712	WHITE BARRACUDINA	*Notolepis rissoi kroyeri*
714	FROSTFISH	*Benthodesmus elongatus simonyi*

Species	Name	Latin Name
720	ATL SAURY,NEEDLEFISH	*Scomberesox saurus*
742	ATLANTIC BATFISH	*Dibranchus atlanticus*
743	AMER BARRELFISH	*Hyperoglyphe perciformis*
744	STOUT BEARD FISH	*Polymixia nobilis*
771	BEARDFISH	*Polymixia lowei*
816	TONGUE FISH	*Symphurus pterospilotus*
880	HOOKEAR SCULPIN,ATL.	*Artediellus atlanticus*
1054	DUCKBILL BARRACUDINA	*Paralepis atlantica kroyer*

Table A3. Invertebrate species included for the deep strata biodiversity analysis.

Species	Name	Latin Name
1028	HALOSAUROPSIS MACROCHIR	*Halosauropsis macrochir*
1030	ADROVANDIA AFFINIS	*Adrovandia affinis*
1056	STEREOMASTIS SCULPTA	*Stereomastis sculpta*
1823	SEA POTATO	*Boltenia sp.*
2211	PANDALUS BOREALIS	*Pandalus borealis*
2212	PANDALUS MONTAGUI	*Pandalus montagui*
2213	PANDALUS PROPINQUUS	*Pandalus propinquus*
2220	SHRIMP	*Pasiphaea tarda*
2221	P. MULTIDENTATA	*Pasiphaea multidentata*
2222	PARAPASIPHAEA SULCATIFRONS	*Parapasiphaea sulcatifrons*
2223	SERGESTES ARCTICUS	*Sergestes arcticus*
2312	LEBBEUS POLARIS	*Lebbeus polaris*
2313	S. LILJEBORGII	*Spirontocaris liljeborgii*
2316	S. SPINUS	*Spirontocaris spinus*
2319	L. GROENLANDICUS	*Lebbeus groenlandicus*
2333	EUALUS GAIMARDII	*Eualus gaimardii*
2415	P. NORVEGICUS	*Pontophilus norvegicus*
2511	JONAH CRAB	*Cancer borealis*
2513	ATL ROCK CRAB	*Cancer irroratus*
2519	SPIDER CRAB (NS)	*Majidae f.*
2523	NORTHERN STONE CRAB	*Lithodes maja*
2525	SPINY CRAB	*Lithodes/neolithodes*
2526	SNOW CRAB (QUEEN)	*Chionoecetes opilio*
2527	TOAD CRAB	*Hyas araneus*
2528	SPINY SPIDER CRAB	*Neolithodes grimaldi*
2532	DEEP SEA RED CRAB	*Geryon quinquedens*
2550	AMERICAN LOBSTER	*Homarus americanus*
2555	MUNIDA IRIS	*Munida iris*
2556	MUNIDA VALIDA	*Munida valida*
2559	HERMIT CRABS	*Paguridae f.*
2611	M. NORVEGICA	*Meganyctiphanes norvegica*
2771	GNATHOPHAUSIA SP.	*Gnathophausia sp.*
2980	ISOPODA O.	*Isopoda o.*
3138	SABELLIDAE F.	*Sabellidae f.*
3200	SEA MOUSE	*Aphrodita hastata*
4321	SEA SCALLOP	*Placopecten magellanicus*
4322	ICELAND SCALLOP	*Chlamys islandicus*
4380	ANOMIA SIMPLEX	*Anomia simplex*
4511	SHORT-FIN SQUID	*Illex illecebrosus*
4536	SEPIOLIDAE F.	*Sepiolodae f.*
4569	GONATUS SP.	*Gonatus sp.*
5100	SEA SPIDER	*Pycnogonida s.p.*
6101	CEREMASTERNAGRANULARIS	*Ceremasternagranularis*
6102	PORANIA PULVILIS	*Porania pulvilis*
6111	PURPLE STARFISH	*Asterias vulgaris*
6114	LEPTASTERIAS SP.	*Leptasterias sp.*
6115	MUD STAR	*Ctenodiscus crispatus*
6116	PSEUDARCHASTER SP	*Pseudarchaster sp*
6117	H. PHRYGIANA	*Hippasteria phrygiana*
6119	BLOOD STAR	*Henricia sanguinolenta*
6121	PURPLE SUNSTAR	*Solaster endeca*
6123	SUN STAR	*Solaster papposus*
6125	PTERASTER MILITARIS	*Pteraster militaris*

Species	Name	Latin Name
6129	P. HISPIDA	*Poraniomorpha hispida*
6131	D. MULTIPES	*Diplopteraster multipes*
6413	HEART URCHIN	*Brisaster fragilis*
6421	PURPLE SEA URCHIN	*Arabacia punctulata*
6511	E. PARMA	*Echinarachnius parma*
6600	SEA CUCUMBERS	*Holothuroidea c.*
6611	CUCUMARIA FRONDOSA	*Cucumaria frondosa*
8318	SEA PEN	*Pennatula borealis*
8322	P. RESEDAEFORMIS	*Primnoa resedaeformis*
8323	PARAGORGIA ARBOREA	*Paragorgia arborea*
8325	GOLD-BANDED/BAMBOONACORAL	*Keratoisisnaornata*
8326	ACANTHOGORGIANAARMATA	*Acanthogorgianaarmata*
8328	ANTHOMASTUS GRANDIFLORUS	*Anthomastus grandiflorus*
8329	ACANELLANAARBUSCULA	*Acanellanaarbuscula*
8330	RADICIPESNAGRACILIS	*Radicipesnagracilis*
8335	CUPNACORAL	*Flabellumnasp*
8346	PSEUDARCHASTERNAPARELII	*Pseudarchasternaparelii*
8347	PSILASTERNAANDROMEDA	*Psilasternaandromeda*
8353	ACANTHEPHYRA PELAGICA	*Acanthephyra pelagica*
8354	SERGIA SP.	*Sergia sp.*
8356	SPONGE	*Rhizaxinella sp.*
8364	GEODIA SPP.	*Geodia spp.*
8520	JELLYFISH	*Pelagia noctiluca*
8601	RUSSIANNAHATS	*Vazellanapourtalesi*
2610	EUPHAUSIIDAE F.	*Euphausiidae f.*
2621	T. RASCHII	*Thysanoessa raschii*

Table A4. Fish species included for the deep strata biodiversity analysis.

Species	Name	Latin Name
10	COD(ATLANTIC)	*Gadus morhua*
11	HADDOCK	*Melanogrammus aeglefinus*
12	WHITE HAKE	*Urophycis tenuis*
13	SQUIRREL OR RED HAKE	*Urophycis chuss*
14	SILVER HAKE	*Merluccius bilinearis*
15	CUSK	*Brosme brosme*
16	POLLOCK	*Pollachius virens*
19	OFF-SHORE HAKE	*Merluccius albidus*
23	REDFISH UNSEPARATED	*Sebastes sp.*
30	HALIBUT(ATLANTIC)	*Hippoglossus hippoglossus*
31	TURBOT,GREENLAND HALIBUT	*Reinhardtius hippoglossoides*
39	BLACK SWALLOWER	*Chiasmodon niger*
40	AMERICAN PLAICE	*Hippoglossoides platessoides*
41	WITCH FLOUNDER	*Glyptocephalus cynoglossus*
42	YELLOWTAIL FLOUNDER	*Limanda ferruginea*
44	GULF STREAM FLOUNDER	*Citharichthys arctifrons*
50	STRIPED ATL WOLFFISH	*Anarhichas lupus*
51	SPOTTED WOLFFISH	*Anarhichas minor*
52	NORTHERN WOLFFISH	*Anarhichas denticulatus*
60	HERRING(ATLANTIC)	*Clupea harengus*
64	CAPELIN	*Mallotus villosus*
112	LONGFIN HAKE	*Phycis chesteri*
113	BLUE ANTIMORA/HAKE	*Antimora rostrata*
114	FOURBEARD ROCKLING	*Enchelyopus cimbrius*
115	THREEBEARD ROCKLING	*Gaidropsarus ensis*
123	ROSEFISH(BLACK BELLY)	*Helicolenus dactylopterus*
138	MIRROR LANTERNFISH	*Lampadena speculigera*
146	L. MACDONALDI	*Lampanyctus macdonaldi*
149	LONGNOSE GREENEYE	*Parasudis truculenta*
152	LANTERNFISH	*Diaphus dumerilii*
155	LONGTOOTH ANGLEMOUTH	*Gonostoma elongatum*
156	SHORT-NOSE GREENEYE	*Chlorophthalmus agassizi*
157	GLACIER LANTERNFISH	*Benthosema glaciale*
158	MULLER'S PEARLSIDES	*Maurolicus muelleri*
159	BOA DRAGONFISH	*Stomias boa ferox*
160	ARGENTINE (ATL)	*Argentina silus*
163	LANTERNFISH,HORNED	*Ceratoscopelus maderensis*
169	VIPERFISH	*Chauliodus sloani*
176	GOITRE BLACKSMELT	*Bathylagus euryops*
180	SPOTTED LANTERNFISH	*Myctophum punctatum*
182	LANTERNFISH KROYER'S	*Notoscopelus elongatus kroyeri*
183	ANTERNFISH PATCHWORK	*Notoscopelus resplendens*
200	BARNDOOR SKATE	*Dipturus laevis*
201	THORNY SKATE	*Amblyraja radiata*
202	SMOOTH SKATE	*Malacoraja senta*
203	LITTLE SKATE	*Leucoraja erinacea*
204	WINTER SKATE	*Leucoraja ocellata*
207	ROUND SKATE	*Rajella fyllae*
220	SPINY DOGFISH	*Squalus acanthias*
221	BLACK DOGFISH	*Centroscyllium fabricii*
223	PORTUGUESE SHARK	*Centroscymnus coelolepis*
224	ROUGH SAGRE	*Etmopterus princeps*
239	DEEPSEA CAT SHARK	*Apristurus profundorum*

Species	Name	Latin Name
240	SEA LAMPREY	*Petromyzon marinus*
241	ATLANTIC HAGFISH	*Myxine glutinosa*
247	LONGNOSE CHIMERA	*Harriotta raleighana*
248	KNIFENOSE CHIMERA	*Rhinochimaera atlantica*
300	LONGHORN SCULPIN	*Myoxocephalus octodecemspinosus*
307	POLAR SCULPIN	*Cottunculus microps*
308	PALLID SCULPIN	*Cottunculus thompsoni*
331	ARMORED SEA ROBIN	*Peristedion miniatum*
356	RONDELETIA LORICATA	*Rondeletia loricata*
400	MONKFISH,GOOSEFISH,ANGLER	*Lophius americanus*
410	MARLIN-SPIKE GRENADIER	*Nezumia bairdii*
411	ROUGHHEAD GRENADIER	*Macrourus berglax*
412	ROUGHNOSE GRENADIER	*Trachyrhynchus murrayi*
414	ROCK GRENADIER(ROUNDNOSE)	*Coryphaenoides rupestris*
505	SEASNAIL,GELATINOUS	*Liparis fabricii*
511	BLACKSNOUT SEASNAIL	*Paraliparis copei*
520	SEA TADPOLE	*Careproctus reinhardi*
588	S. LEPIDUS	*Scopelosaurus lepidus*
594	SMOOTHHEAD,AGASSIZ'S	*Alepocephalus agassizii*
595	RED DORY	*Cyttus roseus*
601	SNUBNOSE EEL	*Simenchelys parasiticus*
602	GRAY'S CUTTHROAT EEL	*Synaphobranchus kaupi*
603	WOLF EELPOUT	*Lycenchelys verrilli*
604	SLENDER SNIPE EEL	*Nemichthys scolopaceus*
607	DUCKBILL OCEANIC EEL	*Nessorhamphus ingolfianus*
610	NORTHERN SAND LANCE	*Ammodytes dubius*
612	NECKEEL	*Derichthys serpentinus*
613	STOUT SAWPALATE	*Serrivomer beani*
614	PELICAN GULPER	*Eurypharynx pelecanoides*
617	COMMON WOLF EEL	*Lycenchelys paxillus*
637	SPOTFIN DRAGONET	*Callionymus agassizi*
640	OCEAN POUT(COMMON)	*Zoarces americanus*
646	ATL SOFT POUT	*Melanostigma atlanticum*
647	CHECKER EELPOUT(VAHL)	*Lycodes vahlii*
700	ATL SILVER HATCHFISH	*Argyropelecus aculeatus*
708	P. ASTEROIDES	*Polyipnus asteroides*
709	TRANSPARENT HATCHETFISH	*Sternoptyx diaphana*
711	SHORT BARRACUDINA	*Paralepis atlantica*
712	WHITE BARRACUDINA	*Notolepis rissoi kroyeri*
714	FROSTFISH	*Benthodesmus elongatus simonyi*
716	STRAIGHTLINE DRAGONFISH	*Borostomias antarcticus*
720	ATL SAURY,NEEDLEFISH	*Scomberesox saurus*
724	BAIRDS SMOOTHEAD	*Alepocephalus bairdii*
725	ATLANTIC GYMNAST	*Xenodermichthys copei*
740	SPINY EEL	*Notacanthus chemnitzi*
742	ATLANTIC BATFISH	*Dibranchus atlanticus*
755	ANGLEMOUTH (NS)	*Cyclothone sp.*
774	OGREFISH	*Anoplogaster cornuta*
795	BEANS BLUEBACK	*Scopelogadus beanii*
814	BATHYSAURUS FEROX	*Bathysaurus ferox*
816	TONGUE FISH	*Symphurus pterospilotus*
862	D. INTRONIGRA	*Dicrolene intronigra*
865	A. PHALACRA	*Aldrovandia phalacra*
883	GONOSTOMA BATHYPHILUM	*Gonostoma bathyphilum*
1054	DUCKBILL BARRACUDINA	*Paralepis atlantica kroyer*

APPENDIX B

Summary of Data Layers

Table B1. Summary of data layers created and used in analysis, with a description of layer and number of cells by class (where discussed in the text). Note that there are some duplicates, which inform the layers used for comparison. For example, in the "Key Species" Layer Group, the top 20% class layers were used to compare to key species abundance.

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
Richness	FiE4Rich20	32968	6661+6626+6573+6528+6580	Fish, Era 4, Richness in 5 classes
	FiE3Rich20	31065	6335+6097+6299+6151+6183	Fish, Era 3, Richness in 5 classes
	FiE2Rich20	30148	6240+5888+5986+6016+6018	Fish, Era 2, Richness in 5 classes
	FiE1Rich20	30240	6091+6031+6471+5622+6025	Fish, Era 1, Richness in 5 classes
	FiAllRich20	33914	6814+6846+6724+6793+6737	Fish, All years, Richness in 5 classes
	InRich20	31120	6237+6236+6246+6206+6195	Invertebrates, 2007-2013, Richness in 5 classes
ESW	FiE4ESW20	32968	6644+6599+6594+6559+6572	Fish, Era 4, Exponential of Shannon-Wiener in 5 classes
	FiE3ESW20	31065	6237+6250+6239+6169+6170	Fish, Era 3, Exponential of Shannon-Wiener in 5 classes
	FiE2ESW20	30148	6123+6015+5956+6076+5978	Fish, Era 2, Exponential of Shannon-Wiener in 5 classes
	FiE1ESW20	30240	6059+6038+6074+6045+6024	Fish, Era 1, Exponential of Shannon-Wiener in 5 classes
	FiAllESW20	33914	6848+6772+6813+6720+6761	Fish, All years, Exponential of Shannon-Wiener in 5 classes
	InESW20	31120	6254+6213+6294+6160+6199	Invertebrates, 2007-2013, Exponential of Shannon-Wiener in 5 classes
Heip's	FiE4Hp20	32968	6621+6629+6561+6593+6564	Fish, Era 4, Heips in 5 classes
	FiE3Hp20	31065	6283+6147+6279+6163+6193	Fish, Era 3, Heips in 5 classes
	FiE2Hp20	30148	6064+6036+6040+5998+6010	Fish, Era 2, Heips in 5 classes
	FiE1Hp20	30240	6059+6097+5990+6068+6026	Fish, Era 1, Heips in 5 classes
	FiAllHp20	33914	6816+6847+6808+6719+6724	Fish, All years, Heips in 5 classes
	InHp20	31120	6401+6057+6217+6274+6171	Invertebrates, 2007-2013, Heips in 5 classes
Top20_RiEswHp	FiE4Metrics3	32968	408	Fish, Era 4, top bin across all metrics
	FiE4Metrics	32560	18591+9446+4523	Fish, Era 4, addition of top 20% across all metrics
	FiE3Metrics3	31065	189	Fish, Era 3, top bin across all metrics
	FiE3Metrics	31065	16957+9859+4060+189	Fish, Era 3, addition of top 20% across all metrics
	FiE2Metrics3	30148	876	Fish, Era 2, top bin across all metrics
	FiE2Metrics	30148	18024+7118+4130+876	Fish, Era 2, addition of top 20% across all metrics
	FiE1Metrics3	30240	798	Fish, Era 1, top bin across all metrics
	FiE1Metrics	30240	18017+7169+4256+798	Fish, Era 1, addition of top 20% across all metrics
	FiE1Ri20T	30240	6025	Fish, Era 1, Richness top 20%

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	FiE1ESW20T	30240	6024	Fish, Era 1, Exponential of Shannon-Wiener top 20%
	FiE1Hp20T	30240	6026	Fish, Era 1, Heip's top 20%
	FiE2Ri20T	30148	6018	Fish, Era 2, Richness top 20%
	FiE2ESW20T	30148	5978	Fish, Era 2, Exponential of Shannon-Wiener top 20%
	FiE2Hp20T	30148	6010	Fish, Era 2, Heip's top 20%
	FiE3Ri20T	31065	6183	Fish, Era 3, Richness top 20%
	FiE3ESW20T	31065	6170	Fish, Era 3, Exponential of Shannon-Wiener top 20%
	FiE3Hp20T	31065	6193	Fish, Era 3, Heip's top 20%
	FiE4Ri20T	32968	6580	Fish, Era 4, Richness top 20%
	FiE4ESW20T	32968	6572	Fish, Era 4, Exponential of Shannon-Wiener top 20%
	FiE4Hp20T	32968	6564	Fish, Era 4, Heip's top 20%
	FiAllMetrics3	33914	172	Fish, All years, top bin across all metrics
	FiAllMetrics	33914	18640+10498+4604+172	Fish, All years, addition of top 20% across all metrics
	FiAllRi20T	33914	6737	Fish, All years, Richness top 20%
	FiAllESW20T	33914	6761	Fish, All years, Exponential of Shannon-Wiener top 20%
	FiAllHp20T	33914	6724	Fish, All years, Heip's top 20%
	InMetrics3	31120	23	Invertebrates, 2007-2013, top bin across all metrics
	InMetrics	31120	17091+9516+4490+23	Invertebrates, 2007-2013, addition of top 20% across all metrics
	InRi20T	31120	6195	Invertebrates, 2007-2013, Richness top 20%
	InHp20T	31120	6171	Invertebrates, 2007-2013, Exponential of Shannon-Wiener top 20%
	InESW20T	31120	6199	Invertebrates, 2007-2013, Heip's top 20%
Combined Metrics	InRiEswHp13+	2331	2331	Invertebrates, 2007-2013, Richness+ESW+Hp, top 3 classes
	FiHpRiEsw13+	4172	4172	Fish, All years, Richness+ESW+Hp, top 3 classes
	InHpRi9+	682	682	Invertebrates, 2007-2013, Hp+Richness, top 2 classes
	InRiEsw9+	3072	3072	Invertebrates, 2007-2013, Richness+ESW, top 2 classes
	InEswHp9+	6970	6970	Invertebrates, 2007-2013, ESW+Hp, top 2 classes
	FiRiHp9+	1190	1190	Fish, All years, Richness+Hp, top 2 classes
	FiEswRi9+	4700	4700	Fish, All years, ESW+Richness, top 2 classes
	FiEswHp9+	6839	6839	Fish, All years, ESW+Hp, top 2 classes
	FiRiHp	33914	189+1415+3303+6367+11064+7059+3327+1018+172	Fish, All years, Richness+Hp
	FiEswHpp	33914	4887+2780+2957+3688+3942+4331+4490+3715+3124	Fish, All years, ESW+Hp
	FiESWRi	33914	1556+3446+4223+4781+6129+4726+4353+2876+1824	Fish, All years, ESW+Richness
	FiEswHpRi	33914	189+1309+1999+2951+4738+4112+4208+3837+3712+2687+2983+1017+172	Fish, All years, ESW+Hp+Richness

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	InRiEswHp	31120	391+901+1576+2878+3620+3597+3763+4654+4733+2676+1720+588+23	Invertebrates, 2007-2013, Richness+ESW+Hp
	InHpRi	31120	421+988+2509+5514+11308+6646+3052+655+27	Invertebrates, 2007-2013, Hp+Richness
	InRiEsw	31120	663+2071+4104+5350+7296+5256+3308+2014+1058	Invertebrates, 2007-2013, Richness+ESW
	InEswHp	31120	5330+1668+3294+3157+3233+3657+3811+3496+3474	Invertebrates, 2007-2013, ESW+Hp
	FiE1RiEswHp	30240	741+1438+1862+3027+3878+3156+3233+2715+3325+1882+2346+1839+798	Fish, Era 1, addition of all metrics
	FiE2RiEswHp	30148	993+1596+1687+2622+3872+2966+3434+2830+3397+1667+2350+1858+876	Fish, Era 2, addition of all metrics
	FiE3RiEswHp	31065	452+825+1616+3022+4350+3975+3586+3758+3285+2285+2514+1208+189	Fish, Era 3, addition of all metrics
	FiE4RiEswHp	32968	542+1192+1833+2854+4556+4201+3860+3664+3476+2210+2729+1443+408	Fish, Era 4, addition of all metrics
	FiE1Met13+	30240	4983	Fish, Era 1, addition of all metrics top 3 classes
	FiE2Met13+	30148	5084	Fish, Era 2, addition of all metrics top 3 classes
	FiE3Met13+	31065	3911	Fish, Era 3, addition of all metrics top 3 classes
	FiE4Met13+	32968	4580	Fish, Era 4, addition of all metrics top 3 classes
	FiInMetRecent	31120	… 3176+2362+1677+1234+918+657+338+141+44+5	Fish + Invertebrates, add all metrics in Era 4 for fish and all for invertebrates
	FiInMetRec24+	31120	2103	Fish + Invertebrates, add all metrics in Era 4 for fish and all for invertebrates top 6 classes
Combined Years	FiHpSumYr17+	3713	3713	Fish, Heips top 20% summed across 4 fishing eras, showing top 4 classes
	FiRiSumYr17+	4945	4945	Fish, Richness top 20% summed across 4 fishing eras, showing top 4 classes
	FiEswSumYr17+	2852	2852	Fish, ESW top 20% summed across 4 fishing eras, showing top 4 classes
Key Species	X10	n/a	n/a	Atlantic cod
	X51	n/a	n/a	Spotted wolffish
	X50	n/a	n/a	Atlantic wolffish
	X64	n/a	n/a	Capelin
	X60	n/a	n/a	Herring
	X70	n/a	n/a	Mackerel
	X610	n/a	n/a	Sand lance
	X41	n/a	n/a	Witch flounder
	X14	n/a	n/a	Silver hake

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X40	n/a	n/a	American plaice
	X11	n/a	n/a	Haddock
	X30	n/a	n/a	Atlantic halibut
	X300	n/a	n/a	Longhorn sculpin
	X16	n/a	n/a	Pollock
	X13	n/a	n/a	Red hake
	X23	n/a	n/a	Redfish
	X202	n/a	n/a	Smooth skate
	X220	n/a	n/a	Dogfish
	X12	n/a	n/a	White hake
	X204	n/a	n/a	Winter skate
	X15	n/a	n/a	Cusk
	X52	n/a	n/a	Northern wolffish
	X6411	n/a	n/a	Sea urchin
	X4511	n/a	n/a	Shortfin squid
	X6600_6611	n/a	n/a	Sea cucumbers
	X2526	n/a	n/a	Snow crab
	X2212	n/a	n/a	Shrimp
	X2211	n/a	n/a	Shrimp
	InRi20T	n/a	n/a	Invertebrates, 2007-2013, Richness top 20%
	InESW20T	n/a	n/a	Invertebrates, 2007-2013, Exponential of Shannon-Wiener top 20%
	InHp20T	n/a	n/a	Invertebrates, 2007-2013, Heip's top 20%
	FiAllRi20T	n/a	n/a	Fish, All years, Richness top 20%
	FiAllESW20T	n/a	n/a	Fish, All years, Exponential of Shannon-Wiener top 20%
	FiAllHp20T	n/a	n/a	Fish, All years, Heip's top 20%
Food Habits	FiAllRi20T	n/a	n/a	Fish, All years, Richness top 20%
	FiAllESW20T	n/a	n/a	Fish, All years, Exponential of Shannon-Wiener top 20%
	FiAllHp20T	n/a	n/a	Fish, All years, Heip's top 20%
	InRi20T	n/a	n/a	Invertebrates, 2007-2013, Richness top 20%
	InHp20T	n/a	n/a	Invertebrates, 2007-2013, Heip's top 20%
	InESW20T	n/a	n/a	Invertebrates, 2007-2013, Exponential of Shannon-Wiener top 20%
	SmallFishGrid	n/a	n/a	Cook and Bundy
	InvertebrateGrid	n/a	n/a	Cook and Bundy
KeySpecies_Ovelap	X10_20	n/a	n/a	Atlantic cod in 5 quantile classes
	X11_20	n/a	n/a	Haddock in 5 quantile classes
	X12_20	n/a	n/a	White hake in 5 quantile classes
	X13_20	n/a	n/a	Red hake in 5 quantile classes
	X14_20	n/a	n/a	Silver hake in 5 quantile classes
	X15_20	n/a	n/a	Cusk in 5 quantile classes
	X16_20	n/a	n/a	Pollock in 5 quantile classes
	X202_20	n/a	n/a	Smooth skate in 5 quantile classes
	X204_20	n/a	n/a	Winter skate in 5 quantile classes
	X220_20	n/a	n/a	Dogfish in 5 quantile classes
	X2211_20	n/a	n/a	Shrimp in 5 quantile classes
	X2212_20	n/a	n/a	Shrimp in 5 quantile classes
	X23_20	n/a	n/a	Redfish in 5 quantile classes
	X2526_20	n/a	n/a	Snow crab in 5 quantile classes
	X2526_20r	n/a	n/a	Snow crab in 5 quantile classes, outlier in bin 5
	X30_20	n/a	n/a	Atlantic halibut in 5 quantile classes
	X300_20	n/a	n/a	Longhorn sculpin in 5 quantile classes
	X40_20	n/a	n/a	American plaice in 5 quantile classes (had 4 outlier cells)

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X40_20r	n/a	n/a	American plaice in 5 quantile classes, outlier in bin 5
	X41_20	n/a	n/a	Witch flounder in 5 quantile classes
	X4511_20	n/a	n/a	Shortfin squid in 5 quantile classes
	X50_20	n/a	n/a	Atlantic wolffish in 5 quantile classes
	X51_20	n/a	n/a	Spotted wolffish in 5 quantile classes
	X52_20	n/a	n/a	Northern wolffish in 5 quantile classes
	X60_20	n/a	n/a	Herring in 5 quantile classes
	X610_20	n/a	n/a	Sand lance in 5 quantile classes
	X64_20	n/a	n/a	Capelin in 5 quantile classes
	X6411_20	n/a	n/a	Sea urchin in 5 quantile classes
	X6600_20	n/a	n/a	Sea cucumbers in 5 quantile classes (1 cell was an outlier)
	X6600_20r	n/a	n/a	Sea cucumbers in 5 quantile classes, outlier in bin 5
	X70_20	n/a	n/a	Mackerel in 5 quantile classes
	X10Ri	n/a	n/a	Atlantic cod combined with species richness
	X11Ri	n/a	n/a	Haddock combined with species richness
	X12Ri	n/a	n/a	White hake combined with species richness
	X13Ri	n/a	n/a	Red hake combined with species richness
	X14Ri	n/a	n/a	Silver hake combined with species richness
	X15Ri	n/a	n/a	Cusk combined with species richness
	X16Ri	n/a	n/a	Pollock combined with species richness
	X202Ri	n/a	n/a	Smooth skate combined with species richness
	X204Ri	n/a	n/a	Winter skate combined with species richness
	X220Ri	n/a	n/a	Dogfish combined with species richness
	X2211Ri	n/a	n/a	Shrimp combined with species richness
	X2212Ri	n/a	n/a	Shrimp combined with species richness
	X23Ri	n/a	n/a	Redfish combined with species richness
	X2526Ri	n/a	n/a	Snow crab combined with species richness
	X30Ri	n/a	n/a	Atlantic halibut combined with species richness
	X300Ri	n/a	n/a	Longhorn sculpin combined with species richness
	X40Ri	n/a	n/a	American plaice combined with species richness
	X41Ri	n/a	n/a	Witch flounder combined with species richness
	X4511Ri	n/a	n/a	Shortfin squid combined with species richness
	X50Ri	n/a	n/a	Atlantic wolffish combined with species richness
	X51Ri	n/a	n/a	Spotted wolffish combined with species richness
	X52Ri	n/a	n/a	Northern wolffish combined with species richness
	X60Ri	n/a	n/a	Herring combined with species richness
	X610Ri	n/a	n/a	Sand lance combined with species richness
	X64Ri	n/a	n/a	Capelin combined with species richness
	X6411Ri	n/a	n/a	Sea urchin combined with species richness
	X6600Ri	n/a	n/a	Sea cucumbers combined with species richness
	X70Ri	n/a	n/a	Mackerel combined with species richness
	X10ESW	n/a	n/a	Atlantic cod combined with ESW
	X11ESW	n/a	n/a	Haddock combined with ESW
	X12ESW	n/a	n/a	White hake combined with ESW
	X13ESW	n/a	n/a	Red hake combined with ESW
	X14ESW	n/a	n/a	Silver hake combined with ESW
	X15ESW	n/a	n/a	Cusk combined with ESW
	X16ESW	n/a	n/a	Pollock combined with ESW

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X202ESW	n/a	n/a	Smooth skate combined with ESW
	X204ESW	n/a	n/a	Winter skate combined with ESW
	X220ESW	n/a	n/a	Dogfish combined with ESW
	X2211ESW	n/a	n/a	Shrimp combined with ESW
	X2212ESW	n/a	n/a	Shrimp combined with ESW
	X23ESW	n/a	n/a	Redfish combined with ESW
	X2526ESW	n/a	n/a	Snow crab combined with ESW
	X30ESW	n/a	n/a	Atlantic halibut combined with ESW
	X300ESW	n/a	n/a	Longhorn sculpin combined with ESW
	X40ESW	n/a	n/a	American plaice combined with ESW
	X41ESW	n/a	n/a	Witch flounder combined with ESW
	X4511ESW	n/a	n/a	Shortfin squid combined with ESW
	X50ESW	n/a	n/a	Atlantic wolffish combined with ESW
	X51ESW	n/a	n/a	Spotted wolffish combined with ESW
	X52ESW	n/a	n/a	Northern wolffish combined with ESW
	X60ESW			Herring combined with ESW
	X610ESW	n/a	n/a	Sand lance combined with ESW
	X64ESW	n/a	n/a	Capelin combined with ESW
	X6411ESW	n/a	n/a	Sea urchin combined with ESW
	X6600ESW	n/a	n/a	Sea cucumbers combined with ESW
	X70ESW	n/a	n/a	Mackerel combined with ESW
	X10Hp	n/a	n/a	Atlantic cod combined with Heip's
	X11Hp	n/a	n/a	Haddock combined with Heip's
	X12Hp	n/a	n/a	White hake combined with Heip's
	X13Hp	n/a	n/a	Red hake combined with Heip's
	X14Hp	n/a	n/a	Silver hake combined with Heip's
	X15Hp	n/a	n/a	Cusk combined with Heip's
	X16Hp	n/a	n/a	Pollock combined with Heip's
	X202Hp	n/a	n/a	Smooth skate combined with Heip's
	X204Hp	n/a	n/a	Winter skate combined with Heip's
	X220Hp	n/a	n/a	Dogfish combined with Heip's
	X2211Hp	n/a	n/a	Shrimp combined with Heip's
	X2212Hp	n/a	n/a	Shrimp combined with Heip's
	X23Hp	n/a	n/a	Redfish combined with Heip's
	X2526Hp	n/a	n/a	Snow crab combined with Heip's
	X30Hp	n/a	n/a	Atlantic halibut combined with Heip's
	X300Hp	n/a	n/a	Longhorn sculpin combined with Heip's
	X40Hp	n/a	n/a	American plaice combined with Heip's
	X41Hp	n/a	n/a	Witch flounder combined with Heip's
	X4511Hp	n/a	n/a	Shortfin squid combined with Heip's
	X50Hp	n/a	n/a	Atlantic wolffish combined with Heip's
	X51Hp	n/a	n/a	Spotted wolffish combined with Heip's
	X52Hp	n/a	n/a	Northern wolffish combined with Heip's
	X60Hp	n/a	n/a	Herring combined with Heip's
	X610Hp	n/a	n/a	Sand lance combined with Heip's
	X64Hp	n/a	n/a	Capelin combined with Heip's
	X6411Hp	n/a	n/a	Sea urchin combined with Heip's
	X6600Hp	n/a	n/a	Sea cucumbers combined with Heip's
	X70Hp	n/a	n/a	Mackerel combined with Heip's
	X10ESW9+	n/a	2824	Atlantic cod combined with ESW, top 2 classes
	X10Hp9+	n/a	3228	Atlantic cod combined with Heip's, top 2 classes
	X10Ri9+	n/a	1877	Atlantic cod combined with species richness, top 2 classes
	X11ESW9+	n/a	3103	Haddock combined with ESW, top 2 classes
	X11Hp9+	n/a	2172	Haddock combined with Heip's, top 2 classes

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X11Ri9+	n/a	3292	Haddock combined with species richness, top 2 classes
	X12ESW9+	n/a	3124	White hake combined with ESW, top 2 classes
	X12Hp9+	n/a	1193	White hake combined with Heip's, top 2 classes
	X12Ri9+	n/a	6366	White hake combined with species richness, top 2 classes
	X13ESW9+	n/a	2509	Red hake combined with ESW, top 2 classes
	X13Hp9+	n/a	1400	Red hake combined with Heip's, top 2 classes
	X13Ri9+	n/a	4157	Red hake combined with species richness, top 2 classes
	X14ESW9+	n/a	1095	Silver hake combined with ESW, top 2 classes
	X14Hp9+	n/a	629	Silver hake combined with Heip's, top 2 classes
	X14Ri9+	n/a	2752	Silver hake combined with species richness, top 2 classes
	X15ESW9+	n/a	2417	Cusk combined with ESW, top 2 classes
	X15Hp9+	n/a	1465	Cusk combined with Heip's, top 2 classes
	X15Ri9+	n/a	3229	Cusk combined with species richness, top 2 classes
	X16ESW9+	n/a	2245	Pollock combined with ESW, top 2 classes
	X16Hp9+	n/a	1287	Pollock combined with Heip's, top 2 classes
	X16Ri9+	n/a	2986	Pollock combined with species richness, top 2 classes
	X202ESW9+	n/a	3998	Smooth skate combined with ESW, top 2 classes
	X202Hp9+	n/a	2830	Smooth skate combined with Heip's, top 2 classes
	X202Ri9+	n/a	4552	Smooth skate combined with species richness, top 2 classes
	X204ESW9+	n/a	640	Winter skate combined with ESW, top 2 classes
	X204Hp9+	n/a	728	Winter skate combined with Heip's, top 2 classes
	X204Ri9+	n/a	1370	Winter skate combined with species richness, top 2 classes
	X220ESW9+	n/a	857	Dogfish combined with ESW, top 2 classes
	X220Hp9+	n/a	66	Dogfish combined with Heip's, top 2 classes
	X220Ri9+	n/a	2625	Dogfish combined with species richness, top 2 classes
	X2211ESW9+	n/a	125	Shrimp combined with ESW, top 2 classes
	X2211Hp9+	n/a	494	Shrimp combined with Heip's, top 2 classes
	X2211Ri9+	n/a	197	Shrimp combined with species richness, top 2 classes
	X2212ESW9+	n/a	568	Shrimp combined with ESW, top 2 classes
	X2212Hp9+	n/a	1406	Shrimp combined with Heip's, top 2 classes
	X2212Ri9+	n/a	1508	Shrimp combined with species richness, top 2 classes
	X23ESW9+	n/a	355	Redfish combined with ESW, top 2 classes
	X23Hp9+	n/a	302	Redfish combined with Heip's, top 2 classes
	X23Ri9+	n/a	1688	Redfish combined with species richness, top 2 classes
	X2526ESW9+	n/a	1933	Snow crab combined with ESW, top 2 classes
	X2526Hp9+	n/a	3021	Snow crab combined with Heip's, top 2 classes
	X2526Ri9+	n/a	357	Snow crab combined with species richness, top 2 classes
	X300ESW9+	n/a	1566	Longhorn sculpin combined with ESW, top 2 classes

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X300Hp9+	n/a	1590	Longhorn sculpin combined with Heip's, top 2 classes
	X300Ri9+	n/a	2448	Longhorn sculpin combined with species richness, top 2 classes
	X30ESW9+	n/a	1797	Atlantic halibut combined with ESW, top 2 classes
	X30Hp9+	n/a	1329	Atlantic halibut combined with Heip's, top 2 classes
	X30Ri9+	n/a	1860	Atlantic halibut combined with species richness, top 2 classes
	X40ESW9+	n/a	4142	American plaice combined with ESW, top 2 classes
	X40Hp9+	n/a	5508	American plaice combined with Heip's, top 2 classes
	X40Ri9+	n/a	2233	American plaice combined with species richness, top 2 classes
	X41ESW9+	n/a	4524	Witch flounder combined with ESW, top 2 classes
	X41Hp9+	n/a	3385	Witch flounder combined with Heip's, top 2 classes
	X41Ri9+	n/a	4544	Witch flounder combined with species richness, top 2 classes
	X4511ESW9+	n/a	1150	Shortfin squid combined with ESW, top 2 classes
	X4511Hp9+	n/a	1090	Shortfin squid combined with Heip's, top 2 classes
	X4511Ri9+	n/a	2170	Shortfin squid combined with species richness, top 2 classes
	X50ESW9+	n/a	2621	Atlantic wolffish combined with ESW, top 2 classes
	X50Hp9+	n/a	2531	Atlantic wolffish combined with Heip's, top 2 classes
	X50Ri9+	n/a	2461	Atlantic wolffish combined with species richness, top 2 classes
	X51ESW9+	n/a	100	Spotted wolffish combined with ESW, top 2 classes
	X51Hp9+	n/a	71	Spotted wolffish combined with Heip's, top 2 classes
	X51Ri9+	n/a	107	Spotted wolffish combined with species richness, top 2 classes
	X52ESW9+	n/a	82	Northern wolffish combined with ESW, top 2 classes
	X52Hp9+	n/a	114	Northern wolffish combined with Heip's, top 2 classes
	X52Ri9+	n/a	115	Northern wolffish combined with species richness, top 2 classes
	X60ESW9+	n/a	298	Herring combined with ESW, top 2 classes
	X60Hp9+	n/a	38	Herring combined with Heip's, top 2 classes
	X60Ri9+	n/a	3024	Herring combined with species richness, top 2 classes
	X610ESW9+	n/a	482	Sand lance combined with ESW, top 2 classes
	X610Hp9+	n/a	1352	Sand lance combined with Heip's, top 2 classes
	X610Ri9+	n/a	16	Sand lance combined with species richness, top 2 classes
	X6411ESW9+	n/a	1552	Sea urchin combined with ESW, top 2 classes
	X6411Hp9+	n/a	2600	Sea urchin combined with Heip's, top 2 classes

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	X6411Ri9+	n/a	60	Sea urchin combined with species richness, top 2 classes
	X64ESW9+	n/a	263	Capelin combined with ESW, top 2 classes
	X64Hp9+	n/a	256	Capelin combined with Heip's, top 2 classes
	X64Ri9+	n/a	183	Capelin combined with species richness, top 2 classes
	X6600ESW9+	n/a	823	Sea cucumbers combined with ESW, top 2 classes
	X6600Hp9+	n/a	1346	Sea cucumbers combined with Heip's, top 2 classes
	X6600Ri9+	n/a	8	Sea cucumbers combined with species richness, top 2 classes
	X70ESW9+	n/a	903	Mackerel combined with ESW, top 2 classes
	X70Hp9+	n/a	561	Mackerel combined with Heip's, top 2 classes
	X70Ri9+	n/a	1128	Mackerel combined with species richness, top 2 classes
Biomass	fishes	n/a	n/a	Fish biomass from Anna Serdynska, kg/tow
	inverts	n/a	n/a	Invertebrate biomass from Anna Serdynska, kg/tow
	InBiomass20	n/a	n/a	Invertebrate biomass from Anna Serdynska, kg/tow, in 5 classes
	FiBiomass20	n/a	n/a	Fish biomass from Anna Serdynska, kg/tow, in 5 classes
	InBiomassRi	n/a	n/a	Invertebrate biomass combined with invertebrate species richness
	InBiomassHp	n/a	n/a	Invertebrate biomass combined with invertebrate Heip's
	InBiomassESW	n/a	n/a	Invertebrate biomass combined with invertebrate ESW
	FiBiomassRi	n/a	n/a	Fish biomass combined with invertebrate species richness
	FiBiomassHp	n/a	n/a	Fish biomass combined with invertebrate Heip's
	FiBiomassESW	n/a	n/a	Fish biomass combined with invertebrate ESW
	InBioRi9+	n/a	2499	Invertebrate biomass combined with invertebrate species richness, top 2 classes
	InBioESW9+	n/a	4261	Invertebrate biomass combined with invertebrate Heip's, top 2 classes
	InBioHp9+	n/a	2883	Invertebrate biomass combined with invertebrate ESW, top 2 classes
	FiBioRi9+	n/a	6383	Fish biomass combined with invertebrate species richness, top 2 classes
	FiBioESW9+	n/a	965	Fish biomass combined with invertebrate Heip's, top 2 classes
	FiBioHp9+	n/a	2802	Fish biomass combined with invertebrate ESW, top 2 classes
Deepsets	In400Ri	n/a	n/a	Raw data for Invertebrates in 400 Strata, Richness
	In400ESW	n/a	n/a	Raw data for Invertebrates in 400 Strata, ESW
	In400Hp	n/a	n/a	Raw data for Invertebrates in 400 Strata, Heip's
	In500Ri	n/a	n/a	Raw data for Invertebrates in 500 Strata, Richness
	Fi400Ri	n/a	n/a	Raw data for Fish in 400 Strata, Richness
	Fi400ESW	n/a	n/a	Raw data for Fish in 400 Strata, ESW
	Fi400Hp	n/a	n/a	Raw data for Fish in 400 Strata, Heip's
	Fi500Ri	n/a	n/a	Raw data for Fish in 500 Strata, Richness
	In400Ri20	n/a	n/a	Raw data for Invertebrates in 400 Strata, Richness - 5 quantile classes

Layer Group	Layer	No. Cells (non-zero)	Cells per Class (lowest to highest)	Description
	In400ESW20	n/a	n/a	Raw data for Invertebrates in 400 Strata, ESW - 5 quantile classes
	In400Hp20	n/a	n/a	Raw data for Invertebrates in 400 Strata, Heip's - 5 quantile classes
	In500Ri20	n/a	n/a	Raw data for Invertebrates in 500 Strata, Richness - 5 quantile classes
	Fi400Ri20	n/a	n/a	Raw data for Fish in 400 Strata, Richness - 5 quantile classes
	Fi400ESW20	n/a	n/a	Raw data for Fish in 400 Strata, ESW - 5 quantile classes
	Fi400Hp20	n/a	n/a	Raw data for Fish in 400 Strata, Heip's - 5 quantile classes
	Fi500Ri20	n/a	n/a	Raw data for Fish in 500 Strata, Richness - 5 quantile classes
	Invert_400Strata	n/a	Contains all Invert data for 400-series Strata	
	Fish_400Strata	n/a		Contains all fish data for 400-series Strata
	Invert_500Strata	n/a	Contains all Invert data for 500-series Strata	
	Fish_500Strata	n/a	n/a	Contains all fish data for 500-series Strata

APPENDIX C

Magnification of the Bay of Fundy and northern parts of 4VSW

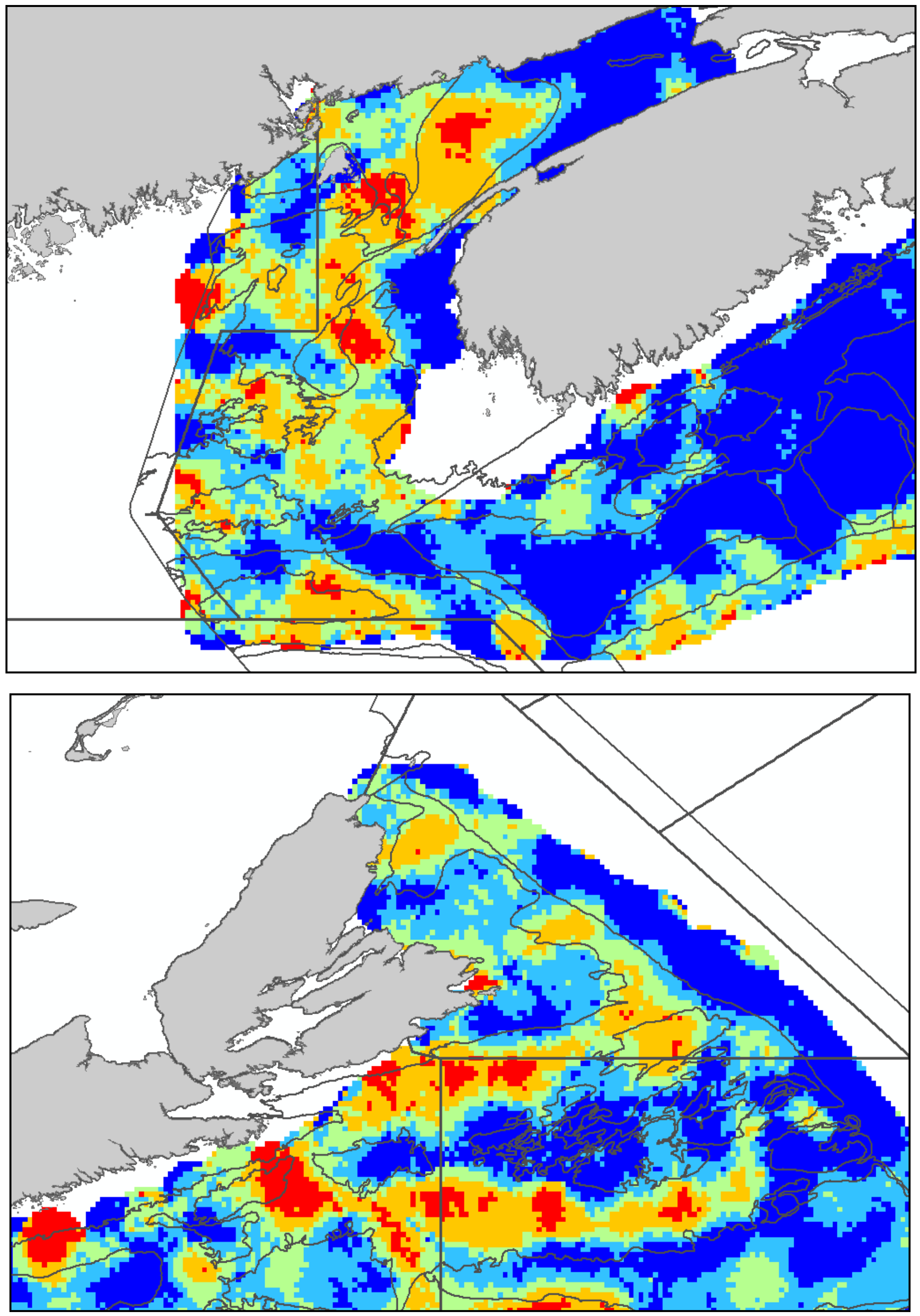


Figure C1. Magnification of Figure 8a showing the Bay of Fundy and northern parts of 4VSW for fish, across all years, combined across all three biodiversity indices.

APPENDIX D

Percent of study area with high key species abundance and high biodiversity

Table D1. Percent of study area with high key species abundance and high biodiversity (Area = number of cells in top 2 classes per total number of cells).

Layer	Description	Area (%)
X10ESW9+	Atlantic cod combined with ESW, top 2 classes	8.33
X10Hp9+	Atlantic cod combined with Heip's, top 2 classes	9.52
X10Ri9+	Atlantic cod combined with species richness, top 2 classes	5.53
X11ESW9+	Haddock combined with ESW, top 2 classes	9.15
X11Hp9+	Haddock combined with Heip's, top 2 classes	6.40
X11Ri9+	Haddock combined with species richness, top 2 classes	9.71
X12ESW9+	White hake combined with ESW, top 2 classes	9.21
X12Hp9+	White hake combined with Heip's, top 2 classes	3.52
X12Ri9+	White hake combined with species richness, top 2 classes	18.77
X13ESW9+	Red hake combined with ESW, top 2 classes	7.40
X13Hp9+	Red hake combined with Heip's, top 2 classes	4.13
X13Ri9+	Red hake combined with species richness, top 2 classes	12.26
X14ESW9+	Silver hake combined with ESW, top 2 classes	3.23
X14Hp9+	Silver hake combined with Heip's, top 2 classes	1.85
X14Ri9+	Silver hake combined with species species richness, top 2 classes	8.11
X15ESW9+	Cusk combined with ESW, top 2 classes	7.13
X15Hp9+	Cusk combined with Heip's, top 2 classes	4.32
X15Ri9+	Cusk combined with species species richness, top 2 classes	9.52
X16ESW9+	Pollock combined with ESW, top 2 classes	6.62
X16Hp9+	Pollock combined with Heip's, top 2 classes	3.79
X16Ri9+	Pollock combined with species richness, top 2 classes	8.80
X202ESW9+	Smooth skate combined with ESW, top 2 classes	11.79
X202Hp9+	Smooth skate combined with Heip's, top 2 classes	8.34
X202Ri9+	Smooth skate combined with species richness, top 2 classes	13.42
X204ESW9+	Winter skate combined with ESW, top 2 classes	1.89
X204Hp9+	Winter skate combined with Heip's, top 2 classes	2.15
X204Ri9+	Winter skate combined with species richness, top 2 classes	4.04
X220ESW9+	Dogfish combined with ESW, top 2 classes	2.53
X220Hp9+	Dogfish combined with Heip's, top 2 classes	0.19
X220Ri9+	Dogfish combined with species richness, top 2 classes	7.74
X2211ESW9+	Shrimp combined with ESW, top 2 classes	0.40
X2211Hp9+	Shrimp combined with Heip's, top 2 classes	1.59
X2211Ri9+	Shrimp combined with species richness, top 2 classes	0.63
X2212ESW9+	Shrimp combined with ESW, top 2 classes	1.83
X2212Hp9+	Shrimp combined with Heip's, top 2 classes	4.52
X2212Ri9+	Shrimp combined with species richness, top 2 classes	4.85
X23ESW9+	Redfish combined with ESW, top 2 classes	1.05
X23Hp9+	Redfish combined with Heip's, top 2 classes	0.89
X23Ri9+	Redfish combined with species richness, top 2 classes	4.98
X2526ESW9+	Snow crab combined with ESW, top 2 classes	6.21
X2526Hp9+	Snow crab combined with Heip's, top 2 classes	9.71
X2526Ri9+	Snow crab combined with species richness, top 2 classes	1.15
X300ESW9+	Longhorn sculpin combined with ESW, top 2 classes	4.62

Layer	Description	Area (%)
X300Hp9+	Longhorn sculpin combined with Heip's, top 2 classes	4.69
X300Ri9+	Longhorn sculpin combined with species richness, top 2 classes	7.22
X30ESW9+	Atlantic halibut combined with ESW, top 2 classes	5.30
X30Hp9+	Atlantic halibut combined with Heip's, top 2 classes	3.92
X30Ri9+	Atlantic halibut combined with species richness, top 2 classes	5.48
X40ESW9+	American plaice combined with ESW, top 2 classes	12.21
X40Hp9+	American plaice combined with Heip's, top 2 classes	16.24
X40Ri9+	American plaice combined with species richness, top 2 classes	6.58
X41ESW9+	Witch flounder combined with ESW, top 2 classes	13.34
X41Hp9+	Witch flounder combined with Heip's, top 2 classes	9.98
X41Ri9+	Witch flounder combined with species richness, top 2 classes	13.40
X4511ESW9+	Shortfin squid combined with ESW, top 2 classes	3.70
X4511Hp9+	Shortfin squid combined with Heip's, top 2 classes	3.50
X4511Ri9+	Shortfin squid combined with species richness, top 2 classes	6.97
X50ESW9+	Atlantic wolffish combined with ESW, top 2 classes	7.73
X50Hp9+	Atlantic wolffish combined with Heip's, top 2 classes	7.46
X50Ri9+	Atlantic wolffish combined with species richness, top 2 classes	7.26
X51ESW9+	Spotted wolffish combined with ESW, top 2 classes	0.29
X51Hp9+	Spotted wolffish combined with Heip's, top 2 classes	0.21
X51Ri9+	Spotted wolffish combined with species richness, top 2 classes	0.32
X52ESW9+	Northern wolffish combined with ESW, top 2 classes	0.24
X52Hp9+	Northern wolffish combined with Heip's, top 2 classes	0.34
X52Ri9+	Northern wolffish combined with species richness, top 2 classes	0.34
X60ESW9+	Herring combined with ESW, top 2 classes	0.88
X60Hp9+	Herring combined with Heip's, top 2 classes	0.11
X60Ri9+	Herring combined with species richness, top 2 classes	8.92
X610ESW9+	Sand lance combined with ESW, top 2 classes	1.42
X610Hp9+	Sand lance combined with Heip's, top 2 classes	3.99
X610Ri9+	Sand lance combined with species richness, top 2 classes	0.05
X6411ESW9+	Sea urchin combined with ESW, top 2 classes	4.99
X6411Hp9+	Sea urchin combined with Heip's, top 2 classes	8.35
X6411Ri9+	Sea urchin combined with species richness, top 2 classes	0.19
X64ESW9+	Capelin combined with ESW, top 2 classes	0.78
X64Hp9+	Capelin combined with Heip's, top 2 classes	0.75
X64Ri9+	Capelin combined with species richness, top 2 classes	0.54
X6600ESW9+	Sea cucumbers combined with ESW, top 2 classes	2.64
X6600Hp9+	Sea cucumbers combined with Heip's, top 2 classes	4.33
X6600Ri9+	Sea cucumbers combined with species richness, top 2 classes	0.03
X70ESW9+	Mackerel combined with ESW, top 2 classes	2.66
X70Hp9+	Mackerel combined with Heip's, top 2 classes	1.65
X70Ri9+	Mackerel combined with species richness, top 2 classes	3.33