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Research Document 2007/085 | **Document de recherche 2007/085**

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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: an update

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

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ISSN 1499-3848 (Printed / Imprimé)

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Abstract

This document presents the information reviewed and analyzed by Fisheries and Oceans (DFO) that can be used by the Committee on Status of Endangered Wildlife in Canada (COSEWIC) in assessing status and extinction risk of the two main redfish species (*Sebastes fasciatus* and *S. mentella*) in the Northwest Atlantic. Redfish population structure was evaluated in the context of Evolutionarily Significant Units (ESU). The review did not provide evidence of the existence of ESUs within current management units. Therefore, all the analyses were carried out on the actual unit stocks. Methods developed to separate redfish by genotype (for Unit 1-3) or meristics (for NAFO Divisions 2GHJ3KLMNO) were applied to the research vessel 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. The Unit 1 stock experienced a substantial decline at the beginning of the 1990 and has not recovered yet. However, a new year-class (2003), which seems to be quite important, was observed since the 2005 survey. The stock in NAFO Divisions 2GHJ 3K experienced declines but has shown some signs of recovery. The redfish stocks in remaining management units have not shown signs of decline or the information available for these stocks may not reflect the abundance. Fishery and/or the lack of recruitment were considered the main causes of abundance decline for the stocks in Unit 1 and in NAFO Div. 2GHJ 3K. However, environmental changes and elevated natural mortality were also identified as possible causes of decline. Mature population abundance indices of all redfish stocks in Atlantic Canada are at from one to three 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 (MPO) 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 évolutives importantes (UÉI). Cette revue n'a pu mettre en évidence l'existence d'UÉIs à l'intérieur des unités de gestion courantes. Toutes les analyses subséquentes ont donc été effectuées en tenant compte des unités de gestion courantes. Les méthodes qui ont été développées pour séparer les sébastes par génotype (unités de gestion 1-3) ou méristiques (divisions 2GHJ3KLMNO de l'OPANO) 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 général ou tendance dans la distribution géographique n'a été observé. Le stock de l'Unité 1 a subi un déclin important au début des années 1990 et ne s'est pas encore rétabli. Cependant, une nouvelle classe d'âge (2003) qui semble assez importante est observée depuis 2005 dans les relevés. Le stock des divisions 2GHJ 3K de l'OPANO a montré un déclin suivi d'un certain rétablissement. Les stocks de sébaste des autres unités de gestion n'ont pas montré de déclin ou les informations disponibles pour ces unités ne reflètent pas l'abondance. L'exploitation par la pêche et/ou le manque de recrutement ont été considérés comme les causes principales de déclin du stock de l'unité 1 et de celui de la division 2GHJ 3K de l'OPANO. Toutefois, des changements environnementaux et une mortalité naturelle élevée ont aussi été identifiés comme causes possibles de déclin. Les indices d'abondance des effectifs matures de tous les stocks de la côte Atlantique du Canada excèdent d'au moins un à trois ordres de grandeur le seuil des 10,000 individus matures établi par le COSEPAC.

Introduction

This manuscript is an update of the Research Document published by Morin et al. (2004). Therefore, most of the information presented can also be found in the previous document. Furthermore, a large part of the information presented here 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/).

This document presents the information reviewed and analyzed by the Department of 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: the Acadian redfish (*Sebastes fasciatus*) and the deep-water redfish (*S. mentella*). A third species, the golden redfish (*S. marinus*), also co-exists in some areas where its presence is very sporadic. The geographic 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). Since, *S. marinus* is not considered important to the Canadian fisheries (Atkinson 1987; Gascon 2003) it will not be considered further in the present document.

Because redfish species are very similar and nearly impossible to distinguish by their appearance they are usually not discriminated in the fishery and are traditionally managed as a single resource. The standard DFO assessments are prepared for *Sebastes* sp. altogether. In order to provide COSEWIC with relevant biological and exploitation information on *S. fasciatus* and *S. mentella* separately, we used the methods of redfish species identification developed by Méthot et al. (2004) to re-analyze the data available in the three different DFO regions (Maritimes, Newfoundland, Quebec) involved in redfish management. In the present document, the information available on *S. fasciatus* and *S. mentella*, for the main indices available, is presented under the four COSEWIC terms of reference (see below).

For the first term of reference, the information on redfish population structure was reviewed. Using the available information, we have suggested Evolutionarily Significant Units (ESU) for each species (Fraser and Bernatchez 2001 for a review). We also determine if the current stock management units comprised different ESUs.

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 were presented. We tried to describe these trends over as long a period 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 presented 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 were 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 was 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, we have identified the 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

Redfish, also known as ocean perch, belong to a group of fish that is 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.

Three characteristics are commonly used to discriminate *S. mentella* from *S. fasciatus* in the Northwest Atlantic. They are (1) number of soft rays in the anal fin (AFC) (≥8 for *S. mentella*, ≤7 for *S. fasciatus*) (Ni, 1982), (2) extrinsic gasbladder muscle passage patterns (EGM) (between ribs 2 and 3 for *S. mentella*, between ribs 3 and 4 or more for *S. fasciatus*) (Ni 1981), (3) genotype at the liver malate dehydrogenase locus (*MDH-A**). The *MDH-A** locus is polymorphic with two codominant alleles, *MDH-A*1* and *MDH-A*2*, that combine to form three possible genotypes. The genotype *MDH-A*11* characterizes *S. mentella*, while *MDH-A*22* is associated with *S. fasciatus* (Payne and Ni 1982; McGlade et al. 1983). However, the significant number of heterozygous specimens (*MDH-A*12*) and a lack of concordance between the three classification criteria in the Gulf of St. Lawrence led Rubec et al. (1991) to hypothesize that introgressive hybridization takes place in this area. Other studies on ribosomal DNA (Desrosiers et al. 1999), body morphometry (Valentin et al. 2002; Valentin 2006) and other molecular tools such as microsatellite markers (Roques et al. 1999, 2001; Valentin 2006) support this hypothesis. In fact, microsatellite markers are very powerful for redfish species discrimination (Roques et al. 1999; Valentin 2006).

In the Northwest Atlantic, 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 southwestern 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; Gascon 2003; Valentin et al. 2006; Figure 1).

Sebastes mentella and *S. fasciatus* are distributed according to a gradient in the Northwest Atlantic. Indeed, *S. mentella* is the dominant species in Baffin Bay and in the Labrador waters while *S. fasciatus* dominates in the Gulf of Maine and on the Scotian shelf. The distribution of both species overlaps in the Gulf of St. Lawrence, the Laurentian Channel, the Grand Banks, the southern Labrador Sea and the Flemish Cap. *Sebastes fasciatus* and *S. mentella* distribution in the Northwest Atlantic is characterized by a large area of sympatry separating the two allopatric zones (Ni 1982; Atkinson 1987; Gascon 2003). A recent study, in which two morphological characters, number of soft rays at the anal fin and extrinsic gasbladder muscle passage patterns, and one genetic criterion (variability at the liver *MDH-A** locus) were used to discriminate the redfish species has shown that, 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* (Gascon 2003; Valentin et al. 2006). In these areas, the concordance between the three usual criteria is very high and much higher than in the Gulf of St. Lawrence – Laurentian Channel area (Valentin et al. 2006; Figure 2).

Sebastes fasciatus and *S. mentella* distribution is 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 the Gulf of St. Lawrence – Laurentian Channel area (management units 1 and 2) and to a lesser extent to the Flemish Cap area. Introgression, while bi-directional, is asymmetrically more important towards *S. mentella* indicating that it does not affect the two species in the same way. Introgression translates into the presence, in these areas, of two introgressed groups which persist together with non-introgressed individuals of the two species (Roques et al. 2001; Valentin 2006). The studies of Roques et al. (2001) and Valentin (2006) have shown that hybridization between *S. fasciatus* and *S. mentella* has important consequences for both species integrity and genetic population structure. Indeed, the genetic distance between the two species in the Gulf of St. Lawrence and the Laurentian Channel, is reduced compare to allopatric areas. Furthermore, since introgression is limited to specific areas of the species distribution, the genetic differentiation on the geographical scale is importantly but not exclusively determined by introgression processes (Roques et al. 2001, 2002; Valentin 2006). The impact of hybridization on redfish species differentiation and integrity will need further investigation. Indeed, Valentin (2006) recently observed that *S. marinus* also hybridizes with *S. fasciatus* and *S. mentella* in the Laurentian Channel, as suggested by Barsukov et al. (1991).

The results of the population genetic studies (Roques et al. 2001, 2002; Valentin 2006) and of the distribution of heterozygotes at the *MDH-A** locus and of the introgressed specimens, suggest that dispersion - migration is more limited than expected. The very low rate of introgression, and the absence of heterozygotes on the Scotian Shelf, for example, suggests a strong barrier to dispersion-migration. This is surprising considering that larvae of the three genotypes at the *MDH-A** locus (*S. mentella*, *S. fasciatus* and heterozygotes) are present in the Gulf of St. Lawrence (Sévigny et al. 2000), and are likely to be transported out of the Gulf on the Scotian Shelf by the main circulation (e.g. Gaspe current).

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 (150-300 m), 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 – 6.0ºC. In Unit 3, temperature preference is somewhat higher at about 5.5 – 7.0ºC. Laboratory experiments on temperature tolerance of larval *S. fasciatus* suggested that larvae tolerated a wide range of water temperature. Although mortalities occurred at all temperature tested, fewer mortalities (18%) over four days were observed in the range 2 – 10°C (Dutil et al. 2003).

Redfish are generally found near the bottom. However, different studies have shown that these species undertake diel vertical migrations, moving off the bottom at night to follow the migration of their euphausiid prey (Atkinson 1989; Gauthier and Rose 2002). The vertical distribution in the water column of these semi-pelagic species varies both diurnally and seasonally. Such vertical migration patterns affect catches and complicate the interpretation of data collected in commercial as well as in DFO research surveys, which are conducted on a 24-h basis.

1.1.2 Life history characteristics

Redfish are a 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.

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 female *S. fasciatus*, or male and female *S. mentella* (Branton et al. 2003).

The reproductive cycle of redfish differs from that of other species. Unlike many other fish species, fertilisation in redfish is internal and females bear live young. Mating take place in the fall most likely between September and December and females carry the developing embryos until they are extruded as free swimming larvae in spring. St-Pierre and de Lafontaine (1995) have estimated that absolute fecundity of Gulf of St. Lawrence redfish, expressed as the total number of oocytes per female, varies between 1 500 and 7 000 and increases as a power function of fish length and weight. Larval extrusion takes place from April to July depending on the areas and species. *Sebastes mentella* releases its larvae about 3 to 4 weeks earlier than *S. fasciatus* in the Gulf of St. Lawrence (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).

1.1.3 Recruitment

Recruitment success in redfish is extremely variable, and strong year-classes generally appear at intervals of 5 to 12 years. The time gap between episodes of strong year-classes seems to be somewhat less in the southern part of redfish distribution. Understanding the recruitment processes is complicated by the fact that, in some management units, year-classes that appeared strong at young ages, based on research surveys, have subsequently disappeared rapidly before contributing to the adult population and to the fishery (Table 1). This phenomenon took place primarily for the 1966, 1974 and 1988 year-classes in Unit 1. Reasons for such decreases in abundance at young age remain unknown. It has been determined, based on the genotypes at the *MDH-A** locus, that the 1988 year-class was largely dominated by *S. fasciatus* (Sévigny and de Lafontaine 1992; Morin and Hurtubise 2003). Relatively strong year-classes for 2003 and to a lesser extent for 2005 were observed in Unit 1 in recent scientific surveys (Figure 3). Analyses of microsatellites markers have shown that the 2003 year-class is also largely dominated by *S. fasciatus* (Sévigny, unpublished results). This year-class did not show sign of important decline in the CCGS *Teleost* survey carried out in Unit 1 in 2007. Another year-class probably from 2005 was observed during the 2007 survey (Figure 3). The importance and the species composition of this year-class have not yet been determined.

Few experiments have been carried out on redfish larvae under laboratory conditions. Laboratory studies suggest that larval survival is greatest at medium prey densities (Laurel et al. 2001). As mentioned previously, experiments on temperature tolerance have shown that *S. fasciatus* larvae tolerate a wide range of temperature with fewer mortalities over four days (18%) occurring in the range of 2 to 10°C (Dutil et al. 2003).

1.1.4 Management

There are currently nine redfish management areas in the Northwest Atlantic (Figure 1). They are based on the Northwest Atlantic Fisheries Organization (NAFO) Divisions: 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 United States or Greenland EEZ. The original management units were based on both geographical and biological considerations arising from discussions at a ICES/ICNAF redfish symposium in 1959 (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. Except for Flemish Cap and in the Gulf of Maine, Canada has prosecuted redfish fisheries in these areas to varying degrees since the late 1940s. The largest landings come from Subarea 2 + NAFO Div. 3K, as well as Units 1, 2 and 3 (DFO 2000a).

As mentioned previously, redfish species in the Northwest Atlantic 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 group.

1.2 Evolutionarily Significant Units and population structure of redfish

Evolutionarily Significant Unit (ESU) is a concept that was first used by Ryder (1986) to facilitate the identification of population possessing characteristics worth preserving for the present and the future generations. It was developed to get a rational basis for prioritizing taxa for conservation effort. Determining how ESU should be defined is still debated (e.g. Fraser & Bernatchez 2001). For a review of ESU in a COSEWIC context see Smedbol et al. (2002). Two approaches have been commonly documented. The US National Marine Fisheries Service definition implies that a substantial 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 coexist in the Northwest Atlantic: *Sebastes mentella*, *S. fasciatus* and *S. marinus*.

Parasites were examined from deepwater redfish (*S. mentella*) collected from five areas representing four management units: Flemish Pass (NAFO Div. 3M), off Labrador (NAFO Div. 2J), in the Laurentian Channel (NAFO 4Vn in August; 3Ps in January = Unit 2), in Cabot Strait (NAFO Subdiv. 3Pn = Unit 2) and from the Gulf of St. Lawrence (NAFO Div. 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. These results are in agreement with those of 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 quite low in some areas, 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 and morphometric studies on *S. fasciatus* and *S. mentella* (Roques et al. 2000, 2001, 2002; Valentin 2006; Tables 2 to 6; Figures 4 and 5). These studies cover a large proportion of *S. fasciatus* and *S. mentella* distribution range. They revealed a population structure that is determined to a large extent but not exclusively by the importance of introgressive hybridization between *S. fasciatus* and *S. mentella* which takes place 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 because it involves exchange of genes from one species to the other. One of the effects, for example, 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 is lower in the area of introgression (149) compare to the area of allopatry (160). The reverse patterns observed for the two species are caused by the lower polymorphism of *S. fasciatus* (Roques et al. 2001). Introgression 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; Valentin 2006). 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 (Roques et al. 2001; Valentin 2006).

For *S. mentella*, three broad populations were detected at the scale of the North Atlantic: (1) the western group comprised of redfish from Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2); (2) the panoceanic group comprised mostly samples collected across the Atlantic, from the Grand Banks and Labrador Sea to the Faroes Islands i.e. a span of 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 $\theta = 0.013$). Significant differences were also found between Norway and all the other groups ($\theta = 0.024$). These differences between the groups may be attributed to oceanographic features and/or to 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 (Units 1 and 2). The weak structuring observed in the panoceanic region could be an indication of extensive larval dispersion across the area. However, it is important to note that the pan-oceanic structure observed by Roques et al. (2002) for *S. mentella* is based on a relatively small number of samples from the Northeast Atlantic. The redfish population structure at the scale of the North Atlantic is most likely more complicated (Schmidt 2005). A recent study (Valentin 2006) in which both genetic and morphometric data were analysed confirms the strong genetic homogeneity for *S. mentella* within the Gulf of St. Lawrence – Laurentian Channel (Unit 1 and 2). Furthermore, the observed homogeneity was also observed in morphometric data. Considering the good geographical coverage achieved by the samples of the two independent studies (Roques et al. 2001; Valentin et al. 2006), homogeneity seems to be the rule for *S. mentella* in the GSL–LCH area. It suggests the presence of a single population for this species, in this area. Valentin (2006) have also shown that this Gulf of St. Lawrence – Laurentian Channel population differs from the *S. mentella* from the northernmost part of the Northwest Atlantic; a result which is in agreement with those of Roques et al. (2001; 2002). Valentin could analyse only 3 *S. mentella* samples from the northern area and found genetic differences between the sample from Labrador Sea and those from the northern Grand Banks and Iceland, which were less differentiated from each other. These results suggest that the redfish population from Iceland and Northern Grand Banks are more connected to each other than they are to Labrador Sea. Additional information is needed to determine the level of connectivity among those areas.

The overall population structure of *S. fasciatus* is more complicated and appears to be weak. For the first time, genetic analyses were carried out *S. fasciatus* specimens from the Grand Banks area (NAFO Div. 3LNO) (Valentin 2006). Results of the different studies (Roques et al 2001; Valentin 2006) carried out on this species suggest the existence of local heterogeneity superimposed with larger scale trends. The population structure of this species appears to be characterized by the presence of 3 broad groups. The first one (the northern *S. fasciatus* group) comprises the samples from the slope of the Grand Banks to the southern tip of St. Pierre Bank with possible ramification on the slope of the Nova Scotia Shelf. The second group comprises the samples from the Gulf of St. Lawrence and the Laurentian Channel. However, genetic heterogeneity is observed within this group. Furthermore, the population from Bonne Bay is genetically differentiated and represents an isolated population. The third group comprises the Gulf of Maine and Nova Scotia Shelf (southern group in Valentin 2006) although Nova Scotia Shelf is weakly differentiated from the Gulf of Maine. Overall, this southern group tends to be genetically differentiated from the northern group and from that of the Gulf of St. Lawrence – Laurentian Channel group.

In summary, we can suggest that the population structure allows the identification of 2 ESUs for *S. mentella* (Gulf of St. Lawrence - Laurentian Channel and northern population) and 4 ESUs for *S. fasciatus* (Bonne Bay, Gulf of St. Lawrence - Laurentian Channel, the northern population around the Grand Banks and the southern population of the Gulf of Maine and Nova Scotia Shelf). However, additional information will be needed, particularly for *S. fasciatus* to confirm those ESUs.

In the following section, the information available for each management unit is reviewed to determine whether 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 species 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 NAFO Div. 3Pn4Vn (Jan. to May), were included with NAFO Div. 4RST in 1993 to constitute the Unit 1 stock (Atkinson and Power 1991).

The results of genetic studies (Roques et al. 2001, 2002; Valentin 2006) indicated that there is homogeneity between the samples of Units 1 and 2 for *S. mentella* and *S. fasciatus*. However, *S. fasciatus* in the Bonne Bay Fjord appears to belong to an isolated population. There is also indication of some *S. fasciatus* heterogeneity, which needs further clarification in this management unit. 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 other than Bonne Bay at a finer scale within the Gulf of St. Lawrence (Unit 1). However, the Bonne Bay population is not commercially exploited.

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 NAFO Div. 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 Nova Scotia Shelf. Thus NAFO Div. 3Pn4Vn (June to December), were included with NAFO Div. 3Ps4Vs4Wfgj to constitute the Unit 2 stock (Atkinson and Power 1991).

As noted above, there was no difference in the genetic characteristics of *S. mentella* from Units 1 and 2 (Roques et al. 2001, 2002; Valentin 2006) but there were differences in the parasite fauna of *S. mentella* between the management units 1 and 2 (Marcogliese et al. 2003).

There was some weak indication of genetic heterogeneity 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 (Roques et al 2001; Table 4). The differentiation of those samples from the others was attributed to variable levels of introgression of redfish aggregations observed in these regions. However, such heterogeneity was not observed for this species in the study by Valentin (2006). Valentin (2006) observed some heterogeneity for *S. fasciatus* (4Vn5) in this unit. Additional information will be needed to clarify the status of *S. fasciatus* in this area. Altogether, there is no indication for the existence of ESU at a finer scale within the Laurentian Channel (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 from about 14 000 t in 1995 to 8 500 t in 2006.

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 NAFO Div. 4VWX. This new management area was first implemented in the 1993 groundfish management 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) (Roques et al. 2001). The study of Valentin (2006) also detected small difference between samples from the Gulf of Maine and those from the Nova Scotia Shelf, suggesting the existence of some structure in the area.

There is no indication for the existence of ESU at a finer scale on the Nova Scotia Shelf (Unit 3).

1.3.4 NAFO Divisions 3O, 3LN and 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 NAFO Div. 3LN, 3O and 3P redfish as separate “stocks”. They considered that redfish of the northern and eastern Grand Banks (NAFO Div. 3LN) constituted a stock different from that of 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 NAFO Div. 3O and 3P separately based on different growth rates. Parsons and Parsons (1974) also provided an assessment of NAFO Div. 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, NAFO Div. 3LN redfish stock is under moratorium to directed fishing while that of NAFO Div. 3M has a TAC of 5 000 t and that of NAFO Div. 3O has a quota of 20 000 t. Recruitment prospects have also been generally poor since the 1990 year-class in Div. 3M, the 1986/1987 year-class in NAFO Div 3LN and the 1988 year-class in NAFO Div. 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). These results are partly in agreement with those of Valentin (2006) who found genetic differences between a sample collected in the Labrador Sea (NAFO Div. 2J) and a sample from NAFO Div. 3L. However, there was some concern that the sample from Labrador may not have been representative of the area.

The genetic characteristics of *Sebastes fasciatus* from NAFO Div. 3LNO areas were studied for the first time by Valentin (2006). Redfish from these NAFO Divisions appear to belong to the same population, which is slightly different from that of the Gulf of Maine and Nova Scotia Shelf and from that of the Gulf of St. Lawrence and the Laurentian Channel.

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, or Div. 3O for *S. fasciatus* and *S. mentella*.

1.3.5 NAFO Divisions 2GHJ 3K

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

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

The genetic analyses carried out by Roques et al. (2002) have shown that *S. mentella* from this management unit is not differentiated from redfish of the southern management unit (NAFO Div. 3LN and 3O) and may belong to a much larger population of the Atlantic Ocean (Panoceanic in Roques et al. 2002). The only additional information about this area is the result of the genetic analyses of one sample collected in NAFO Div. 2J, which was different from a sample collected in NAFO Div. 3L. However, it is very difficult to draw conclusions based on the analyses of only one sample.

There is no information to suggest the existence of an ESU at a finer scale within the boundaries of the NAFO 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 NAFO SA2 + Div. 3K (Roques et al. 2002). Furthermore, the analyses of one sample from Iceland suggest that this population may be connected to that of the Northern Grand Banks (Valentin 2006).

1.4 Comparisons some biological information between stocks

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

First, routine investigations of sexual maturity between stocks show that redfish reach maturity at different length and age in each management unit. These differences suggest separation by management unit. Individuals of the three genotypes at the *MDH-A** locus mature younger in Unit 1 then in other areas. As expected, males mature younger then females and *S. fasciatus* mature younger then *S. mentella* (Figure 6; Tables 7 and 8; Branton et al. 2003).

Second, the growth is similar for all stocks, although male *S. fasciatus* and heterozygous individuals as well as female *S. fasciatus* caught in Unit 2 seem to grow faster after the age of 10 (Figure 6). As was mentioned before, they reach the limit currently set as a fisheries management 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 six very abundant year-classes have been reported since 1946 (Table 1). Some of them (1966, 1974 and 1988) vanished before reaching fishery exploitable size (>20 cm). The species composition of the 1966 and 1974 year-class remains unknown but the 1988 year-class was largely dominated by *S. fasciatus* (Sévigny and de Lafontaine 1992). The 2003 year-class is also dominated by *S. fasciatus*. Based on DFO surveys, the abundance of this year-class had decreased from 2005 to 2006 and appeared to be stable in 2007. Unit 2 observations were very similar to those of Unit 1 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 influenced by the phenomenon of introgressive hybridization that is taking place in the Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2).

The population structure of *S. fasciatus* is generally weak based on genetic studies and difference observed between samples will have to be confirmed by further studies. Three broad stocks were detected with genetic studies: (1) Gulf of St. Lawrence and Laurentian Channel: Units 1 and 2, (2) the Northern Grand Banks stock and (3) the southern stock: Unit 3 - Gulf of Maine. An isolated population was also observed in Bonne Bay Fjord (Gulf of St. Lawrence). Genetic differences between the Gulf of St. Lawrence/Laurentian Channel area (Units 1 and 2) and the other populations (Unit 3, northern Grand Banks) are largely but not only driven by introgression between the two species that is taking place in the Gulf of St. Lawrence - Laurentian Channel. The difference between Unit 3 and the Gulf of Maine are very small and would need to be confirmed by further studies.

Two populations were detected for *S. mentella*: (1) the Gulf of St. Lawrence - Laurentian Channel: Units 1 and 2 and (2): the northern population (other management units) based on the genetic studies. However, parasite studies suggest differences between Unit 1 and Unit 2 (Marcogliese et al. 2003). As was the case for *S. fasciatus*, introgressive hybridization is the most likely (but not the only) explanation for the structure observed.

An important conclusion that can be drawn from 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. mentella.* For this species, the scale at which genetic differentiation is observed appears to be much larger than the management units are. For *S. fasciatus*, the status of some of the samples will have to be assessed. However, for this species, the differentiation between populations is generally weak except for Bonne Bay. It can be argued, for both species, that the suggested ESUs 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 used to separate redfish by genotype

2.1.1 Introduction

The three redfish species of the Northwest Atlantic (*S. mentella, S. fasciatus* and *S. marinus*) can be identified using several techniques. The usual criteria for discrimination between *S. fasciatus* and *S. mentella* are the number of soft rays at the anal fin (AFC), the extrinsic gasbladder muscle rib passage patterns (EGM) and the malate dehydrogenase (MDH) electrophoretic mobility patterns. 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 (Power and Ni 1985). However, these characters were essentially only useful for fish larger than 25 cm. 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; Gascon 2003; Valentin et al. 2006). In addition, they are often time consuming and are not routinely applied in field surveys or commercial sampling. As a result, redfish have been exploited in fisheries and managed as a group and information on the abundance and distribution of individual redfish by species does not exist for many 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. 2004; 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 used 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) carried out from 1995 to 1998 and was used to describe the general pattern of species distribution in recent years (Gascon 2003; Valentin et al. 2006). 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 splitting the survey catches by species since redfish species have different depth range distributions (Rubec et al. 1991; Gascon 2003) and the stratification scheme of the DFO RV surveys (Department of Fisheries and Oceans Research Vessel surveys) used depth as the main factor to define strata. These species depth proportions were used to attribute proportion of the survey catches to redfish species by tow and by depth zone.

Species identification data collected during the HPMRRP were considered insufficient to derive proportions of *S. fasciatus* and *S. mentella* for management units other than Units 1, 2 and 3. However, a more extensive source of data but less reliable in term of species separation is the meristic database described 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 (NAFO SA2+Div. 3K, Div. 3LN, and Div. 3O). NAFO 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 from stratified-random surveys conducted by the European Union in NAFO 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. (2004).

2.1.2.1 Unit 1

For the Gulf of St. Lawrence redfish, AFC and genotypes at the *MDH-A** locus 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 electrophoretic patterns) 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 year by length-AFC keys for each depth interval (Méthot et al. 2004) for years 1985 to 1987 and 1993 to 2007. This is the basis of the method used to get numbers by genotype caught in each tow (Méthot et al. 2004).

To estimate the abundance of mature fish, length-AFC keys for each depth interval were estimated (Méthot et al. 2004). 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 at the *MDH-A** locus 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. Subsequently PACES application, which is a stratified analysis written in SAS (Hugo Bourdages, DFO Quebec Region) to obtain abundance by length was used to estimate total abundance for each species.

In 1984 and for the 1988 to 1992 period, since no AFC data have been collected or can be used, assumptions were made to get an abundance index by species. We 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, since three vessels using different fishing gears were used to conduct research survey (*Lady Hammond*, CCGS *Alfred Needler* and CCGS *Teleost*), conversion had to be made to allow the comparison of the different series. We first applied a conversion factor at length (Hugo Bourdages, DFO Quebec Region and Doug Swain, DFO Gulf Region) and used a multiplicative model to obtain estimation of the strata that were not sampled some years to convert the *Lady Hammond* series (1984-1989) to the CCGS *Alfred Needler* series (see Méthot et al. 2004). Then, the *Lady Hammond*-CCGS *Needler* series were converted to CCGS *Teleost* equivalent using a constant[1] (2,289; Bourdages et al. 2007).

Caution is necessary when interpreting the results of the separation by genotypes at the *MDH-A** locus particularly for years with no data on species identification. The data used to establish the depth distribution by species is obtained 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, 1988 and 2003 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. 2004). These proportions have been applied to split genotypes by tow. Subsequently PACES application was used to estimate 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. 2004). 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 analyses have 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+Division 3K

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 (e.g. 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 9). The only exception to this was that proportions for NAFO Div. 2G and 2H were calculated separately from NAFO Div. 2J and 3K for the

[1] There was no difference between the length frequencies caught from the CCGS *Needler* and the CCGS *Teleost* during the comparative survey.

SA2+3K stock area because it is believed that the abundance of *S. fasciatus* drops off significantly north of NAFO Div. 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 were insufficient genetic samples collected from the NAFO Div. 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 (22 cm for *S. fasciatus* and 24 cm 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. Several approaches could be used to estimate the rate of decline (Smedbol et al. 2002). In this paper, we decided 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 carried out in August from 1984 to 1989 with the *Lady Hammond*, from 1990 to 2003 with the CCGS *Alfred Needler* and since 2004 with the CCGS *Teleost*. The areas covered by the surveys in Unit 1 are NAFO Div. 4R, 4S and St. Lawrence Estuary and the southern portion of the Laurentian channel in NAFO Div. 4T. Because redfish is not abundant in the shallower waters of Div. 4T (Méthot et al. 2004), the surveys with the three vessels give a good overview of redfish abundance in all Unit 1 since 1984 and correction factors were applied to the data series of the *Lady Hammond* and CCGS *Alfred Needler* series to construct a comparable series to CCGS *Teleost* (see Méthot et al. 2004; Bourdages et. al. 2007).

Evaluation of decline

Stratified abundance estimates are available for this stock since 1984. Total relative abundance has declined from 6940 million redfish individuals in 1984 to 2607 million in 2007 (Table 10; Figure 7). For all genotypes, juveniles and matures, a rapid decline was observed at the beginning of the 1990's. Redfish abundance remains low until 2005. The increase in abundance observed in 2005 is due to the appearance of a new year-class. Indeed, the abundance of the mature population did not increase significantly in 2005 and in subsequent years (Table 10; Figure 7). Given the high variability of recruitment with high variation of survival (or migration), we believe that the mature population abundance is a better indicator of redfish rate of decline.

Sebastes fasciatus shows two peaks of abundance, one from the 1988 year-class and the other from the 2003 year-class. The lowest abundance was observed in 1995-1996 when *S. fasciatus* abundance was around 3% of the 1984 value. The strong recruitment of *S. fasciatus* in 2003 detected in 2005 raised the overall abundance but not that of the mature population. From 1984 to 2007, the abundance of mature *S. fasciatus* continues to decline from 1813 to 50 million of individuals.

Sebastes mentella shows a constant decline from 1984 to 1994. The abundance was low and stable until 2005 when the abundance increases. As was the case for *S. fasciatus*, the abundance of the mature population remains low. It is worth mentioning that the increase in the total abundance observed for *S. mentella* may be an artefact caused by the discrimination method used (Méthot et al. 2004). Higher abundance of juvenile redfish was observed from 2005 to 2007. This higher abundance is caused by the recruitment of a strong *S. fasciatus* year-class (Sévigny, unpublished results). Since the discrimination method was developed for the 1993-1998 period, it does not take into account change in genotype proportion. Therefore, a proportion of the strong recruitment may have been wrongly attributed to *S. mentella*.

The abundance trend of heterozygous individual follows that of *S. mentella* (Table 10; Figure 7).

We consider that the year 1984 is not appropriate for determination of the decline rate by species since AFC data was limited for that year. We suggest evaluating the percentage of decline based on two periods. The first period would be the average of the values obtained from 1985 to 1987. The second would be the average of the values obtained for the period 2004 to 2006. As mentioned previously, the abundance of *S. mentella* juveniles may be overestimated due the method used. We therefore suggest using the mature population abundance to evaluate rate of decline.

Evaluation of cause of decline

In the Gulf of St. Lawrence, strong recruitment has been intermittent, occurring every 6-12 years. Strong year-classes were observed in 1946, 1956, 1958, 1970 and 1980. In addition, some year-classes that were very abundant at age 2 to 4, based on research survey data, were not found in subsequent years and never contributed significantly to the adult population and to the fishery. Abundant year-classes that did not contribute significantly to the fisheries were observed in 1966, 1974 and 1988 (Sandeman 1973; Parsons and Parsons 1976; Morin et al. 1999; Table 1). 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 to the rapid decline are: fishing mortality due to by-catches in the shrimp fishery and the natural mortality due to poor environmental conditions or predation. These factors were reviewed (Morin and Hurtubise 2003) but the impact of each on the rapid decline of the 1988 year-class could not be identified 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 pers. 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 suggests 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 and the early 2000 (DFO 2000a).

Fishing contributed to the decline of the adult population in the early 1990s. The redfish fishery in the Gulf of St. Lawrence is 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. A Redfish Industry Survey (RIS) program was initiated in 1998. The TAC for purposes of the RIS program was set at 1 000 t in 1998 and 2 000 t since 1999.

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 and Stenson 2004).

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 1994, the amount of redfish by-catch (in tonnage) in the shrimp fishery has decreased significantly. However, the decrease in the number of fish captured is less important because they are of a smaller size (Fréchet et al. 2006). Indeed, the Nordmore grate is effective at reducing bycatch of larger fish but the grate is not effective in reducing bycatch of small redfish. Shrimp fisheries may still have a significant impact on mortality of small redfish before the grate becomes effective.

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 in 1995. The 2003 year-class detected in 2005 survey is the first new year-class since 1988-1989 (Figure 3). *Sebastes fasciatus* is the species composing the 1988 and 2003 year-classes. As mentioned previously, the 1988 year-class did not contribute significantly to the fishery in Unit 1. It is not know whether the 2003 will remain abundant. Another year-class was also detected in the 2007 CCGS *Teleost* survey in the Gulf. The abundance of this year-class appears to be much smaller than the 2003 and its species composition has not been determined.

2.2.2 Unit 2

Stratified-random research surveys were conducted in NAFO 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 183 m – 732 m. 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 DFO stratified-random groundfish surveys are conducted within the management unit. These are (1) the 4VW summer groundfish surveys 1970-2006 to 200 fathoms (367 m) 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 (458 m) 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 2006 to 400 fathoms (732 m) 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. (2004).

Evaluation of decline

Over the time period covered by the DFO summer series in Unit 2 (1994-2002), the survey abundance index 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 11; Figure 8) from 565 million individuals in 1994 to 322 million in 1996, increased sharply to 535 million in 1997 and increased marginally again to 561 million 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 the 1994 to 1996 surveys. 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 heterozygotes at the *MDH-A** locus shows trends similar to those of *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 74 million to 56 million for heterozygotes). 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.

Abundance of mature population of *S. fasciatus* show similar variations to that of the total population while the mature populations of *S. mentella* and heterozygotes decrease slightly over the period (Table 11; Figure 8).

Evaluation of cause of decline

There has been a directed fishery 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. This decline was also seen over a number of years in both the 3Ps and 4VW surveys (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 25 cm, 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* / heterozygotes 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 comprised most of the catches from the commercial fishery from 1988 to at least 2002.

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 1970-2006. Prior to 1982 a different vessel and a different gear were 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 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). However, Branton and Halliday (1994) used the redfish conversion factor of 1.33 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 402 million in 1970 compared to an estimate of 645 million in 2006 (Table 12; Figure 9). 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 does 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 by-catch. 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 NAFO Div. 3O includes areas beyond the 200-mile limit. Stratified random Canadian bottom trawl surveys have been conducted in NAFO 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 (1998). Only those years where reasonably good coverage was accomplished in NAFO Div. 3O are considered.

In summary, only the 1991-2006 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 regarding 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 had coverage only in the spring to 200 fathoms with a Yankee 41-5 otter trawl. These estimates 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*. Patterns for the mature populations of both species closely resemble that of total population (Table 13; Figure 10).

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 in 1989 to 926 million in 1986. For *S. mentella*, there is a trend of decline over the period from about 10 million in 1984 to about 650 thousand in 1990. Trends observed for the mature populations of both species are similar to those of the total population (Table 13; Figure 11).

Total survey population estimates in the 1991-2006 period for both the spring (Table 13; Figure 12) and autumn (Table 13; Figure 13) series to 400 fathoms are available in Campelen trawl equivalents. For the spring series, survey abundance for *S. fasciatus* has ranged from 81 million in to 2.2 billion. The abundance 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) and increase from 2002 to 2005. The low 1997 value is considered an anomaly as it is extremely low compared to adjacent years. 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 (Table 13; Figure 13). Survey estimates have ranged between 92 million and 955 million. The lowest estimate was in 2003 and the 2006 estimate is at 260 million. The spring survey estimates for *S. mentella*, ranging from 12 million to 68 million, exhibit greater between-year fluctuations than for *S. fasciatus*. There is an indication of an increase from 1991 to 1999 with a decline followed by a slight increase from 2002 to 2005. The autumn survey estimates for *S. mentella* are highly variable, ranging from 8.5 to 107 million. Although highly variable, there seems to be a tendency for a slight increase towards 2006.

The variability observed for the mature populations of the two species for the spring and the fall survey closely resemble that of the total population.

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 trawling from 200-400 fathoms is more difficult. 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 importance 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. From 2002-2003 catches averaged 17 200 t then declined dramatically to about 3 800 t in 2004, but rose again in 2005 to about 11 000 t and was about the same in 2006. Since 2002 about 75% of the catch has been taken by foreign fleets outside the 200-mile limit.

2.2.5 NAFO Divisions 3LN

Redfish habitat in NAFO Div. 3LN includes areas beyond the 200-mile limit. Stratified random Canadian bottom trawl surveys have been conducted in NAFO 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 NAFO Div. 3O. Only those years where reasonably good coverage of both NAFO 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 1991-2006 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 NAFO 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 in 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*. For both species, estimates were greater in the latter part of the series although this may simply be related to incomplete coverage in the earlier surveys (Table 14; Figure 14).

Total survey population estimates in the 1985-1990 period in the spring to 200 fathoms with an Engel 145 otter trawl for *S. fasciatus* range from 34 million to 134 million with a trend of decline over the time period. 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 (Table 14; Figure 15).

Total survey population estimates in the 1991-2006 period for both the spring (Table 14; Figure 16) and autumn (Table 14; Figure 17) 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 322 million. The abundance index declined from 1991 to its lowest level in 1994, increased to the highest value in the series in 2005 after a marginal decline in 2002 at 101.6 million and another one in 2006 to 196 million. The autumn series for *S. fasciatus*, with estimates ranging from 30 million to 1 billion, generally exhibits more interannnual variability. The estimate of 1 billion in autumn 1992 was highly influenced by one set in the survey in NAFO Div. 3N that captured 53 000 fish. The next highest value in the autumn series was in 2001 (estimate at 736 million). 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, a marginal decline from 2001 to 2003 followed by a slight increase in 2004 and then a decline to 2006. However, the 2006 spring survey did not cover NAFO Div. 3N. 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).

Variability patterns of the mature populations of both species generally follow that of the total population.

Evaluation of cause of decline

It is not possible to compare the survey information throughout the entire time period. The only comparable information (1991-2006 indices) suggests a decline to 1994 with an increase to 2005. 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 depleted by cumulative effect of the large catches of the 1980s. A moratorium on directed fishing was implemented in 1998. However, since the moratorium, the catches taken as by-catch in other fisheries have ranged from 200 t in 2007 to 3 100 t in 2000. 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 25 cm. 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 NAFO 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

DFO stratified random multispecies trawl surveys have been conducted in the fall in NAFO Div. 2J and 3K since 1978 and in Div. 2G and 2H sporadically since 1987. These surveys adequately covered strata to depths of 1 000 m. Beginning in 1995, the surveys covered to 1 500 m more consistently due to the deployment of a replacement vessel that could fish the deeper water more effectively. Generally, the abundance of redfish drops off sharply beyond 800 m 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 1978-1992. These surveys were conducted with an Engels 145 high lift otter trawl from 1978-1994 and a Campelen 1800 trawl from 1995-2006. 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 NAFO Div. 2GH survey data are presented separately from those of Div. 2J3K because they are sporadic, frequently have unsampled strata and only NAFO Div. 2H has been covered since 1999. The most intensively covered surveys are 1987-1988, 1991, 1996-1999.

Evaluation of decline

Total survey population estimates for the NAFO Div. 2J3K series show large fluctuations between some years. The series shows a continuous decline from high value in 1978 to the lowest in 1994, a moderately sharp increase in 1995 with a continued trend of increase to 2006 for both *S. fasciatus* and *S. mentella* (Table 15; Figure 18). The rate of increase from 1995-2006 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 2006 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 1978-2006 period range from about 4 million to 4 billion with the most recent estimate at 287 million. Estimates for *S. mentella* from 1978-2006 vary range from 32 million to 5.4 billion with the 2006 estimate at 790 million.

Variability of the mature populations of both *S. fasciatus* and *S. mentella* are very similar to that of the total population until 1991. From 1992 to 2006, the difference in the abundance index of the mature and total populations is more important and reflects improvement in recruitment within the area (Table 15; Figure 18).

Total survey population estimates for the NAFO 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 1997 with a subsequent decline to 1999 for both *S. fasciatus* and *S. mentella* (Table 15; Figure 19). A similar argument can be made for these survey results as with NAFO 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. The survey coverage since 1999 has only been on Div. 2H and every other year beginning in 2001. In total, there has been an increase in redfish spp. from 2001 to 2006. Survey population estimates for *S. fasciatus*, which is at the northern extent of its distribution, over the 1987-2006 period range from about 1 million to 14 million with the most recent estimate in 2006 at 9.7 million (for NAFO Div. 2H only). Estimates for *S. mentella* from 1987-2006 vary from 29 million to 368 million with the 2006 estimate at 149 million (for NAFO Div. 2H only). For this division the patterns of variation of the mature population are similar to those of the total population although the abundance index of the mature population is lower (Table 15; Figure 19).

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 180 t from 1998-2000 and are primarily the result of by-catch discarded from shrimp fisheries throughout the NAFO Div. 2GHJ3K areas. Approximately 2.5 million redfish in the length range from 5 cm to 19 cm were discarded during the 2000 shrimp fishery, which represents a relative exploitation of less than 1% (Power 2001). Since 2002 an average of about 4 000 t annually have been taken in NAFO Div. 2J 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 but has been monitored by international summer acoustic surveys in the NAFO Div. 1F and Div. 2GHJK area in upper layers over oceanic depths (>2000m). A connection has not been established between the pelagic stock and the demersal stock that resides in the area on the slopes of the continental shelf (<1000m).

DFO RV multispecies trawl surveys indicate the demersal 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 NAFO Div. 3LN redfish, seals also prey on redfish in the area. It is assumed that most of the estimated 35 000 t of redfish consumed in the NAFO 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

DFO 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 25 cm, it is estimated that more than 175 million redfish are consumed per year based on the average weight of a 25 cm redfish (0.2 kg) and the 35 000 t consumption estimate of Hammill and Stenson (2000) which is for the NAFO Div. 2J3KL.

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) was calculated for each year by species or genotypes using the following equation:

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

Where n is the number of tows in the survey in 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 tows were 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; Benoit et al. 2003) and Gini index (Myers and Cadigan 1995).

The D_{95} index describes changes in geographic concentration. This index represents the minimum area where 95% of the stock is distributed. To estimate the index, we first 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 ($G(_{C05})$). Finally, the minimum area containing 95% of redfish is given by:

$D_{95} = A_T - G(c_{05})$

Where A_t is the total survey area.

For details on equations to calculate D_{95} see Swain and Sinclair (1994), Smedbol et al. (2002) and Benoit et al. 2003.

The 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

Except for last years, the total area surveyed for the *Lady Hammond* and CCGS *Alfred Needler* series since 1986 is usually fairly constant over years averaging around 92 000 km^2 (Figure 20). Since 1990 additional shallow strata are surveyed but only few small catches of redfish have been observed in these areas, thus we decided to eliminate those strata to get a consistent area covered.

The methods used for redfish species discrimination do not allow us to calculate the area of occupancy index for each 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. The area of occupancy for *Sebastes* sp. decreases from 94 013 km^2 at the end of the 1980s to 68 992 in 2004 (Figure 20). This index remains almost unchanged despite the decline of abundance observed at the end of the 1980s. The fluctuation observed in the 1984-1986 period and in recent years is mainly caused by the variation in area surveyed.

No correction was possible to merge the *Lady Hammond* and the *CCGS Alfred Needler/Teleost* at a tow level for each species, thus the two series have been analysed separately. The geographic range (D_{95}) of *S. fasciatus* rose sharply from 1993 to 1995 and declined since then to reach a minimum at 12 423 km^2 in 2005 (Figure 21, panel A). Two low values were observed, probably in response to the appearance of the strong 1988 and 2003 year-classes. 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 and recent years. The geographic range of mature population did not necessarily drop as total population did. The general trends of D_{95} for *S. mentella* and for the heterozygous individuals are very similar. The highest values were reached in 2000 for both groups and steadily decline since then. Again, as mentioned before, in reason due to the limits of the discrimination method (Méthot et al. 2004), many redfish could have been wrongly identified as *S. mentella* in the abundant 1988 and 2003 year-classes that were largely dominated by *S. fasciatus*. Thus, the decreases are not necessarily representative of the reality.

The Gini index shows roughly the opposite trends of D_{95}. *Sebastes fasciatus* was more concentrated in the early 1990s and in recent years. *Sebastes mentella* and heterozygous individuals show similar pattern (Figure 21, panel B).

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 of *S. fasciatus* are plotted for 1986, 2003 and 2006 (Figure 22) and for 1986 and 2003 for *S. mentella* (Figure 23) and heterozygous individuals at the *MDH-A** locus (Figure 24). Because of the limit of the discrimination method, the distributions of *S. mentella* and of heterozygotes in 2006 are not appropriate and are not shown. For each genotype, there was a decrease in catch rate from mid-80 to early 2000. For *S. fasciatus*, there was an increase in the catch in recent years (Figure 22). Large catches of small *S. fasciatus* have been made in the recent years particularly in the Esquiman Channel.

3.2.2 Unit 2

The DFO Unit 2 summer surveys were only conducted between 1994 and 2002. The area of occupancy of *Sebastes* spp. is constant over the survey years at 50 000 km^2 (Figure 25). In general, no important change of concentration (D_{95} and Gini indices) for each genotype was observed between 1994 and 2002 (Figure 26), which is also noted in a plot of the survey results by tow in 1994 and 2002 (Figures 27, 28, 29). 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 artefact of increased recruitment noted above coupled with the realization that recruitment tends to first occur in the shallower depths of the area surveyed which represent a smaller proportion of the whole area. For *S. mentella* and heterozygous individual variations occurred in years 2000 and 2002 in D_{95}, 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 important changes for the first (1994) and last (2002) years for the three genotypes (Figures 27 to 29).

3.2.3 Unit 3

Area of occupancy of *S. fasciatus* varied from 23 180 to 72 320 km^2 and did not show any trends that reflect changes in the survey abundance estimates over time (Figure 30, panel A). 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 (Figure 30, panel B).

The Gini index is very stable over time, with the exception of one data point (Figure 30, panel C). 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 2006 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 multispecies surveys since 1991 has remained relatively stable within each series which had intended coverage from 30 fathoms (55 m) 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 Banks from 100 m to 750 m. Within this zone, the area of occupancy in the spring surveys has increased from about 7 600 km^2 in 1991 to about 22 000 km^2 in 2005 (Figure 32, panel A) and from about 6 300 km^2 in 1991 to about 27 400 km^2 in 2006 in the autumn survey series (Figure 33, panel A). The spring 2006 value is not comparable because this survey did not sufficiently cover depths beyond 50 fathoms (92 m). 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, panel B) since 1991. The spring Gini index (Figure 32, panel C) shows no trend for *S. fasciatus* until 2003 and a slight decline until 2005. For *S. mentella* this index shows a slight decline suggesting no concentrating effect. 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, panel C). The D_{95} appears to decrease and the Gini increase which, taken together, suggest a decline in geographic range or a concentrating effect. As noted previously, there are seasonal differences in distribution which may influence the interpretation of these results.

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 2005 and autumn (Figures 36 and 37) for 1990 and 2006. 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. *Sebastes fasciatus* was more abundant at the shallower end of the slope and catches were generally larger in the earlier survey. For *S. mentella*, catches were more abundant in the deeper slope water and were larger in 2005 than the earlier survey 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 Banks. The area of occupancy in the spring surveys has increased from about 21 400 km^2 in 1991 to about 51 500 km^2 in 2005 (Figure 38, panel A) and from about 20 200 km^2 in 1991 to about 55 300 km^2 in 2006 in the autumn survey series (Figure 39, panel A). The spring 2006 value is not comparable because this survey did not sufficiently cover NAFO Div. 3N in depths beyond 50 fathoms (92 m). 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 (100 m-732 m), 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, panels B and C). For *S. mentella,* the D_{95} index 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 yet becoming more concentrated. The autumn indices are variable but stable for *S. fasciatus* (Figure 39, panels B and C). For *S. mentella*, the D_{95} index shows an increase while the Gini index shows a trend of decline, suggesting no concentrating effect, which complements the results of the D_{95} index.

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) denoting the distribution at the beginning and end of each survey series as described in Section 2.2.5. 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 2006 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 2005, noting however, that the 1984 survey only covered to 200 fathoms. For *S. fasciatus* in the spring, 1984 appears to be less abundant than 2005 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 NAFO Div. 2J3K from 1980 to 1995, ranging between 176 500 and 184 700 km^2 with strata covered adequately to 1 000 m. The 29 000 km^2 increase in 1996 was the result of adding inshore strata which generally devoid of redfish. Surveys in NAFO Div. 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 NAFO Div. 2G. In NAFO Div. 2J3K, the area of occupancy (Figure 46, panel A) decreased from about 126 000 km^2 in 1978 to about 59 000 km^2 in 1994, increased sharply to 109 000 km^2 in 1995 was stable to 2000 then continued to increase 134 000 km^2 in 2006. The large increase in 1995 was coincident with the change in survey gear and vessel. The area of occupancy for NAFO 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 2006. 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 NAFO 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 NAFO 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 2006 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. Subsequent surveys have only covered NAFO Div. 2H in 2001, 2004 and 2006.

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 2 500, as endangered. As mentioned in the cod document (Smedbol et al. 2002), even if some stocks have been subject to drastic decline, the population size of 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 for the most recent survey of the Unit 2 area 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, 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 over 250 million in 2006. 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 NAFO Div. 3O were averaged between autumn in 2005 and 2006 because no survey was conducted in redfish habitat in spring 2006. For *S. fasciatus* the estimate is 155 million and for *S. mentella* the estimate is 28 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 NAFO Div. 3LN were averaged between autumn in 2005 and 2006 because no survey was conducted in redfish habitat in spring 2006 in Div. 3N. For *S. fasciatus* the estimate is 183 million and for *S. mentella* the estimate is 56 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 NAFO Div. 2J3K was estimated from the 2006 autumn survey. The estimates were 71 million for *S. fasciatus* and 263 million for *S. mentella*. In NAFO Div. 2GH, the most recent estimates of minimum trawlable abundance of the mature population for each species were derived from the 2006 survey which only covered NAFO Div. 2H. For *S. fasciatus*, that estimate was about 560 000 and for *S. mentella*, the estimate was about 20 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 although genetic differentiation is low. In the Northwest Atlantic, two populations were detected for *S. mentella*: Units 1 and 2 and all other management units. The population structure of *S. fasciatus* is more complex and differentiation is generally weak. Four populations were observed: the Gulf of St. Lawrence - Laurentian Channel (Units 1 and 2), the northern population around the Grand Bank and southern population (Nova Scotia Shelf and Gulf of Maine). The population in Bonne Bay Fjord is an isolated population. The population of Bonne Bay excepted, it seems 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 and for most areas there has been an improvement in total population abundance for both *S. fasciatus* and *S. mentella* since the last review of the abundance and distribution utilizing survey information to 2001 in a species-at-risk context (see Morin et al. 2004).

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

Acknowledgements

We would like to thank Brigitte Bernier for providing data on the redfish year-classes of Unit 1. Alexandra Valentin provided very useful comments on the manuscript. The authors also thank Martin Castonguay, Denis Bernier and Sonia Dubé for revising this document.

References

Anon. 1995. Report of the zonal working group meeting on redfish in Unit 1, 2, and 3, and Div. 3O. MS, 39p.

Atkinson, D.B. 1987. The redfish resources off Canada's east coast. p. 15-33. *In*: Proc. Int. Rockfish Symp. Oct. 1986, Anchorage, Alaska. Alaska Sea Grant Report No. 87-2, Univ. Alaska, 393p.

Atkinson, D.B. 1989. Diel movements of beaked redfish and the implications of these for stratified random bottom trawl estimates of biomass and abundance. North American J. Fisheries Management, 9: 163-170.

Atkinson, D.B. and D. Power. 1991. The redfish stock issue in 3P, 4RST and 4VWX. CAFSAC Res. Doc. 91/38. 47p.

Ávila de Melo, A., R. Alpoim and F. Saborido-Rey. 2002. The Present Status of Beaked Redfish (*S. mentella* and *S. fasciatus*) in NAFO Division 3M and Medium Term Projections Under A Low Commercial Catch/ High Shrimp Fishery By-Catch Regime. NAFO SCR Doc. 02/54, Ser. No. N4666, 60p.

Bainbridge, V. and G.A. Cooper. 1971. Populations of *Sebastes* larvae in the North Atlantic. Int. Comm. Northwest Atl. Fish. Res. Bull. 8: 27-35.

Barsukov, V.V., I.A. Oganin and A.I. Pavlov.1991. Morphological and ecological differences between *Sebastes fasciatus* and *S. mentella* on the Newfoundland Shelf and Flemish Cap. J. Ichthyology, 31: 1-17.

Benoit, H.P., M.-J. Abgrall and D.P. Swain. 2003. An assessment of the general status of marine and diadromous fish species in the southern Gulf of St. Lawrence based on annual bottom-trawl surveys (1971-2002). Can. Rech. Rep. Fish. Aquat. Sci. No. 2472: iv + 183 p.

Bishop, C.A. 1994. Revisions and additions to stratification schemes used during research vessel surveys in NAFO areas 2 and 3. NAFO SCR Doc. 94/43 Ser. No. N2413. 23p.

Bourdages, H., L. Savard, D. Archambault and S. Valois. 2007. Résultats des expériences de pêche comparative d'août 2004 et 2005 dans le nord du golfe du Saint-Laurent, entre le NGCC *Alfred Needler* et le NGCC *Teleost*. Rapp. tech. can. sci. halieut. aquat. 2750: ix + 57 p.

Bourgeois, C. E. and I.-H. Ni. 1984. Metazoan parasites of Northwest Atlantic redfishes (*Sebastes* spp.). Can. J. Zool. 62:1879-1885.

Branton, R. 1999. Update on the Status of Unit 3 Redfish, 1999. Can. Stock Assessment Secretariat Res. Doc. 99/152.

Branton, R.M. and R.G. Halliday. 1994. Unit 3 Redfish Population and Fishery Trends. DFO Atlantic Fisheries Res. Doc. 94/38.

Branton, R.M., B. Morin, D. Power and J.-M. Sévigny. 2003. Standardised inter-regional redfish survey sampling and analysis of growth and maturity in management units 1,2,3 & NAFO Div. 3O. pp. 49-56 in Gascon, D. (ed.). Redfish Multidisciplinary Research Zonal Program (1995-1998): Final Report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiii + 139 p.

Campana, S.E., K.C.T. Zwanenburg and J.N. Smith. 1990. 210Pb/226Ra determination of longevity in redfish. Can. J. Fish. Aquat. Sci. 47: 163-165.

Cavalli-Sforza, L. L. & A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. Evolution 32: 550–570.

Desrosiers, B., J.-M. Sévigny and J.P. Chanut. 1999. Restriction fragment length polymorphism of rDNA in the redfish *Sebastes fasciatus* and *S. mentella* (Scorpaenidae) from the Gulf of St. Lawrence. Can. J. Zool. 77: 267-277.

DFO 2000 a. Status of Redfish Stocks in the Northwest Atlantic: Redfish in Units 1, 2, and 3, and in Division 3O. DFO Science stock status report A1-01(2000). 24p.

DFO 2000 b. Northwest Atlantic harp seals. DFO Science stock status report E1-01. 7p.

Dutil, J.-D., Y. Lambert, R. Larocque and J.-M. Sévigny. 2003. Temperature preference and tolerance in larval and adult redfish *S. fasciatus* and *S. mentella*. p. 73-78. *In*: Gascon, D. (ed.). Redfish Multidisciplinary Research Zonal Program (1995-1998): Final Report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiii + 139p.

Fanning, L.P. 1985. Intercalibration of Research Survey Results Obtained by Different Vessels. CAFSAC Res. Doc. 85/3.

Fréchet, A., C. Savenkoff and J. Gauthier. 2006. Updates concerning unaccounted fishing mortalities. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/086.

Fraser, D.J. and L. Bernachez. 2001. Adaptative conservation: toward a unified concept for defining conservation units. Mol. Ecol. 10: 2741-2752.

Gascon, D. (ed.) 2003. Redfish Multidisciplinary Research Zonal Program (1995-1998): Final Report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiii + 155 p.

Gauthier, S. and G.A. Rose. 2002. Acoustic observation of diel vertical migration and shoaling behaviour in Atlantic redfish. J. Fish Biol. 61: 1135-1153.

Hammill, M.O. and G.B. Stenson. 2000. Estimated Prey Consumption by Harp seals (*Phoca groenlandica*), Hooded seals (*Cystophora cristata*), Grey seals (*Halichoerus grypus*) and Harbour seals (*Phoca vitulina*) in Atlantic Canada. J. Northw. Atl. Fish. Sci. 26: 1–23.

Hammil, M.O. and G.B. Stenson. 2004. Estimated consumption of Atlantic cod (*Gadus morhua*) by harp seal (*Phoca groendlendica*), in NAFO zone 4RS. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/093.

ICNAF. 1973. Annual report 23: 82. Int. Comm. Northwest Atl. Fish. 1973.

Laurel, B.J., J.A. Brown and R. Anderson. 2001. Behaviour, growth and survival of redfish larvae in relation to prey availability. J. Fish Biol. 59: 884-901.

Marcogliese, D.J., E. Albert, P. Gagnon and J.-M. Sévigny. 2003. Use of parasites in stock identification of the deepwater redfish (*Sebastes mentella*) in the Northwest Atlantic. Fish. Bull. 101: 183-188.

Mayo, R.K., J.K.T. Brodziak, M. Thompson, J.M. Burnett and S.X. Cadrin. 2002. Biological characteristics, population dynamics, and current status of redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine-Georges Bank region. Northeast Fish. Sci. Cent. Ref. Doc. 02-05; 130p.

Mead, G.W. and C.J. Sinderman. 1961. Systematics and natural marks. ICNAF Spec. Publ., No. 3:9-11.

Méthot, R., B. Morin and D. Power. 2004. Description of the methods used to discriminate *Sebastes fasciatus* and *S. mentella* in Units 1 and 2. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/92.

McGlade, J.M., M.C. Annand and T.J. Kenchington. 1983. Electrophoretic identification of *Sebastes* and *Helicolenus* in the northwestern Atlantic. Can. J. Fish. Aquat. Sci. 40: 1861-1870.

Morin, B. and S. Hurtubise. 2003. Shrimp fishery bycatches of redfish and review of the possible causes of the disappearance of the 1988 year-class. pp. 95-98 in Gascon, D. (ed.) 2003. Redfish Multidisciplinary Research Zonal Program (1995-1998): Final Report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiii + 139 p.

Morin, B., R. Méthot, J.-M. Sévigny, D. Power, B. Branton and T. McIntyre. 2004. Review of the structure, the abundance and distribution of *Sebastes mentella* and S. *fasciatus* in Atlantic Canada in a species-at-risk context. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/58.

Morin, B., B. Bernier and N. St-Hilaire. 1999. L'état du stock de sébaste de l'unité 1 (Golfe du Saint-Laurent) en 1998. DFO Can. Stock Assess. Res. Doc. 99/132.

Moritz, C. 1994. Defining ‘evolutionarily significant units’ for conservation. Trends Ecol. Evol. 9: 373-375.

Myers, R.A. and N.G. Cadigan. 1995. Was an increase in natural mortality responsible for the collapse of northern cod? Can. J. Fish. Aquat. Sci. 52: 1274-1285.

Ni, I.-H. 1981. Separation of sharp-beaked redfishes, *Sebastes mentella* and *S. fasciatus*, from Northeastern Grand Bank by morphology of extrinsic gasbladder musculature. J. Northwest Atl. Fish. Sci. 2: 7-12.

Ni, I-H. 1982. Meristic variation in beaked redfishes, *Sebastes mentella* and *S. fasciatus*, in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 39: 1664-1685.

Ni, I.-H. and W.D. McKone. 1983. Distribution and concentration of redfishes in Newfoundland and Labrador waters. Northwest Atl. Fish. Organ. Sci. Counc. Stud. 6: 7-14.

Ni, I.-H. and W. Templeman. 1985. Reproductive cycles of redfish (*Sebastes*) in Southern Newfoundland waters. J. Northwest Atl. Fish. Sci. 6: 57-63.

Parsons, L.S. and D.G. Parsons. 1973. An evaluation of the status of ICNAF Divisions 3P, 3O and 3LN redfish. Int. Comm. Northwest Atl. Fish. Res. Doc. 73/88, Ser. No. 3042, 16p.

Parsons, L.S. and D.G. Parsons. 1974. An evaluation of the status of Flemish Cap redfish. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/78, Ser. No. 3311, 18p.

Parsons, L.S. and D.G. Parson. 1976. Status of the Gulf of St. Lawrence redfish stock. Background report for the Offshore Groundfish Advisory Committee. Fisheries and Marine Service. Biological Station. St. John’s, Newfoundland. 14p.

Parsons, L.S., A.T. Pinhorn and D.G. Parsons. 1976. An evaluation of the Northern Newfoundland-Labrador and Flemish Cap redfish fisheries. Res. Bull. Int. Comm. Northwest Atlant. Fish. 12: 37-48.

Payne, R.H. and I.-H. Ni. 1982. Biochemical population genetics of redfishes (*Sebastes*) off Newfoundland. J. Northwest Atl. Fish. Sci. 3:169-172.

Pinhorn, A.T. and L.S. Parsons. 1974. Status of the redfish fishery in ICNAF Subarea 2 and Division 3K. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/5, Ser. No. 3148, 5p.

Power, D. 2000. The status of redfish in Division 3O. DFO Can. Stock Assess. Res. Doc. 2000/137, 21p.

Power, D. 2001. An Assessment of the Status of the Redfish Resource in NAFO Divisions 3LN. NAFO SCR. Doc. 01/62, Ser. No. N4440, 22p.

Power, D. and D. B. Atkinson. 1998. Update on the status of Redfish in 3O. DFO Can. Stock Assess. Res. Doc. 98/110. 20p.

Power, D., D. Maddock and L.S. Parsons. 1998. Canadian Research Survey Data Conversions for Redfish in Div. 3LN based on Comparative Fishing Trials between an Engel 145 Otter Trawl and a Campelen 1800 Shrimp Trawl. NAFO SCR Doc. 98/71. Serial No. N3063, 21p.

Power, D. and F. Mowbray. 2000. The status of redfish in Unit 2. DFO Can. Stock Assess. Res. Doc. 2000/136, 55p.

Power, D. and Ni, I.-H. 1985. Morphometric differences between golden redfish (*Sebastes marinus*) and beaked redfish (*S. mentella* and *S. fasciatus*). J. Northwest Atl. Fish. Sci. 6: 1-7.

Power, D and D.C. Orr. 2001. Canadian research survey data conversions for redfish in SA2+Div. 3K based on comparative fishing trials between and Engel 145 otter trawl and a Campelen 1800 shrimp trawl. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/103, 15p.

Roques, S., P. Duchesne, and L. Bernatchez. 1999. Potential of microsatellites for individual assignment**:** the North Atlantic redfish (genus *Sebastes*) species complex as case study. Mol. Ecol. 8: 1703-1717.

Roques, S., J.-M. Sévigny, L. Bernatchez and D. Power. 2000. Redfish species distribution and population genetic structure in the Northwest Atlantic: Preliminary results. NAFO SCR Doc. 00/48.

Roques, S., J.-M. Sévigny and L. Bernatchez. 2001. Evidence for broadscale introgressive hybridization between two redfish (genus *Sebastes*) in the North-west Atlantic: a rare marine example. Mol. Ecol. 10: 149-165.

Roques, S., J.-M. Sévigny and L. Bernatchez. 2002. Genetic structure of deep-water redfish, *Sebastes mentella*, populations across the North Atlantic. Mar. Biol. 140: 297-307.

Rubec, P.J., J.M. McGlade, B.L., Trottier and A. Ferron. 1991. Evaluation of methods for separation of Gulf of St. Lawrence beaked redfishes, *Sebastes fasciatus* and *S. mentella*: malate dehydrogenase mobility pattern compared with extrinsic gasbladder muscle passages and anal fin ray counts. Can. J. Fish. Aquat. Sci. 48: 640-660.

Ryder, O.A. 1986. Species conservation and systematics: the dilemma of subspecies. Trends in Ecology and Evolution, 1: 9-10.

Schmidt, C. 2005. Molecular genetic studies of species and population structure of North Atlantic redfish (genus *Sebastes*; Cuvier 1829). Ph D thesis. University of Hamburg. 303 p.

Sandeman, E.J. 1973. The redfish of the Gulf of St. Lawrence biological considerations – past, present and future? Fisheries and Marine Service. Biological Station. St. John's, Newfoundland. 19p.

Sévigny, J.-M. and de Lafontaine, Y. 1992. Identification of redfish juveniles in the Gulf of St. Lawrence using genotypic specific variations. P.69-73. In Y. de Lafontaine, Lambert, T., Lilly, G.R., McKone, W.D., Miller, R.J. (eds.) Juvenile Stages : the missing link in fisheries research. Rapp. Tech. Can. Sci. Halieut. Aquat. 1890 : vii + 139pp.

Sévigny, J.-M., P. Gagné, Y. de Lafontaine and J. Dodson. 2000. Identification and distribution of the larvae of redfish species (*Sebastes fasciatus* and *S. mentella*: Scorpaenidae) in the Gulf of St. Lawrence. Fish. Bull. 98: 375-388.

Smedbol, R.K., P.A. Shelton, D.P. Swain, A. Fréchet and G.A. Chouinard. 2002. Review of population structure, distribution and abundance of cod (*Gadus morhua*) in Atlantic Canada in a species-at-risk context. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/082.

St-Pierre, J.-F. and Y. de Lafontaine, Y. 1995. Fecundity and reproduction characteristics of beaked redfish (*Sebastes fasciatus* and *S. mentella*) in the Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 2059: 32 + vii p.

Swain, D.P. and Q.A.F. Sinclair. 1994. Fish distribution and catchability: What is the appropriate measure of distribution? Can. J. Fish. Aquat. Sci. 51: 1046-1054.

Templeman, W. and H. J. Squires. 1960. Incidence and distribution of infestation by *Sphyrion lumpi* (Kroyer) on the redfish, *Sebastes marinus* (L.), of the western North Atlantic. J. Fish. Res. Board Can. 17: 5-31.

Templeman, W.T. 1980. Incidence of subcaudal melanophores in pre-extrusion larvae of redfish species in the Newfoundland-Labrador area. J. Northw. Atl. Fish. Sci. 1: 7-19.

Valentin, A. 2006. Structure des populations de sébaste de l'Atlantique du nord-ouest dans un contexte de gestion des stocks et d'évolution. Thèse de Doctorat. Université du Québec à Rimouski. 212p.

Valentin, A., J.-M. Sévigny and J.-P. Chanut. 2002. Geometric morphometrics reveals body shape differences between sympatric redfish *Sebastes mentella*, *Sebastes fasciatus* and their hybrids in the Gulf of St. Lawrence. J. Fish. Biol. 60: 857-875.

Valentin, A., J.-M. Sévigny, D. Power, R.M. Branton and B. Morin. 2006. Extensive sampling and concomitant use of meristic characteristics and variation at the *MDH-A** locus reveal new information on redfish species distribution and spatial patterns introgressive hybridisation in the Northwest Atlantic. J. Northw. Atl. Fish. Sci. 36: 65-80.

Vazquez, A. 2002. Results from the bottom trawl survey on Flemish Cap of July 2001. NAFO SCR. Doc. 01/12, Ser. No. N4390, 43p.

Weir, B.S. and C.C. Cockerham. 1984. Estimating *F*-statistics for the analysis of population structure. Evolution, 18: 1358-1370.

Yanulov, K.P. 1960a. Parasites as indicators of local rosefish stocks. p. 266-276. *In*: Soviet Fisheries Investigations in the Northwest Atlantic (PINRO) Moscow 1960.

Yanulov, K.P.1960b. On the groups of rosefish (*Sebastes mentella* Travin) in the Labrador-Newfoundland area. p. 277-289. *In*: Soviet Fisheries Investigations in the Northwest Atlantic (PINRO) Moscow 1960.

Table 1. Variation in redfish recruitment strength for each stock (Unit 3 excluded) based on survey information and the fishery.

			Stocks										
Year	Unit 1	Unit 2	2GH	2J3K	3LN	3O	Year	Unit 1	Unit 2	2GH	2J3K	3LN	3O
1945							1976						
1946	■	■					1977						
1947							1978						■
1948							1979						
1949							1980	■	■			■	
1950							1981						
1951							1982						
1952							1983						
1953							1984						▨
1954							1985	▨	▨				
1955							1986						
1956	■	■			■		1987					■	
1957							1988	▨	■				■
1958	■	■			■		1989						
1959							1990						
1960							1991			■			
1961							1992						
1962							1993						
1963							1994			▨			
1964							1995			■			
1965				■	■		1996						
1966	▨	▨				■	1997						
1967							1998						
1968							1999						
1969							2000						
1970	■	■			■		2001						
1971						■	2002						
1972				■			2003						
1973							2004						
1974	▨	▨					2005						
1975							2006						

■ Relatively strong at young age and contributing to the fishery
▨ Relatively strong at young age but disappear before contributing to the fishery

Table 2. Names, geographical origins and sizes (*N*) of 17 redfish samples used for the assessment of the population genetic structure of *Sebastes 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; SYMPFAS and SYMPMEN represent samples of *S. fasciatus* and *S. mentella* collected in the sympatric zone (see Roques et al. 2000; 2001 for the localisation of the sites 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	Grand Banks	44
MEA2	Grand 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 3. Description of the samples used for the population structure analyses of *Sebastes fasciatus* and *S. mentella* based on microsatellite DNA markers and morphometry (Valentin 2006). *N*, sample size.

S. fasciatus							Males			Females			TOT
Sample Name	**Date**		**NAFO Div.**	**Longitude**	**Latitude**	**Depth (m)**	**Mean Size (cm)**	**SD**	***N***	**Mean Size (cm)**	**SD**	***N***	***N***
NE outside GSL-LCH													
3L65	fall	2001	3L	47°16.6	46°51.8	404	20.9	1.2	17	22.9	3.7	7	**24**
3N23	fall	2001	3N	50°22.2	42°47.5	408	23.5	2.4	14	26.1	3.5	18	**32**
3O44	fall	2001	3O	52°56.0	44°11.6	408	20.4	0.9	18	20.8	1.2	14	**32**
3PS1	summer	2002	3PS	55°10.2	45°08.2	202	24.7	1.5	16	26.3	2.2	16	**32**
3PS138	fall	2002	3PS	56°01.8	44°51.9	448	24.4	2.8	8	27.3	2.3	24	**32**
3PS26	summer	2002	3PS	56°14.4	44°52.2	354	22.1	1.2	17	25.6	2.9	15	**32**
Inside GSL-LCH													
3PS114	summer	2002	3PS	56°50.2	47°19.4	241	26.0	5.1	9	29.1	6.7	23	**32**
3PS88b	fall	2002	3PS	57°27.3	47°07.6	234	27.5	2.2	15	30.1	4.0	14	**29**
4R107	summer	2001	4R	59°10.8	49°45.5	217	26.8	1.5	18	30.6	1.9	13	**31**
4VN67	summer	2002	4VN	58°19.7	45°55.0	219	26.1	2.8	14	31.6	3.2	18	**32**
4VS36	summer	2002	4VS	57°42.2	45°16.3	217	25.1	1.2	12	27.3	2.5	20	**32**
4R53	fall	2002	4R	59°44.3	48°17.8	248	23.7	1.6	12	26.6	2.4	20	**32**
4VN5	fall	2002	4VN	58°07.0	45°47.1	245	24.9	1.5	6	28.9	2.4	26	**32**
BonBay	spring	2002	4R	—	—	—	24.1	1.4	9	29.0	3.3	23	**32**
SW outside GSL-LCH													
NS85	summer	2001	4X	65°19.5	43°00.0	153	22.7	2.0	10	25.3	3.7	22	**32**
NS95	summer	2001	4W	60°03.2	43°27.4	504	27.5	1.3	7	34.1	2.9	25	**32**
s261	fall	2001	5Z	67°04.1	42°18.9	297	25.0	1.5	7	30.5	3.9	25	**32**
s266	fall	2002	5Z	69°54.3	42°18.7	203	22.3	1.1	20	26.3	1.6	12	**32**
s327	fall	2001	5Y	67°17.7	43°49.0	197	22.3	0.8	16	25.4	2.4	16	**32**
									245			**351**	**596**
S. mentella													
NE outside GSL-LCH													
2J42	fall	2001	2J	53°15.8	54°33.7	671	26.1	2.4	12	26.2	2.5	19	**31**
3L29	fall	2001	3L	47°25.4	48°03.1	506	24.4	2.1	10	24.9	1.7	18	**28**
s1050	fall	2001	1F	47°09.5	60°09.2	357	21.3	1.3	15	21.3	1.6	16	**31**
Inside GSL-LCH													
3PN1	summer	2002	3PN	58°50.0	46°53.3	434	29.1	1.5	21	30.2	2.1	11	**32**
3PN77	fall	2002	3PN	58°24.0	47°08.3	390	28.1	1.8	13	29.7	1.4	19	**32**
3PS133	fall	2002	3PS	56°49.2	45°32.0	394	29.3	2.8	13	30.8	1.8	18	**31**
4R48	summer	2002	4R	59°46.0	48°07.3	315	27.6	1.2	11	30.0	3.9	18	**29**
4R51	fall	2002	4R	59°58.9	48°19.1	392	30.3	1.4	18	32.7	1.0	14	**32**
4S35	fall	2002	4S	60°50.5	48°19.5	429	30.0	2.0	17	33.3	1.4	14	**31**
4S44	summer	2002	4S	60°34.2	48°03.6	447	29.7	2.2	15	31.4	2.0	16	**31**
4VN12	fall	2002	4VN	59°37.2	46°58.3	431	29.6	2.2	19	32.1	2.1	12	**31**
4VN2	fall	2002	4VN	57°53.0	45°42.8	425	29.3	1.9	15	31.7	1.5	17	**32**
4VN77	summer	2002	4VN	58°55.4	46°22.8	348	29.3	1.9	16	30.2	1.7	16	**32**
4VS13	summer	2002	4VS	58°02.8	44°13.8	515	30.0	1.6	15	31.7	1.6	15	**30**
4VS147	fall	2002	4VS	57°07.9	44°46.3	420	28.9	2.7	12	31.4	1.8	19	**31**
Sag	winter	2003	SAG	—	—	—	25.5	0.8	19	26.0	1.1	12	**31**
									241			**254**	**495**
S. marinus													
3PN73	fall	2002	3PN	58°51.8	47°24.9	203	38.4	3.3	**19**	45.8	2.0	**11**	**30**
TOTAL									**505**			**616**	**1121**

Table 4. Pairwise F_{ST} values (Weir and Cockerham 1984) between 17 redfish samples. *Sebastes fasciatus* and *S. mentella* samples are delineated by dotted lines (Roques et al. 2001; 2002). ( ) non-significant allelic frequency heterogeneity following the method of Fisher (α=0.001); * non significant following Bonferroni corrections (k=120, α=0.05/120=0.0004).

Sample	FAA1	FAA2	FAS1	FAS2	FAS3	FAS4	MEA1	MEA2	MEA3	MEA4	MES5	MES6	MES7	MES1	MES2	MES3
FAA1																
FAA2	0.013*															
FAS1	0.009*	0.020														
FAS2	0.019	0.024	(-0.005*)													
FAS3	0.020	0.027	(-0.000)	(-0.006*)												
FAS4	0.009*	0.015	(-0.004*)	(-0.001*)	(0.004*)											
MEA1	0.136	0.164	0.135	0.122	0.118	0.126										
MEA2	0.115	0.141	0.111	0.104	0.099	0.107	(-0.004*)									
MEA3	0.119	0.150	0.115	0.110	0.102	0.111	(-0.001*)	(0.003*)								
MEA4	0.109	0.142	0.113	0.103	0.097	0.106	(0.006*)	0.001*	(-0.001*)							
MES5	0.083	0.112	0.082	0.078	0.074	0.074	0.006*	0.015	0.008	0.004*						
MES6	0.078	0.110	0.088	0.085	0.082	0.079	0.010	0.015	0.010	0.009	(0.000)					
MES7	0.101	0.131	0.102	0.098	0.094	0.093	0.011	0.017	0.016	0.018	(0.001*)	(-0.001*)				
MES1	0.079	0.114	0.083	0.083	0.079	0.077	0.005*	0.015	0.013	0.010	(0.002*)	(0.002*)	(-0.003*)			
MES2	0.104	0.135	0.102	0.101	0.096	0.093	0.008	0.018	0.012	0.0156	(0.000)	(0.002*)	(-0.005*)	(0.000)		
MES3	0.107	0.141	0.104	0.107	0.103	0.098	0.008*	0.022	0.016	0.016	0.009	0.004*	0.004*	0.010	0.005*	
MES4	0.082	0.114	0.084	0.087	0.084	0.079	0.017	0.027	0.019	0.021	0.001	(0.004*)	0.006*	0.010	-0.009	0.019

Table 5. Pairwise F_{ST} values (Weir and Cockerham 1984) between *Sebastes mentella* samples with significativity tests below diagonal (Valentin 2006). (-) non significant, (+) significant before Bonferroni correction, + significant after Bonferroni correction. Symbols are as in Table 3.

	2J42	**3L29**	**s1050**	**3PN1**	**3PN77**	**3PS133**	**4R48**	**4R51**	**4S35**	**4S44**	**4VN12**	**4VN2**	**4VN77**	**4VS13**	**4VS147**	**Sag**
2J42		0.012	0.027	0.039	0.033	0.043	0.041	0.041	0.040	0.037	0.039	0.034	0.043	0.040	0.033	0.042
3L29	(+)		0.007	0.025	0.018	0.027	0.027	0.025	0.022	0.020	0.025	0.021	0.024	0.022	0.019	0.025
s1050	**+**	–		0.016	0.012	0.014	0.016	0.018	0.012	0.012	0.016	0.015	0.014	0.013	0.013	0.015
3PN1	**+**	**+**	**+**		-0.001	-0.003	0.001	0.007	-0.003	0.000	0.000	-0.002	-0.003	-0.001	-0.001	-0.001
3PN77	**+**	**+**	**+**	–		0.003	0.003	-0.001	0.001	0.000	0.001	-0.003	-0.001	0.001	-0.002	0.002
3PS133	**+**	**+**	**+**	–	–		0.004	0.007	0.002	0.003	0.004	0.003	0.002	0.000	0.005	-0.001
4R48	**+**	**+**	**+**	–	–	–		0.004	0.007	0.001	0.005	0.005	0.001	0.004	0.006	0.004
4R51	**+**	**+**	**+**	(+)	–	(+)	–		0.008	-0.001	0.003	0.004	0.005	0.006	0.006	0.004
4S35	**+**	**+**	**+**	–	–	–	(+)	(+)		-0.002	0.001	-0.002	-0.002	0.005	-0.001	-0.003
4S44	**+**	**+**	(+)	–	–	–	–	–	–		0.000	-0.002	-0.002	0.003	0.001	-0.001
4VN12	**+**	**+**	**+**	–	–	–	–	–	–	–		0.001	0.000	0.004	-0.001	0.001
4VN2	**+**	**+**	**+**	–	–	–	(+)	–	–	–	–		-0.001	0.003	0.001	0.003
4VN77	**+**	**+**	**+**	–	–	–	–	–	–	–	–	–		0.000	0.002	-0.002
4VS13	**+**	**+**	**+**	–	–	–	–	(+)	–	–	–	–	–		0.005	0.005
4VS147	**+**	**+**	**+**	–	–	–	(+)	(+)	–	–	–	–	–	–		0.002
Sag	**+**	**+**	**+**	–	–	–	–	–	–	–	–	–	–	–	–	

Table 6. Pairwise F_{ST} values (Weir and Cockerham 1984) between *Sebastes fasciatus* samples with significativity tests below diagonal (Valentin 2006). (-) non significant, (+) significant before Bonferroni correction, + significant after Bonferroni correction (Valentin 2006). Symbols are as in Table 3.

	3L65	3N23	3O44	3PS1	3PS138	3PS26	3PS114	3PS88b	4R107	4VN67	4VS36	4R53	4VN5	BonBay	NS85	NS95	s261	s266	s327
3L65		-0.002	0.006	0.001	-0.003	0.000	0.003	0.006	0.013	0.007	0.007	0.016	0.019	0.052	0.016	0.005	0.010	0.007	0.012
3N23	–		0.001	0.003	0.000	-0.003	0.004	0.004	0.008	0.006	0.004	0.016	0.017	0.042	0.014	0.002	0.005	0.005	0.011
3O44	–	–		0.001	-0.001	0.000	0.001	0.002	0.008	0.006	0.006	0.014	0.016	0.044	0.017	0.002	0.010	0.008	0.014
3PS1	–	–	–		0.000	-0.002	0.000	-0.003	0.006	0.004	-0.001	0.007	0.014	0.039	0.008	0.001	0.003	-0.001	0.001
3PS138	–	–	–	–		-0.003	-0.001	0.004	0.010	0.006	0.005	0.017	0.017	0.047	0.019	0.004	0.009	0.004	0.007
3PS26	–	–	–	–	–		0.002	0.004	0.010	0.008	0.002	0.012	0.018	0.051	0.016	0.004	0.003	0.001	0.006
3PS114	–	–	–	–	–	–		-0.004	0.002	-0.001	0.001	0.008	0.017	0.038	0.007	0.006	0.003	0.002	0.006
3PS88b	–	–	–	–	–	–	–		0.004	0.000	0.001	0.010	0.023	0.041	0.008	0.003	0.001	0.005	0.007
4R107	(+)	(+)	(+)	(+)	(+)	(+)	–	–		0.005	0.002	0.011	0.014	0.035	0.013	0.005	0.002	0.010	0.010
4VN67	–	(+)	–	–	(+)	(+)	–	–	–		0.001	0.015	0.019	0.044	0.010	0.008	0.005	0.003	0.009
4VS36	(+)	–	(+)	–	–	–	–	–	–	–		0.006	0.009	0.038	0.008	0.002	0.001	0.001	0.007
4R53	+	+	+	(+)	+	(+)	(+)	(+)	(+)	+	(+)		0.010	0.038	0.004	0.015	0.009	0.006	0.010
4VN5	+	+	+	(+)	+	+	+	+	+	+	(+)	(+)		0.029	0.007	0.017	0.019	0.010	0.012
BonBay	+	+	+	+	+	+	+	+	+	+	+	+	+		0.032	0.042	0.046	0.041	0.038
NS85	+	+	+	(+)	+	+	(+)	(+)	+	(+)	(+)	–	(+)	+		0.019	0.006	0.004	0.004
NS95	–	–	–	–	–	–	(+)	–	–	(+)	–	+	+	+	+		0.008	0.009	0.010
s261	(+)	–	(+)	–	(+)	–	–	–	–	–	–	(+)	+	+	–	(+)		0.000	0.001
s266	–	–	(+)	–	–	–	–	–	(+)	–	–	–	(+)	+	–	(+)	–		-0.005
s327	(+)	(+)	(+)	–	(+)	–	(+)	(+)	(+)	(+)	(+)	(+)	(+)	+	–	(+)	–	–	

Table 7. Length (L50) and age (A50) at 50% maturity of the males *Sebastes fasciatus*, *S. mentella* and heterozygous individuals for Units 1, 2 and 3. *N*, sample size.

	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 8. Length (L50) and age (A50) at 50% of maturity of the females *Sebastes fasciatus*, *S. mentella* and heterozygous individuals for Units 1, 2 and 3, NAFO Divisions 3O and 3LN. *N*, sample size.

	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 9. Proportions of *Sebastes mentella* and *S. fasciatus* by depth zone based on the meristic data from Ni (1982) (see text) for stocks in NAFO Divisions 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 10. Indices of abundance of total (all ages) and mature *Sebastes fasciatus*, *S. mentella* and of heterozygous redfish for DFO groundfish surveys 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	3162	2826	952	1813	2002	645
1985	3824	1751	670	1327	1013	346
1986	2832	1705	628	1640	935	314
1987	3378	2453	846	2161	1506	492
1988	3256	3103	1031	2500	2293	739
1989	2894	2456	830	2327	2165	713
1990	1633	797	278	345	563	166
1991	1808	649	265	381	418	131
1992	441	224	82	451	332	116
1993	323	361	109	186	306	88
1994	187	136	47	117	106	36
1995	94	119	37	41	97	28
1996	92	99	31	39	75	22
1997	123	106	34	51	81	24
1998	338	111	42	140	58	20
1999	205	113	40	35	60	17
2000	320	142	52	41	65	19
2001	196	111	38	36	61	17
2002	139	119	38	36	87	24
2003	344	287	92	158	216	64
2004	189	68	26	57	34	11
2005	3822	587	304	66	59	18
2006	1662	334	161	91	50	16
2007	1967	437	203	50	36	11

Table 11. Indices of abundance of total (all ages) and mature *Sebastes fasciatus*, *S. mentella* and heterozygous redfish for DFO groundfish surveys in Unit 2.

Survey year	Index of abundance (10^6)					
	All ages			Mature population		
	S. fasciatus	*S. mentella*	heterozygous	*S. fasciatus*	*S. mentella*	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 12. Indices of abundance of total (all ages) and mature *Sebastes fasciatus* for DFO groundfish surveys in Unit 3.

Survey year	Index of abundance (10^6)	
	All ages *S. fasciatus*	Mature population *S. fasciatus*
1970	402	233
1971	428	275
1972	521	445
1973	526	499
1974	172	82
1975	572	564
1976	80	59
1977	299	288
1978	434	430
1979	50	46
1980	49	45
1981	81	77
1982	208	186
1983	330	317
1984	244	191
1985	49	29
1986	195	162
1987	157	143
1988	248	222
1989	79	51
1990	222	172
1991	104	56
1992	324	316
1993	206	177
1994	208	137
1995	166	119
1996	217	143
1997	586	302
1998	125	64
1999	329	248
2000	282	183
2001	352	331
2002	151	118
2003	392	189
2004	195	125
2005	446	343
2006	645	294

Table 13. Indices of abundance of total (all ages) and mature *Sebastes fasciatus* and *S. mentella* for DFO groundfish surveys in NAFO Division 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	232.7	39.9	77.4	11.8
2003	202.9	15.1	107.5	7.3	92.1	21.4	49.2	8.1
2004	485.7	19.4	354.4	16.2	130.4	28.5	76.5	15.0
2005	400.0	26.8	206.2	20.8	190.1	43.7	120.5	22.3
2006	NS	NS	NS	NS	260.1	71.7	190.0	33.5

Table 14. Indices of abundance of total (all ages) and mature *Sebastes fasciatus* and *S. mentella* for the spring and the autumn DFO groundfish surveys in NAFO Divisions 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	159.2	85.7	94.3	60.7
2003	129.0	46.6	53.5	20.5	324.7	88.7	146.2	54.5
2004	200.2	117.8	143.7	103.3	111.5	83.2	80.8	56.6
2005	322.1	62.4	151.0	43.7	216.5	80.0	114.1	51.3
2006	196.0	21.1	95.0	10.4	428.4	97.5	252.1	61.6

Table 15. Indices of abundance of total (all ages) and mature *Sebastes fasciatus* and *S. mentella* for DFO autumn groundfish surveys in NAFO Divisions 2J3K, 2GH (1987-1999) and in Division 2H only (2001-2006).

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	2GH			
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	2H Only			
2001	145.2	268.8	6.8	91.1	3.0	96.4	0.4	5.4
2002	109.9	265.0	5.5	62.7				
2003	178.2	366.4	2.6	42.0				
2004	325.6	520.3	8.4	103.3	6.0	129.2	0.2	16.4
2005	305.3	559.5	35.4	81.6				
2006	286.6	790.5	71.1	263.0	9.7	148.8	0.6	20.1

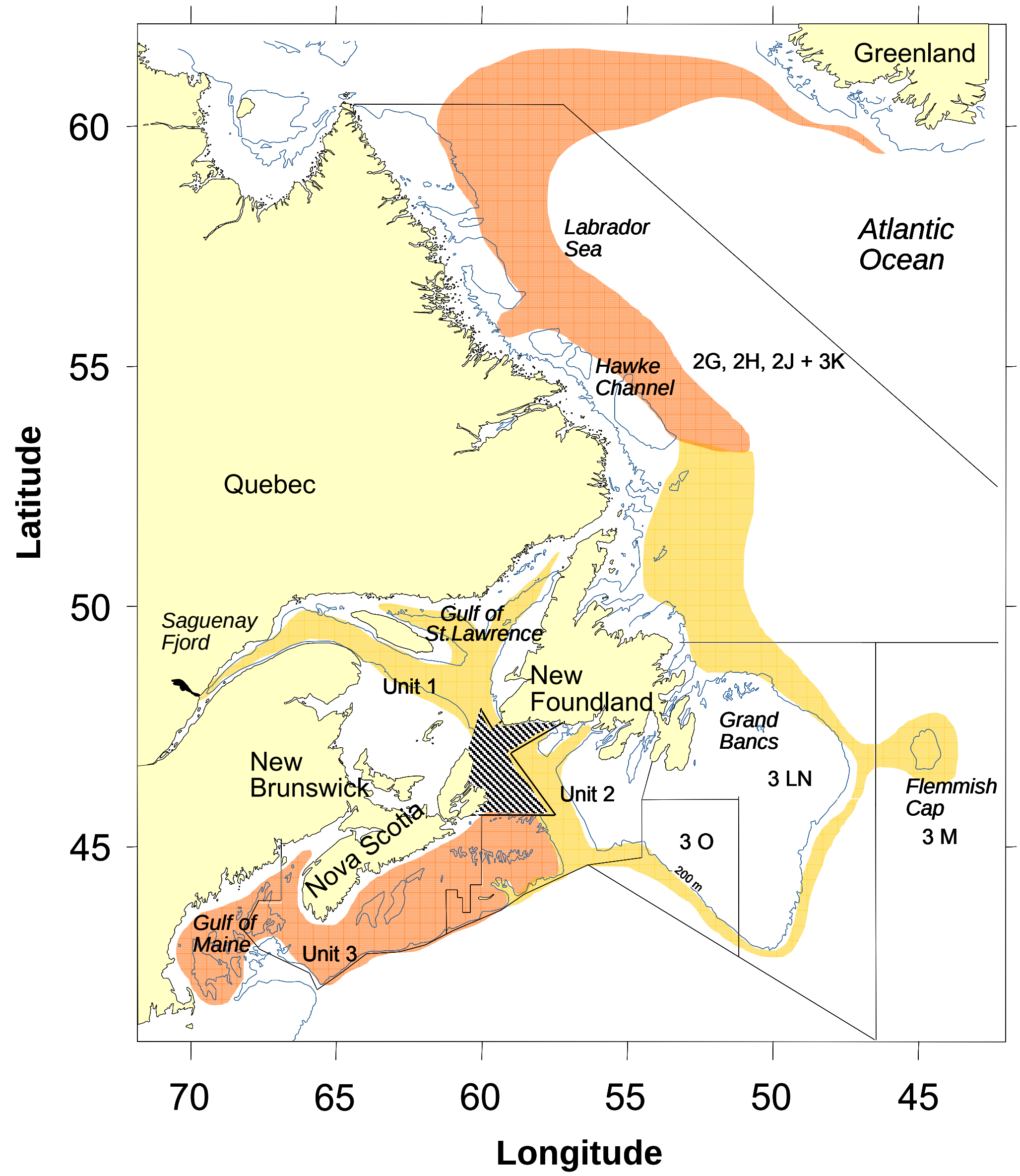


Figure 1. Map of the Northwest Atlantic summarising the general distribution of *Sebastes fasciatus* and *S. mentella* based on data of anal fin ray counts (AFC), extrinsic gasbladder muscle passage patterns (EGM) and genotype at the liver malate dehydrogenase locus (*MDH-A**). The approximate location 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 corresponding to NAFO subdivisions 3Pn and 4Vn (hatched) indicated the area of seasonal overlap between Units 1 and 2.

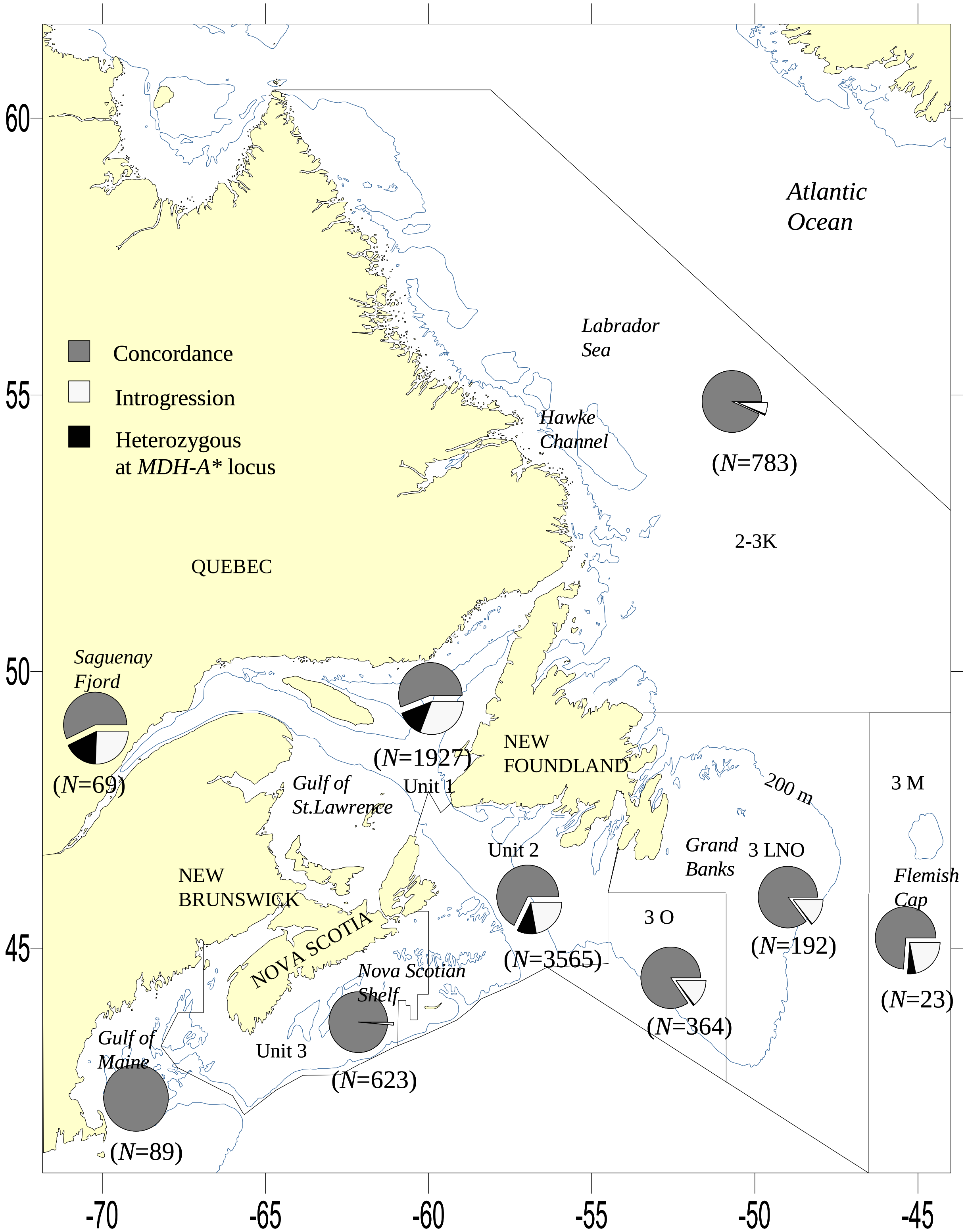


Figure 2. Map of the Northwest Atlantic showing the relative frequency of individuals for which, the three characters are concordant (concordance), the three characters are not concordant (introgression), and of heterozygous specimens at the *MDH-A** locus in the current redfish management areas NAFO Subarea 2 + Divisions 3K, 3LN, 3M, 3O, Unit 1-3 and the Gulf of Maine (modified from Valentin et al. 2006).

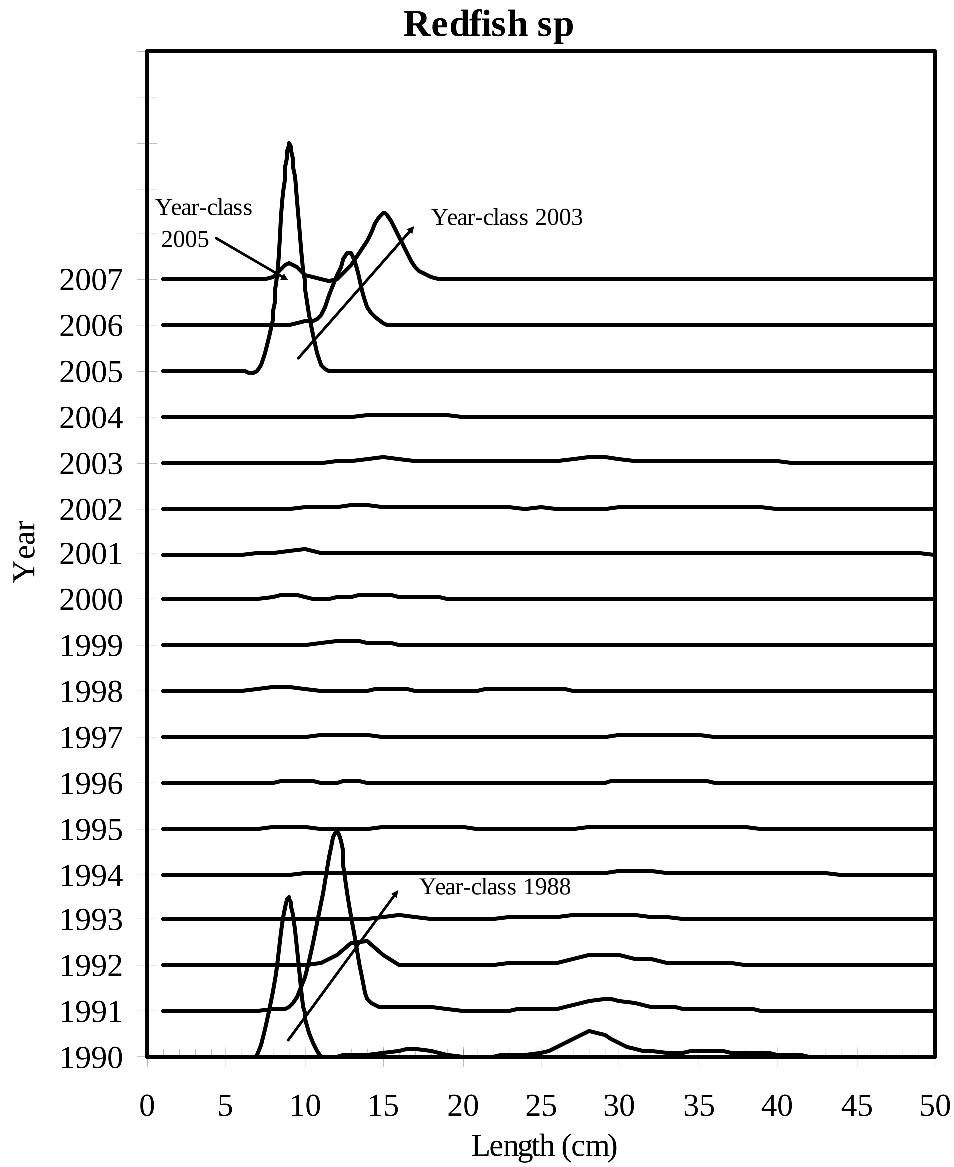


Figure 3. Length frequency distribution of redfish since 1990 in Unit 1.

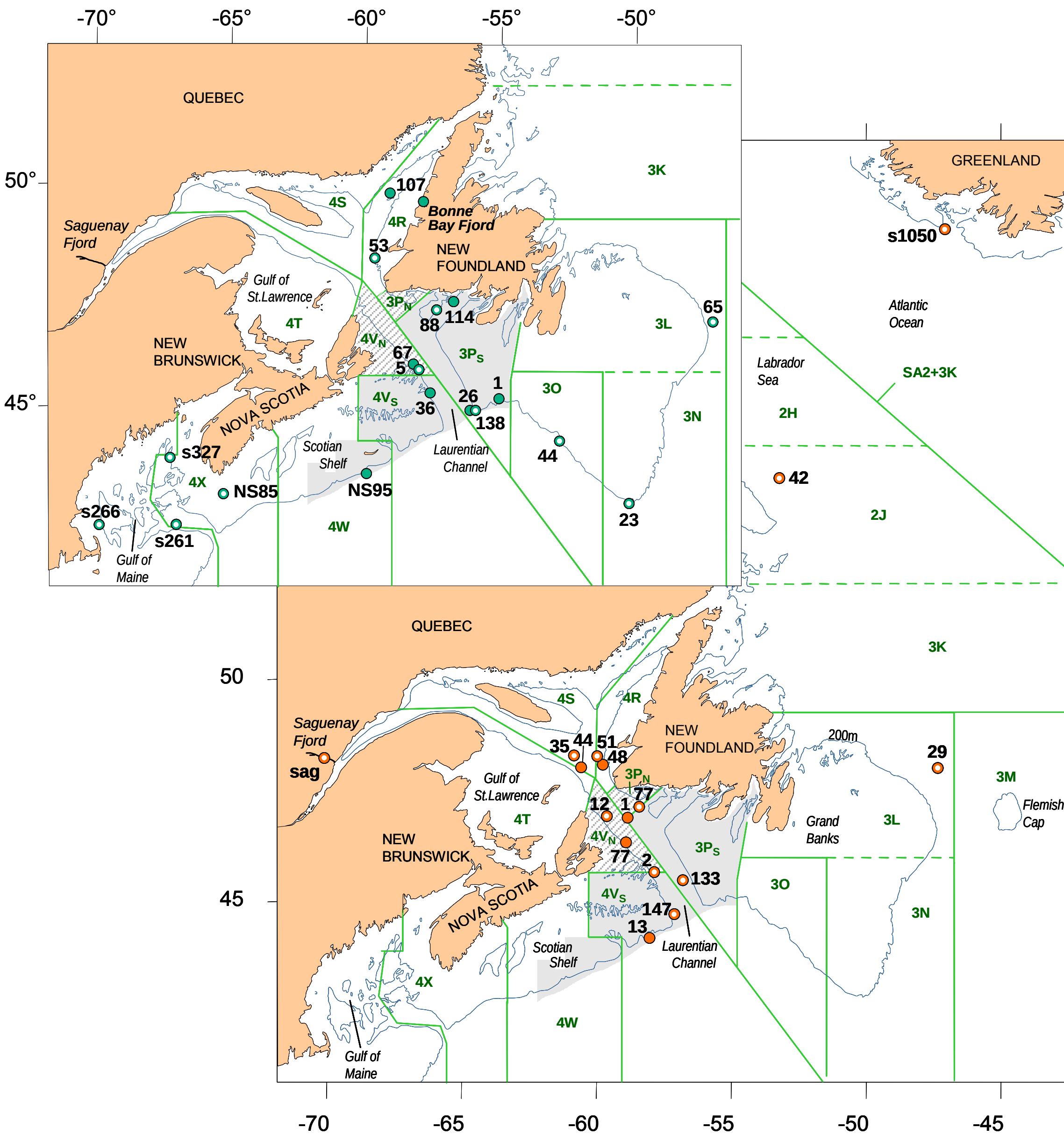


Figure 4. Geographical position of the 19 *Sebastes fasciatus* (upper map), the single *S. marinus* and 16 *S. mentella* samples (lower map) used to assess redfish population structure (Valentin 2006). NAFO Divisions are also indicated.

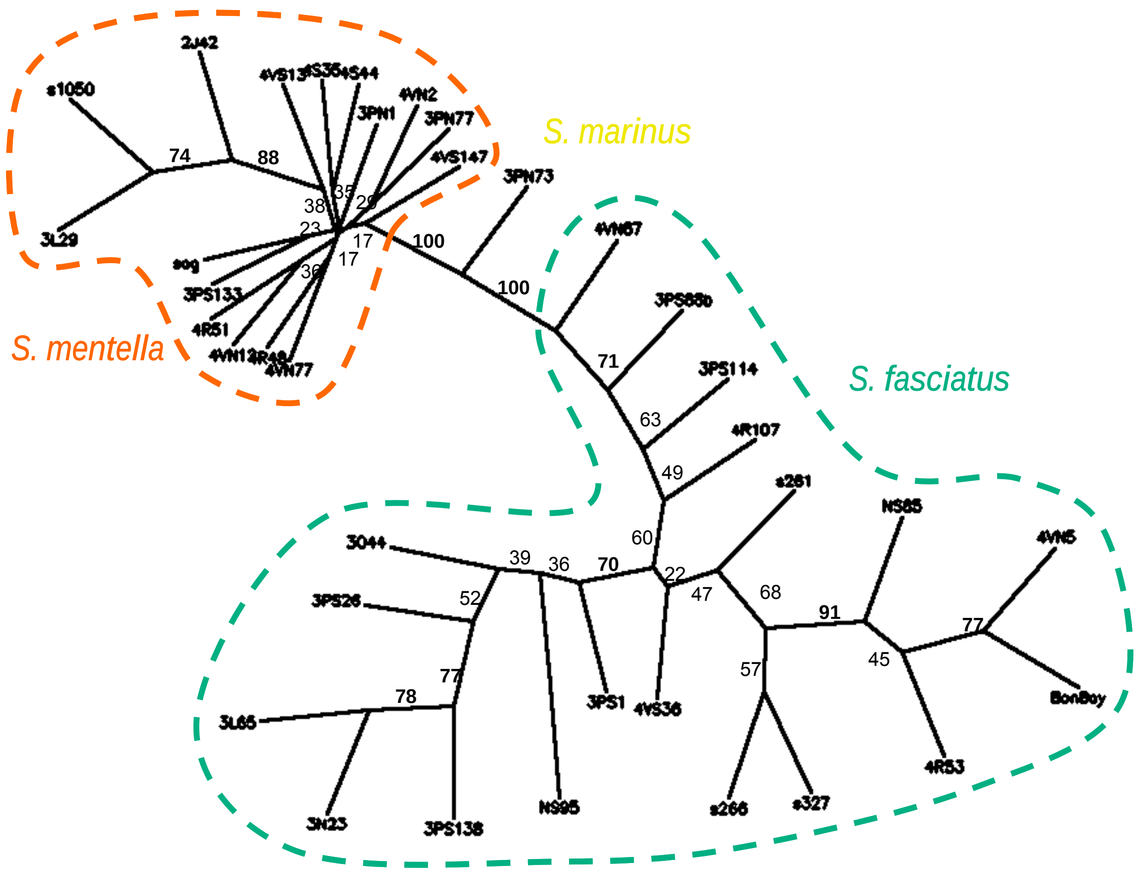


Figure 5. Neighbour-joining tree based on Cavalli-Sforza and Edwards (1967) chord distances illustrating the relationships between the 36 samples representing *Sebastes fasciatus*, *S. mentella* and *S. marinus.* Bootstrap values (%) indicate the degree of support of the nodes (Valentin 2006).

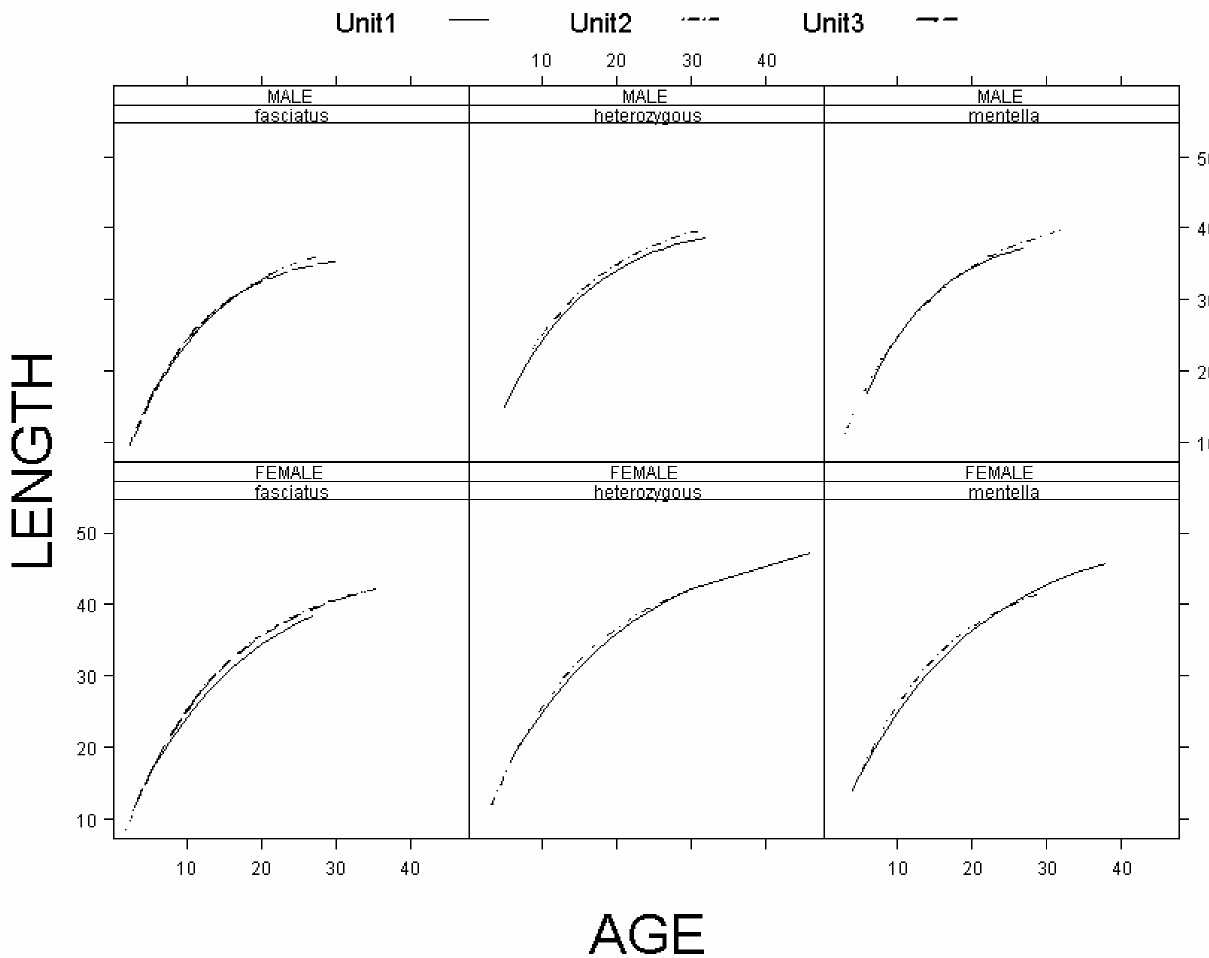


Figure 6. Growth curve for male and female *Sebastes fasciatus*, *S. mentella* and for the heterozygous redfish in Units 1, 2 and 3 (Branton et al. 2003).

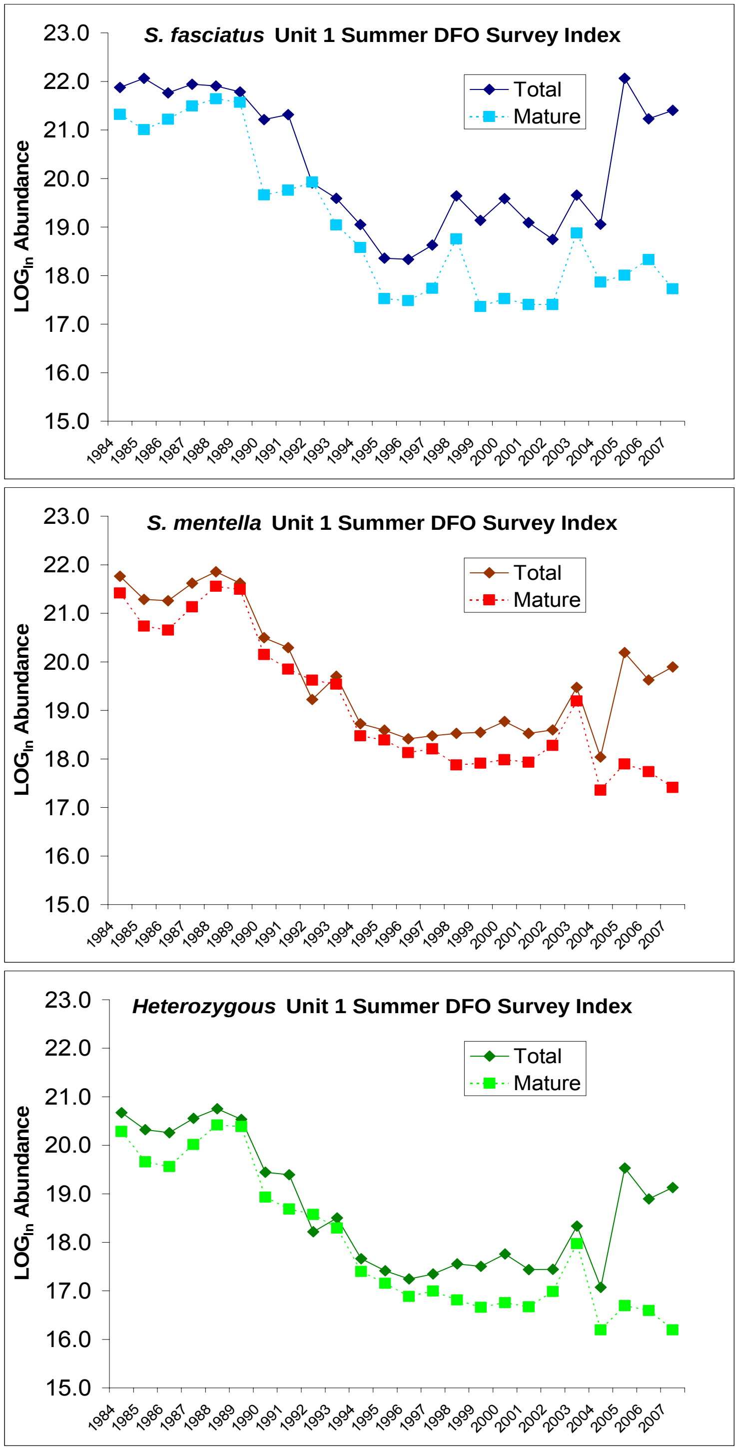


Figure 7. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel), *S. mentella* (middle panel) and heterozygous redfish (bottom panel) from stratified-random surveys conducted in Unit 1 in the summer from 1984-2007.

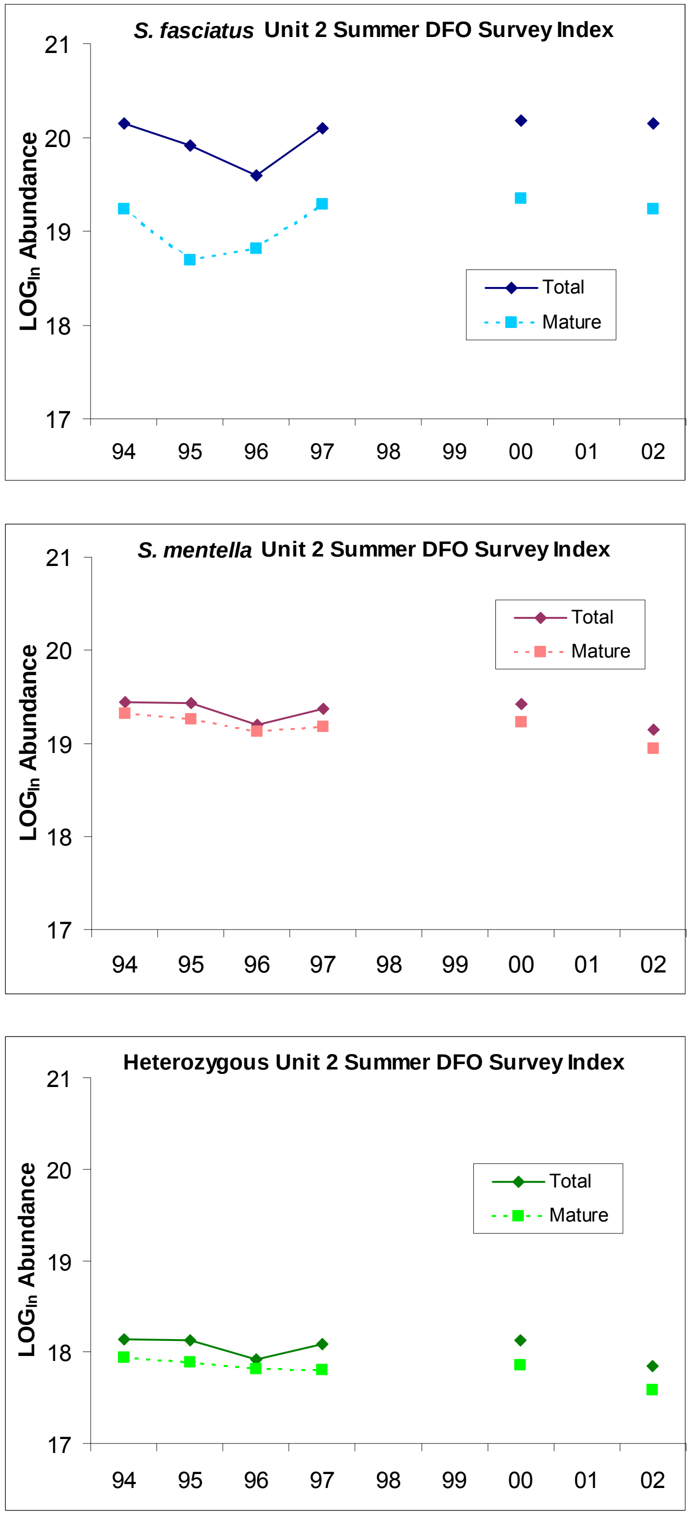


Figure 8. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel), *Sebastes mentella* (middle panel) and heterozygous redfish (bottom panel) from stratified-random surveys conducted from 1994 to 2002 in Unit 2 during the summer.

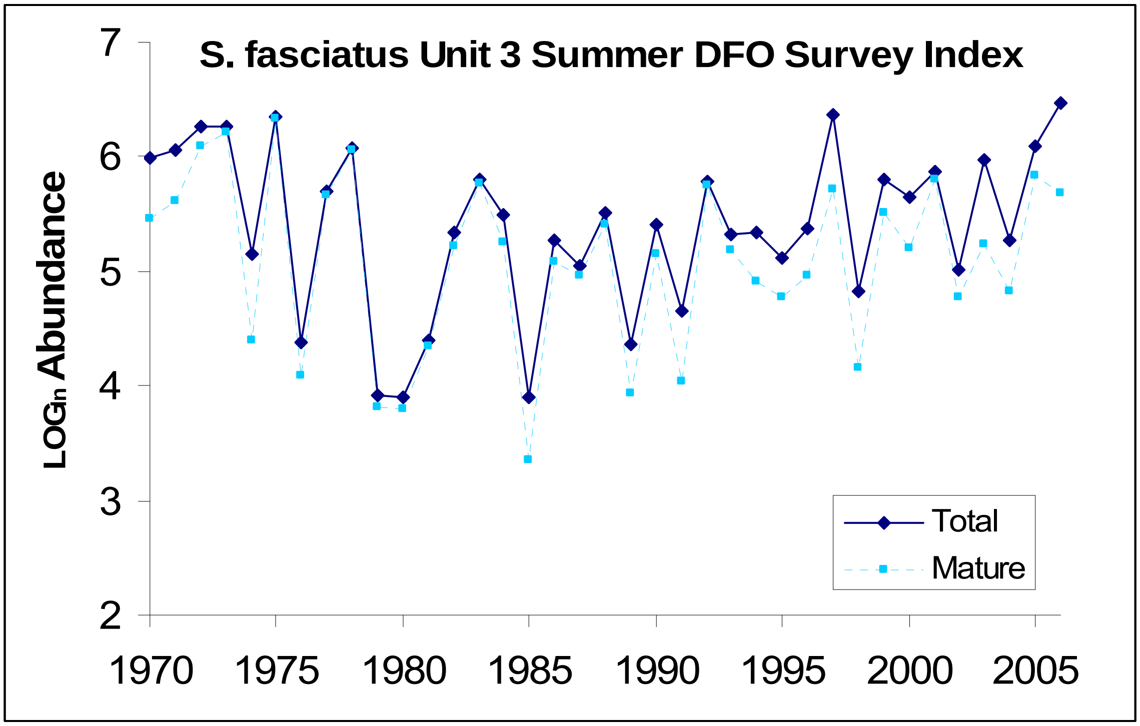


Figure 9. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* from stratified-random surveys conducted in Unit 3 in the summer from 1970-2006.

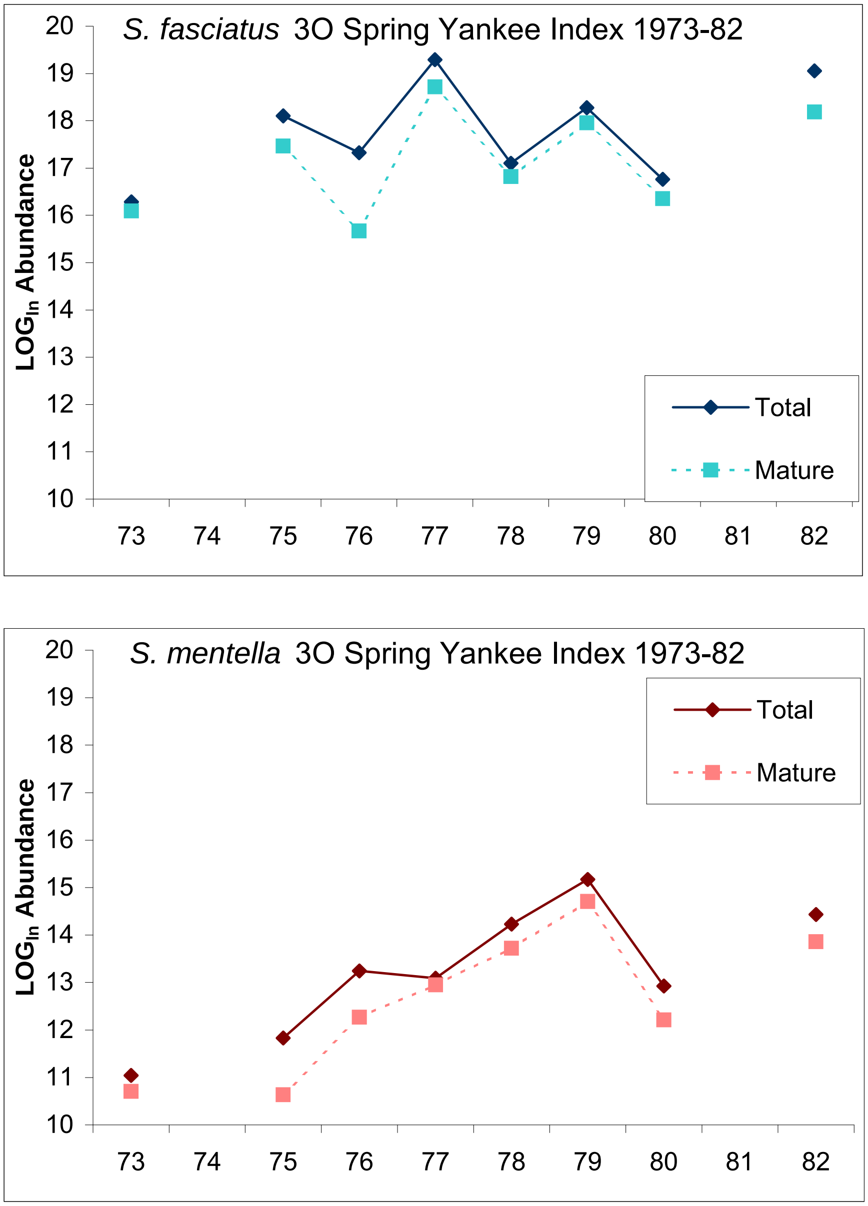


Figure 10. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Division 3O in the spring from 1973-1982 utilizing a lined Yankee 41-5 bottom trawl to a maximum depth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

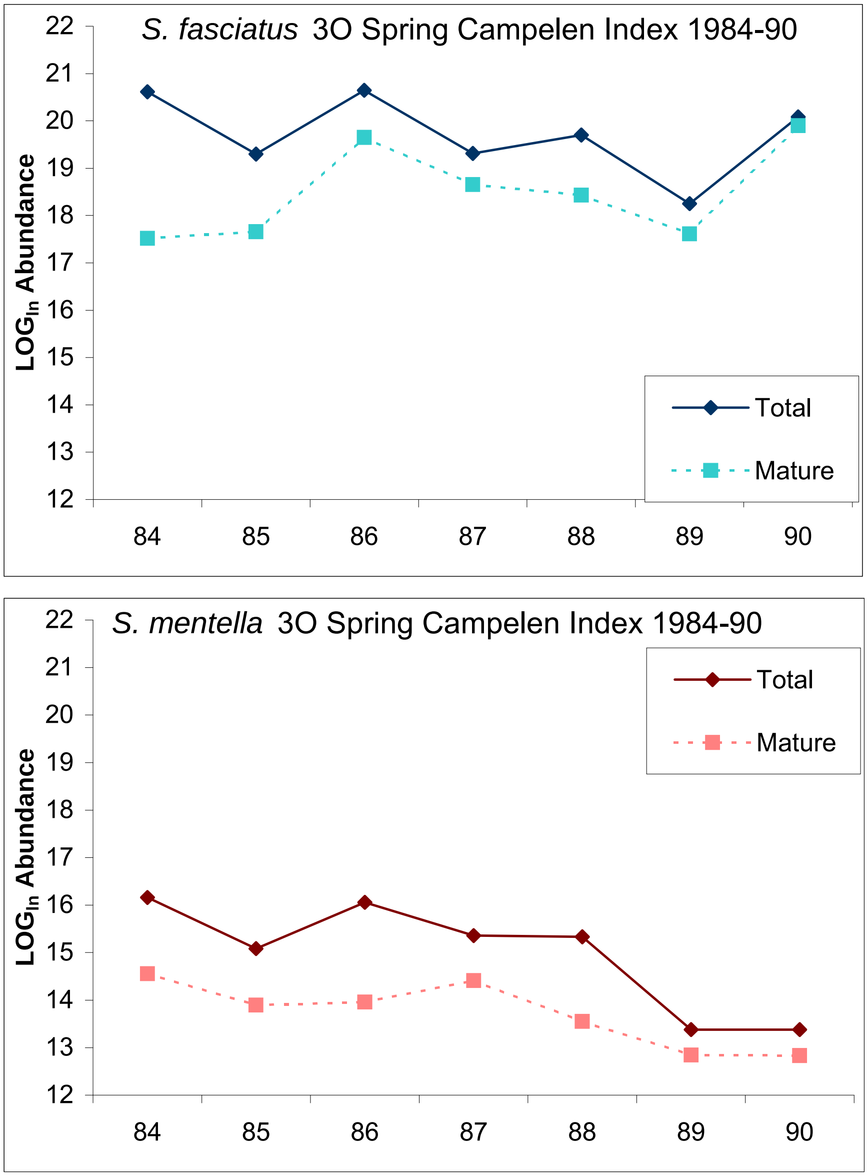
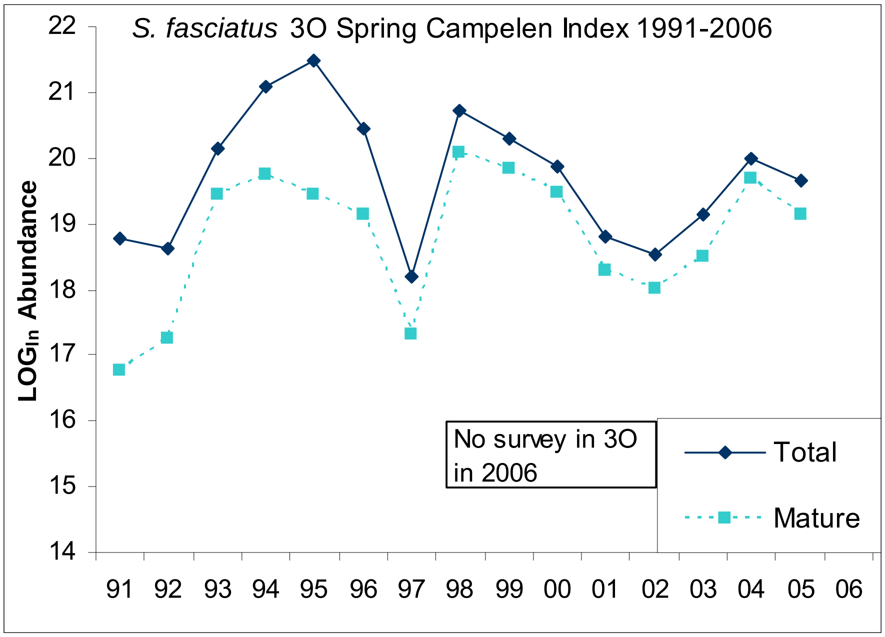


Figure 11. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Division 3O in the spring from 1984-1990 utilizing a lined Engel 145 bottom trawl to a maximum depth of 200 fathoms (367 m). Data are in Campelen trawl equivalents (see text).



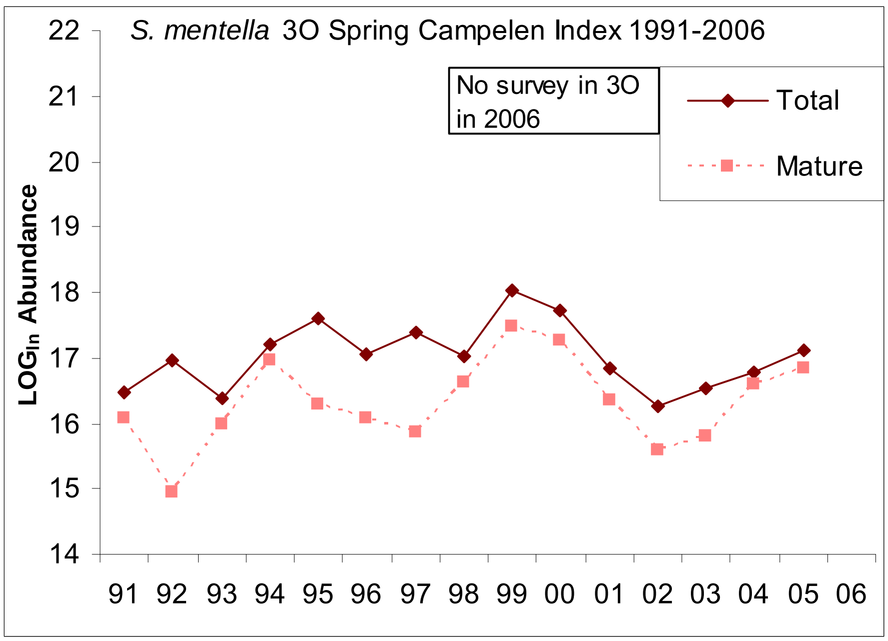
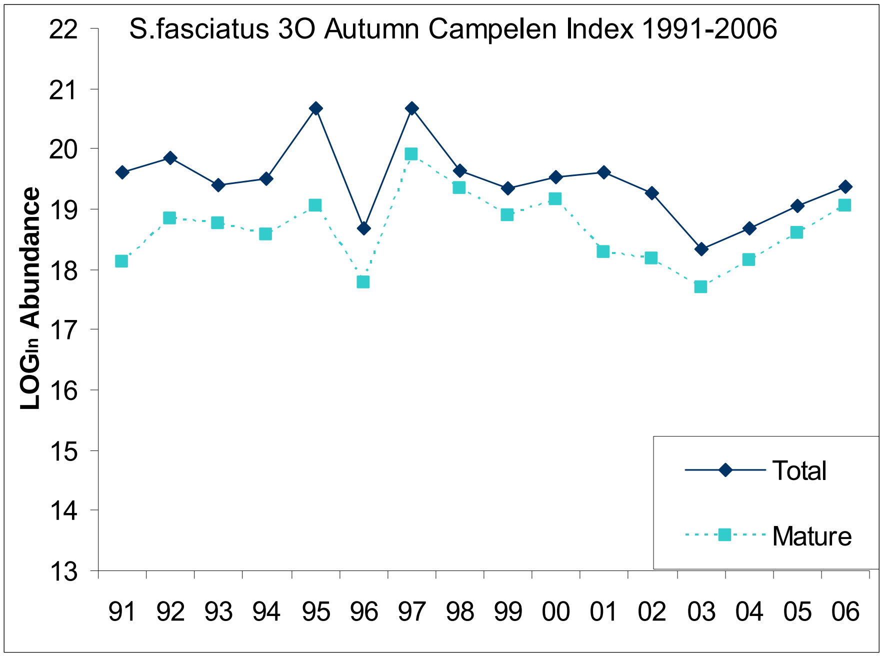


Figure 12. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in NAFO Division 3O in the spring from 1991-2006 to a maximum depth of 400 fathoms (732 m). Surveys from 1991-1995 utilized a lined Engel 145 bottom trawl and survey post 1995 utilized a Campelen trawl Engels data are in Campelen trawl equivalents (see text).



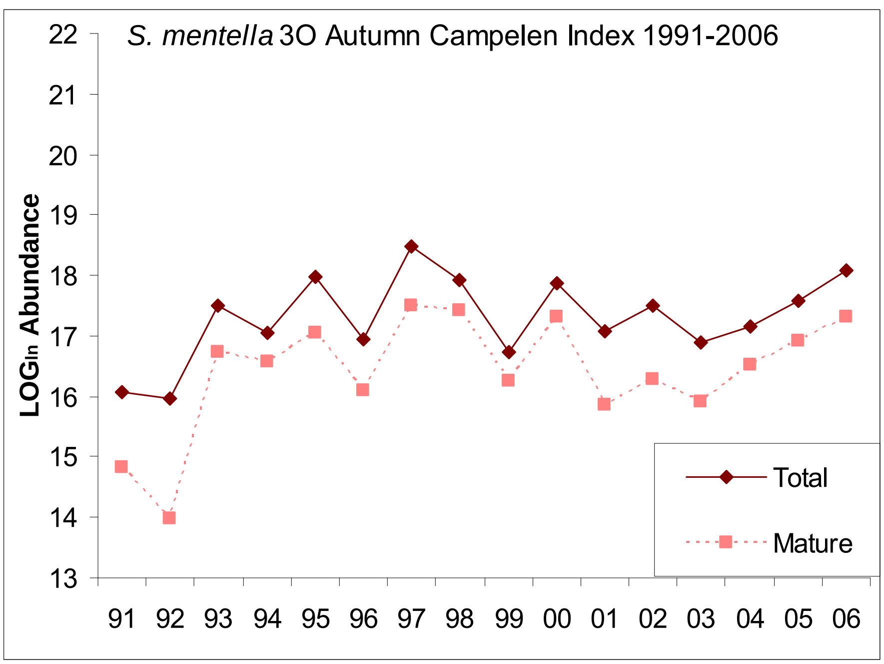
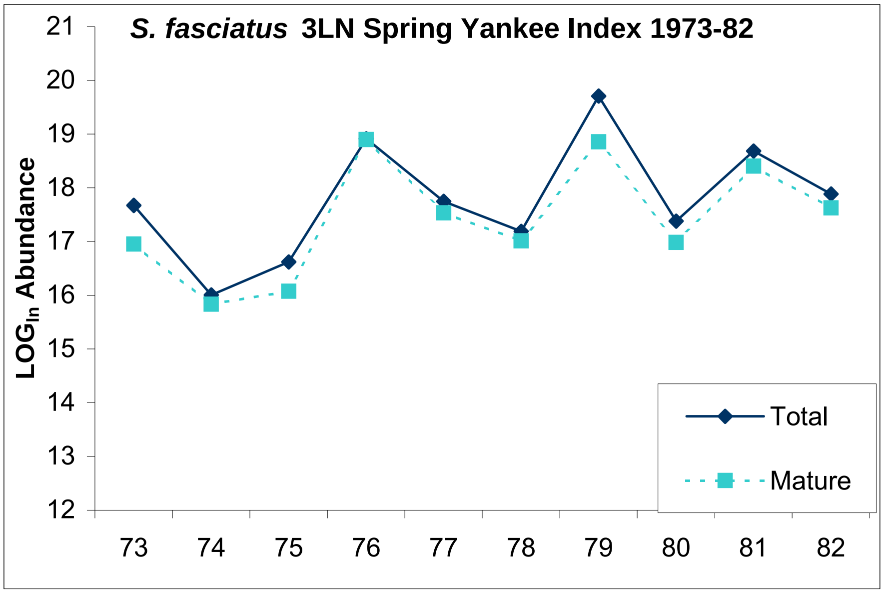


Figure 13. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Division 3O in the autumn from 1991-2006 to a maximum depth of 400 fathoms.



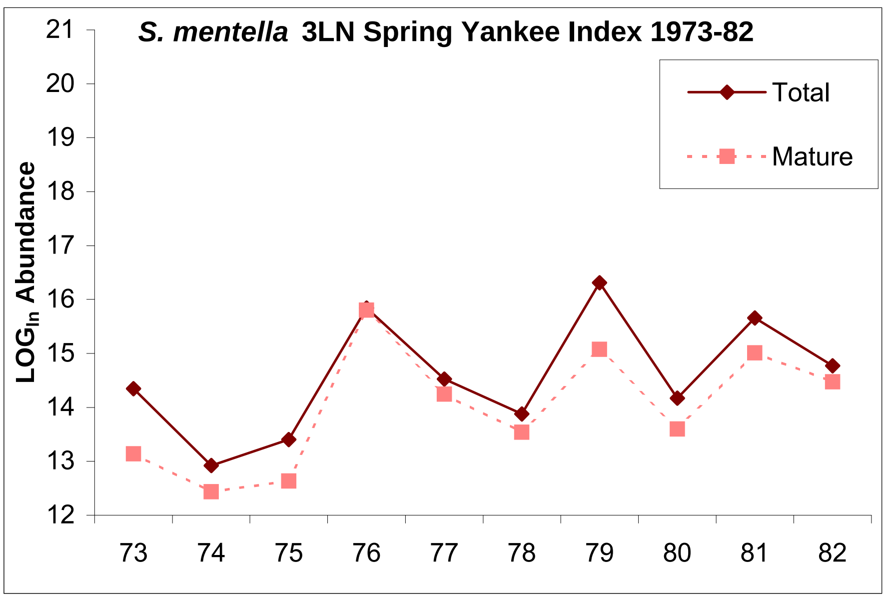
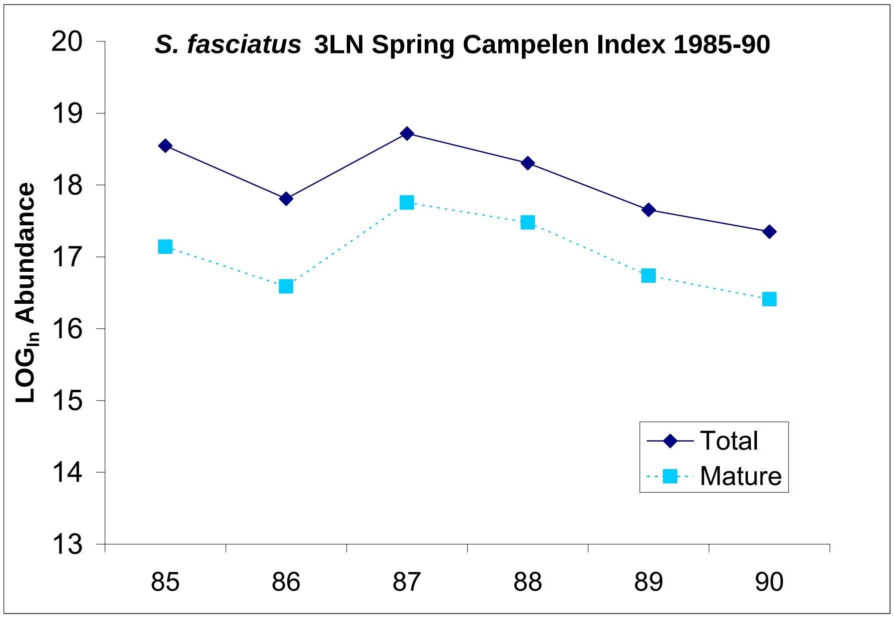


Figure 14. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 3LN in the spring from 1973-1982 utilizing a lined Yankee 41-5 bottom trawl to a maximum depth of 200 fathoms (367 m).



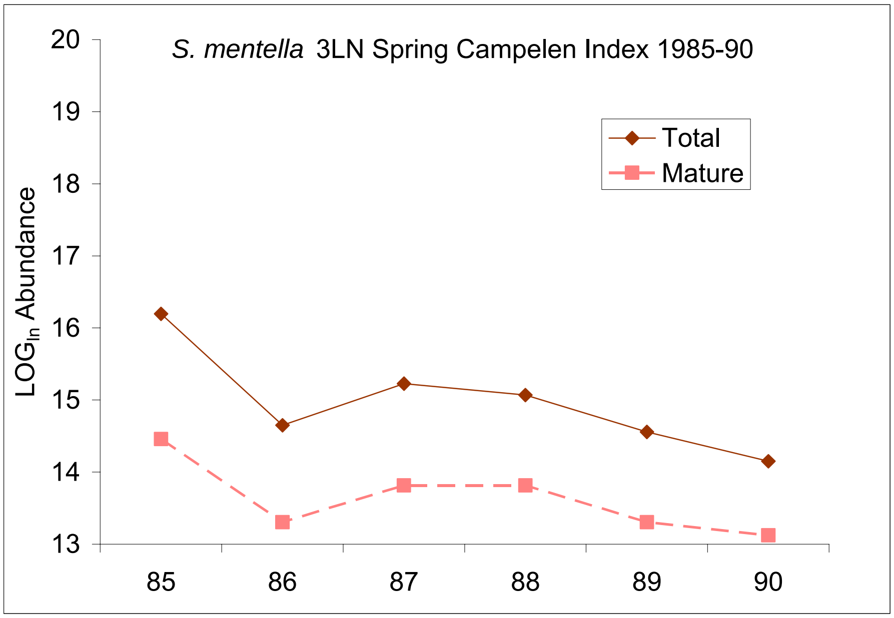
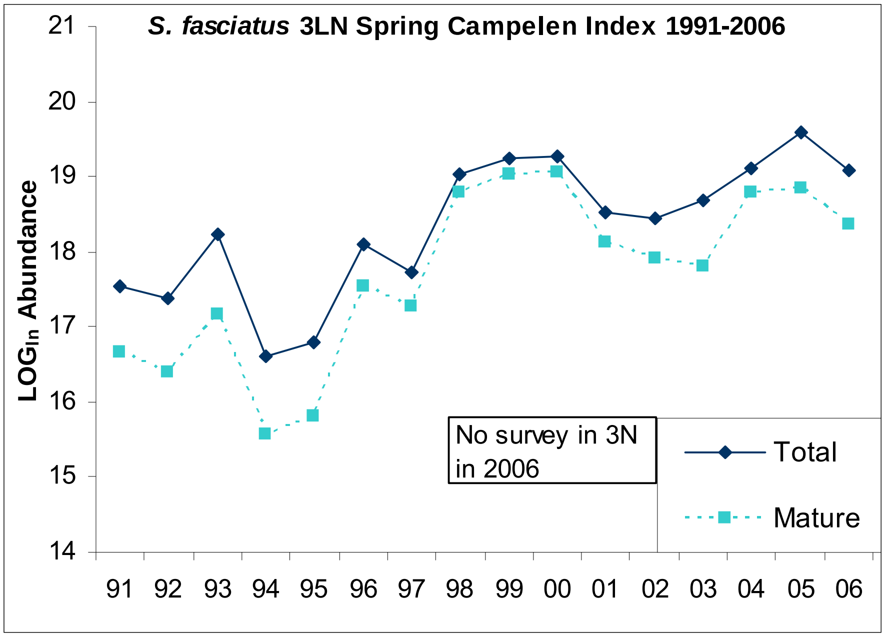


Figure 15. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 3LN in the spring from 1985-1990 utilizing a lined Engel 145 bottom trawl to a maximum depth of 200 fathoms (367 m). Data are in Campelen trawl equivalents (see text).



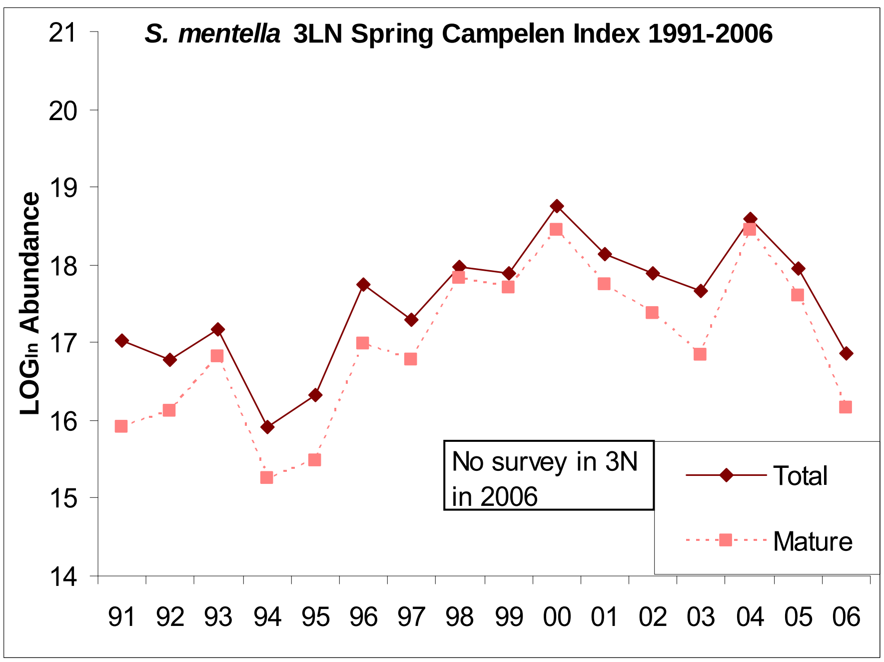
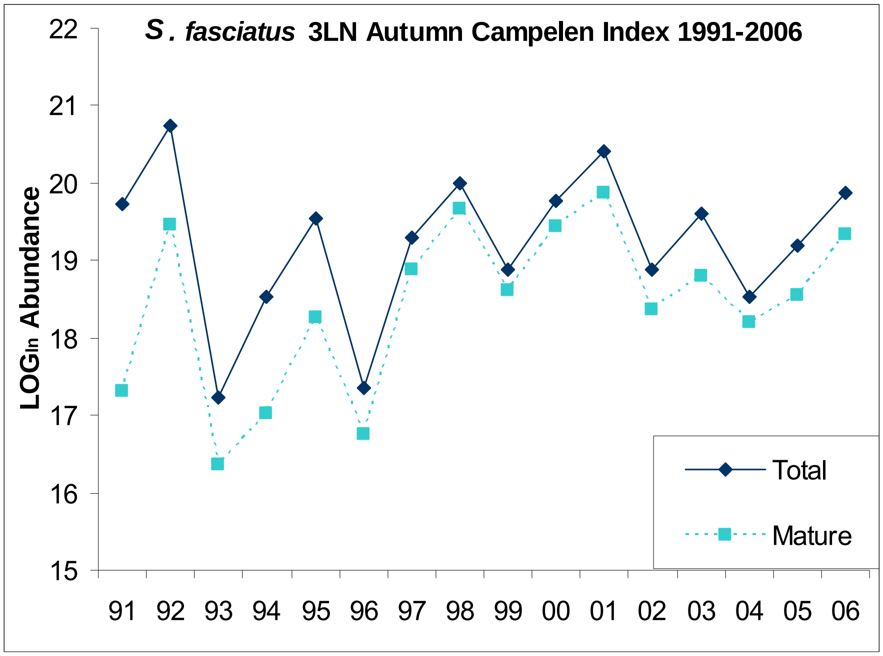


Figure 16. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 3LN in the spring from 1991-2006 to a maximum depth of 400 fathoms (732 m). Surveys from 1991-1995 utilized a lined Engel 145 bottom trawl and surveys post 1995 utilized a Campelen trawl. Engel data are in Campelen trawl equivalents (see text).



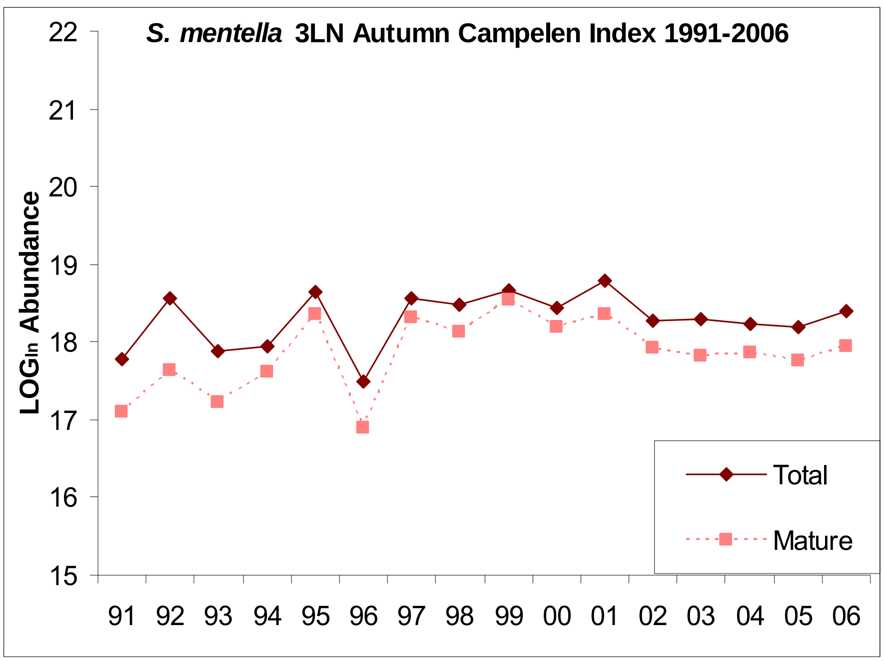


Figure 17. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *Sebastes mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 3LN in the autumn from 1991-2006 to a maximum depth of 400 fathoms (732 m). Surveys from 1991-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engel data are in Campelen trawl equivalents (see text).

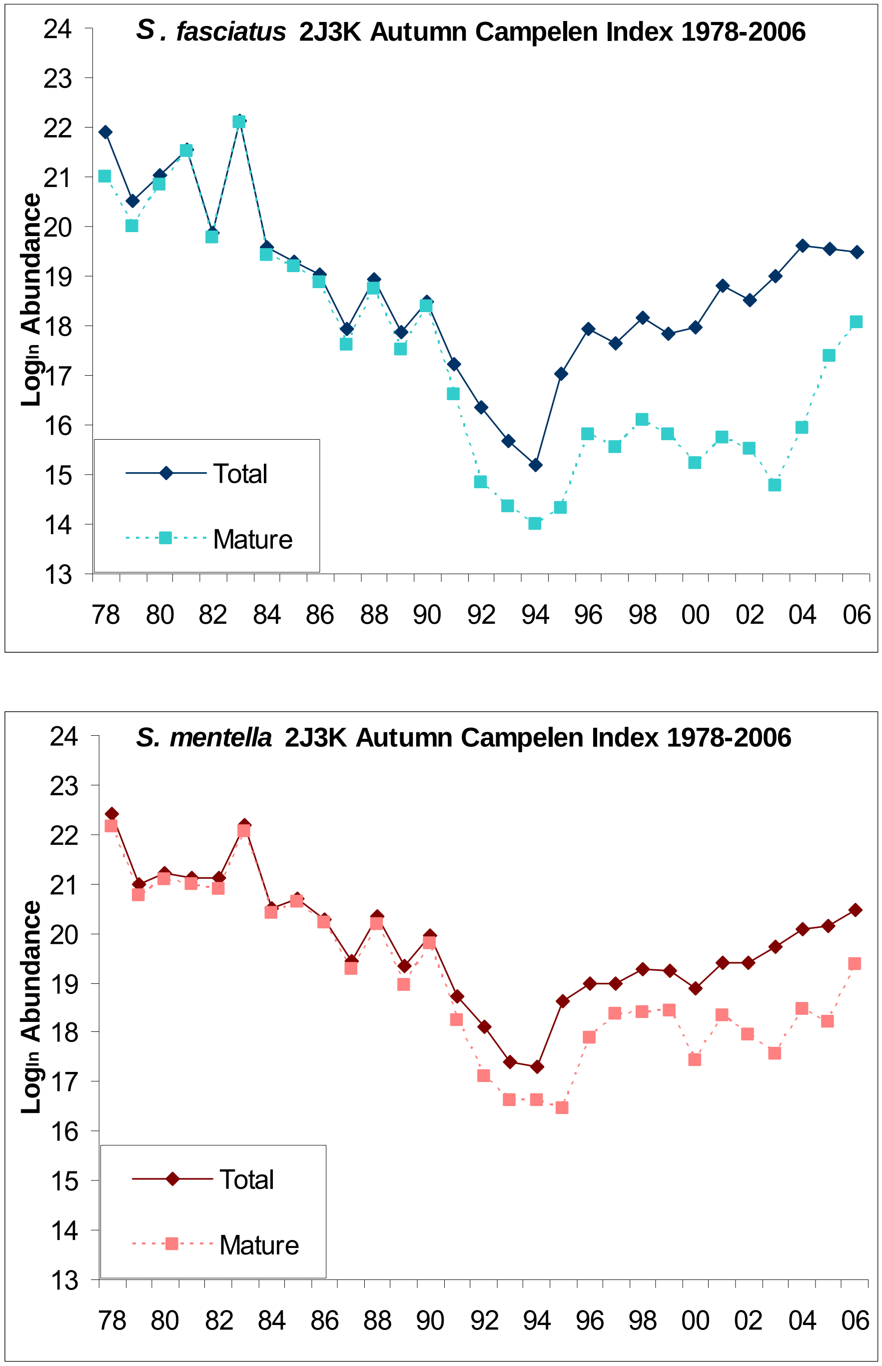
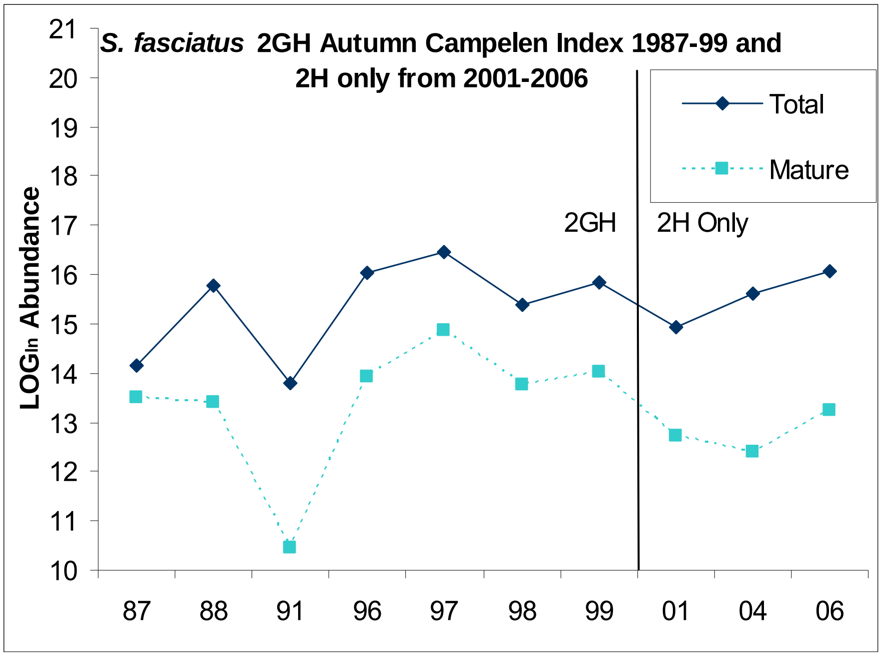


Figure 18. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 2J3K in the autumn from 1978-2006. Surveys from 1978-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engel data are in Campelen trawl equivalents (see text).



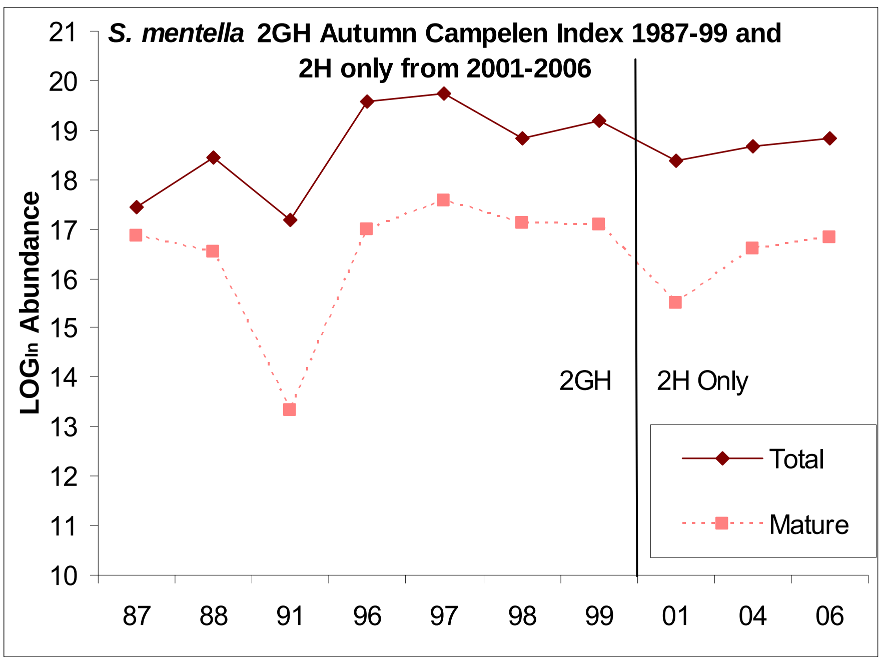


Figure 19. Natural log survey abundance estimates of total (all ages) and mature *Sebastes fasciatus* (upper panel) and *S. mentella* (lower panel) from stratified-random surveys conducted in NAFO Divisions 2GH in the autumn from 1987-1999 and in Div. 2H only from 2001-2006. Surveys from 1987-1994 utilized a lined Engel 145 bottom trawl and surveys post 1994 utilized a Campelen trawl. Engel data are in Campelen trawl equivalents (see text).

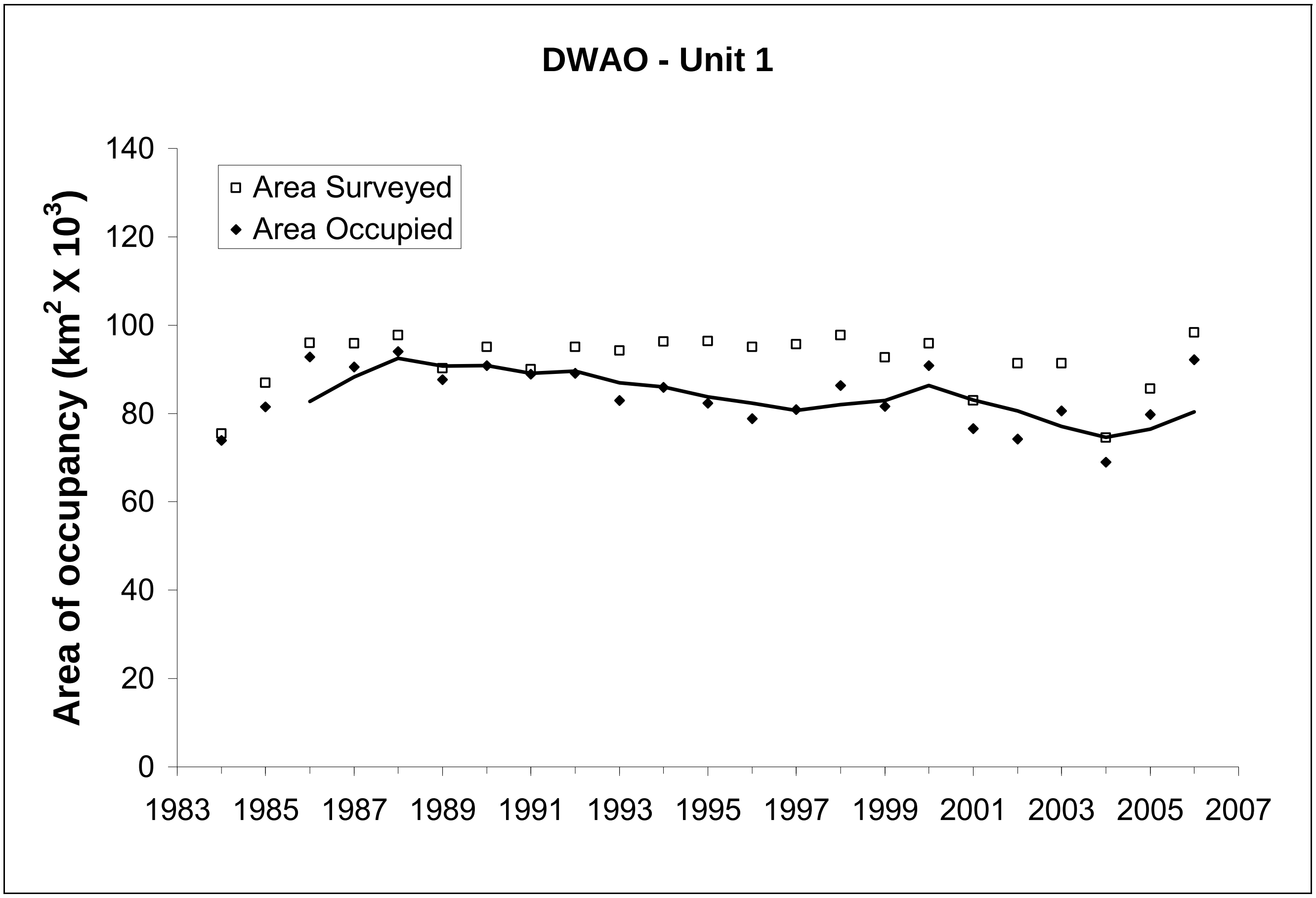


Figure 20. Area of occupancy (DWAO) of redfish species in Unit 1.

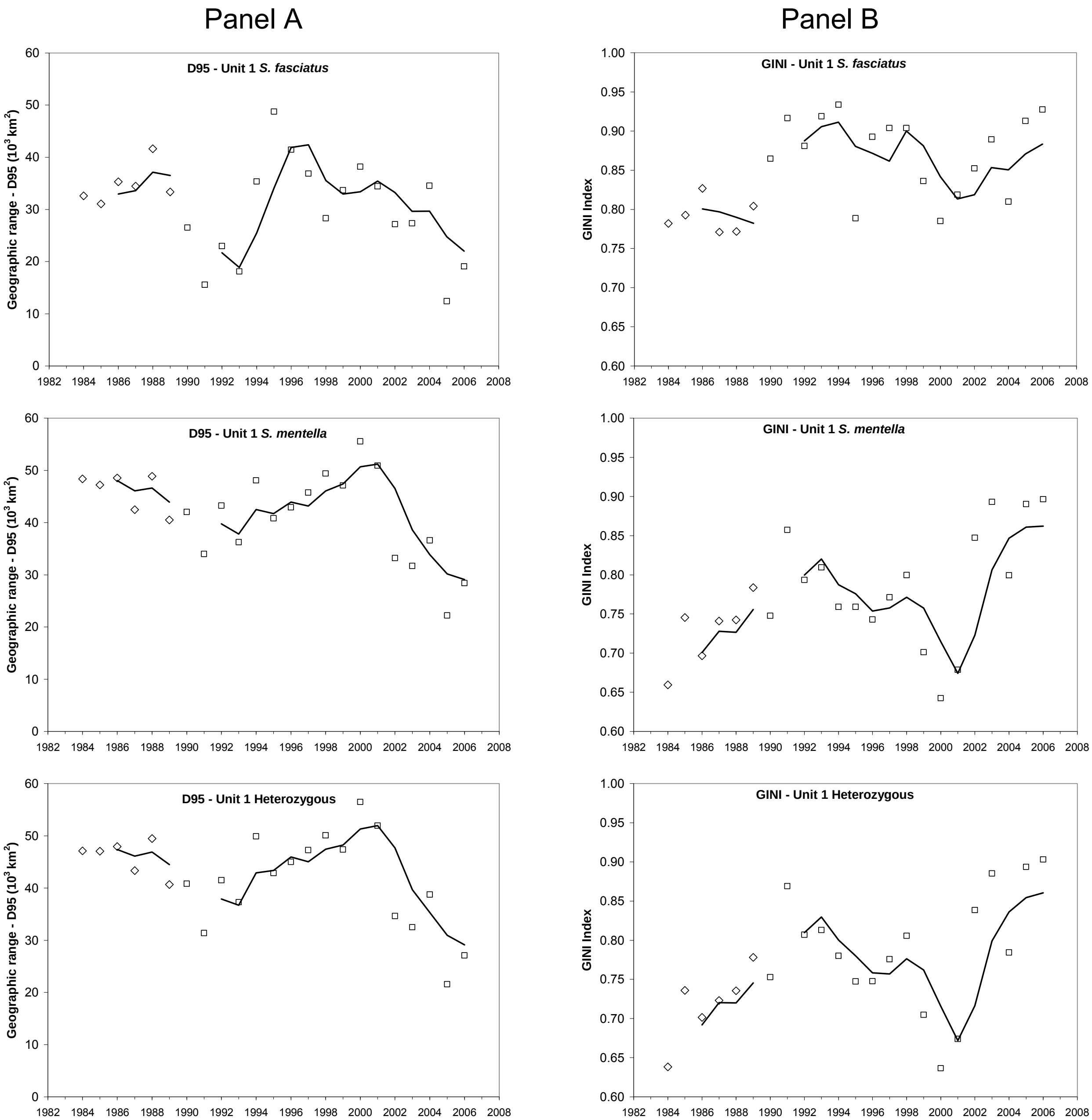


Figure 21. Indices of concentration (D_{95}, panel A and Gini, panel B) of *Sebastes fasciatus*, *S. mentella* and heterozygous redfish in Unit 1 from summer surveys conducted from 1984-2006. Surveys conducted from 1984-1989 utilized a Western IIA trawl, surveys from 1990-2003 utilized a URI trawl (converted to Campelen units) and surveys from 2003-2006 utilized a Campelen trawl.

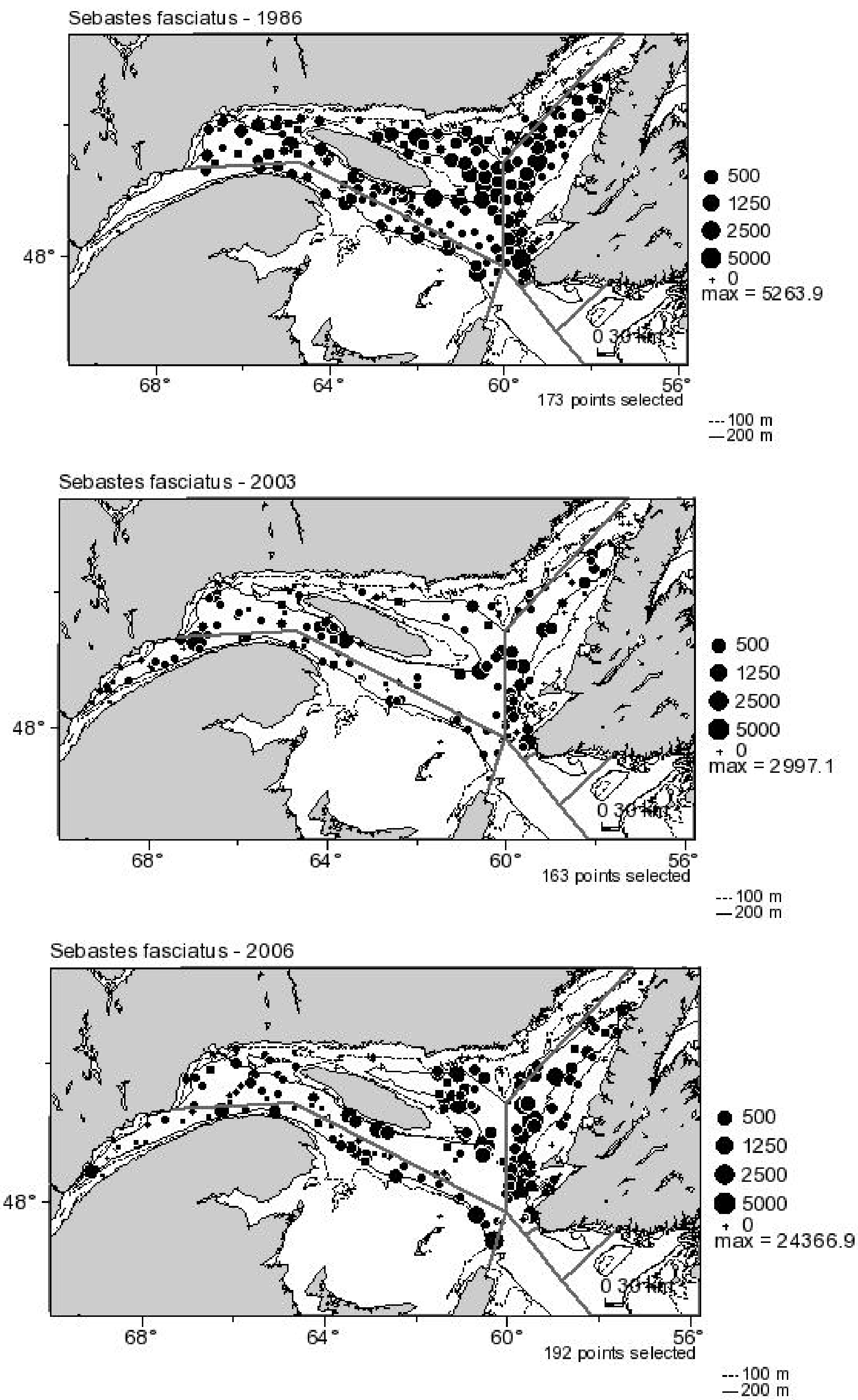
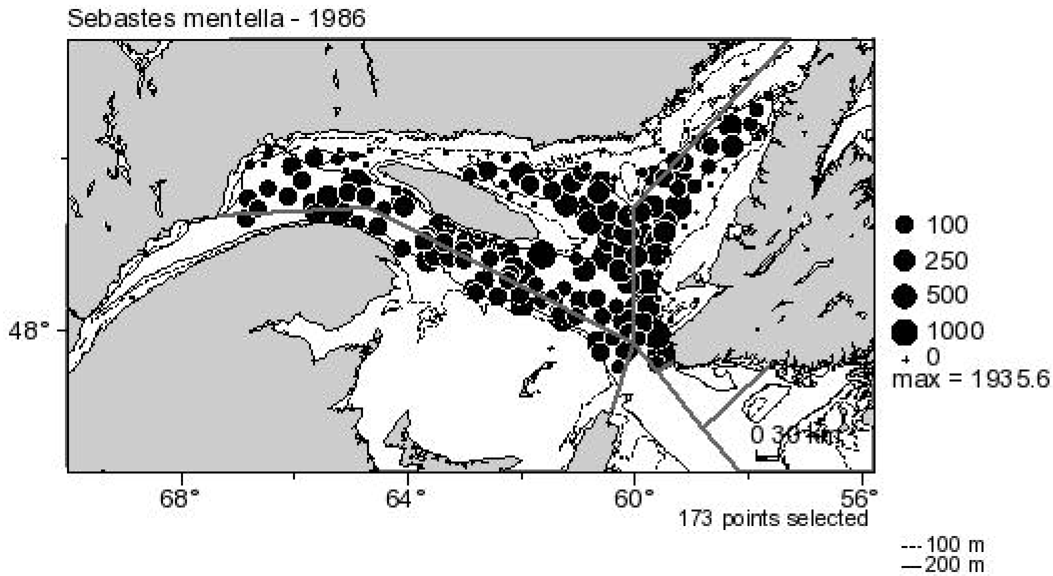


Figure 22. Distribution of the catches of *Sebastes fasciatus* (in number) in 1986, 2003 and 2006 in Unit 1. The 1986 survey was standardized to 0.8 nm with a Western IIA trawl, survey of 2003 was of 0.75 nm with a URI trawl (converted to Campelen units) and survey of 2006 was of 0.75 nm with a Campelen trawl.



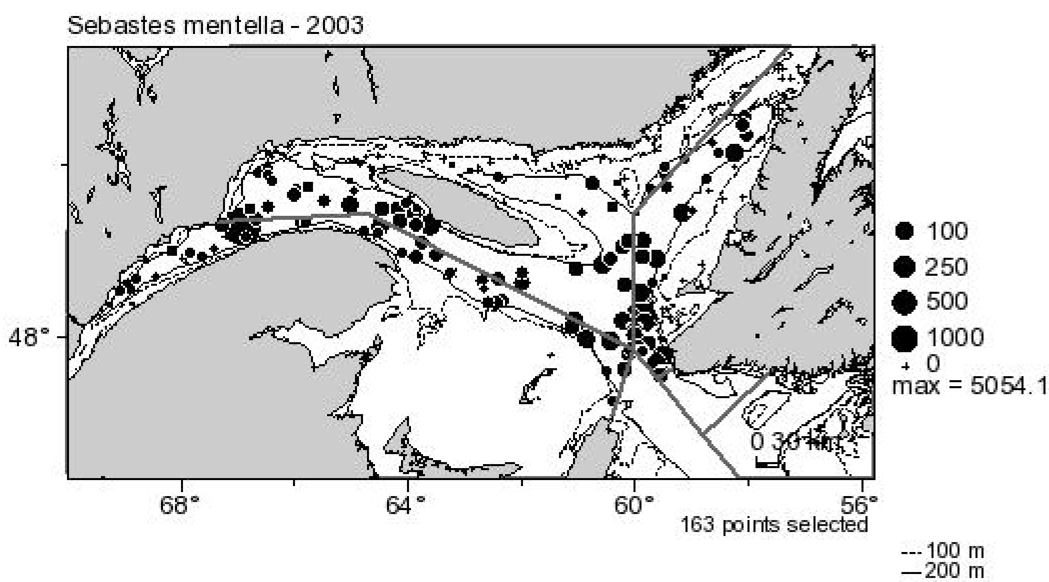
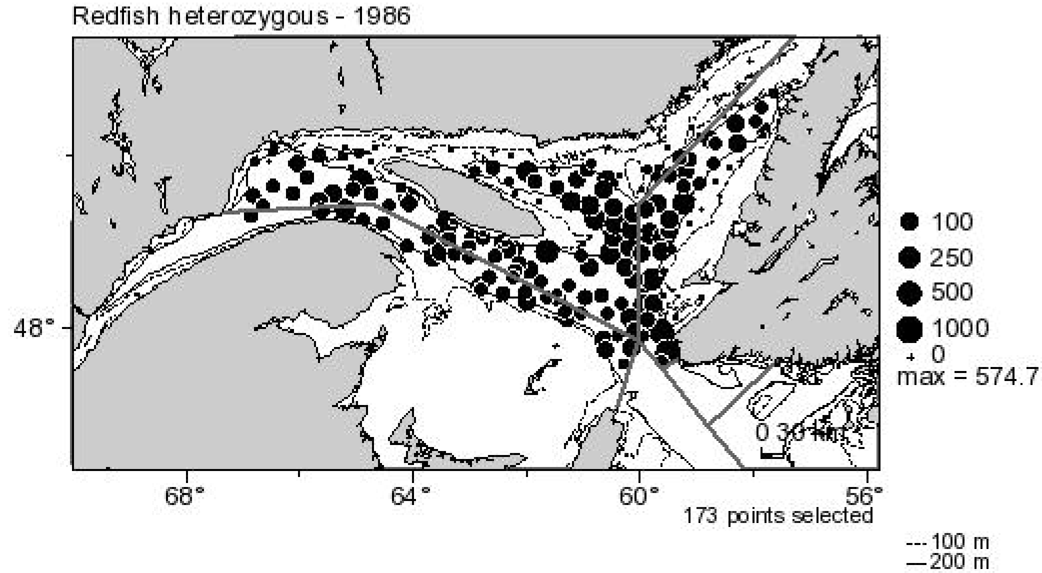


Figure 23. Distribution of the catches of *Sebastes mentella* (in number) in 1986 and 2003 in Unit 1. The 1986 survey was standardized to 0.8 nm with a Western IIA trawl and survey of 2003 was of 0.75 nm with a URI trawl (converted to Campelen units).



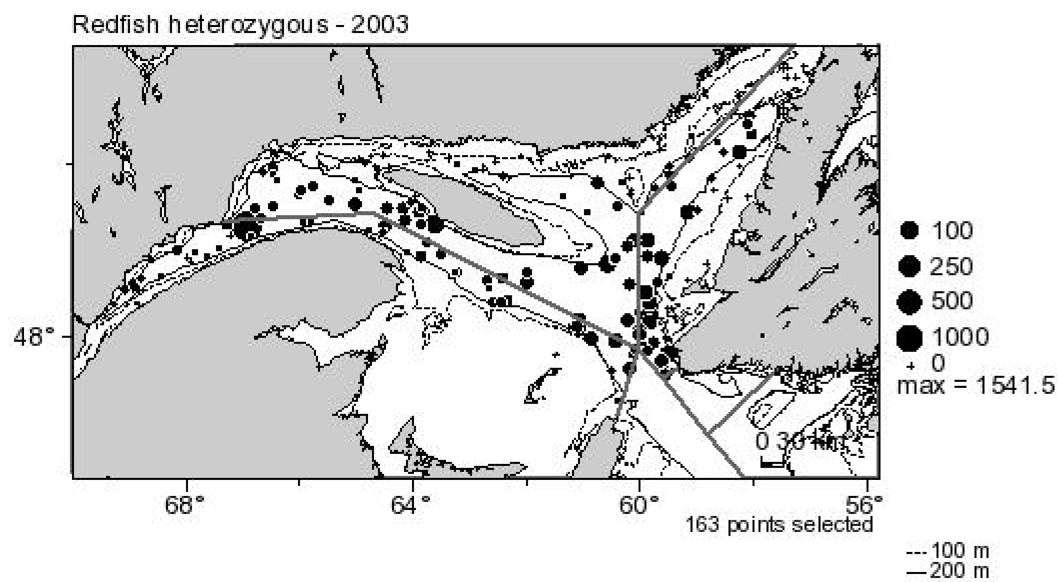


Figure 24. Distribution of the catches (in number) heterozygous redfish in 1986 and 2003 in Unit 1. The 1986 survey was standardized to 0.8 nm with a Western IIA trawl and survey of 2003 was of 0.75 nm with a URI trawl (converted to Campelen units).

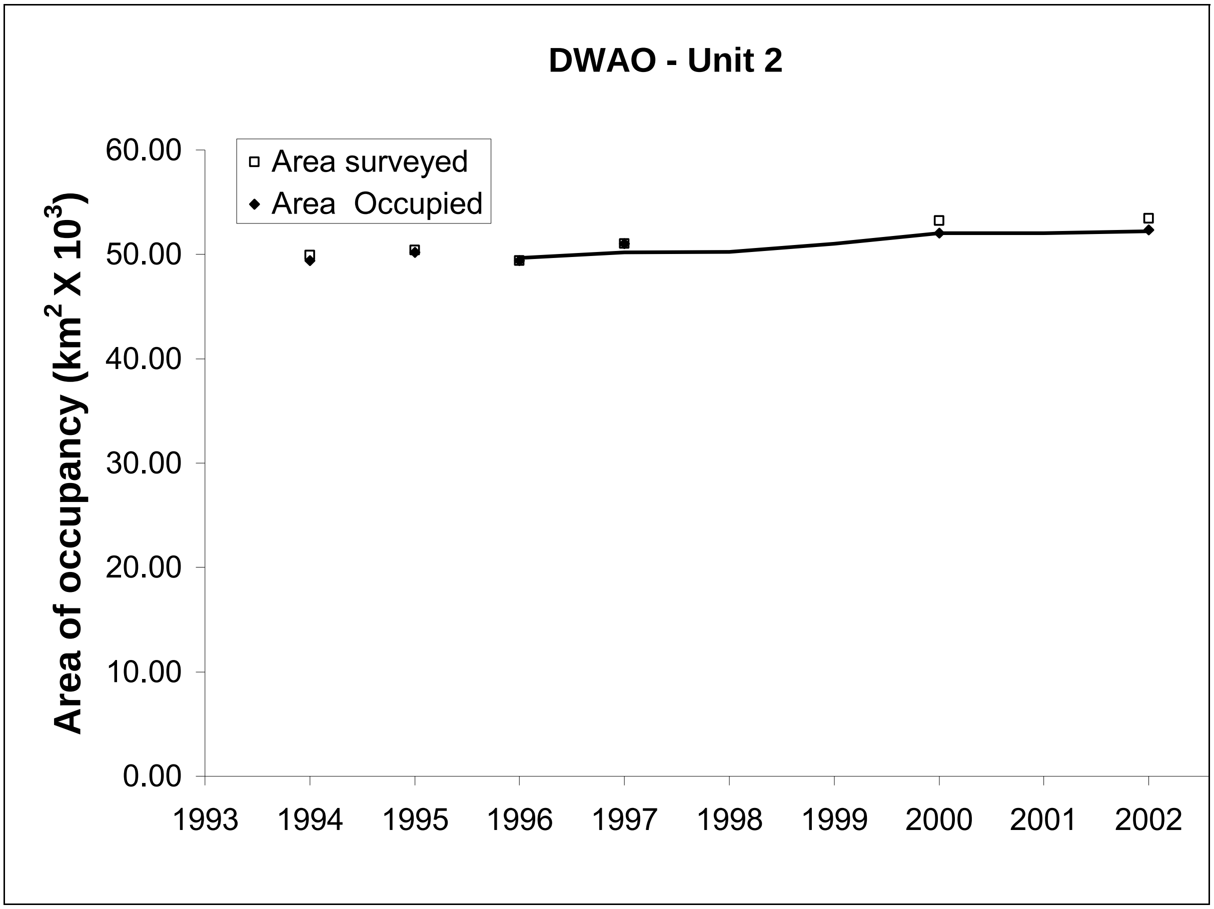


Figure 25. Area of occupancy (DWAO) of redfish species in Unit 2.

Panel A

Panel B

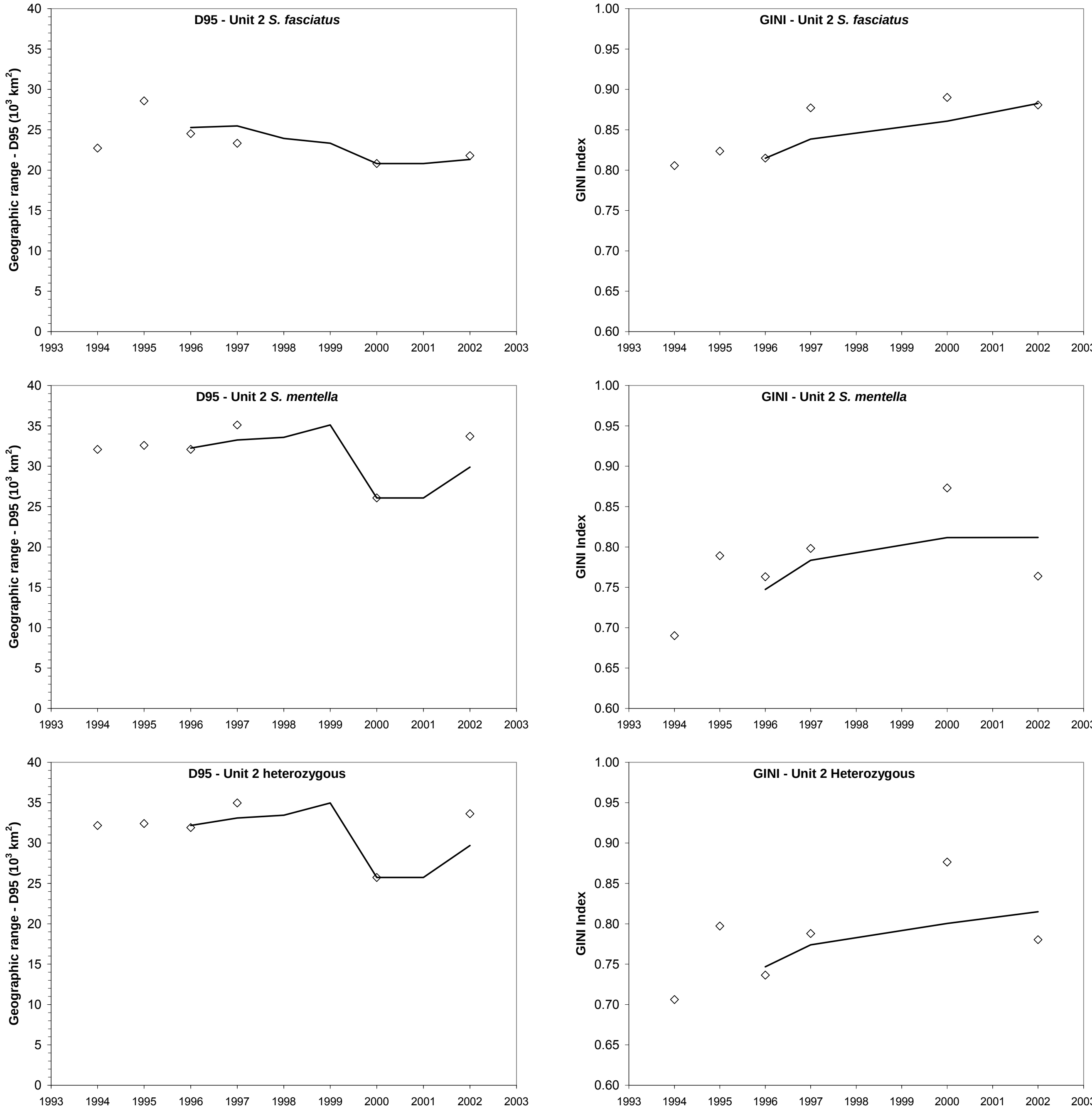
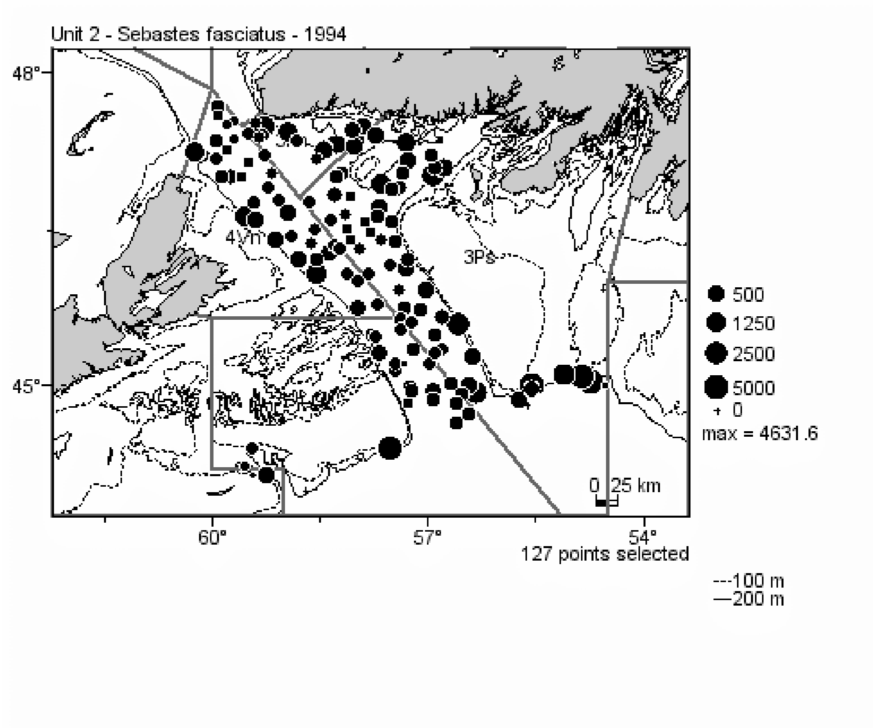


Figure 26. Indices of concentration (D_{95}, panel A and Gini, panel B) of *Sebastes fasciatus*, *S. mentella* and heterozygous redfish in Unit 2 from summer surveys conducted from 1994 to 2002 using a Campelen trawl.



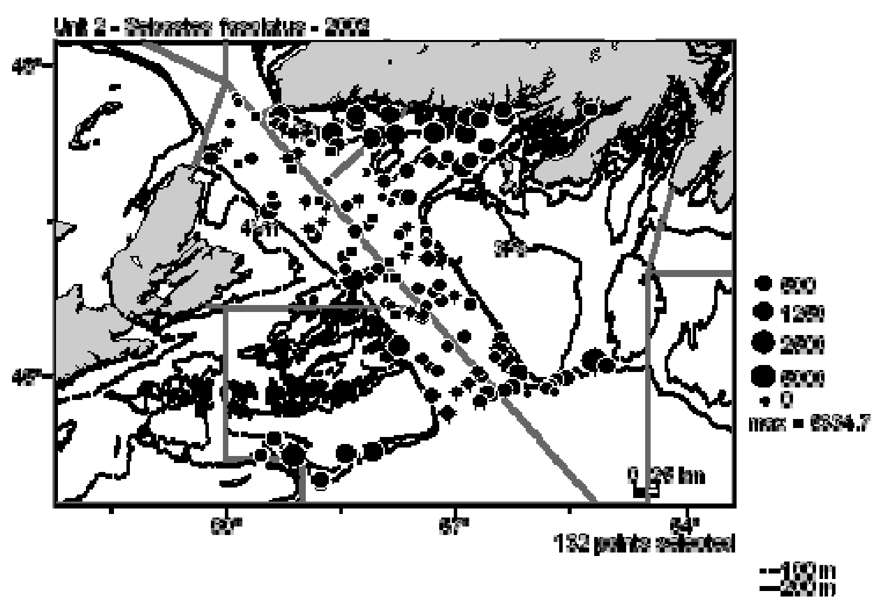


Figure 27. Distribution of the catches (in number) of *Sebastes fasciatus* in 1994 and 2002 in Unit 2.

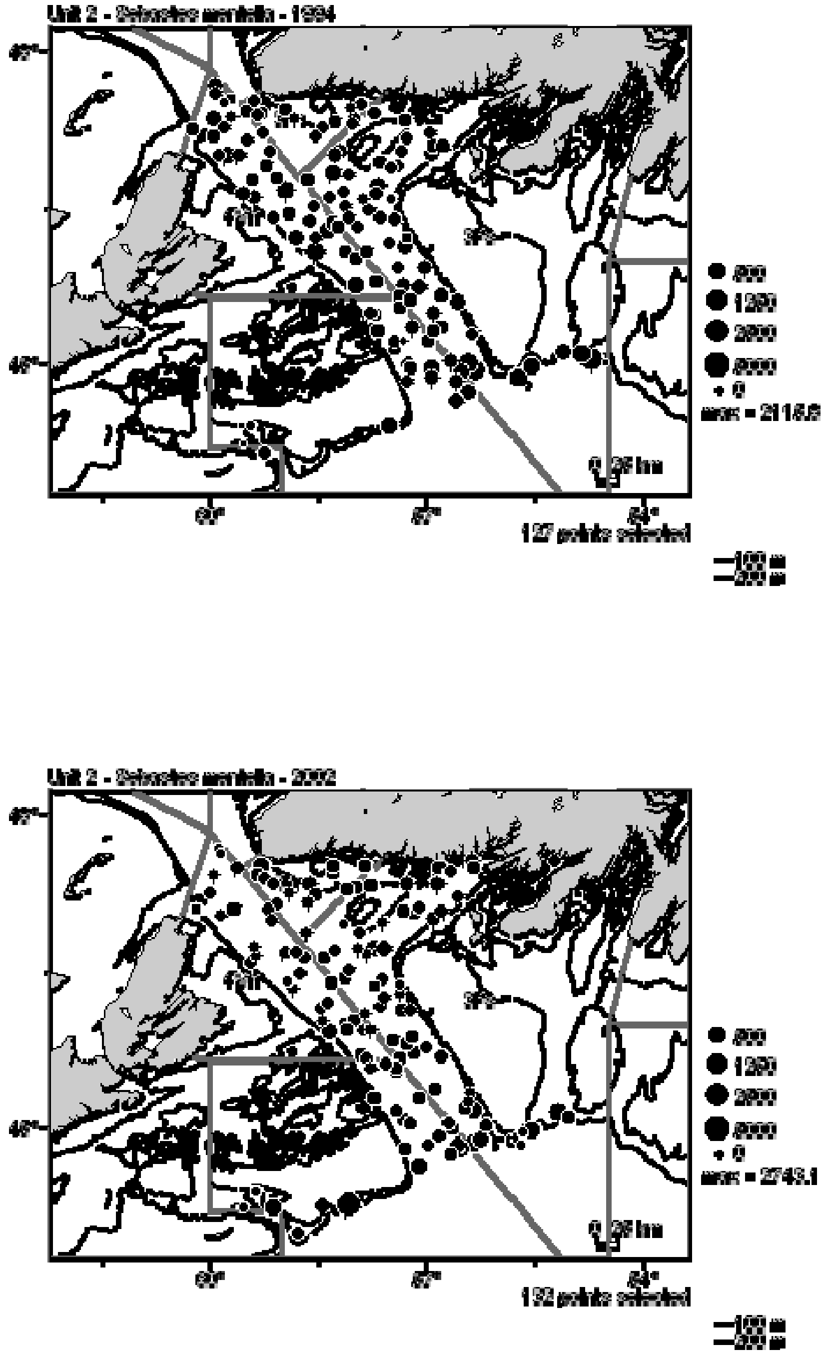


Figure 28. Distribution of the catches (in number) of *Sebastes mentella* in 1994 and 2002 in Unit 2.

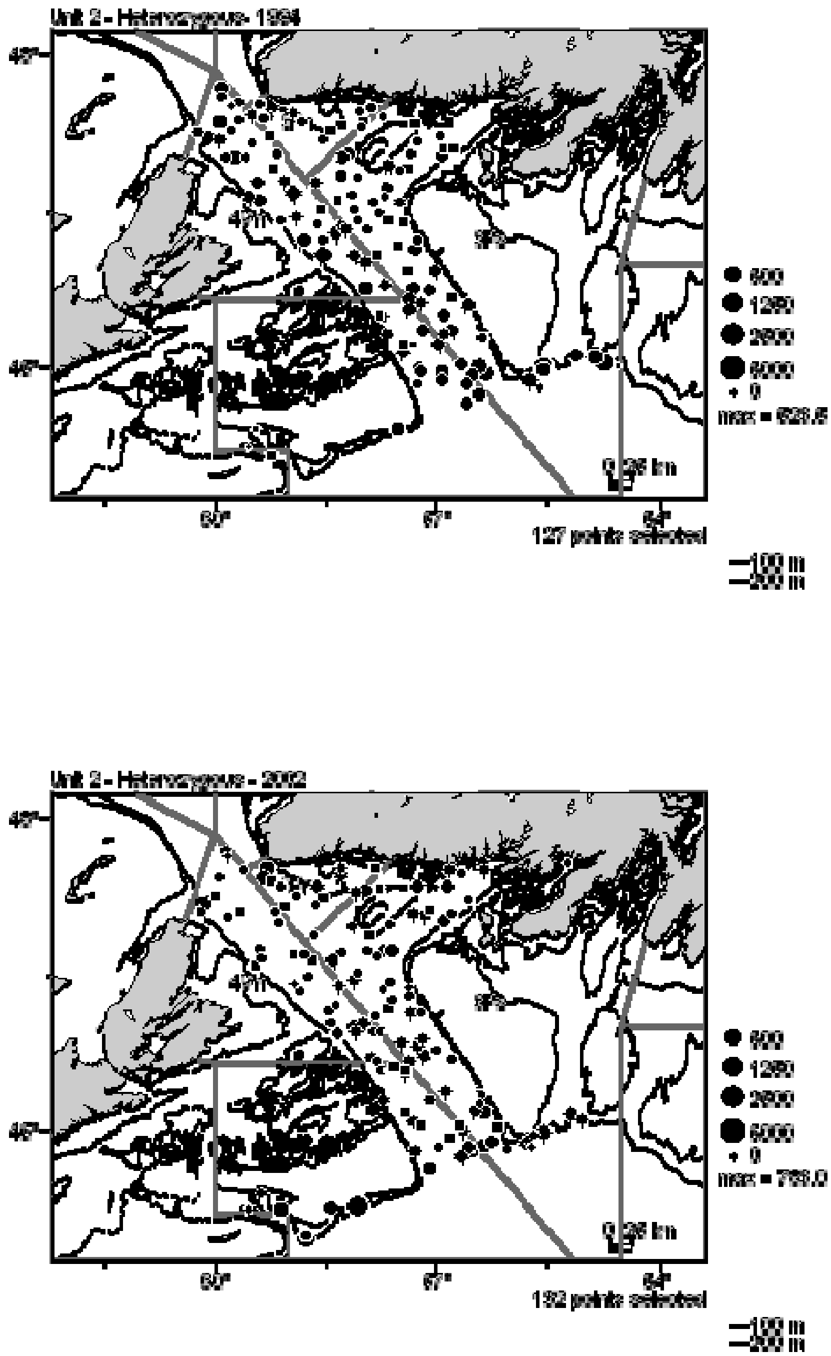


Figure 29. Distribution of the catches (in number) of the heterozygous redfish in 1994 and 2002 in Unit 2.

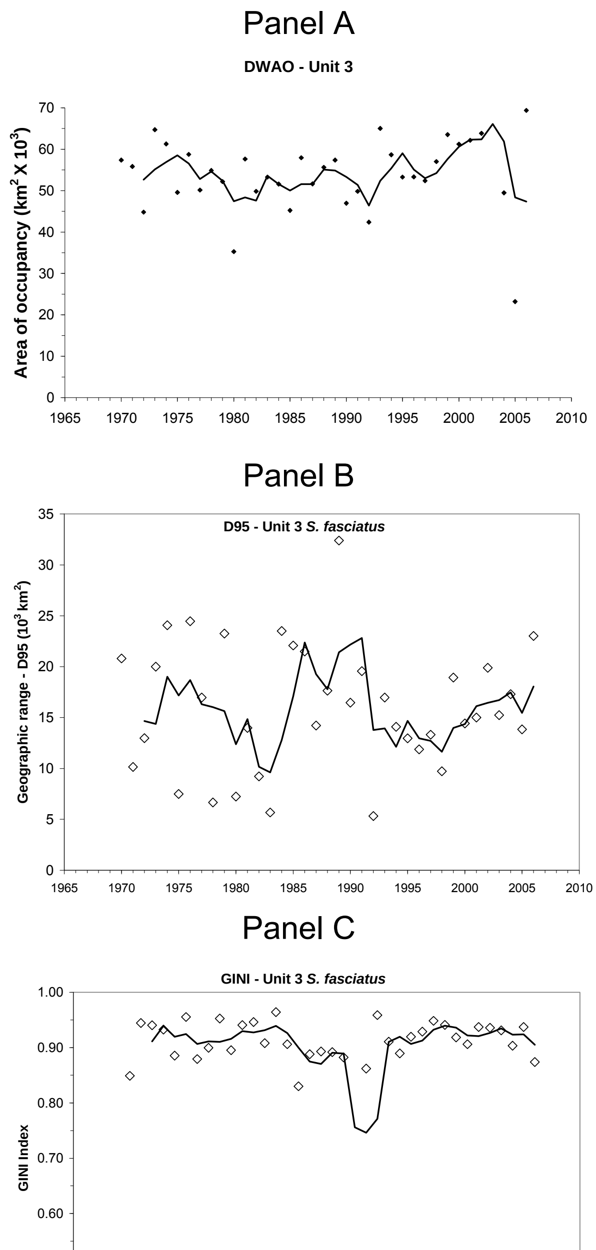
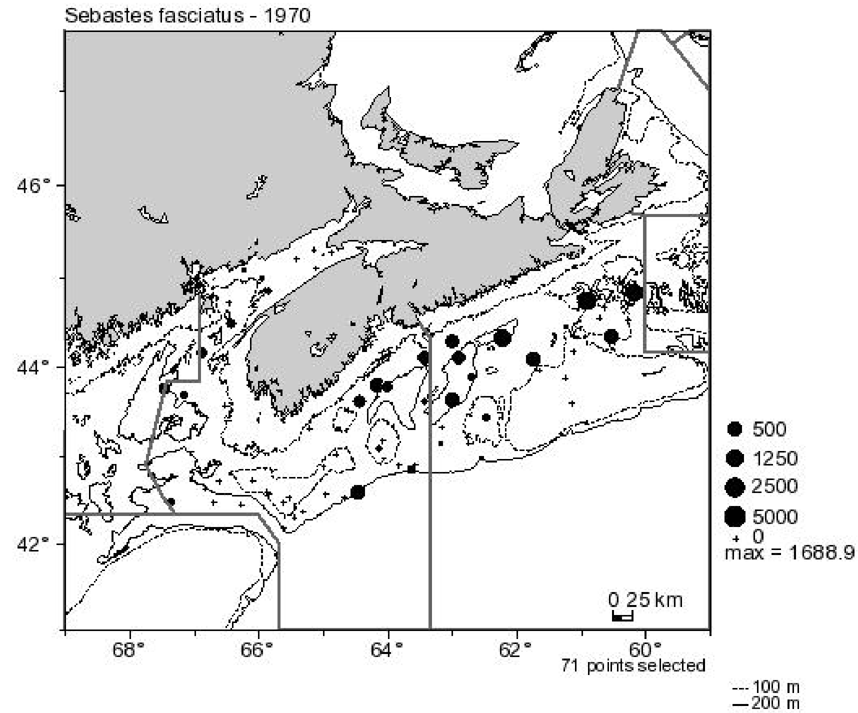


Figure 30. Area of occupancy (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* in Unit 3.



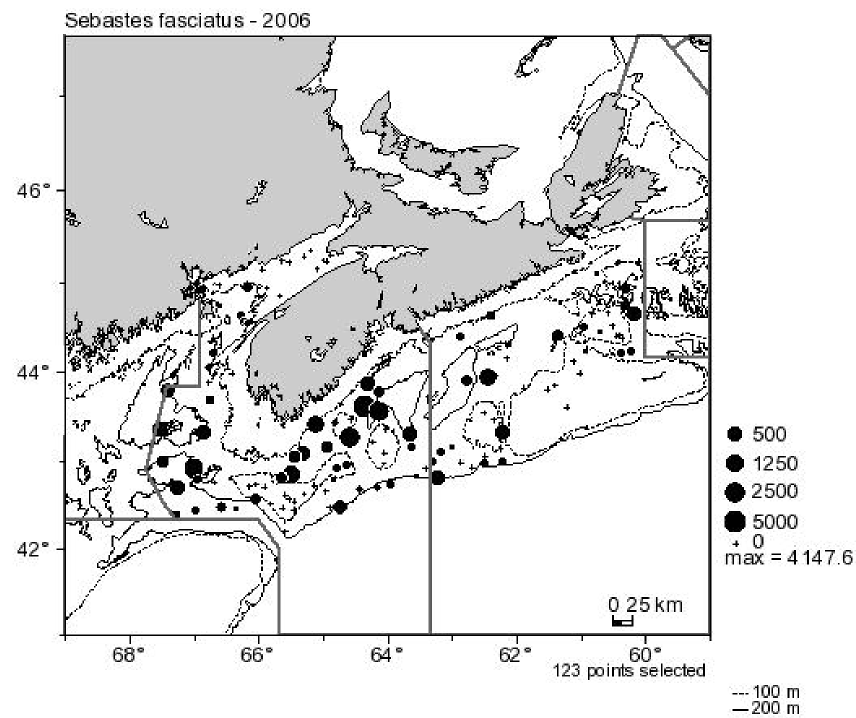
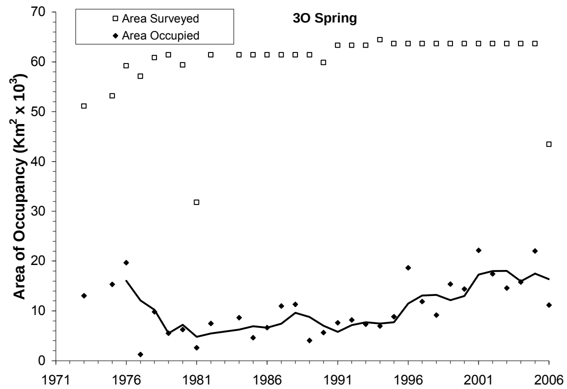
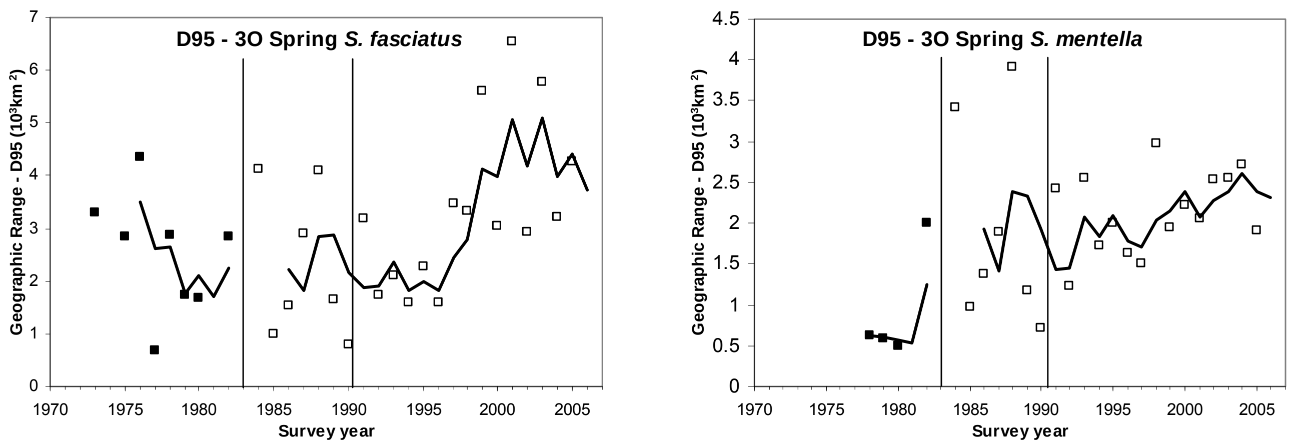


Figure 31. Distribution of the catches (in number) of *Sebastes fasciatus* in 1970 and 2006 in Unit 3.

Panel A



Panel B



Panel C

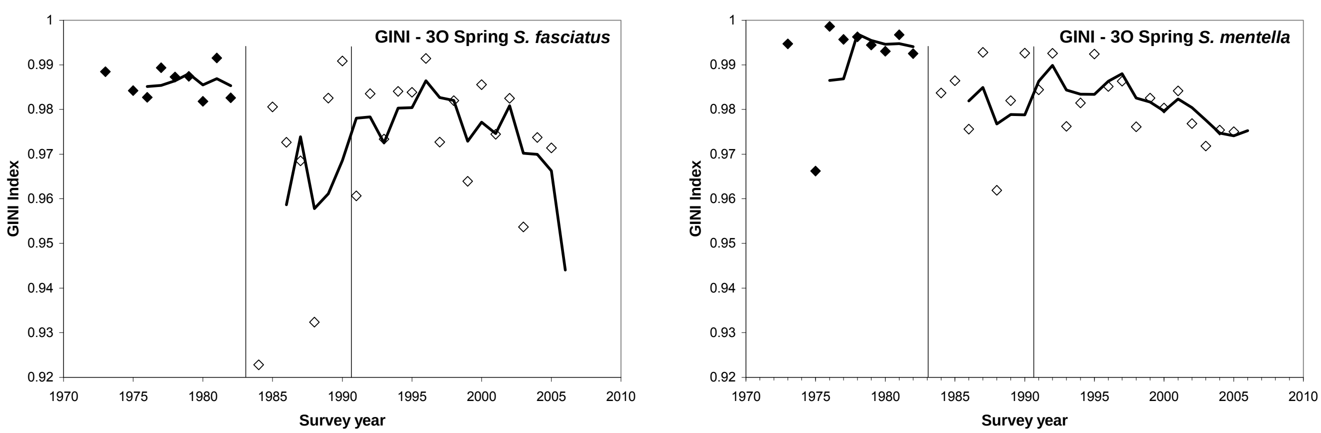


Figure 32. Distribution indices for redfish spp (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Division 3O from spring surveys from 1973-2006. Surveys from 1973-1982 were to 200 fathoms (367 m) with a Yankee 41-5 otter trawl, surveys from 1984-1990 were to 200 fathoms (367 m) with an Engel 145 trawl (converted to Campelen units) and surveys from 1991-2006 were to 400 fathoms (732 m) with a Campelen trawl.

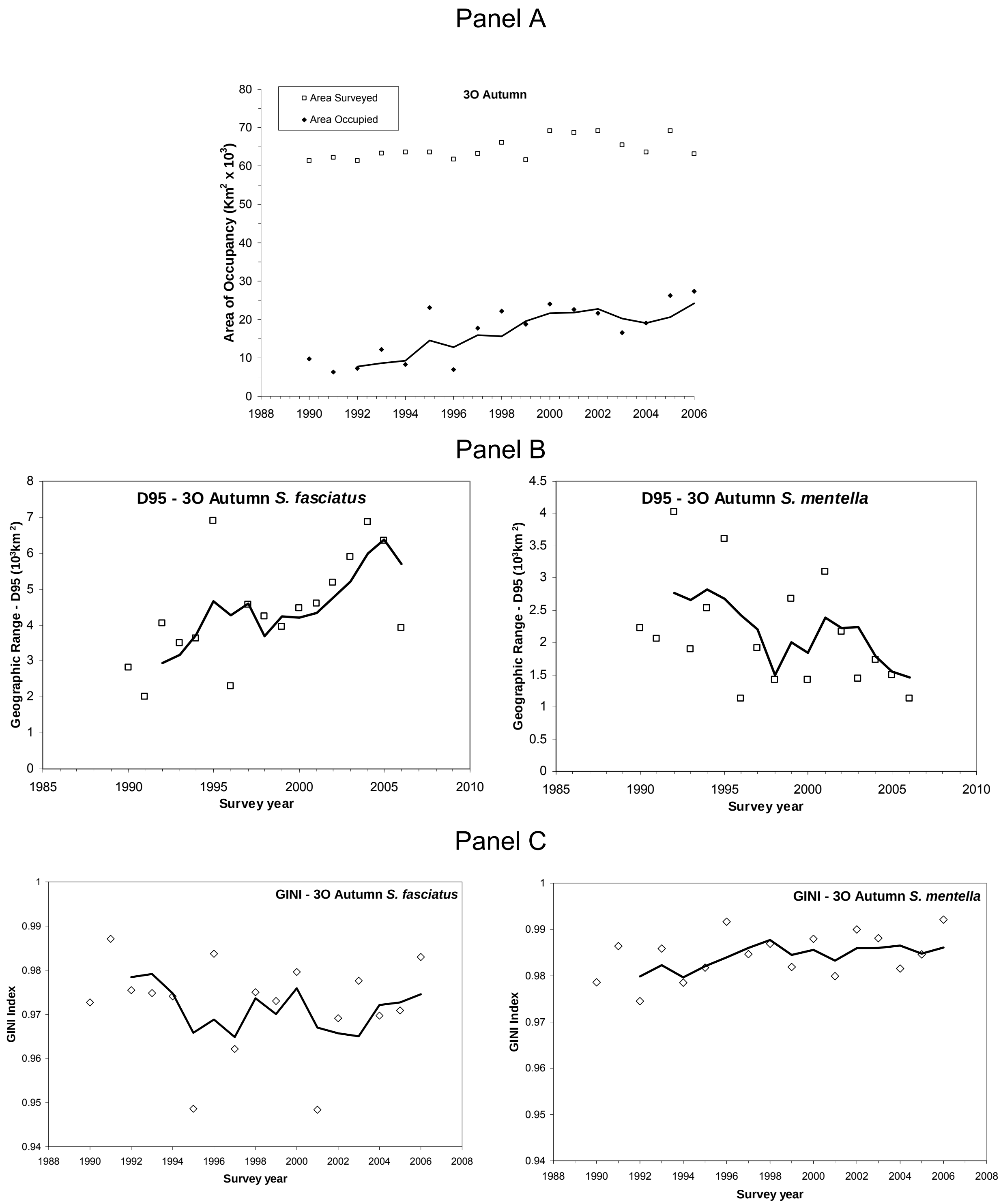


Figure 33. Distribution indices for redfish spp. (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Division 3O from autumn surveys from 1990-2006. Surveys from 1990-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1995-2006 utilized a Campelen trawl. All surveys were to a maximum of 400 fathoms (732 m).

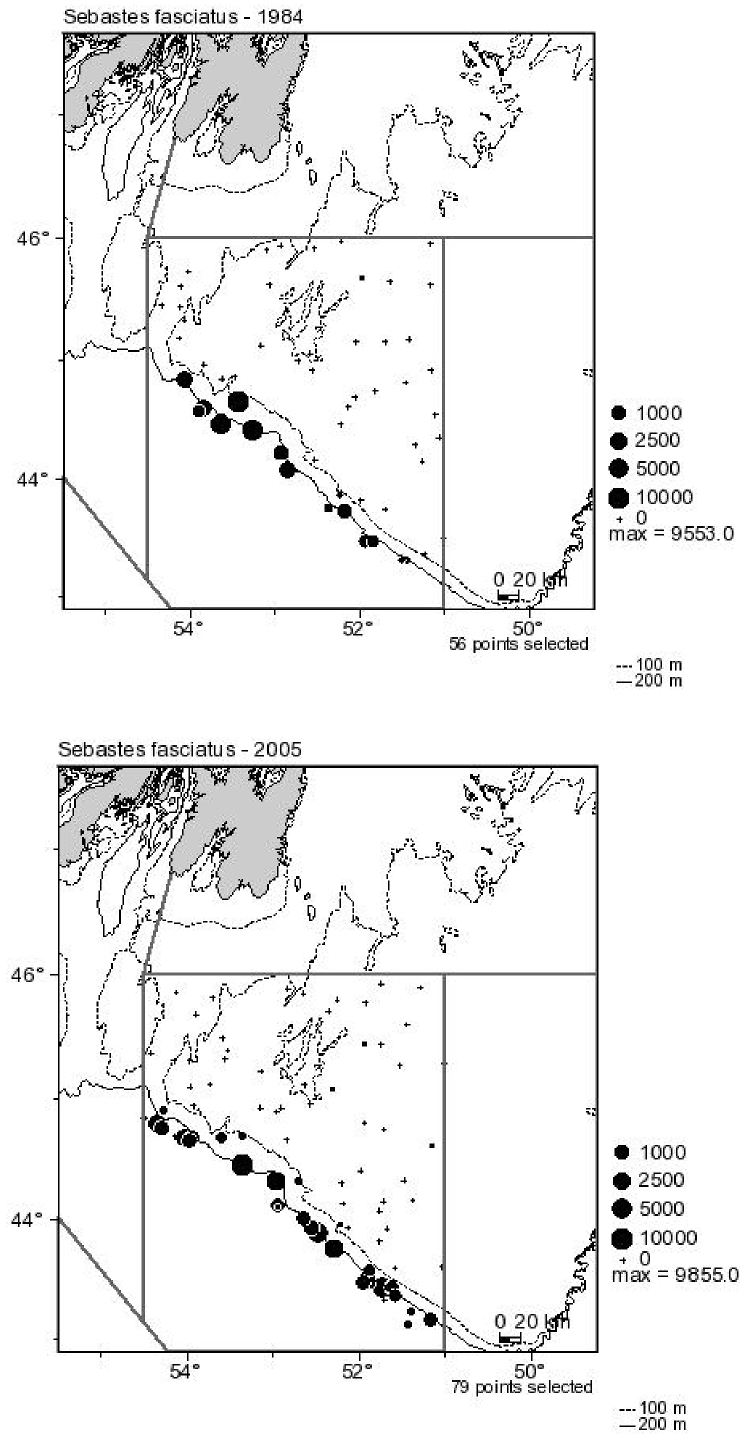
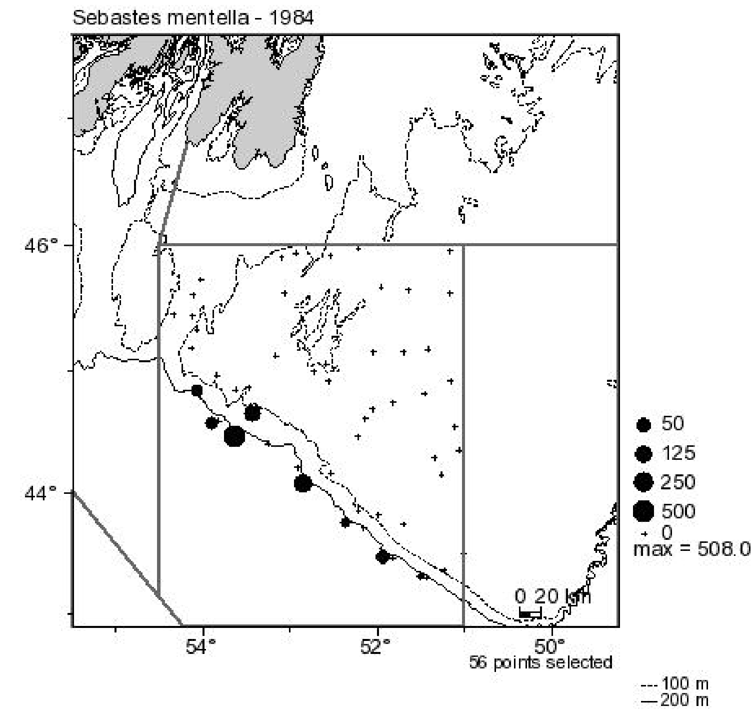


Figure 34. Distribution of the catches of *Sebastes fasciatus* (in number) in NAFO Division 3O from spring surveys in 1984 and 2005.



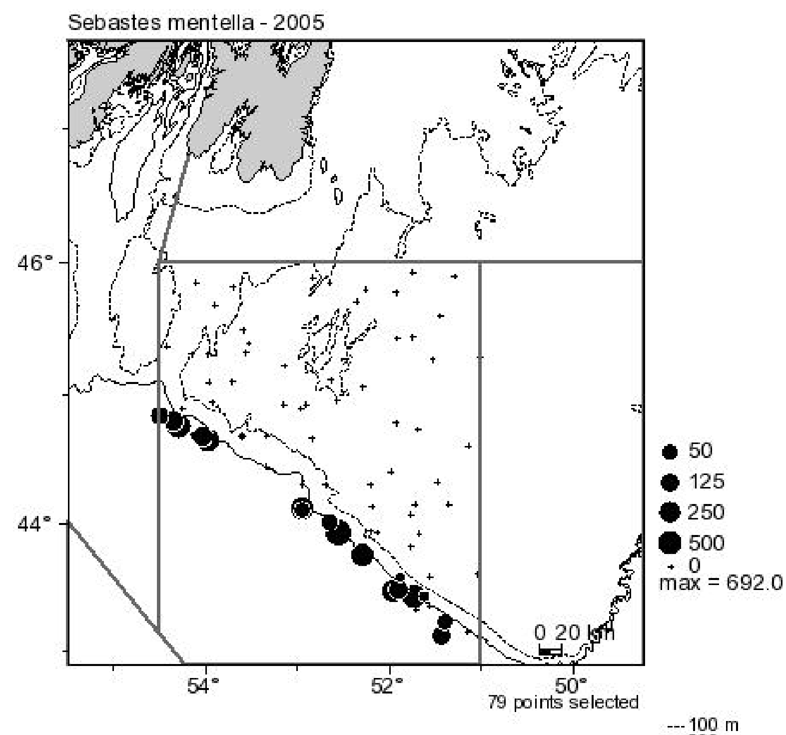


Figure 35. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Division 3O from spring surveys in 1984 and 2005.

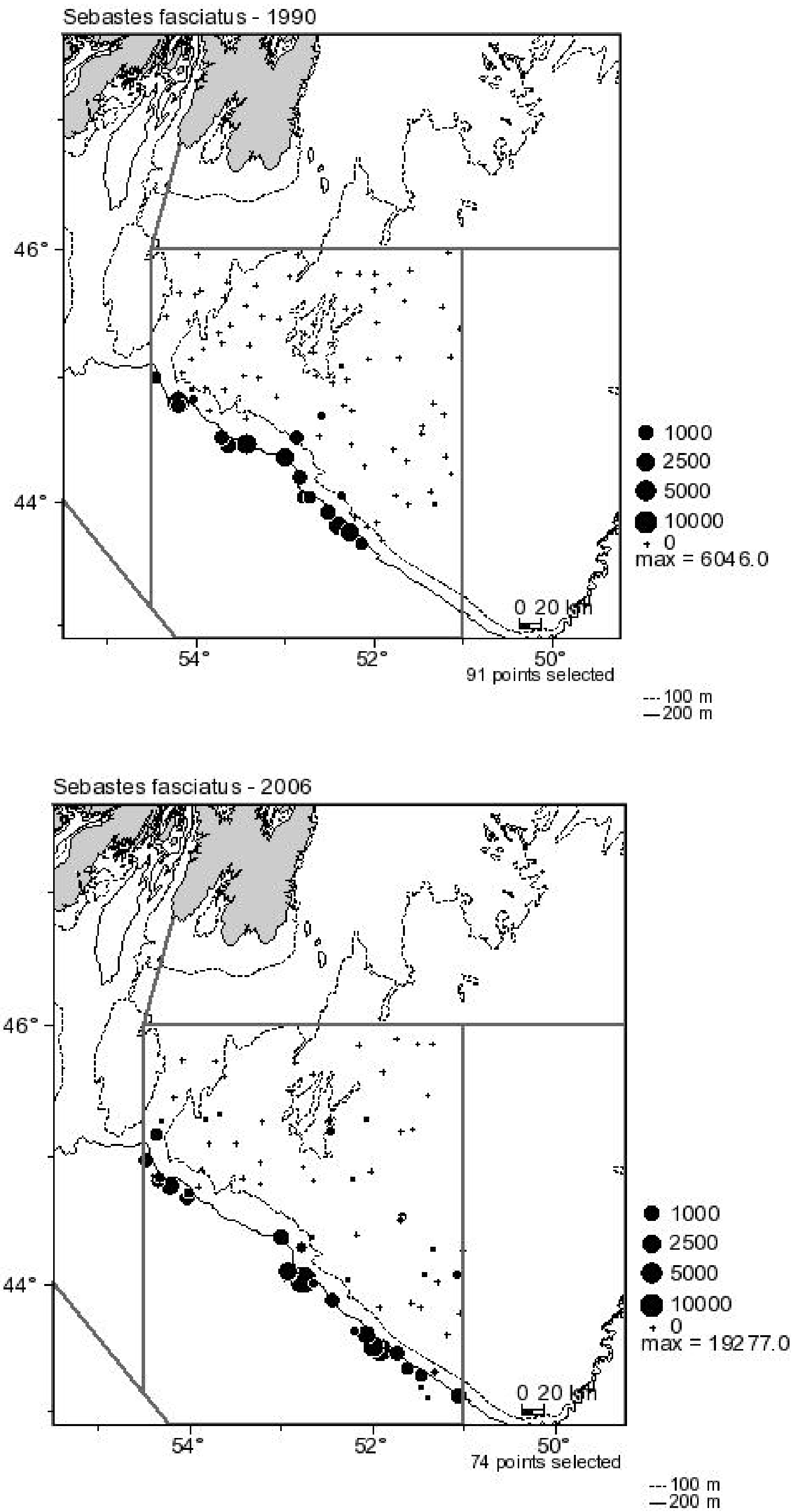
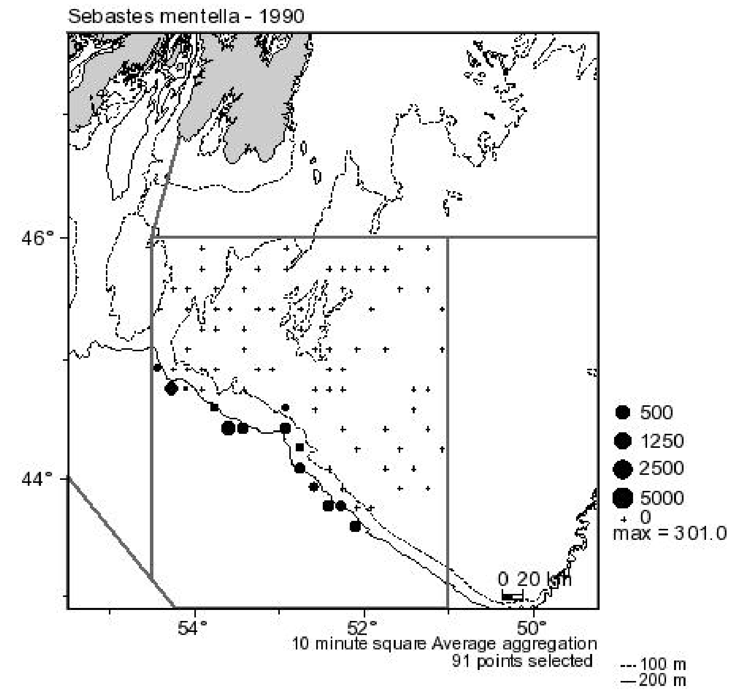


Figure 36. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Division 3O from autumn surveys in 1990 and 2006.



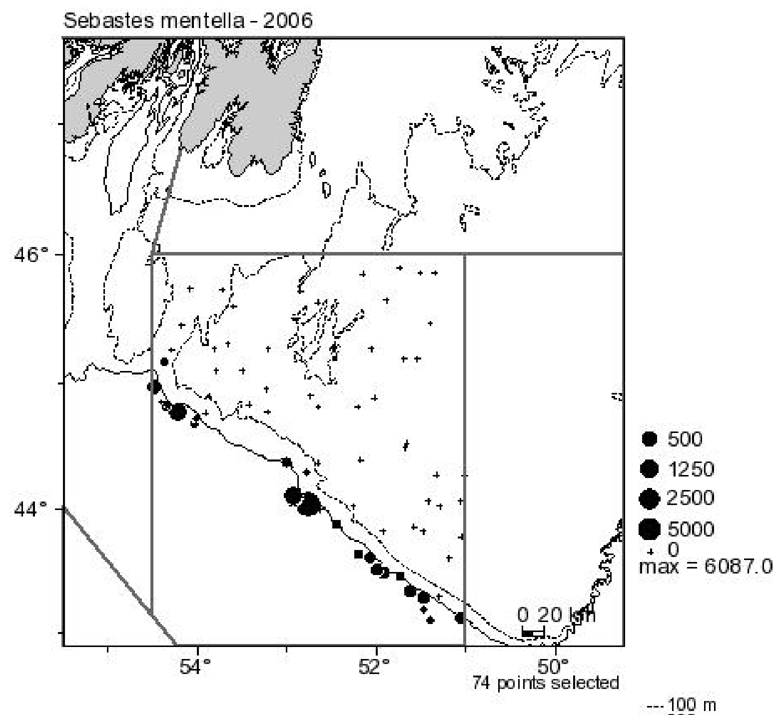
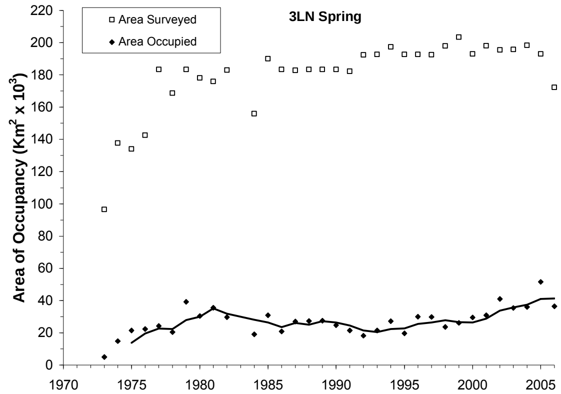
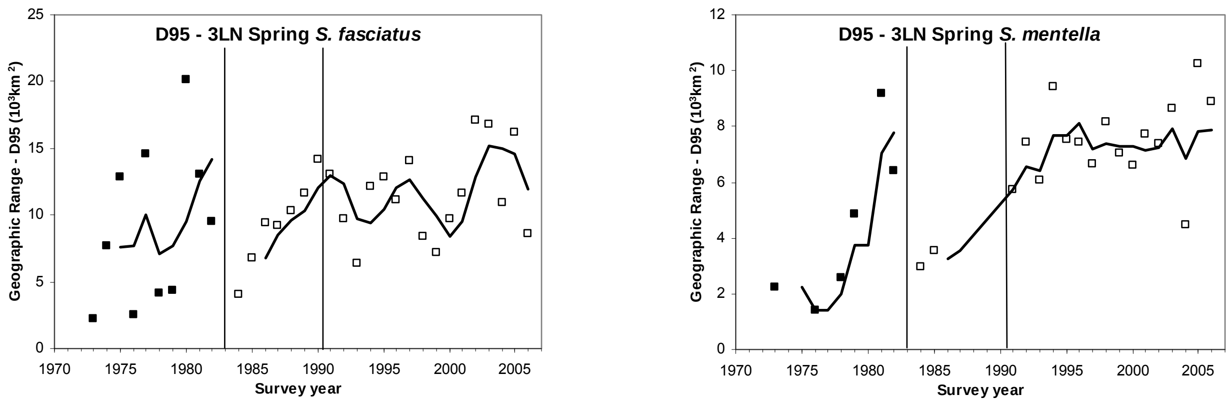


Figure 37. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Division 3O from autumn surveys in 1990 and 2006.

Panel A



Panel B



Panel C

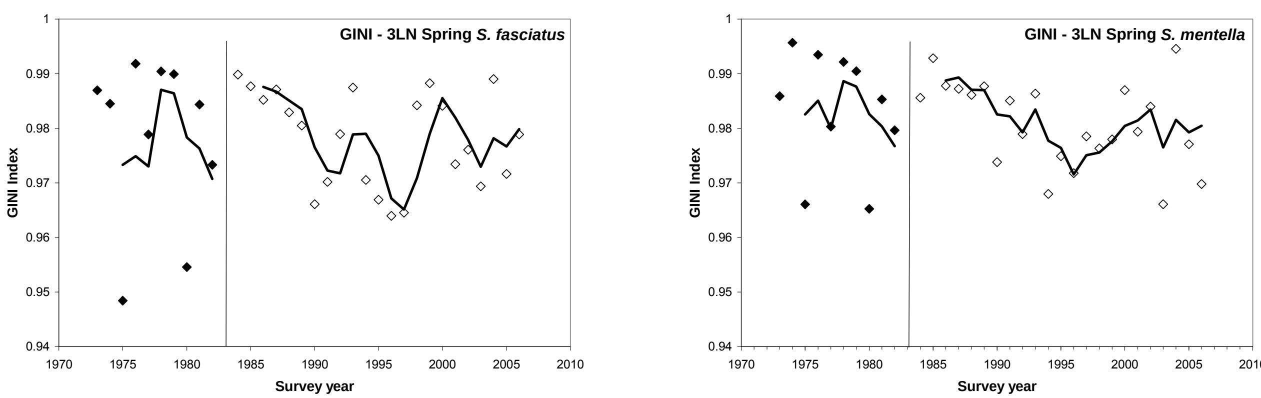
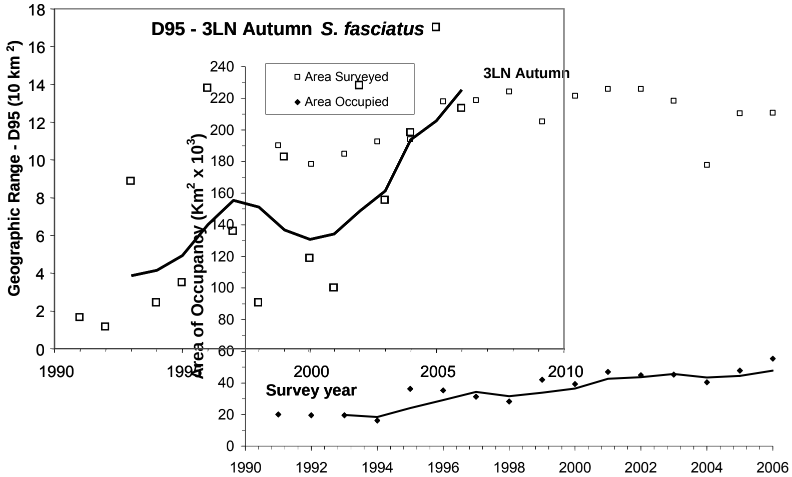
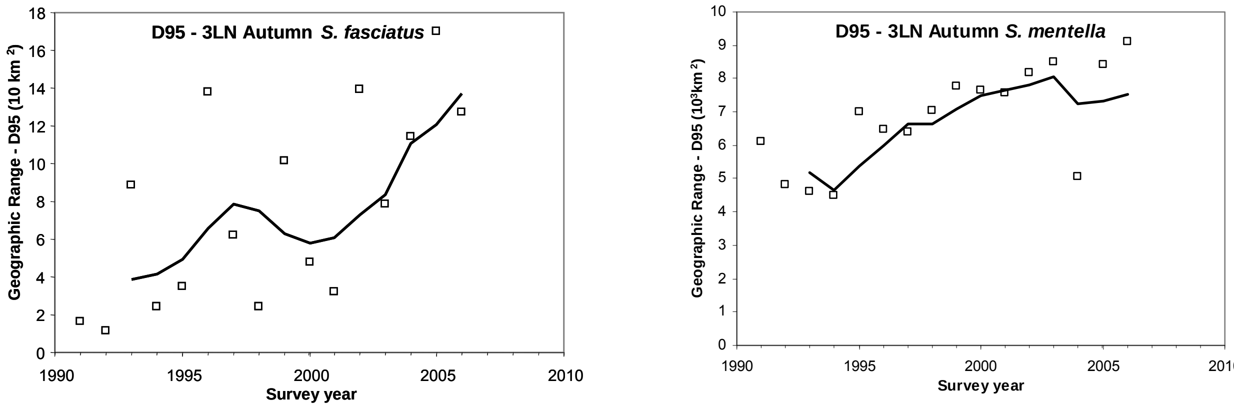


Figure 38. Distribution indices for redfish spp. (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Divisions 3LN from spring surveys from 1973-2006. Surveys from 1973-1982 were to 200 fathoms (367 m) with a Yankee 41-5 otter trawl, surveys from 1984-1990 were to 200 fathoms (367 m) with an Engel 145 trawl (converted to Campelen units) and surveys from 1991-2005 were to 400 fathoms (732 m) with a Campelen trawl.

Panel A



Panel B



Panel C

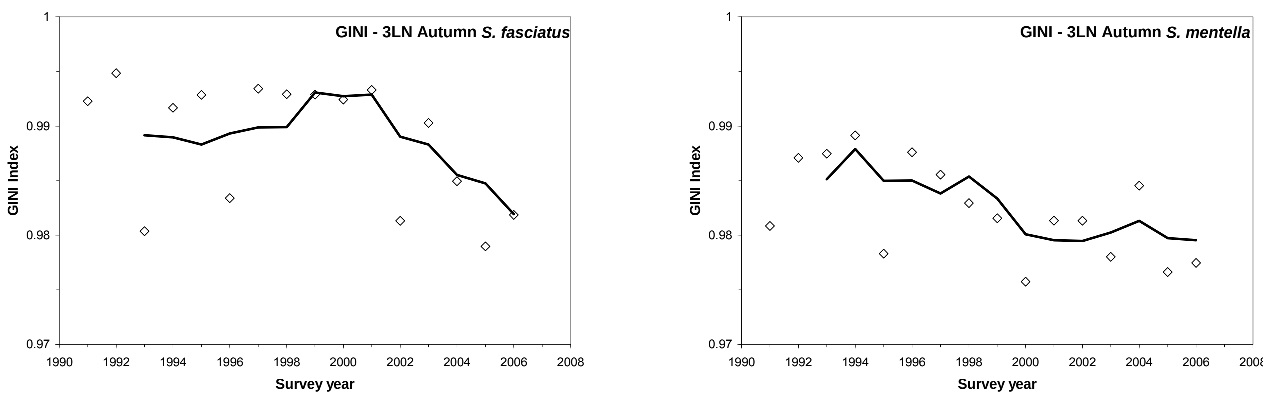
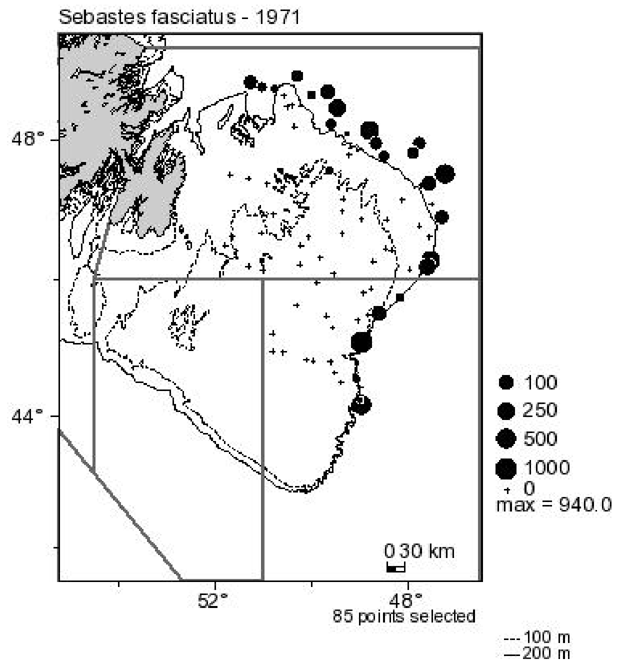


Figure 39. Distribution indices for redfish spp. (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Divisions 3LN from autumn surveys from 1991-2006. Surveys from 1991-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1995-2006 utilized a Campelen trawl. All surveys were to a maximum of 400 fathoms (732m).



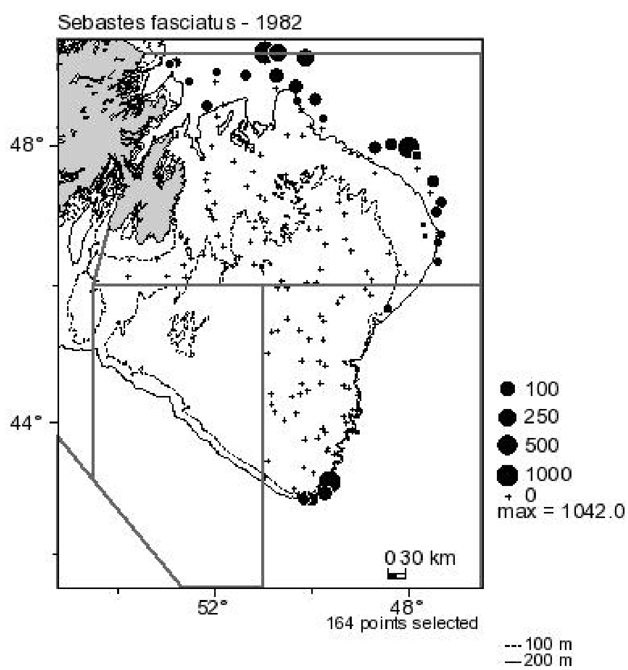
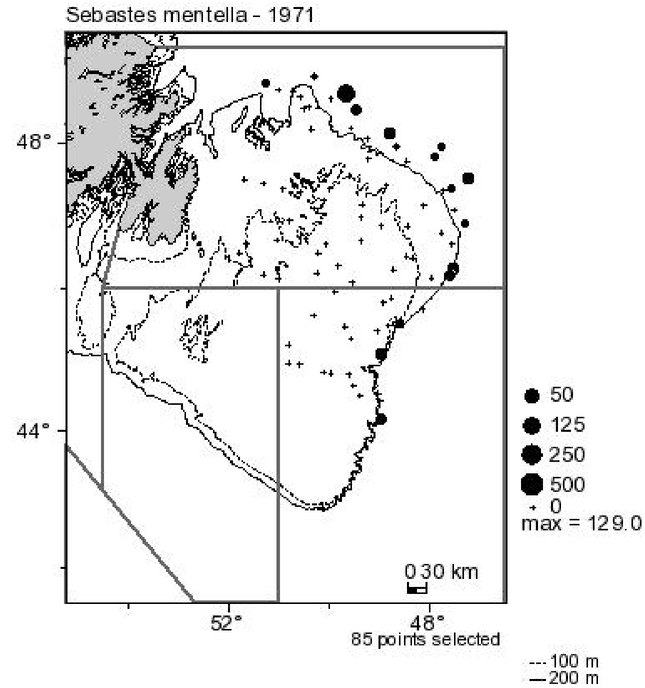


Figure 40. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Divisions 3LN from spring surveys in 1971 and 1982.



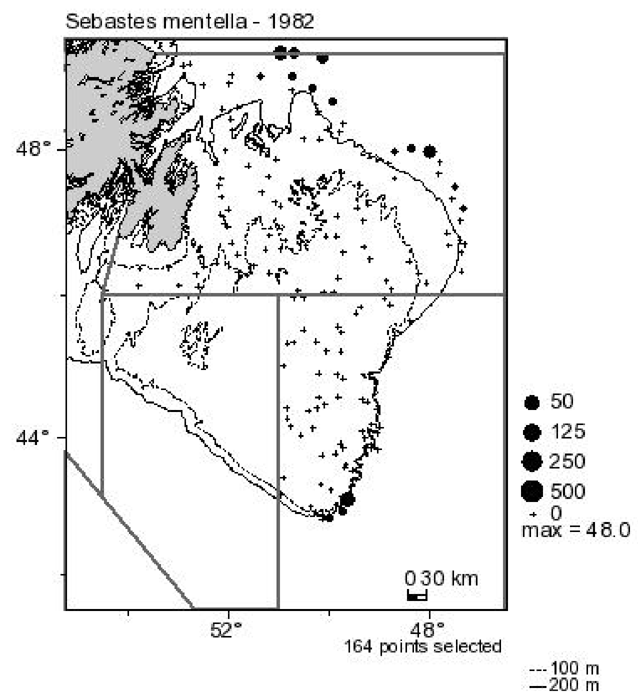
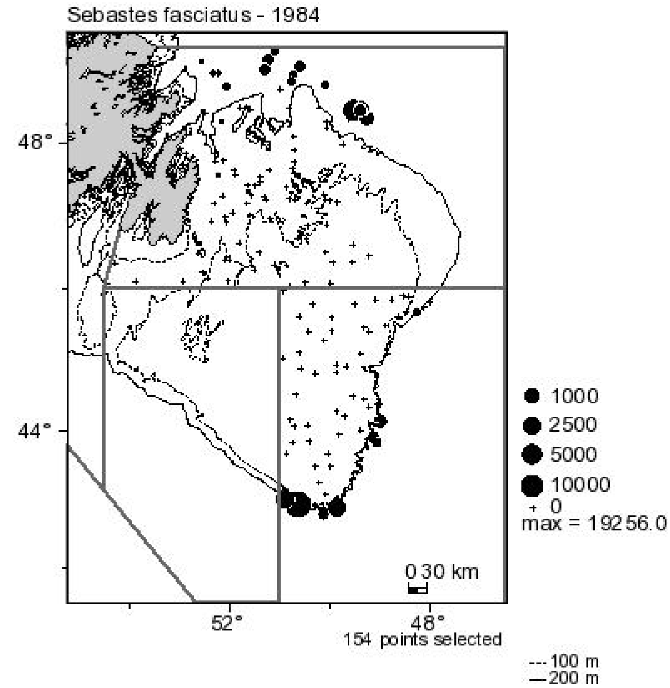


Figure 41. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Divisions 3LN from spring surveys in 1971 and 1982.



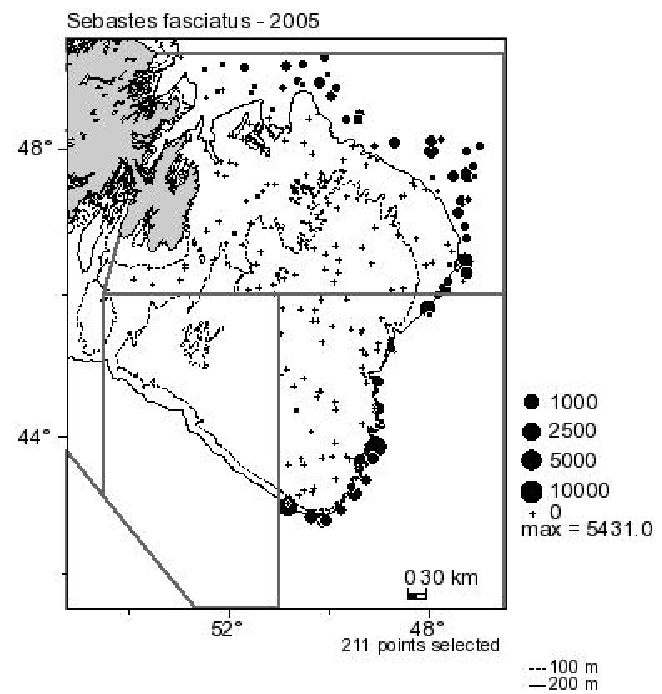
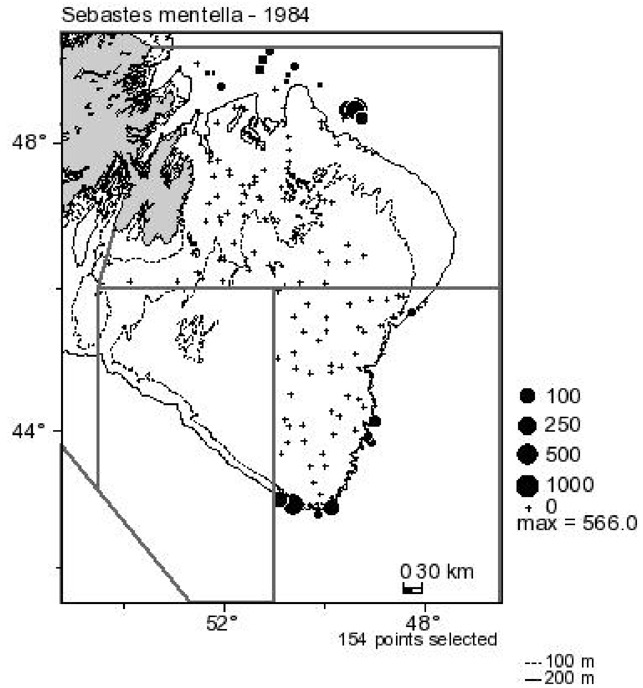


Figure 42. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Divisions 3LN from spring surveys in 1984 and 2005.



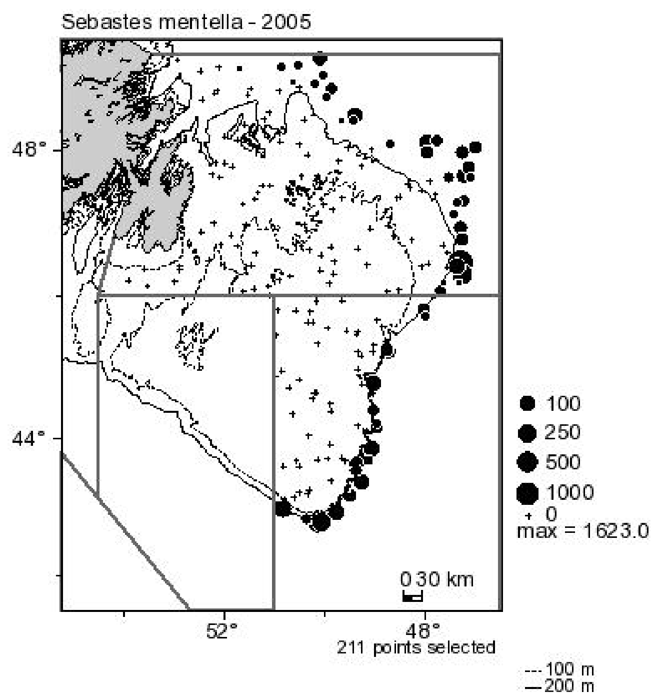
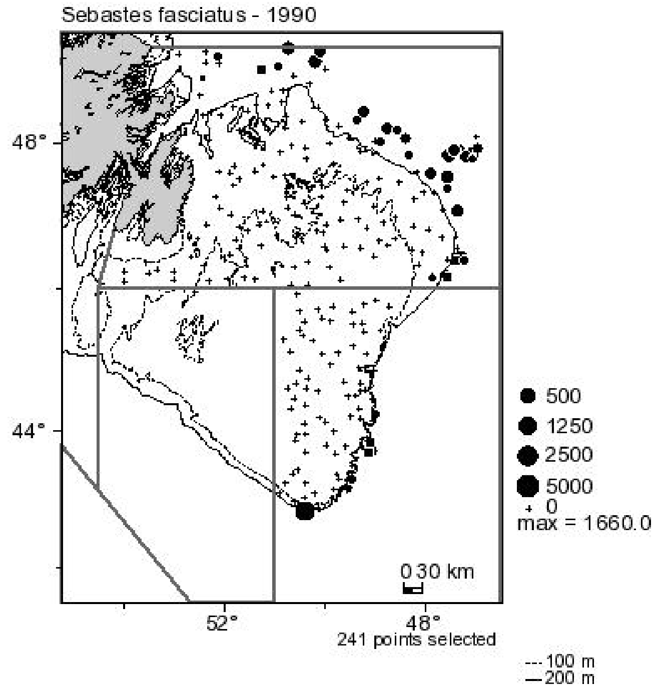


Figure 43. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Divisions 3LN from spring surveys in 1984 and 2005.



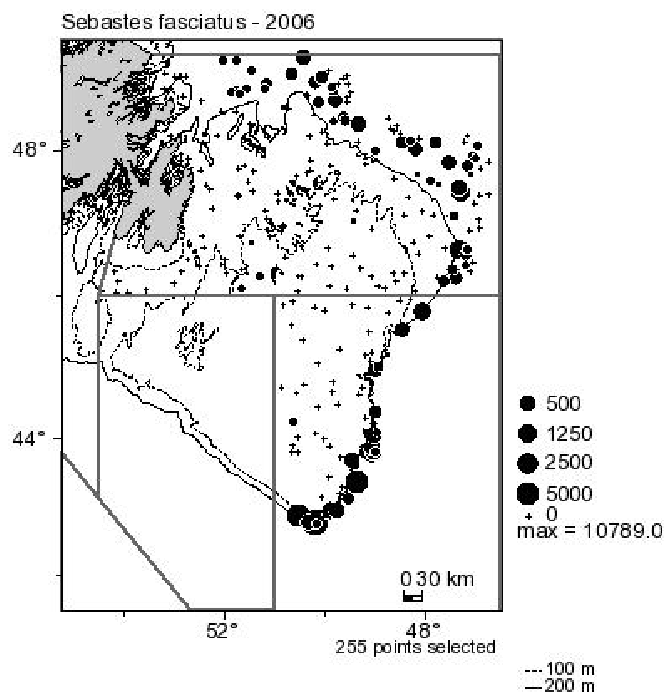
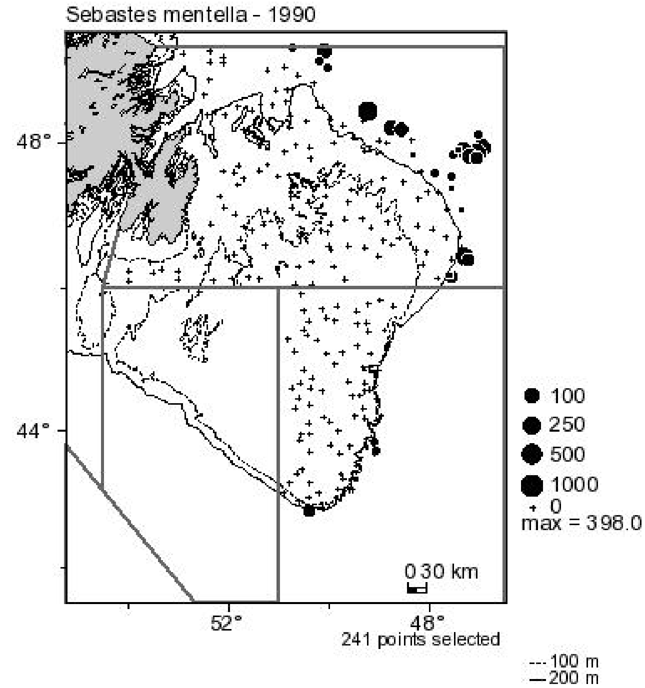


Figure 44. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Divisions 3LN from autumn surveys in 1990 and 2006.



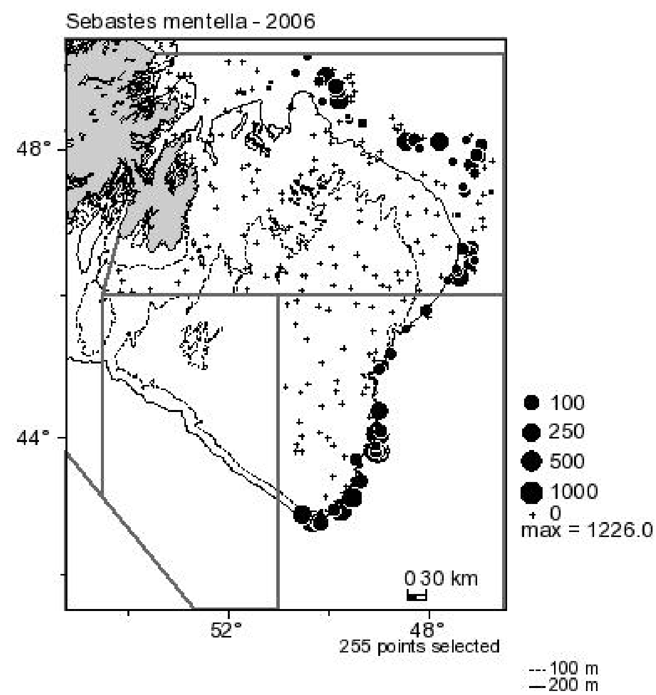
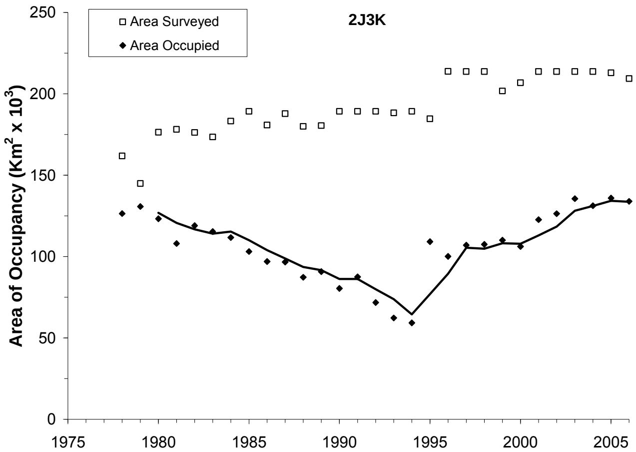
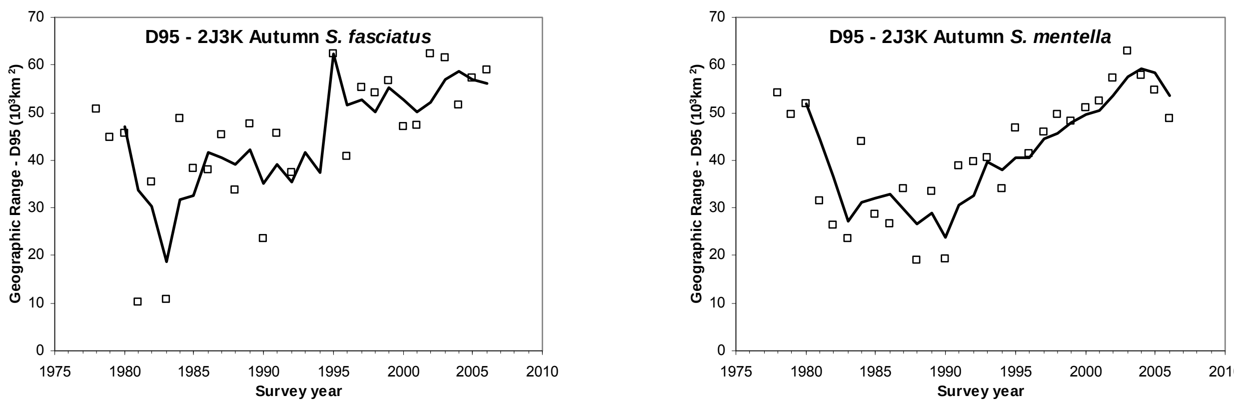


Figure 45. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Divisions 3LN from autumn surveys in 1990 and 2006.

Panel A



Panel B



Panel C

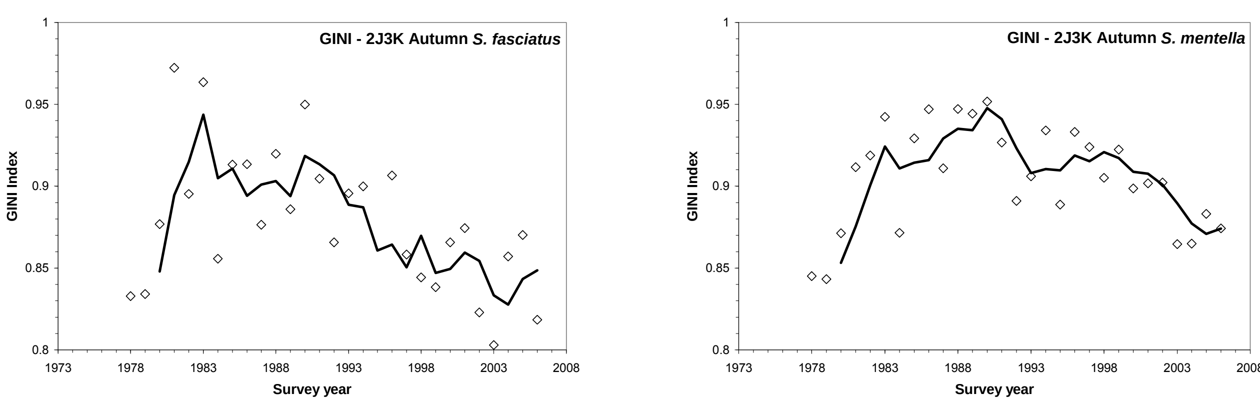
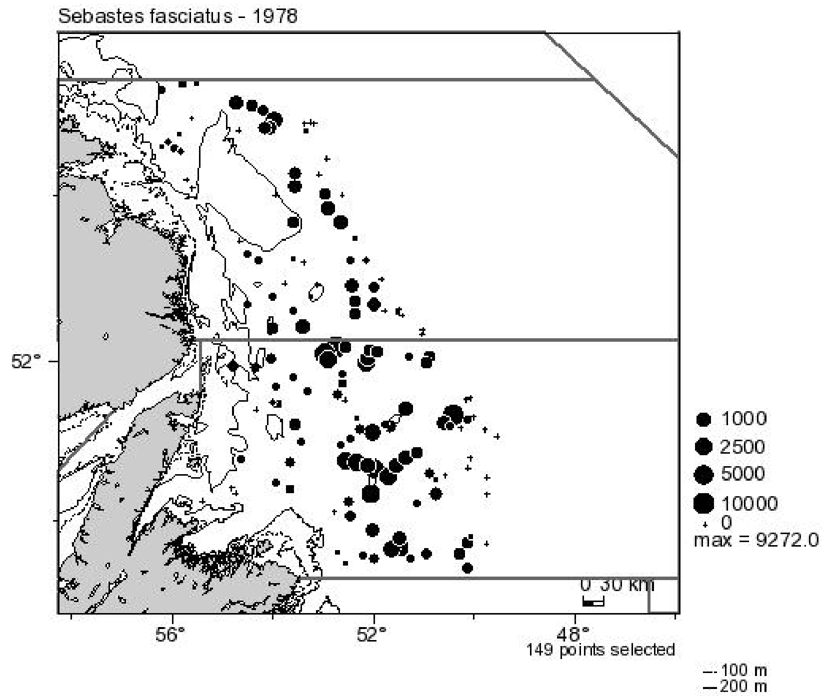


Figure 46. Distribution indices for redfish spp. (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Divisions 2J3K from autumn surveys from 1978-2006. Surveys from 1978-1994 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1996-2001 utilized a Campelen trawl. Surveys were to a maximum of 1 000 m to 1995 and to 1 500 m from 1996-2006.



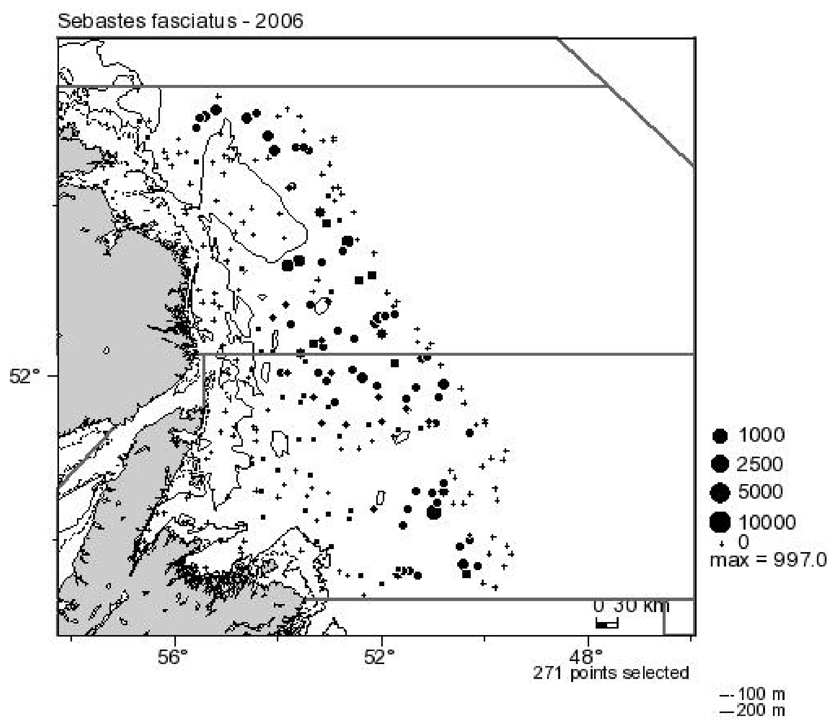
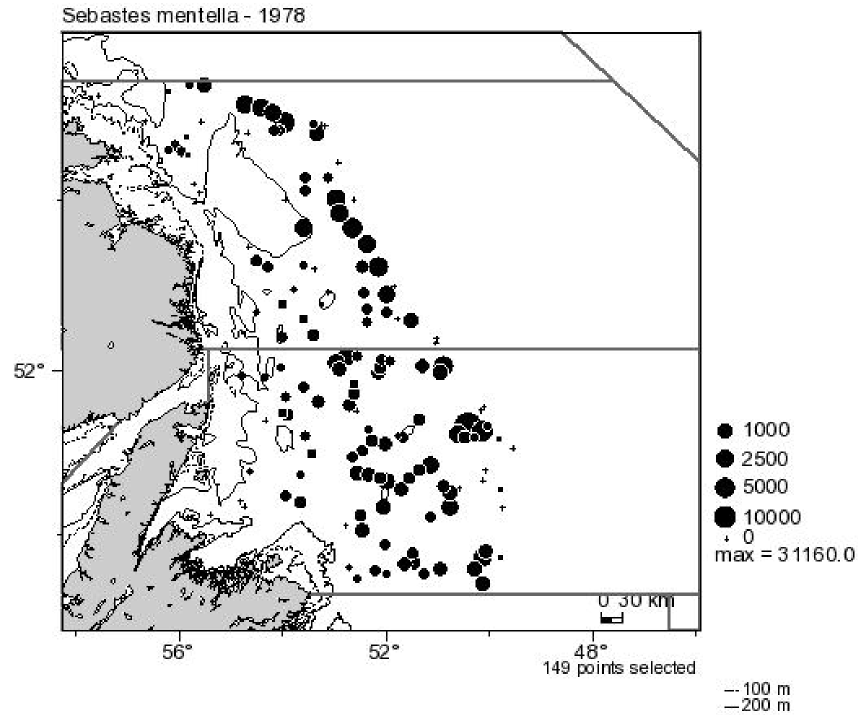


Figure 47. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Divisions 2J3K from autumn surveys in 1978 and 2006.



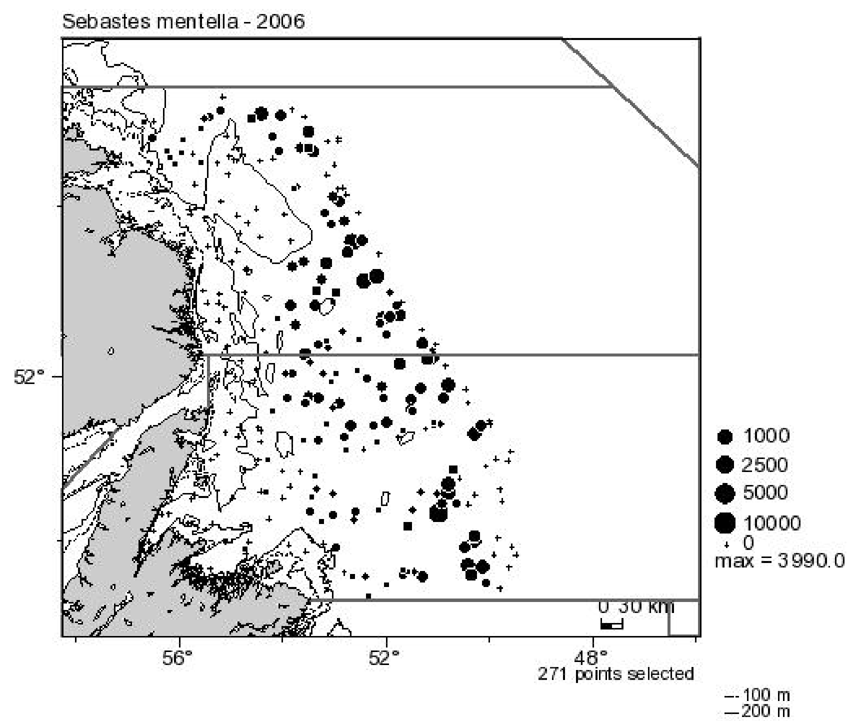
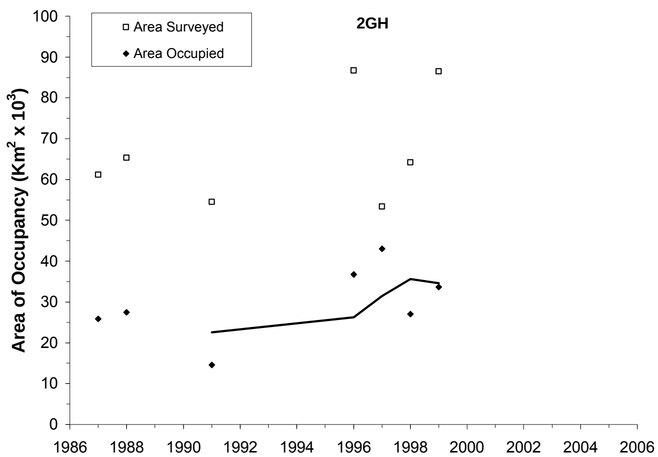


Figure 48. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Divisions 2J3K from autumn surveys in 1978 and 2006.

Panel A



Panel B

Panel C

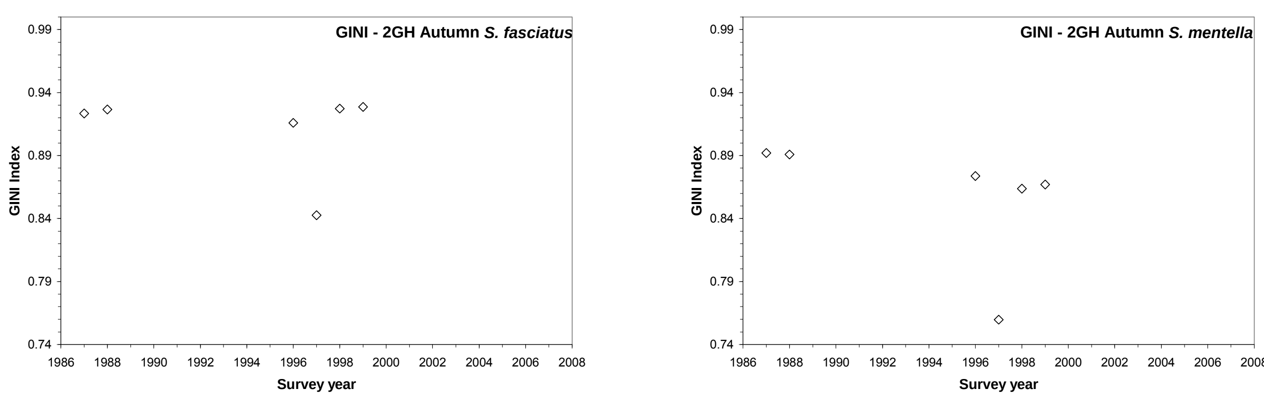
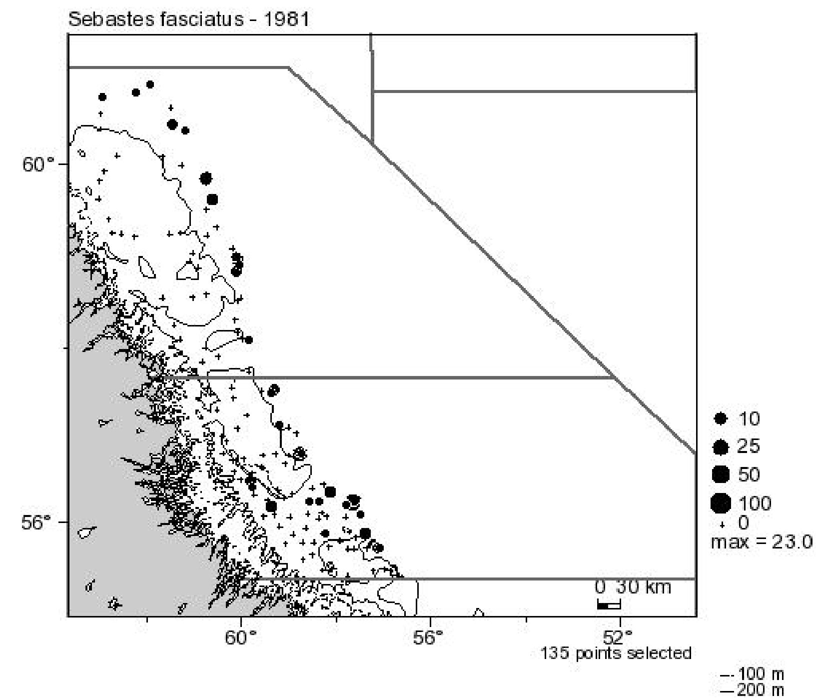


Figure 49. Distribution indices for redfish spp. (DWAO, panel A) and indices of concentration (D_{95}, panel B and Gini, panel C) of *Sebastes fasciatus* and *S. mentella* in NAFO Divisions 2GH from autumn surveys from 1987-1999. Surveys in 1987-1988 utilized an Engel 145 trawl (converted to Campelen units) and surveys from 1996-1999 utilized a Campelen trawl. Surveys were to a maximum of 1 000 m to 1995 and to 1 500 m from 1996-1999.



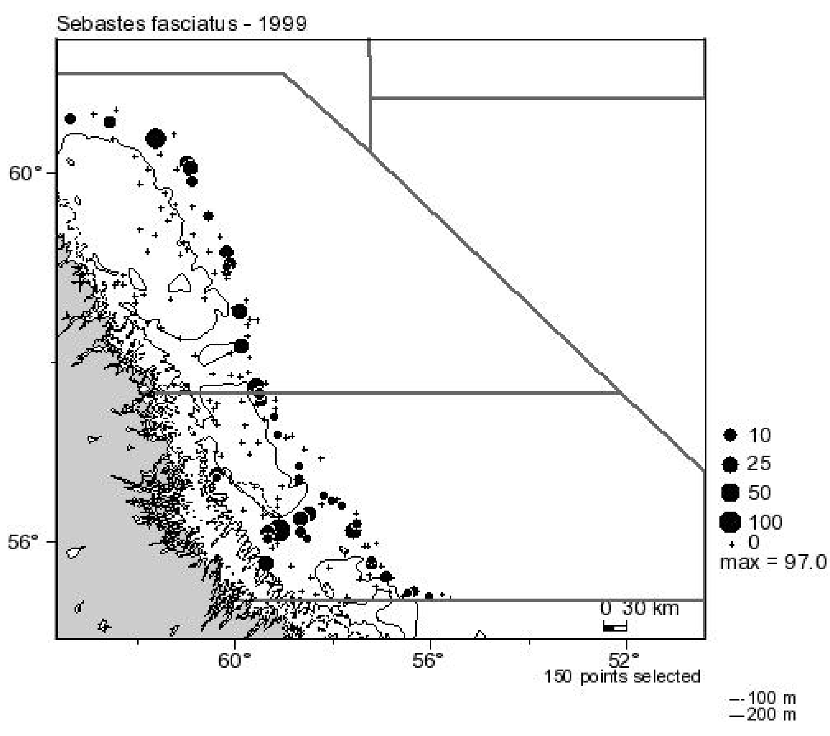
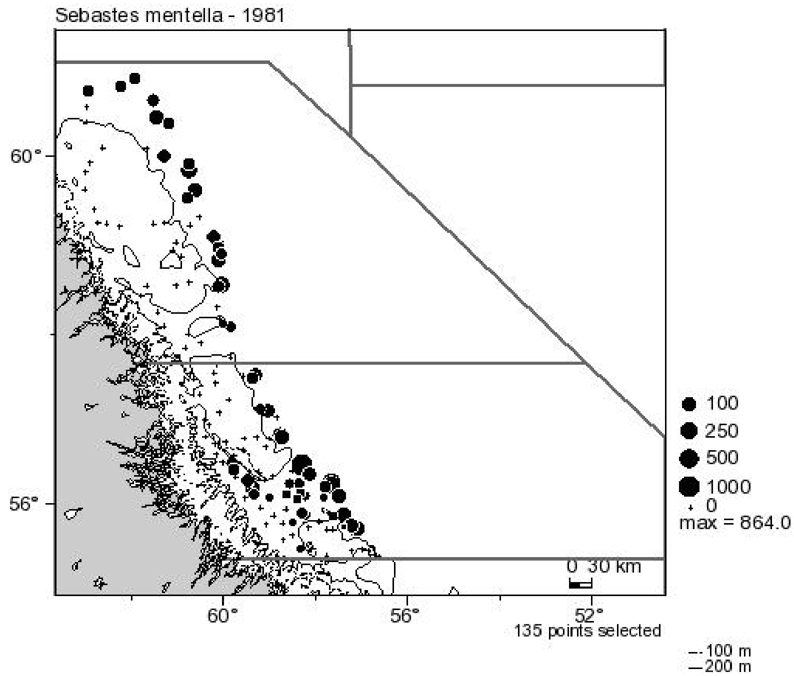


Figure 50. Distribution of the catches (in number) of *Sebastes fasciatus* in NAFO Divisions 2GH from autumn surveys in 1981 and 1999.



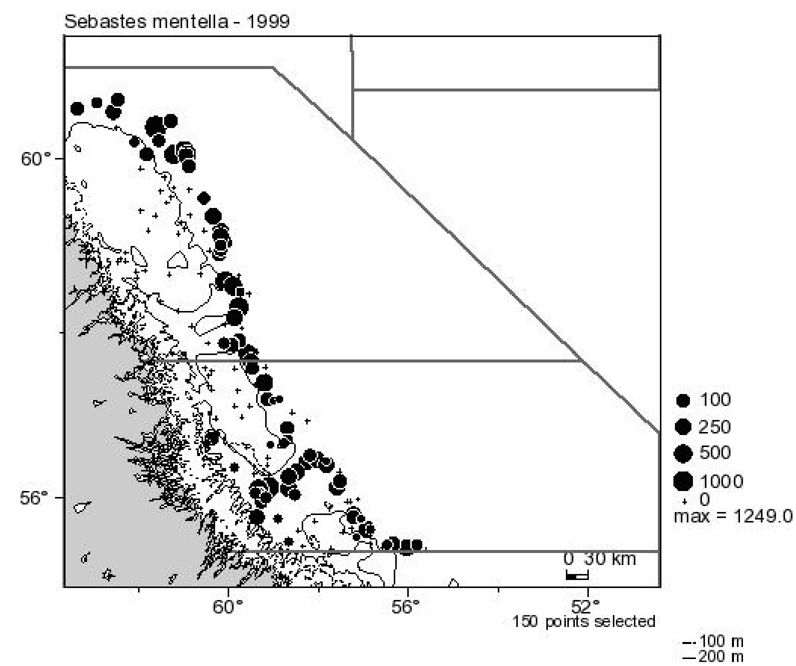


Figure 51. Distribution of the catches (in number) of *Sebastes mentella* in NAFO Divisions 2GH from autumn surveys in 1981 and 1999.