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Review of the structure, the abundance and distribution of *Sebastes mentella* and *S. fasciatus* in Atlantic Canada in a species-at-risk context

Revue de la structure, de l'abondance et de la répartition de *Sebastes mentella* et *S. fasciatus* dans le Canada atlantique dans le contexte des espèces en péril.

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Abstract

This document presents the information reviewed and analyzed by Fisheries and Oceans (DFO) that could be used by the Committee on Status of Endangered Wildlife in Canada (COSEWIC) in assessing status and extinction risk of the two main species of redfish (*Sebastes fasciatus* and S. *mentella*) in the Northwest Atlantic. Redfish population structure was evaluated in the context of "evolutionarily significant units". The review did not provide evidence to indicate the existence of ESUs within current management units, therefore all the analyses were realized on the current unit stocks. Methods have been developed to separate redfish by genotype and applied to the research vessel (RV) survey data to obtain abundance indices. Three distribution indices were calculated: the area of occupancy, the minimum area occupied by 95% of the stock, and the Gini index of aggregation. No general pattern or trend in geographic distribution was evident. One stock experienced a substantial decline and had not recovered (Unit 1). One stock experienced declines but has shown some recovery (NAFO divisions 2GHJ 3K). The remaining management units have not shown a decline or the information available may not reflect the abundance. Fishery exploitation and the lack of recruitment were considered the main causes of abundance decline for two stocks (Unit 1 and 2GHJ 3K), although environmental changes and elevated natural mortality were identified as possible factors. Mature population abundance indices of all redfish stocks in Atlantic Canada are at least two orders of magnitude greater than the COSEWIC threshold of 10 000 mature individuals.

Résumé

Ce document présente les informations revues et analysées par Pêches et Océans qui peuvent être utilisées par le Comité sur la situation des espèces en péril au Canada (COSEPAC) afin d'évaluer l'état des deux principales espèces de sébaste (*Sebastes fasciatus* and S. *mentella*) dans l'Atlantique du nord-ouest. La structure de la population du sébaste a été évaluée dans le contexte d'unités importantes sur le plan de l'évolution (UIPÉ). Cette revue n'a pu mettre en évidence d'UIPÉ à l'intérieur des unités de gestion courantes, donc toutes les analyses subséquentes ont été faites selon la définition actuelle des stocks. Des méthodes ont été développées pour séparer les sébastes par génotype et elles ont été appliquées aux données des relevés de recherche afin d'obtenir des indices d'abondance. Trois indices de distribution ont été calculés : l'aire occupée, la surface minimale occupée par 95 % de l'abondance du stock et l'indice d'agrégation GINI. Aucun patron ou tendance dans la distribution géographique n'a été observé. Un stock a montré un déclin important mais ne s'est pas rétabli (Unité 1). Un stock a montré un déclin et un certain rétablissement (Divisions 2GHJ 3K de l'OPANO). Les autres unités de gestion n'ont pas montré de déclin ou les informations disponibles ne reflètent peut-être pas l'abondance. L'exploitation par la pêche et le manque de recrutement ont été considérés comme les causes principales de déclin pour les deux stocks (Unité 1 et 2GHJ 3K). Toutefois, des changements environnementaux et une mortalité naturelle élevée ont été identifiés comme causes possibles de déclin. L'estimation des effectifs matures de tous les stocks de la côte Atlantique du Canada excède par au moins deux ordres de grandeur le seuil des 10,000 individus matures établi par le COSEPAC.

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Introduction

This document presents a review of information reviewed and analyzed by Fisheries and Oceans (DFO) that could be used by the Committee on Status of Endangered Wildlife in Canada (COSEWIC) in assessing status and extinction risk of the two main species of redfish in the Northwest Atlantic (*Sebastes fasciatus* and S. *mentella*). A third species, *S. marinus*, also co-exists in some areas but is relatively abundant only in the Flemish Cap area. This species is not considered to be important to the Canadian fisheries (Atkinson 1987). A large part of the information presented in the present document is already available as primary publications and in stock assessment Research Documents that are available from the CSAS website (http://www.dfo-mpo.gc.ca/csas/).

Redfish species are usually not discriminated in the fishery and are managed together as one “species”. The standard DFO assessments are prepared for *Sebastes* sp all together. Therefore, in order to provide COSEWIC with relevant biological and exploitation information on each species, a protocol for species identification had to be developed to re-analyze the data available in the three different DFO regions involved in redfish management. This protocol is presented in a separate document for Units 1 and 2 (Méthot et al. in prep.). In the present document, the information available on *Sebastes fasciatus* and *S. mentella*, for the main indices available, is presented under the four terms of reference of COSEWIC.

For the first term of reference, the population structure is reviewed in the context of “Evolutionarily Significant Units”(ESU). We also determined if stock management units currently used are composed of different evolutionary significant units or not using the results of the most recent studies available.

For the second term of reference, the overall trends in population size estimated by the number of mature individuals and the total numbers of individuals in the populations or management units are presented. We try to describe these trends over as long a period of time as possible and at least over a period representing the past three generations as determined by the mean age of spawners. Where declines have occurred over the past three generations, the degree to which the causes of the declines are understood, and the evidence that the declines are a result of natural variability, habitat loss, fishing, or other human activities are summarised. In these cases we also summarised the evidence that the declines have ceased, are reversible, and estimate the likely time scales for reversibility.

For the third term of reference, changes in area of occupancy over as long a period of time as possible, and in particular, over the past three generations are described. Any evidence that there have been changes in the degree of fragmentation of the populations or management units, or a reduction in the number of meta-population units is presented.

Finally, under the fourth term of reference, the best scientific estimates of the number of mature individuals are summarised. If there are likely to be fewer than 10 000 mature individuals, we estimated trends in numbers of mature individuals over the past 10 years or three generations, and, to the extent possible, causes for the trends

Terms of reference 1: Population structure of redfish stocks in Canada in the context of « evolutionarily significant units »

1.1 General biology of redfish

1.1.1 Species identification and distribution (geographic, with depth)

Redfish, also known as ocean perch, belong to a group of fish that are commercially exploited in both the Atlantic and Pacific Oceans. Four species of the genus *Sebastes* are recognised in the North Atlantic. *Sebastes marinus* (Linnaeus 1758) and *S. mentella* (Travin 1951) are distributed on both side of the North Atlantic while *S. fasciatus* (Storer 1854) and *S. viviparus* (Krøyer 1845) distributions are restricted to the Northwest and Northeast Atlantic respectively. Recent studies using molecular biology tools (Roques et al. 1999a) have established that these redfish belong to four genetically differentiated groups (Roques et al. 1999b). However, in the Northwest Atlantic, the genetic differentiation between redfish species is complicated by the presence of introgressed individuals between *S. fasciatus* and *S. mentella* in the Gulf of St. Lawrence and the waters south of Newfoundland (Desrosiers et al. 1999; Roques et al. 2000, 2001, 2002; Valentin et al. 2002; Sévigny et al. 2003).

In the Northwest Atlantic, the redfish distribution ranges from the Gulf of Maine, northwards off Nova Scotia and Newfoundland banks, in the Gulf of St. Lawrence and along the continental slope from the south-western Grand Banks and in the area of Flemish Cap. They are also present off Labrador and Baffin Island and west of Greenland (Atkinson 1987 and references therein).

Redfish species distribution at the scale of the Northwest Atlantic was examined in a recent study in which two morphological (AFC [Anal Fin Rays Count], EGM [Extrinsic gasbladder musculature]) and one genetic criteria (locus *MDH-A** [Malate dehydrogenase]) were used to discriminate the redfish species (Sévigny et al. 2003). The results of this study were in general agreement with those of previous studies that have shown that the northern Labrador Sea (NAFO Divisions 2G-2H) and the Gulf of Maine and Scotian Shelf represent allopatric zones for *S. mentella* and *S. fasciatus* respectively (Barsukov and Zakharov 1973; Ni 1982; 1984; Atkinson 1987). Indeed, 98% of the specimens sampled in Northern Labrador Sea belong to *S. mentella* while more than 97 % of those collected in the Scotian Shelf-Gulf of Maine area belong to *S. fasciatus*. The Gulf of St. Lawrence, the Laurentian Channel, the Grand Banks, southern Labrador Sea and the Flemish Cap form a large area of sympatry separating the two allopatric zones as suggested by previous studies (Figure 1). *Sebastes fasciatus* and *S. mentella* distributions are also characterized by the presence of an area of introgressive hybridization (incorporation of genes of one species into the gene pool of another) which occupies only part of the broader sympatric zone. Indeed, introgression between the two species is geographically circumscribed to Units 1 and 2 and to a lesser extent to the Flemish Cap area, where the two introgressed groups persist together with non introgressed individuals of the two species. Furthermore, since introgression is geographically limited, the genetic integrity of both species outside the defined zone of introgression is maintained. This maintenance takes place despite high potential for gene flow through larval dispersion.

The distribution of *S. marinus* is not well known (Atkinson 1987) but this species is not abundant in most areas of the Northwest Atlantic with the exception of Flemish cap (Ni and McKone 1983; Rubec et al. 1991; Gascon 2003).

Redfish inhabit cool waters along the slopes of banks and deep channels in depths of 100-700 m. *Sebastes fasciatus* typically occurs in shallower waters (150-300m), whereas *S. mentella* is distributed at depths varying between 350 and 500 m (Atkinson 1987). The temperature preference for redfish in Units 1 and 2 is about the same, being between about 4.5 – 6.0º C, in Unit 3 it is somewhat warmer at about 5.5 – 7.0º C.

In addition to being found near the bottom, redfish are often distributed well up in the water column. The vertical distribution in the water column of these semi-pelagic species varies both diurnally and seasonally. Such vertical migration patterns affects catches and complicates the interpretation of data collected in commercial as well as in DFO research surveys.

1.1.2 Life history characteristics (growth, fecundity, larval extrusion etc…)

Redfish are slow growing and long lived species. Specimens have been aged to at least 75 years (Campana et al. 1990). *Sebastes fasciatus* does not grow as fast as *S. mentella*, although the differences in growth rate become apparent only after about age 10. In both species, females grow faster than males after about age 10. Growth is also usually faster in southern areas than in northern areas (Branton et al. 2003). On average, redfish takes approximately 6 to 8 years to reach the minimum fishable size of 22 cm as dictated by small fish protocols in Conservation Harvesting Plans.

Males mature 1-2 years earlier than females of the same species and at a size which is 3-5 cm smaller than females. Comparison between species showed that *S. fasciatus* of a given sex mature 1-2 years earlier than *S. mentella* of the same sex and at a size which is 1-3 cm smaller than that of a maturing *S. mentella*. *Sebastes fasciatus* males mature at a younger age and smaller size than either the female *S. fasciatus* or the male and female *S. mentella* (Branton et al. 2003).

The reproductive cycle of redfish differs from that of other species. Indeed, unlike many other fish species, fertilisation in redfish is internal and females bear live young. Mating is believed to occur in the fall most likely between September and December. Females carry the developing embryos until the spring. Larval extrusion takes place from April to July depending on the areas. Of the two species of beaked redfish, *S. mentella* releases its larvae about 3 to 4 weeks earlier than *S. fasciatus* in the Gulf of St. Lawrence (Gagné 1995; Sévigny et al. 2000) and on Flemish Cap (Templeman 1980). On the south coast of Newfoundland, *S. marinus* spawns earlier than beaked redfish thought to be predominantly *S. fasciatus* (Ni and Templeman 1985). It has been suggested that stress (such as fishing) on females prior to larval release may affect survival of the larvae (DFO 2000a). St-Pierre and de Lafontaine (1995) evaluated the absolute fecundity, expressed as the total number of oocytes per female, of Gulf of St. Lawrence redfish to vary between 1 500 and 7 000 and increase as a power function of fish length and weight.

1.1.3 Recruitment

Recruitment success in redfish is extremely variable, and significant year-classes have been observed at intervals of 5 to 12 years. The differences between strong and weak year-classes appear to be somewhat less in the southern part of the range of redfish. Recent laboratory studies suggest that larval survival is greatest at medium prey densities (Laurel et al. 2001).

In Unit 1, some year-classes that appeared strong at young ages in research surveys have subsequently disappeared rapidly before contributing to the adult population. This occurred for the 1964, 1974 and 1988 year-classes. Reasons for these decrease in abundance remain unknown, although it has been determined that the 1988 year-class was predominantly *S. fasciatus* (Morin and Hurtubise 2003).

1.1.4 Management

There are currently nine redfish management areas in the Northwest Atlantic which are based on NAFO Divisions (Fig. 1): West Greenland (SA1), Labrador Shelf (2GHJ 3K), Flemish Cap (3M), North and East Grand Banks (3LN), South Western Grand Banks (3O), Gulf of St. Lawrence (“Unit 1” consisting of 4RST, 3Pn4Vn [Jan. to May]), Laurentian Channel (“Unit 2” consisting of 3Ps4Vs4Wfgj, 3Pn4Vn [June to Dec.]), Scotian Shelf (“Unit 3” consisting of 4WdehklX) and Gulf of Maine (subArea 5). Some of these management areas are entirely located within the Canadian economic exclusive zone (EEZ), but others extend into or lie entirely in international waters or in the EEZ of the United States or Greenland. The original management units appear to have been based on both geographical and biological considerations arising from discussions at a ICES/ICNAF redfish symposium in 1959 (see Mead and Sinderman 1961). Since then, only UNITS 1-3 have been re-defined from the previous three management areas (i.e. 4RST, 3P and 4VWX) that were in existence up to 1992 (Atkinson and Power 1991). A description of each management units is presented in section 1.3. In these areas, except for Flemish Cap and in the Gulf of Maine, Canada has prosecuted redfish fisheries to varying degrees since the late 1940s. The most commonly fished areas were Subarea 2 + Div. 3K, as well as Units 1, 2 and 3 (DFO 2000a).

The three Northwestern species are morphologically similar and are nearly impossible to distinguish by visual examination. They are not separated in the fishery, and they are managed together as one “species”.

1.2 Evolutionarily Significant Units and population structure of redfish

Evolutionarily Significant Unit (ESU) is a concept developed to get a rational basis for prioritizing taxa for conservation effort but how it should be defined is still debated (e.g. Fraser & Bernatchez 2001). For a review of ESU in COSEWIC context see Smedbol et al. (2002). Basically, two approaches have been commonly documented. The US National Marine Fisheries Service definition implies that a substantially reproductive isolation occurs from other populations and that the population represents an important component in the evolutionary legacy of the species to indicate an ESU. The major inconvenience of this approach is the presence of subjectivity to determine what is substantial or important enough to justify a separation as ESU.

The second approach is the phylogeographical methods. Moritz (1994) wrote: “ESUs should be reciprocally monophyletic for mtDNA alleles and show significant divergence of allele frequencies at nuclear loci”. Phylogeographical methods are more rigorous and objective since requirement of reciprocal monophyly is a qualitative criterion. However results of phylogenies could vary according to the method used.

1.2.1 General population structure of redfish

The description of redfish stock structure and the determination of ESU is complex since three species are currently recognised in the Northwest Atlantic: *Sebastes mentella* (Travin 1951), *S. fasciatus* (Storer 1854) and *S. marinus* (Linnaeus 1758).

The stock structure of redfish was recently addressed in two types of studies: 1) tagging using parasites as natural tags (Marcogliese et al. 2003) and genetic analyses (Roques et al. 2000; 2001; 2002).

Parasites were examined from deepwater redfish (*Sebastes mentella*) collected from five areas representing four management units: Flemish Pass (3M), off Labrador (2J), in the Laurentian Channel (4Vn in August; 3Ps in January = Unit 2), in Cabot Strait (3Pn = Unit 2) and from the Gulf of St. Lawrence (4T = Unit 1) between August 1996 and January 1997). Multiple non-parametric analyses demonstrated that distinct stocks of redfish occurred off Labrador and on the Flemish Cap, which agrees with earlier studies (Bourgeois and Ni 1984; Templeman and Squires 1960). Analyses also suggested that fish could be separated from the Gulf of St. Lawrence (summer), and the Cabot Strait (summer) or Laurentian Channel (summer or winter). Parasitological data therefore suggest that redfish from Unit 1 and Unit 2 may belong to separate stocks (Marcogliese et al. 2003). In fact, all areas sampled in this study are currently managed as separate stocks, and although sample size is low in some area, the results do not suggest that this strategy should be changed (Marcogliese et al. 2003).

Stock structure based on parasites (Marcogliese et al. 2003) are only partly supported by those of recent population genetic studies on *S. fasciatus* and *S. mentella* based on the analyses of microsatellites markers (Roques et al. 2000; 2001; 2002; Tables 1 and 2). These studies, carried out throughout *S. fasciatus* and *S. mentella* distribution range have revealed a population structure that is determined to a large extent by the importance of introgressive hybridization between *S. fasciatus* and *S. mentella* which only takes place within a particular part of the area of sympatry, more specifically in the Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2). Indeed, introgression has very important effects on genetic diversity and population structure of both species. One of the effects was a modification of genetic variability of both species. For *S. fasciatus,* heterozygosity increased from 0.757 in allopatric samples to 0.832 in the area of introgression. For *S. mentella* the number of alleles decreased in the area of introgression (149 compare to 160). Introgression, since it involves exchange of genes from one species to the other, also tends to decrease divergence between *S. fasciatus* and *S. mentella* in area of introgression compared to areas where this phenomenon does not take place (Roques et al. 2001) For a given species, sympatric individuals were genetically closer to the individuals of the other species, than were allopatric individuals. Furthermore, the sympatric samples comprised individuals possessing alleles of both *S. fasciatus* and *S. mentella*, rather than an admixture of pure individuals from the two taxa. These studies also revealed that introgression, while bi-directional, was asymmetrically more important towards *S. mentella* indicating that it did not affect both species in the same way.

For *S. mentella* three broad populations were detected at the scale of the North Atlantic: 1) the western group is comprised of redfish from Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2); 2) the panoceanic group is comprised mostly of samples collected across the Atlantic, from the Grand Banks and Labrador Sea to the Faeroe Islands i.e. 5 000 km; 3) the eastern group is comprised of Norway and Barents Sea samples (Roques et al. 2002). At this scale, genetic breaks were found at both extremes of the range of *S. mentella*, with clear differentiation of samples from the western group from all other groups in both allelic frequencies and in other indices of genetic differentiation (mean θ =0.0127). Significant differences were also found between Norway and all the other groups (θ =0.0239). These differences between the groups may be attributed to oceanographic features and/or vicariance (discontinuous biogeographical distribution of organisms that previously inhabited a continuous range) events in the eastern regions (Norway and Barents Sea) and to the existence of an introgressive hybridisation zone in the Gulf of St. Lawrence and the Laurentian Channel (Units1 and 2). Indeed, incorporation of genes from *S. fasciatus* into the genome of *S. mentella* from these areas of sympatry will increase the genetic difference between *S. mentella* from the area where introgression occurs with those from the allopatric area (e.g. Labrador Sea). The weak structuring observed in the panoceanic region could be an indication of extensive larval dispersion across the area.

For *S. fasciatus*, three populations appear to exist: 1) Units 1 and 2; 2) Unit3; 3) Gulf of Maine. The homogeneity observed between samples from Units 1 and 2 is in agreement with the studies showing that introgressive hybridisation is taking place in these two areas. The differentiation of these *S. fasciatus* from those of Unit 3 is most likely the result of introgressive hybridisation with *S. mentella* that is taking place in the Gulf of St. Lawrence and in the Laurentian Channel. The difference observed between *S. fasciatus* from the Gulf of Maine and those from Unit 3 is more difficult to explain and additional sampling and analyses will be needed to confirm the results of the present study. These differences were small and the θ values, the Fst estimator of Weir and Cockerham (1984) were neither significant among the samples collected in the area of sympatry or between the Gulf of Maine (FAA1) and Unit 3 (FAA2) (Table 2).

In the following section the information available for each management unit is reviewed to determine whether or not more than one ESUs is present within current management units.

1.3 Description of redfish stocks and ESU

1.3.1 Unit 1

Unit 1 represents a relatively new management unit. Redfish in the Gulf of St. Lawrence were previously managed as NAFO div. 4RST only. In 1991, based on a detailed examination of available data, a recommendation was made to modify the management units to consider the winter migration of redfish to the Cabot Strait area. Thus 3Pn4Vn (Jan. to May), were included with 4RST in 1993 to constitute the Unit 1 stock (Atkinson and Power 1991).

The results of genetic studies (Roques et al. 2001) indicated that there were no differences between the samples of these two units for *S. fasciatus* as well as for *S. mentella*. There was also no indication of heterogeneity among the samples of *S. fasciatus* and *S. mentella* within this management unit (Table 2). However, results of the stock identification study based on parasites indicates that *S. mentella* from Unit 1 differ from those of Unit 2 (Marcogliese et al. 2003).

Altogether, there is no indication for the existence of ESU at a finer scale within the Gulf of St. Lawrence (Unit 1).

The directed redfish fishery in Unit 1 was closed in 1995 due to low stock abundance and the absence of significant recruitment since the early 1980s.

1.3.2 Unit 2

Unit 2 was implemented in 1993. Redfish in Subarea 3 west of 3O and Subarea 4 were previously managed as two management units, NAFO Div. 3P and NAFO Div. 4VWX. In 1991, based on a detailed examination of available data, a recommendation was made to modify the management units to consider the winter migration of redfish into the Cabot Strait area and to take into account the apparent break in distribution along the southern edge of the Scotian Shelf. Thus 3Pn4Vn (June to December), were included with 3Ps4Vs4Wfgj to constitute the Unit 2 stock (Atkinson and Power 1991).

As noted above, there was no difference in the genetic characteristics of redfish from Units 1 and 2 (Roques et al. 2001) but there were differences in the parasite fauna of *S. mentella* between the two management units (Marcogliese et al. 2003).

There was some weak indication of genetic heterogenity between some *S. mentella* samples collected within this management unit. Differences were observed between the Newfoundland sample MES4, and the other samples from the same region, MES1-MES3. MES3 was also significantly different from MES1 and MES5 (Table 1). The differentiation of those samples from the others was attributed to variable levels of introgression of redfish aggregations observed in these regions. However, the θ values calculated among these samples were not significant (Roques et al. 2001; Table 2). An ongoing study addresses this question.

Study of parasites (Marcogliese et al. 2003) also found difference between *S. mentella* of this Unit with those of Unit 1.

Altogether, there is no indication for the existence of ESU at a finer scale within the Laurentian Channel management Unit (Unit 2).

The directed redfish fishery in Unit 2 has remained open throughout the closure in Unit 1 although the total allowable catch (TAC) has declined over the period.

1.3.3 Unit 3

Unit 3 encompasses NAFO Div. 4X and the statistical unit areas 4Wdehkl. The redfish in these areas were previously managed as part of Div. 4VWX. This new management area was first implemented in the 1993 groundfish ganagement plan. This modification resulted after an examination of the biological characteristics of the redfish in the previous management units (Atkinson and Power 1991). Genetic and morphological analyses have shown that *S. fasciatus* is almost the only species represented in Unit 3. Results of the microsatellite analyses suggest the existence of slight differences in allelic frequencies between samples collected in the Gulf of Maine (FAA1) and in Unit 3 (FAA2) (θ =0.0132). There was no difference among the four sampling sites of the Gulf of St. Lawrence and of the Laurentian Channel FAS1, 2, 3, 4 (averaged θ =0.0006). The θ values, however, were neither significant among the samples collected in the area of sympatry or between FAA1 and FAA2 (Roques et al. 2001)

There is no indication for the existence of ESU at a finer scale on the Scotian shelf (Unit 3).

1.3.4 NAFO division 3O, Divisions 3LN and Division 3M

Quota regulation of redfish began in and around the Grand Banks of Newfoundland in 1974 (ICNAF 1973). Parsons and Parsons (1973) provided an evaluation of the status of 3LN, 3O and 3P redfish as separate “stocks”. They considered that redfish of the northern and eastern Grand Banks (3LN) constituted a different stock than 3OP based on the discussions of Mead and Sinderman (1961) and the larval research of Bainbridge and Cooper (1971). They also provided the status of redfish in 3O and 3P separately based on different growth rates. Parsons and Parsons (1974) also provided an assessment of 3M redfish as previous studies (Yanulov 1960a and b; Bainbridge and Cooper 1971) had concluded that redfish in this area constituted a self contained stock.

Currently, 3LN is under moratorium to directed fishing, 3M has a TAC of 5 000 tons and 3O has a quota of 10 000 tons. Recruitment prospects have also been generally poor since the 1990 year class in 3M, the 1986/1987 year class in 3LN and the 1988 year class in 3O.

Sebastes mentella sampled in these management units were genetically differentiated from those of Unit 2 but no difference could be detected between these redfish and those collected from a much larger area of the Atlantic (panoceanic region of Roques et al. 2002).

There is no information to suggest the existence of ESU at a finer scale within the boundaries of each of the separate management units of Div. 3LN, Div. 3O or Div. 3M for *S. fasciatus* and *S. mentella*.

1.3.5 NAFO divisions 2GHJ 3K

Quota regulation of redfish in Sub-Area (NAFO) 2 + Div. 3K began in 1975. Pinhorn and Parsons (1974) provided the first assessment of redfish in these areas. Parsons et al. (1976) suggest that redfish in SA2+3K were assessed as a unit stock according to ‘current ICNAF practise’. The origin of this ‘current ICNAF practise’ can not be identified.

Currently, redfish in SA2+3K is under moratorium to directed fishing. Recruitment has been poor since the year classes of the early 1970s.

Results of a genetic analysis (Roques et al. 2002) has shown that *S. mentella* from this management unit is not differentiated from those of the southern management unit (3LN, 3O) and may belong to a much larger area of the Atlantic Ocean (Panoceanic in Roques et al. 2002.)

There is no information to suggest the existence of an ESU at a finer scale within the boundaries of the SA2+Div. 3K management unit. It has even been hypothesized that larval drift from the Irminger Sea oceanic stock of *S. mentella* may play an important role in the population dynamics SA2 + Div. 3K (Roques et al. 2002).

1.4 Comparisons of stock for some biological information

In order to describe a possible relationship or differences between stocks, some life history characteristics are compared.

First, sexual maturity between stocks shows that redfish reach maturity at different length and age in each unit. Those differences suggest separation by management unit. Individuals of the three MDH genotypes seem to mature younger in Unit 1 then other areas (Table 3). As expected, males mature younger then females and *S. fasciatus* mature younger then S. mentella.

Second, the growth is similar for all stock, although the males *S. fasciatus* and heterozygous and the females *S. fasciatus* caught in unit 2 seems to grow faster after the age of 10 (Figure 2). As it was mentioned before they reach the limit currently set as a small fish protocol (22 cm) at age 8.

Finally, strong year-classes appear around the same years in several stocks. For example, in Unit 1 five very abundant year classes have been reported since 1946 (Table 4). Some year classes vanish before reaching the minimum cacheable size (years 1966, 1974 and 1988). The 1988 was likely made of *S. fasciatus*, while it remains speculative to identify species of other years since specie separation was not performed at this time. Unit 2 observations were very similar to Unit1 with the exception that the 1988 year class persisted in Unit 2.

1.5 Conclusions on population structure and approach chosen

Studies dealing with redfish population structure have shown the existence of some stock structure for *S. fasciatus* as well as for *S. mentella* in the Northwest Atlantic. For both species the population structure is largely influenced by the phenomenon of introgressive hybridization that is taking place in the Gulf of St. Lawrence and Laurentian Channel. For *S. fasciatus*, three stocks were detected with genetic studies: Gulf of St. Lawrence and Laurentian Channel (Units 1 and 2), Scotian Shelf (Unit 3) and the Gulf of Maine. Genetic differences between Units 1 and 2 and Unit 3 are largely driven by introgression between the two species that is taking place in the Laurentian Channel. The difference betweeen Unit 3 and the Gulf of Maine are very small and would need to be confirmed in further studies. Two populations were detected for *S. mentella*: Units 1 and 2 and all other management units, based on the genetic studies. However, parasite studies suggest differences between Unit 1 and Unit 2. As it was the case for *S. fasciatus*, introgressive hybridization is the most likely explanation for the structure observed. An important conclusion that can be drawn for the genetic studies is that there is no evidence of population structure (ESU) at a scale smaller then the redfish management units currently used for *S. fasciatus* as well as to *S. mentella*. The scale at which genetic differentiation is observed appears to be much larger than these management units. It may be argued at the existence of one ESU for each of the two species examined in this review, these ESUs would correspond to the allopatric area of distribution of each of them. For both species, the ESU comprise more than one management units.

For our concern, as for cod (Smedbol et al. 2002), the current redfish management units are already defined on a finer scale than potential ESUs and thus it was concluded that management unit is the best approach.

Terms of reference 2: Declining Total Population

2.1 Summary of the methods to separate redfish by genotype

2.1.1 Introduction

The three species currently recognised in the Northwest Atlantic (*S. mentella, S. fasciatus* and *S. marinus*) can be identified using several techniques. The anal fin ray counts (AFC), the extrinsic gasbladder muscle (EGM) rib passage patterns and the malate dehydrogenase (MDH) electrophoretic mobility patterns are the most currently used to discriminate among the species. Prior to the use of these methods in the 1980s, only beaked redfish collectively (*S. fasciatus* and *S. mentella*) could be distinguished from *S. marinus* based on differences in color (flame red versus yellow-red respectively), eye size (*S. marinus* has a relatively smaller eye) and the degree of development of the bony protrusion on the lower jaw (sharp versus blunt respectively). However, these characters were essentially only useful for fish larger than 25cm. The current methods (AFC, EGM and MDH) have met with varying degrees of success (Ni 1981 1982, Payne and Ni 1982; McGlade et al. 1983, Rubec et al. 1991, Sévigny and de Lafontaine 1992). In addition, they are often time consuming and are not routinely applied in field surveys nor commercial sampling. As a result, redfish is exploited and managed as one species. Therefore information on the abundance and distribution of individual redfish species is missing for several years. In order to lessen the impact of this weakness in the data set, a method for estimating redfish species identification and distribution was developed (Méthot et al. in prep. See below).

The species identification data from DFO surveys were analysed to separate the survey data by species or genotype and to provide independent estimates for each species when possible .

2.1.2 Methods to identify redfish species by stock

The species data used for Units 1-3 came mainly from the High Priority Multidisciplinary Redfish Research Program (HPMRRP) 1995-1998 and was used to describe the general pattern of species distribution in recent years (Gascon 1003. For each stock, the available species data information was described in terms of the proportions of the species and genotype at the *MDH-A** locus to 1) determine if it would be possible or necessary to split the abundance indices by species and 2) to get the proportions of redfish species by depth zone. This factor was retained as the main variable to consider to split the catches by species since redfish species have different depth range distributions (Rubec et al. 1991) and the stratification scheme of the DFO RV surveys used depth as the main aspect to define strata. These depth proportions of species were used to attribute proportion of the catches of redfish by tow and by depth zone.

Species identification data collected from the HPMRRP were considered insufficient to derive proportions of *S. fasciatus* and *S. mentella* for management units other than UNITS 1-3. A more extensive but less reliable source of data for species separation is the meristic database utilized in Ni (1982). This database was used to derive proportions of each species by depth zone based on the survey stratification for various survey series within three “stock” areas (SA2+Div. 3K, Div. 3LN, and Div. 3O). Div. 3M was not included in these analyses because there is insufficient Canadian survey data within the depths where redfish normally reside to analyse beyond 1985. However, recent stock assessments contain information on redfish spp. abundance at length by year stratified-random surveys conducted by the European Union in Div. 3M since 1988 (Ávila de Melo et al. 2002, see also Vasquez 2002).

In the next sections, the methods used for the main survey indices of each stock are summarised. For more details on the methods used, see Méthot et al. (In prep.).

2.1.2.1 Unit 1

For the Gulf of St. Lawrence redfish AFC and MDH were used to separate the abundance by species. Because an overlap occurs between AFC of *S. fasciatus* and *S. mentella*, a correction had to be made. The proportions of genotype (based on MDH) for each AFC count at each depth interval was estimated from the HPMRRP data. These proportions were used for the correction of AFC at each tow (Méthot et al. In prep.) for tows with AFC data of the years 1985 to 1987 and 1993 to 2002. This is the basis of the method used to get numbers by genotype caught at each tow. For all the tows with redfish catches but with no AFC data, we used the genotype proportions by depth intervals (Méthot et al. in prep.).

To estimate the abundance of mature fish, length-AFC keys for each depth interval were estimated (Méthot et al. In prep.). When no AFC data were available, the key of the closest year was used. The lengths at which 50 % of the fish are mature (L50) for the genotypes were estimated for males and females combined. The abundance at length equal and higher to that of the L50 (*S. fasciatus* = 20.4 cm; *S. mentella* = 23.8 cm, heterozygotes = 22.7 cm) have been added for each year to get the total abundance of mature fish.

In 1984 and for the 1988 to 1992 period, since no AFC data have been collected or can be used, assumptions have to be made to get an abundance index by species. It was decided to use the AFC-length key methods (using 1985 keys for 1984, 1987 keys for 1988-1989 and 1993 for 1990 to 1992). These keys were applied to the abundance at length of each year.

Finally, to allow the comparison of the *Lady Hammond* series (1984 to 1989) with the CCGS *Alfred Needler* series (1990 to 2002), we applied a conversion factor by length (Hugo Bourdages and Doug Swain per. com.) and used a multiplicative model to obtain estimation of the strata that were not sampled some years (see Méthot et al. In prep).

Caution is necessary when interpreting the results of the separation by MDH genotype analysed particularly for years with no species identification data. The data used to establish the depth distribution by species is coming from a relatively short period (1993 to 1996) when the abundance of juveniles was low. The presence of good recruitment of one species (1980, 1985 and 1988 year-classes) could affect these distributions as could any changes in time due to environmental factors.

2.1.2.2 Unit 2

No AFC discrimination criteria have been recorded systematically during the DFO summer surveys of Unit 2 that started in 1994. Assumptions have been made using genotype proportion by depth zone calculated from the HPMRRP 1995-1998 data (Méthot et al. In prep.). These proportions have been applied to split genotypes by tow. Subsequently PACES application (SAS) was used to get total abundance for each species.

It should be noted that the genotype proportions of years 2000 and 2002 may be different than the time period analysed (1995-1998).

The same method used in Unit 1 was applied in Unit 2 to get length frequencies by genotypes and estimates of the abundance of mature fish (Méthot et al. In prep.). The L50 estimated for males and females combined are *S. fasciatus* = 22.5 cm, *S. mentella* = 23.7 cm and heterozygotes = 24.4 cm.

2.1.2.3 Unit 3

Unit 3 redfish are not typically examined to discriminate species during DFO research surveys in this area. As previously mentioned, genetic research has shown that Unit 3 redfish are almost exclusively *S. fasciatus*. Based on MDH analysis of 608 redfish collected in Unit 3 during the High

Priority Multidisciplinary Redfish Research program (1995-1998), 16 fish were determined to be *S.mentella* and 592 *S.fasciatus*. Therefore, all further analysis of data from Unit 3 assumed that the redfish population is entirely *S. fasciatus*.

2.1.2.4 NAFO Division 3O, Divisions 3LN, SA2+Division3K

As indicated above, the meristic database utilized in Ni (1982) was used to derive proportions of each species by depth zone based on the survey stratification for various survey series within three “stock” areas (SA2+Div. 3K, Div. 3LN, and Div. 3O).

Based on a published literature review tabled in Ni (1982), studies of meristic characters by various researchers suggest the following: *S. mentella* has 30 vertebrae (V), 8-9 anal fin rays (AFR), 15 dorsal fin rays (DFR) while *S. fasciatus* has 29 V, 7-8 AFR, 14 DFR. Individual fish from the meristic database were assigned to one or the other species if two of the three characters exhibited the typical count. Ambiguous specimens were not used (eg. a fish with 30 V, 8 AFR and 14 DFR). The data were then partitioned into two groups, dependent on whether the data were collected in the first half or the second half of the year. Proportions of each species were then calculated from the database by “stock” area, depth zone and separately for each half year. These proportions were then applied to stratum by stratum estimates of abundance at length for each spring survey (using the first half year proportions) and autumn survey (using the second half year proportions) for surveys conducted within the “stock” area (Table 5). The only exception to this was that proportions for 2G and 2H were calculated separately from 2J and 3K for the SA2+3K stock area because it is believed that the abundance of *S. fasciatus* drops off significantly north of 2J. Finally, proportions based on fewer than 10 fish in any depth zone were pooled with the most appropriate adjacent depth zone before being applied to the survey abundance data.

There was insufficient genetic samples collected from the 2GHJ3KLNO area to allow for estimates of L50 separately by management unit. To estimate the abundance of mature fish for each species, the L50 values derived for males and females from Unit 2 were averaged (22cm for *S. fasciatus* and 24cm for *S. mentella*) and used as a criteria for those management units within the 2GH2J3KLNO area. Mature fish were those fish equal to or greater than this sex averaged L50.

2.2 Evaluation of Declining Total Population by management unit

For each stock the main indices of abundance are presented with a description of the factors that could be responsible for any decline in the indices. There are several approaches that could be used to estimate the rate of decline (Smedbol et al. 2002). In this paper, we agreed not to compute any rate of decline but we are providing the numbers of the indices and any suggestion/limitation that could be useful for their estimations

2.2.1 Unit 1

In Unit 1, the stratified random surveys were done in August since 1984 with the *Lady Hammond* and 1990 with the CCGS *Alfred Needler*. The areas covered by the survey in Unit 1 are 4R, 4S and the south portion of the Laurentian channel in 4T. Very little redfish occur in the rest of 4T in shallower waters (Méthot et al. in prep.) so these surveys give a good overview of all Unit 1 since 1984.

Evaluation of decline

Stratified abundance estimates are available for this stock since 1984. Total abundance has declined from 2601 millions redfish individuals in 1984 to 241 million in 2002 (Table 6 and Figure 3). This decline is more important for *S. fasciatus* then for *S. mentella*, because juvenile of a strong year class (1988) have disappeared quickly at the beginning of the 1990. For all genotypes, juveniles and matures, a rapid decline was observed at the beginning of the 1990’s. Also, the previous strong year-class (1980) consisted of a mix of the two species in the middle of 1980 when the fish were juveniles but, *S. fasciatus* contributed little to the fishery. The mature population is now dominated by *S. mentella*.

We suggest not to consider year 1984 for decline rate determination by species since AFC data was limited, which make that year unsuitable for abundance estimation . Years 1985 to 1987 could be averaged to get early years of RV surveys and 2000 to 2002 the last years if the percentage of decline for two periods approach is used.

Evaluation of cause of decline

In the Gulf of St. Lawrence, strong recruitment has been intermittent, occurring every 6-12 years. There have been strong year classes in 1946, 1956, 1958, 1970 and 1980. Also, year-classes that were present in very large numbers at age 2 to 4 (based on research survey data) were not found in subsequent years and never contributed significantly to the fishery. These year-classes were in 1966, 1974 and 1988 (Sandeman 1973, Parsons and Parsons 1976; Morin et al. 1999). For example, the estimate for the 1988 year-class in 1991 was 2.2 billion, but by 1994, the estimate had dropped to 48 million (Morin et al. 1999). The factors responsible for the disappearance of these small immature redfish are unknown. One possibility was migration, but there are no data that suggests that the 1988 year-class moved out of the Gulf (Anon. 1995). Other factors that may have contributed are fishing mortality due to by-catches in the shrimp fishery and the natural mortality due to poor environmental conditions or predation were reviewed (Gascon 2003) but could not be shown clearly.

Larval surveys have been conducted in the Gulf of St. Lawrence at the end of the 1990s to study the effect of oceanographic conditions on redfish larvae. Preliminary results of these surveys showed that the majority of the larvae observed were *S. mentella* (J. Plourde DFO Quebec region per. comm.). This observation is consistent with the fact that the adult population in the Gulf is also mainly from this species. However, the juveniles for the last 20 years (after the 1980 year-class) have been dominated by *S. fasciatus*. This information would suggest a failure of the survival of larvae of *S. mentella* that might be related to the cold temperature regime observed in the Gulf since the end of the 1980's (DFO 2000a).

Fishing contributed to the decline of the adult population in the early 1990s. The redfish fishery in the Gulf of St. Lawrence has been characterized by two periods of high exploitation; the first one at the beginning of the 1970s and the second in the 1990s. These two periods are closely linked to the recruitment of strong year-classes. Following these peaks, landings dropped rapidly. For the most recent years, landings decreased from 77 000 t in 1992 (old management units) to about 19 500 t in 1994. The TAC for Unit 1 redfish was set at 60 000 t in 1993 and reduced to 30 000 t in 1994. Fishery in Unit 1 has been closed since 1995 due to low stock abundance and the absence of strong recruitment since the early 1980s. The Redfish Industry Survey (RIS) program was put in place in 1998. The TAC for purposes of the RIS program was 1 000 t in 1998 and 2 000 t for 1999-2002.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

The decline of the adult population has stopped since the fishery has been closed. However, no significant new year-class that could contribute to the fishery has been observed in the stock since the 1980 year-classes. Although the diet composition of harp seals sampled in this period showed that redfish was an important component of the diet (Hammill and Stenson 2000) the most recent harp seal diet information showed that redfish were rarely found in stomachs (Hammill per. com.).

Information from the shrimp fishery in the Gulf at the beginning of the 1990 showed that the highest amount of discards was observed in 1991 but the total abundance of fish < 25 cm would account only for a small proportion of these discards (Gascon 2003). With the introduction of the Nordmore grid in the shrimp fishery in 1993, the amount of juvenile redfish discards decreased significantly.

2.2.2 Unit 2

Stratified-random research surveys were conducted in Subdiv. 3Ps, 3Pn, 4Vs and 4Vn during summer in 1994-1997, 2000 and 2002 using a Campelen 1800 shrimp trawl with a 12.5-mm liner covering strata from 183m – 732m . Station allocation is based on proportion of stratum area. These surveys comprise the only series that cover a sufficient area of the redfish habitat within the management unit and are conducted at a time when it is believed that there is no mixing of Unit 1 and Unit 2 fish, thus providing the only essential index of abundance. Three other departmental stratified-random groundfish surveys are conducted within the management unit. These are (1) the 4VW summer groundfish surveys 1970-2002 to 200 fathoms (367m) conducted by the DFO Maritimes Region; (2) the 4VsW spring cod-directed surveys from 1986 to 2002 to 200 fathoms with an extension to 250 fathoms (458m) in the Laurentian Channel portion of 4Vs from 1993 to 2002 conducted by the DFO Maritimes Region; and (3) the 3Ps winter/spring surveys from 1973 to 2002 to 400 fathoms (732m) conducted by the DFO Newfoundland and Labrador Region. These are of limited value in determining the status of the redfish species in Unit 2 because they cover only part of the entire area where redfish occur. This makes it difficult to interpret apparent trends over time because they may not reflect the changes occurring throughout the entire management unit. There may also be some unknown component of migration into and/or out of the surveyed areas reflected in the survey results. Furthermore, a variety of vessel/gear combinations over the time periods was also used during these surveys, a factor that limits their use in any comparative sense. For these reasons, these survey series are not considered as being reliable indicators of stock status and are therefore not presented here. However, for illustrative purposes, only the 4VW series have been presented in the more detailed account of Méthot et al. (In prep.).

Evaluation of decline

Over the time period covered by the series (1994-2002), the abundance index from the surveys has ranged from 600-900 million redfish with *S. fasciatus* comprising more than 60% annually. A concurrent acoustic estimate from the 2000 survey suggests that about 80% of the redfish spp. abundance were available to the survey gear, which means that the survey estimates are conservative (Power and Mowbray 2000).

From this relatively short series, survey abundance declined for *S. fasciatus* (Table 7 and Figure 4) from 565 million individuals in 1994 to 322 million in 1996, increased sharply to 535 million in 1997 and increased marginally again to 561 millions in 2002. It is difficult to interpret year to year changes in bottom trawl survey estimates for a semi-pelagic species such as redfish as being reflective of true changes in the population. However, the declines were consistent across a number of year classes, particularly the 1985 and 1988, from 1994 to 1996. The sharp increase in 1997 and further increases to 2002 are due to the recruitment of the 1994 year class, first estimated in the 1997 survey, and the 1998 year class, first estimated in the 2000 survey.

The survey abundance for *S. mentella* and the MDH heterozygotes show trends similar to *S. fasciatus* except that the magnitudes of change are not as great in some years. The notable exception is the relatively large decline between the 2000 and 2002 surveys (from 272 million to 206 million for *S. mentella* and from 75 million to 56 million for heterozygote). These are the lowest estimates over the time series for both whereas the 2002 estimate for *S. fasciatus* was amongst the highest in the time series.

Evaluation of cause of decline

There has been a directed fishery in existence since the late 1950s. From 1960 to 1968, catches averaged about 20 000 t, increased to an average of 43 000 t up to 1975 mainly due to increased catches by foreign fleets. Catches then declined to the lowest on record in 1984 at 8 100 t Since then, catch steadily increased to 27 000 t by 1993 but declined subsequently to about 10 000 t in 1997 due to reductions in TACs. Since 1997, the TAC has been taken each year resulting in catches between 8 000 t and –11 000 t over the period.

There was a rapid reduction of the 1985 *S. fasciatus* year class between 1994 and 1995 in the Unit 2 survey, which was also seen over a number of years in both the 3Ps and 4VW surveys (see Power and Mowbray 2000). There was also a successive reduction in the estimate of the 1988 *S. fasciatus* year class from 1994 to 1996 in the Unit 2 survey. It is difficult to reconcile the magnitude of these reductions as being solely the result of removals from the redfish directed fishery in Unit 2 from 1994-1996. A small fish protocol, currently at 22 cm, was implemented in 1996 and 1997 at 25cm, protecting the 1988 and younger year classes from harvest. From the mid-1990s to 2001, the redfish fishery in Unit 2 has been targeting the 1980 year class of *S. mentella*/heterozygote because they were a better market size, even though the 1988 year class of *S. fasciatus* had become more and more vulnerable to the fishery. Therefore, the reduction in the 1985 and 1988 year classes of *S. fasciatus* has occurred despite low exploitation. The decline in *S. mentella* and heterozygotes over the time series was expected because the fishery has been targeting this group since the mid-1990s. In addition, there has been poor recruitment for these species since the 1980s year class.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

The decline in the *S. fasciatus* population was offset by the recruitment of the 1994 and 1998 year classes. However, new fishery regulations have been implemented since 2002 to harvest *S. fasciatus* in proportion to its relative distribution in the survey estimates. This should also act to reduce the rate of decline in *S. mentella*. However, *S. mentella* has shown poor recruitment since the strong 1980 year class which has basically supported the commercial fishery for the past 13 years.

2.2.3 Unit 3

The longest time series of data for Unit 3 redfish is the DFO Summer Groundfish survey of the Maritimes region. This survey spans the years of 1970-2002. Prior to 1982 there was a different vessel and a different gear being used for this annual summer survey. Fanning (1985) calculated conversion factors for 10 species from comparative fishing experiments to compare the survey results of the two vessels. However, because of small sample sizes or badly distributed data the conversion factor for redfish (1.33 applied to the first survey vessel), among other species examined, is unreliable. To make a consistent comparison of the survey data among the years, only the data from 1982-present have been compared in the annual regional assessment process (Branton 1999). Branton and Halliday (1994) used the redfish conversion factor to investigate the effects of applying it to the pre-1982 biomass estimates, even though it was deemed inadequate, because there was a difference in weight and numbers per tow between the comparative fishing sets.

Due to the highly variable population estimates produced by the summer survey it has also been the practice to compare the survey data from 1982-present by using a moving average of the data. A five-year running average is what is typically chosen for looking at catch rates over time in regional assessments.

Evaluation of decline

Estimated abundance of *S. fasciatus* was 401 million in 1970 compared to an estimate of 151 million in 2002 (Table 8 and Figure 5). For reasons stated in the above section, we suggest to calculate a 5 year running average of the data from the start and the end of the summer survey series to evaluate the decline of the population over time. This would give estimated abundance of *S. fasciatus* as 334.8 million at the start of the survey series and 202.9 million at the end of the survey series. Using a running average and omitting the data prior to 1982, as is done in regional assessments, actually suggests an increase in the Unit 3 redfish population.

Evaluation of cause of decline

The data doest not reflect a true decline in the population of redfish in Unit 3. Summer survey abundance estimates are highly variable, but do not illustrate a declining trend over time. As well, commercial landings have been steady over the past decade.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Year classes in the Unit 3 population do not show up in the length frequency profiles as clearly as in the other populations. However, industry has recently reported seeing more small redfish in their catches.

The Gulf of Maine-Georges Bank redfish population is immediately adjacent to the Unit 3 population and the U.S. survey covers a portion of Unit 3. It was most recently reported in the U.S. assessment of this stock that the biomass of redfish in the Gulf of Maine – Georges Bank region has increased considerably during the past decade. This is thought to be primarily due to improved recruitment from several year classes in the early 1990s (Mayo et al. 2002).

Unit 3 does have an active fishery for redfish, but is restricted in various ways to protect small redfish and other groundfish that are caught as bycatch. Although this is a small mesh fishery, there is a minimum size limit of 22 cm managed by Small Fish Protocol and there is a closed area inside 4X, nominally called the 'Bowtie', to prevent high proportions of small redfish from being caught. Fishing with small mesh gear is not permitted in waters less than 50 fathoms, in the Bay of Fundy and on Brown's Bank during spawning closures. All groundfish gear is also excluded from the haddock nursery area.

2.2.4 NAFO division 3O

Redfish habitat in Div. 3O include areas beyond the 200-mile limit. Stratified random Canadian bottom trawl surveys have been conducted in Div. 3O in the spring since 1973 and in autumn since 1991. In both series there have been differences in coverage and/or changes in vessel/gear which makes them incomparable over the entire range of years for each series. The spring series was conducted as follows: from 1973-1982 to 200 fathoms (367 m) with a Yankee 41-5 otter trawl, from 1984-1990 to 200 fathoms with an Engel 145 otter trawl, from 1991-1995 to 400 fathoms (730 m) with an Engel 145 otter trawl and from 1996-present to 400 fathoms with a Campelen 1800 shrimp trawl. The autumn series has been conducted to 400 fathoms from 1991-1994 with an Engel 145 otter trawl and from 1995-present with a Campelen 1800 shrimp trawl. The estimates of both series between the time period from 1984 to 1995 (spring) Engel 145 were converted into Campelen 1800 trawl equivalent estimates. Details of the comparative fishing trials and data modelling for this conversion can be found in Power and Atkinson (MS 1998). Only those years where reasonably good coverage was accomplished in Div. 3O are considered.

In summary, only the 1991-2002 series is comparable in terms of proposed depth coverage and equivalent sampling gear units. There are differences in the magnitude of abundance estimates between spring and autumn surveys related to changes in either catchability or availability between these seasons. The spring surveys prior to 1991, in which coverage was only to 200 fathoms, effectively only cover about 60% of the areas of highest density for redfish. An additional caveat in consideration of the bottom trawl survey estimates for Div. 3O is the difficulty in conducting trawling operations in strata from 200-400 fathoms because of the steep gradient of the slope and the rough bottom.

Evaluation of decline

Total survey population estimates in the 1973-1982 period, which had coverage only in the spring to 200 fathoms with a Yankee 41-5 otter trawl, are highly variable without trend, ranging from about

12 million to 239 million for *S. fasciatus* and from about 100 thousand to 4 million for *S. mentella* (Table 9 and Figure 6).

Total survey population estimates in the 1984–1990 period, which had coverage only in the spring to 200 fathoms with an Engel 145 otter trawl were converted to Campelen trawl equivalents as noted above. The estimates are highly variable without trend for *S. fasciatus* ranging from about 84 million to 899 million. For *S. mentella*, there is a trend of decline over the period from about 10 million in 1984 to about 650 thousand in 1990 (Table 9 and Figure 7).

Total survey population estimates in the 1991-2002 period for both the spring (Table 9 and Figure 8) and autumn (Table 9 and Figure 9) series to 400 fathoms are available in Campelen trawl equivalents. For the spring series, survey abundance for *S. fasciatus* has ranged from 81 million to 2.2 billion. The index increased sharply from 1991 to 1995 and generally declined thereafter to 2002 which was at the level observed at the beginning of the series (about 112 million). The low 1997 value is considered an anomaly. The autumn series generally suggests a more stable series for *S. fasciatus* with the exception of a period of higher abundance in the mid-1990s. Survey estimates have ranged between 131 million and 955 million. The lowest estimate in 1996 was based on an incomplete survey and the 2002 estimate is at 260 million. The spring survey estimates for *S. mentella*, ranging from 12 million to 68 million, exhibit greater between year fluctuation than for *S. fasciatus*. There is an indication of an increase from 1991 to 1999 with a decline thereafter. The 2002 estimate is at 12 million. The autumn survey estimates for *S. mentella* are highly variable, ranging from 10 million to 107 million.

In general, it is difficult to interpret year to year trends in the data for bottom trawl surveys for redfish, particularly in this management unit where you have more difficulty trawling from 200-400 fathoms. There appears to be higher abundance in the mid-1990s than in the more recent years. A historical perspective prior to 1991 is not possible because earlier surveys are not comparable, due to differences in vessels, sampling gear and coverage.

Another observation of note is the fact that the size distributions from the commercial fisheries in the mid-1990s were comprised of higher proportion of larger fish than size distributions caught by the research survey (Power 2000). This suggests that the surveys are only monitoring a portion of the stock size range, and therefore limits its usefulness as an indicator of total stock abundance.

Evaluation of cause of decline

Given the caveats noted above, it is not possible to determine if a decline in the survey index is a true decline in the *Sebastes* populations. There has been a directed fishery in existence since the late 1950s. Canada has only accounted for about 10% of reported catches since 1960. Foreign fleets have increased activity for redfish outside the 200 mile limit since 1998. Nominal catches have ranged between 3 000 t and 35 000 t since 1960. The average catch from 1960-2002 is about 13 000 t, and this is about the level at which the catch has been since 1998 with the exception of 22 000 t in 2001. There has been little sign from the RV surveys of good recruitment to the stock since the relatively strong 1988 year class, which the fishery is now targeting. Given this scenario, it is reasonable to assume that the fishery will have an impact on the stock , however, the absolute rate of depletion cannot be measured.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

As noted above it is not possible to determine if a decline in the population has occurred. RV surveys do not adequately sample fish greater than 25 cm which up to 1997 have generally comprised the main portion of the fishery. This makes it difficult to interpret survey estimates in relation to what is happening to the stock as a whole. However, there is concern about the poor recruitment to the stock since the relatively strong 1988 year class. The stock will certainly decline if the fishery removals are greater than the yield produced from the poor recruitment years.

Preliminary information for 2002 suggests that about 19 000 t has been taken, mostly by foreign fleets outside the 200 mile limit.

2.2.5 NAFO divisions 3LN

Redfish habitat in Div. 3LN include areas beyond the 200-mile limit. Stratified random Canadian bottom trawl surveys have been conducted in Div. 3LN in the spring since 1973 and in autumn since 1991. In both series, there have been differences in coverage and/or changes in vessel/gear which makes them incomparable over the entire range of years for each series. The description of the spring series in terms of gear used and depth coverage is similar to the description provided above for Div. 3O. Only those years where reasonably good coverage of both Div. 3L and 3N exists are considered here. The estimates of spring and autumn series between the time period from 1985 to 1995 (spring) Engel 145 were converted into Campelen 1800 trawl equivalent estimates. Details of the comparative fishing trials and data modelling for this conversion can be found in Power et al. (1998).

In summary, only the 1991-2002 series is comparable in terms of proposed depth coverage and equivalent sampling gear units. There are differences in the magnitude of abundance estimates between spring and autumn surveys, mainly in Div. 3N, related to changes in either catchability or availability between these seasons. The 3LN spring surveys prior to 1991, in which coverage was only to 200 fathoms, effectively only cover about 50% of the areas of highest density for redfish.

Evaluation of decline

Total survey population estimates in the 1973-1982 period, which had coverage only in the spring to 200 fathoms with a Yankee 41-5 otter trawl, are highly variable, ranging from about 9 million to 361 million for *S. fasciatus* and from about 410 thousand to 12 million for *S. mentella* (Table 10 and Figure 10). For both species, estimates were greater in the latter part of the series although this may be simply be related to incomplete coverage in the earlier surveys.

Total survey population estimates in the 1985 – 1990 period, which had coverage of both Div. only in the spring to 200 fathoms with an Engel 145 otter trawl, were converted to Campelen trawl equivalents as noted above. The survey estimates for *S. fasciatus* range from 34 million to 134 million with a trend of decline over the time period (Table 10 and Figure 11). For *S. mentella*, a similar trend of decline is evident over the time period with survey populations within a range of about 10 million in 1985 to about 1.5 million in 1990.

Total survey population estimates in the 1991-2002 period for both the spring (Table 10 and Figure 12) and autumn (Table 10 and Figure 13) series to 400 fathoms are available in Campelen trawl equivalents. For the spring series, survey abundance for *S. fasciatus* has ranged from 16 million to 234 million. The index declined from 1991 to its lowest level in 1994, increased to the highest value in the series in 2000 and has since indicated a marginal decline to 2002 (at 161 million). The autumn series for *S. fasciatus,* ranging from estimates of 30 million to 1 billion, generally exhibits more interannnual variability but suggests the recent years estimates are amongst the highest in the time series (2002 estimate at 736 million). The estimate of 1 billion was highly influenced by one set in the survey in Div. 3N that captured 53 000 fish. The spring survey estimates for *S. mentella*, which range from 8 million to 140 million, exhibit a similar pattern to *S. fasciatus* with a decline from 1991 to 1994 followed by an increase to 2000 and, finally, a marginal decline in 2001 and 2002 (at 59 million). The autumn series for *S. mentella*, with estimates ranging from 39 million to 145 million, indicates stability over the time series, particularly since 1997 (average about 119 million).

Evaluation of cause of decline

It is not possible to compare the survey information throughout the entire time period. The only comparable information (1991-2002 indices) suggest a decline to 1994 with an increase to 2002. There has been a fishery in existence for redfish since the late 1950s. Canada has only accounted for about 10% of reported catches. Catches averaged about 22 000 t from 1959 to 1985, increased sharply to a historical high of 79 000 t in 1987 then declined steadily to 850 t by 1998. It is likely that the stock was greatly depleted by cumulative effect of the large catches of the 1980s. A moratorium on directed fishing was implemented in 1998, however, catches taken as bycatch in other fisheries have since ranged from 1 400 - 2 000 t Seal species, primarily harp (*Phoca groenlandica*) and hooded (*Cystophora cristata*) are also predators of redfish in the 3L area. The most recent estimates of prey consumption by seals (Hammill and Stenson, 2000) suggested that in 1996 approximately 35 000 t of redfish were consumed in the 2J3KL area with approximately 50% eaten by harp seals and 50% by hooded seals. A breakdown by division was not possible but the majority of the estimate is comprised of fish less than 25cm. In 1996 the harp seal population was about 5 million animals compared to about 600 000 hooded seals. The population size of harp seals has remained stable since 1996 (DFO 2000b).

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Interpretation of available data remains difficult for this stock. The surveys demonstrate considerable inter-annual variability, the changes frequently being the result of single large catches being taken in different years. It is reasonable to speculate that estimates from recent surveys are considerably lower than those from the 1980's because poor recruitment has persisted in Div. 3L since the early 1980's and in Div. 3N since the 1987 (Power 2001). The populations appear to have shown an increase since 1994.

2.2.6 NAFO divisions 2GHJ 3K

Stratified random groundfish surveys have been conducted in the fall in Div. 2J and 3K since 1977 and in Div. 2G and 2H sporadically since 1978. These surveys adequately covered strata to depths of 1 000m. Beginning in 1995, the surveys covered to 1500m more consistently due to the deployment of a replacement vessel that could fish the deeper water more effectively. Generally though, the abundance of redfish drops off sharply beyond 800m in the slope area. The stratification scheme was redesigned for the 1993 survey to redefine stratum boundaries based on more recent information on depth soundings (Bishop 1994). Although it is difficult to compare the results of certain strata to those previous to 1993, in general the total area of revised stratification is only slightly different from the previous scheme used from 1977-1992. These surveys were conducted with an Engels 145 high lift otter trawl from 1978-1994 and a Campelen 1800 trawl from 1995-2001. The Engel data were converted into Campelen equivalents. Details of the comparative fishing trials and data modelling for this conversion can be found in (Power and Orr 2001). The Div. 2GH surveys are presented separately from Div. 2J3K because they are sporadic and frequently have unsampled strata. The most intensely covered surveys are 1987-1988, 1991 and 1996-1999, although there was poor coverage in 2G in 1991 and 1998.

Evaluation of decline

Total survey population estimates for the Div. 2J3K series show large fluctuations between some years. The series shows a continuous decline from highest value in 1978 to the lowest in 1994, a moderately sharp increase in 1995 with a continued trend of increase to 2001 for both *S. fasciatus* and *S. mentella* (Table 11 and Figure 14). The rate of increase from 1995-2001 is greater for *S. fasciatus* than *S. mentella*. As noted above, the data from 1978-1994 were converted into Campelen equivalent units. For both species, the moderate increase in 1995, and magnitude of the estimates to 2001 above this level, suggest that the conversions for fish sizes currently in the survey catch may actually be larger back to 1978. This would indicate that the rate of decline over the 1978-1994 period may be greater. Survey population estimates for *S. fasciatus* over the 1978-2001 period range from about 4 million to 4 billion with the most recent estimate at 145 million. Estimates for *S. mentella* from 1978-2001 range from 32 million to 5.4 billion with the 2001 estimate at 269 million.

Total survey population estimates for the Div. 2GH series also exhibit large fluctuations between some years and are due in part to unsampled strata. The series increases dramatically from 1987 to 1996 with a subsequent decline to 1999 for both *S. fasciatus* and *S. mentella* (Table 11 and Figure 15). A similar argument can be made for these survey results as with Div. 2J3K with regard to the conversions of the pre-1996 data, suggesting that the estimates may be higher which may result in more stable index over the entire series. Survey population estimates for *S. fasciatus*, which is at the northern extent of its distribution, over the 1987-1999 period range from about 980 thousand to 14 million with the most recent estimate in 1999 at 7 million. Estimates for *S. mentella* from 1987-1999 range from 29 million to 368 million with the 1999 estimate at 213 million.

Evaluation of cause of decline

The highest reported catch from this stock was 187 000 t in 1959. From 1961 to 1985 catches ranged between 15 000 t to 56 000 t and averaged about 27 000 t. Catches declined dramatically from about 29 000 t in 1985 to 280 t in 1991 when directed fisheries essentially ceased. In 1997 the stock was put under moratorium to direct fishing which is still in effect. Catches averaged about 160 t from 1998-2000 and are primarily the result of bycatch discarded from shrimp fisheries throughout the NAFO Div. 2GHJ3K areas. Approximately 2.5 million redfish in the length range from 5cm to 19cm were discarded during the 2000 shrimp fishery, which represents a relative exploitation of less than 1% (Power 2001). Preliminary catch data for the 2001-2002 fishing year indicates 1 300 t have been taken in Div. 2J in August by Russia and Lithuania. This catch was taken outside the 200-mile limit utilizing large midwater trawls and is likely from the pelagic stock of redfish that resides primarily in the Irminger Sea. RV surveys indicate the population declined very rapidly over a ten-year period from 1980 to 1990. The relative exploitation rate generated from catches over this time period cannot totally account for the decline in the biomass. As noted above in the discussion of 3LN redfish, seals also prey on redfish in the area. It is assumed that most of the estimated 35 000 tons of redfish consumed in the Div. 2J3KL area would be taken in Div. 2J3K because it is the area that encompasses the highest concentration of harp seals.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

RV survey index show an increase since 1995, suggesting the decline has ceased. However, the surveys continue to indicate there has been over 25 years of poor recruitment. Most of the removals from the stock are apparently through seal consumption and by-catch in shrimp fisheries. Assuming seals focus on fish less than 25cm, it is estimated that more than 175 million redfish are consumed per year based on the average weight of a 25cm redfish (0.2 kg) and the 35 000 t consumption estimate of Hammill and Stenson (2000) which is for the 2J3KL area.

Terms of reference 3: Area of occupancy and change or fluctuation in spatial distribution

3.1 Introduction and methods applied to all stock

One criterion of COSEWIC to classify a species or a population is the change in spatial distribution over time. The object of this section is to describe geographic distribution of redfish species of each stock and determine if there has been any change in the distribution.

Design weighted area of occupancy (DWAO; Smedbol et al. 2002) has been calculated for each year by species or genotypes.

$$A_t = \sum_{i=1}^{n} A_i I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_i > 0 \\ 0 \text{ otherwise} \end{cases}$$

Where *n* is the number of tows in the survey in a given year *t*, Y_i is the number of individuals caught in tow *i*, and A_i is the area of the stratum fished by tow *i* divided by the number of sites fished in the stratum. Strata with less then 2 sets have not been considered.

If the stock is concentrated in smaller area, it could become more vulnerable to threat. Since the area of occupancy does not provide information on the density distribution of fish, we also calculated two additional indices of concentration to get a better understanding of change in distribution: D_{95} (Swain and Sinclair 1994; Smedbol et al. 2002) and Gini index (Myers and Cadigan 1995).

The D_{95} index represents the minimum area where 95% of the stock is distributed. First, we calculate the density at or below which the less concentrated 5% of redfish are distributed. Then the area covered by those 5% redfish is calculate ($G(c_{05})$). Finally the minimum area containing 95% of redfish is given by:

$$D95 = A_T - G(c_{05})$$

Where A_t is the total survey area.

For details on equations to calculate D_{95} see Swain and Sinclair (1994) and Smedbol et al. (2002).

Gini Index is calculated using the Lorenz curve (Myers and Cadigan 1995). This curve has for it abscissa the cumulative area percentage of each strata arrayed by increasing abundance and for its ordinate the corresponding proportion of the total abundance of fish. An equal repartition will lead to the identity function. Then, when the fish is more concentrated the Lorenz curve gets more concave. The Gini index is twice the area between identity function and Lorenz curves. Thus, Gini index increases as fish become more concentrated.

Since redfish perform seasonal migration. Distribution and concentration might change over a year, the indices presented are thus only representative for the period surveyed.

3.2 Results

3.2.1 Unit 1

The total area surveyed for the *L. Hammond* and CCGS *Alfred Needler* series since 1984 is usually fairly constant over years averaging around 92 000 km^2. Since 1990 additional shallow strata are surveyed but only few small catches of redfish have been observed in these area, thus we decided to eliminate those strata to get a consistent area covered.

The area of occupancy for redfish sp. varied from 739 400 to 940 000 km^2 and remain basically unchanged since the decline of abundance (Figure 16). Species discrimination methods does not allow us to calculate this index separated by species, because those indices are based on presence or absence of fish by tow and there is always some proportion for the three genotypes when redfish is caught.

No correction was possible to merge the L. Hammond and the CCGS *Alfred Needler* at a tow level for each species, thus the two series has been analyses separately. The geographic range (D_{95}) of *S. fasciatus* showed a decline from 1988 to 1989 and from 1990 to 1993 (possibly in response to the appearance of the strong year class of 1988 in the catches) and then reached a higher level in the last years (Figures 17 to 19). Only a few very high catches can lead to great proportions of total catches in a limited number of strata and then explain the increase of concentration in the late 1980. The geographic range of mature population did not necessarily drop as total population did. D_{95} varied less for *S. mentella* and heterozygous individuals. The D_{95} decreased in the Lady Hammond series, while it increased in the CCGS *Alfred Needler*.

The Gini index shows roughly the opposite of D_{95}. *Sebastes. fasciatus* was more concentrated at the early 1990s and then got back to initial level. *Sebastes mentella* and heterozygous individuals show similar pattern but are more sparsely distributed.

Distribution indices for mature fish could not be estimated since it is not possible to obtain the number of mature fish at every tow for many years.

The distributions are plotted for 1984 and 2002 for each genotype showing decrease in catch rate (Figures 20 to 22)

3.2.2 Unit 2

The area of occupancy of *Sebastes* sp is constant over years at 50 000 km^2 (Figure 23). In general, no important change of concentration (D_{95} and Gini indices) for each genotype was observed in the last 8 years, which is also noted in a plot of the survey results by tow in 1994 and 2002 (Figures 24 to 26). However a slight decrease in D_{95} and increase in Gini index for *S. fasciatus* suggests that the fish are more concentrated in recent years, but this could be an artifact of increased recruitment noted above coupled with the realization that recruitment tends to first occur in the shallower depths of the area surveyed. For *S. mentella* and heterozygous individuals variations occurred in years 2000 and 2002 in D95, but there is no evidence of change in concentration in the whole series. The Gini indices are stable for those genotypes.

Distribution maps of the catches are not showing any changes for the first (1994) and last (2002) years for the 3 genotypes (Figures 27 to 29).

3.2.3 Unit 3

Area of occupancy varied from 35,280 to 65, 030 km^2 and did not show any trends that reflect changes in the survey abundance estimates over time (Figure 30). The number of stations sampled in Unit 3 has increased since the start of the survey series, but there is also no trend in the area of occupancy figure that would be resultant of this change.

The geographic range (D_{95}) of *S. fasciatus* in Unit 3 varied between 5 000 and 32 000 km^2 over the length of the survey series, but the lower and higher ranges in this index do not coincide with changes in the abundance of the population.

The Gini index is very stable over time, with the exception of one data point. This is the complete opposite of the D_{95} index and does not reflect the abundance estimates of the redfish population in Unit 3.

Distribution of the catches between 1970 and 2002 show that *S. fasciatus* were more abundant to the Northeast area of the survey at the beginning of the series than during the most recent years (Figure 31).

3.2.4 NAFO division 3O

The area covered by the surveys since 1991 has remained relatively stable within each series which had intended coverage to at least 400 fathoms (732 m). The area occupied is generally much less because redfish essentially only occupy the slope area of the Grand Bank from 100 m to 750 m. Within this zone, the area of occupancy in the spring surveys has increased from about 2 200 km in 1991 to about 5 000 km in 2002 (Figure 32) and from about 1800 km in 1991 to about 6 600 km in 2001 in the autumn survey series (Figure 33). The differences between spring and autumn are likely due to redfish inhabiting shallower water in the second half of the year. Surveys earlier than 1991 only covered to 200 fathoms (367 m) and are not comparable.

The indices of concentration (D_{95} and Gini) for both spring and autumn surveys generally show positive results since 1991 which is the period of optimal coverage of redfish habitat (100 m-732 m). For the spring series, there are indications of an increase in geographic range (D_{95}) for both *S. fasciatus* and *S. mentella* (Figure 32) since 1991. The spring Gini index shows no trend for *S. fasciatus* and a slight decline for *S. mentella* suggesting no concentrating effect which complements the results of the D_{95}. The indices of concentration for the autumn surveys show a similar trend for *S. fasciatus*, however, there is an opposite trend in the autumn for *S. mentella* (Figure 33). The D_{95} appears to decrease and the Gini increase which, taken together, suggest a decline in geographic range or a concentrating effect.

The survey results (mean number per standard tow) are plotted for illustrative purposes for both species in spring (Figures 34 and 35) for 1984 and 2002 and autumn (Figures 36 and 37) for 1990 and 2001. As noted before, prior to 1991 coverage was to 200 fathoms (367 m) in spring. Most of the redfish were caught deeper than 100m. In the 2002 autumn survey it is also evident that some of the deepest tows greater than 400 fathoms (732 m) do not capture redfish. *S. fasciatus* is more abundant at the shallower end of the slope and catches were generally larger in the earlier surveys. For *S. mentella*, catches are larger in 2002 than the earlier surveys for both seasons.

3.2.5 NAFO divisions 3LN

The area covered by the surveys since 1991 has remained relatively stable within each series which had intended coverage to at least 400 fathoms (732 m). As noted above, redfish essentially occupy the slope area of the Grand Bank. The area of occupancy in the spring surveys has increased from about 6 000 km in 1991 to about 12 000 km in 2002 (Figure 38) and from about 6 000 km in 1991 to about 14 000 km in 2001 in the autumn survey series (Figure 39). The differences between spring and autumn are likely due to redfish inhabiting shallower water in the second half of the year. Surveys earlier than 1991 only covered to 200 fathoms (367 m) and are not comparable.

The indices of concentration (D_{95} and Gini) for the spring and autumn surveys since 1991, the period of optimal coverage of redfish habitat (100m-732m), generally show inconclusive to positive results. For the spring series, there are quite variable results in geographic range (D_{95}) and the Gini index for *S. fasciatus* (Figure 38). For *S. mentella*, the (D_{95}) shows a marginal increase since 1991 while the Gini index also shows a trend of increase since 1994 which suggests the species is both increasing its geographic range and becoming more concentrated. The autumn indices are variable but stable for *S. fasciatus* (Figure 39). For *S. mentella*, the D_{95} shows an increase while the Gini shows a trend of decline, suggesting no concentrating effect which complements the results of the D_{95}.

The survey results (mean number per standard tow) are plotted for illustrative purposes for both species in spring (Figures 40 to 43) and autumn (Figures 44 and 45). As noted before, prior to 1991 coverage was to 200 fathoms (367 m) in spring. Most of the redfish were caught deeper than 100 m. It is also clear that there is far greater habitat area in Div. 3L than Div. 3N. Both *S. fasciatus* and *S. mentella* are more abundant in 2002 autumn survey compared to the 1990 survey (Figures 44 and 45). The same can be said for *S. mentella* for comparable areas of coverage in the spring surveys in 1984 and 2002, noting however, that the 1984 survey only covered to 200 fathoms. For *S. fasciatus* in the spring, 1984 appears to be more abundant than 2002 for comparable areas. In general, over the time period since 1971 where comparable, there does not appear to be major shifts in distribution or any particular areas devoid of redfish.

3.2.6 NAFO divisions 2GHJ 3K

The surveyed area has remained relatively stable in Div. 2J3K from 1980 to 1995, ranging between 53 000 and 55 000 sq. km. with strata covered adequately to 1 000 m. The 9 000 sq. km. increase in 1996 was the result of adding inshore strata which generally devoid of redfish. Surveys in 2GH have been sporadic over the years with the most consistent coverage occurring in Div. 2H because of the difficulty in fishing the deeper water of Div. 2G. In Div. 2J3K, the area of occupancy (Figure 46 panel A) decreased from about 37 000 sq. km in 1978 to about 17 000 sq. km in 1994, increased sharply to 29 000 sq. km. in 1995 and has remained between 31 000 sq km to 36 000 sq km since. The large increase in 1995 was coincident with the change in survey gear and vessel. Since 1995 the index has shown an increasing trend. The area of occupancy for Div. 2GH is highly variable and inconclusive with regard to trend because the coverage has been inconsistent (Figure 49, panel A).

The indices of concentration for *S. fasciatus* in 2J3K (D_{95} and GINI, Figure 46 panels B and C). suggest positive effects over the past 15 years. The geographic range (D_{95}) shows a general increase over the period and the Gini index a decrease, taken together suggests an expansion of geographic range with no concentrating effect. For *S. mentella* in Div. 2J3K, there was a trend of decline in D_{95} from the highest level in 1978 to the lowest in 1990, then an increase to 2001 which is at the 1978 level. The Gini index shows an increase to 1990 and a decline thereafter which complements the results of the D_{95}. The indices of concentration for both species in Div. 2GH are inconclusive (Figure 49, panels b and C).

The survey results (mean number per standard tow) are plotted for illustrative purposes for both species in Div. 2J3K (Figures 47 and 48) and Div. 2GH (Figures 50 and 51). It is clear that density has declined substantially in Div. 2J3K between 1978 and 2001 for both species, however, there does not appear to be major shifts in distribution or any particular areas devoid of redfish. For Div. 2GH, the density has increased between the 1981 and 1999 surveys for both species throughout the entire range.

Terms of reference 4: Small Total Population Size and Decline and Very Small and Restricted

4.1. Introduction and methods applied to all stocks

With this term of reference, COSEWIC use the number of mature individuals evaluated for a given species to class them into categories of vulnerability. For example, if the mature number is under 10 000 individuals it is classed as threatened and under 2500, as endangered. As mentionned in the cod document (Smedbol et al. 2002), even if some stocks have been subject to drastic decline, the population size of mature mature fish may still be widely over 10 000 individuals.

4.2. Evaluation of Small Total Population Size and Decline by management unit

4.2.1 Unit 1

After species separation we evaluated the minimum trawlable abundance of the mature population of *S. fasciatus* at 13.5 million, *S. mentella* at 41.5 million and heterozygous individuals at 11.5 million in 2002.

Even if many assumptions had to be made to get those numbers (use of length-key to get AFC and conversion into genotypes), it is clear that the population size of mature fish of both species is much larger than 10 000 individuals limit criteria used by COSEWIC to class a species threatened.

4.2.2 Unit 2

Abundance indices of mature redfish are estimated to be 220 million for *S. fasciatus*, 177 million for *S. mentella* and 46 million heterozygotes in 2002 which is clearly of much greater magnitude than the COSEWIC criteria for a threatened species. These estimates are also considered minimum trawlable estimates. As noted earlier in the paper, concurrent acoustic data suggest that about 80% of the fish were available to the survey gear in the 2000 survey (Power and Mowbray, MS 2000)

4.2.3 Unit 3

We estimated the minimum trawlable abundance of the mature population of *S. fasciatus* in Unit 3 to have been 286 million in 1970 and 124.7 million in 2002. The mature population of Unit 3 redfish is clearly above the 10 000 individuals limit criteria used by COSEWIC to classify a species as threatened.

4.2.4 NAFO division 3O

Abundance indices of mature redfish in Div. 3O were averaged between spring and autumn in 2002. For *S. fasciatus* the estimate is 80 million and for *S. mentella* the estimate is 9 million, which are considered minimum trawlable estimates and are clearly greater than the 10 000 COSEWIC criteria for a threatened species.

4.2.5 NAFO divisions 3LN

Abundance indices of mature redfish in Div. 3LN were averaged between autumn in 2001 and spring in 2002. For *S. fasciatus* the estimate is 243 million and for *S. mentella* the estimate is 65 million. These minimum trawlable estimates are clearly greater than the 10 000 COSEWIC criteria for a threatened species.

4.2.6 NAFO divisions 2GHJ 3K

The minimum trawlable abundance of the mature population in Div. 2J3K was estimated from the 2001 autumn survey. The estimates were 42 million for *S. fasciatus* and 91 million for *S. mentella*. In Div. 2GH, the most recent estimates of minimum trawlable abundance of the mature population for each species were derived from the 1999 survey. For *S. fasciatus*, that estimate was about one million and for *S. mentella*, the estimate was about 27 million which are greater than the COSEWIC criteria of 10 000 mature fish for a threatened species.

Summary

All studies dealing with redfish stock identification have shown the existence of some stock structure for *S. fasciatus* and *S. mentella* in the Northwest Atlantic. For *S. fasciatus*, three stocks were detected: Gulf of St. Lawrence and Laurentian Channel (Units 1 and 2), Scotian Shelf (Unit 3) and the Gulf of Maine. Genetic differences between Units 1 and 2 are largely driven by the phenomenon of introgression between the two species that is taking place in the Gulf of St. Lawrence and the Laurentian Channel. The difference between Unit 3 and the Gulf of Maine are very small and would need to be confirmed in further studies. In the Northwest, two populations were detected for *S. mentella*: Units 1 and 2 and all other management units. As it was the case for *S. fasciatus*, introgressive hybridization is the most likely explanation for the structure observed. An important conclusion that can be drawn for the genetic studies is that there is no evidence of population structure (ESU) at a scale smaller then the redfish management units currently used. Furthermore, we can conclude that ESUs for each species comprise more than one management units.

There is no evidence of a reduction of species distribution range

For all management units, the mature population size largely exceeds the number of 10 000 individuals, the COSEWIC criteria for a threatened species.

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Table 1. Sample names, geographical origins and sizes (*N*) of 17 redfish samples used for the assessment of the population genetic structure of *S. fasciatus* and *S. mentella* in the Northwest Atlantic. Samples are pooled into four groups : ALLOFAS and ALLOMEN represent samples of *S. fasciatus* and *S. mentella* collected in the allopatric zone respectively; SYMPFAS and SYMPMEN represent samples of *S. fasciatus* and *S. mentella* collected in the sympatric zone respectively (see Roques et al. 2000; 2001 for the localisation on a map).

Samples	Geographical origin	*N*
ALLOFAS		
FAA1	Gulf of Maine	30
FAA2	Nova Scotia	35
SYMPFAS		
FAS1	Newfoundland	54
FAS2	St. Lawrence	49
FAS3	St. Lawrence	48
FAS4	St. Lawrence	47
ALLOMEN		
MEA1	Grands Banks	44
MEA2	Grands Banks	47
MEA3	Labrador (U2G)	52
MEA4	Labrador (U2H)	52
SYMPMEN		
MES1	South Newfoundland	48
MES2	South Newfoundland	51
MES3	South Newfoundland	51
MES4	South Newfoundland	48
MES5	St. Lawrence	49
MES6	St. Lawrence	48
MES7	St. Lawrence	50

Table 2. Pairwise sample differentiation estimates based on allelic variance at 8 microsatellites loci in 17 redfish samples. Dotted lines circumscribe between taxa comparisons values. The extent of gene flow among samples was estimated by the unbiased Fst estimator (θ) of Weir and Cockerham (1984). Form Roques et al. 2001.

Sample	FAA1	FAA2	FAS1	FAS2	FAS3	FAS4	MEA1	MEA2	MEA3	MEA4	MES5	MES6	MES7	MES1	MES2	MES3	MES4
FAA1																	
FAA2	0.0132*																
FAS1	0.0091*	0.0196															
FAS2	0.0185	0.0235	(-0.0050*)														
FAS3	0.0196	0.0274	(-0.0003*)	(-0.0058*)													
FAS4	0.0093*	0.0152	(-0.0043*)	(-0.0013*)	(0.0040*)												
MEA1	0.1355	0.1636	0.1354	0.1219	0.1178	0.1255											
MEA2	0.1154	0.1412	0.1113	0.1042	0.0991	0.1067	(-0.0039*)										
MEA3	0.1189	0.1504	0.1145	0.1101	0.1023	0.1105	(-0.0008*)	(0.0026*)									
MEA4	0.1085	0.1424	0.1125	0.1032	0.0974	0.1059	(0.0062*)	0.0014*	(-0.0006*)								
MES5	0.0830	0.1118	0.0817	0.0777	0.0741	0.0743	0.0063*	0.0153	0.0082	0.0044*							
MES6	0.0778	0.1095	0.0883	0.0846	0.0819	0.0792	0.0103	0.0154	0.0096	0.0090	(0.0002*)						
MES7	0.1009	0.1313	0.1015	0.0977	0.0941	0.0927	0.0109	0.0167	0.0156	0.0181	(0.0011*)	(-0.0005*)					
MES1	0.0794	0.1135	0.0829	0.0829	0.0794	0.0766	0.0052*	0.0149	0.0125	0.0103	(0.0020*)	(0.0020*)	(-0.0030*)				
MES2	0.1035	0.1349	0.1016	0.1005	0.0962	0.0933	0.0077	0.0181	0.0117	0.0146	(0.0003*)	(0.0017*)	(-0.0046*)	(0.0000*)			
MES3	0.1065	0.1410	0.1035	0.1070	0.1027	0.0987	0.0078*	0.0224	0.0158	0.0163	0.0093	0.0043*	0.0038*	0.0101	0.0045*		
MES4	0.0817	0.1143	0.0836	0.0865	0.0839	0.0793	0.0169	0.0274	0.0193	0.0213	0.0095	(0.0036*)	0.0057*	0.0098	-0.0094	0.0186	

( ) indicates non significant allelic frequency heterogenity following the method of Fisher (α=0.001).
* indicates non significant following Bonferroni corrections (k=120, α=0.05/120=0.0004

Table 3a. Length (L50) and age (A50) at 50% of maturity of males for the different stocks

	Length			*Age*		
Genotype Stock	L50	Error	N	A50	Error	N
S. fasciatus						
Unit 1	18.88	0.305	177	6.12	0.189	61
Unit 2	20.11	0.06	280	7.67	0.046	277
Unit 3	20.4	0.267	147	6.85	0.191	134
S. mentella						
Unit 1	22.04	0.105	206	8.55	0.104	68
Unit 2	23.14	0.155	177	8.88	0.18	172
Heterozygous						
Unit 1	20.3	0.168	60	8.9	0.153	57

Table 3b. Length (L50) and age (A50) at 50% of maturity of females for the different stocks

	Length			*Age*		
Genotype Stock	L50	Error	N	A50	Error	N
S.fasciatus						
Unit 1	20.17	0.169	210	7.67	0.126	86
Unit 2	25.64	0.036	309	10.31	0.029	304
Unit 3	22.37	0.112	204	8.03	0.147	193
3O	25.47	0.118	73	10.31	0.11	30
3LN	23.98	0.298	116			
S. mentella						
Unit 1	24.35	0.169	238	10.36	0.173	93
Unit 2	25.44	0.133	155	10.6	0.086	143
3O	33.13	0.325	25	15.08	0.38	19
Heterozygous						
Unit 1	23.88	0.193	74	9.04	0.29	69
Unit 2	27.88	0.189	48	12.57	0.193	47

Table 4. Strong recruitment year for each stock (not Unit 3) based on survey information and the fishery

Year	Stock Unit 1	Unit 2	2GH	2J3K	3LN	3O	Year	Unit 1	Unit 2	2GH	2J3K	3LN	3O
1945							1974	▒	▒				
1946	■	■					1975						
1947							1976						
1948							1977						
1949							1978						■
1950							1979						
1951							1980	■	■			■	
1952							1981						
1953							1982						
1954							1983						
1955							1984						▒
1956	■	■			■		1985	▒	▒				
1957							1986						
1958	■	■			■		1987					■	
1959							1988	▒	■				■
1960							1989						
1961							1990						
1962							1991			■			
1963							1992						
1964							1993						
1965				■	■		1994			▒			
1966	▒	▒				■	1995			■			
1967							1996						
1968							1997						
1969							1998						
1970	■	■			■		1999						
1971						■	2000						
1972				■			2001						
1973							2002						

■ Relatively strong
▒ Relatively strong but disappear before contributing to the fishery

Table 5. Proportions of *S. mentella* and *S. fasciatus* by depth zone based on the meristic data from Ni (1982) (see text) for stocks in Div. 2GHJ3KLNO. Individuals were assigned to species on the basis of whether two out of three meristic characters were typical for the species.

		Depth Interval (m)											
NAFO	Species	<200		201-300		301-400		401-500		501-750		751-1000	
		n	pct	n	pct	n	pct	n	pct	n	pct	n	pct
2G	S. mentella			14	**1**	106	**0.955**	90	**1**	118	**0.959**		
	S. fasciatus				**0**	5	**0.045**		**0**	5	**0.041**		
2H	S. mentella					322	**0.917**	226	**0.978**	167	**0.994**		
	S. fasciatus					29	**0.083**	5	**0.022**	1	**0.006**		
2J3K	S. mentella			26	**0.232**	436	**0.8**	286	**0.92**	325	**0.997**		
	S. fasciatus			86	**0.768**	109	**0.2**	25	**0.08**	1	**0.003**		

		Depth Interval (ftm)									
NAFO	Species	<100		101-150		151-200		201-300		>300	
		n	pct	n	pct	n	pct	n	pct	n	pct
3LN_AUT	S. mentella	1	**0.017**	37	**0.069**	9	**0.018**	392	**0.725**	29	**0.906**
	S. fasciatus	59	**0.983**	501	**0.931**	500	**0.982**	149	**0.275**	3	**0.094**
3LN_SPG	S. mentella			4	**0.025**	8	**0.044**	250	**0.504**		
	S. fasciatus			156	**0.975**	172	**0.956**	246	**0.496**		
3O_AUT	S. mentella	2	**0.017**	10	**0.025**	6	**0.017**	84	**0.24**	42	**0.275**
	S. fasciatus	113	**0.983**	391	**0.975**	347	**0.983**	266	**0.76**	111	**0.725**
3O_SPG	S. mentella	1	**0.01**	0	**0**	5	**0.076**	26	**0.388**	11	**0.846**
	S. fasciatus	101	**0.99**	80	**1**	61	**0.924**	41	**0.612**	2	**0.154**

Table 6. Indices of abundance of redfish species for DFO ground fish survey in Unit 1.

Survey year	Indices of abundance (10^6)					
	All ages			Mature population		
	S. fasciatus	*S. mentella*	Heterozygous	*S. fasciatus*	*S. mentella*	heterozygous
1984	1555	763	283	347	331	107
1985	837	374	141	263	196	66
1986	597	374	136	338	188	63
1987	1033	520	188	507	217	75
1988	706	660	218	474	455	144
1989	616	520	175	430	425	138
1990	1499	662	237	275	439	131
1991	1913	683	278	174	187	59
1992	472	235	86	199	145	51
1993	200	132	43	81	126	37
1994	116	61	20	51	46	16
1995	50	58	18	17	40	12
1996	49	57	18	17	33	10
1997	101	62	21	22	35	11
1998	224	68	27	60	26	9
1999	111	60	21	15	26	7
2000	167	78	28	18	29	8
2001	107	54	19	16	26	8
2002	83	119	39	13	41	12

Table 7. Indices of abundance of redfish species for DFO ground fish survey in Unit 2.

Survey year	Index of abundance (10^6) All ages *S. fasciatus*	All ages *S. mentella*	All ages heterozygous	Mature population *S. fasciatus*	Mature population *S. mentella*	Mature population heterozygous
1994	565	279	75	225	245	62
1995	445	273	74	131	231	58
1996	322	218	60	149	204	55
1997	535	259	71	238	214	54
2000	578	272	74	253	223	57
2002	561	206	56	226	169	43

Table 8. Indices of abundance of redfish species for DFO ground fish survey in Unit 3.

Survey year	Index of abundance (10^6) All ages *S. fasciatus*	Mature population *S. fasciatus*
1970	401	286
1971	428	313
1972	522	480
1973	527	512
1974	171	84
1975	569	565
1976	80	67
1977	302	296
1978	434	431
1979	50	47
1980	50	47
1981	81	78
1982	209	192
1983	331	320
1984	245	194
1985	49	30
1986	195	173
1987	157	146
1988	249	226
1989	79	52
1990	222	181
1991	104	60
1992	323	318
1993	206	182
1994	208	140
1995	166	131
1996	217	154
1997	586	384
1998	125	70
1999	329	274
2000	282	209
2001	352	338
2002	151	125

Table 9. Indices of abundance of redfish species for DFO ground fish survey in 3O.

Survey year	Index of abundance (10^6)							
	Spring				Autumn			
	All ages		Mature population		All ages		Mature population	
	S. fasciatus	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*
1973	11.8	0.1	9.7	0.0				
1974								
1975	72.9	0.1	38.4	0.0				
1976	33.4	0.6	6.4	0.2				
1977	239.1	0.5	134.8	0.4				
1978	26.7	1.5	20.1	0.9				
1979	86.3	3.9	62.8	2.4				
1980	19.0	0.4	12.7	0.2				
1981								
1982	188.3	1.9	79.4	1.0				
1983								
1984	899.1	10.4	40.5	2.1				
1985	241.0	3.6	46.7	1.1				
1986	925.7	9.4	342.4	1.2				
1987	243.5	4.7	126.1	1.8				
1988	358.9	4.6	100.7	0.8				
1989	84.5	0.6	44.5	0.4				
1990	529.4	0.6	438.9	0.4				
1991	141.3	14.1	19.2	9.5	326.7	9.6	75.1	2.8
1992	123.7	23.1	30.9	3.1	413.3	8.5	153.2	1.2
1993	555.3	13.0	275.9	8.8	262.7	39.5	140.5	18.4
1994	1430.0	29.6	380.8	23.2	296.0	25.4	117.1	15.9
1995	2152.8	44.8	275.4	11.9	955.2	64.9	186.1	25.2
1996	756.4	25.4	204.8	9.7	130.7	22.6	52.2	9.8
1997	81.0	36.2	32.6	7.8	952.8	106.7	442.9	39.8
1998	1008.1	24.7	530.8	16.8	336.5	61.5	252.6	36.9
1999	651.1	67.8	415.1	38.8	249.8	18.5	162.4	11.6
2000	422.4	50.1	291.4	31.8	300.6	58.2	210.8	32.8
2001	148.8	20.5	88.9	12.4	329.4	26.3	87.7	7.7
2002	112.0	11.5	67.0	5.9	259.5	41.3	92.1	12.4

Table 10. Indices of abundance of redfish species for DFO ground fish survey in 3LN.

Survey year	Index of abundance (10^6)							
	Spring				Autumn			
	All ages		Mature population		All ages		Mature population	
	S. fasciatus	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*
1973	47.4	1.7	23.1	0.5				
1974	8.9	0.4	7.5	0.3				
1975	16.5	0.7	9.6	0.3				
1976	164.2	7.6	160.9	7.3				
1977	51.0	2.0	41.3	1.5				
1978	29.2	1.1	24.4	0.8				
1979	361.0	12.2	154.4	3.5				
1980	35.3	1.4	23.7	0.8				
1981	130.5	6.3	98.1	3.3				
1982	58.5	2.6	45.2	1.9				
1983								
1984								
1985	113.6	10.8	27.8	1.9				
1986	54.2	2.3	16.0	0.6				
1987	134.6	4.1	51.5	1.0				
1988	89.1	3.5	39.0	1.0				
1989	46.5	2.1	18.6	0.6				
1990	34.3	1.4	13.4	0.5				
1991	41.2	24.9	17.1	8.1	369.5	52.5	33.1	26.5
1992	35.1	19.4	13.0	9.9	1014.7	115.5	280.6	45.6
1993	81.8	28.9	28.7	20.0	30.3	58.3	12.7	30.0
1994	16.2	8.1	5.7	4.2	112.5	62.7	24.7	44.6
1995	19.8	12.2	7.4	5.3	307.9	124.4	84.8	91.8
1996	72.5	51.5	41.5	23.9	34.7	38.8	18.9	21.1
1997	50.5	32.6	31.4	19.5	241.5	113.6	160.1	88.7
1998	185.5	63.6	145.0	55.3	485.9	106.0	346.7	74.7
1999	226.8	58.5	186.3	49.1	159.0	128.0	122.2	111.5
2000	233.8	140.6	189.2	102.9	384.7	102.2	275.3	79.0
2001	111.9	75.2	74.6	51.2	736.3	145.0	425.9	94.4
2002	101.6	58.9	59.7	35.0				

Table 11. Indices of abundance of redfish species for DFO autumn ground fish surveys in 2J3K and 2GH.

Survey year	Index of abundance (10^6)							
	2J3K				2GH			
	All ages		Mature population		All ages		Mature population	
	S. fasciatus	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*
1978	3253.1	5386.9	1297.9	4238.2				
1979	817.2	1322.3	481.9	1055.6				
1980	1361.7	1617.1	1130.7	1431.0				
1981	2304.1	1503.7	2224.8	1307.0				
1982	431.0	1469.7	388.9	1172.8				
1983	4024.6	4260.1	4001.2	3751.9				
1984	316.9	799.1	270.3	723.2				
1985	236.5	965.2	213.4	901.3				
1986	186.1	651.9	154.6	593.0				
1987	61.4	275.1	44.8	234.6	1.4	37.4	0.7	20.7
1988	168.5	689.7	137.7	585.5	7.1	101.6	0.7	15.3
1989	58.6	250.9	40.1	170.2				
1990	106.9	469.1	96.5	398.2				
1991	29.8	134.4	16.5	84.7	1.0	28.9	0.0	0.6
1992	12.9	73.3	2.7	27.2				
1993	6.5	35.7	1.7	16.8				
1994	4.0	32.3	1.2	16.8				
1995	25.0	123.0	1.7	13.9				
1996	62.3	178.0	7.3	59.2	9.1	321.9	1.1	24.2
1997	46.5	178.6	5.6	93.8	13.9	367.9	2.8	42.9
1998	76.3	236.0	9.9	99.0	4.9	150.8	0.9	27.2
1999	56.2	224.6	7.2	100.2	7.5	212.9	1.2	26.6
2000	64.6	160.2	4.1	37.3				
2001	145.2	268.8	41.6	91.1				

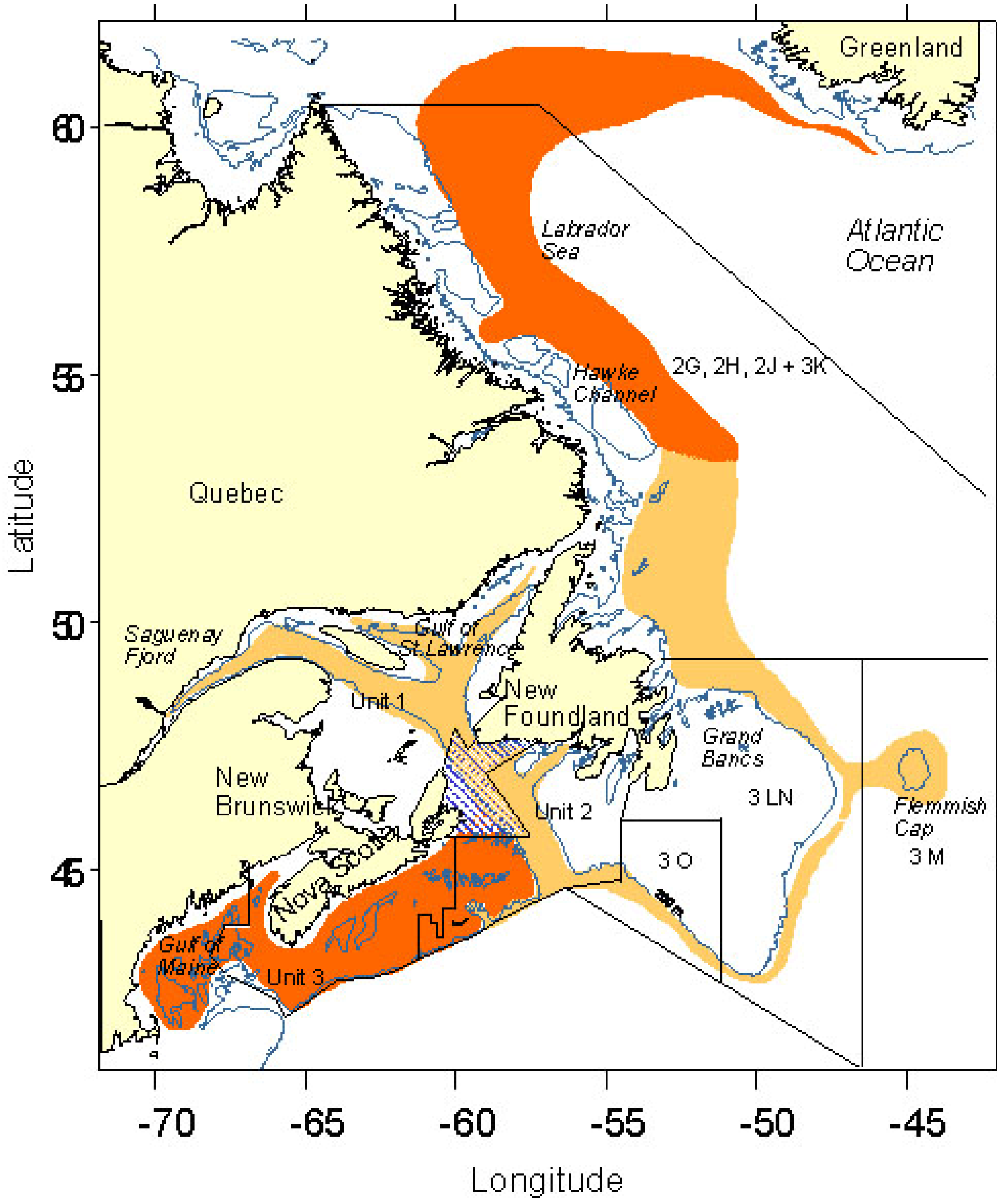


Figure 1. Map of the Northwest Atlantic summarising the general distribution of *Sebastes fasciatus* and *S. mentella* based on MDH, EGM and AFC data. The approximate location of the two allopatric (darker zone) and of the sympatric (lighter zone) areas are illustrated. The boundaries of redfish management units within NAFO divisions are also indicated. The area correspounding to NAFO subdivisions 3Pn and 4Vn (hatched) indicates the area of seasonal overlap between Units 1 and 2.

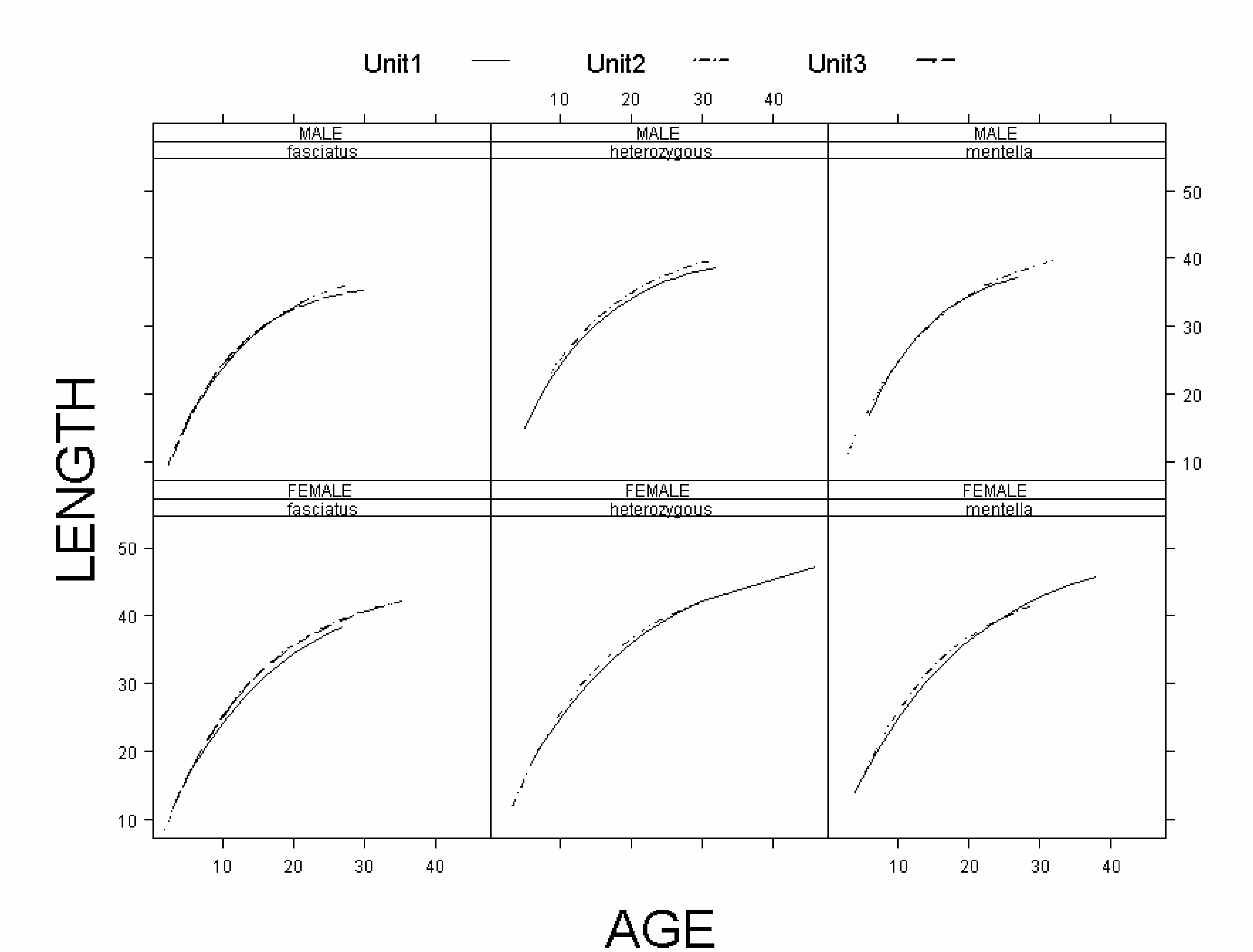


Figure 2. Comparison of growth curve for male and female *S. fasciatus* and *S. mentella* and for the MDH heterozygous individuals in management units 1 to 3.

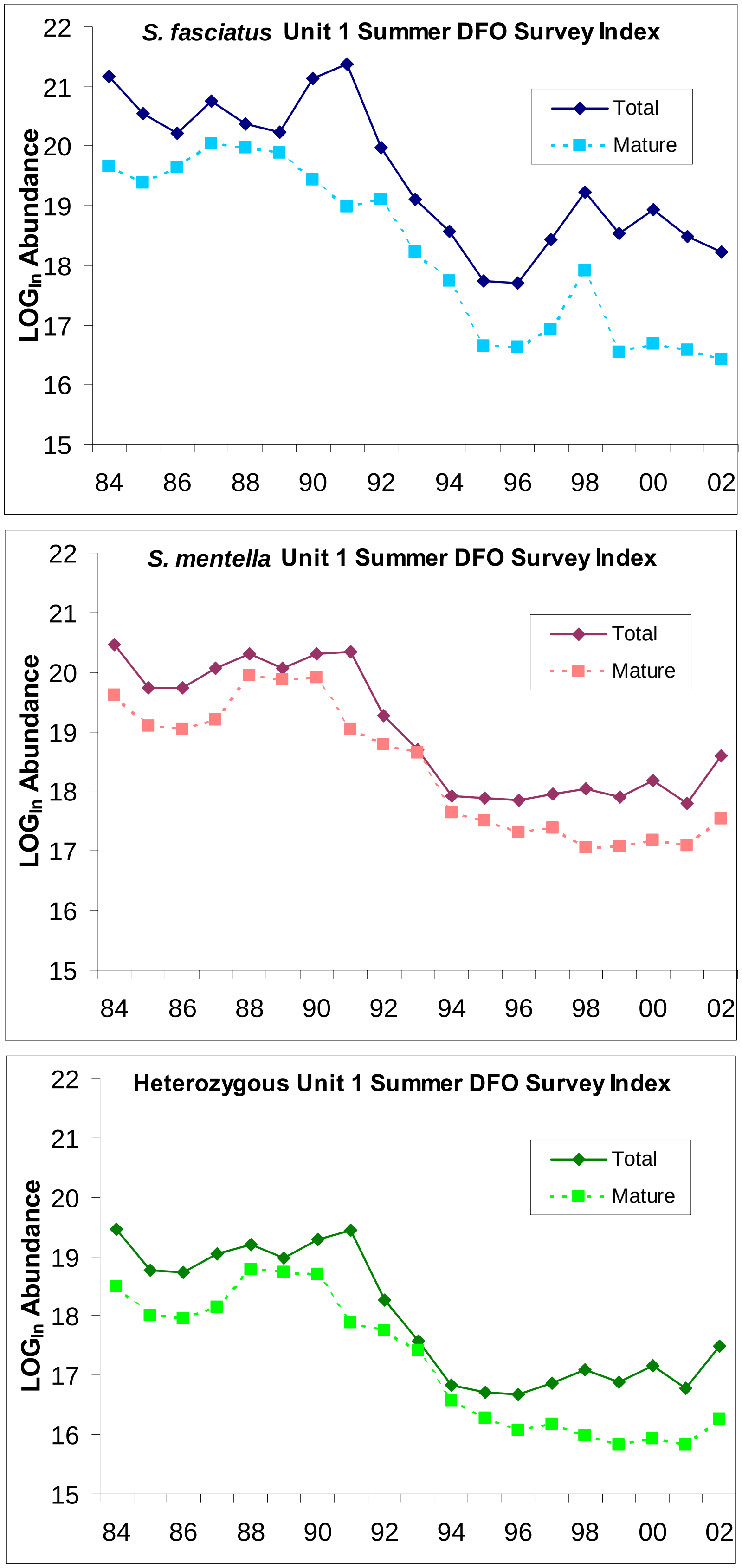


Figure 3. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel), *S. mentella* (middle panel) and MDH heterozygous (bottom panel) from stratified-random surveys conducted in Division 4RST in the summer from 1984-2002.

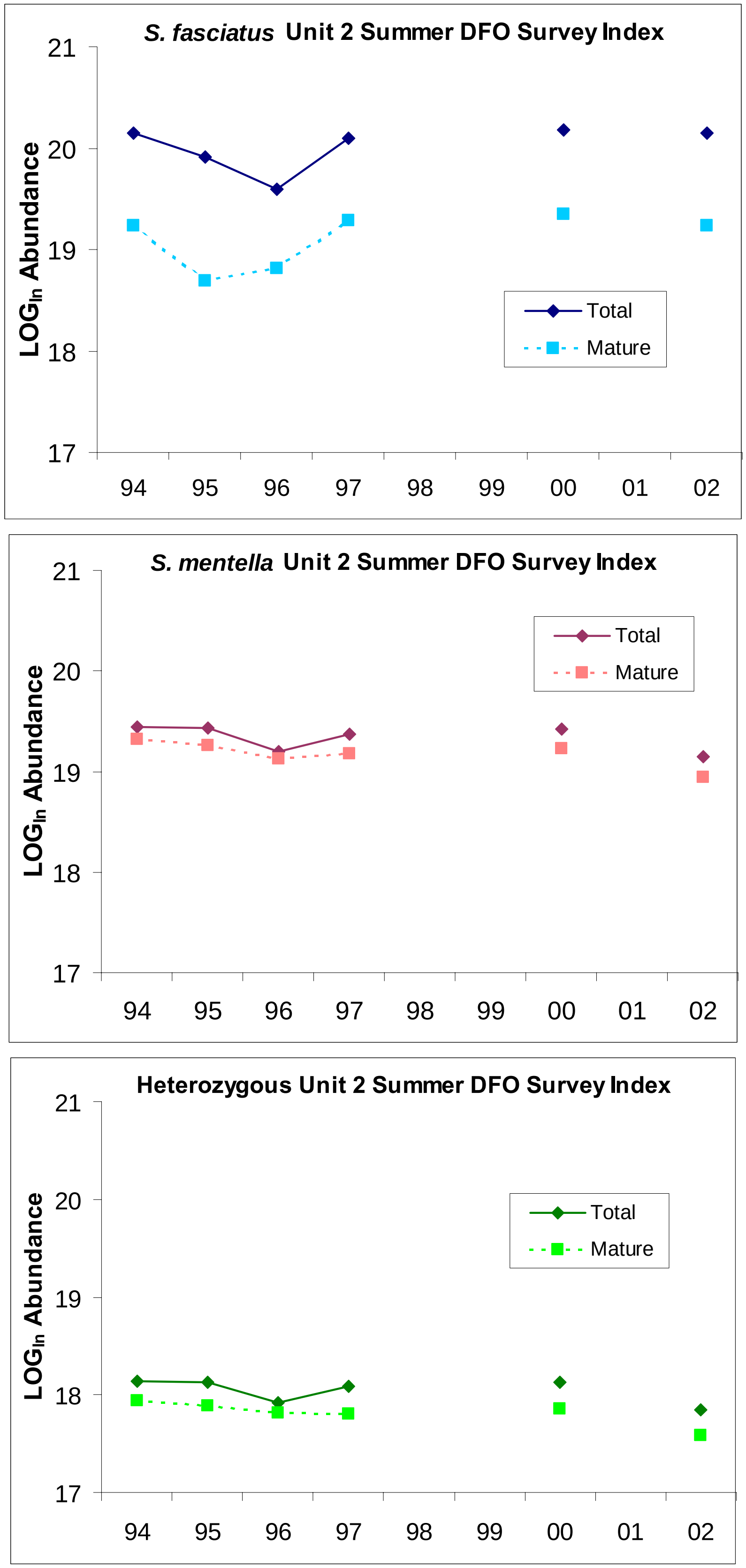


Figure 4 Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel), *S. mentella* (middle panel) and MDH heterozygous (bottom panel) from stratified-random surveys conducted in Unit 2 in the summer from 1994-2002.

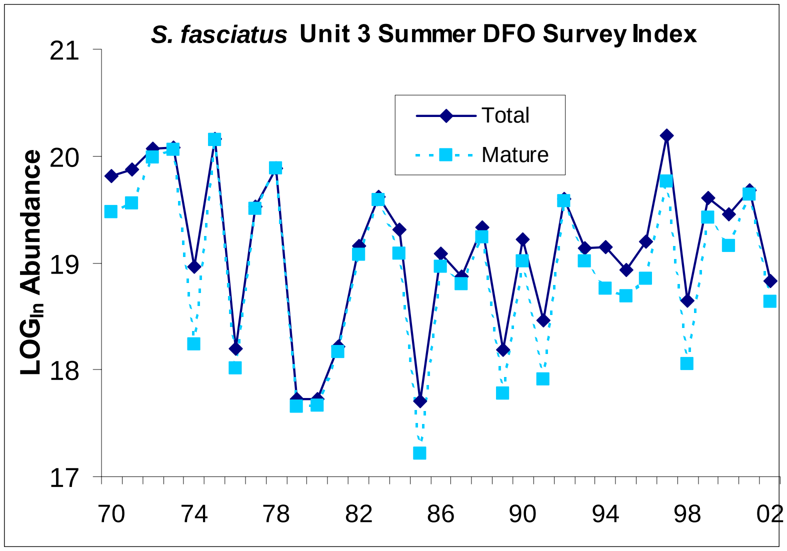
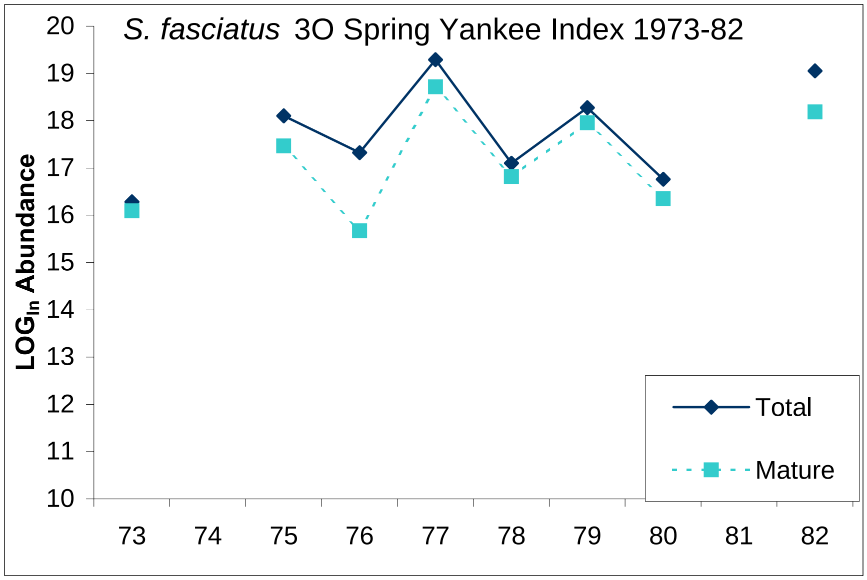


Figure 5 Natural log survey abundance estimates of *S. fasciatus* from stratified-random surveys conducted in Unit 3 in the summer from 1970-2002.



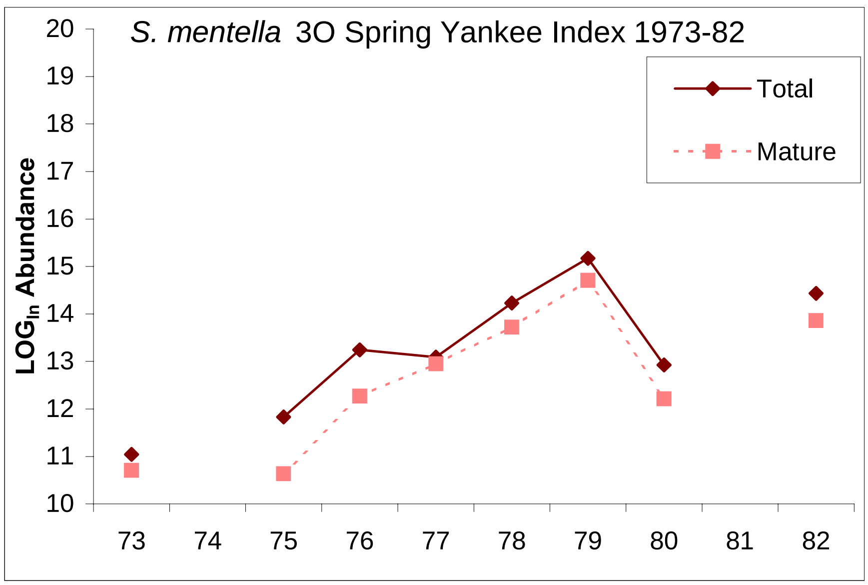
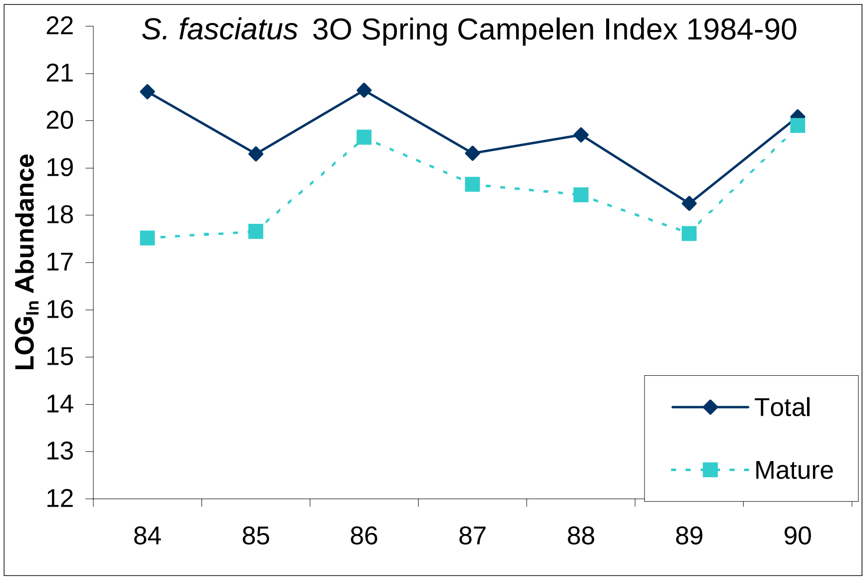


Figure 6. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) *and S. mentella* (lower panel) from stratified-random surveys conducted in Division 3O in the spring from 1973-1982 utilizing a lined Yankee 41-5 bottom trawl to a maximum depth of 200 fathoms (367m).



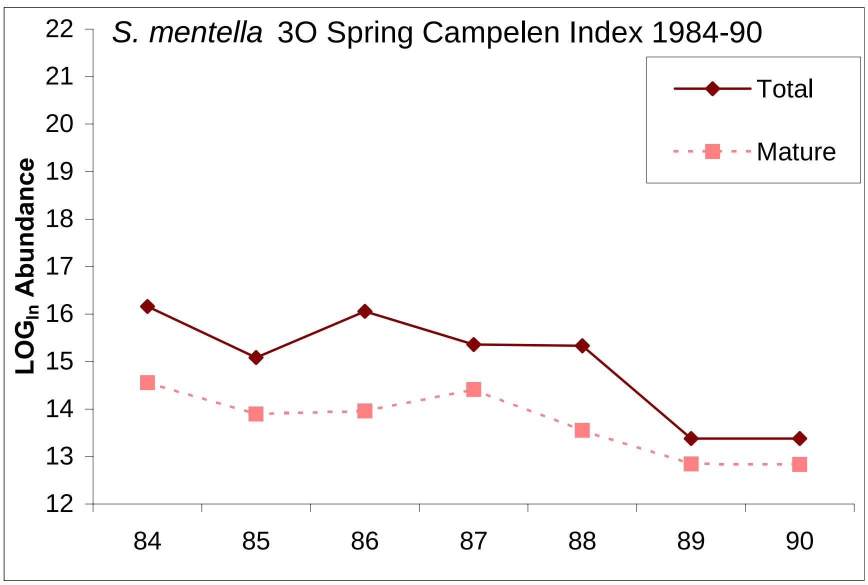
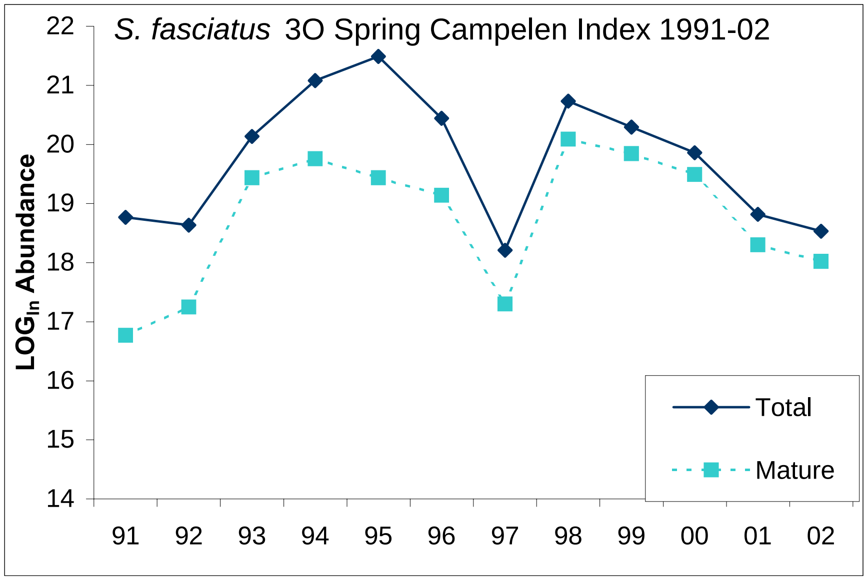


Figure 7. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3O in the spring from 1984-1990 utilizing a lined Engel 145 bottom trawl to a maximum depth of 200 fathoms (367m). Data are in Campelen trawl equivalents (see text).



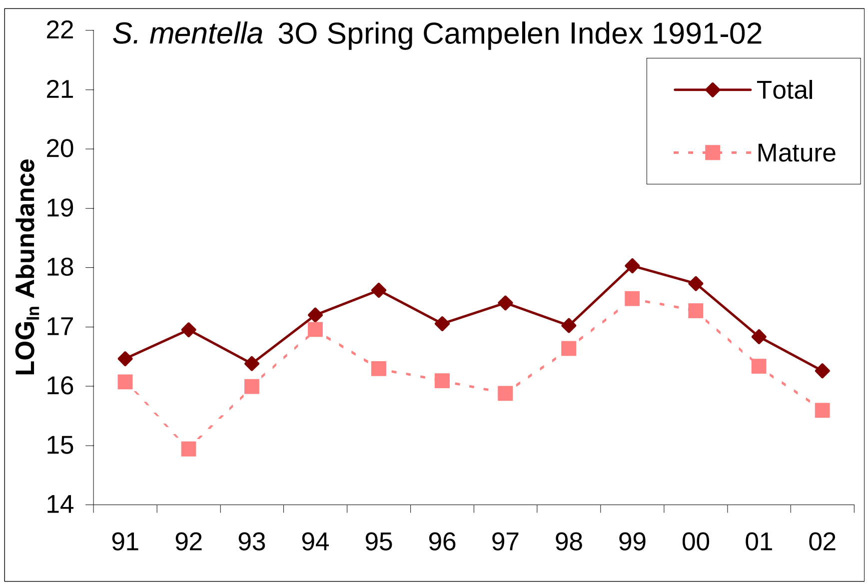


Figure 8. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3O in the spring from 1991-2002 to a maximum depth of 400 fathoms (732m). Surveys from 1991-1995 utilized a lined Engel 145 bottom trawl and surveys post 1995 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).

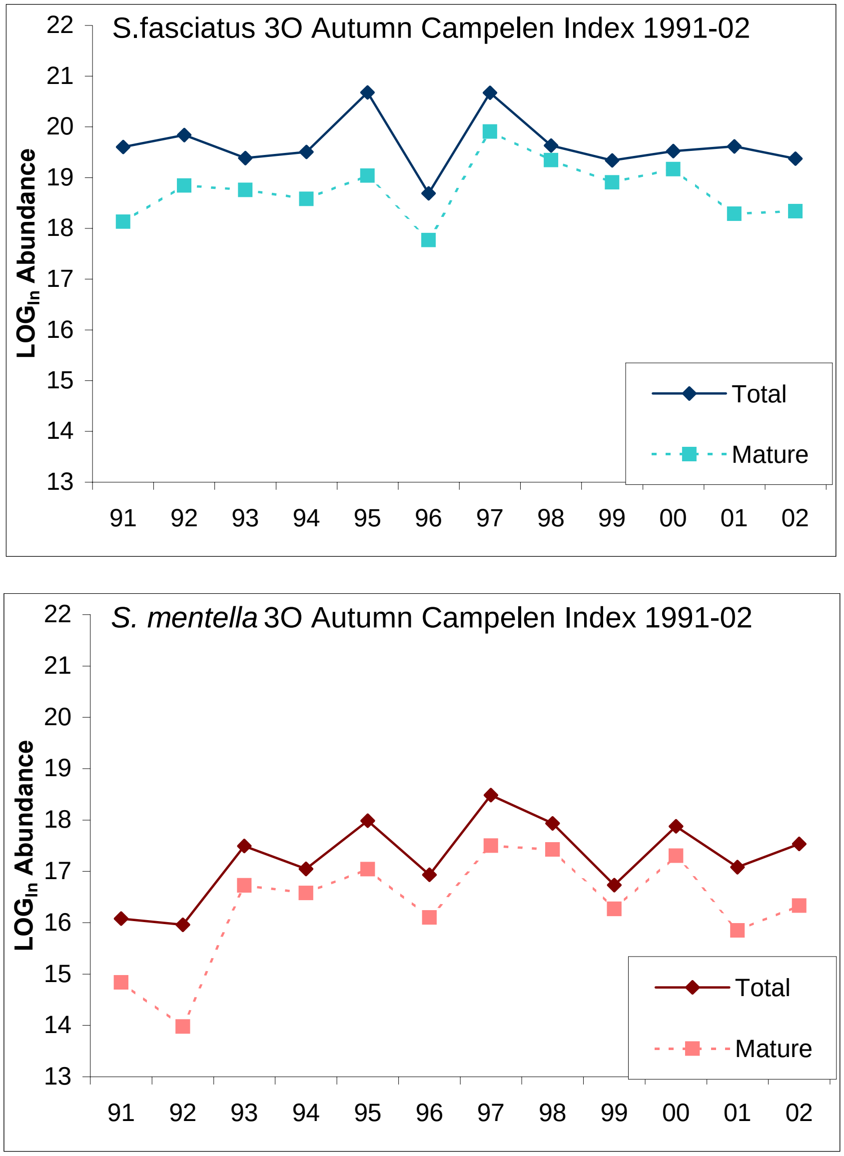


Figure 9. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) *and S. mentella* (lower panel) from stratified-random surveys conducted in Division 3O in the autumn from 1991-2001 to a maximum depth of 400 fathoms (732m). Surveys from 1991-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).

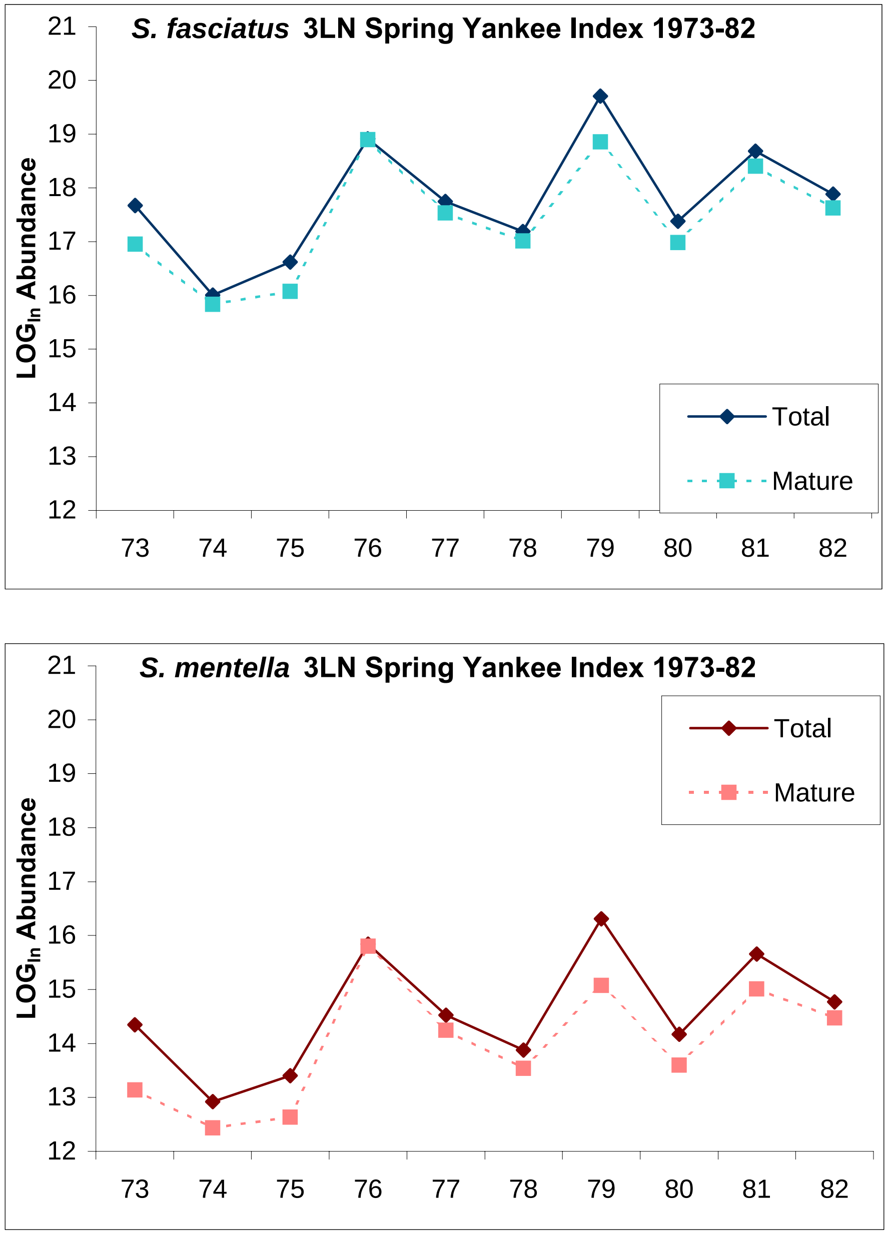
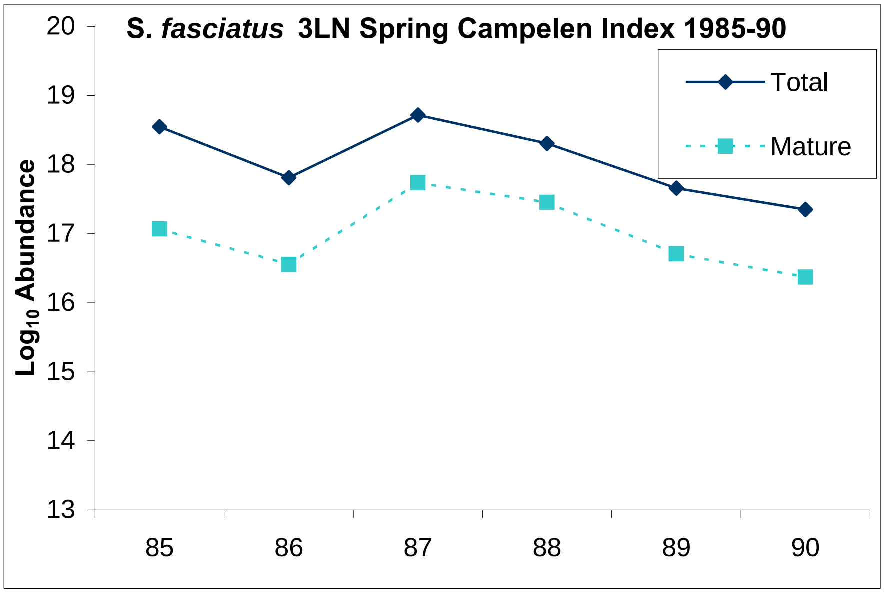


Figure 10. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3LN in the spring from 1973-1982 utilizing a lined Yankee 41-5 bottom trawl to a maximum depth of 200 fathoms (367m).



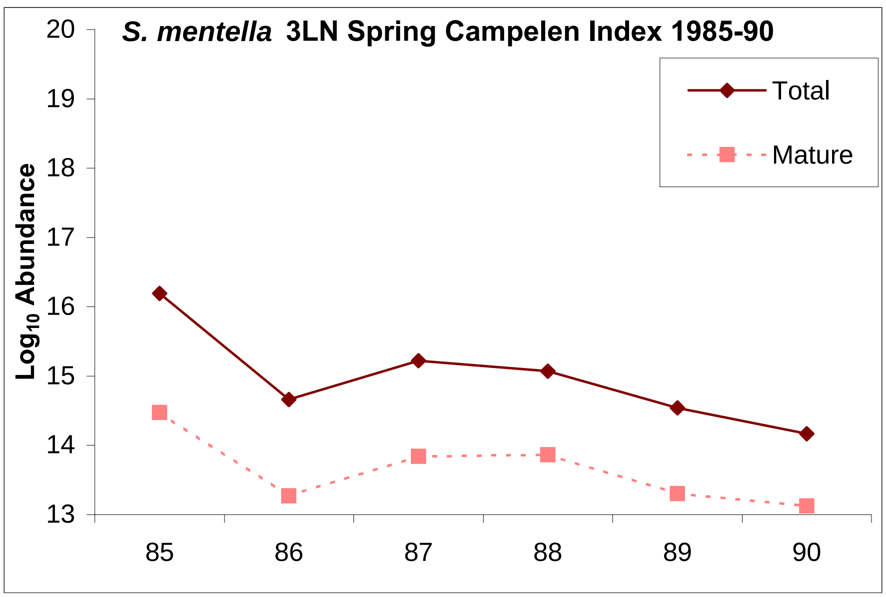
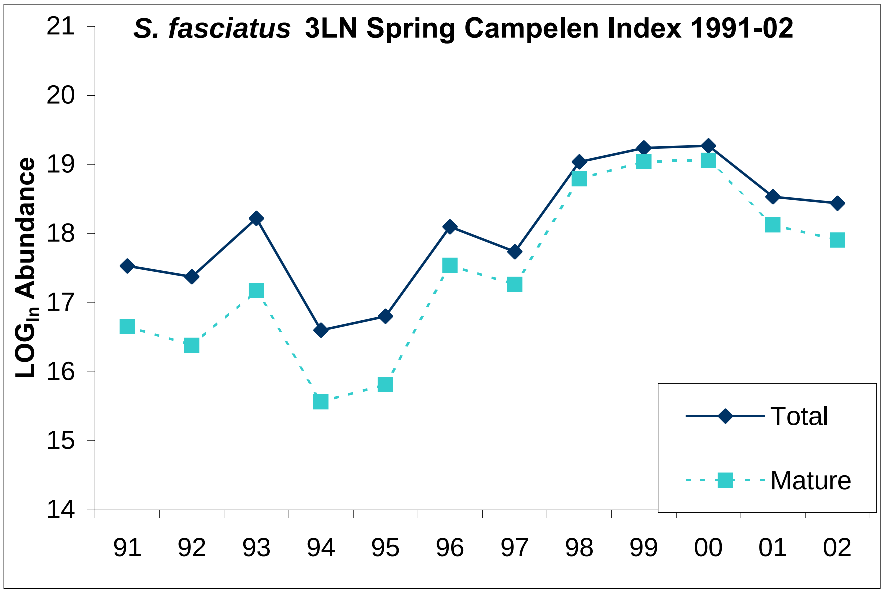


Figure 11. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3LN in the spring from 1985-1990 utilizing a lined Engel 145 bottom trawl to a maximum depth of 200 fathoms (367m). Data are in Campelen trawl equivalents (see text).



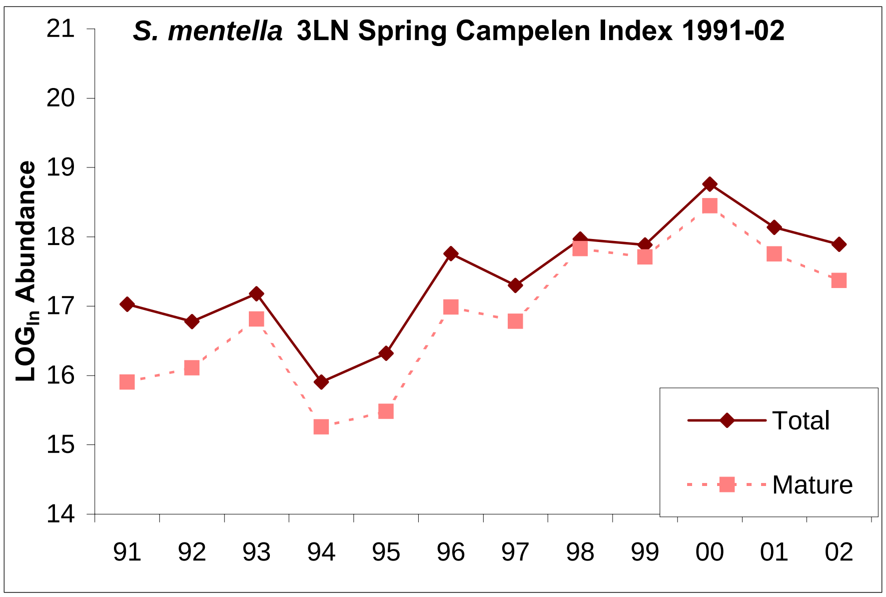


Figure 12. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3LN in the spring from 1991-2002 to a maximum depth of 400 fathoms (732m). Surveys from 1991-1995 utilized a lined Engel 145 bottom trawl and surveys post 1995 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).

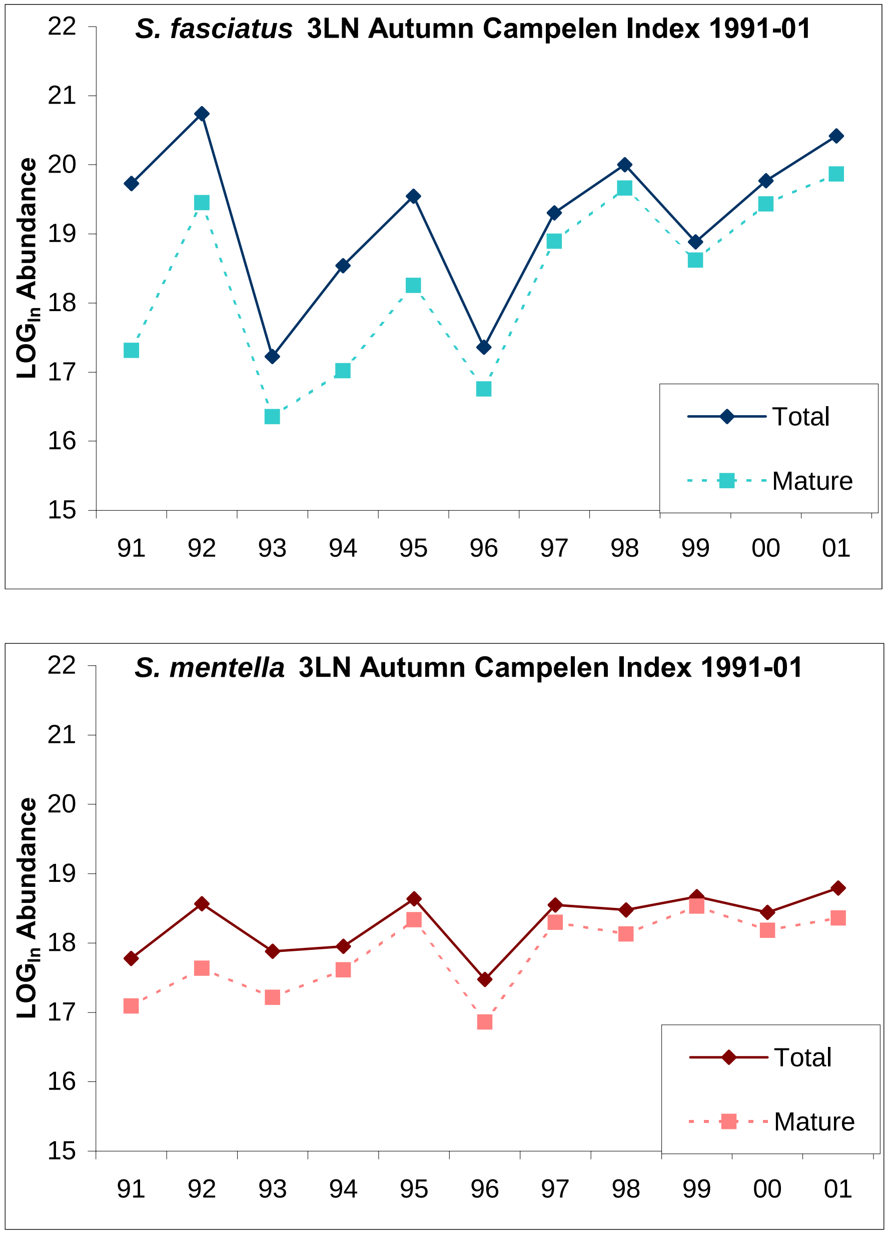


Figure 13. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 3LN in the autumn from 1991-2001 to a maximum depth of 400 fathoms (732m). Surveys from 1991-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).

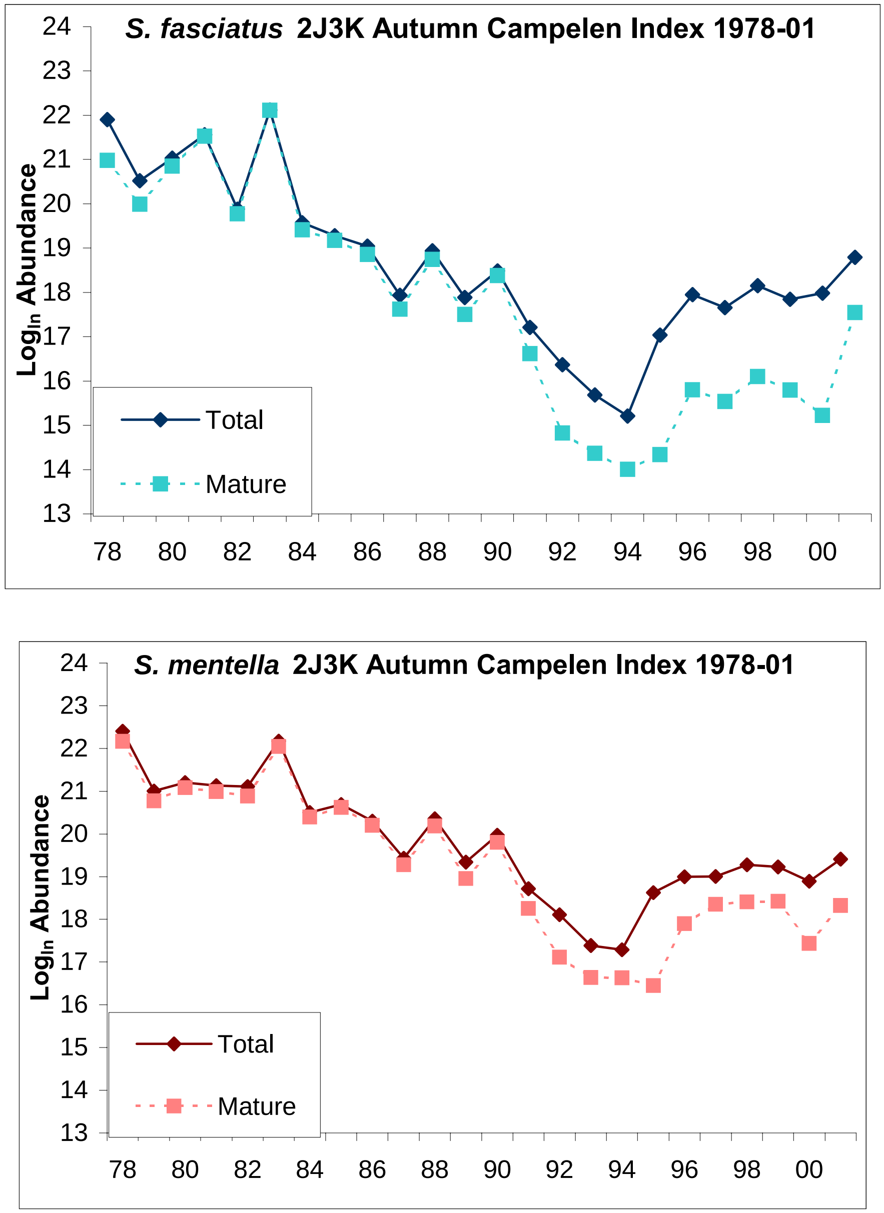
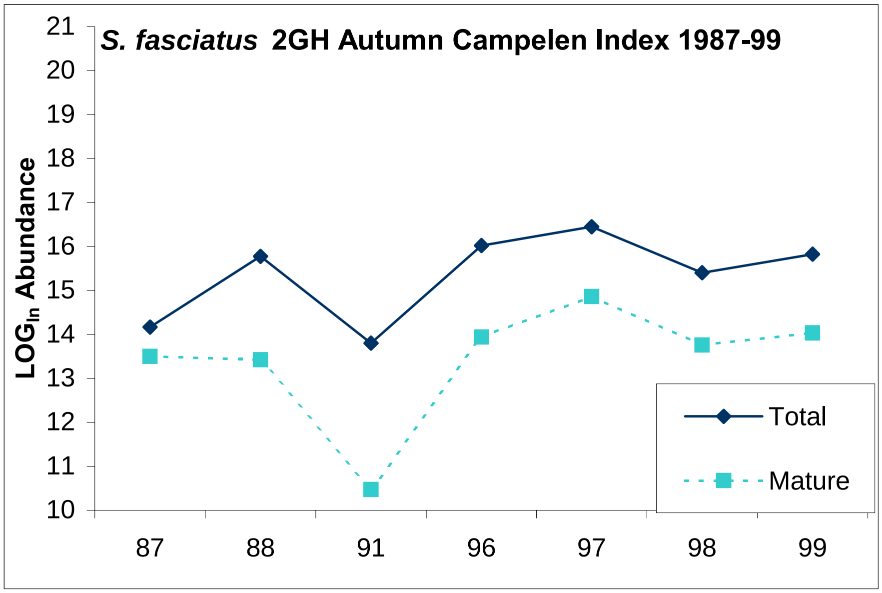


Figure 14. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in Division 2J3K in the autumn from 1978-2001. Surveys from 1978-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).



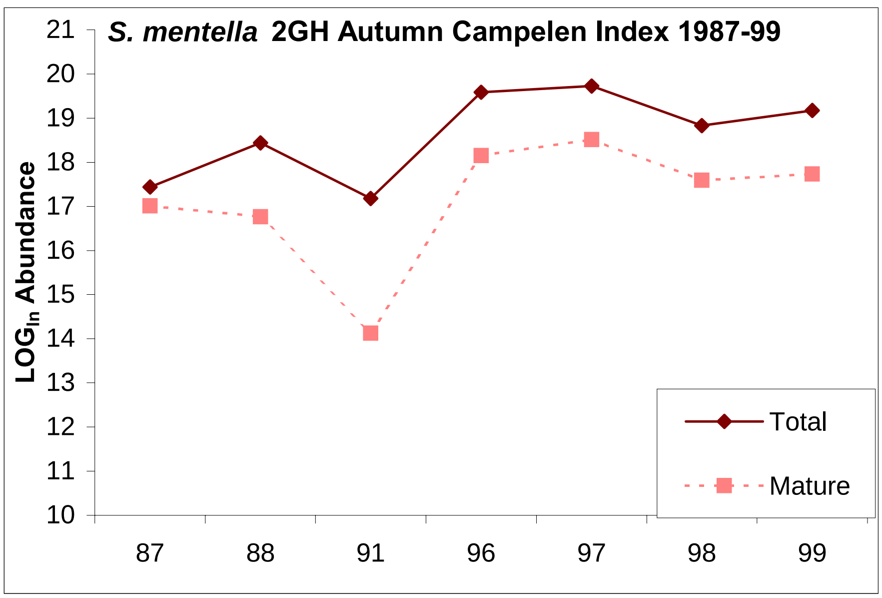


Figure 15. Natural log survey abundance estimates of *Sebastes fasciatus* (upper panel) *and S. mentella* (lower panel) from stratified-random surveys conducted in Division 2GH in the autumn from 1987-1999. Surveys from 1987-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engels data are in Campelen trawl equivalents (see text).

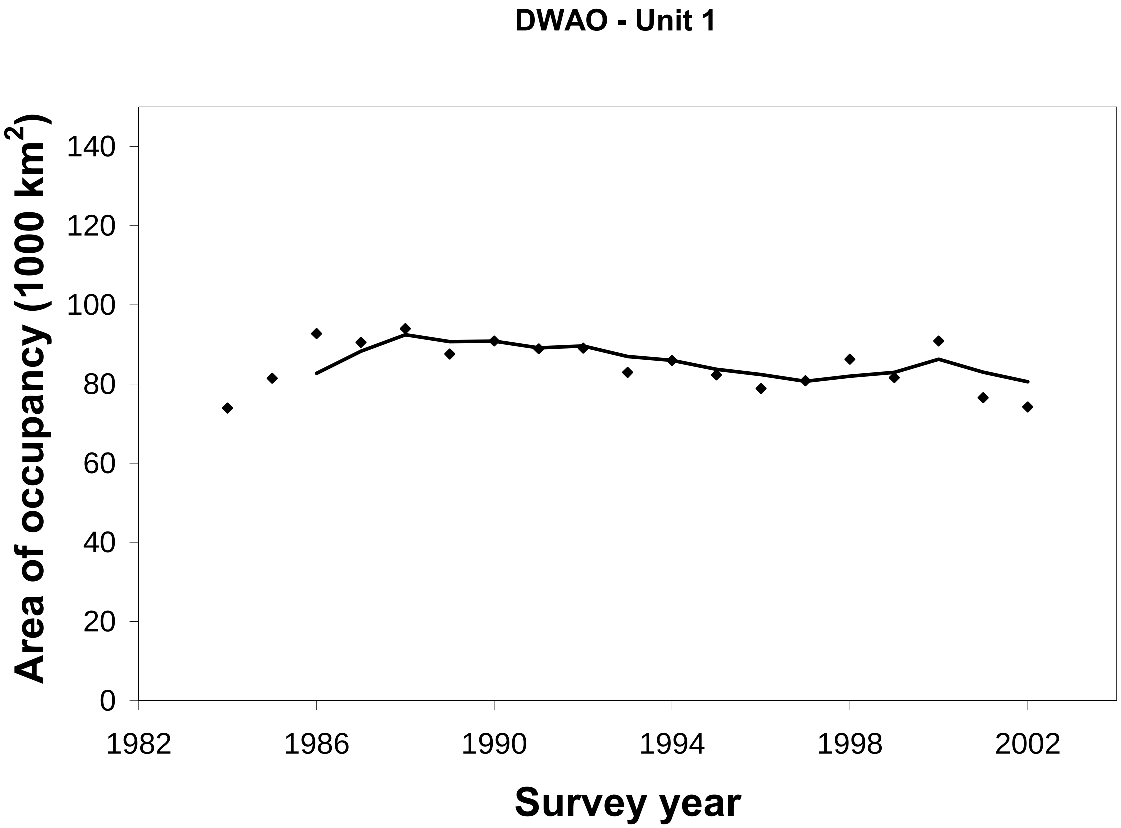
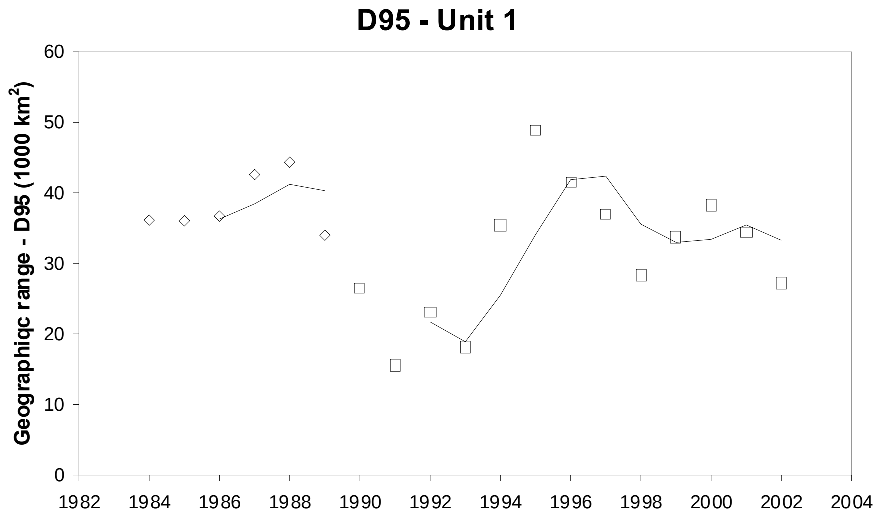


Figure 16. Area of occupancy (DWAO) of redfish sp in Unit 1. A correction was applied to merge the L. Hammond series (1984-1989) to the *A. needler* series (1990-2002).



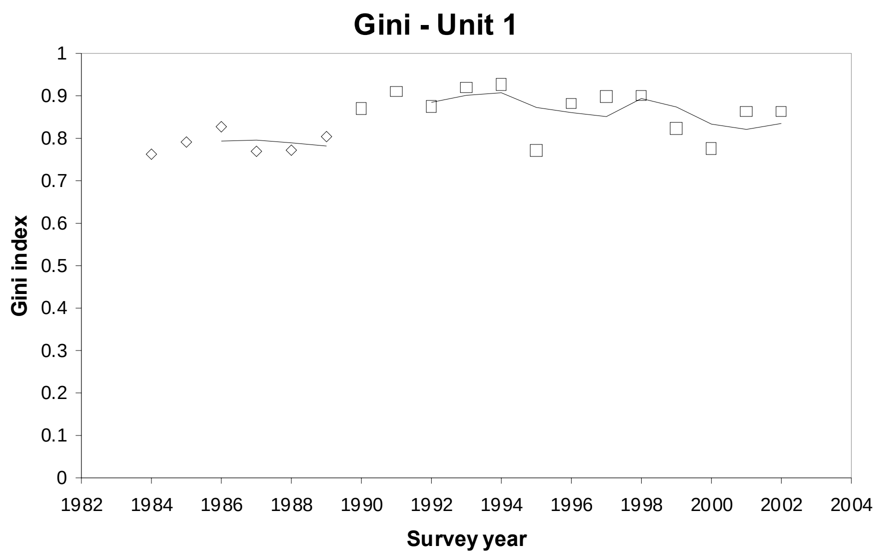


Figure 17. Indices of concentration of *S. fasciatus* in Unit 1. The data are from the *L. Hammond* from 1984 to 1989 and the A. Needler from 1990 to 2002

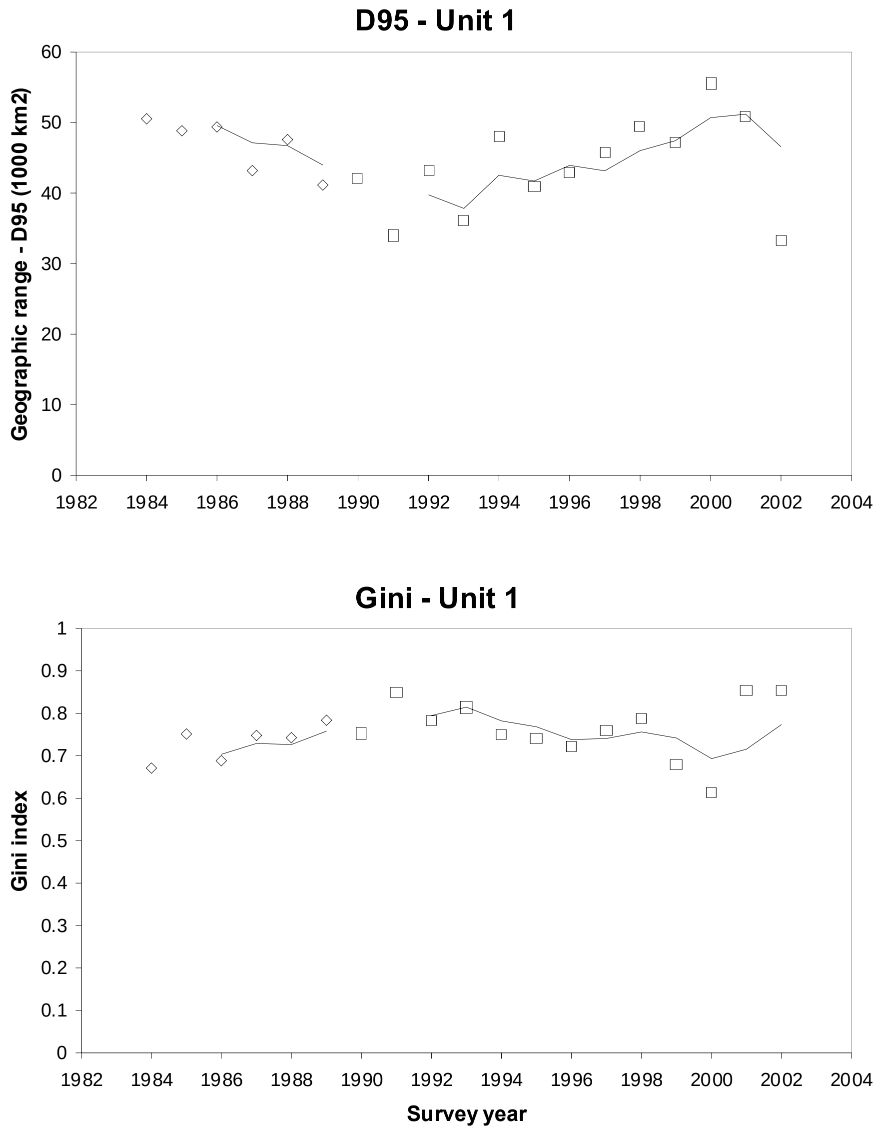
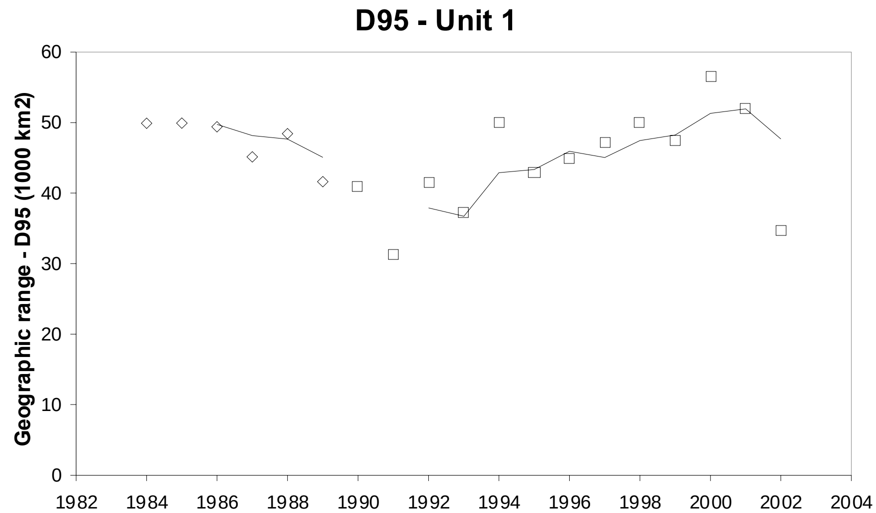


Figure 18. Indices of concentration of *S. mentella* in Unit 1. The data are from the *L. Hammond* from 1984 to 1989 and the *A. Needler* from 1990 to 2002



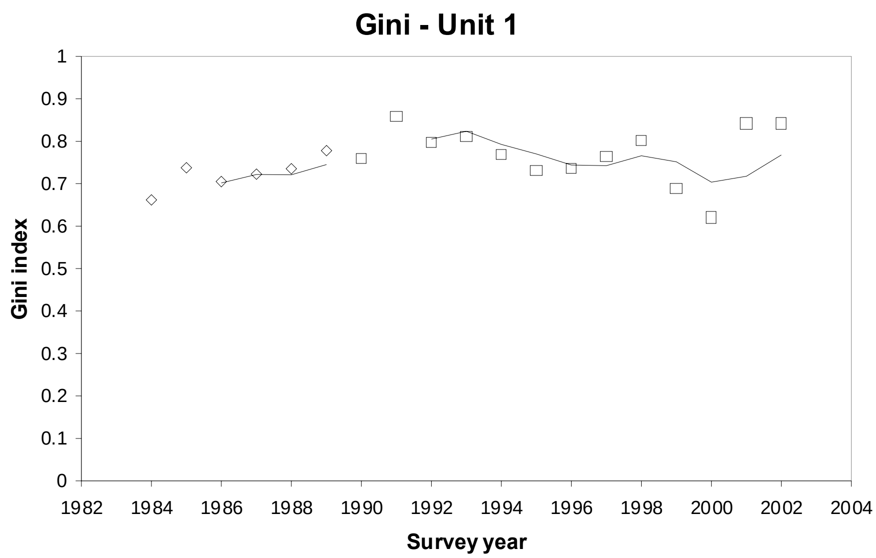


Figure 19. Indices of concentration of heterozygous individuals in Unit 1. The data are from *the L. Hammond* from 1984 to 1989 and the *A. Needler* from 1990 to 2002

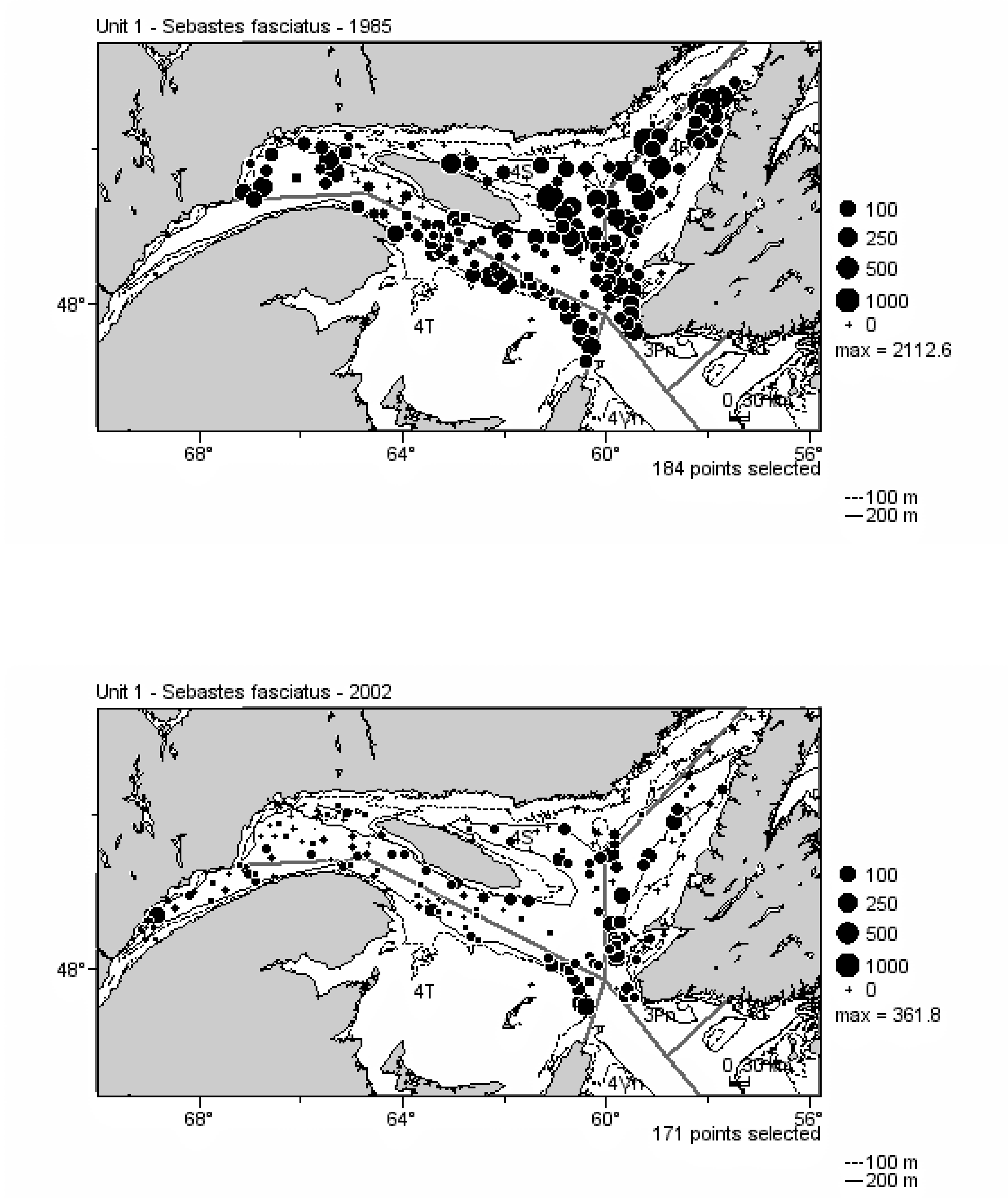


Figure 20. Distribution of the catches of *S. fasciatus* (in number) in 1985 and 2002 in Unit 1

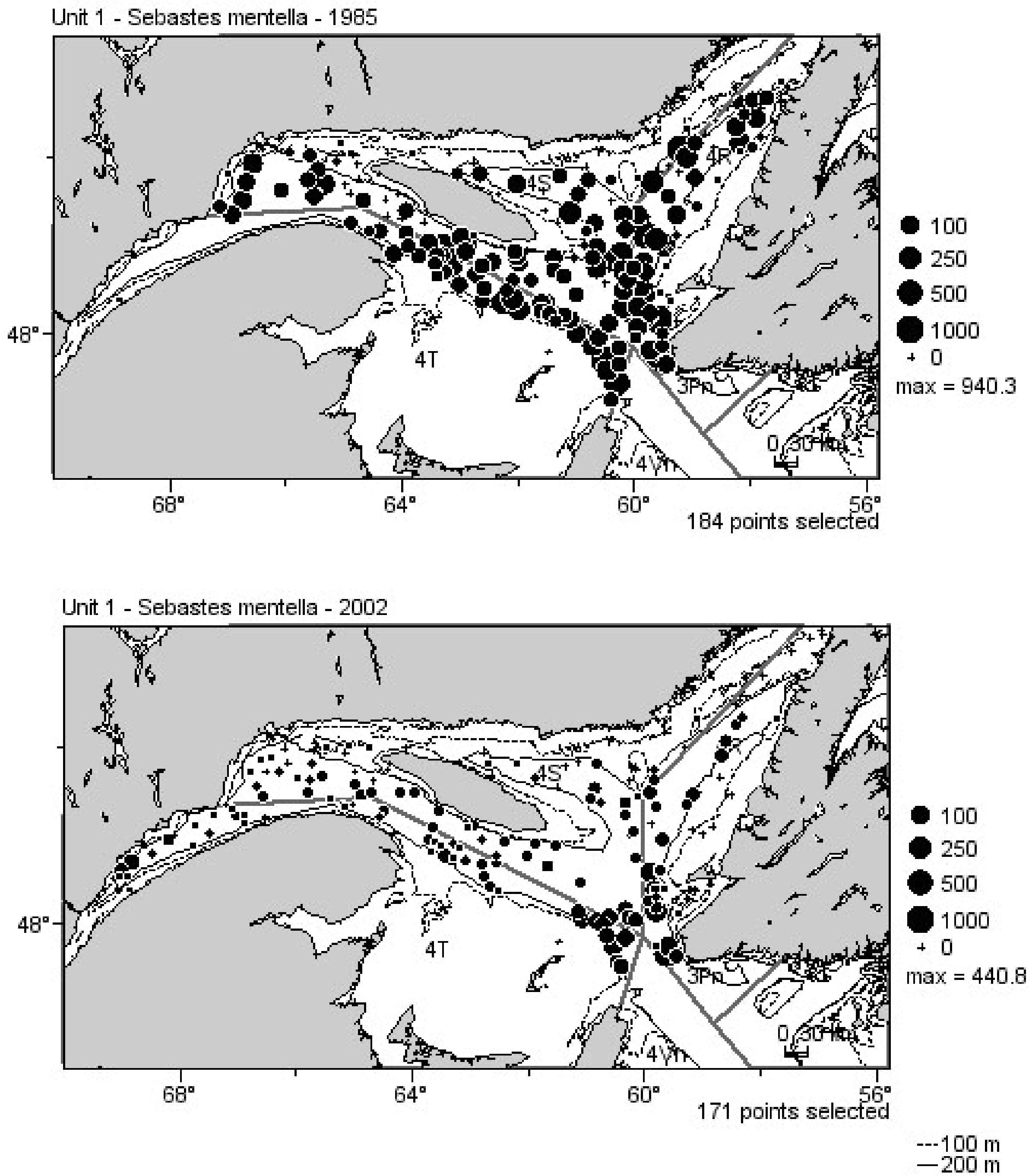


Figure 21. Distribution of the catches of *S. mentella* (in number) in 1985 and 2002 in Unit 1

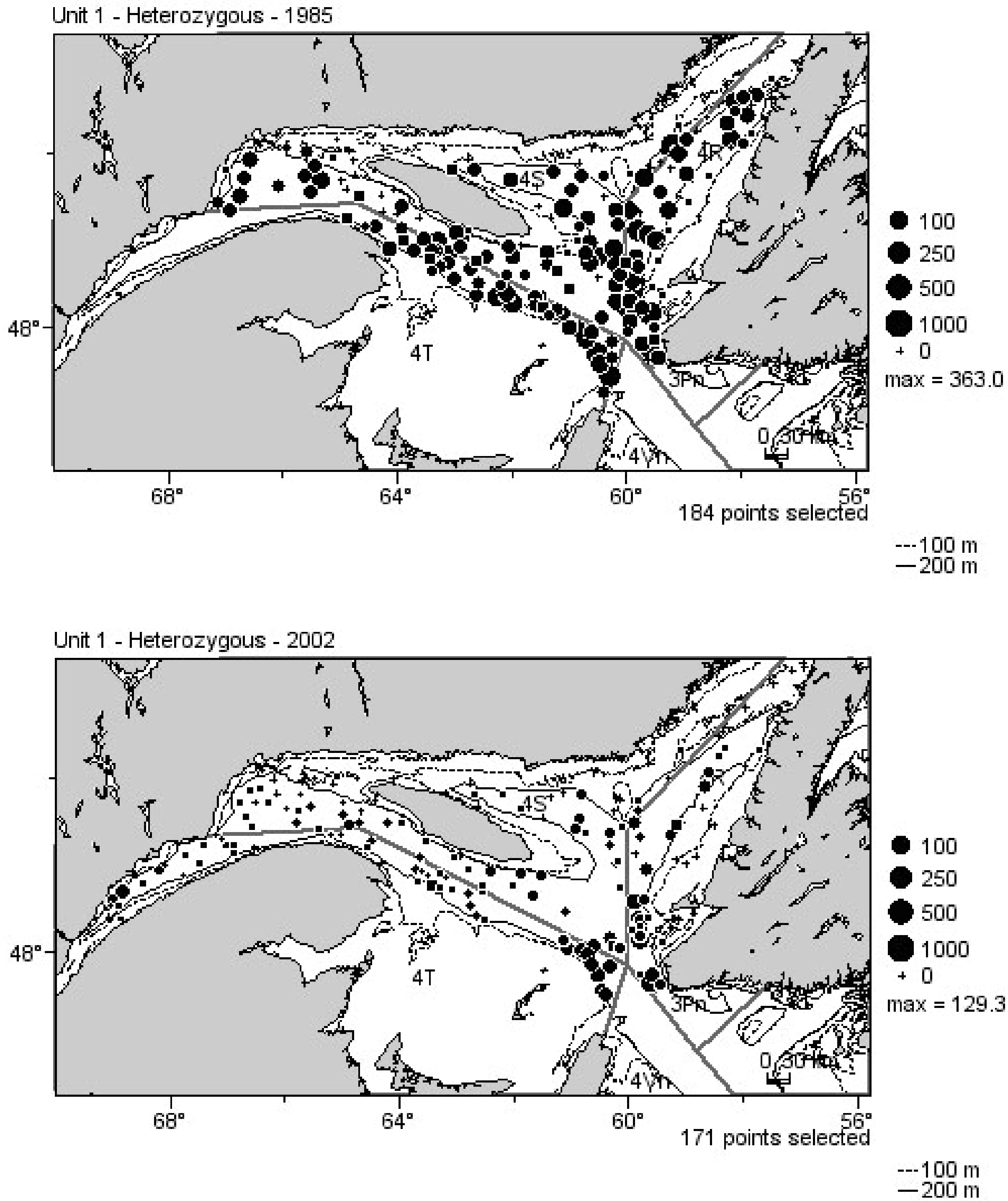


Figure 22. Distribution of the catches of redfish heterozygous(in number) in 1985 and 2002 in Unit 1.

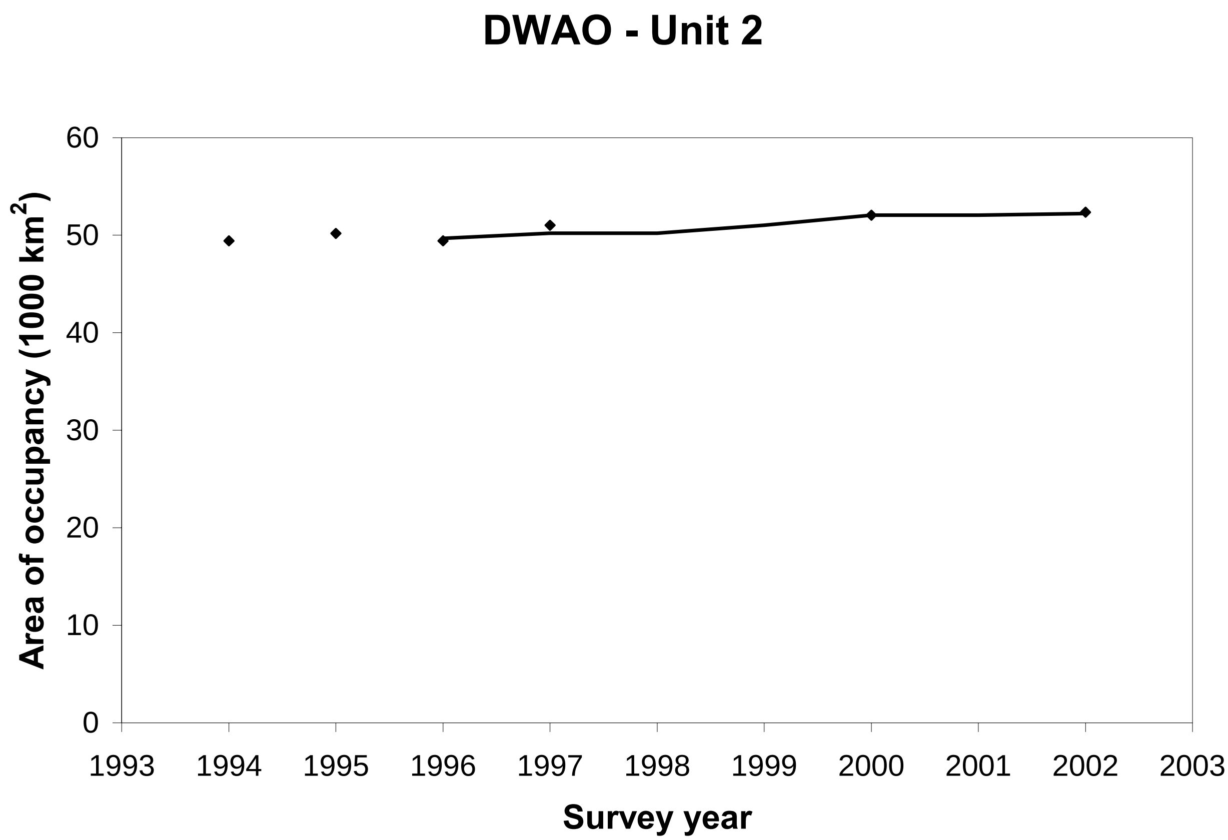
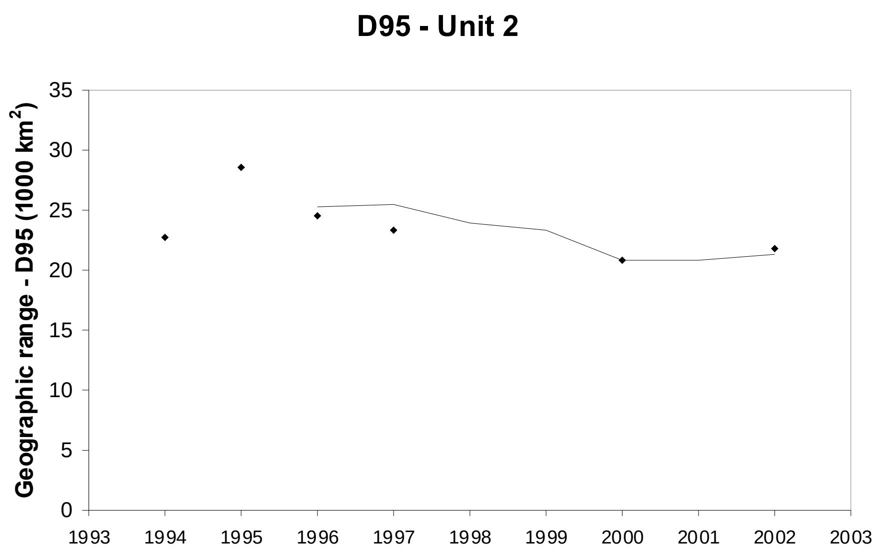


Figure 23. Area of occupancy (DWAO) of redfish sp in Unit 2



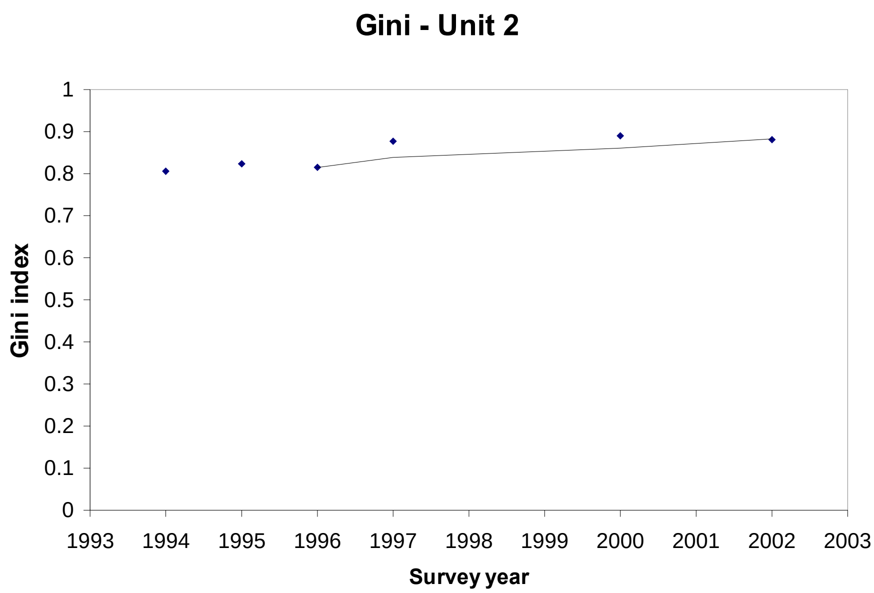
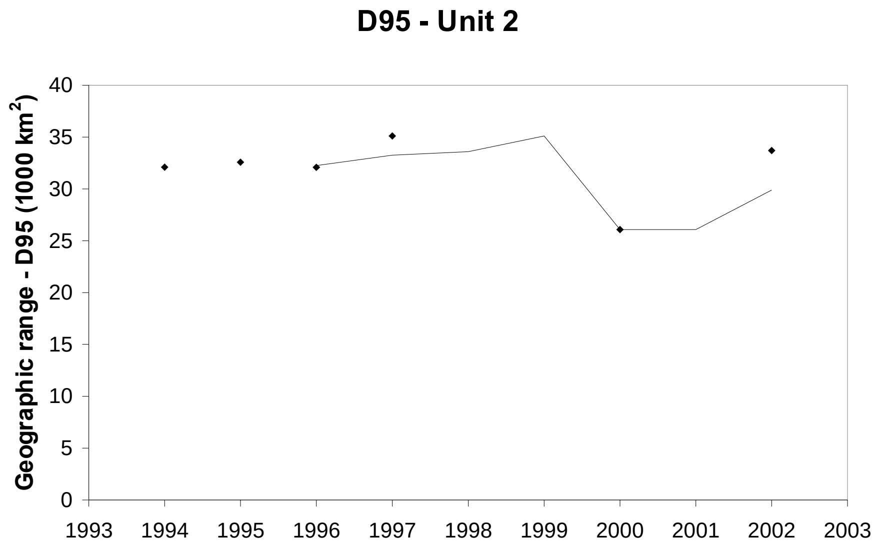


Figure 24. Indices of concentration of *S. fasciatus* in Unit 2



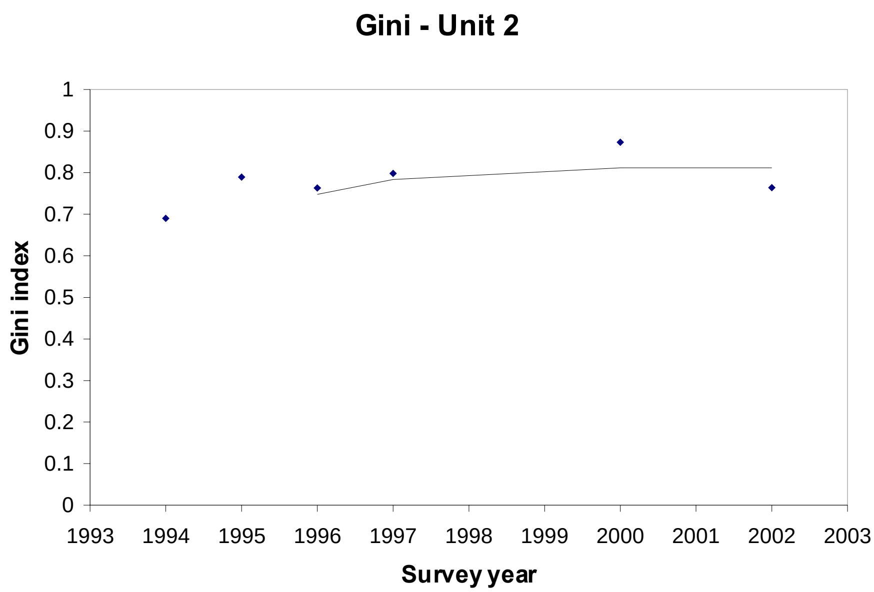
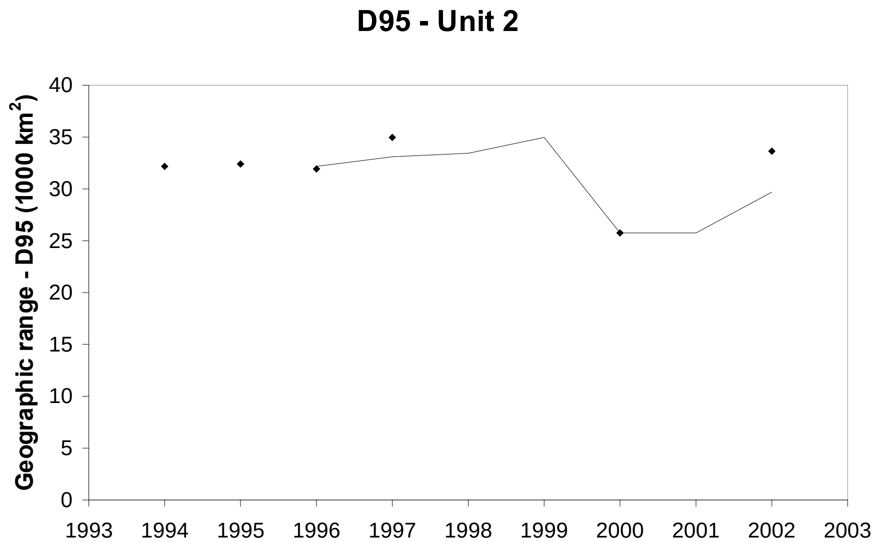


Figure 25. Indices of concentration of *S. mentella* in Unit 2.



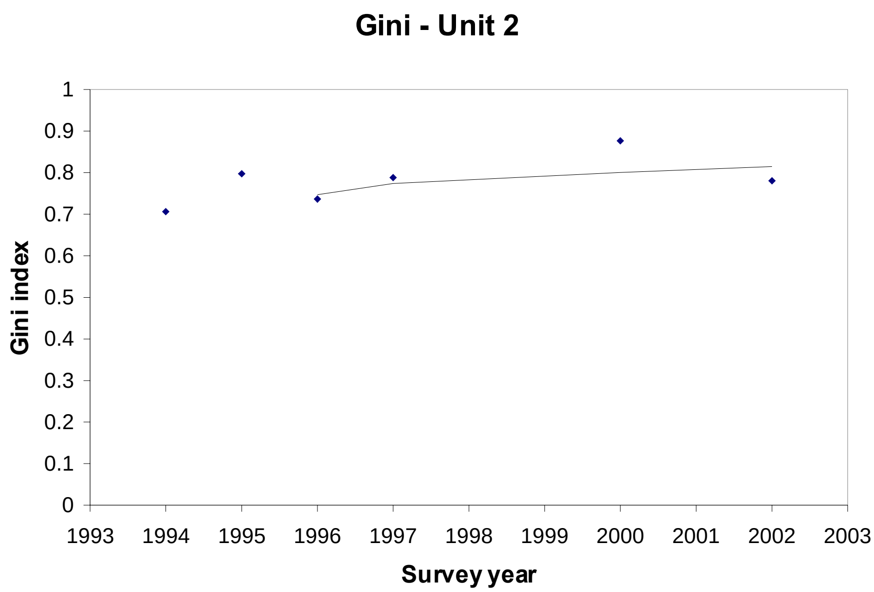
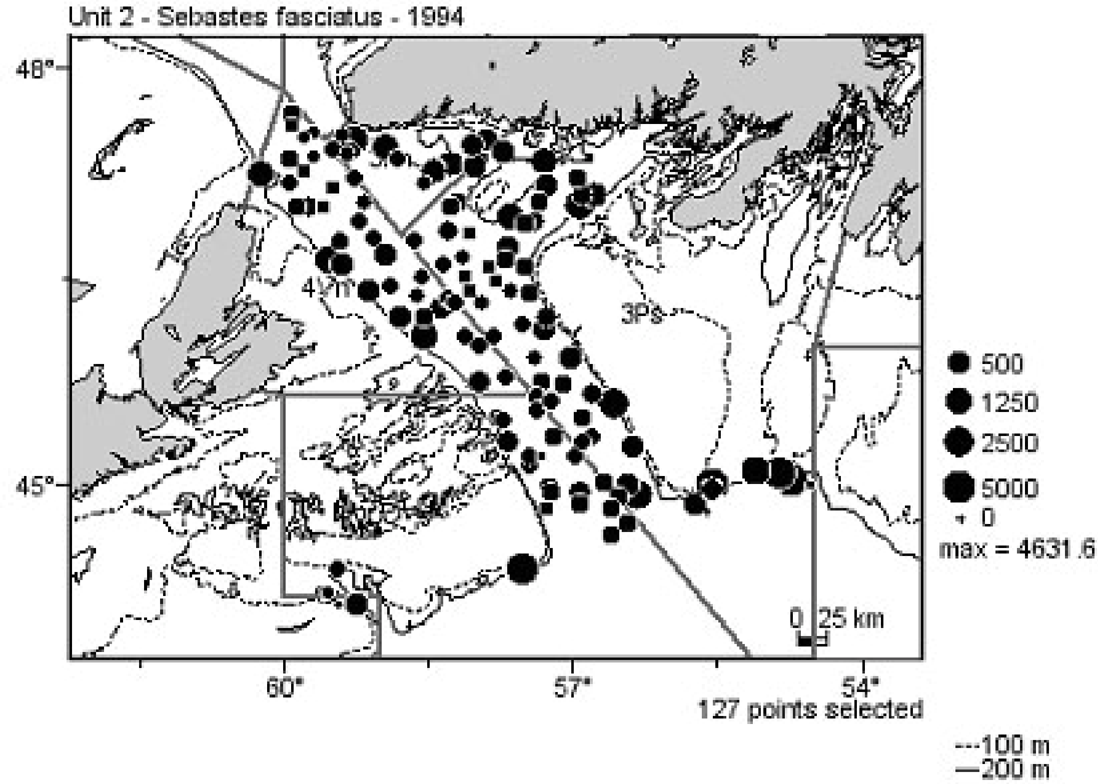


Figure 26. Indices of concentration of *S. mentella* in Unit 2



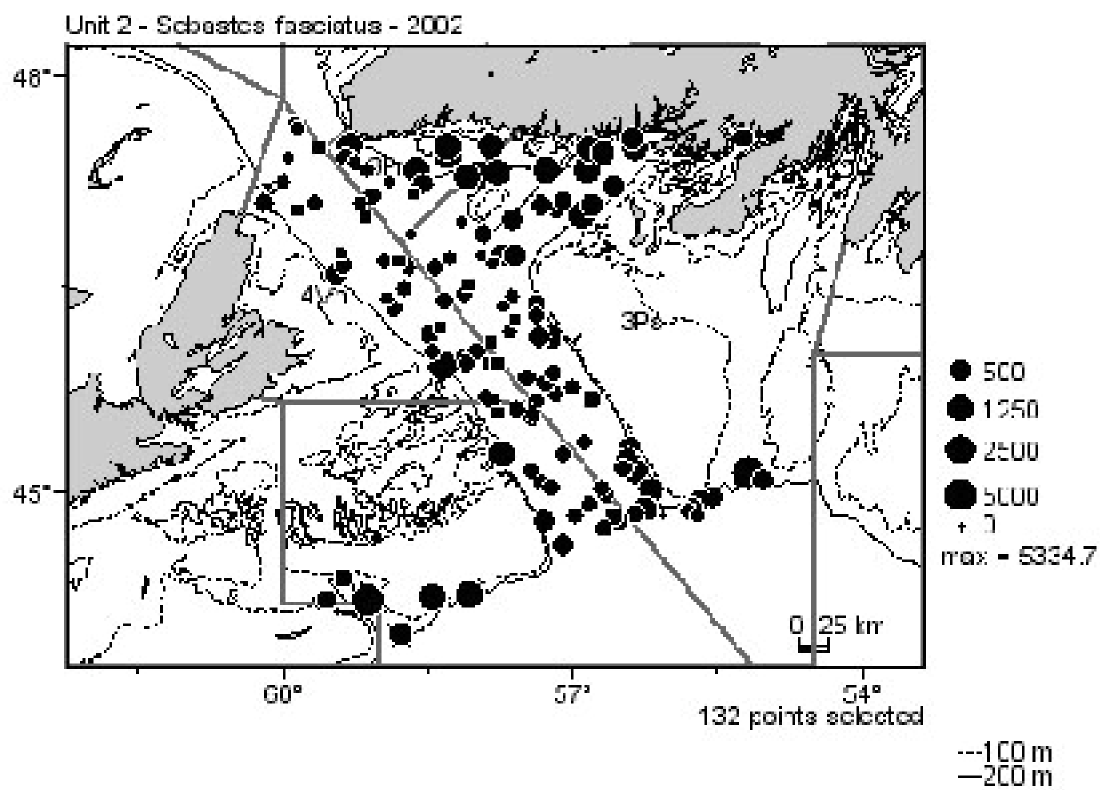
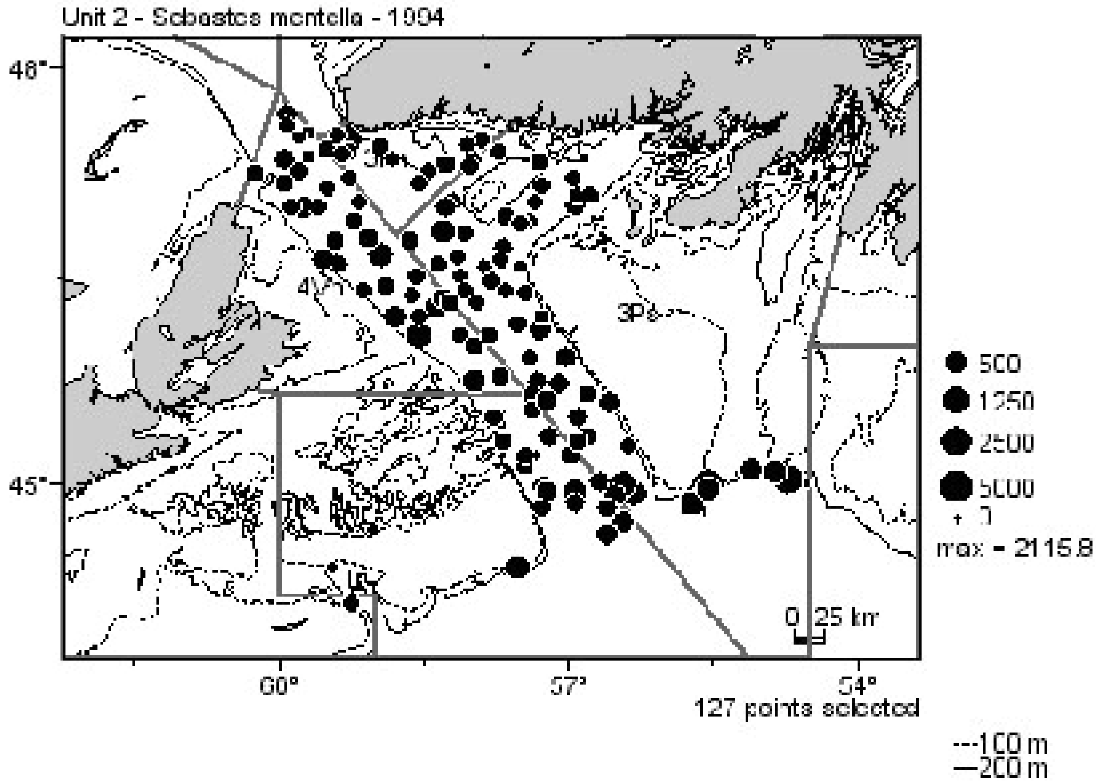


Figure 27. Distribution of the catches of *S. fasciatus* (in number) in 1994 and 2002 in Unit 2



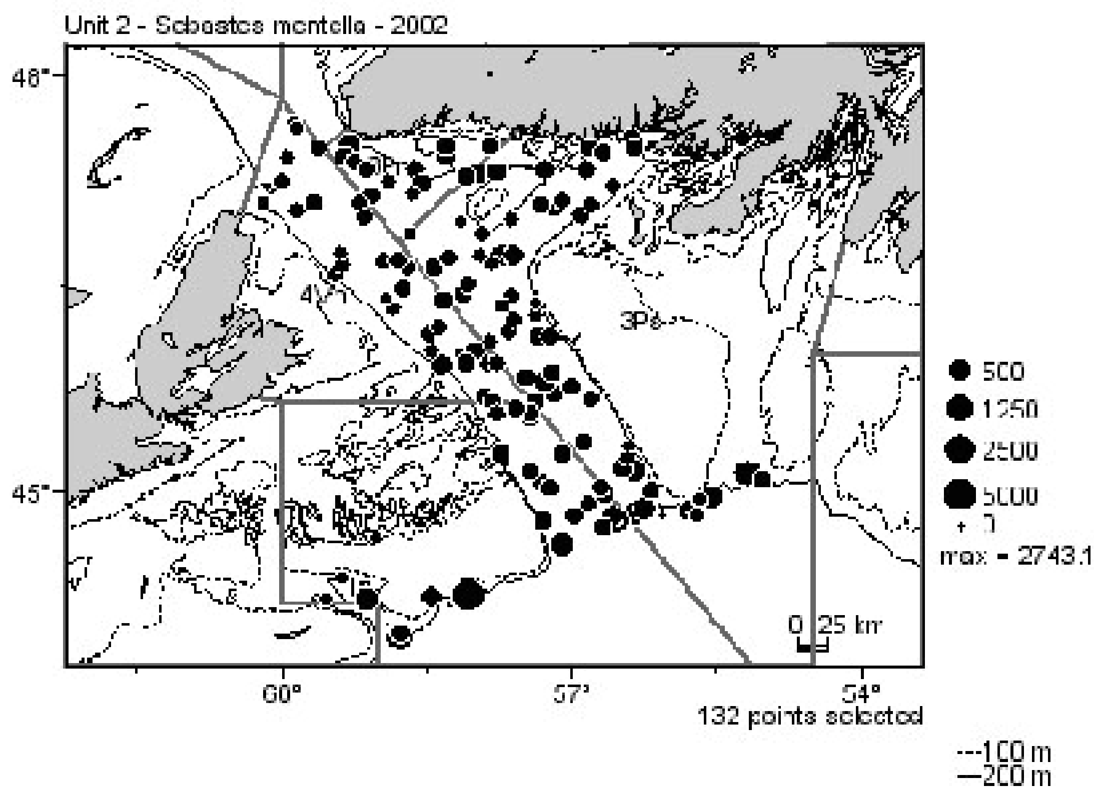
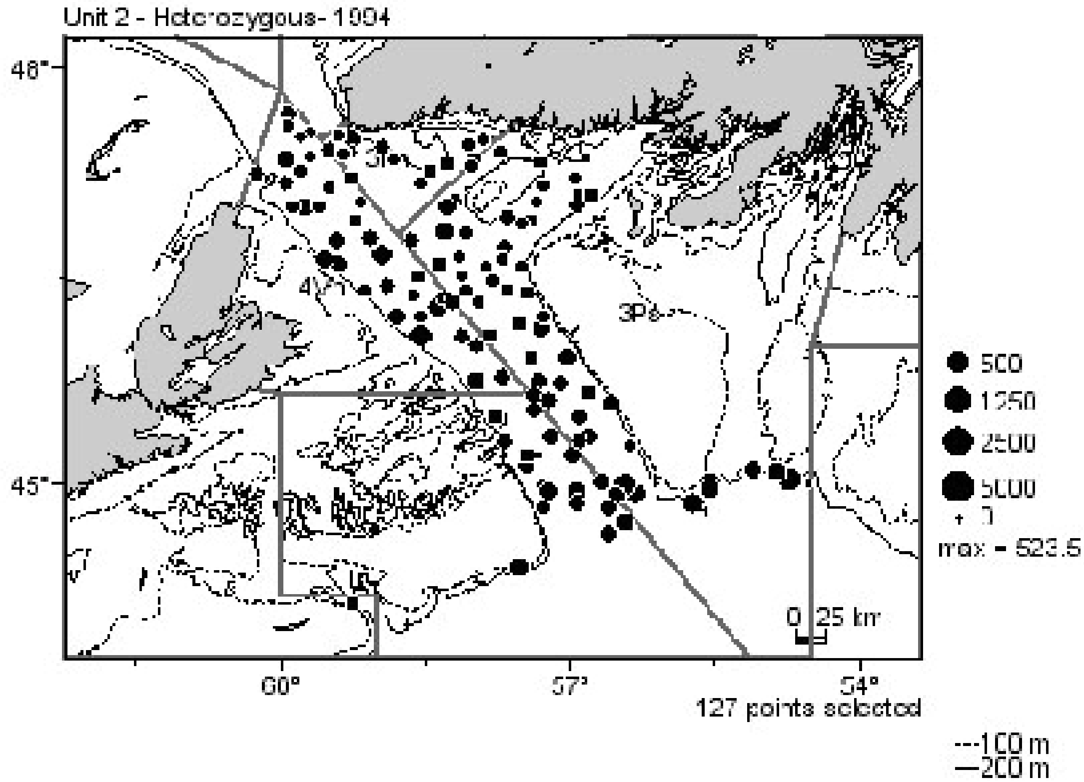


Figure 28. Distribution of the catches of *S. mentella* (in number) in 1994 and 2002 in Unit 2



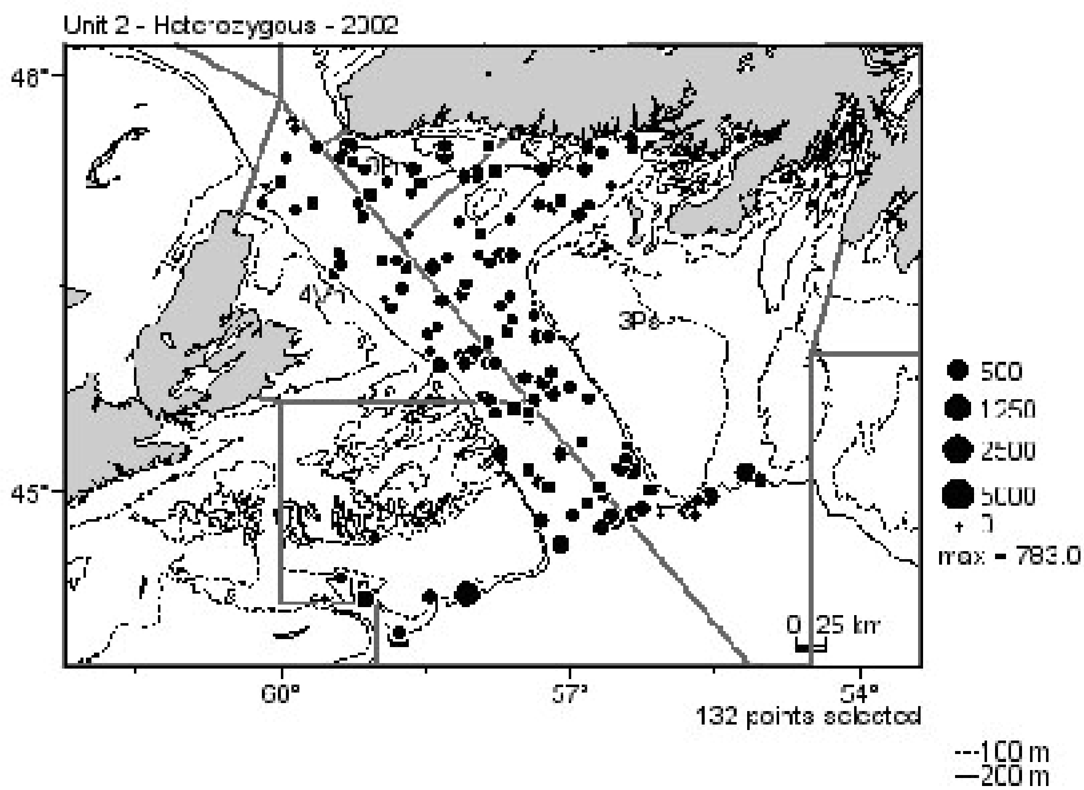


Figure 29. Distribution of the catches of redfish heterozygous (in number) in 1994 and 2002 in Unit 2

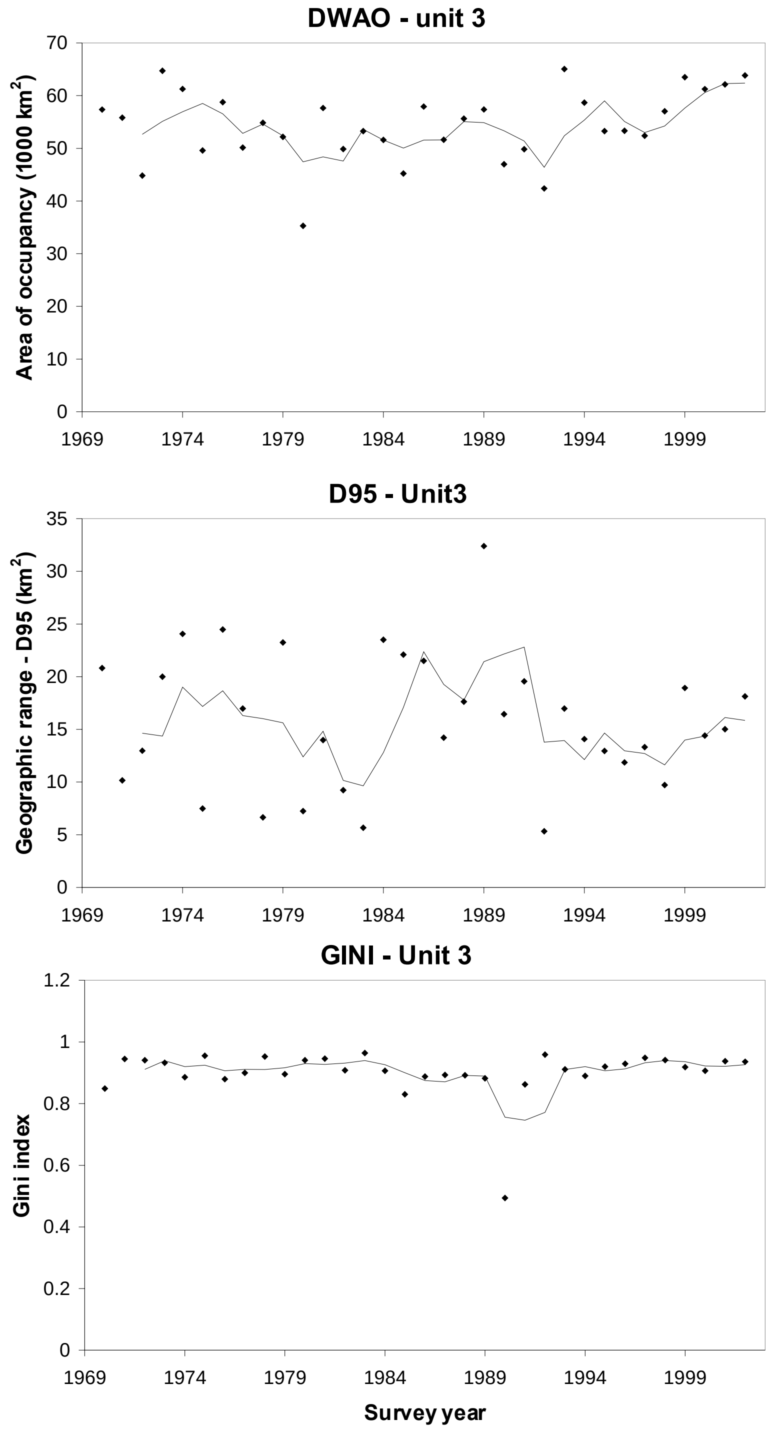


Figure 30. Indices of distribution and concentration of *S. fasciatus* in Unit 3

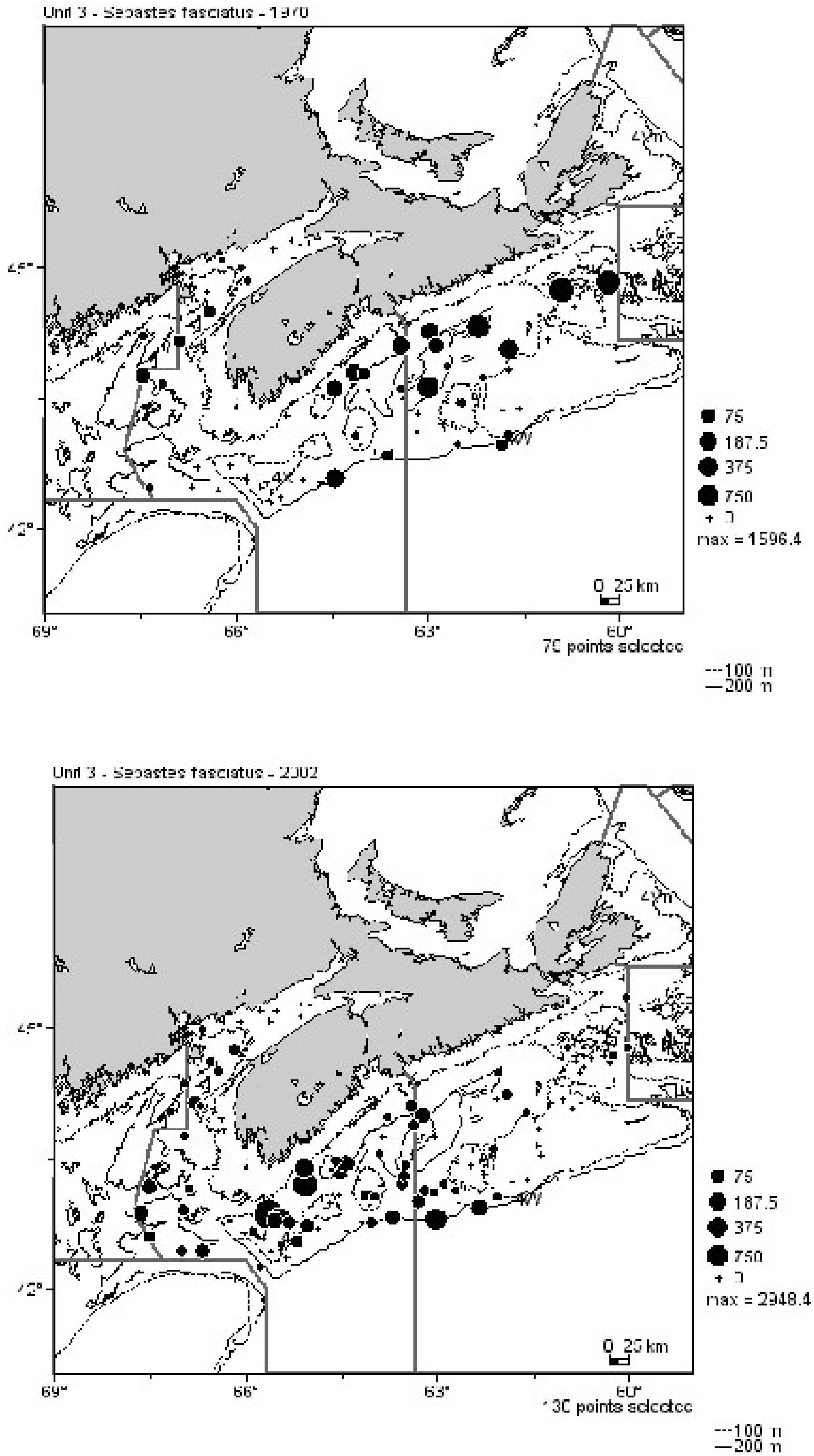


Figure 31. Distribution of the catches of *S. fasciatus* (in number) in 1970 and 2002 in Unit 3

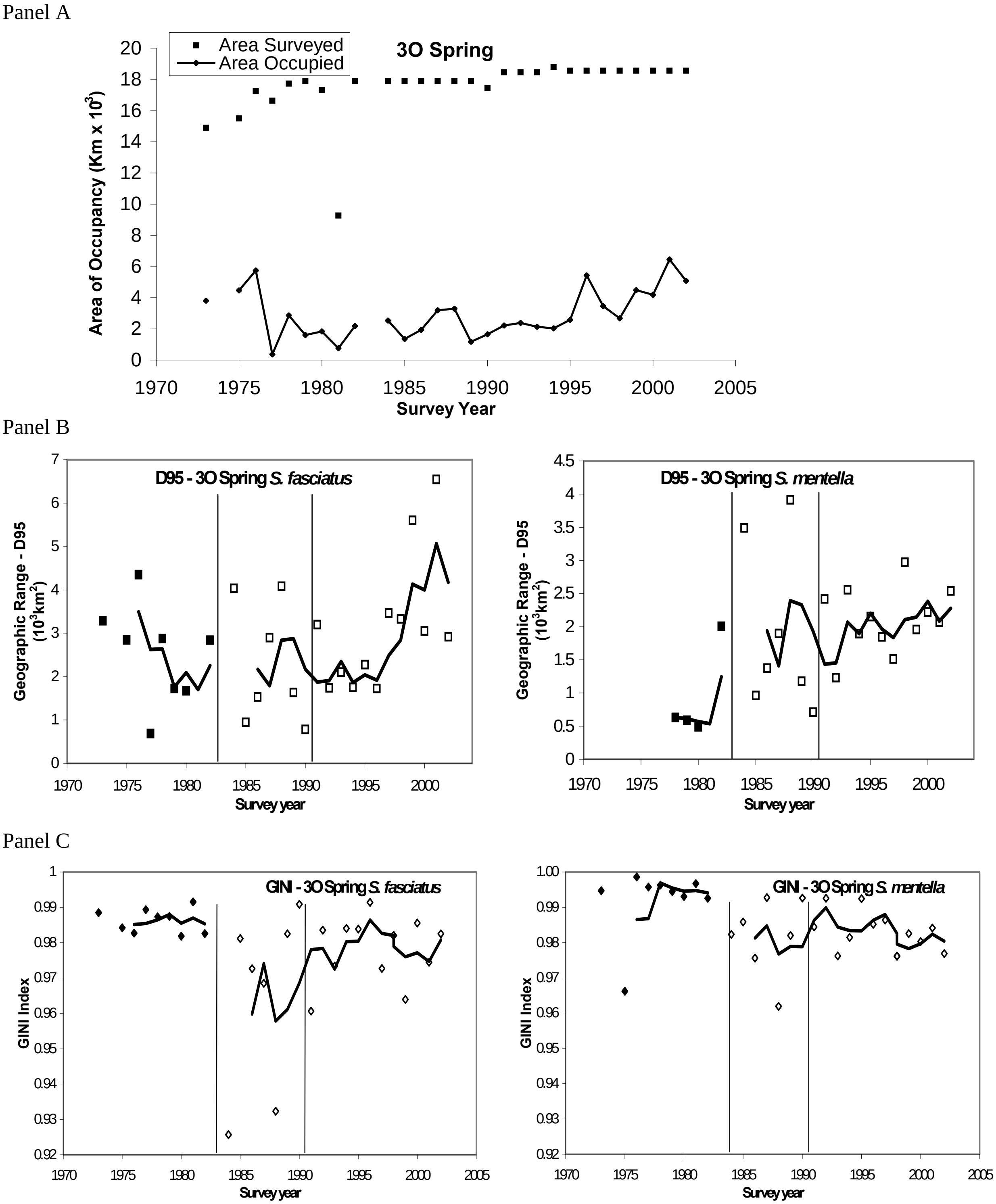
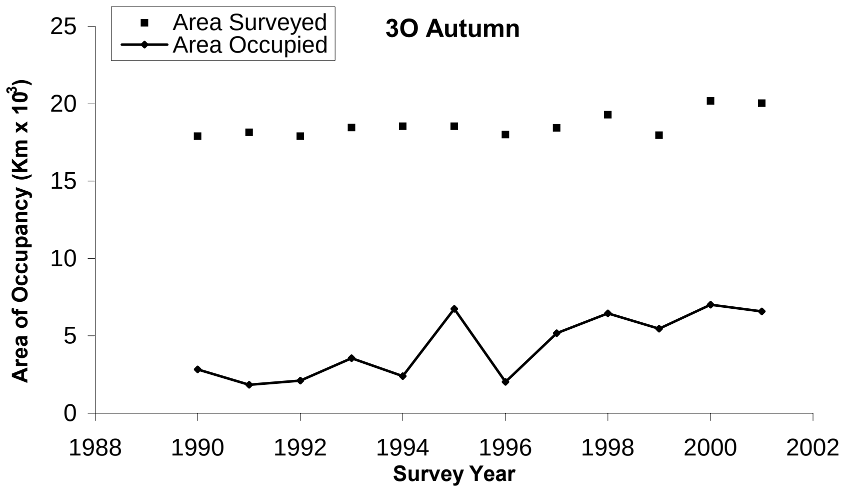
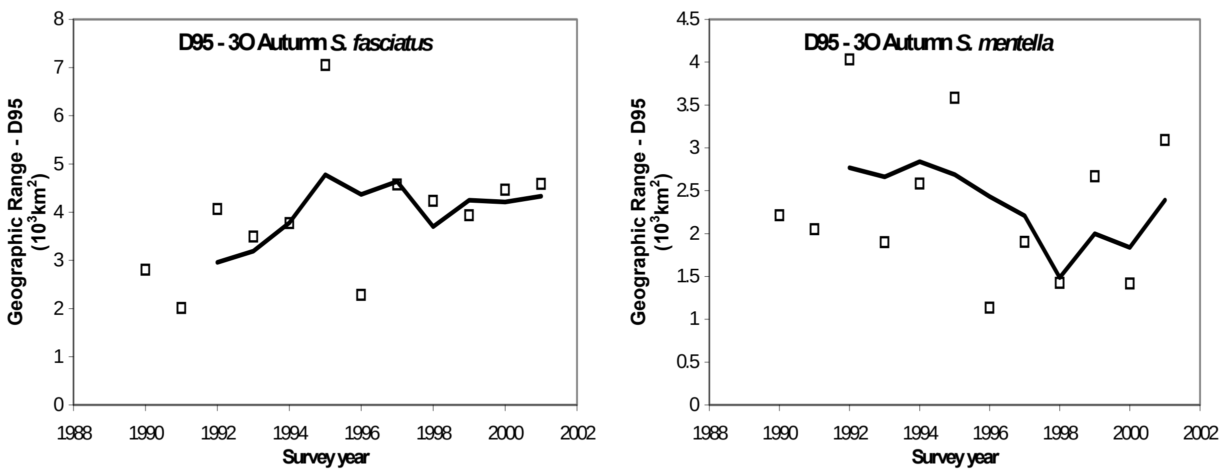


Figure 32. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in Division 3O from spring surveys from 1973-2002. Surveys from 1973-1982 were to 200 fathoms (367m) with a Yankee 41-5 otter trawl, surveys from 1984-1990 were to 200 fathoms (367m) with an Engel 145 trawl (converted to Campelen units) and surveys from 1991-2002 were to 400 fathoms (732m) with a Campelen trawl.

Panel A



Panel B



Panel C

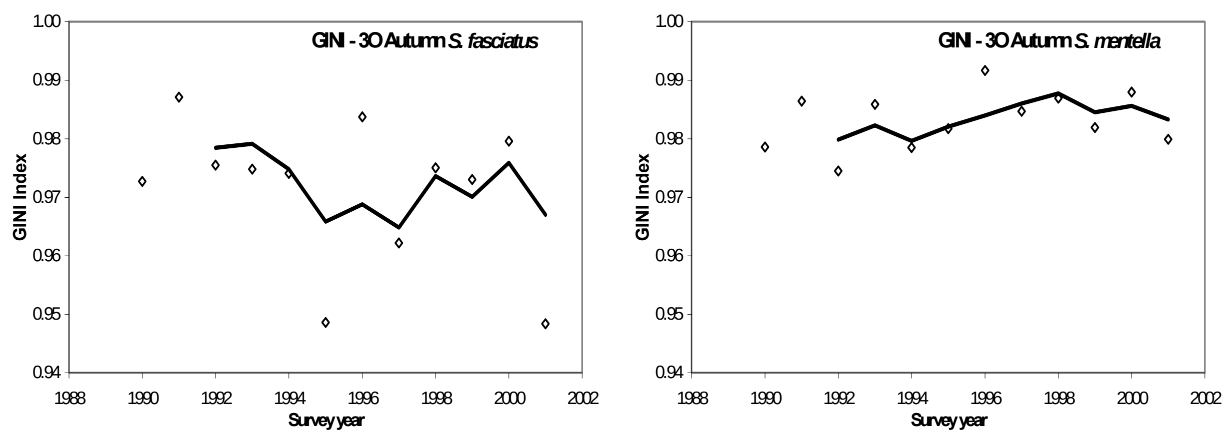


Figure 33. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in Division 3O from autumn surveys from 1990-2001. Surveys from 1990-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1995-2001 utilized a Campelen trawl. All surveys were to a maximum of 400 fathoms (732m).

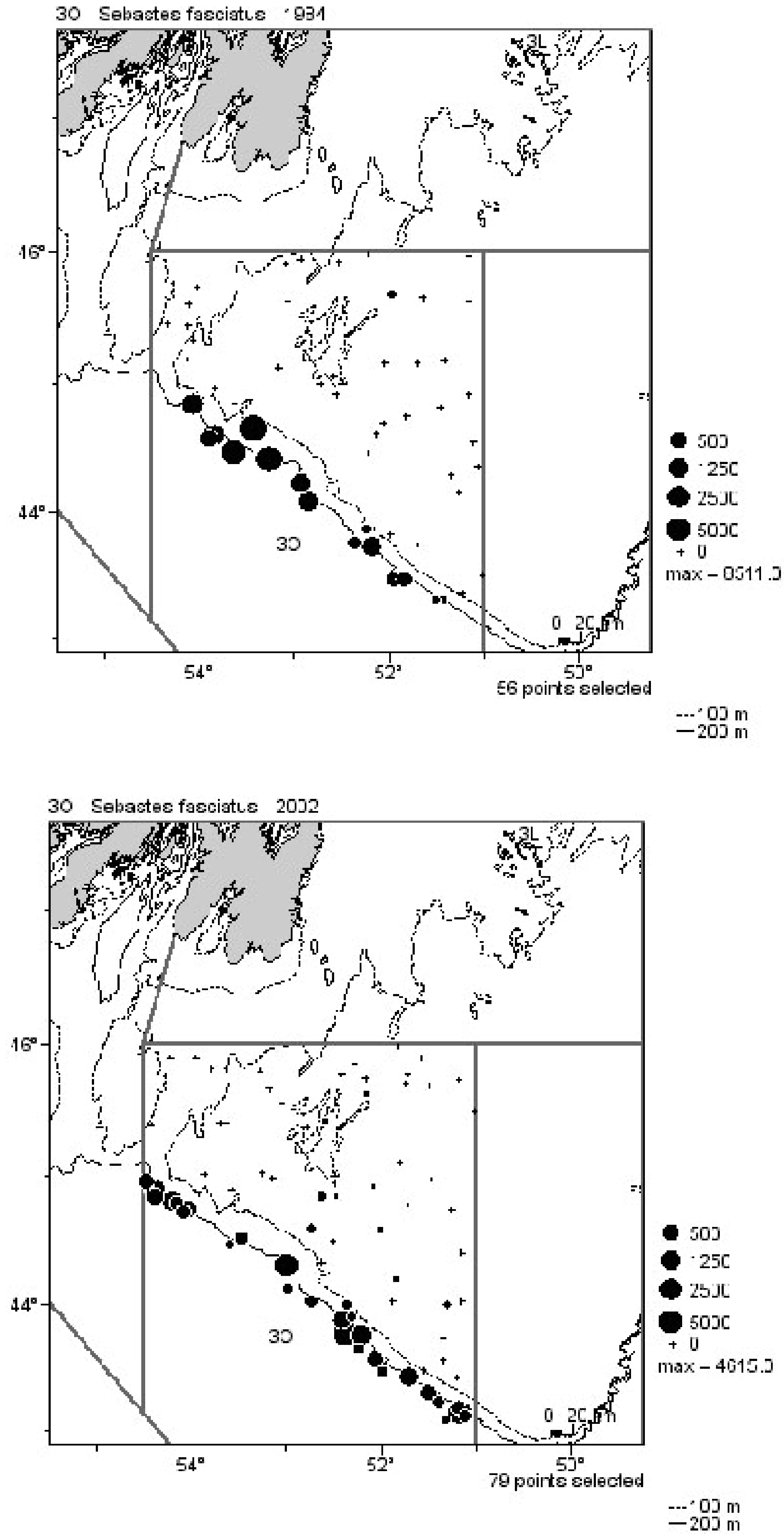


Figure 34. Distribution of the catches of *S. fasciatus* (in number) in 3O from spring surveys in 1984 and 2002.

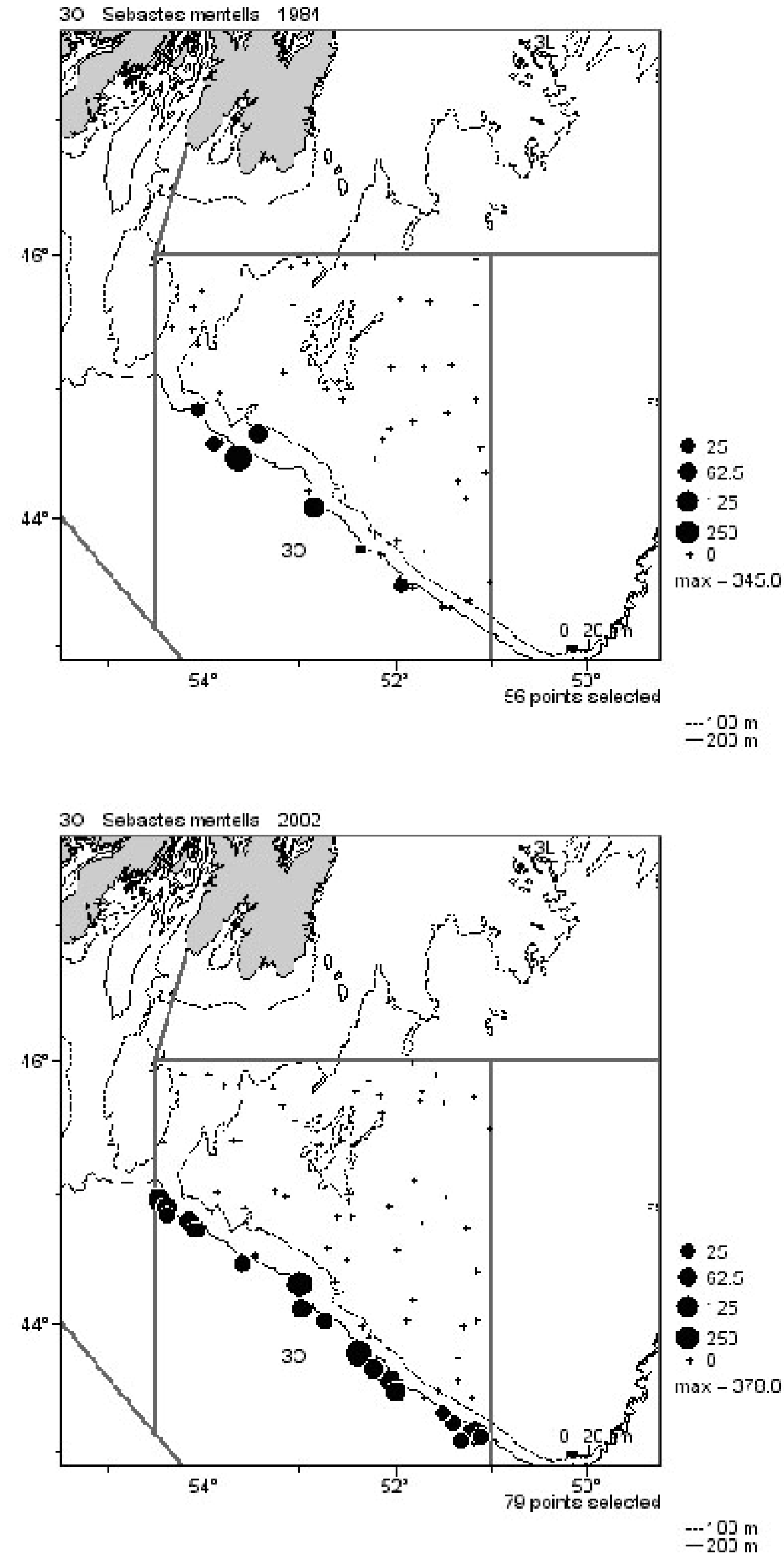
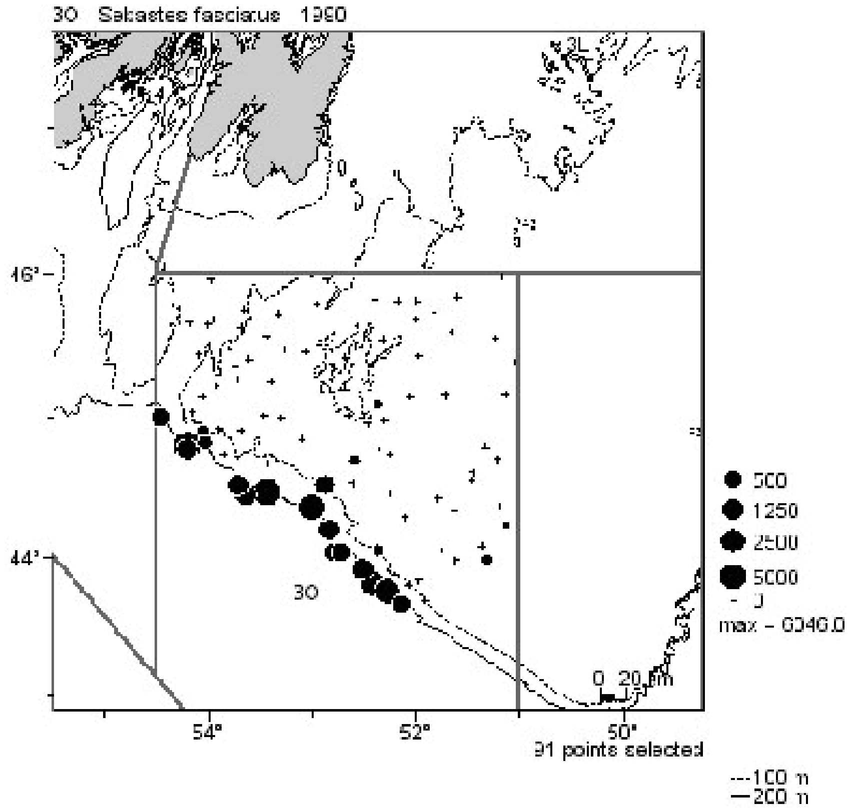


Figure 35. Distribution of the catches of *S. mentella* (in number) in 3O from spring surveys in 1984 and 2002.



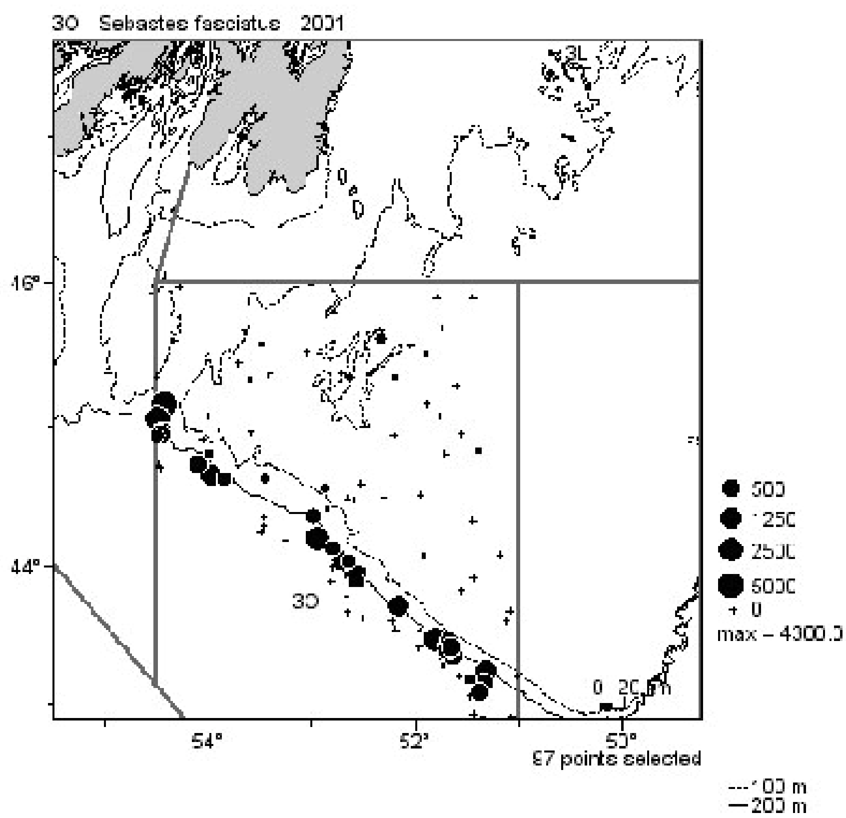
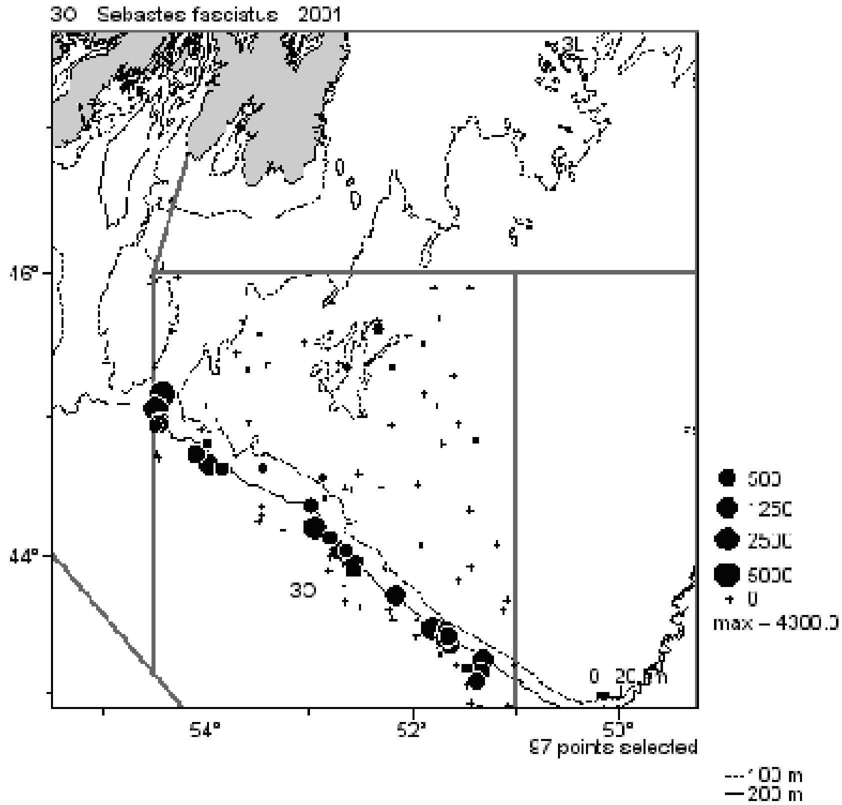


Figure 36. Distribution of the catches of *S. fasciatus* (in number) in 3O from autumn surveys in 1990 and 2001.



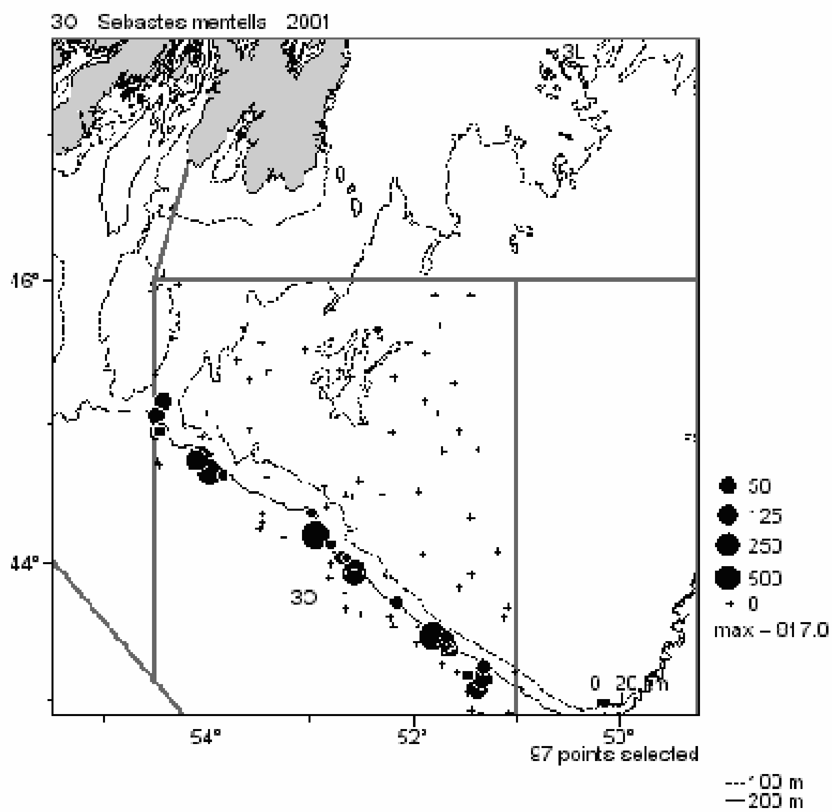
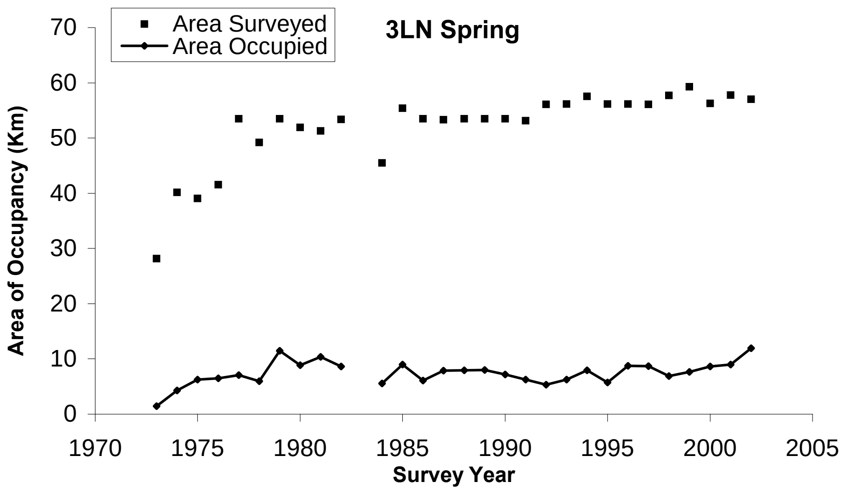
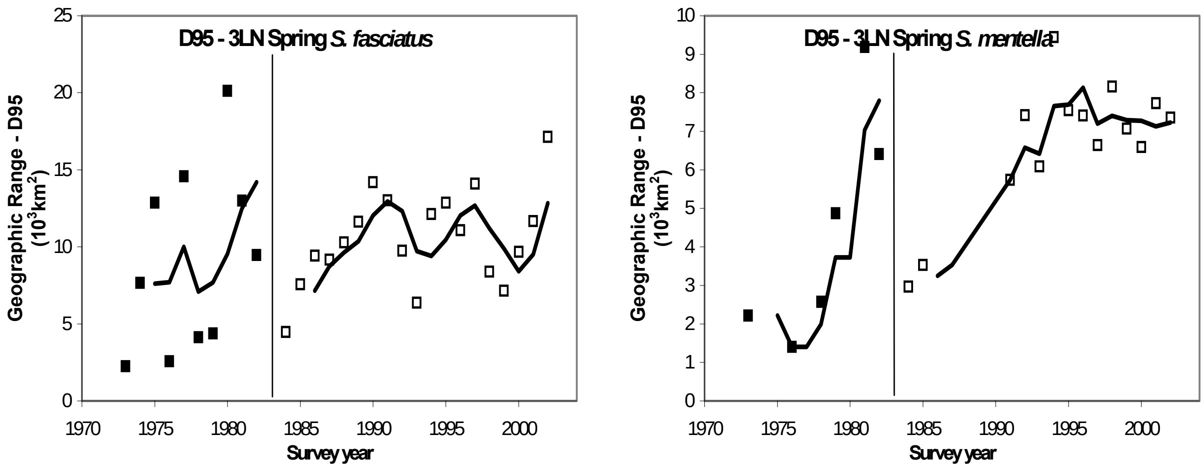


Figure 37. Distribution of the catches of *S. mentella* (in number) in 3O from autumn surveys in 1990 and 2001.

Panel A



Panel B



Panel C

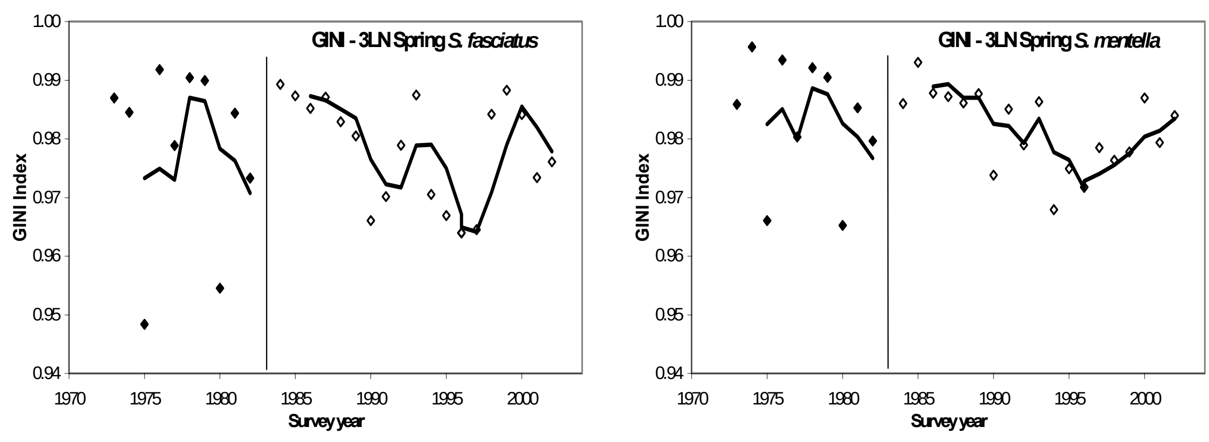
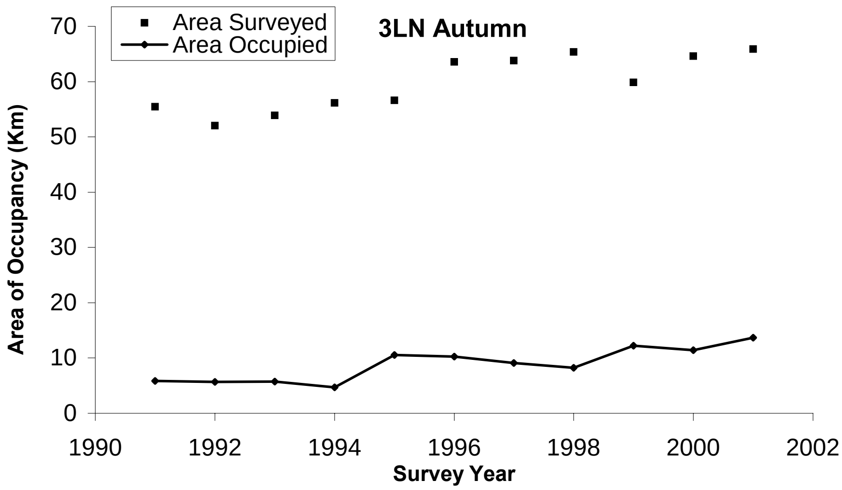
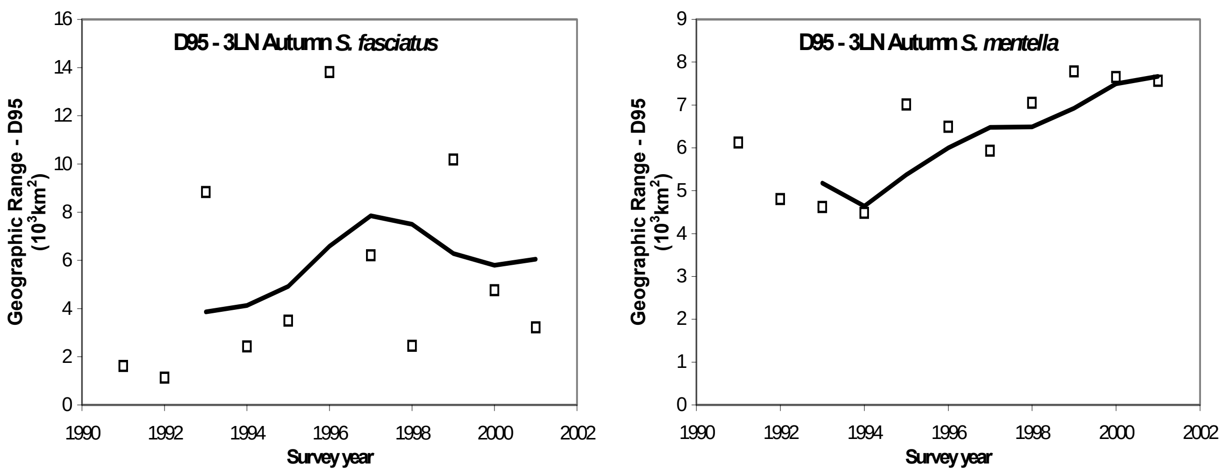


Figure 38. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of Sebastes fasciatus and S. mentella in Division 3LN from spring surveys from 1973-2002. Surveys from 1973-1982 were to 200 fathoms (367m) with a Yankee 41-5 otter trawl, surveys from 1984-1990 were to 200 fathoms (367m) with an Engel 145 trawl (converted to Campelen units) and surveys from 1991-2002 were to 400 fathoms (732m) with a Campelen trawl.

Panel A



Panel B



Panel C

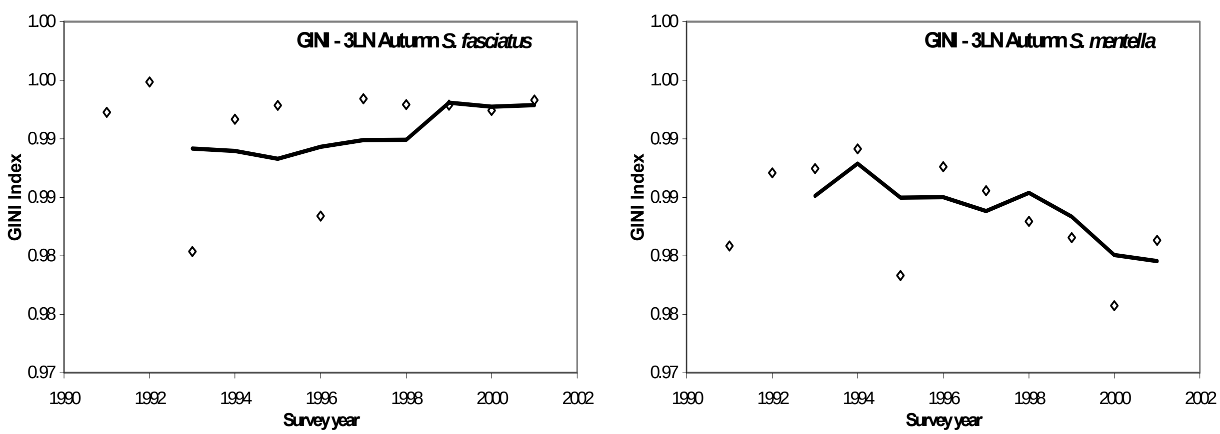


Figure 39. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of Sebastes fasciatus and S. mentella in Division 3LN from autumn surveys from 1991-2001. Surveys from 1991-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1995-2001 utilized a Campelen trawl. All surveys were to a maximum of 400 fathoms (732m).

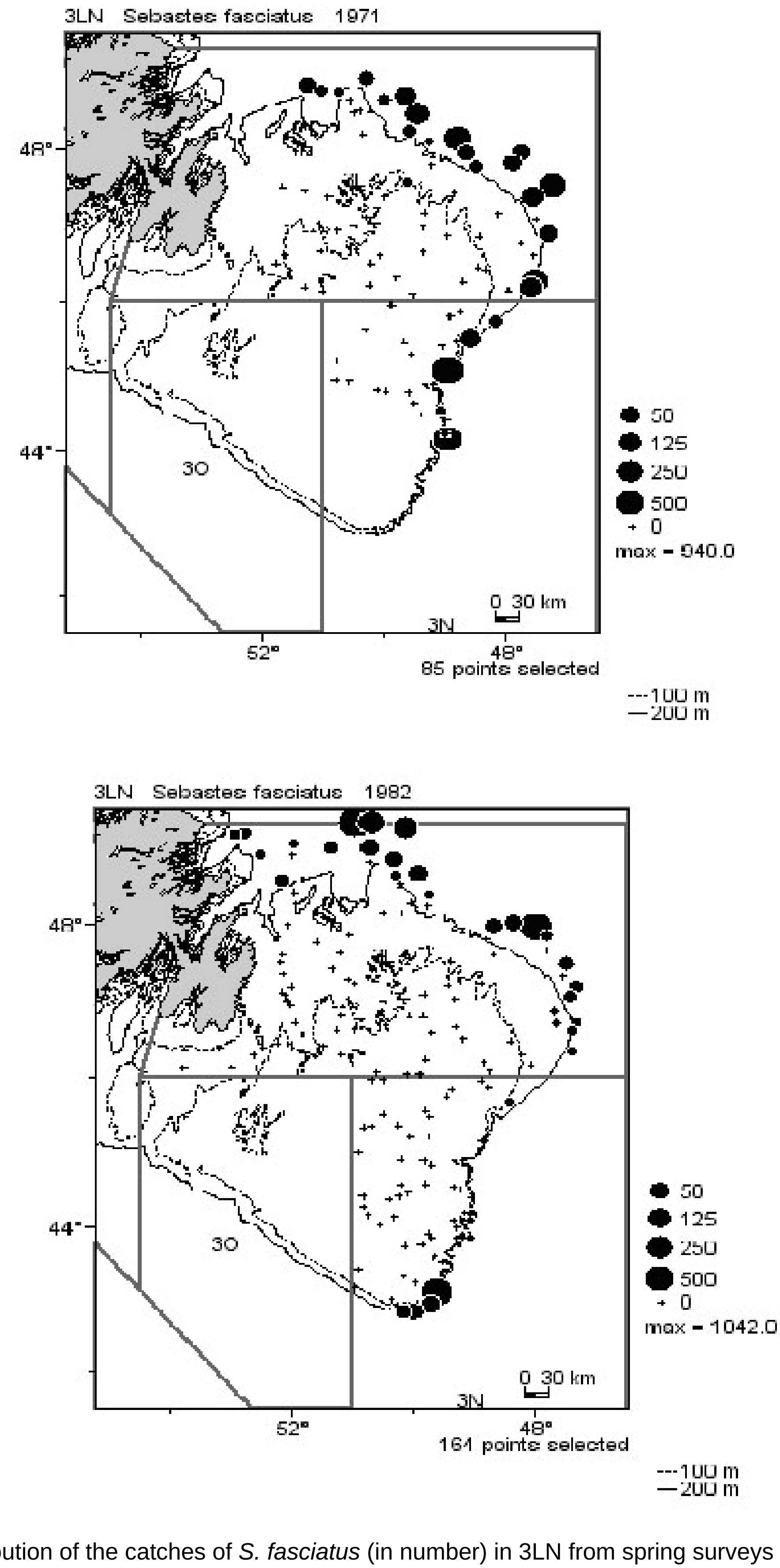


Figure 40. Distribution of the catches of *S. fasciatus* (in number) in 3LN from spring surveys in 1971 and 1982.

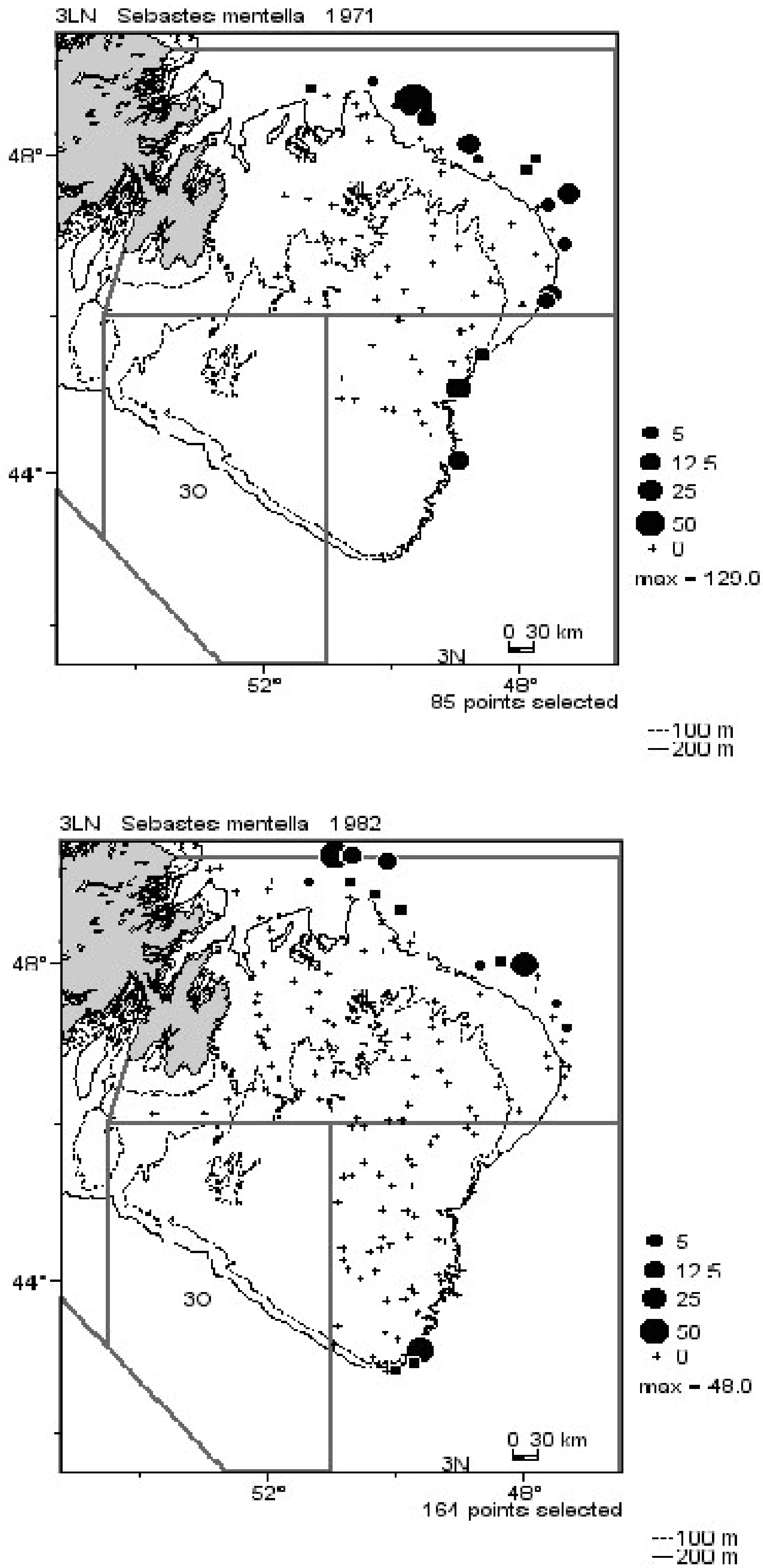
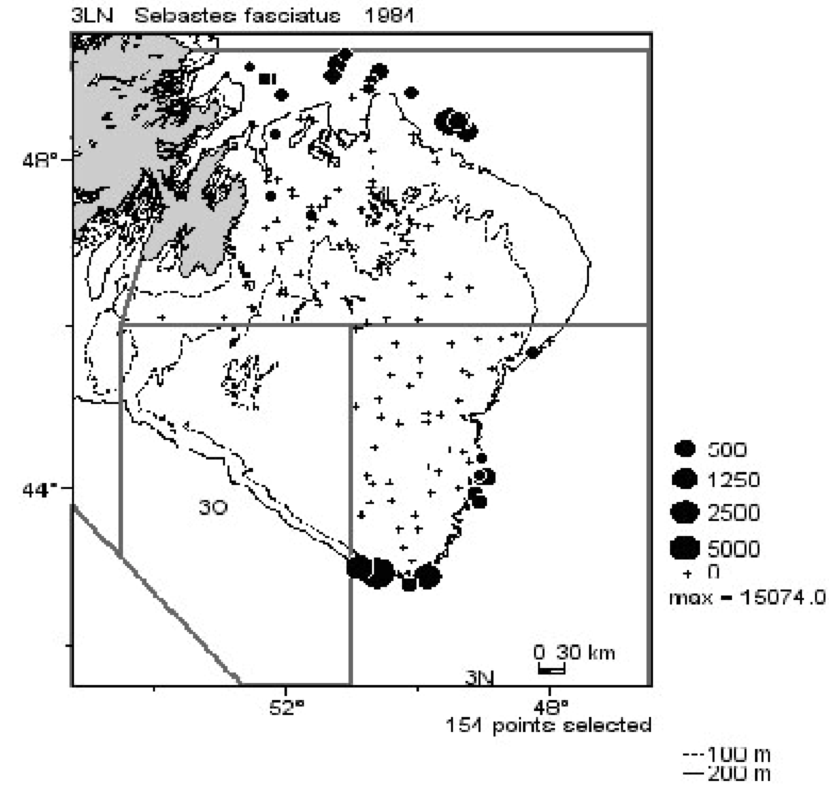


Figure 41. Distribution of the catches of *S. mentella* (in number) in 3LN from spring surveys in 1971 and 1982.



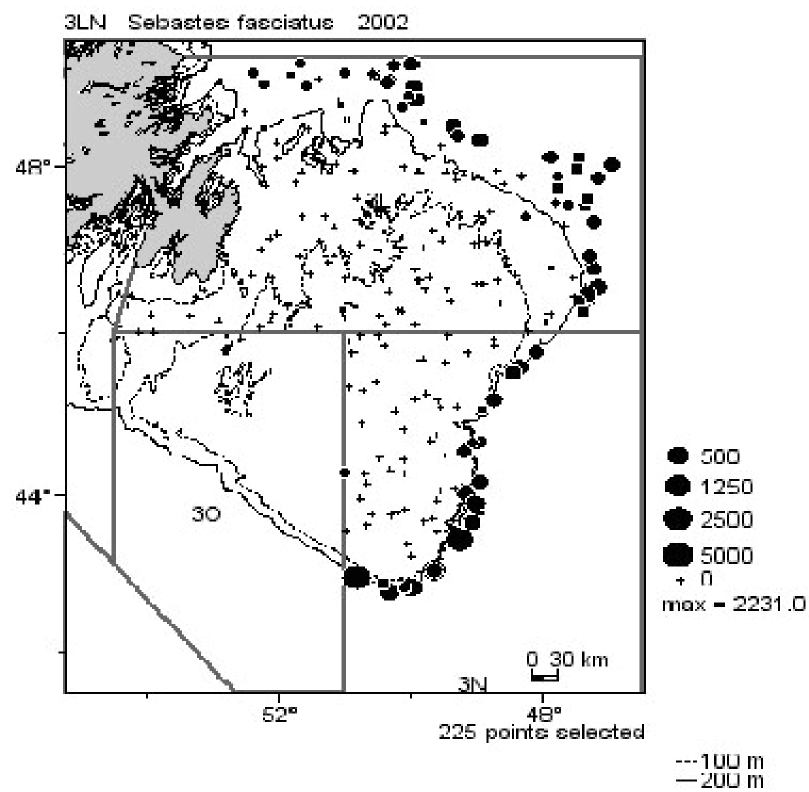
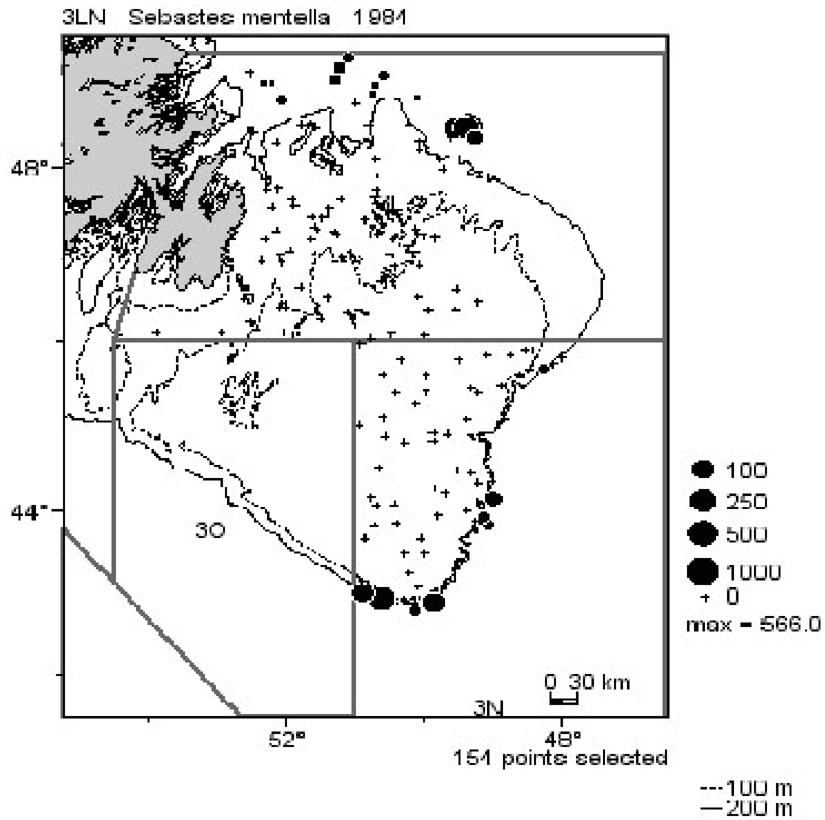


Figure 42. Distribution of the catches of *S. fasciatus* (in number) in 3LN from spring surveys in 1984 and 2002.



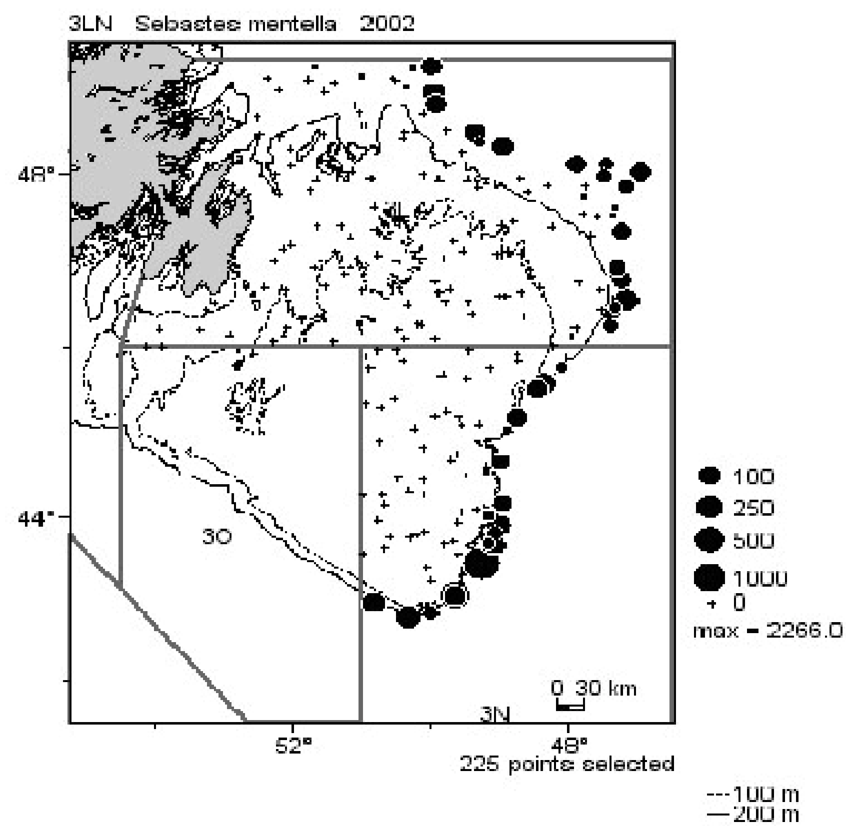
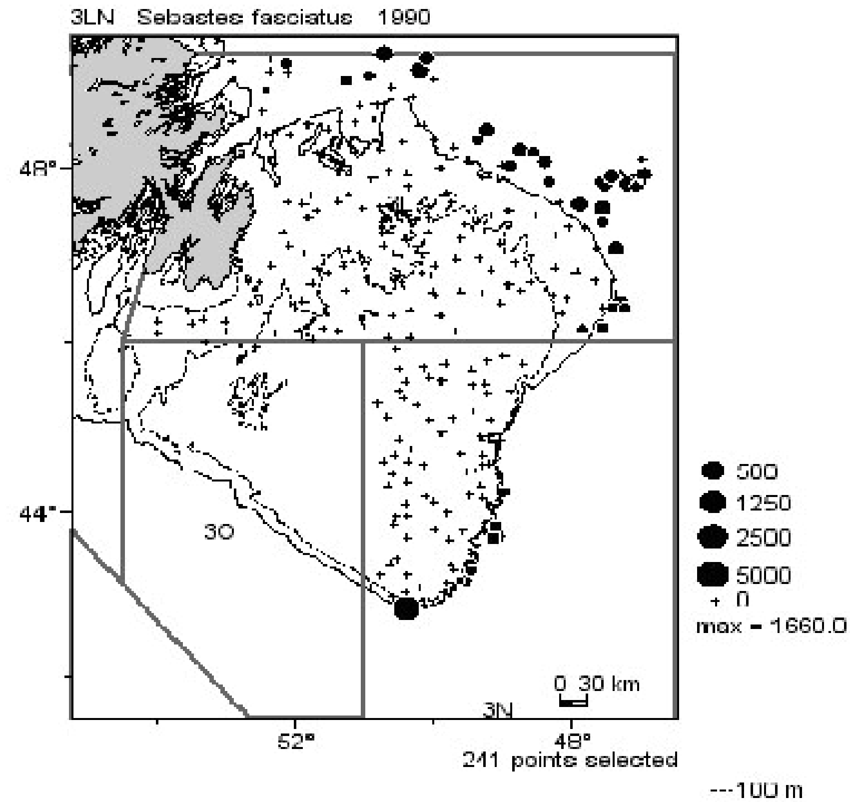


Figure 43. Distribution of the catches of *S. mentella* (in number) in 3LN from spring surveys in 1984 and 2002.



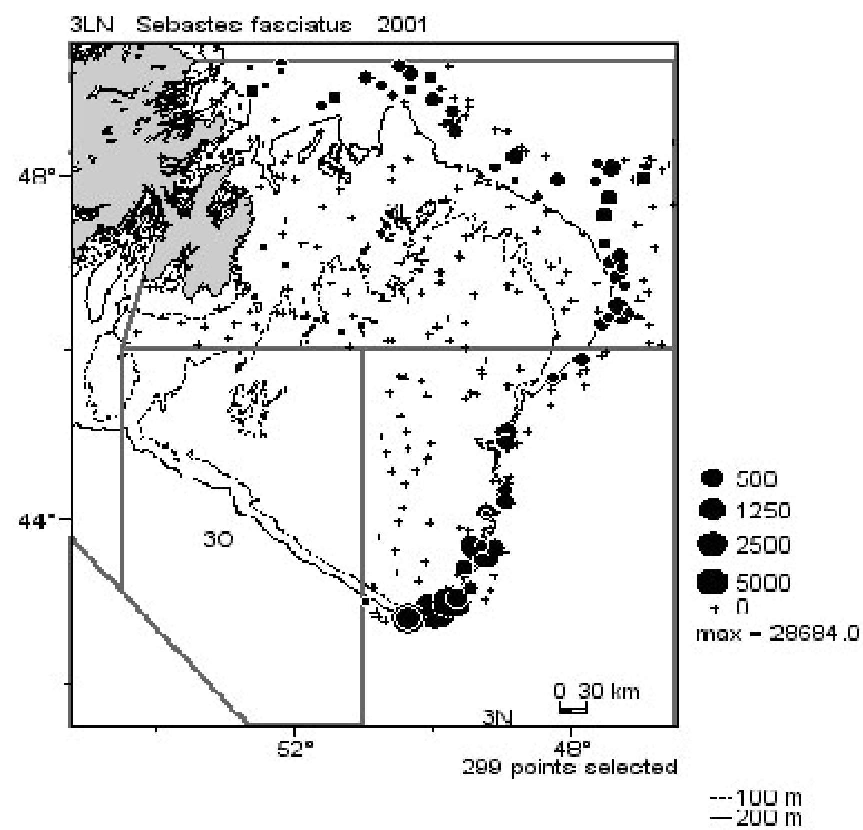
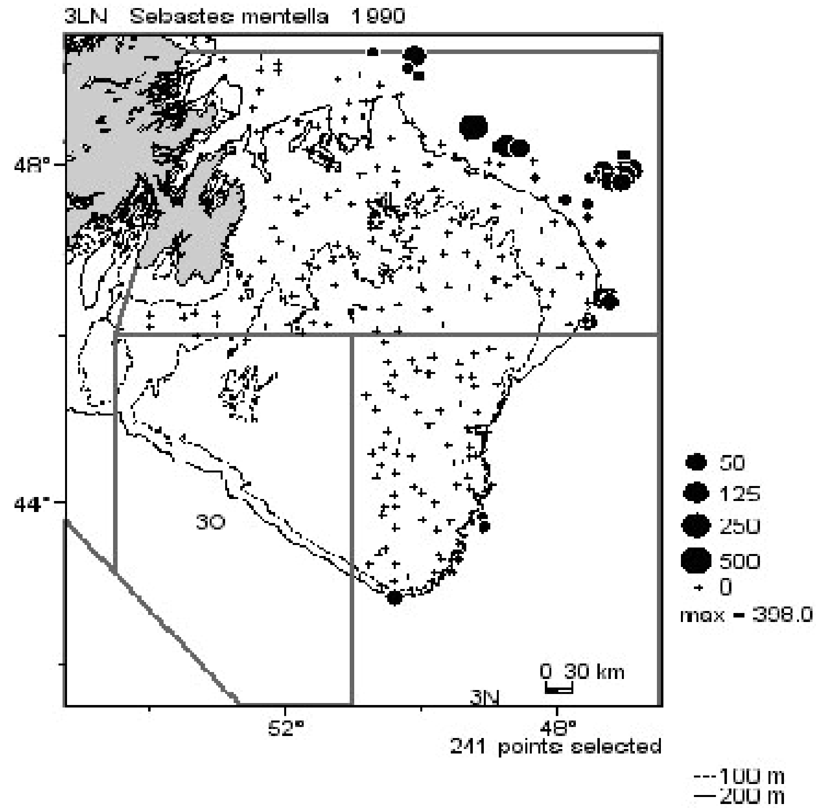


Figure 44. Distribution of the catches of *S. fasciatus* (in number) in 3LN from autumn surveys in 1990 and 2001.



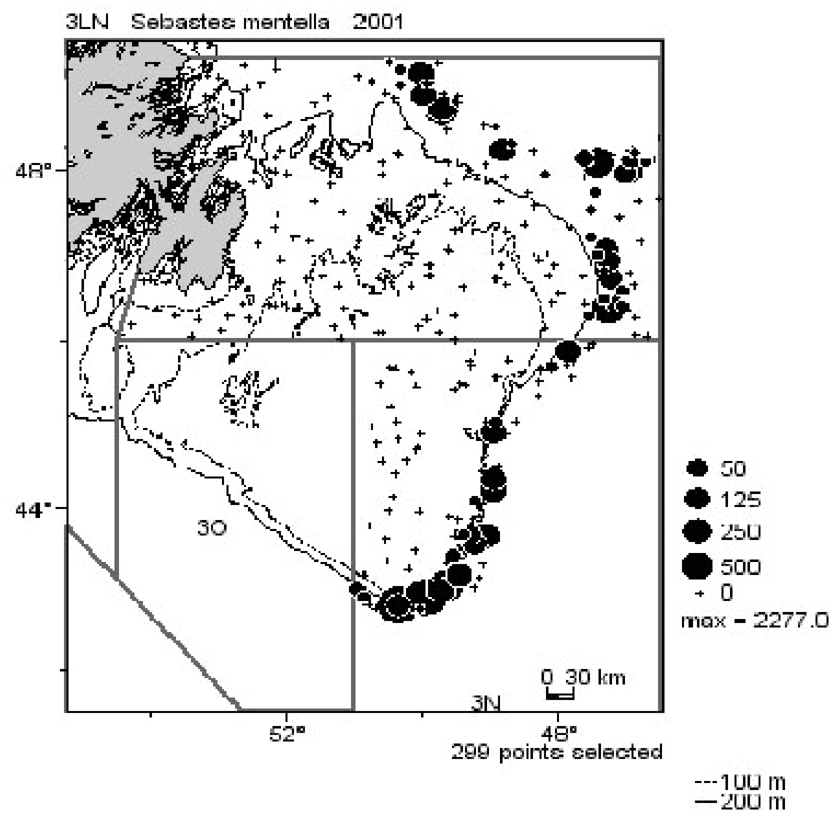
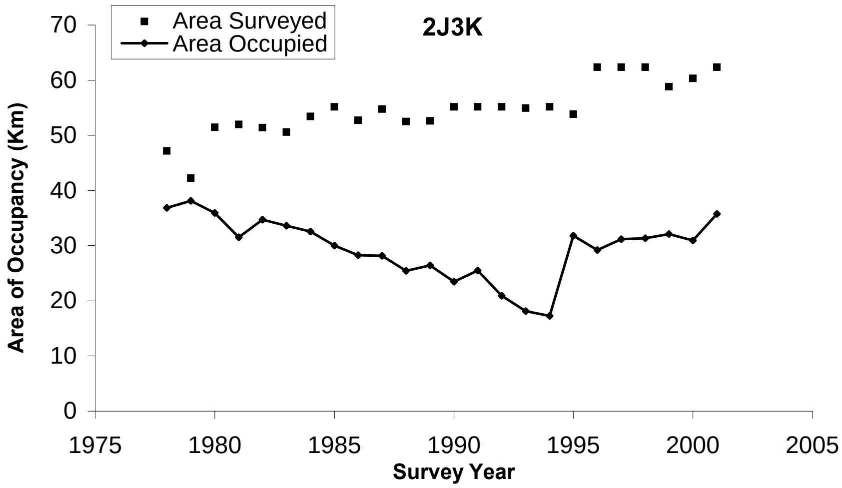
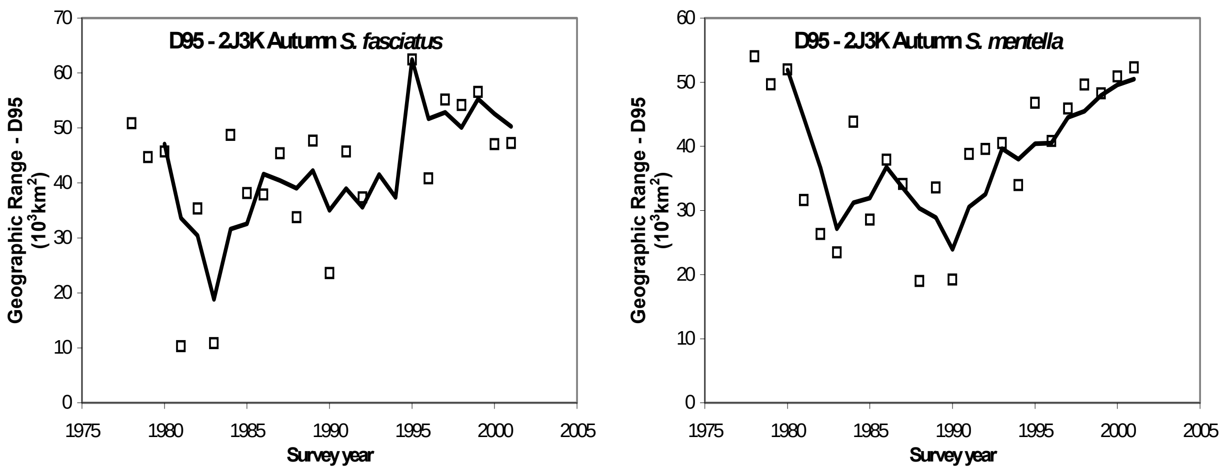


Figure 45. Distribution of the catches of *S. mentella* (in number) in 3LN from autumn surveys in 1990 and 2001.

Panel A



Panel B



Panel C

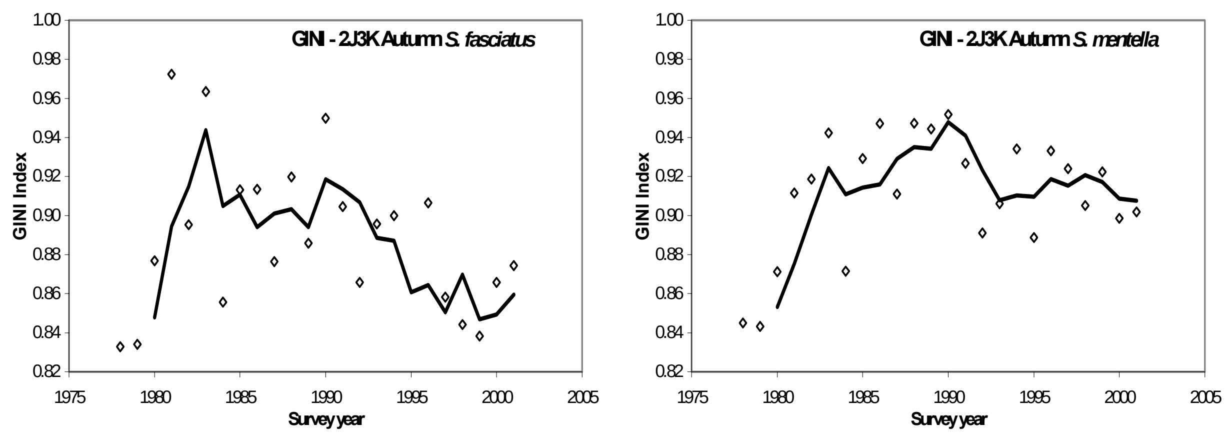


Figure 46. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in Division 2J3K from autumn surveys from 1978-2001. Surveys from 1978-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1995-2001 utilized a Campelen trawl. Surveys were to a maximum of 1000m to 1995 and to 1500m from 1996-2001.

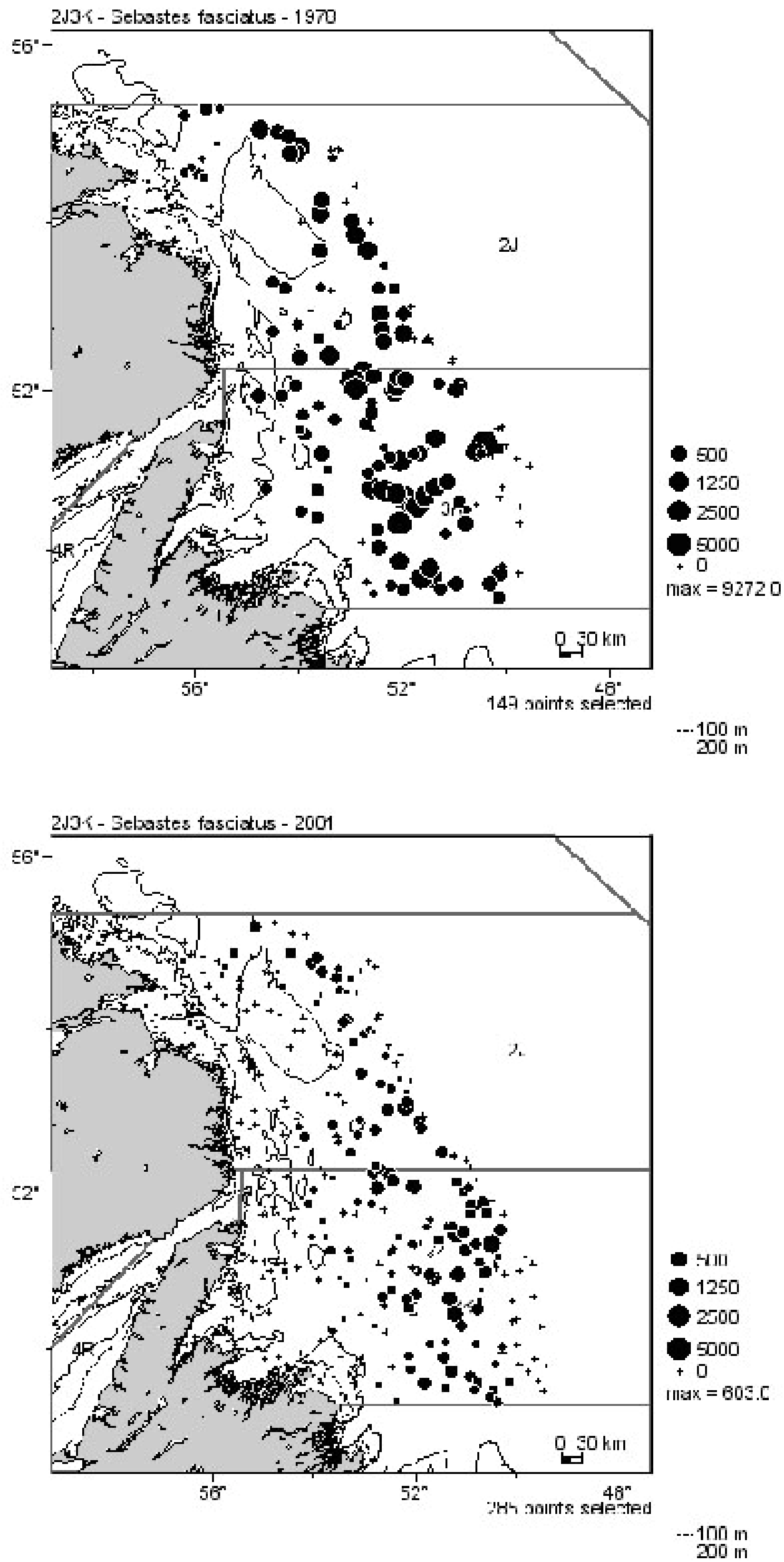


Figure 47. Distribution of the catches of *S. fasciatus* (in number) in 2J3K from autumn surveys in 1978 and 2001.

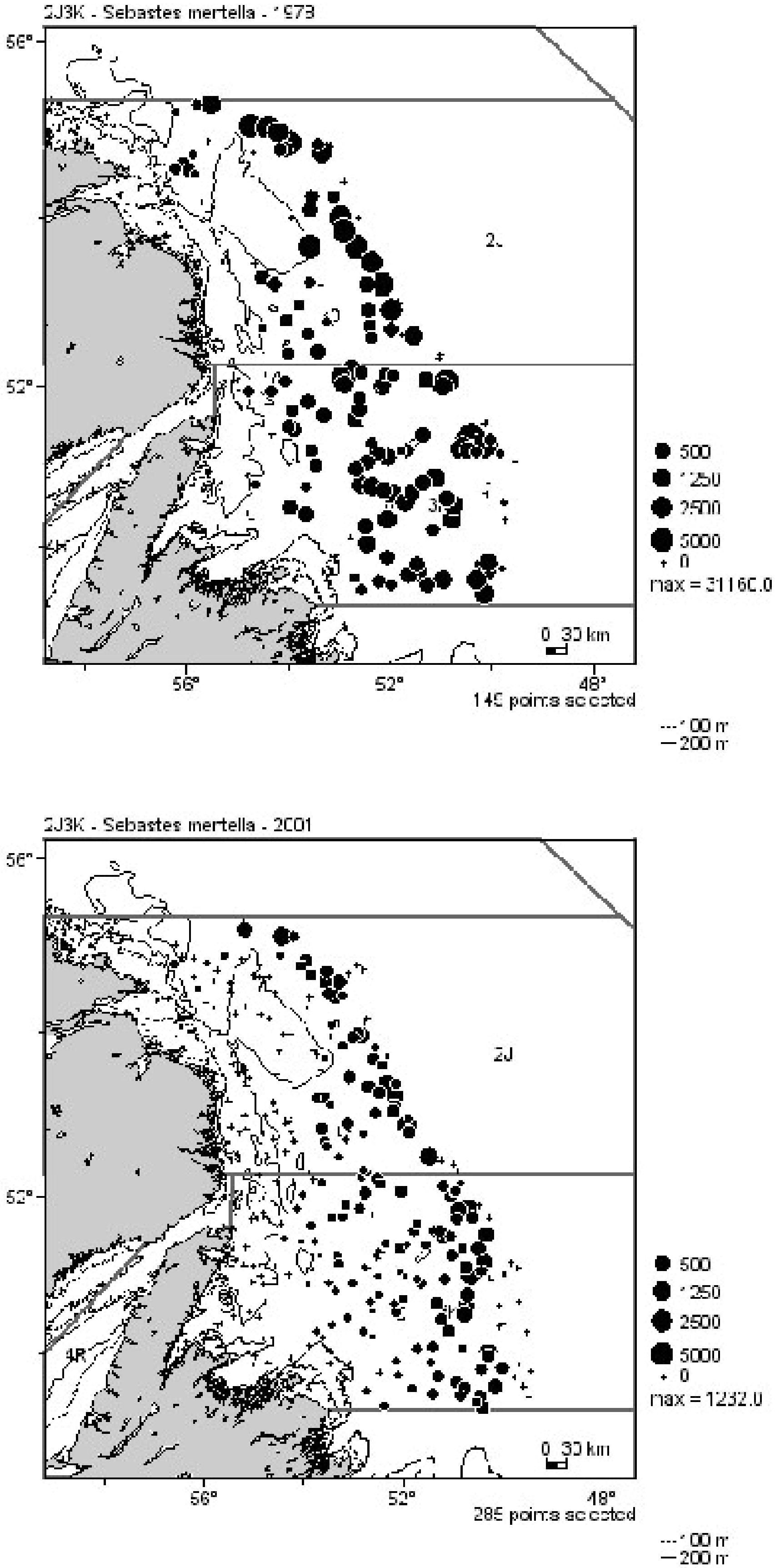
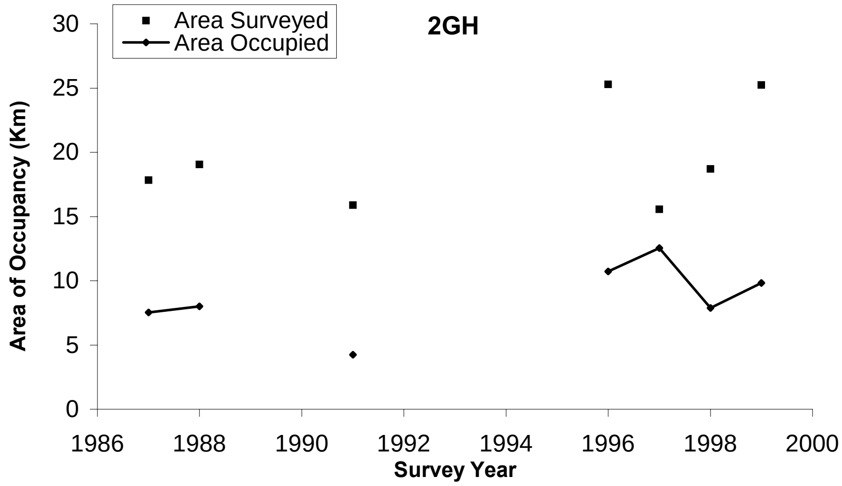
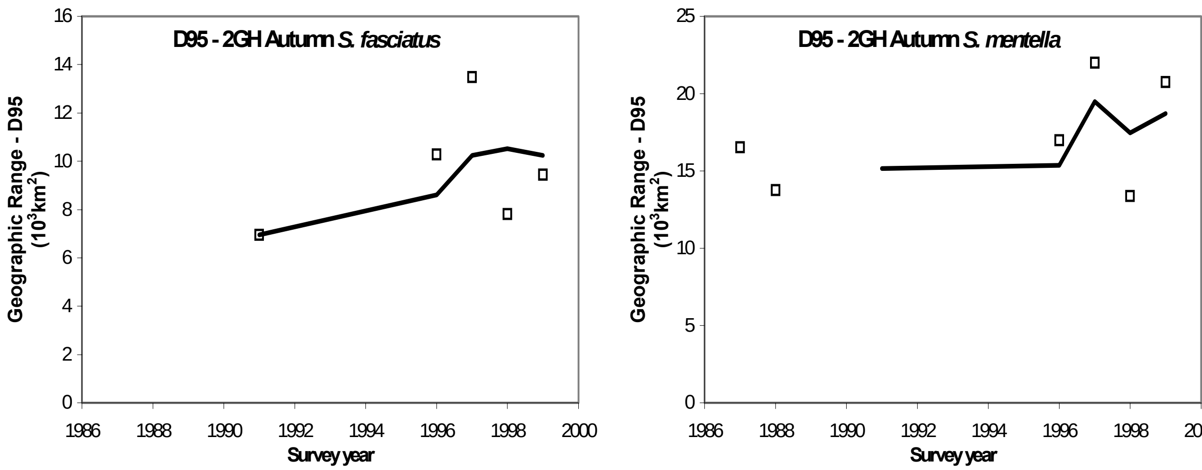


Figure 48. Distribution of the catches of *S. mentella* (in number) in 2J3K from autumn surveys in 1978 and 2001.

Panel A



Panel B



Panel C

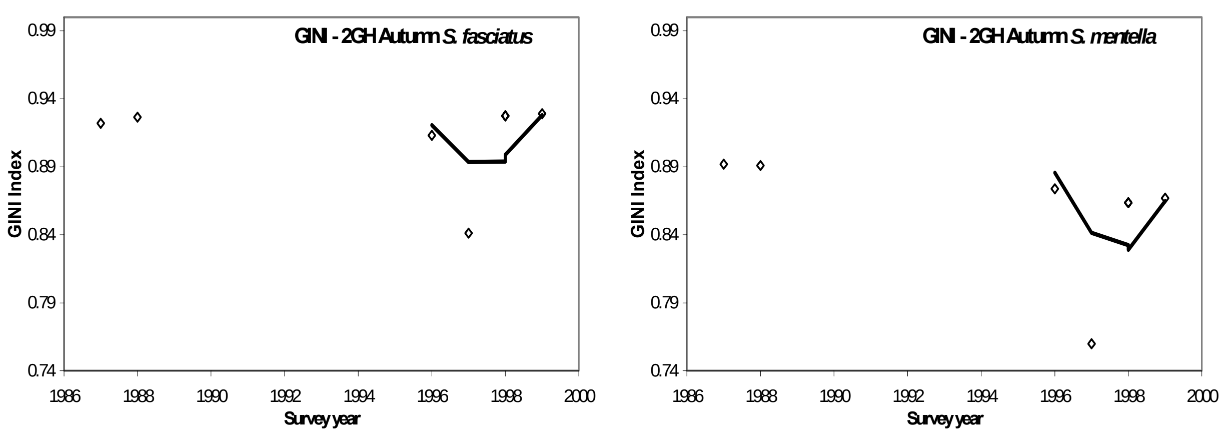


Figure 49. Distribution indices (DWAO for redfish spp, panel A) and indices of concentration (D95, panel B and Gini, panel C) of Sebastes fasciatus and S. mentella in Division 2GH from autumn surveys from 1987-1999. Surveys in 1987-1988 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1996-1999 utilized a Campelen trawl. Surveys were to a maximum of 1000m to 1995 and to 1500m from 1996-1999.

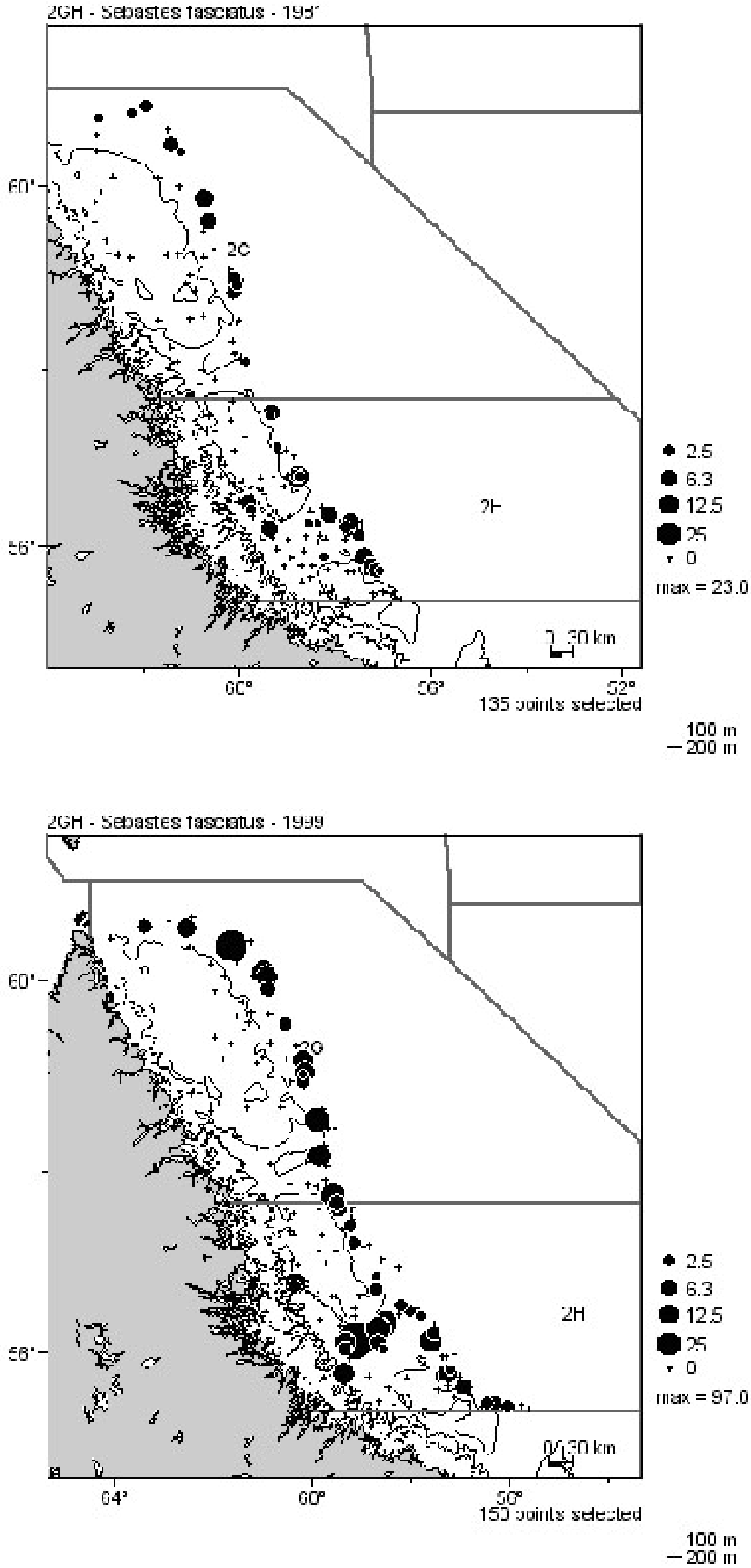


Figure 50. Distribution of the catches of *S. fasciatus* (in number) in 2GH from autumn surveys in 1981 and 1999.

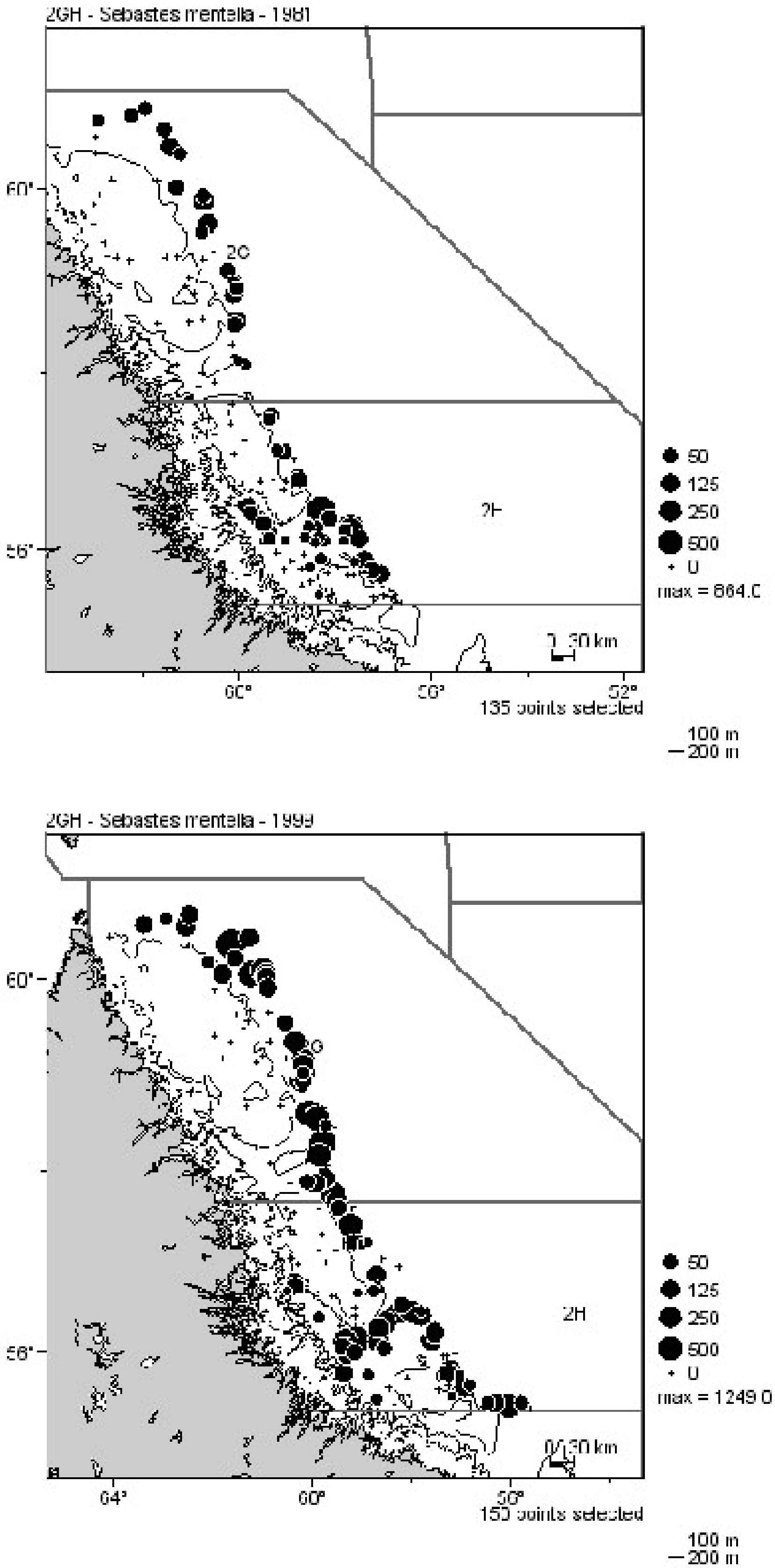


Figure 51. Distribution of the catches of *S. fasciatus* (in number) in 2GH from autumn surveys in 1981 and 1999.