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Review of the structure, the abundance and distribution of American plaice (*Hippoglossoides platessoides)* in Atlantic Canada in a species-at-risk context

Examen de la structure, de l'abondance et de la répartition de la plie canadienne (*Hippoglossoides platessoides*) dans l'Atlantique canadien, dans le contexte des espèces en péril

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ABSTRACT

The structure, abundance and distribution of six stocks of American plaice (*Hippoglossoides platessoides*) in Canadian waters were reviewed by Fisheries and Oceans Canada (DFO) under the terms of reference for the Committee on Status of Endangered Wildlife in Canada (COSEWIC) species-at-risk. The American plaice population structure was evaluated to ascertain if the current management units, which are primarily based on life history traits of the species, are indicative of 'Designatable Units' (DUs) at the species level. Life history traits, survey distributions, including the location of spawning fish, abundance indices and biological information (length at age, age/length at maturity and year-class strengths) were inconclusive in assigning DUs to the management areas. Therefore, information for each area is presented separately and abundance trends are modeled for progressively grouped combinations of stock components, culminating with one for the Canadian northwest Atlantic. All stocks underwent declines and in stocks where data was sufficient for analysis, the overall model suggested declines in the range of 86.4 to 94.8%. Exploitation is likely the main cause of decline, although increase in natural mortality played a role in some areas. Since the rapid decline all stocks have remained at low abundance levels. Three spatial indices were calculated: the design-weighted area of occupancy (DWAO), the minimum area occupied by 95% of the stock (D95) and the Gini index of aggregation.

RÉSUMÉ

La structure, l'abondance et la répartition de six stocks de plie canadienne (*Hippoglossoides platessoides*) dans les eaux canadiennes ont été examinées par Pêches et Océans (MPO) conformément au mandat du Comité sur la situation des espèces en péril au Canada. La structure de la population de plie canadienne a été évaluée en vue de vérifier si les unités de gestion actuelles, qui sont principalement basées sur les traits du cycle biologique de l'espèce, sont toujours représentatives des « unités désignables » (UD) à l'échelle de l'espèce. Les traits du cycle biologique, la répartition selon les relevés, y compris l'emplacement des géniteurs, les indices d'abondance et l'information biologique (longueur selon l'âge, âge/longueur à la maturité et effectif de classes d'âge), n'étaient pas concluants pour l'assignation d'une UD aux zones de gestion. Par conséquent, l'information pour chaque zone est présentée séparément et les tendances de l'abondance ont été modélisées pour des combinaisons de composantes de stocks regroupées de façon progressive, ce qui a abouti à une unité pour l'Atlantique Nord-Ouest canadien. Tous les stocks ont connu des baisses et, dans le cas des stocks dont les données étaient suffisantes pour en faire l'analyse, le modèle global laisse croire à des baisses de l'ordre de 89,4 à 94,8 %. L'exploitation est vraisemblablement la principale cause de la baisse, même si l'augmentation du taux de mortalité naturelle a joué un rôle dans certaines zones. Depuis la baisse rapide, tous les stocks sont demeurés à de faibles niveaux d'abondance. Trois indices de répartition spatiale ont été calculés : la superficie occupée pondérée, la superficie minimale occupée par 95 % du stock (D95) et l'indice d'agrégation Gini.

SPECIES INFORMATION

NAME AND CLASSIFICATION

The American plaice, *Hippoglossoides platessoides* (Fabricius 1780), belongs to the Class Actinopterygii, Order Pleuronectiformes, and Family Pleuronectidae*,* the right-eyed flounders (Cooper and Chapleau 1998). Other common names include plaice, Canadian plaice, plie canadienne (Fr.), sand dab, long rough dab (UK, Isle of Mann, Europe), American dab, dab, flounder, and sole (Froese and Pauly 2000; Nelson *et al*. 2004; Scott and Scott 1988; Wheeler 1992). Former taxonomic nomenclature included species names *Hippoglossoides limandoides* (Bloch 1787) and *Pleuronectes platessoides* (Fabricius 1780). Subspecies names differentiating the eastern and western occurrence of the species have also been used; the western Atlantic form was considered to be *Hippoglossoides platessoides platessoides* and the European form, *Hippoglossoides platessoides limandoides* (Scott and Scott 1988). The currently recognized species name for American plaice over its entire distribution is *Hippoglossoides platessoides* (ITIS 2007).

MORPHOLOGICAL DESCRIPTION

The American plaice (Figure 1) is a benthic marine flatfish with an elongated, strongly laterally compressed body (Scott and Scott 1988). When the young fish hatch from the egg at or near the surface they have the 'normal' fish orientation. During development they undergo a metamorphosis resulting in lateral compression and the head twisting so that they swim on their side and both eyes are on the upper side of the body. In plaice, the twisting of the head occurs in such a way that the eyes are on the right, thus giving them the name right-eyed flounders (Pitt 1989). The head is small with a relatively large mouth that extends to below the middle of the eye and with the lower jaw protruding. They have a row of small conical teeth in each jaw (Scott and Scott 1988). The dorsal fin, with 76 to 101 rays, originates in front of the middle of the left eye and terminates at the base of the caudal peduncle. The anal fin, 60-79 rays, extends from under the posterior part of the operculum to the dorsal prominent pre-anal bony spine. The pectoral fins (9 to 12 rays) are rounded and situated behind the pelvic fins (6 rays). The caudal fin is slightly rounded, convex. The lateral line on the eyed side is obvious, slightly arched over the pectoral fin, otherwise straight. The scales on the eyed side are ctenoid, giving the upper side of the fish a 'rough' feel. The blind side scales are primarily smooth and cycloid. Vertebral counts range from 42-48. The size varies with locality but most specimens are not over 61 cm long. Colouration is fairly uniform, ranging from reddish to greyish brown on the eyed side and white on the blind side. The tips of the rays on the long dorsal and anal fins are white. Small plaice are frequently seen marked with three to five dark spots along each side of the body (Bigelow and Schroeder 1953; Scott and Scott 1988).

GENETIC DESCRIPTION

There has been some preliminary work undertaken on the genetic population structure of American plaice in the Gulf of St. Lawrence and the Grand Bank (Stott *et al*. 1992). Samples collected from six sites in the Gulf of St. Lawrence in a single year showed little heterogeneity in allele frequencies, and no differences in mitochondrial DNA markers were identified between the stocks. Samples (n = 43) of Grand Bank American plaice (Division

3N) suggested that there was little genetic differentiation between Gulf of St. Lawrence and Grand Bank populations (Stott *et al*. 1992). Other than this single study no other genetic investigation of American plaice population structure has been conducted.

GenBank® lists fifteen nucleotide and four protein sequences in its database for *Hippoglossoides platessoides* (http://www.ncbi.nlm.nih.gov/Genbank/).

DISTRIBUTION

GLOBAL RANGE

The American plaice is an arctic-boreal to temperate-marine species occurring on both sides of the North Atlantic on the continental shelves of northeastern North America and northern Europe (Figure 2). On the eastern side of the Atlantic, it ranges from approximately 70° to 50°N, occurring from Iceland and along the Norwegian coast to Spitsbergen and the Barents Sea. It can be found in the North Sea, the western Baltic, and as far south as the British Isles and English Channel (Bigelow and Schroeder 1953; Scott and Scott 1988). It is common in west Greenland waters as far north as Upernavik (near the Arctic circle, near latitude 72° N) (Bigelow and Schroeder 1953). In the western Atlantic, it is found from Baffin Bay and Davis Strait, south to Labrador and the Grand Bank and the Flemish Cap and southwards to the Gulf of Maine and Rhode Island (Bowering and Brodie 1991; Pitt 1989; Scott and Scott 1988;Treble unpublished data).

CANADIAN RANGE

American plaice are widespread throughout the Canadian Atlantic (Figure 3) and at one time was probably the most abundant flatfish species in the Northwest Atlantic (Pitt 1989). The Canadian distribution range for this species extends from Baffin Bay (72°N) south to Davis Strait and western Hudson Bay to the Bay of Fundy and the Gulf of Maine in the south (Bigelow and Schroeder 1953; Scott and Scott 1988; Treble unpublished data). North of 56° latitude, catches of American plaice are very low but they have been found in multispecies research surveys up to 72°N on the Canadian side and on the Greenland side of Baffin Bay (Treble 2007 unpublished data). Historically, the highest densities have occurred in the Grand Bank area off Newfoundland, particularly in the northern 3L portion where the largest commercial fishing operation for this species occurred (Bowering and Brodie 1991). Areas of greatest abundance have generally been found on the tops of the major fishing banks throughout the northwest Atlantic such as the Hamilton Bank (2J), northeastern Newfoundland shelf (3K), St. Pierre Bank (3Ps) and the Grand Bank (3LNO) (Bowering and Brodie 1991).

The more southerly distributions are on the Magdalen shoals of the Gulf of St. Lawrence; off the coast of Nova Scotia, American plaice are found from Sydney Bight on the northeast coast of Cape Breton to the Bay of Fundy (Bigelow and Schroeder 1953; Scott and Scott 1988). Stocks further south than this generally inhabit US waters with the only other Canadian component being the northeast end of Georges Bank (Pitt 1989).

DESIGNATABLE UNITS

In the absence of detailed examination of the genetic population structure of American plaice in Canadian waters to identify population structure below that of the species, the assignment of Designatable Units is dependent on life history traits and spatial separation between the populations. The initial establishment of the Fisheries Management Units in the 1970s (which are still in effect today) defined the stocks primarily on life-history traits and distribution of the adults. In so much that a fish stock can be defined as ‘an intra-specific group of randomly mating individuals with temporal and spatial integrity” (Ihssen *et. al*. 1981), and no recorded information of interbreeding or genetic mixing in American plaice populations is documented, it has been generally accepted that the population boundaries for American plaice population units follow the management units (Walsh 1994a). These units are based on the NAFO (Northwest Atlantic Fisheries Organization) Divisions (Figure 4) in the northwest Atlantic:

1. Labrador and northeast Newfoundland (Subarea 2 (Divisions 2G, 2H, 2J) plus Division 3K)
2. Newfoundland Grand Bank (Divisions 3LNO)
3. Flemish Cap (Division 3M)
4. St. Pierre Bank (Subdivision 3Ps)
5. Gulf of St. Lawrence (Division 4T)
6. Scotian Shelf (Divisions 4VW and 4X)
7. Georges Bank, New England (Subareas 5 and 6)

American plaice, on the Flemish Cap (NAFO Division 3M) and the majority of the stock in NAFO Subareas 5 and 6, except for a small area of Georges Bank, lie outside of Canadian waters (Pitt 1989). American plaice are found in multispecies surveys in the Davis Strait, NAFO Divisions 0A and 0B but are not assessed as a fisheries stock (M. Treble pers. comm.). The American plaice in Division 3Pn on the southwest corner of Newfoundland and plaice in the northern Gulf, Division 4RS, are not under quota management. Therefore, in Canadian waters, the stocks or populations of American plaice that are herein examined for evidence of Designatable Unit status are:

1. Labrador and Northeast Newfoundland (SA2 + 3K)
2. Newfoundland Grand Bank (3LNO)
3. St. Pierre Bank (3Ps, plus 3Pn)
4. Gulf of St. Lawrence (4RST)
5. Scotian Shelf (4VWX)
6. Davis Strait (0AB)

The following sections will review the life history traits and the geographic distributions of these populations in an attempt to define the Designatable Units of American plaice in Canadian waters.

AMERICAN PLAICE IN LABRADOR AND NORTHEAST NEWFOUNDLAND (SUBAREA 2 + DIVISION 3K)

The American plaice in the Labrador and northeastern Newfoundland area (Subarea 2 + Division 3K) has been the subject of limited scientific study (Bowering *et al*. 1997). However, there is evidence to indicate that American plaice in this area are a separate population from Divisions 3LNO plaice and that movement of fish between these areas is limited. The first TAC for plaice in this area was introduced by ICNAF in 1974. In the ICNAF Redbook 1974 (pg. 28), it is stated "From a knowledge of the extent of migration in Division 3L and 3N it is quite probable that very little mixing occurs between adult plaice in Division 3K and those to the south in Division 3LNO." Based on the assessment by Pitt (1974).

Pitt (1963) compared vertebral numbers of American plaice in the North Atlantic and found a low degree of variability over the whole area of study. No significant differences in vertebral numbers in any of the samples collected over the Grand Bank area were identified, but averages for the Grand Bank were significantly higher than some of the nearby areas including the Gulf of St. Lawrence, Flemish Cap and Labrador Shelf. No differences in anal fin ray counts were found between Grand Bank, St. Mary's Bay and St. Pierre Bank fish (Pitt 1975b).

Bowering *et al.* (1998) examined morphometric data from American plaice collected from eighteen sites in NAFO Subareas 2+3 using a novel statistical approach. Analysis using this method indicated that each sample was statistically different from the others resulting in eighteen populations of plaice. This was not considered reasonable and they concluded that morphometrics is of limited use in delineating stocks of American plaice. Although the authors noted the limitations of this approach for stock identification, they also ranked the samples on a linear scale and were able to draw some conclusions about similarities and differences between the populations. They noted that samples from the northernmost edge of the range (Division 2H) appeared to be 'most different' from samples collected elsewhere, particularly from those fish collected on the northern Grand Bank (Division 3L), and that there was similarity among the three samples from Division 2J and 3K.

There have been no tagging or genetic studies of American plaice in Subarea 2 + Division 3K. Pitt (1969) reported on 4653 American plaice tagged at various locations on the Grand Bank. He found no returns north of Division 3L, and concluded that "most American plaice were recovered less than 30 n. miles from the tagging site, even up to seven years after tagging." Morgan (1996) also found that American plaice on the Grand Bank were relatively sedentary. Tagged juveniles were recaptured an average of 34 n. miles from the release site and adults averaged 52 n. miles from the site of release. The mean number of days free after release was 400.0 (s.e. ± 35.1) days. No evidence of large scale migration was observed and no fish were found to have migrated from Division 3L area northward to Division 3K.

There is some suggestion that because of the surface circulation in the northwest Atlantic, and the strong southward flow of the Labrador Current, there could be considerable movement of eggs and larvae from the more northerly areas of Labrador and the Northeast Newfoundland Shelf to the Grand Bank area (Pitt 1963; Pitt 1975a,b). Bigelow and Schroeder (1953) reported that the period occupied by larval growth and metamorphosis in American plaice in the Gulf of Maine is probably 3 to 4 months. In more northerly areas, such as those in Subarea 2 + Division 3K, where the temperatures are cooler, this period of larval drift would likely be extended such that eggs and larvae from spawning in Labrador and the North-eastern shelf of Newfoundland could be dispersed to the northern Grand Banks (Pitt 1963). The reverse, however, would be unlikely because of the southward moving currents. Pitt (1963) proposed this larval drift theory to account for the low variability in vertebral numbers observed between populations. In drift simulations modeling cod egg and larval distribution, using current flows of the Labrador

Current and running over 200 days, Helbig *et al*. (1992) found that most particles released on the Hamilton Bank and Northeast Newfoundland Shelf tended to remain on the shelf. Those entrained into the offshore branch of the Labrador Current are swept 'downstream' but not into the inshore bays or onto the Grand Bank. The offshore branch of the Labrador Current seemed to act as a barrier between the northeast Newfoundland shelf and the Grand Bank. This model was supported by drifting buoy tracks available from that time. In a subsequent study, however, it was demonstrated using drifters that cross-shelf mixing and/or dispersal of particles was substantially underestimated and that storm or eddy induced current fluctuations may make a significant contribution to the cross-isobath displacement of organisms (Pepin and Helbig 1997).

Growth and age at maturation, and spawning data have also been used to help delineate stocks of American plaice in the northwest Atlantic (Pitt 1975a,b) prior to heavy exploitation and severe stock size reductions of the 1980 and 1990's. Growth curves for the Labrador – North-eastern Newfoundland stocks were clearly different from those of the adjacent Grand Bank areas suggesting that at least for the adult stages, there was little intermingling of these populations (Pitt 1967a). Females from Subarea 2 + Division 3K matured at an older age (14.79 years) than females from the northern Grand Bank area (13.98 years) (Pitt 1967a) and spawning occurred earlier in the more southerly stocks (end of April) as opposed to the northern stocks which spawned later (early June) (Nevinsky and Serebryvakov 1973; Pitt 1966).

Parasitic fauna of the American plaice from six offshore locations of the Newfoundland and Labrador area was examined from an ecological point of view by Zubchenko (1985). Parasite composition and degree of infestation differences exist between fish of Hamilton Bank (Division 2J), Funk Island Bank (Division 3K), Flemish Cap (Division 3M) and Grand Bank (Divisions 3LNO) adding further support that at least the juvenile and adult fish of Subarea 2 + Division 3K are sedentary and do not migrate or mingle with stocks on the Grand Bank, confirming the conclusions of Pitt (1963, 1969 and 1975a,b) that ecological isolation of the northwest Atlantic stocks of American plaice is quite feasible. Even though some genetic mixing resulting from eggs and larval drift from the northern areas to the more southerly areas may occur, as previously discussed, the intermixing of juveniles and adults is low enough to consider the fish as separate populations (Zubchenko 1985).

AMERICAN PLAICE ON THE GRAND BANK (NAFO DIVISIONS 3LNO)

The American plaice on the on the Grand Bank forms the most complex of all the stocks surrounding Newfoundland (Bowering and Brodie 1991). Because of variations within Divisions 3LNO, in terms of growth rates, maturity rates and the suggestion of various spawning components and nursery areas, questions have been raised as to whether the fish in Divisions 3LNO belong to a single spawning unit or whether they are made up of discrete spawning stocks (Bowering and Brodie 1991; Brodie 2002).

The preliminary assessments of American plaice on the Grand Bank were carried out by Pitt in the 1970s (Pitt 1975b). He considered that there were two main stocks, one in Division 3L and the second smaller one in Division 3N as based on the then current fishery. His tagging study revealed little movement between the northern and southern parts of the bank and there were little differences in growth rates and age compositions of the two areas. He did however note that recruitment in Division 3N probably depended on Division 3L in terms of larval drift from the north. The first TAC set by ICNAF in 1972 for

Grand Bank American plaice grouped the three divisions of the Grand Bank into a single stock for Divisions 3LNO (ICNAF 1972). Genetic differentiation of Grand Bank plaice has not been undertaken.

In 2001, following a recommendation made by STACFIS (Standing Committee on Fisheries Science of NAFO) a detailed review of the American plaice in Divisions 3LNO was undertaken to determine if there was any merit in there being separate populations within this stock area or if indeed the American plaice on the Grand Bank form a single population unit (Brodie 2002). The conclusion reached, based on biological justifications outlined below, and on fisheries management considerations, was that a single stock of American plaice exists in Divisions 3LNO.

There are no defined spawning grounds for American plaice on the Grand Bank but rather spawning is widely distributed over the bank with most intense spawning coincident with areas where the higher abundance of adults are found. Nevinsky and Serebryakov (1973) found spawning of American plaice to be more intensive over the northern part of the Grand Bank and less intense on the southern parts and that the adult plaice were generally observed in the same habitat as their eggs. Morgan (2001) examined the times and locations of American plaice spawning in Divisions 3LNO from Canadian survey data (1971 to 1999) the results of which were in agreement with previous studies (Nevinsky and Serebryakov 1973; Pitt 1966), that spawning appeared to be widespread over the bank. Ollerhead *et al.* (2004) also found spawning of American plaice on the Grand Bank to be widespread over the entirety of the Bank with peak spawning activity observed in May. It has been suggested that the low current velocities on the Grand Bank prevent the larvae from drifting too far from the spawning grounds (Frank *et al*. 1992; Nevinsky and Serebryakov 1973).

The tagging programs that have been conducted on American plaice in Divisions 3LNO indicate that the juvenile and adult plaice are generally sedentary and do not participate in any large scale migratory behavior as discussed previously (Morgan 1996; Pitt 1969). Inshore migrations within Division 3L have been reported in tagging studies conducted by USSR researchers: three fish tagged in the western region of Division 3L on the Grand Bank were recaptured one year later in the inshore areas of the same Division (Konstantinov and Noskov 1972).

American plaice on the Grand Bank (Divisions 3LNO) are clearly delineated from the adjacent Flemish Cap (Division 3M) population. Pitt (1963) found significant differences in vertebrae number between the two populations. Additionally, the parasitic fauna of the two areas differ significantly (Zubchenko 1985). Flemish Cap plaice were distributed in warmer waters, were larger at age and had a truncated age distribution compared to fish on the Grand Bank (Bowering and Brodie 1994). In the late 1980's and early 1990's, American plaice were found in the deep waters of the Flemish Pass (Iglesias *et al*. 1996) and on the Grand Bank, the population as a whole was found inhabiting deeper waters (Morgan and Colbourne 1999; Morgan 2001). This raised the possibility of mixing between the two populations, recently investigated by Morgan and Bowering (2006). They found that fish from the western (Division 3L) and eastern (Division 3M) sides of the Flemish pass were clearly different in their mean length-at-age and maturation-at-age. Fish from the Flemish Cap area were larger at age and females matured earlier than their counterparts on the Grand Bank indicating little if any mixing of juveniles and adults between the two populations. Distribution maps generated from surveys that have spanned the Flemish Pass (Figure 6) indicate a discontinuity in the distribution of

American plaice across this deep channel (Morgan and Bowering 2006). American plaice in Division 3M commence spawning earlier (mid-March) than the adjacent populations (April to May) (Nevinsky and Serebryakov 1973; Ollerhead *et al*. 2004). Distribution of eggs and larvae across the Flemish pass is also considered to be unlikely. Nevinsky and Serebryakov (1973) in their analyses of icthyoplankton and distribution currents concluded that eggs and larvae of American plaice spawning in the Grand Bank area would not drift long distances. The flow pattern of the Labrador Current through the Flemish Pass and skirting the Grand Bank as it travels southward would likely restrict movement of particles from the Flemish Cap westward to the Grand Bank (Helbig *et al*. 1992). The southward movement of the Labrador Current through the Flemish Pass and over the Flemish Cap may, however, be a source of distribution of genetic material from the Labrador plaice populations (Helbig *et al*. 1992) although the deep waters and distance separating Division 3M from Subarea 2 + Division 3K would most likely restrict distribution of the adult and juvenile fish. Over the shallowest part of the Flemish Cap itself, an anti-cyclonic eddy exists that has been shown to retain icthyoplankton and is proven to maintain cod and redfish stock in the area as separate populations from other areas (Borovkov *et al*. 2007). It is conceivable that same retentive mechanism would function for American plaice on the Flemish Cap.

[*Delineation of Divisions 3LNO population from the more northerly population of Subarea 2* + Division *3K was discussed in the previous section and from the adjacent stocks to the southwest in the following sections*].

AMERICAN PLAICE ON THE ST. PIERRE BANK (NAFO SUBDIVISION 3Ps)

American plaice that occur in NAFO Subdivision 3Ps, which extends southward from Newfoundland are not well studied. As part of a larger study, Pitt (1966, 1967a) published some information on age, growth and sexual maturity. He found that growth patterns and maturity rates differed between the St. Pierre Bank and the adjacent western Grand Bank. Data from French surveys looking at growth curves (Mahé and Moguedet 1991) and winter distributions (Moguedet and Mahé 1993) established that American plaice in the offshore area of the St. Pierre Bank (Subdivision 3Ps) are considered to constitute a self-sustaining population that mingles little with either adjacent banks or inshore areas. The same conclusion was reached by Bowering *et al*. (1996).

Spawning on the St. Pierre Bank, according to Nevinsky and Serebryakov (1973) occurs during May and June, with peak spawning in May and at depths of 50 to 250 m and not in the deeper water of the Laurentian Channel. Ollerhead *et al*. (2004) mapped spawning times and locations for American plaice on the Grand Bank (Divisions 3LNO) and St. Pierre Bank (Subdivision 3Ps) using information from Fisheries and Oceans Canada research vessel surveys over two time periods 1987 to 1997 and 1998 to 2002. Their distribution maps show American plaice spawning over the entire area of the St. Pierre Bank, with peak spawning occurring in April during both time periods.

The dispersal of genetic products, the eggs and larvae, into and out of the St. Pierre Bank area is largely unknown. Nevinsky and Serebryakov (1973) postulated that eggs found in the deeper waters of the Laurentian Channel likely originated from the Gulf of St. Lawrence or from the banks on either side of the channel; however, they had no direct evidence of this. Simulations modeling cod egg and larval drift from products originating on the Grand Bank suggest that under certain conditions, the area to the southwest of

Newfoundland, i.e. Subdivision 3Ps could potentially be a nursery site for juvenile cod of Grand Bank origin (Helbig *et al*. 1992). Whether American plaice egg and larval distributions could follow a similar distribution pattern remains to be investigated.

AMERICAN PLAICE IN NAFO SUBDIVISION 3Pn

American plaice are found in surveys conducted in Subdivision 3Pn, although at low numbers. Fish in this Subdivision are not under quota management. References in the literature to the plaice population in this area are almost non-existent. Pitt (1977) reported there being a small boat fishery in this area with catches ranging from 6 to 510 tons in the years 1960 to 1976. The biology of the plaice in this Subdivision has not been studied.

AMERICAN PLAICE IN THE GULF OF ST. LAWRENCE (NAFO DIVISIONS 4RST)

American plaice are distributed throughout the Gulf of St. Lawrence, including the Lower Estuary. The southern Gulf (Division 4T) constitutes a single stock unit from at least a management perspective. Northern Gulf plaice (Divisions 4RS) are not under quota management and there have been no studies of stock identity in this area. Plaice in the southern Gulf occupy the cold intermediate depths during the summer months (Swain and Morin 1997), moving into deeper channel waters during winter (Swain *et al*. 1998). In the northern Gulf, plaice are encountered in intermediate depth strata, between 100 and 200m in summer (Bourdages *et al*. 2003). The Laurentian Channel may contribute to the separation of northern and southern Gulf plaice, although there have been no studies to confirm this.

Powles (1965) considered that southern Gulf plaice form a discrete stock unit comprising two components, an eastern group off Cape Breton and a western group belonging to the Shediac Valley, Chaleur Bay and the Orphan Bank off Gaspé. He based his interpretation on the concentration of fisheries in these two areas, as well as trawl surveys, tagging data and plaice meristics. The possibility of two stock sub-units in the southern Gulf continues to attract attention. Stott *et al*. (1992) failed to distinguish eastern and western components, nor neighbouring stocks in the northern Gulf and on the Grand Banks, on the basis of allozyme variants and mitochondrial DNA markers. Swain and Morin (1996) found no difference in year-class abundance in eastern and western strata surveyed over the 1971 to 1992 period that would indicate different stock components. Morin *et al*. (1998) extended the comparison of eastern and western Division 4T plaice to mortality, year-class strength and growth. In each case, they found no basis to distinguish eastern and western groups.

Several tagging studies were conducted on southern Gulf plaice between 1958 and 1980 (Stobo and Fowler 2006). Unpublished results of tagging (M. Fowler, R. Morin unpublished data) tend to confirm the interpretations of Powles (1965), based on 1958 to 1960 tagging. Plaice tagged off Cape Breton show limited summer movements to the north-west, with limited straying occurring between all areas of Division 4T. Survey data for the southern Gulf since 1971 show a stronger trend of increase in abundance of plaice in the late 1970s in western 4T, followed by a more abrupt decline, than occurred in eastern Division 4T (Morin *et al.* 2001). McClelland and Melendy (2007) have reported that the presence of two acanthocephalan parasites correctly classified plaice samples from eastern and western Division 4T at a rate of 79%. This may be the strongest evidence to date for the presence of two sub-unit stocks of American plaice in the southern Gulf.

AMERICAN PLAICE ON THE SCOTIAN SHELF (NAFO DIVISIONS 4VWX)

Extending from Sydney Bight off the northeast end of Cape Breton to the Bay of Fundy, this area contains American plaice within the eastern (Divisions 4VW) and western (Division 4X) Scotian Shelf management units. In this instance the management units do not reflect separate populations of American plaice, instead representing boundaries between populations of other species, as several flatfish species of the Scotian Shelf and Bay of Fundy (American plaice, witch flounder, yellowtail flounder, and winter flounder) are managed as stock complexes. Prior to the fishery downturns since the 1980's, Scotian Shelf plaice rarely exceeded 5% of the biomass of this species in the Northwest Atlantic.

The Scotian Shelf population may be reinforced from either of Gulf of St Lawrence adult migrants or Grand Banks spawning, but has its own major spawning ground at its eastern extremity on Banquereau. The Gulf of St. Lawrence population migrates into the Laurentian Channel and into Division 4V on the Scotian Shelf during the winter, where it mixes with the eastern portion of the Scotian Shelf population, but they do not appear to mix during the spring spawning period. The identity of Sydney Bight (Subdivision 4Vn) plaice is uncertain, but they are currently regarded as mixed populations during the winter and Scotian Shelf during the remainder of the year, although not necessarily associated with Banquereau spawners. Sydney Bight plaice might be a local population in their own right (Fowler and Stobo 2000). This assumes the Gulf population is a transient occupant of the area, returning to the Gulf in the spring. Coupled with the depth-imposed discontinuity in plaice distribution represented by the Laurentian Channel, it seems clear that Scotian Shelf plaice are at least a population in their own right, but not necessarily genetically distinct from Grand Banks and/or Gulf of St Lawrence plaice.

Spawning of American plaice shows a continuum from Banquereau through to western Bank (Scott 1983), but declining rapidly to the west of Banquereau. Western Bank spawning may simply be a continuum of Banquereau. Browns Bank is topographically separate and distant from Banquereau and Western Bank, and is associated with plaice egg concentrations (Neilson *et al*. 1988), but does not appear to be a very large spawning component. It may be that plaice are inclined to spawn wherever they happen to be in the spring, just to lesser degrees with distance from suitable spawning grounds. This impression is further supported by the decline in plaice abundance from east to west on the Scotian Shelf, consistent since surveys began in the 1970's (Fowler and Stobo 2000). Taking spawning concentrations and plaice abundance together suggests a predominantly Banquereau origin for Scotian Shelf plaice.

Variations in length and age at maturity (Beacham 1983) demonstrate a northerly cline (in order Division 4X, Division 4W, Banquereau) of increase; this geographic cline was maintained even as length and age at maturity declined with time. The gradational nature of this cline, along with the parallel decreases in age and length of maturity over time, suggests it may simply reflect a temperature-regulated cline in growth rate, rather than genetic differences between areas.

AMERICAN PLAICE IN BAFFIN BAY AND DAVIS STRAIT (NAFO DIVISIONS 0AB)

There have been no studies of American plaice in Divisions 0A or 0B so there is no information with which to determine stock identity or affiliation. Information on distribution is available from multi-species surveys initiated in 1999 which alternated between areas and from data on by-catch recorded by observers in the Greenland halibut and northern shrimp fisheries. These data show that American plaice are generally well distributed in Divisions 0B and 0A from approximately 300 m down to 1000 m (Figure 5) Information on plaice distribution in depths <300 m was not available for Division 0B. A Division 0A survey in 2006 included depths 100 m to 800 m and revealed an absence of American plaice in depths <300 m. They are also absent from waters above 72^{o} N. The very cold and relatively fresh arctic waters may limit the distribution in these areas. In Division 0A American plaice have been found in greatest abundance along the shelf break in the southeast and southwest portions of Baffin Bay. In Division 0B they were most abundant east of Resolution Island between 62^{o} and 63^{o} N. However, abundance is very low compared to southern areas. A summary of length data from the Division 0A surveys showed length ranged from 12 cm to 43 cm with a majority falling between 20 cm and 36 cm.

There has never been a directed fishery for American plaice in NAFO Division 0A or Division 0B. American plaice are caught as by-catch in both the shrimp and Greenland halibut fisheries in these areas, although the shrimp fishery accounts for the vast majority. The introduction of the Nordmore sorting grid into the shrimp gear in the mid 1990's has resulted in a reduction of the by-catch to < 20 t annually.

The American plaice in Division 0A and 0B may be part of a larger stock complex that could include the adjacent areas of Division 2G and Greenland waters of Subarea 1. In particular eggs and larvae of American plaice on the fishing banks off West Greenland could be carried by the West Greenland current into Canadian waters of Davis Strait (southern Division 0A and 0B). American plaice are widely distributed in both offshore and inshore waters of West Greenland but there is no information on specific spawning locations (O. Jørgensen pers. comm.). Lloret (1997) noted a greater abundance of juvenile fish in surveyed strata off that portion of the West Greenland coast adjacent to Davis Strait. American plaice were abundant in Subarea 1 during the 1980's and comprised a portion of the directed fishery for demersal fish in West Greenland but the stock declined significantly in the early 1990's (Rätz 1999) and there has been no directed fishery since 1995 (NAFO 1995). The Subarea stock was last assessed by NAFO in 2005 and found to still be in a depleted state. Signs of good recruitment suggested some potential for recovery, although it was noted that even low amounts of by-catch in the shrimp fishery would be sufficient to reduce recovery potential (Siegstad *et al*. 2005).

FURTHER INVESTIGATIONS INTO DESIGNATABLE UNITS

To further investigate designatable units for American plaice, several sources of information were considered including survey distributions, including the location of spawning fish, abundance indices and biological information (length at age, age/length at maturity and year-class strengths). Little information was available for Subarea 0 and Divisions 2GH.

Distribution of American plaice in several survey series was examined to identify and investigate areas of geographic separation of the Newfoundland populations. The distribution of plaice appeared continuous from Division 2J south to Subdivision 3Ps and there did not seem to be any geographic separation of the population between (or within) management units, with the exception of the Flemish pass which functions as a deepwater barrier to plaice in Division 3M (Figure 6). Subarea 0 and Divisions 2GH have been surveyed sporadically and patterns in distribution are more difficult to discern. The Laurentian Channel is characterized by trough depths of at least 300 meters throughout its length, posing a potential barrier between plaice residing in Division 3P south of Newfoundland, and those occupying waters of the Scotian Shelf (4V) or southern Gulf of St Lawrence (4T) (Figures 7 to 9). Surveys of the Gulf of St. Lawrence in the 1980s, when the same vessel and trawl were used, indicate that few plaice are captured below the 200-m contour of the Laurentian and Esquiman channels (Figure 8). More recent surveys of the northern Gulf, using a different survey trawl, suggest a continuous distribution between the northern and southern Gulf of St. Lawrence management units (Divisions 4RS and 4T) where the two areas meet near the Gaspé Peninsula (Figure 9). Elsewhere in the Gulf, few plaice are found in the Laurentian Channel (Figures 8 and 9).

Spawning of plaice generally occurs throughout the range the population inhabits (Walsh 1994a), but certain areas are associated with much greater spawning activity. Known or inferred spawning locations comprise the inshore areas of the Gulf of Maine and Georges Bank (Johnson 2004), the offshore banks (Banquereau, Western, and Browns) of the Scotian Shelf (Nielson *et al*. 1988. On the Grand Banks the northern portion of the Grand Bank and the Tail of the Grand Bank (Morgan 2001; Ollerhead *et al*. 2004) have contained the largest number of spawners but the distribution of spawners mirrors the distribution of the population as a whole and does not indicate that the fish actively form concentrations to spawn. There is limited information on the location of spawning in the Gulf of St. Lawrence. In late winter, plaice migrate to the southern Gulf from over-wintering areas in the Laurentian Channel. Powles (1965) speculated that there were two spawning concentrations; east and west of the Magdalen Shallows (see section on Designatable Units). A subset of spawning areas in the western Atlantic (inshore Gulf of Maine, Banquereau, Magdalen Shallows, and north and southeastern Grand Bank) appears to be the primary source of spawning for their respective regions.

No long-distance spawning movements are apparent for plaice on the Grand Bank, Scotian Shelf, or Gulf of Maine. In contrast, southern Gulf of St. Lawrence plaice are characterized by pronounced seasonal movements, and their spawning period coincides with a return to the Magdalen Shallows from over wintering areas in and along the Laurentian Channel. Powles (1965) found that plaice were in spent condition by mid-May, although gravid females may be seen in the fishery up to mid-June (R. Morin unpublished data). de Lafontaine (1990) reported plaice eggs and larvae throughout May in Chaleur Bay. Able (1978) found plaice eggs in the Gulf estuary in mid-June and along the northern shore of the Gulf (Division 4R) in late June. The spawning period of Gulf of St. Lawrence plaice may be of considerably shorter duration than those of the non-migratory populations.

Length at age eight for males and females from research vessel survey data was compared for Divisions 4VWX, Division 4T, Divisions 2J3K, Divisions 3LNO and Subdivision 3Ps. Length at age eight for both males and females was clearly lower for 4T than for the other management areas. Divisions 3LNO and Subdivision 3Ps seemed to be more similar to each other than to Divisions 2J3K (Figure 10).

Synchrony in year-class strength could indicate that the populations were linked. Estimates of year-class strength from multiplicative models of survey numbers at age were available for Divisions 2J3K, Divisions 3LNO, Subdivision 3Ps and Division 4T. These had the general form:

$$\log(N_{a,y}) = \mu + Y_y + \varepsilon_{a,y}$$

where:

μ = intercept

a = age subscript, age 3-5 2J3K, 3LNO; 2-5 3Ps; 4-7 4T

y = cohort subscript

N = Index (numbers)

Y = cohort effect

ε = residuals from the fitted model.

Survey and other effects were added depending on the stock. To allow easier comparison the results of the year-class strength models for each stock were standardized to the mean of series for that stock. Year-class strength showed a general decline in 4T, 3Ps, Divisions 3LNO and 2J3K but this could be the result of declining SSB in all four areas. There appeared to be little consistency in the peaks in recruitment between the areas (Figure 11).

Trends in survey abundance indices were compared for Division 2J3K, Divisions 3LNO, Subdivision 3Ps, Division 4T, Division 4WV and Division 4X. Since the magnitude of the abundance indices varied greatly between stocks, the series for each stock was standardized by dividing the index for each year in a series by the mean for that series. This allows easier comparison of the trends between areas. All areas showed a general decline in abundance however, the start of the decline varies between the six areas examined (Figure 12).

Age and length at 50% maturity varied between areas with northern (Division 2J3K, Divisions 3LNO, Subdivision 3Ps) areas generally maturing older and later than more southern areas, but there was no clear evidence of a consistent north to south cline. For example the most southerly of the 'northern' areas, Subdivision 3Ps, mature at the oldest age and largest size (Figure 13).

It is unlikely that American plaice in Canadian waters form one single population given their relatively sedentary nature and the large geographic area considered. There are channels which may form barriers to distribution and some discontinuity in spawning areas. Although there are obvious differences in biological characteristics between areas it is not clear if the differences are indicative of different populations or simple phenotypic response to differences in environment and fishing pressure. Without genetic analyses it is not really possible to determine where the boundaries should be for designatable units. Therefore, we present results for each management unit (stock) separately, as well as modeling abundance trends for all stocks in the Canadian Northwest Atlantic combined.

HABITAT

HABITAT REQUIREMENTS

American plaice are bottom dwelling like most other flatfishes and are found from inshore to oceanic environments (Bigelow and Schroeder 1953). Female, and older plaice, tend to occupy a greater stock area (Swain and Morin 1996) and habitat selection in terms of depth and temperature preference may also be associated with sex in that females are generally found in warmer and deeper waters than males (Swain 1997; Swain and Morgan 2001).

In the southern Gulf of St. Lawrence, plaice of all ages tended to occupy the same area during periods of high and low abundance, despite a 5-fold change in abundance over time (Swain and Morin 1996). This result contrasted with a similar analysis of southern Gulf cod (Swain and Wade 1993) and with optimal foraging theory that would predict plaice to concentrate in areas of preferred habitats during periods of low stock abundance. Other analyses of plaice in the southern Gulf indicate that summer depth selection is similar for most ages (10 and 11-year-old males and females aged 12+ years tended to occupy a greater range of depths) and for both sexes (females tended to be more widely spread out than males (Swain and Morin 1997).

SEDIMENT

Although American plaice have been found across most bottom types they seem to prefer the firmer sediments and are generally more abundant on substrates of fine sand or gravel (Scott 1982b; Scott and Scott 1988). This is somewhat consistent with the topography of the tops of the banks where they occur (Bowering and Brodie 1991). Sediment type is considered to be a major factor in determining the distribution of flatfishes and is probably a more important factor for newly settled juveniles than adults since it would play a role in feeding and predator avoidance (Gibson and Robb 1992). Juvenile American plaice on the Grand Bank have been found distributed across several sediment types, with the highest catches being found on sand/shell hash sediments, less abundant on muddy sand, rock/sand and boulder/rock and almost absent from mud sediments (Walsh *et al*. 2004a). Under laboratory conditions plaice have demonstrated a clear preference for gravely sand particles over coarse gravel substrate, continuing to choose the preferred substrate even in temperatures outside of their preference (Morgan 2000). Preferred substrate may be associated with geographical area or food availability. In the deeper western side of the Gulf of St. Lawrence, plaice have been caught in high numbers from soft oozy mud substrates (Bigelow and Schroeder 1953). In eastern Newfoundland, plaice have been found occupying sandy areas near bedrock outcroppings because the bedrock is the preferred habitat of an important prey species, the green sea urchin (Keats 1991).

TEMPERATURE AND DEPTH

Once settled, adults and juveniles frequently inhabit the same areas over depths ranging from 20 to 700 m (Bowering and Brodie 1991) with a preference for depths in the range of 100 to 300 m (Bowering and Brodie 1991; Scott and Scott 1988). Fishing for the species at depths where the greatest concentration of individuals occurs is usually at 64 to 110 m (Pitt 1967a). Reports of deeper occurrences are published; Iglesias *et al*. (1996) reported catching American plaice at depths of 1400 m in Division 3L and Walsh and Brodie (1987) reported concentrations of fish in excess of 700 m, both of which are considered to be anomalies. Variability in depth distribution of the plaice on the Grand Bank has normally been associated with spawning and feeding near the shelf edges (Bowering and Brodie 1991); however, as noted by Pitt (1969), these movements between depth strata near the shelf edges generally do not require a large lateral movement. Seasonal variation in depth preference has been recognized in plaice and has been attributed to preferred temperature selection with the fish moving into deeper and warmer waters in winter (Morgan and Brodie 1991; Powles 1965). On the Grand Bank, juvenile plaice tend to occupy restricted habitats within the range of the adults and are found mostly in the 100 to 200 m depth range in the northern area and in waters less than 100 m in the southern areas, while the adults are distributed in depths from 40 to 1500 m (Walsh 1994b; Walsh *et al*. 2004a).

American plaice are usually considered a cold-water species with reported catches in temperatures from -1.5 to 13^{o}C, but they are most numerous within a temperature range from just below zero to around -1.5^{o}C (Bowering and Brodie 1991; Pitt 1989). They have been found on the Scotian Shelf occurring in water temperatures from 0 to 13^{o}C (Scott 1982a). Plaice are known to withstand long periods of cold water exposure (up to 77 days -1.4^{o}C) but under these conditions they do not eat and lose weight suggesting that declines in biomass associated with cold water may be due to starvation (Morgan 1992). Morgan (1992) reported an upper temperature tolerance of over 15^{o}C. Plaice on the Grand Bank have been found to move out of areas of colder water (≤ -1.2^{o}C) under some circumstances, resulting in what seems to be a seasonal distribution pattern related to water temperature (Morgan and Brodie 1991; Swain *et al*. 1998).

SALINITY

American plaice are described as a euryhaline species, inhabiting a wide range of salinities over their distributional range. On the Scotian Shelf, plaice are commonly found in a range of salinities from 31 to 34 ppt, with highest abundances occurring at 33 ppt (Scott 1982a). It has been found in brackish waters in Hamilton Inlet off Labrador at salinity of 20 to 22 ppt (Backus 1957) although there have been no reports of its occurrence in brackish waters off the Maritime Provinces in Canada (Bigelow and Schroeder 1953). In offshore Atlantic waters they are found in full seawater of 34 ppt. (Bigelow and Schroeder 1953).

OXYGEN REQUIREMENTS

Habitat requirement in terms of water oxygen content is of interest in American plaice since large areas of the Gulf of St. Lawrence are temperature stratified and experience chronic hypoxic conditions (Gilbert and Pettigrew 1997). Cod show low tolerance and reduced growth when exposed to chronic hypoxia and several studies have investigated this relationship (Chabot and Dutil 1999; Chabot *et al*. 2001). However, little is known of the oxygen tolerance of American plaice. MacIsaac *et al*. (1997) compared routine oxygen consumption (ROC) of three species of flatfish, American plaice included. At cold (2^{o}C) temperature, plaice had slightly higher ROC than winter and yellowtail flounder, but at increased temperatures (11 and 14°C), it was able to maintain the ROC at significantly lower rates than the other flatfish. How this would translate to performance under hypoxic conditions is not known.

PREY AVAILABILITY

Habitat selection by fish may also be influenced by prey availability. Plaice distribution has been shown to differ between the sexes with females occupying warmer waters than males in most years (Swain 1997; Swain and Morgan 2001). This tendency for female and larger fish to occupy deeper warmer waters may be associated with preferred prey distribution and foraging strategy (Swain 1997; Swain and Morin 1996).

SEASONAL AND TEMPERATURE CHANGES

Plaice may show significant seasonal variation in geographic distribution. Powles (1965) reported migrations of plaice in the Magdalen Shallows area of the Gulf of St. Lawrence from inshore summer feeding grounds to over-wintering deeper water locations in the Laurentian Channel and Swain et al. (1998) showed that plaice in the southern Gulf of St. Lawrence occupied warmer and deeper waters in winter than in summer (5.2 to 5.4°C and 374 to 426m in January; -0.1 to 0.3°C and 58 to 67m in September). On the Grand Bank off Newfoundland, plaice have been observed to aggregate more in winter than in other seasons in what seems to be related to winter avoidance of cold water (Morgan and Brodie 1991). Seasonal changes in habitat are less pronounced in waters with less extreme temperature profiles such as in the southern limit of their distribution off the northeastern coast of the United States where no seasonal changes in distribution are observed (Murawski 1993).

In recent years, large declines in population biomass of all three stocks of American plaice off Newfoundland have occurred during a period of anomalous environmental conditions. During the 1990s the Northwest Atlantic experienced some of the most extreme variations in ocean conditions since measurements began in the 1940s (Colbourne 2004). During this decade, the waters off Newfoundland and Labrador ranged from near record lows during 1991 to some of the highest values on record by the late 1990s. This temperature trend was accompanied by salinities that were also below average (Colbourne 2004).

It is only recently that distribution of plaice has been examined with consideration to sediment type (Walsh *et al*. 2004a) so it is difficult to ascertain if there have been any changes or trends in habitat based on sediment type.

HABITAT PROTECTION

There are currently no geographical areas that are protected with concern for American plaice. Whether or not such measures are necessary to protect the species or if they would be successful is largely unknown. Habitat protection for the eastern Scotian Shelf haddock stocks (Division 4W) has been established by the implementation of the "Haddock Box", an area of the Emerald and western Banks of the Scotian Shelf that is closed to fishing to protect the nursery grounds for juvenile haddock (DFO 2001). Spawning of American plaice is likely more widespread and subject to more variation than that of haddock which could make implementing such a program to protect key habitats for plaice more problematic.

Walsh (1992) identified certain areas on the Newfoundland Grand Bank that had higher numbers of juvenile plaice and suggested that there are preferred areas for juveniles that function as nursery areas. In a subsequent analysis (Walsh *et al*. 2004a) found that there was no spatial separation of adults and juveniles, at least when the abundance of adults and juveniles was high and all of the nursery area was occupied. Nevertheless, they found that juvenile plaice will occupy a restricted habitat within the range of adults since juveniles are mostly distributed in water depths less than 200 m and the adults range over depths from 40 to 1500 m. The majority of the American plaice population in Canadian waters exists within the 200-mile limit. However, a significant portion of the stock from Divisions 3LNO, including significant areas or 'nursery' grounds lie outside of Canadian waters in areas commonly referred to as the 'nose' and 'tail' of the Grand Bank. This would make protecting the juvenile habitat more problematic.

BIOLOGY

Most of the life history studies on American plaice were carried out by Pitt in the 1960s and 1970s for the Newfoundland area and by Powles in 1965 for the stocks in the Gulf of St. Lawrence. Over the range of its distribution, American plaice show regional variations in life history traits, growth and spawning characteristics. Walsh (1994a) summarized the life history strategies of American plaice into two general categories which seem to exist primarily in response to latitudinal variation; (1) southern populations that are characterized by faster growing, early maturing, winter-spring spawners exhibiting low stock-dependent responses and, (2) northern populations characterized by slow-growing, late maturing, spring-summer spawners exhibiting strong stock-dependent responses. The following review aims to provide an overview of the biology of the plaice in the northwest Atlantic.

LIFE CYCLE AND REPRODUCTION

American plaice are generally a slow growing and moderately long-lived species (Scott and Scott 1988) that exhibit sexual dimorphism in that the females grow faster and are larger than the males for any given age. There is a general decline in growth rates from north to south in plaice populations on both sides of the Atlantic (Walsh 1994a).

NATURAL MORTALITY

Several studies of natural mortality for American plaice have been conducted over the extent of its Canadian distribution. Estimates have ranged from 0.13 to 0.26 and it has been concluded that an estimate of 0.2 is reasonable for this species (Bakken 1987; Hunstman 1918; Pitt 1972, 1982; Powles 1969).

Natural mortality is of course not fixed and analyses of several stocks in the Newfoundland Region suggest that natural mortality in American plaice may have increased in the late 1980s and remained high until at least the mid 1990s. In analyses conducted for 3LNO, Morgan and Brodie (2001) found that several methods provided estimates of M that were substantially higher than 0.2. These results were used to adjust the M in the VPA for this stock for the 1989 to 1996 period to M = 0.53. A rapid decline in the population of American plaice in Subarea 2 + Division 3K population over this same time period during which there was low exploitation of the stock suggests that there was an increase in M throughout the area (Bowering *et al*. 1997; Morgan *et al*. 2000).

GENERATION TIME

Generation time as defined by COSEWIC (2007) and the IUCN refers to the average age of the parents of the current cohort, and is a reflection of the turnover rate of breeding individuals in a population. Exploitation usually reduces the mean size and age of individuals in populations of marine fish. If generation time is estimated using data from an exploited population, the generation time will be less than if it had been estimated from a population not subject to exploitation. A shorter time period will be less precautionary than a longer one, with the extent of the difference depending on the species' history of population change. In Canada, large changes in size and age at maturity have occurred in American plaice since the 1960s (Morgan and Colbourne 1999). In all three populations surrounding Newfoundland, female A_{50} (age at 50% maturity) estimates have decreased from around 11 years in the 1960s to an average of 7.5 years in recent years (Dwyer *et al*. 2003, 2005, 2007; Morgan *et al*. 2005). Calculating generation time from the pre-exploitation A_{50} value for Newfoundland populations, with a natural mortality estimate of 0.2, gives a generation time of 16 years. In all analyses, with the exception of Scotian Shelf, the time series of the surveys was less than three generations (48 years) so the duration of the time series was used.

AGE (A_{50}) AND LENGTH (L_{50}) AT 50% MATURITY

Size and age at maturity for the different stocks were included in the early literature of the life history and biology of American plaice (Pitt 1966; Powles 1965). On the Grand Bank, Pitt (1966) found the age at 50% maturity to be approximately 13 to 14 years and 43 to 54 cm for females and 5 to 7 years for males at a length of 24 to 29 cm. The female population on the Flemish Cap (Division 3M) matured considerably earlier, at an average age of 7 to 8 years (41cm) and on the St. Pierre Bank females were found to mature slightly later at an average age of 14.2 years (45 cm). The male A_{50} for these areas did not vary much. Further north, on the northeast Newfoundland Bank and off Labrador, females mature at an average age of 14.8 years at around 43 cm and 6 to 7 years for males at a length of 24 cm (Pitt 1966). More recently, Morgan and Colbourne (1999) analyzed research survey data by cohort to look at variation in maturity-at-age and size in the three populations of American plaice surrounding Newfoundland. It is clear from their results, that large changes in age and size at maturity have occurred among cohorts since the 1960s, with males and females in each population maturing at an earlier age and smaller size in the later part of the time series. The changes observed were most closely related to total population abundance over the life of a cohort, that is, when population size was low, fish matured earlier and at a smaller size. Similar responses occurred in cohorts that experienced higher temperatures and cohorts that displayed higher juvenile growth and increased adult mortality.

In the southern Gulf of St Lawrence, Powles (1965) reported that female plaice attain sexual maturity at an age of about 10 years or 41 cm (age 6, 25cm for males). More recent survey data from the southern Gulf indicate a decline in the age and size of maturity. The median age at 50% maturity (A_{50}) since 1997 is 6.1 years of age for females and 3.7 years for male plaice. The corresponding lengths at 50% maturity (L_{50}) are 26.4 cm for females and 18.9 cm for males.

Early estimates thought to be close to unexploited maturation rates (1959 to 1968) for age and size at maturity on the Scotian Shelf (Divisions 4X and 4W, and Subdivisions 4Vs and 4Vn) for females was 10.5 to 11.5 years (33.0 to 41.4 cm). By 1979, age and size at maturity had undergone large reductions so that females were maturing at 4.7 to 6.7 years (27.2 to 30.8 cm) (Bakken 1987; Beacham 1983). Maturity data for the more recent decades are not available.

SPAWNING

In the western North Atlantic, American plaice are spring – summer spawners with spawning taking place from February to August, generally peaking in the spring months (Bigelow and Schroeder 1953; Nevinsky and Serebryakov 1973; Ollerhead *et al*. 2004). Although there are reports of this species making spawning migrations in the Barents Sea (Milinsky 1944), no spawning migration occurs in this species in the western North Atlantic with the exception of the southern Gulf as discussed previously. Spawning generally occurs throughout the range the population inhabits (Walsh 1994c) with the onset likely related to environmental cues such as increasing water temperature or daylength (Nevinsky and Serebryakov 1973) to correlate with peak zooplankton production times (Walsh 1994c). The timing of spawning has been found to vary with fish size/age and depth. Pitt (1966) found that larger fish and fish in shallower waters generally begin spawning earlier than younger fish and fish in deeper waters. Morgan (2001, 2003) also found that spawning was later for fish in deeper waters but found that the effect of age on spawning time changed with younger fish spawning earlier than older fish prior to the 1990's but later than older fish in the 1990's. This seemed to be related to a greater change in depth (to deeper waters) for younger fish in the 1990's. In the Gulf of Maine/Georges Bank, spawning occurs earliest, in February, followed by fish from the Flemish Cap, commencing in mid-March. On the St. Pierre Bank, Scotian Shelf, Grand Bank and northeastern Newfoundland Shelf, spawning commences in April to May and in the more northerly areas, along the Labrador Coast, spawning is slightly delayed, beginning in May (Nevinsky and Serebryakov 1973; Ollerhead *et al*. 2004). Although geographic variations exist, spawning generally occurs in cold waters: bottom water temperatures during spawning have been reported to range from -1.5°C (Grand Bank) to 4.4°C in the Gulf of Maine/St. Georges Bank area (Bigelow and Schroeder 1953; Nevisnky and Serebryakov 1973). On the Grand Bank, Pitt (1966) found most spawning to occur when bottom temperatures were in the range of 0 to 2.5°C.

American plaice are group synchronous, batch spawners that generally release eggs in batches every few days. In captivity, they have been shown to produce upwards of ten batches of eggs over a protracted period of time (>1 month) (Nagler *et al*. 1999). Fecundity for the following season is thought to be determined at the onset of vitellogenesis in the previous year (Zamarro 1992), however histological observations made by Maddock and Burton (1999) suggest that American plaice may have the capacity to push oocytes through vitellogenesis from a pre-vitellogenic condition during the spawning period. Fecundity of American plaice has not been studied to any great extent especially in terms of variations that may occur inter-annually and by age and size

(Rideout and Morgan 2007). Pitt (1964) provided absolute fecundity estimates for southern Grand Bank plaice at ~417,000 (length 30 cm); northern Grand Bank plaice at ~148,000 (30 cm) and on the southern Labrador Shelf at ~125,000 (32 cm). Zamarro (1992) reported relative fecundity for Grand Bank plaice to be an average of 409 eggs per gram of female somatic weight (i.e. less ovary mass). Rideout and Morgan (2007) compared relative fecundity for Subdivison 3Ps and Divisions 3LNO plaice and found that relative fecundity was significantly higher in Subdivision 3Ps fish. Relative fecundity ranged from 117 to 1077 (median = 353) eggs g^{-1} for Divisions 3LNO plaice and 78 – 1071 (median = 367) eggs g^{-1} for Subdivision 3Ps plaice.

The eggs are spherical, 1.5 to 2.8 mm in diameter, buoyant, with a large perivittiline space and no oil globule (Fahay 1983). Spawning and fertilization of the eggs occurs near the bottom (Pitt 1989). Once fertilized the eggs become buoyant and rise up in the water column to float near the surface. Time to hatching is water temperature dependant and has been reported to be 11 to 14 days at around $4^{o}C$ with a hatching size of 4 to 6mm; the yolk sac is absorbed approximately five days after hatching when the larvae are 6.2 to 7.5 mm (Fahay 1983). The migration of the left eye commences at a size of 18 to 24 mm (Fahay 1983) before the larvae settle in oceanic nursery areas almost exclusively on the offshore banks where they mix with the older juveniles and adult fish (Walsh 1982). Bigelow and Schroeder (1953) estimated the time of larval growth in the Gulf of Maine population to be three to four months before settlement occurred.

FEEDING

The feeding ecology of American plaice has been fairly well documented. American plaice are considered to be highly opportunistic feeders throughout their life cycle, feeding on whatever prey items are available in appropriate sizes for ingestion and varying with fish size, locality and season. Adults and juveniles feed on polychaetes, echinoderms, molluscs, crustaceans and fish (capelin, sand lance, other flatfish, etc.). Diet varies with fish size and region (Scott and Scott 1988). Smaller fish (0 to 9 cm) tend to feed on polychaetes and small crustaceans with fish forming relatively larger portions of the diet as the plaice get larger. By the time the plaice are 30 to 50 cm in length; other fish comprise upwards of 80% of the diet (González *et al*. 2003; Johnson 2004; Link *et al*. 2002; Pitt 1973; Powles 1965; Zamarro 1992). Pelagic larvae feed on zooplankton, which is primarily copepods, for which they would compete with other planktonic larvae. Little incidence of cannibalism is observed (González *et al*. 2003). On the Grand Bank (Pitt 1973; Zamarro 1992) and in the Gulf of St. Lawrence (Powles 1965) winter feeding cessation is followed by an intensive feeding period from May to October.

In the Northern Gulf of St. Lawrence, from studies involving at sea sampling and modelling, Echinoderms, capelin, large zooplankton and molluscs make up the most significant portions of the diet of American plaice (Morissette *et al*. 2003; Savenkoff *et al*. 2004; Savenkoff *et al*. 2005). For the Southern Gulf, the diet of the small American plaice (<35 cm) was found to be mainly composed of large zooplankton and other benthic invertebrates (Savenkoff *et al*. 2004). The same studies showed that for the large American plaice (≥35 cm), the diet was mainly composed of Echinoderms, large zooplankton and polychaetes.

BEHAVIOUR

Most of the known behaviours of American plaice can be associated with feeding. Although they are bottom dwelling, they are also known to leave the bottom and swim at shallow depths. Pitt (1967b) reported two American plaice caught by a research vessel by surface trawl line set at 9 to 18 m, in water that was about 146 m in depth.

During the less sedentary juvenile stage, American plaice forage actively along the seafloor for small benthic crustaceans and polychaetes. As plaice grow larger they adapt their daytime feeding strategy to match abundant prey items. Thus they might forage actively where highly sedentary prey (echinoderms, molluscs, polychaetes) are abundant, or adopt a more sedentary feeding mode as ambush predators where more mobile prey (fish, crustaceans) are abundant. Diurnal activity is reported in American plaice from echogram soundings, with the fish moving off the bottom during the night (Beamish 1966). It is suspected that these movements may be associated with following the diurnal movements of prey such as sand lance (Pitt 1967b). Despite the day-night differences in feeding behaviour, there is no consistent evidence of an effect on catchability to survey trawls for American plaice. In southern Gulf surveys, Benoît and Swain (2003) could not detect any diel variation in catchability, other than a significant effect for small plaice (<10 cm) which had slightly higher catch rates at nighttime. However, anecdotal observations by fishers suggest that flatfish are not worth targeting over the winter because they 'bury themselves in the sand' to such an extent that they are not susceptible to the herding behaviour necessary for a trawl to catch them.

PHYSIOLOGY

Few directed studies on the physiology of American plaice have been conducted. However, some information pertaining to temperature and salinity, oxygen requirements, salinity tolerance, reproductive physiology, swimming endurance, development rate and blood parameters are available.

Munro *et al*. (1994) examined the physiological responses of American plaice to low salinities and determined that although the species is moderately tolerant to changes in salinity it should not be held for aquaculture purposes in estuarine conditions at salinities below 14 g/L. They also found that exposure to low salinity (7 g/L) resulted in the plaice exhibiting elevated levels of plasma cortisol concentrations compared to control fish (28 g/L).

Nagler *et al*. (1999) examined the reproductive performance of individual female American plaice during a spawning season under laboratory conditions. They looked at fecundity, spawning duration, hatch success and fertility. Their work confirmed that this species is a spring, batch spawner and identified that there were three distinct peaks in egg production after the first batch of eggs are released, over a two month period, indicative of a general spawning rhythm in the species. Whether this same pattern occurs in the wild is not known. Under laboratory conditions, it was found that the percentage of viable eggs and the number of larvae hatched was substantially lower than actual fecundity, and that some females at the end of the experiment still had very high gonado-somatic index (GSI) levels suggesting that a high number of oocytes in these fish had either failed to develop or ovulate and that oocyte atresia may be occurring. Alternative to failed or reduced spawning activity, the occurrence of "jellied muscle" in American plaice (Templeman and

Andrews 1956) is postulated to be the result of the fish using protein resources from it musculature to fuel the development of additional batches of eggs (Maddock and Burton 1999).

American plaice have a remarkable ability to withstand periods of extremely cold water temperature and has been caught in water temperatures as low as -1.8^{o}C (Pitt 1975a). Morgan (1992) showed that American plaice can withstand rapid declines in temperature over 96 hours and are able to survive up to at least 77 days at -1.4^{o}C water temperatures. This tolerance may be related to the presence of antifreeze proteins. An almost entirely alpha-helical, highly symmetrical antifreeze protein has been recently identified in American plaice (Gauthier *et al*. 2005). American plaice may also use temperature to down-regulate their metabolism and save energy in times of food shortage. Morgan (1993) showed that American plaice maintained at low rations moved to lower temperature environments. Audet *et al*. (1993) looked at seasonal and diel fluctuations in American plaice blood parameters. Diel variations were not found to be characteristic of the species; however, in January, plasma cortisol levels were elevated significantly suggesting that cold water temperatures may be stressful for the fish.

The aerobic capacity of some flatfish species is thought to be a limiting factor preventing them from being able to swim at their optimum swimming speeds (Priede and Holliday 1980). Swimming endurance studies of American plaice, examined in terms of implications for catchability, indicate that American plaice are capable of a number of swimming strategies. These strategies include steady cruising, swim and settle and burst and glide, with fish size and water temperature determining to some extent which strategy is utilized (Winger *et al*. 1999). The effect of development rate on swimming and escape response in larvae has also been investigated in American plaice where it was found that developmental rate (raised at different temperatures) had an effect on swimming performance. The results of this study, however, were inconclusive and further investigations to determine how developmental rate affects muscle physiology are required (Shepherd *et al*. 2000).

As discussed in the previous ‘Habitat’ section, the oxygen requirement of American plaice has received little attention, with the exception of one study comparing the routine oxygen consumption measurements between several species of flatfish, American plaice included (MacIsaac *et al*. 1997). How American plaice may perform in areas of chronic hypoxia remains to be investigated.

MIGRATION AND DISPERSAL

American plaice in the western North Atlantic are not known to undergo any significant migrations such as those made by their counterparts in the Barents Sea for spawning purposes (Walsh 1994a), with the exception of the population in the southwestern Gulf of St. Lawrence. Migrations known to occur in Canadian plaice populations are limited to local movements made seasonally for temperature selection and/or feeding as discussed in more detail in the previous Designatable Units section (Morgan and Brodie 1991; Pitt 1969; Powles 1965; Swain *et al*. 1998). In the Grand Bank area, American plaice have been observed to move seasonally to avoid prolonged exposure to cold water temperatures (Morgan and Brodie 1991). On the slopes of the Grand Bank, the move to deeper, warmer waters in winter does not necessarily mean a large lateral migration because of rapidly changing depth profiles (Pitt 1969).

In the Magdalen shallows in the southwestern Gulf of St. Lawrence, American plaice migrate in late fall from inshore summer feeding grounds (40 to 110m) to deeper offshore waters along the Laurentian Channel (185 to 457m) where water temperatures were warmer (Powles 1965). A similar pattern has been observed, comparing the distribution of plaice in the southern Gulf during September surveys with plaice in Cabot Strait during January surveys (Swain *et al*. 1998). Migrations from the Grand Bank to inshore areas were not observed in the tagging studies by Pitt (1969) or by Morgan (1996). However, inshore migrations in Division 3L have been reported in tagging studies conducted by USSR researchers: three fish tagged in the western Division 3L region of the Grand Bank were recaptured one year later in the inshore areas of the same Division (Konstantinov and Noskov 1972).

Dispersal of American plaice through egg and larval drift is not well understood, but inferred from known spawning times and locations and knowledge of current flows. Nevinsky and Serebryakov (1973) examined the temporal and spatial distribution of American plaice spawning in the northwest Atlantic from icthyoplankton samples taken by PINRO (Polar Research Institute of Marine Fisheries) during the period 1959 to 1970. They found that spawning occurred on the continental shelves at depths of 50 to 250 m, in areas of eddying and turbulence caused by the cold Labrador Current in the Grand Bank area, and by the cold waters flowing out of the Gulf of St. Lawrence in the northern Scotian Shelf area. Eggs, and plaice larvae in different stages of development (3 to 22mm), were generally observed together in the same habitat over or near the spawning grounds. Based on these observations, it was concluded that plaice in the early stages of development do not drift far from the spawning grounds. Similar conclusions were reached by Frank *et al*. (1992) who found that the early larval stages of American plaice on the Grand bank tended to be retained on the bank because of the broad plateau and weak sub-tidal currents in the area.

INTERSPECIFIC INTERACTIONS

The interaction of American plaice with other species is likely limited to competition with other fish for food and space and incidences of predation by other species.

Powles (1958, 1965) studied the diet of Atlantic cod in the southern Gulf and found that plaice was the second most abundant fish prey, after Atlantic herring. Plaice were consumed mainly by large cod (>78 cm). He estimated that approximately 1.5% of plaice under 35 cm in length were consumed annually by cod. Powles (1965) also noted that the number of large cod in the southern Gulf stock was in decline and that his estimate of mortality due to cod predation was likely overestimated. Southern Gulf Atlantic cod suffered a collapse in the early 1990s, commensurate with a truncation of the size distribution and a reduction in the maximum size (Benoît *et al.* 2003).

Hanson and Chouinard (2002) reviewed diet studies of Atlantic cod in the southern Gulf from 1959 to 2000. American plaice and other flatfishes occurred sporadically; amongst cod >46 cm, they contributed less than 6% of the total mass of organisms consumed. Savenkoff *et al.* (2004) constructed a mass-balance ecosystem model of the southern Gulf of St. Lawrence (Division 4T), which suggested an increase in the importance of plaice in cod diets: 2.9% of cod diets in the mid-1980s and 22.7% in the mid-1990s. According to the model (% of the total diet of the predator), the other important predators of small (≤

35 cm) American plaice were the harp seal (5.9 to 6.6%), grey seal (5.3 to 6.1%) and small demersal fish (25.4 to 29.1%). For the large (>35 cm) American plaice, except for the grey seal for which the large plaice composed 5.0% of its total diet in mid-1990s, the predation by the previous other predators represented less than 3% of the total diet.

The same mass-balance ecosystem model was achieved for the northern Gulf (Divisions 4RS). In the mid-1980's, 2.9% of the diet of large cod (>35 cm) was found to be American plaice; for small cod (≤ 35 cm), American plaice were totally absent from the diets of the small cod (Morissette *et al*. 2003). For 2000 to 2002, Savenkoff *et al*. (2005) showed an important increase in the American plaice contribution to the large cod diet composition, reaching 13.0% while remaining absent from the diet of small cod. Other principal predators (% of American plaice consumption) in the northern Gulf were the harp and grey seals for which plaice constituted between 3 and 5% of their diet. American plaice have been found to contribute up to 9% of the diets of small demersal feeders (e.g. sculpins, small eelpouts, etc.

American plaice are known prey items for seals on the Scotian Shelf and in the Gulf of St Lawrence (Benoît and Bowen 1990a, 1990b) and foraging on plaice by seals is also known to occur off Newfoundland (Hammill and Stenson 2000; Lawson *et al*. 1998). Juvenile and adult plaice also fall prey to adult cod, halibut, lobster, and dogfish wherever these species co-exist with plaice (Johnson 2004; Powles 1965; Scott and Scott 1988). The eggs and larvae would be prey items for most species that feed in the upper pelagic zone during the spring. Unfortunately stomach sampling of pelagic species such as herring, mackerel, and capelin from offshore areas is scant, as the fisheries for them tend to be inshore.

ADAPTABILITY

American plaice have characteristics that should allow them to withstand and adapt to moderate changes in their environment. They are considered to be a euryhaline and eurybathic species in that they can live under a range of salinities and over a wide range of water depths [as discussed in depth in the Habitat and Physiology sections above]. Their choice of substrate seems to vary over their distribution so it is likely that they can live in areas where sediments may change. Their opportunistic feeding habits and variety in prey items would allow for dietary adaptations. American plaice are also know to seek out waters of their preferred temperature, or at least move to avoid areas of cold water (Morgan and Brodie 1991; Swain *et al*. 1998).

As with many fish species, the life history characteristics of American plaice are not fixed and may change in response to changes in the environment, natural or fishing mortality, population structure, latitude, etc. Considerable variability in maturity-at-age and size exists between populations, and over time periods within populations in American plaice. These variations have been linked to changes in temperature, population abundance, growth and mortality (Morgan and Colbourne 1999).

It is unknown how American plaice will adapt to ongoing oil and gas exploration and development in their habitat areas. Concern exists for disruption of spawning behaviour and studies have been recently undertaken to gain a better understanding of where and when American plaice on the Grand Bank spawn (Ollerhead *et al*. 2004). It is also believed that flatfish can sense the approach of a trawl, in that they swim directly away from the trawl before they could be expected to see it. However, other roles that the fishes sysmo-sensory system (e.g. lateral line and other sensory organs) might serve and how seismic exploration may influence behaviour.

POPULATION SIZES AND TRENDS

SEARCH EFFORT

Newfoundland Region (Subarea 2, Divisions 3LNO and Division 3M)

Annual multi-species, stratified-random bottom trawl surveys have been conducted by the Newfoundland Region of Fisheries and Oceans, Canada in NAFO Divisions 3LNO in the spring (April to June) since 1971 and in autumn (late-September to mid-December) since 1977. Detailed descriptions of the surveys can be found in Walsh *et al.* (2004b) and Brodie (2005) and Brodie and Stansbury (2007). The stratification scheme is based on depth. The survey design is stratified random, with the allocation of sets proportional to stratum area within a Division; a minimum of two sets in every stratum. A description of the basic survey design and protocol can be found in Doubleday (1981). The spring surveys have been covering depths from 45 to 731 m since 1984. The fall surveys covered the same depths and area until 1990 when they were expanded to cover the offshore areas of Division 2J, 3K and 3LNO down to 1000 m.

In the fall of 1995, the RV *Gadus Atlantica* was replaced by the RV *Teleost*, and the Engel 145 trawls were replaced with a Campelen 1800 shrimp trawl. Conversion factors have been derived to allow comparability between the gear types and survey series (Morgan *et al*. 1998; Warren 1997; Warren *et al*. 1997). With the adoption of the Campelen trawl, the fall survey was again extended to include new strata in the inshore areas of Division 3KL, extended coverage of Division 3M and Divisions 2GH, and coverage of strata deeper than 1000 m in most areas (Brodie 2005). The fall survey is designed to be carried out by two vessels, both using identical Campelen trawls, monitored with Scanmar trawl sensors. The usual plan is for the RV *W. Templeman* to survey Divisions 3LNO out to 731 m, as well as a substantial part of Division 3K, generally the inshore and western strata. The RV *Teleost* is usually scheduled to survey Subarea 2, most of Division 3K, Divisions 3LNO (deeper than 731 m), and the 9 deep strata in Division 3M (Flemish Pass and adjacent area). On two occasions (1996, 2001), the RV *Alfred Needler*, outfitted with an identical Campelen 1800 trawl, was used in the survey. The average number of sets per year surveyed is summarized in Table 1.

For the spring surveys, the Campelen trawl has been used from 1996 onward. There was no vessel change in the spring survey during the period considered. Coverage has been relatively constant in recent years; the notable exception to this is 2006, when mechanical problems allowed only minimal coverage in Division 3NO where some sets were made only in the shallowest strata and with the survey extending to near the end of June, much later than usual.

The fall surveys have been subjected to more variation, some unplanned and some planned. Many of the unplanned changes have occurred because vessel breakdowns have not allowed full or timely completion of the surveys. These problems resulted in missed coverage, particularly in the deepwater strata, in some years, notably 2004 and

2006. In five years, including 2002 to 2005, the survey extended into January. Planned changes included the decision to exclude Division 2G from the survey and to survey Division 2H every second year. A full survey of Division 3M was carried out in 1996 and since that time only the deep strata in the northern and western areas of the Flemish Cap were included in the survey design.

Canadian juvenile groundfish surveys

Annual juvenile groundfish surveys of the Grand Bank were conducted in the years 1985 to 1994 to investigate the distribution of juvenile yellowtail flounder and American plaice. The survey covered depths inside the 91 m depth contour from 1985 to 1988, were extended to 183 m in the 1989 to 1991 surveys and further to 273 m in the 1992 to 1994 surveys, in particular in Division 3L. The juvenile groundfish surveys used a stratified-random sampling design similar to that used in the annual spring and fall Canadian groundfish surveys of the Grand Bank. The survey gear was a two-bridle Yankee 41 shrimp trawl with a mesh size of 38 mm throughout and included a 12-mm stretched mesh liner inside the codend (see McCallum and Walsh 1996 for details). The surveys were generally conducted from mid- August to mid-September in the 1985-86 and 1988-93 periods, and September-October in 1994, and November 1 to 13 in 1987 aboard the R. V. *Wilfred Templeman*, a 50-m stern trawler (Morgan *et al*. 1997). After the gear change in 1995, the juvenile surveys were discontinued because the new gear adequately sampled juvenile fish.

Newfoundland Region (Subdivisions 3Ps and 3Pn)

Stratified-random surveys have been conducted by Canada in Subdivisions 3Ps and 3Pn in each year from 1972 to 2005. Coverage prior to 1980 was poor. There were two surveys in 1993, one in February and one in April. Most of the surveys prior to 1993 were in February/March, while those since 1993 have been in April. The data can be split into three time periods based on the trawl used in each period: 1971 to 1982 was Yankee 36, 1983 to 95 was Engel 145 and 1996 to 2005 was Campelen 1800. There is a conversion between the second and third survey gears (Morgan *et al*. 1998) but not the first and third (Morgan *et al*. 2005). Division 3P is generally surveyed from early April to early May (Brodie and Stansbury 2007). The survey in 2006 was not complete because of breakdown of the survey vessel.

Index strata

To allow for consistency, index strata have been used wherever possible for assessment of the populations. Due to incomplete coverage over the time series, the recently added inshore and deep water strata from the fall surveys have been excluded from the analysis. Additionally, the 2004 fall Divisions 3LNO and 2006 spring Divisions 3LNO and Subdivision 3Ps surveys are excluded because of poor coverage. The index strata which have been used for the Newfoundland Region assessment are summarized in Table 2. There has been some variation in coverage, even using index strata, but in most years coverage was 95% or more of the index area. Further, there was no relationship between trends in abundance or distribution and survey coverage.

Northern Gulf of St. Lawrence

Annual surveys of the northern Gulf (Divisions 4RS) and Subdivision 3Pn, as well as strata deeper than 100 fathoms in Division 4T, administered by the DFO Quebec Region, are conducted in August. The survey extends from the Lower Estuary, across the northern Gulf of St. Lawrence including Subdivision 3Pn, south of Newfoundland. This last region was sampled from 1993 to 2003. The area is divided into 59 strata, of which 52 are covered regularly in Divisions 4RS.

This survey began in 1984 with the RV *Lady Hammond* fishing with a Western IIa trawl which was the same gear used by the DFO Gulf Region in surveys of the southern Gulf. In 1990, the vessels and survey gear were changed, partly to improve the sampling of shrimp and redfish stocks. The trawler CCGS *Alfred Needler* was used with a University of Rhode Island (URI) shrimp trawl 81'/114' (codend liner mesh size of 19 mm). The same depth-stratified sampling protocol was maintained, but other procedures, such as tow speed and duration, were changed. A comparative fishing experiment conducted in 1990 between the two vessel-gear combinations (Hammond-Western IIA and Needler-URI) could not establish a conversion factor for American plaice. As a result, a new time series for this survey began in 1990.

The northern Gulf survey incurred a second change of vessels and survey gears in 2004 when the CCGS *Teleost* and the Campelen 1800 shrimp trawl (codend liner mesh size of 12.9 mm) were adopted. Comparative fishing experiments were conducted in 2004 and 2005 (Bourdages *et al.* 2007). A length-based conversion factor was established for American plaice to make catch rates comparable between the two vessels-gear combinations (Needler-URI and Teleost-Campelen).

In 1991, survey coverage was extended to include strata off western Newfoundland and northward to the Strait of Belle-Isle (strata 835 to 851). As a result, abundance trends for the northern Gulf summer surveys are presented for 1991 to 2006. Abundance has been standardized to *Teleost*-equivalent catches using the conversion factors provided by Bourdages *et al*. (2007). Mechanical vessel failures during the 2004 survey caused six strata to be missed and an additional ten strata to be sampled only once. As a result, we have dropped the 2004 survey from calculations of abundance and area of occupancy. Stratum 840, located in the Strait of Belle-Isle, has been missed nine times in surveys since 1991. The survey index is based on 51 strata, covering an area of 115,350 km^2.

Southern Gulf of St. Lawrence

Surveys of the southern Gulf (Division 4T) have been conducted every September since 1971. This survey has been administered by the DFO Gulf Region since 1982. Survey protocols are described by Hurlbut and Clay (1990). The southern Gulf survey area is divided into 24 strata (three inshore strata were added in 1984, but these are not used in analyses of American plaice).

Four research trawlers have been used in this survey: the *E.E. Prince* from 1971 to 1985, the *Lady Hammond* from 1985 to 1991, the *Alfred Needler* from 1991 to 2005, and the *Teleost* since 2004. Two changes have been made to the fishing gear: the Yankee 35 trawl was used until 1985, replaced by the Western IIa trawl. Comparative fishing experiments were conducted in 1985, 1992, and during 2004 and 2005 to establish conversion factors, as required (Benoît 2006; Benoît and Swain 2003).

The 2003 survey has been excluded from analyses of abundance and area of occupancy because an un-calibrated research trawler was used.

Scotian Shelf (Divisions 4VWX)

Monitoring of American plaice population and biological trends is accomplished by stratified random research vessel surveys that have been conducted in the summer of every year since 1970. Estimates of abundance from this survey, typically expressed as stratified number per tow, are often regarded as relative abundance estimates due to indeterminate or dubious catchability of the species by the survey trawl, and concerns about the applicability of the stratification scheme for the particular species being treated. The stratification scheme was designed with a focus on a few species of prime commercial interest in the 1960’s (primarily cod, haddock, and yellowtail). The criteria for stratification were based mostly on depth, plus some knowledge of likely habitat differences due to historical distributions of fish. These criteria will not be appropriate for all species. It is worth noting that in cases where the default stratification is suboptimal, it is likely to be too detailed, which can often be remedied by simply combining strata. The stratification appears reasonable enough for American plaice, likely a consequence of heeding another flatfish species, yellowtail flounder, in the original design. The biggest problem with survey estimates of plaice appears to be a paucity of sampling – the set allocation within strata, not the stratification itself. The low numbers of sets provide highly variable estimates, such that only long consistent trends (or a very dramatic short-term change) can be reliably discerned. As plaice is characterized by a long-term decline, the survey estimates are probably good enough for this exercise.

Estimates of abundance in 2004, 2006 and 2007 are currently not considered suitable for monitoring stock status due to substitution of a research vessel for the regular survey vessel (suffered a fire, being refitted). These years will be incorporated into the time series when the catchability of the substitute vessel has been determined for plaice (comparative trawling was conducted in 2005 to enable the vessels to be standardized). For the generation of indices of population status, 2004 has been retained for convenience, and does not demonstrate any potential to confuse interpretations.

ABUNDANCE

Newfoundland Region (Subarea 2 + Divisions 3K, 3LNO, and Subdivisions 3Ps and 3Pn)

Abundance trends (thousands of fish) of males and females are presented for American plaice by management unit (Subarea 2 + Division 3K, Divisions 3LNO (fall and spring), Subivision 3Ps). Abundance of American plaice was calculated using (1) indexed strata (Table 2) and (2) all strata from the research vessel surveys (Figures 14 to 17). Non-converted data (Engels data units) are provided from the early survey series in Divisions 2GH and Subdivision 3Pn, where no conversion factors are available.

Abundance of American plaice for Divisions 2GH was examined separately, as data prior to 1995 is not converted to the current Campelen data units. Trends in abundance in the Campelen time series are difficult to determine due to the inconsistency in survey coverage (Figure 14). Abundance was high in the early 1980s, decreased to a low in the early 1990s and has been increasing since.

Abundance of American plaice in Division 2J3K has declined from the beginning of the time series in 1978 and remained at a very low level since 1990 with no indication of recovery since that time (Figure 14). The Divisions 3LNO spring index has shown a declining trend in abundance since the late 1980s, but with a somewhat increasing trend since 1998 (Figure 15). The fall index for Divisions 3LNO shows a decline from the beginning of the time series (1990) to about 1998, with a slight increase since then (Figure 15).

Abundance in Subivision 3Ps declined from the late 1980s to 1990, and has remained stable since that time (Figure 16). Although American plaice in Subivision 3Pn are not assessed as a stock, data are available from research vessel surveys from the Newfoundland and Quebec regions and abundance trends are considered. Data from the Newfoundland region prior to 1996 has not been converted to Campelen units, and therefore cannot be compared with the recent time series. There appears to be no trend in abundance in the more recent Campelen series (Figure 16). Data from the Quebec surveys of Subdivision 3Pn are not included.

Abundance and associated confidence intervals of the three major stocks (Divisions 2J3K, Divisions 3LNO spring and fall, and Subdivision 3Ps) are shown in Figure 17. Abundance was calculated using all strata surveyed.

Scotian Shelf (Divisions 4VWX)

Abundance of American plaice on the Scotian Shelf declined around 70% from the mid-1970’s through the early 1990’s (Figure 18). Since that time abundance has remained low, showing no indication of recovery. Minimum trawlable numbers (smallest possible numbers when catchability by survey gear unknown) range from a high of about 95 million to a low of about 14 million fish.

Gulf of St. Lawrence

The index of population abundance for Division 4T American plaice peaked in the late 1970s with the appearance of strong recruiting year-classes from the early 1970s (Figure 19). The stock declined sharply in the early 1980s, levelled during the late 1980s, and then declined further.

The time series for plaice in the northern Gulf survey, beginning in 1991, is relatively short in comparison to most surveys considered in this report. The abundance index has varied widely from year to year (Figure 20). The confidence intervals were wider for plaice in this survey compared to the Division 4T survey, despite the inclusion of strata that were sampled only once in the survey.

Although there was no evident trend in the abundance of plaice in the northern Gulf survey, the last two survey estimates were below the long term average for this stock (Figure 20).

Baffin Bay and Davis Strait

Survey time series in Divisions 0A and 0B are too short to determine population abundance trends.

FLUCTUATIONS AND TRENDS IN THE MATURE COMPONENT OF THE STOCK

Newfoundland Region (Subdivision 2 + Divisions 3K, 3LNO, and Subdivisions 3Ps and 3Pn)

The number of mature individuals in Divisions 2J3K, Divisions 3LNO spring, Divisions 3LNO fall and Subivision 3Ps were calculated by applying male and female maturity ogives by length to the males and females, respectively, in the stock. These numbers were added together to produce the number of mature individuals. Additionally, for Divisions 3LNO, population numbers from the Virtual Population Analysis (VPA) were applied to a female sex ratio, and then a maturity ogive applied to get the proportion of females mature; the males were derived from the total stock estimate minus the females and a male maturity ogive applied to produce the proportion of males mature for each year. Again, these numbers were added to produce the number of mature individuals.

In Divisions 2J3K, the number of mature individuals has shown a steady decline since the 1980s and has remained at a low level since 1990 (Figure 21). The number of mature individuals *remaining* was calculated as the percentage of the average of the last 3 years' abundance of mature individuals to the average of the first 3 years' abundance of the time series (Table 3). For Divisions 2J3K, the number of mature individuals at the end of the time series is only 7.4% of the number at the beginning. In Divisions 3LNO spring, the number of mature individuals in the survey index at the end of the times series is only 25.9% that at the beginning, whereas for Divisions 3LNO fall, this value was 45.7% (Table 3). Although a decline in mature individuals was observed from the beginning of the time series to the early to mid 1990's, the trend in mature individuals since 1995 in Divisions 3LNO has been stable or slightly increasing (Figures 21 and 22). It must also be considered that the time series is very short and numbers may have been higher (or lower) prior to the beginning of the time series. Overall, the stock shows a decline in the number of mature individuals. The number of mature individuals from the Divisions 3LNO VPA population number estimates reveals two periods of decline; the first in the mid-1970s and the second in the late 1980s, from which there has been no increase (Figure 23). The number of mature individuals in recent years is 15.2% compared to the beginning of the time series. In Subdivisions 3Ps the number of mature individuals is 20.8% of the estimates at the beginning of the time series.

Rate of decline:

Rate of decline was estimated from the slope of the linear regression of the natural log Ln ($\log_e$) abundance of mature individuals (N_t) versus time (t, in years). The resulting regression equation is:

$$Ln (N_t) = \alpha + \beta * t$$

The percentage decline over t years (number of years in time series) can be calculated as:

$$(1-exp(\beta * t))*100$$

The number of years in each time series was used to calculate rate of decline and percentage decline (Table 3) because in each case there were fewer 3x the generation time recommended by COSEWIC (3*16 years = 48). For Divisions 2J3K the percentage decline over a 28-year period (1978 to 2005) was 97.4%. The r^2 value was 0.92 which indicates a good fit of the model to the data. For the Divisions 3LNO spring survey, the percentage decline was 81.4% over 21 years but the decline was lower for the fall survey at 49.3% over 17 years. The r^2 values were 0.48 and 0.25 respectively, indicating a poor fit of a linear model to the data. This is due to the fact that since around 1995 there has been a slight increase in abundance; there has not been a continuous decline over the time period. The percentage decline in Divisions 3LNO from the entire time series (1960 to 2005) based on VPA estimates is 93.7% (r^2= 0.75). In Subdivision 3Ps, the percentage decline over the period from 1985 to 2005 is 84.1% (r^2= 0.44, when the low point of 1995 is included). Again, there has been a slight increase, or at least the abundance has stabilized since 1995, and therefore a linear model does not fit the data well.

Regression lines of Ln abundance mature individuals over various time periods were examined to determine trends over the time series (Figure 24). It is obvious that all stocks showed a steep decline through the years 1987 to 1995 with the slopes ranging from -0.22 to -0.36. Since fishing pressure was not consistent over all areas, this suggests a factor other than overfishing as a possible contributor to the declines. Some stocks/indices have recovered slightly; however the population residing in Divisions 2J3K has not.

Scotian Shelf (Divisions 4VWX)

The length at 50% maturity for American plaice in Divisions 4VW, the area where most of the 4VWX population resides, is currently about 27 cm, having declined from about 37 cm in the 1960's. Given an age at 50% maturity of 10.5 for the presumably unexploited St Margaret's Bay plaice during 1966 to 1968, as compared to 11.2 and 11.5 for the progressively more northerly Divisions 4W and 4V plaice during the early 1960's, the earliest available estimates of age and length at maturity might be close to the values we would expect for an unexploited population (Table 4). Thus a generation time of 17 years, based on age at maturity during the 1960's, may be a reasonable estimate. The length at 50% maturity for American plaice further south in 4X is roughly estimated to be about 31 cm, with an associated age of 9.7 (a generation time of about 15 years).

Declining age and size at maturity from the 1960's through the 1970's has been demonstrated across the Shelf, with no associated age and maturity data available since 1979 to determine if this trend has continued. In the absence of year-specific maturity for much of the time period, and given sparse maturity data for many of the sampled years, a minimum length of 31 cm has been used to reflect abundance of mature plaice.

The abundance of mature plaice in Divisions 4VWX has declined by 69% (Figure 25). Declines in Divisions 4VW and 4X separately are 71% and 53% (Figures 26 and 27). The low numbers of plaice in Division 4X have little influence on the overall trend. Uncertainty of abundance estimates is depicted by 95% confidence intervals.

Southern Gulf (Division 4T)

Figure 28 shows the abundance indices for adult plaice in the Division 4T survey. Over the 1971 to 2006 period, the adult stock declined by 86%. From its peak in 1976 to 1983, an 8-year time span, the adult stock declined by 69%; over the longer period, from 1990 to 2002, the stock declined by 76%. The survey results for 2002 and 2004 were the lowest recorded levels of abundance for plaice in this time series. However, the last two years of the survey, 2005 and 2006, indicate a return to stock levels that were recorded at the beginning of the decade, in 2000 and 2001.

Northern Gulf (Divisions 4RS)

The adult population index, calculated using the 1997-2006 maturity ogives established for Division 4T plaice, fail to show any significant trend. The regression of the mean log of the adult catch over time (Figure 29) was not statistically significant (P > 0.05).

TRENDS IN AREA OCCUPIED

Methods

This section presents information on any changes in area occupied and degree of concentration of American plaice in Canadian waters. The data used are from stratified random surveys (Doubleday and Rivard 1981) and the indices calculated are based on this design. There were insufficient data to calculate area occupied for Subarea 0.

For all other stocks the design weighted area occupied (DWAO) was calculated.

$$A_t = \sum_{i=1}^{S}\sum_{j=1}^{n} \frac{a_i}{n_i} I \ \ where\ I = \begin{cases} 1\ if\ Y_j > 0 \\ \hline 0\ otherwise \end{cases}$$

where A_t is the DWAO in year *t*, *S* is the number of strata, n_i is the number of sets in stratum *i*, a_i is the area of stratum *i*, and Y_j is the number of fish caught in set *j*.

The area containing 95% of the population (D_{95}) was also calculated for each stock except Subarea 0. To do this catch-weighted cumulative distribution functions were first calculated.

$$F(c)_t = \sum_{j=1}^{n} w_j \frac{Y_j}{\bar{\bar{Y}}} I \ \ where\ I = \begin{cases} 1\ if\ Y_j \le c \\ \hline 0\ otherwise \end{cases}$$

where w_j is the proportion of the survey area in the stratum fished by tow *j* divided by the number of sets in that stratum, $\overline{Y}$ is the stratified mean number per tow of American plaice. $F(c)_t$ is an estimate of the number of fish that occur at a density of *c* or less in year *t*. *F* was evaluated at intervals of 0.01 and the density corresponding to *F=0.05,* calculated (c_{05}). This is the density at or below which the most sparsely distributed 5% of the fish are estimated to occur. The area containing this most sparely distributed 5% of American plaice was calculated as:

$$G(c_{05}) = \sum_{i=1}^{S}\sum_{j=1}^{n} \frac{a_i}{n_i} I \ \ where\ I = \begin{cases} 1\ if\ Y_j \le c_{05} \\ 0\ otherwise \end{cases}$$

The area containing 95% of American plaice is:

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

where SA_T is the total survey area.

For Subarea 2 + Division 3K (only the Divisions 2J3K portion), Divisions 3LNO and Subivision 3Ps, the Gini index was also calculated. This is calculated using Lorenz curves constructed by calculating the estimated proportion of the population associated with each tow *j* ($N_j = w_j Y_j / \overline{Y}$) and the proportion of the area (w_j) associated with each tow. The tows were then sorted by N_j and accumulated along the x-axis and abundance on the y-axis. The resulting Lorenz curve is more concave when the fish are more concentrated. The Gini index is twice the area between the Lorenz curve and the identity (1:1) line and the larger it is the more concentrated the fish are.

Subarea 2 + Division 3K

Divisions 2GH

Inconsistent survey coverage in Divisions 2GH does not allow calculation of the DWAO or D95 for these areas. Distribution plots for six selected years (Figure 30) show the sporadic nature of the sampling in and the low abundance and widespread distribution of American plaice in Divisions 2GH.

Divisions 2J3K

Index strata and data from 1978 to 2006 only were used in the construction of the indices for Divisions 2J3K. The increase in DWAO in the first few years while the proportion of the surveyed area occupied declined reflects the fact that despite using index strata there was an increase in area surveyed in Divisions 2J3K over the first six years of the survey. DWAO was variable but declined starting in about 1987 to until 1994 (that is the fish occupied less area), and has been variable since. The smallest DWAO was 132 000 km^2 and in most years greater than 80% of the surveyed area was occupied. The Gini showed a general declined starting in 1982 and continuing until at least 1998. That is the fish became less concentrated over that time period. D95 showed a general increase from the beginning of the time series until at least 2002 (Figure 31).

Divisions 3LNO

As for Divisions 2J3K, index strata were used to construct indices of area occupied for Divisions 3LNO. This mainly meant that deeper water strata and inshore strata that were added to the survey area were not included. Data from both the spring (1985-2005) and fall (1990-2006, excluding 2004) were used. Surveyed area was lower in the spring survey until 1992 and in the fall survey before 1994.

DWAO showed a large decline in the spring survey from 1985 to 1995. There was then a large increase coincident with the introduction Campelen then some further decline. The minimum DWAO was 202 000 km^2 and more than 95% of the surveyed area was occupied in most years. The Gini generally increased to 1995, dropped when the survey gear changed, and has shown no trend since. D95 is quite variable, with a general increase to 1996, followed by a decline (Figure 32). The changes which occurred with the change in survey gear could indicate an effect of the change in gear, even though only Campelen equivalent data are used. However, this abrupt transition does not occur for all indices or all stocks.

In the fall in Divisions 3LNO, DWAO showed some increase from 1992 to 1996 and then relative stability since. The smallest DWAO was 227 000 km^2 and as with the spring survey, the stock occupied more than 95% of the surveyed area in most years. The Gini index declined to 1997 then increase to 2000 (the population became less concentrated to 1997 and then increased in concentration to 2000). The D95 increased to 1997 then declined to 2000, opposite to the Gini index (Figure 33). There was some indication of an effect of change in survey gear for DWAO but not for the other indices.

Subdivision 3Ps

Index strata were used to construct indices of area occupied for Subdivision 3Ps. This mainly meant that inshore strata that were added to the survey area were not included. Data from 1983-2005 were used. Surveyed area was lower after the modification of 5 strata in 1994.

DWAO declined until 1995. There was a large increase in 1996 with the introduction of the Campelen. DWAO has been relatively stable since then. The minimum DWAO was 32 000 km^2. In many years greater than 80% of the surveyed area contained American plaice. The Gini index showed little trend to 1995, a large decline with the start of the Campelen series and has been variable since with perhaps some trend to a lower value (Figure 34). The D95 increased to 1993 then showed a general decline to 2005.

Subdivision 3Pn

For Subdivision 3Pn data were available for 1983 to 2005 (except 1984 and 1985) from a survey conducted by NL region. This survey had a gear change (Engel to Campelen) in 1996 and converted data are not available. Therefore, 1983 to 1995 and 1996 to 2005 are not directly comparable. There are also data available for 1993-2003 from a survey conducted by Quebec region. D95 was calculated for each year in each of these series.

From 1983 to 1990 there was an increasing trend in D95 calculated from the survey conducted by NL. There has been a declining trend since at least 1996 and possibly since 1993. D95 from the Quebec survey shows a general increase and the two surveys show opposite trends in D95 since 1995 (Figure 35).

Relationship between indices of area occupied with abundance and temperature in NL Region

Although the trend was generally positive (negative relationship for Divisions 2J3K driven by 1 outlier), the relationship between abundance and DWAO was not significant for any area. There was generally a positive, but not significant, correlation between Gini index and abundance, except a significant negative relationship for Divisions 3LNO spring. The relationship between D95 and abundance was negative in all cases, and the correlation was significant for three out of four indices (Table 5).

The relationship between DWAO and bottom temperature was positive for all areas except 2J3K and these positive correlations were significant for the two Divisions 3LNO indices. The Gini index generally showed a negative relationship with bottom temperature, with a significant correlation for Divisions 2J3K and Subdivision 3Ps. There was little relationship between temperature and D95.

There were as many significant correlations between indices of area occupied and temperature as there were between indices of area occupied and abundance. D95 was most correlated with abundance and DWAO with temperature.

Scotian Shelf (Divisions 4VWX)

Indicators of distributional trends, Design-Weighted Area Occupied (DWAO) and the minimum area containing 95% of the population (D95), show no trends in Divisions 4VWX over the time period (Figures 36 and 37). Within Divisions 4VW alone a slight decline in DWAO (but not D95) is apparent between the first and last decades of the time series (Figure 38). Within Division 4X alone a slight decline in D95 (but not DWAO) can be discerned between first and last halves of the time series (Figure 39). It is known, based on the proportion of non-zero sets in the survey, that the distribution of larger (mature) plaice has contracted over the time period for any of Divisions 4VWX, 4VW, or 4X. This parallels the decline in abundance of mature fish, but as the bulk of the population is comprised of smaller fish, DWAO and D95 are little affected.

Gulf of St. Lawrence

Southern Gulf (Division 4T)

American plaice are widely distributed in the southern Gulf. Plaice were found on average to occupy 86% of the area surveyed yearly since 1971 (design-weighted area occupied, DWAO). There was no evident trend over time in DWAO (Figure 40). The minimum area occupied by 95% of the population (D95) showed an increasing trend over the 1980s and 1990s, but appears to have leveled since 2000 (Figure 40). If habitat selection is density dependent, then foragers should occupy preferred habitats as their populations decline. This does not appear to be the case for Division 4T American plaice which appear to maintain or increase their area occupied as their population size declines.

Northern Gulf (Divisions 4RS)

The area occupied by American plaice in the northern Gulf survey was stable over most years, but appears to have increased in recent surveys (Figure 41). DWAO was highest in the time series during surveys since 2003; similarly, D95 was estimated at its highest level in surveys since 2002. On average, plaice occupied 60% of the area surveyed (DWAO), but reached 84% in the 2006 survey. As with the Division 4T survey, the area occupied by American plaice in the Divisions 4RS survey has not expanded and contracted relative to population size, as expected by theory.

Baffin Bay and Davis Strait (Subarea 0)

Information is too sparse to determine trends in area occupied.

Analyses of rate of decline all areas combined

Since the boundary between designatable units was not clear, analyses were done combining all units. A generalized linear model with a log link and Gamma error was used. Survey was included as a factor and year as a covariate with a common slope over all surveys.

$$abundance = e^{intercept + \gamma + B}$$

where: $\gamma = year\ effect\ (the\ common\ slope)$

$B = survey\ effect$

It is not known what catchabilities of the different surveys are, so it is not possible to put them in a common unit of abundance (for example even in Divisions 3LNO where there are 2 surveys using the same gear, the q estimated in the VPA is different for these 2 surveys). To try to address this, some model fits included a weighting factor, where the weighting was the area covered by the survey. In all cases abundance (in thousands) of adult fish (or proxy of adult fish) was used. Three different series of data were used. In the first set of model fits all surveys were included: Divisions 2J3K (1978-2005), Divisions 3LNO spring (1985-2005), Divisions 3LNO fall (1990-2006, no 2004), Subdivision 3Ps (1983-2005), Subdivision 3Pn (1995-2005), Divisions 4RS (1991-2006, no 2004), Division 4T (1971-2006, no 2003), Divisions 4VW (1970-2005) and Division 4X (1970-2005). In the second set of model fits the same series of data was used except that 3LNO fall was not included. In the third set of model fits the Divisions 3LNO surveys (spring and fall) were replaced by the VPA for that stock (1960-2006). Each set of model fits included a run with and without the weighting factor. In addition the model was fit to each data survey data set separately (except Divisions 3LNO fall) and an average of all the slopes (no weighting) calculated.

No single model run was able to fit all data equally well. That is, the common slope described the data relatively well in some series but not in others. For the sets of model runs including only survey data, including Divisions 3LNO fall seemed to provide a better fit. The fit was improved slightly by weighting by survey area. For the runs using the VPA for Divisions 3LNO the run with no weighting fit most of the data better than when weighting was included, even though the standard error on the slope was slightly greater. It was not clear which of the 6 model formulations was the best.

Estimates of the common slope ranged from -0.054 to -0.074 with un-weighted runs giving a lower slope (Table 6). The decline ranged from 86 to 95%. These estimates combining all areas are in the range of those estimated for Divisions 2J3K, Divisions 3LNO, Subdivision 3Ps and Division 4T separately, using only regression of ln abundance against year but are higher than the separate estimates for Divisions 4VW, 4X, 4RS and Subdivision 3Pn (see sections on each stock above). When the model was fit to each survey series separately, the average slope was -0.045. The individual slope estimates were: Divisions 2J3K -0.13, Divisions 3LNO -0.08, Subdivision 3Ps -0.08, Subdivision 3Pn +0.04, Divisions 4RS +0.003, Division 4T -0.06, Divisions 4VW -0.03, Division 4X -0.02.

RESCUE EFFORT

Plaice inhabit vast geographic ranges in Canadian waters and it is seen from the analyses herein that despite their having undergone recent dramatic declines in abundance, it is still widely distributed. In the future, should it be deemed necessary in instigate a rescue effort for American plaice, considerations could include aquaculture, re-population of areas from adjacent stocks, catch and release programs, moratoria, closed fishing areas such as the 'haddock box', an area closed to fishing on the Scotian Shelf or Marine Protected Areas (MPAs).

In terms of aquaculture, American plaice are not raised commercially, nor are they a species that has received much research directed toward future aquaculture development. Nevertheless, it is known that American plaice can be held in captivity and they will produce eggs that can be successfully fertilized. The eggs can be incubated and hatched and larvae raised much in the way of other commercialized flatfish species (Nagler *et al*. 1999; Shepherd *et al*. 2000). Although this major hurdle in culturing marine fish is feasible, it is not known how successful a release program of larvae or juvenile plaice would be in re-populating an area and much more work in this are would need to be conducted before aquaculture could be considered a viable rescue option.

The success of catch and release programs in terms of survival of fish after release is not well known. It is known that under certain circumstances, American plaice can survive catch and release because of the successful tagging programs that have been conducted (Morgan 1996; Pitt 1969; Powles 1965). Additionally, Ross and Hokenson (1997) investigated the conditions under which various flatfish are able to survive for catch and release purposes. Their conclusion for American plaice is that survival post-release can be enhanced by considering capture and handling strategies, the time the fish spend on deck, fishing season, water and air temperatures and seabird predation. Stocking, either from adjacent areas or cultured native fish, might also be an option but has not been explored for American plaice.

The ability of American plaice in one area to re-populate adjacent areas is unknown. To date and by current knowledge this has not previously occurred but due to the sedentary lifestyle of juvenile and adult American plaice, re-population of adjacent areas would likely need to occur through the distribution of the pelagic phase of the life history, that is, through the distribution of eggs and larvae. This in turn, would likely depend on water currents over the spawning areas, as previously discussed.

CAUSES OF DECLINE

There have been drastic declines in abundance (see Figure 12) of all the American plaice stocks in Canadian waters. From the overall model including all stocks, abundance has declined in the range of 86.4 to 94.8%.

OVERFISHING

It is generally agreed that overfishing contributed to the declines of American plaice. On the Grand Bank (Divisions 3LNO) fishing mortality, as measured by commercial catch divided by survey biomass, doubled from the mid-1980s to the early 1990s (Morgan *et al*. 1997) and in the VPA was high through 1980's until the moratorium in the mid 1990's (Dwyer *et al.* 2007). In contrast, overfishing has not been able to account for the declines observed off Labrador and northeastern Newfoundland where increased total mortality has occurred under low fishing effort, including directed and bycatch/discards (Bowering *et al*. 1997; Morgan *et al*. 2000). Also, Bowering et al. (1996) concluded that not all of the decline in the 3Ps area could be attributed to fishing.

In the southern Gulf fishery (Division 4T), the rapid decline in the plaice stock recorded in research surveys during the late-1970s to mid-1980s cannot be directly accounted for by recorded landings during this period, or trends in relative fishing mortality. Misreporting of catches and discarding at sea are possible factors. The 4T plaice fishery was noted for persistent discarding by mobile gear, often with a third or more of the weight of the catch discarded (Cliché and Côté 1985; Halliday *et al.* 1989; Jean 1963). Several management measures were introduced in the 1990s to reduce discarding in the plaice fishery, including mandatory landing of all catches, increased mesh sizes, and enhanced monitoring of commercial fishing. Despite these measures, some degree of discarding has continued in the fishery (e.g. Morin *et al.* 1998) and the 4T plaice stock continued to decline through the 1990s (Figure 19). It is possible that a combination of commercial exploitation and high natural mortality has contributed to the decline of 4T plaice since the mid-1970s.

CHANGES TO ECOSYSTEMS

The impact of global warming is yet unknown on the biology of American plaice. Frank *et al*. (1990) predicted that temperature and salinity changes in the North Atlantic induced by climate change would see a shift in the distribution of many cold water marine fishes, including plaice, northward. In the same way warmer water species would shift northwards, filling the current niches of the cold water species. For fishes, climate change may strongly influence distribution and abundance through changes in growth, survival, reproduction, or responses to changes at other trophic levels. Species-specific responses are likely to vary according to rates of population turnover and species with slower life histories, which are already more vulnerable to overexploitation, may also be less able to compensate for warming through rapid demographic responses (Perry *et al*. 2005, and references therein).

It is hard to predict how changes to ecosystems may affect American plaice. In the western North Atlantic, major displacements in the fisheries and changes to ecosystems occurred over a relatively short time period during the 1990s. During this time, major groundfish stocks, American plaice included, collapsed and have been closed to commercial exploitation since. Concurrently, the physical environment of the Northwest Atlantic was characterized by prolonged below-normal sea temperatures (Colbourne 2004). It has proved difficult to disentangle the role of fishing and environmental factors on the ecosystems affected (Lilly *et al*. 1999). The failure of cod, and other groundfish stocks, to recover after collapse in the western North Atlantic suggest that induced changes to the ecosystem may be preventing recovery (Frank *et al*. 2005).

The Newfoundland-Labrador ecosystem was modelled by Bundy (2001) to examine the interplay of fishing and predation on the collapse and subsequent recovery failure of major groundfish stocks including cod and American plaice. Using this model it was concluded that excess fishing was the primary cause of the cod stock collapse, and that predation by harp seals is hindering recovery. For American plaice, the model scenarios and assumptions were not able to represent the biomass trends observed in Divisions 2J3K and 3LNO. Raising fishing effort to 100% in the model was able to collapse the stock, however even with this induced collapse, the model predicted a rapid population rebound which has not occurred in the stocks. The author concluded that the recovery failure of the stock, while the model predicted a rapid recovery, could be attributed to tropic interactions of American plaice not being well defined in the model, and/or that fishing mortality is greater than the assumed model values due to discarding and non-reporting of catch. It was also concluded that adverse environmental changes, not included in the model, may be preventing stock recovery. Bowering *et al*. (1997) suggested that the collapse of the Labrador and northeastern Newfoundland (Division 2J3K) American plaice was unlikely to be due to commercial exploitation. Although they did not define a direct cause for the collapse, they indicated that unusual environmental trends may have played a role. Thus, significant 'other' mortality (discarding, disease, starvation, temperature, environmental or ecosystem changes) seems to be contributing to the slow recovery of American plaice stocks (Bundy 2001).

HABITAT DESTRUCTION BY FISHING

Otter trawling, the most commonly used method to capture American plaice, changes the habitat from which it drags for fish. The impacts of bottom trawl gears are initially greater on sandy and muddy bottoms than on hard, complex bottoms. However, the duration of impacts is usually greater on hard complex bottoms than on sandy bottoms and probably longer than on muddy bottoms (Rice 2006). Schwinghamer *et al.* (1998) examined the effects of a three year trawling experiment on a sandy sediment substrate on the Grand Bank. No changes in sediment type were induced and the conclusion reached was that the physical effects of trawling were considered 'moderate' with recovery taking approximately one year. Biological changes in the macrofauna were considered for this experiment by Kenchington *et al.* (2001) who found that the changes induced by trawling disturbance were similar to that by natural disturbance (i.e. an 'undisturbed' area close by that underwent a detectable difference in the fine fraction (<500 μm) of the sediment). Rice (2006), however, concluded in their review of habitat alteration by trawling, that mobile bottom-contacting gears can change the relative abundance of benthic species and hence can alter the composition of benthic communities. They noted that one of the greatest impacts may be seen in the decreased abundance of long-lived species with low turnover rates, such as American plaice.

BYCATCH OF AMERICAN PLAICE IN OTHER FISHERIES

Labrador and the Northeastern Newfoundland Shelf (Subarea 2+ Divison 3K)

There has been no directed fishery for American plaice since a moratorium on the stock was implemented in 1994, which was accompanied with a bycatch limit of 500 t. This advice was implemented in 1994 and was followed by similar advice in 1995 to 1997, with bycatches in this period limited to 100 t per year within this period. In 1998 to 2003, the bycatch limit was not referenced and the TAC was set at 0. The reported bycatches from 1994 to 1999 were in effect less than 30 t per year, mostly as bycatch in gillnet fisheries. The low bycatch was due to a drastic reduction in the TAC in 1994 and the moratorium and limited fisheries for northern (Divisions 2J3KL) cod which, after 1992, essentially eliminated a major source of American plaice bycatch (Dwyer *et al*. 2003). An increase in the catch of American plaice in 2000 to 2002 was observed mainly as a result of the increased effort directed toward Greenland halibut in Division 3K (Brodie and Power 2003). It is of some concern that bycatch sampled in 2001 and 2002 from the Greenland halibut fishery consisted of 97 to 98% females. In most years the bycatches came from Division 3K; catches from Divisions 2GH have been negligible (zero reported since 1990). Only 2 tons of catch has been reported in Division 2J from 1993 to 2002 (Dwyer *et al*. 2003).

Grand Bank (NAFO Division 3LNO)

The Grand Bank stock of American plaice has been under moratoria since 1995 and from this time, catches have primarily been bycatch from other directed fisheries in the area, primarily skate, redfish, yellowtail and Greenland halibut. Catches decreased following the moratorium for a few years, however, the opening of the yellowtail flounder fishery in 2000 in Divisions 3LNO saw an increase in American plaice bycatch levels. In 2005, the total Canadian catch of American plaice in Divisions 3LNO was 1464 tons, ninety-seven percent (97%) of which came from the directed fishery for yellowtail flounder in Divisions 3LNO. In 2006, there was virtually no fishery for yellowtail, and bycatch was relatively small at only 92 t and derived from the Division 3O redfish fishery. Five year projections showed that spawning stock biomass would increase by twice as much over the time period at F=0 compared to current levels of bycatch mortality (Dwyer *et al*. 2007).

St. Pierre Bank (Subdivision 3Ps)

Bycatch of American plaice in the St. Pierre Bank region, Subdivision 3Ps, is considered to be a serious threat to the stock and stock recovery. The fishery in Subdivision 3Ps has been under moratoria since 1993, but bycatch taken in the regions directed fisheries for cod and witch flounder have increased substantially since 1995. Since 1999, the bycatch of plaice as a percentage of the witch flounder fishery has been over 20%. In the cod fishery it was less than 5% overall, except for 2002 when bycatch was 6.5%. More recently, with increased quotas for cod, most bycatch has occurred alongside that fishery. However, from 1999 to 2005, 25 to 30% of the total American plaice catch has been taken in the witch flounder otter trawl fishery. The allowable bycatch of American plaice in this fishery is 50%, compared to 10% in other fisheries, actual bycatch rates have been in the range of 49 to 143%. The last stock assessment concluded that catches at recent levels are contributing to the lack of recovery (Morgan *et al*. 2005).

Scotian Shelf Stocks

Most of the American plaice fisheries in Canada are under moratoria, such that bycatch in the few open fisheries is the largest source of fishing mortality since the mid-1990's. The only directed quotas applicable to American plaice are the multi-species flatfish TACs on Scotian Shelf stocks (Divisions 4VW and 4X). These TACs are frequently taken as bycatch in Division 4X cod and haddock fisheries, where they have the potential to be discarded so as to continue fishing on the target species. In Divisions 4VW, where flatfish is the only open bottom trawl fishery in shoal waters, there is often a problem with catching undesired members of the flatfish complex itself when directing for a more valuable member (witch flounder is likeliest to be targeted, with plaice often using up much of the TAC as bycatch). Market demand for flatfish species in general has been poor in recent years, such that the absence of any other shallow trawl ground fisheries in Divisions 4VW precludes the potential for discarding. This could change if market demand increased, and Division 4X could present a similar problem if cod and haddock fisheries were closed to leave flatfish the only bottom trawl fishery.

MANAGEMENT OF DIRECTED FISHERIES

Inability to enforce bycatch limits of Newfoundland plaice stocks, including by foreign fisheries on the Grand Banks, is regarded as the greatest impediment to recovery of these stocks. Inability to prevent discarding of small fish is considered the main reason that the Gulf of St Lawrence stock has not shown signs of recovery.

The multispecies flatfish stocks of the Scotian Shelf and Bay of Fundy (Divisions 4VW and 4X stocks) do not facilitate management strategies at the level of a species or population. The component species are undifferentiated so as not to require identification in the commercial landings data. In recent years the quotas have been appropriate with respect to whichever species was in the worst shape. However there are no explicit decision rules to ensure sustainability of the component stocks.

SPECIES IDENTIFICATION IN THE COMMERCIAL LANDINGS DATA

Allowance of labelling flatfish species as Unspecified Flounder in the Maritimes Region (Divisions 4VW and 4X combined flatfish species stocks) has proven a major problem for assessing the status of the various flatfish populations on the Scotian Shelf and in the Bay of Fundy. Past and potential magnitudes of Unspecified Flounder confound and often preclude the use of commercial catch data for assessment purposes. Thus Virtual Population Analysis (VPA) cannot be considered, and therefore only DFO surveys of abundance can be considered as indicators of stock status.

INCIDENTAL MORTALITY

Incidental mortality can be divided into two components, fatal damage to uncaught fish and discarded bycatch. There is insufficient quantitative data on post-selection and ghost-fishing mortality to provide estimates of these sources of incidental mortality to plaice, but they are not believed to be a concern for flatfish species. Discard mortality, on the other hand, is a major consideration for plaice. It is thought to be a primary source of unusual and/or unpredictable changes associated with population trends, especially prior to the rash of fishery collapses in the 1990's. Plaice are especially susceptible to high grading, as so many are just below the size limit. The Gulf of St Lawrence population has proven extremely vulnerable to this type of mortality due to discarding of smaller fish in the catch, and has been closed in the past due to differences in apparent length compositions between observed fishing trips and commercial landings of unobserved fishing trips (Morin *et al*. 2001). The allocation of mixed-species flatfish TACs for Scotian Shelf stocks also poses much potential for discarding of less valuable flatfish species to high-grade a more valuable species.

NATURAL MORTALITY

In some areas it is possible that an increase in natural mortality contributed to the decline of American plaice. In 2+3K, analyses of landings data, observer catch records and overlap in distribution of American plaice and fisheries directed for cod (the main potential for bycatch) indicated that fishing mortality was not great enough to cause the decline in that area (Morgan et al 2000). The results of several methods used to estimate M in 3LNO, indicated that it increased substantially in that area from the late 1980's to mid 1990's (Morgan and Brodie, 2001). Analyses of survey and landings data led Bowering et al. (1996) to conclude that it was likely that not all of the decrease in the 3Ps area could be attributed to fishing.

MORATORIA, EFFECTIVENESS, VULNERABILITY TO POLITICAL CHANGES (DURABILITY, VIABILITY)

There is currently no directed fishery for American plaice in the Newfoundland stocks (Subarea 2 + Divisions 3K, 3LNO and Subdivision 3Ps), as all stocks are under a fishing moratorium which was established in 1993/1994 and the only catches of plaice since this time has been through bycatch from other directed fisheries both inside and outside of the 200-mile limit. Effectiveness of moratoria as a means to protect and recover collapsed fish stocks have proven variable. A successful moratorium of yellowtail flounder on the

Grand Bank is one example of moratoria effectiveness (Walsh *et al*. 2006). Some of the failures to recover, however, may stem, at least in part, from environmental trends and ecosystem changes that closures cannot resolve, many seem attributable to bycatch in fisheries on non-moratoria stocks. It is difficult to prevent the harvest of moratorium populations as bycatch by open fisheries on other populations. Possibly a variation on the strategy that makes use of completely closed areas, devoid of bycatch potential, might address the issue.

SPECIAL SIGNIFICANCE OF THE SPECIES

American plaice was probably at one time the most abundant flatfish in the northwest Atlantic, and became one of the major commercially exploited groundfish species (Pitt 1989). However, as a non-schooling fish with an ambush feeding form of predation, American plaice were not available to commercial fishing interests until the development of bottom trawls towed by gasoline-engined vessels in the 1930 to 1940's, which made the species readily accessible for the first time. By the 1930's, American plaice was a potential target of 'pulse' fisheries on offshore banks whenever traditional species (cod, herring, mackerel, halibut, haddock, pollock) were depleted. In the 1950's, the introduction of freezing and filleting had led to development of a fresh fish market, for which American plaice became the object of dedicated fisheries in its own right. The American plaice fishery of the Grand Banks of Newfoundland was the largest fishery for a flatfish species anywhere in the world, at times approaching 10% of the entire Canadian Atlantic ground fishery (both landings and value). With the extension of the 200-mile limit, the fishery for plaice evolved into an almost exclusively Canadian fishery. Closures of traditional fisheries in the 1990's initially increased commercial interest in American plaice wherever fishing was still allowed, but a combination of bycatch restrictions on other species, market conditions, stock status concerns, and low TACS have kept overall landings at about 1% of historical catches. Should American plaice demonstrate a potential to succeed over other depleted species in their habitats, they would likely become a major objective of future fishing interests.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

In Canada, American plaice are protected by the *Fisheries Act* and the *Oceans Act*. American plaice are not listed in the Canadian Species at Risk Act, or the IUCN Redlist (ICUN 2006) of endangered or threatened species, and their Global Heritage Status Rank is GNR (unrated).

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TABLES

Table 1. Average number of sets surveyed per year in each NAFO Management Division for the Newfoundland Region. 'Index' strata exclude the inshore and deepwater strata added in the later years of the survey. 'All' strata include the inshore and deep water strata. Letters refer to the start dates of the survey series that differ between Divisions. The early surveys are those conducted prior to the gear change in the Fall of 1995 when the Campelen 1800 trawl replaced the Engel 145 as the standard survey gear. Some data have not been converted and these are noted with an asterisk.

Season	**Fall**											
Division	**2J**		**3K**		**3L**		**3N**	**3O**	**2G**		**2H**	
Series	**Index**	**All**	**Index**	**All**	**Index**	**All**	**All**	**All**				
Full												
(1978-2006)	106	111	133	147								
(1983-2006)					161	186						
(1990-2006)							76	81				
Early												
(1978-1994)	109	109	135[a]	136						29*		18*
(1983-1994)					182	182						
(1990-1994)							65	76				
Late												
(1995-2006)	103	114	131	163	139	190	81	84	57**		39	

Season	**Spring**				**Spring/Winter**			
Division	**3L**		**3N**	**3O**	**3Ps**		**3Pn**	
Series	**Index**	**All**	**All**	**All**	**Index**	**All**		
Full								
(1984-2006)	156	160	80	84				
(1983-2006)					14[b]	164		
Early								
(1984-1995)	164	165	86	90				
(1983-1995)					164	167		
(1975-1995)								8*
Late								
(1996-2006)	147	155	74	78	132	160	14	

* Unconverted data.
** Surveyed only in years 1997-1999.

Table 2. Index strata used for COSEWIC assessment of American plaice in Newfoundland Region.

Division	Indexed Strata
2J	201-219, 222-224, 227-231, 234-240
3K	617-642, 645-647, 650-652
3L	328 to 736
3N	357 to 728
3O	329 to 722
3Ps	306 to 716
3Pn	302 to 305

Table 3. Percent mature individuals remaining (as an average of the last 3 years of the time period compared to the first 3 years) and rate of decline for each index.

	Div. 2J3K	Div. 3LNO Fall	Div. 3LNO Spring	Div. 3LNO (from VPA)	Div. 3Ps
Percent mature individuals remaining	7.4	45.7	25.2	15.2	20.8
Rate of decline	97.4	49.3	81.4	93.7	84.1
No. years in time series	28	17	21	46	23

Table 4. Scotian Shelf American plaice recent and earliest age at maturity and generation time estimates and rates of change of abundance and area occupied.

Recent Estimate (1990's)		Earliest Estimate (1960's)		Rates of change				
Age at Maturity	**Gen. Time**	**Age at Maturity**	**Gen. Time**	**Data Source**	**Data Type**	**Time Period**	**Abundance**	**Area Occupied**
5	10	11.5	17	survey	mean no. per tow	1970-2003	-70	-46 Area

Table 5. Results of correlations (correlation coefficient and p value) between indices of area occupied and abundance and bottom temperature for Div. 2J3K, 3LNO and Subdiv. 3Ps.

	Abundance		Bottom temperature	
	r	p	r	p
DWAO				
2J3K	-0.2	0.3	-0.04	0.83
3LNO spring	0.08	0.7	0.45	0.04
3LNO fall	-0.25	0.4	0.66	0.005
3Ps	0.03	0.9	0.36	0.09
Gini				
2J3K	0.02	0.9	-0.42	0.02
3LNO spring	-0.4	0.05	-0.16	0.5
3LNO fall	0.29	0.3	0.03	0.9
3Ps	0.25	0.2	-0.46	0.03
D95				
2J3K	-0.89	<0.0001	0.29	0.1
3LNO spring	-0.26	0.3	0.25	0.3
3LNO fall	-0.52	0.04	0.01	0.96
3Ps	-0.69	<0.001	-0.33	0.1

Table 6. Results of six model runs combining data from all areas to estimate a common slope as an overall rate of decline.

Model Run	Time Series	Time Period	Slope	S.E. Slope	Percent Decline
3LNO fall included	1970-2006	37 years			
weighted			-0.072	0.0042	93.0
not weighted			-0.054	0.0039	86.4
3LNO fall out	1970-2006	37 years			
weighted			-0.074	0.0044	93.5
not weighted			-0.054	0.0041	86.4
3LNO VPA	1960-2006	47 years			
weighted			-0.063	0.0031	94.8
not weighted			-0.054	0.0034	92.1

FIGURES

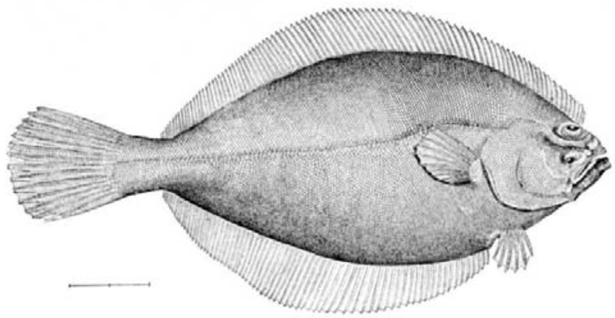

Figure 1. American plaice, *Hippoglossoides platessoides*. (Brown and Bean 1896).

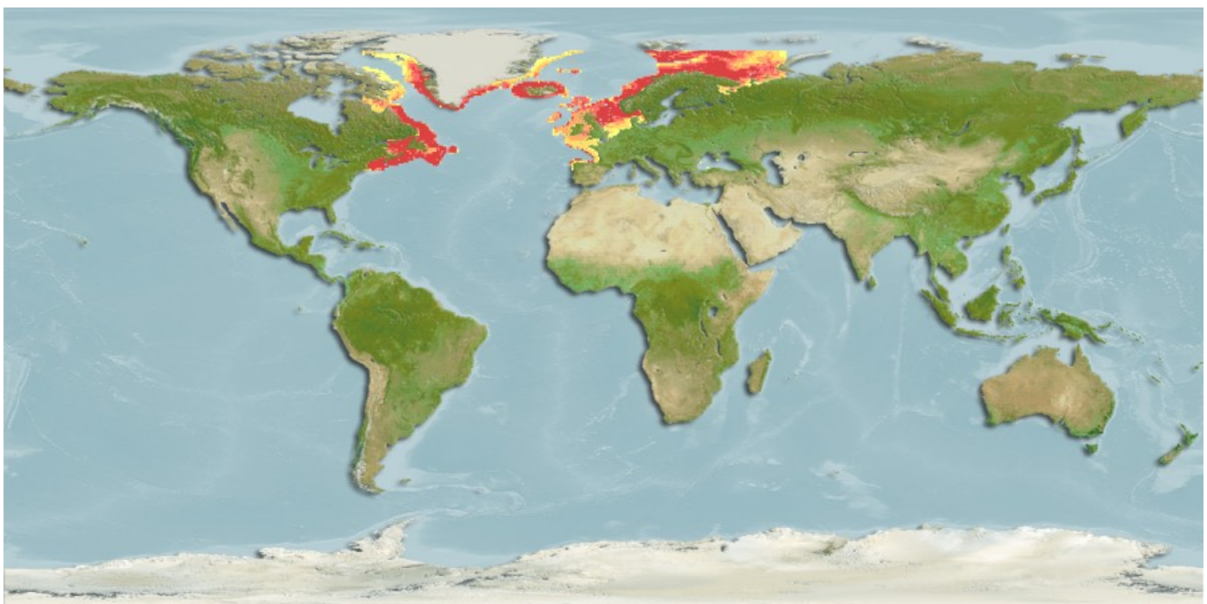

Figure 2. Global distribution of American plaice, *Hippoglossoides platessoides* (AquaMaps: Fishbase) (Kaschner *et al*. 2007).

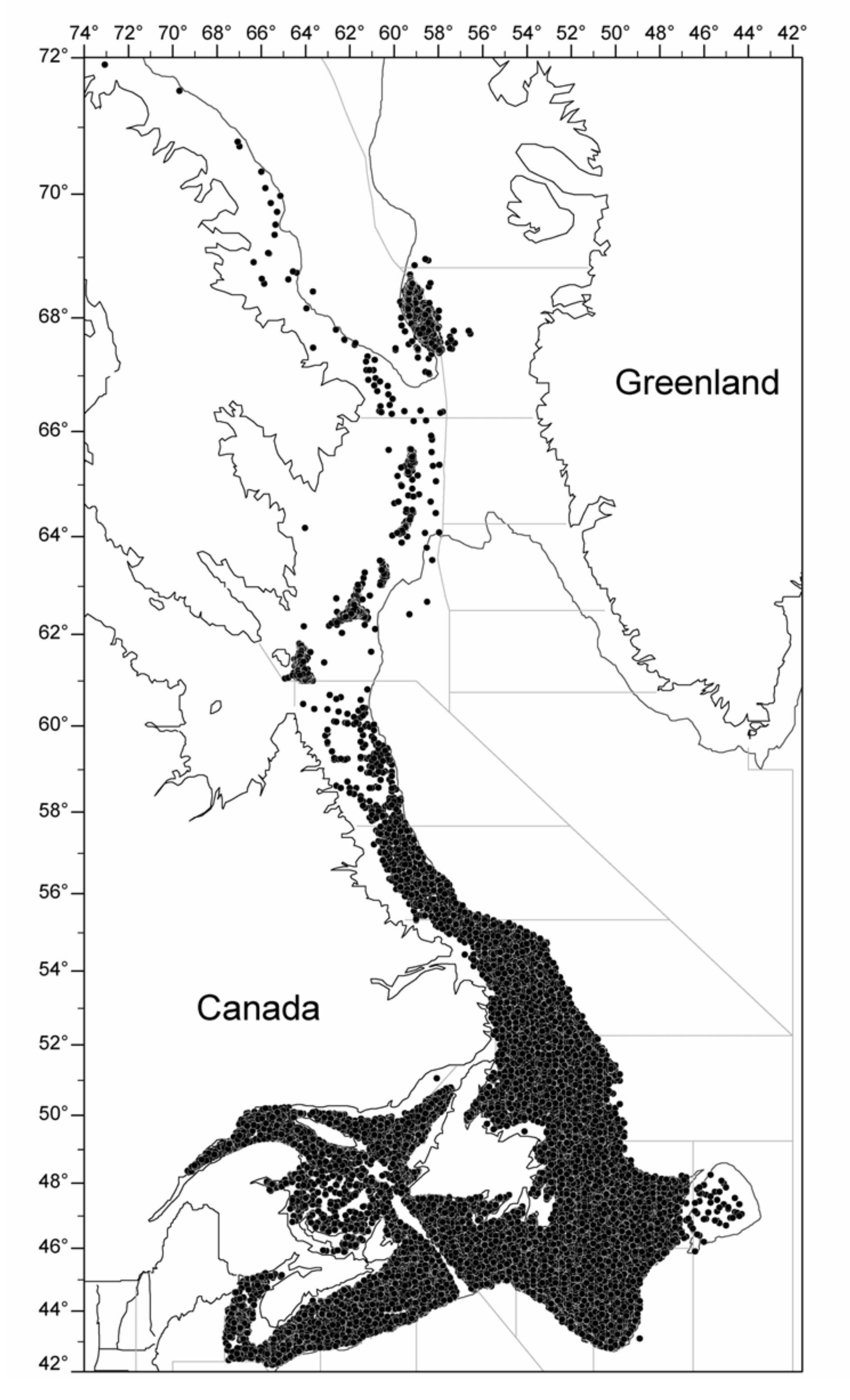

Figure 3. Canadian distribution of American plaice, *Hippoglossoides platessoides.*

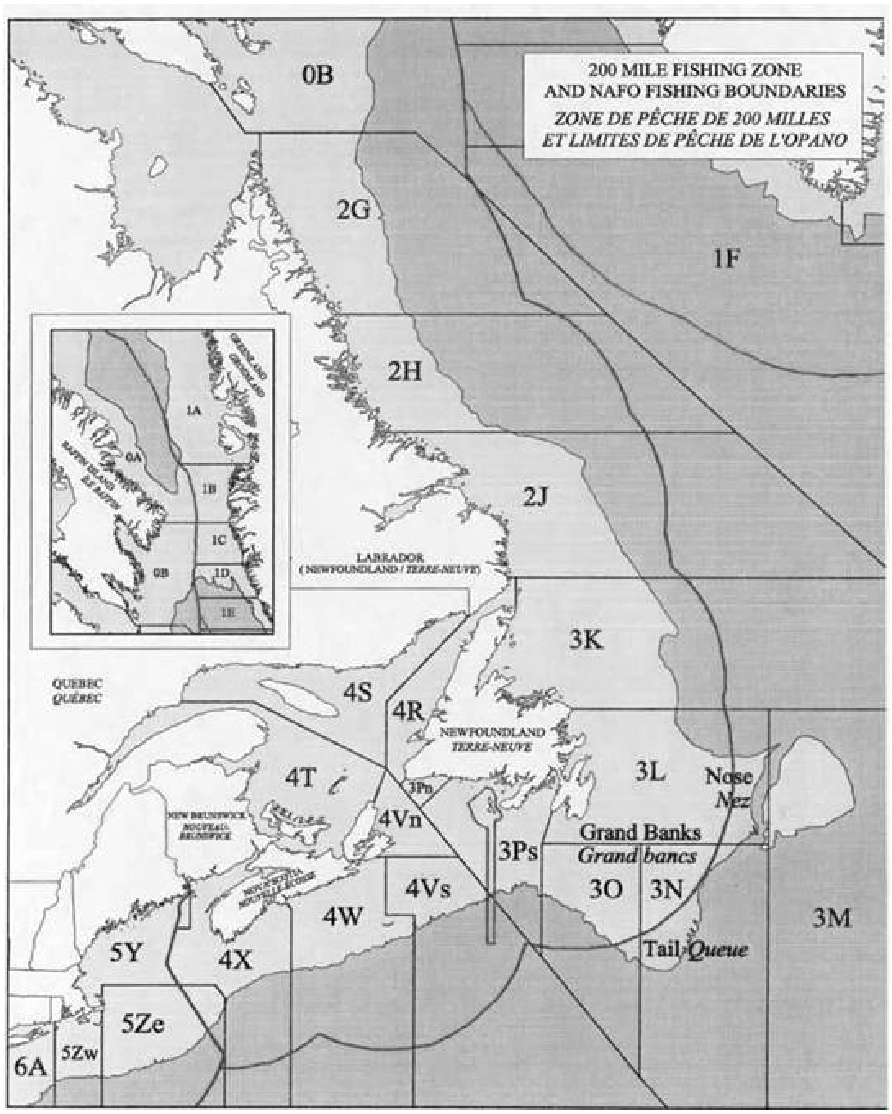

Figure 4. NAFO Divisional boundaries and Canadian 200 mile limit.

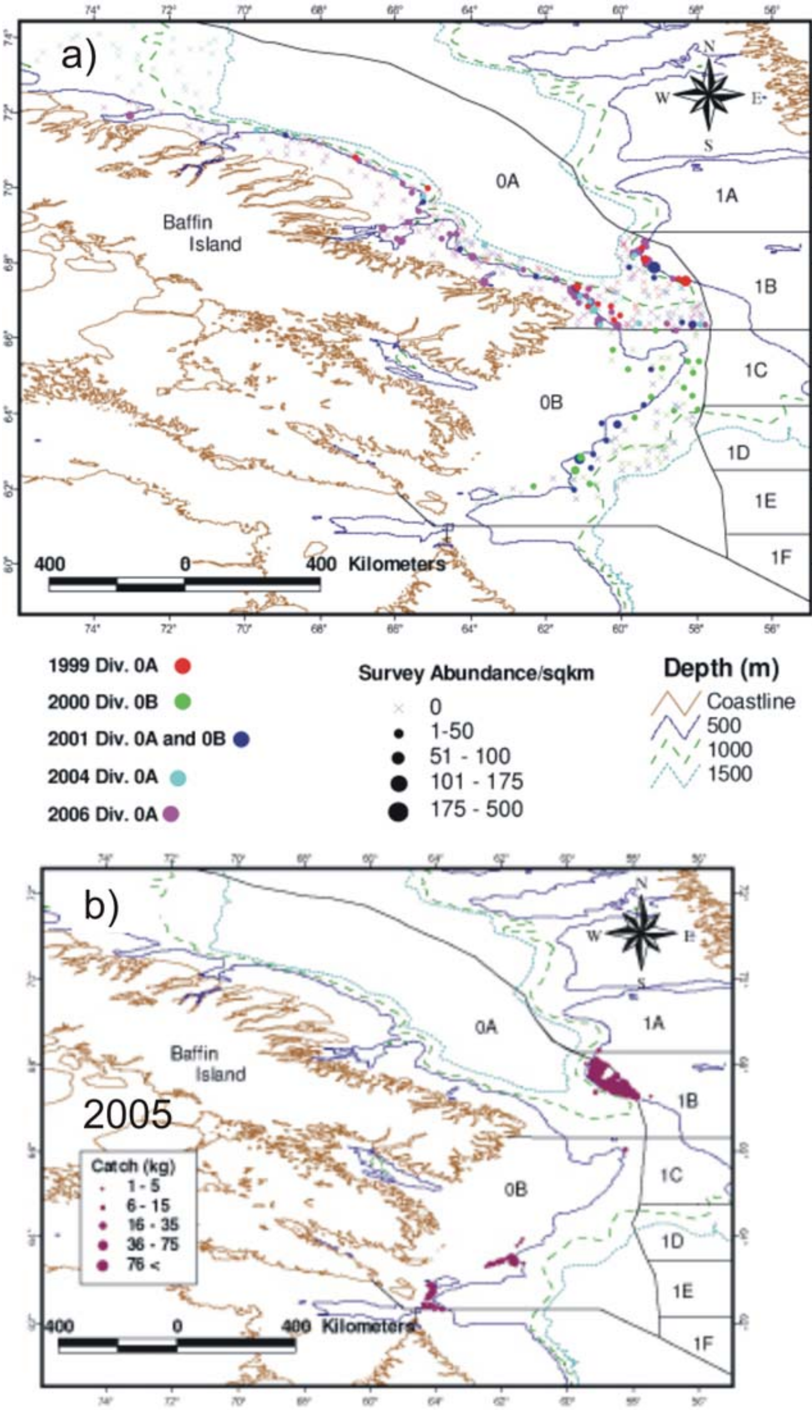

Figure 5. Distribution of American plaice in Div. 0A an 0B: a) from multi-species random stratified surveys (1999-2006); and b) as by-catch in the shrimp fishery (e.g. 2005).

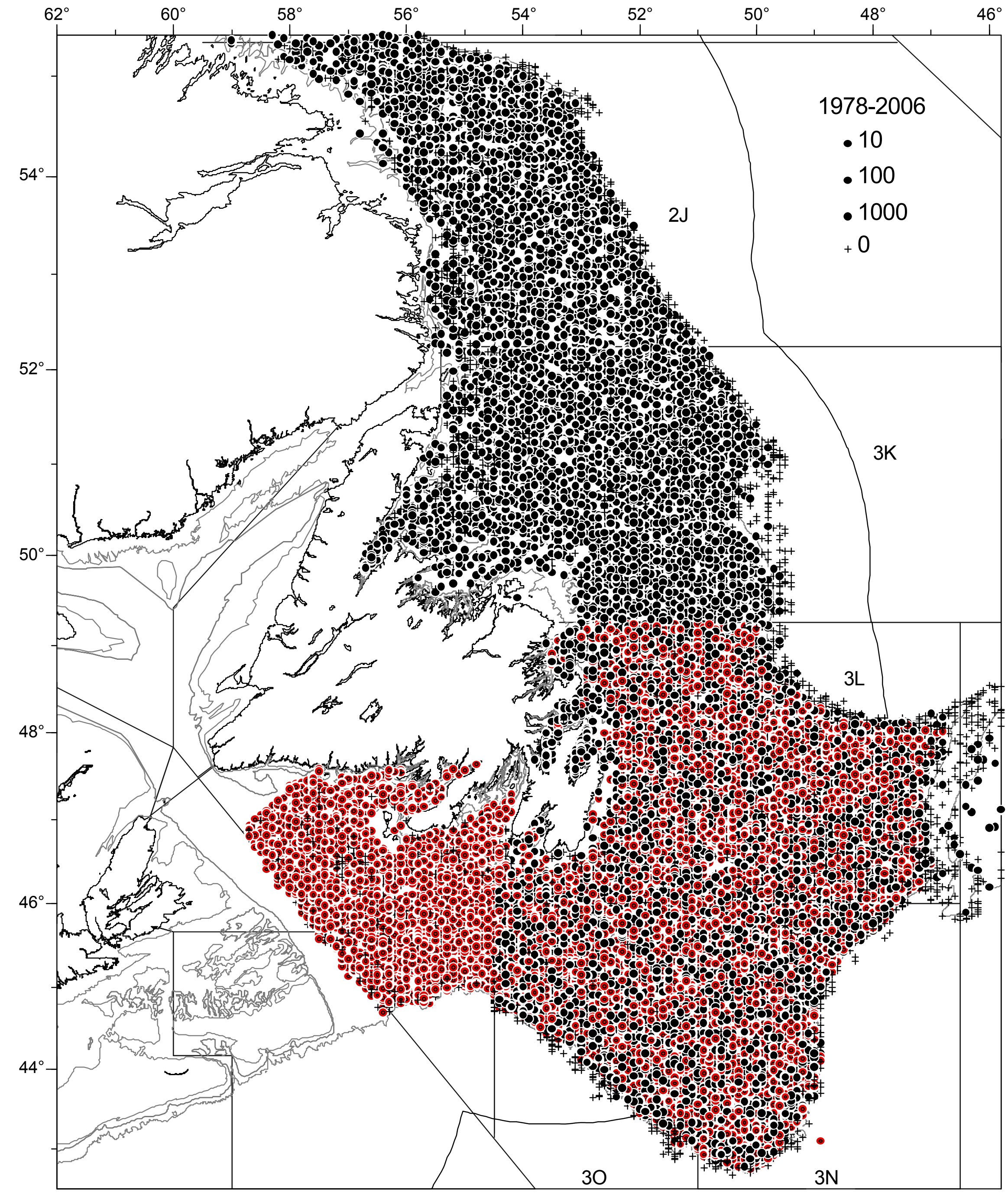

Figure 6. Distribution of American plaice (number per standard tow) from Canadian surveys in NAFO divisions 2J3KLNOPS during 1978-2006.

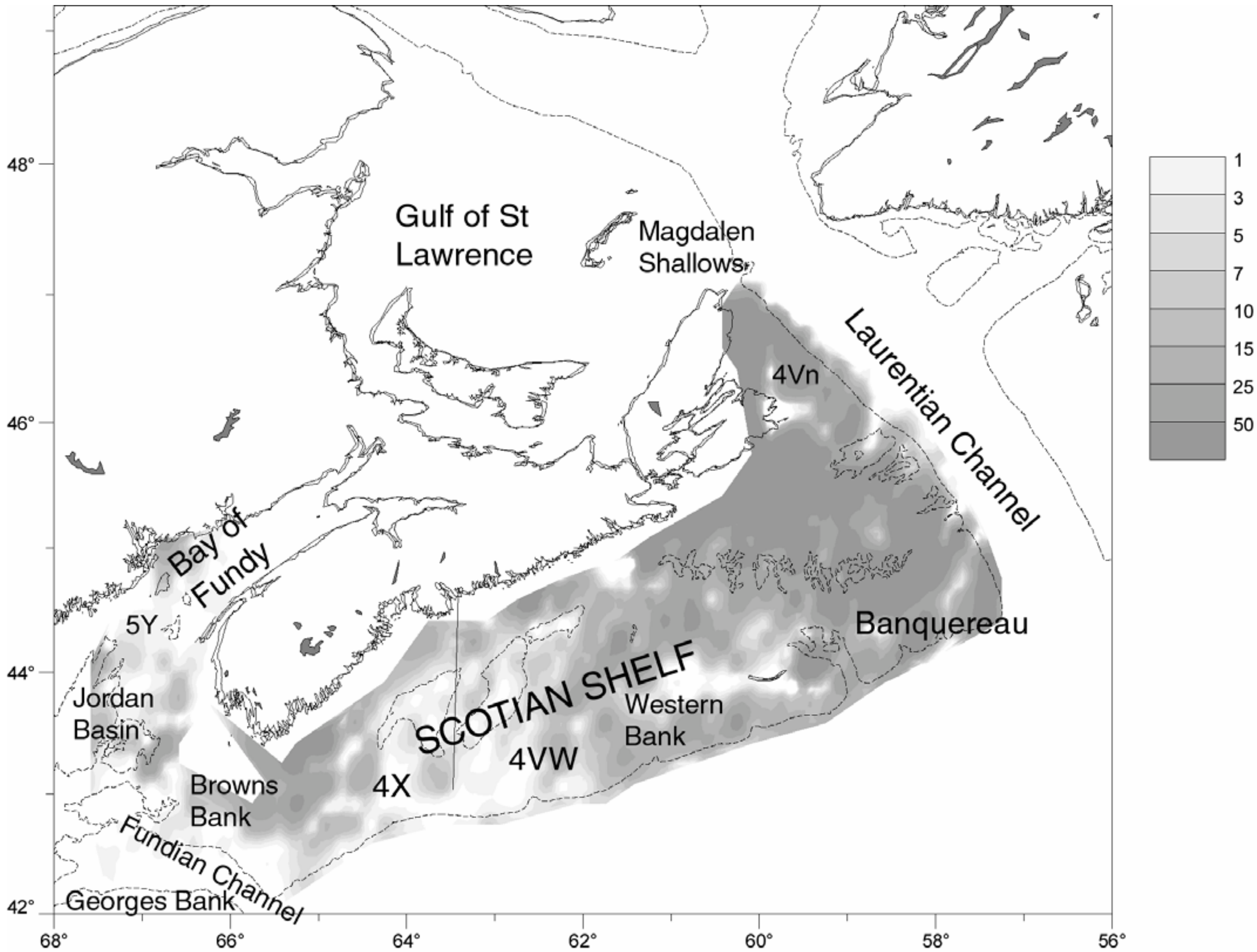

Figure 7. Distribution of American plaice (catch in kgs) from summer research vessel surveys.

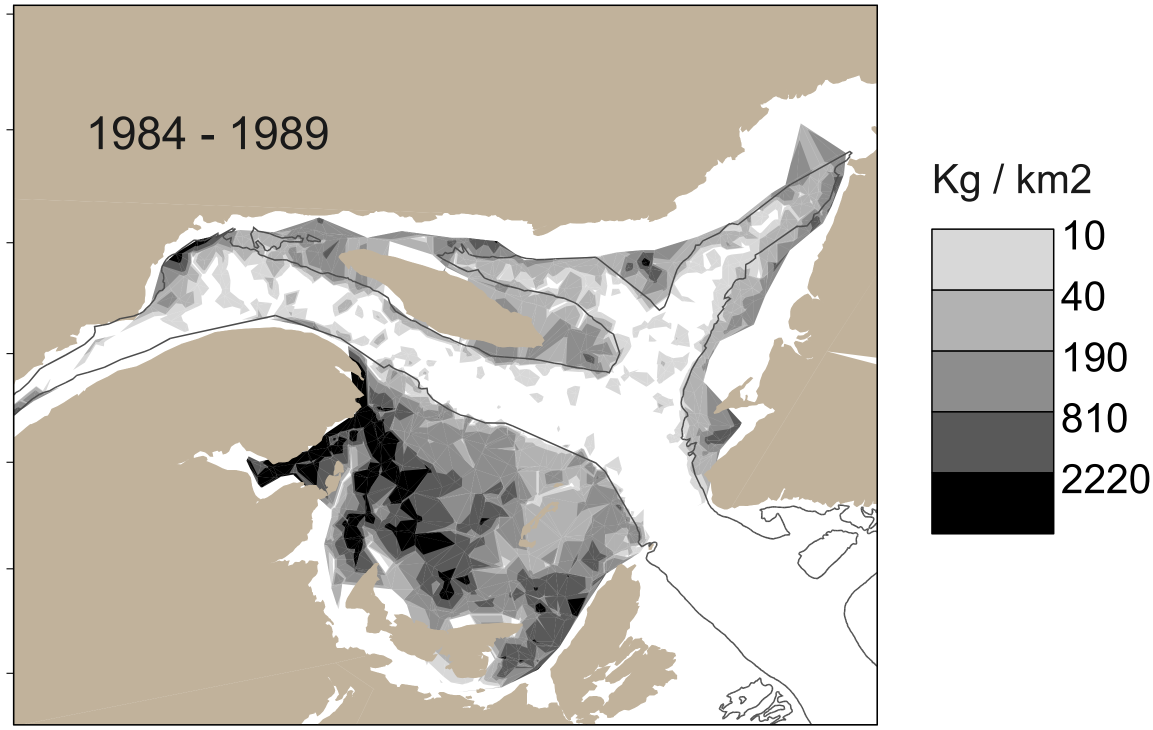

Figure 8. Distribution of American plaice catches in the northern and southern Gulf surveys, 1984-1989. Sampling throughout the Gulf of St. Lawrence during this period was made with the same vessel and trawl. Contour levels of catches correspond to the 10th, 25th, 50th, 75th and 90th percentiles of non-zero catches. The 200-m depth contour is indicated.

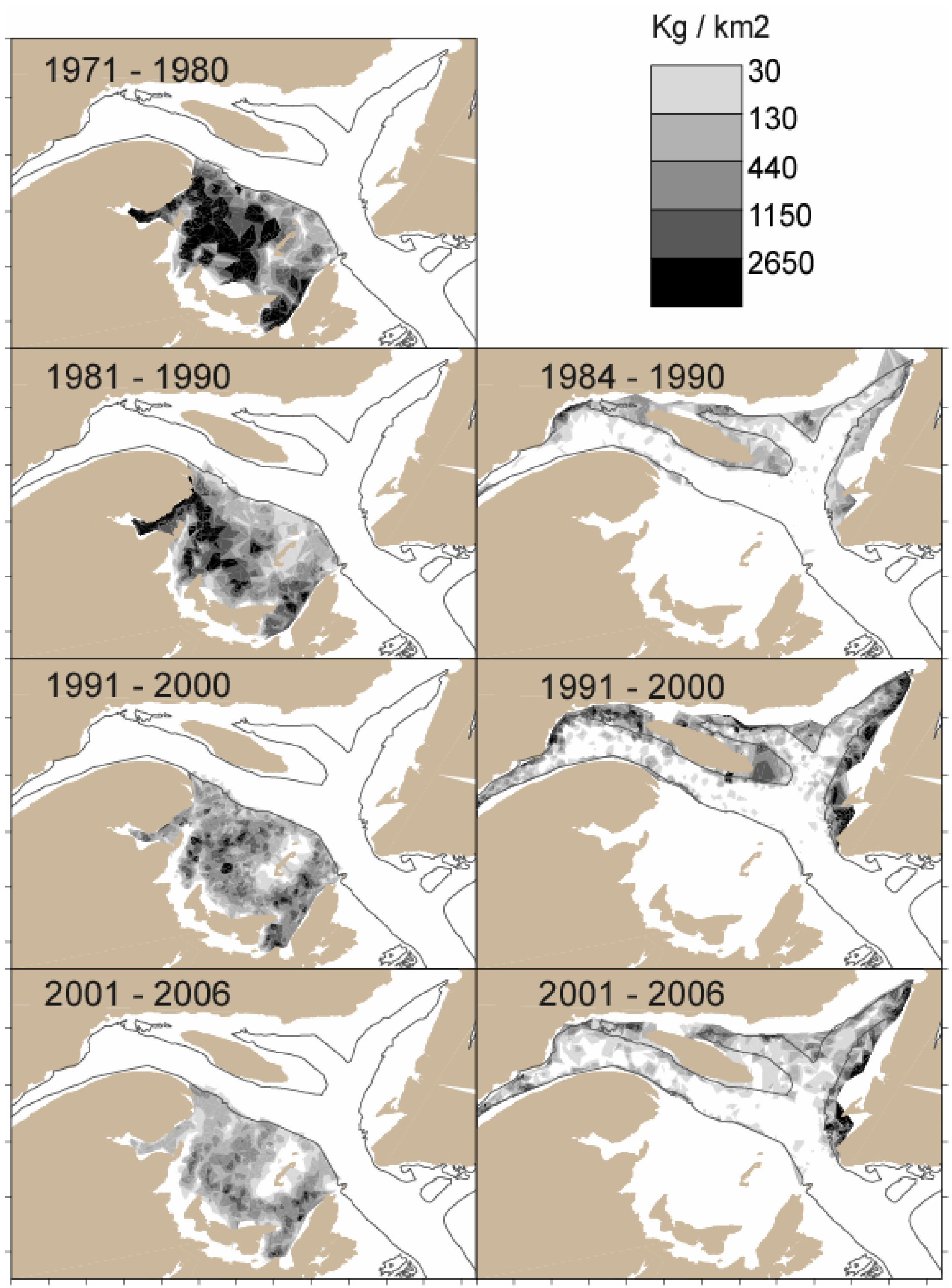

Figure 9. Distribution of American plaice (kg/km^2) in the southern (left panel) and northern gulf from research vessel surveys.

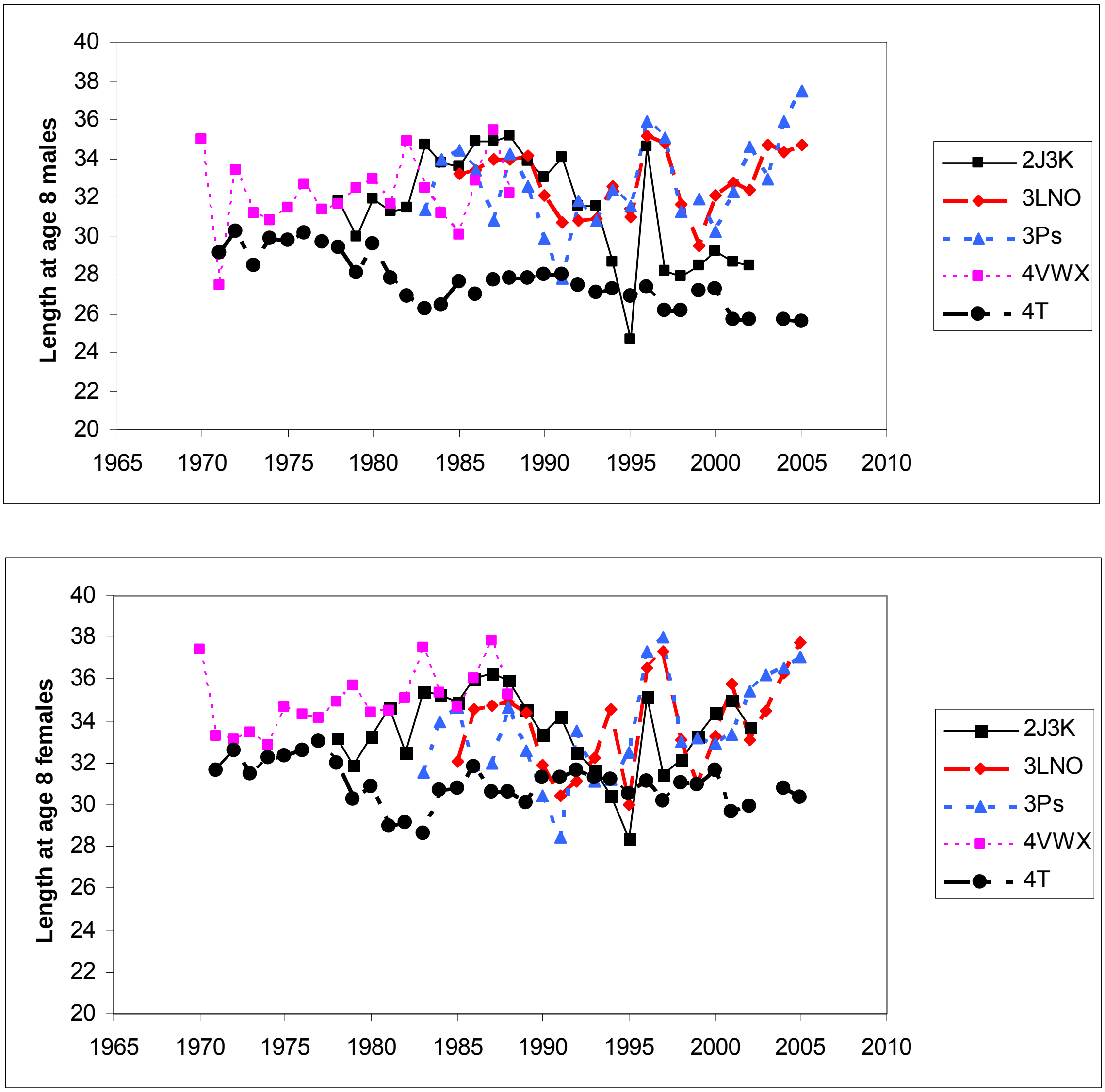

Figure 10. Mean length at age 8 for male and female American plaice from Div. 2J3K, 3LNO, Subdiv. 3Ps and Div. 4T.

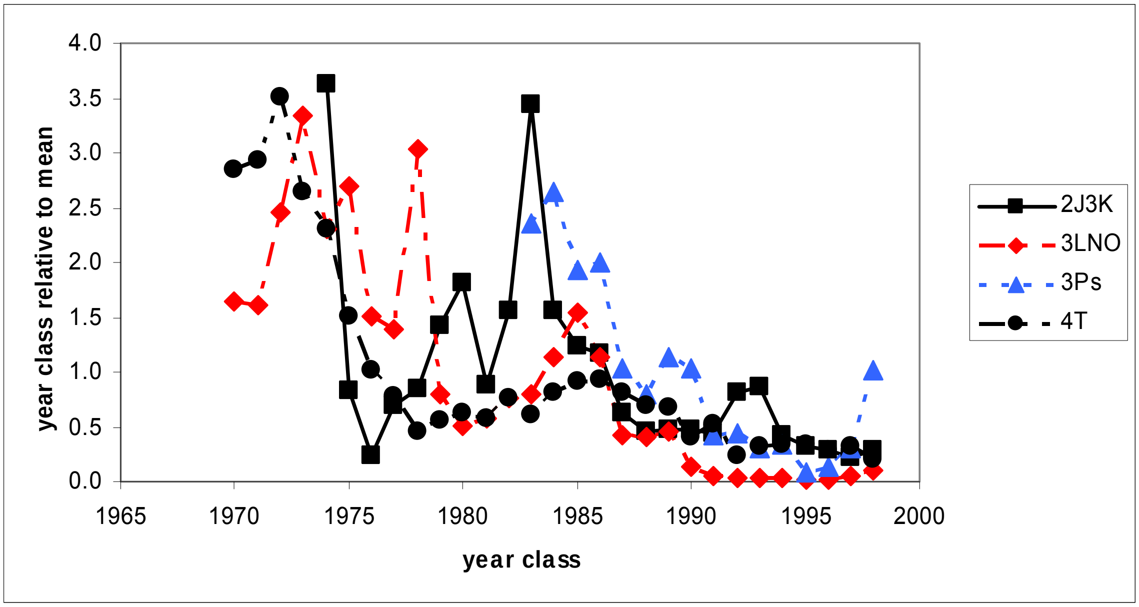

Figure 11. Relative year-class strength for American plaice from Div. 2J3K, 3LNO, Subdiv. 3Ps and Div. 4T. Each series is standardized to its own mean.

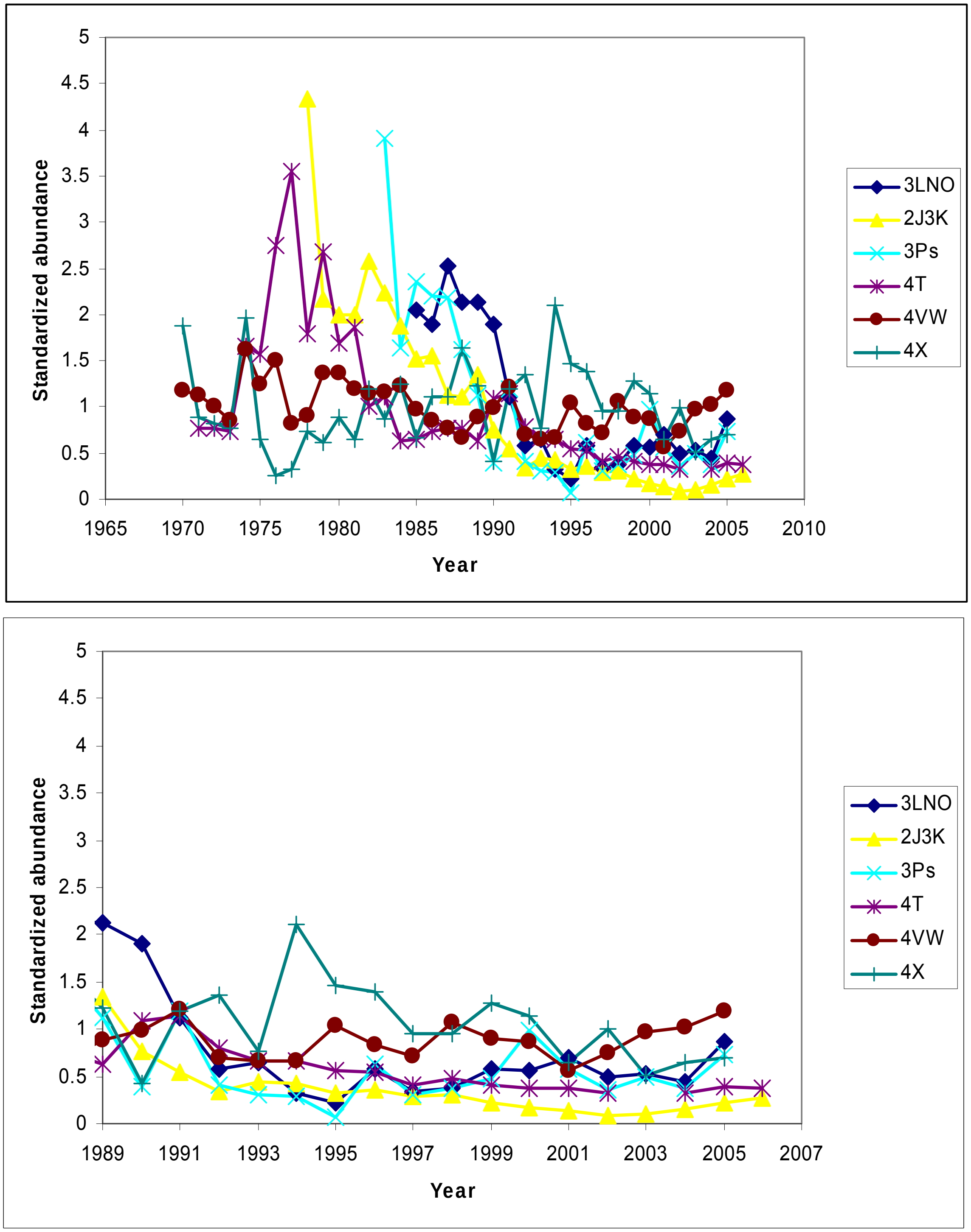

Figure 12. Abundance for American plaice from Div. 2J3K, 3LNO, Subdiv. 3Ps, Div. 4T, Div. 4VW, and Div. 4X. Each series is standardized to its own mean. The bottom panel shows from 1989 only.

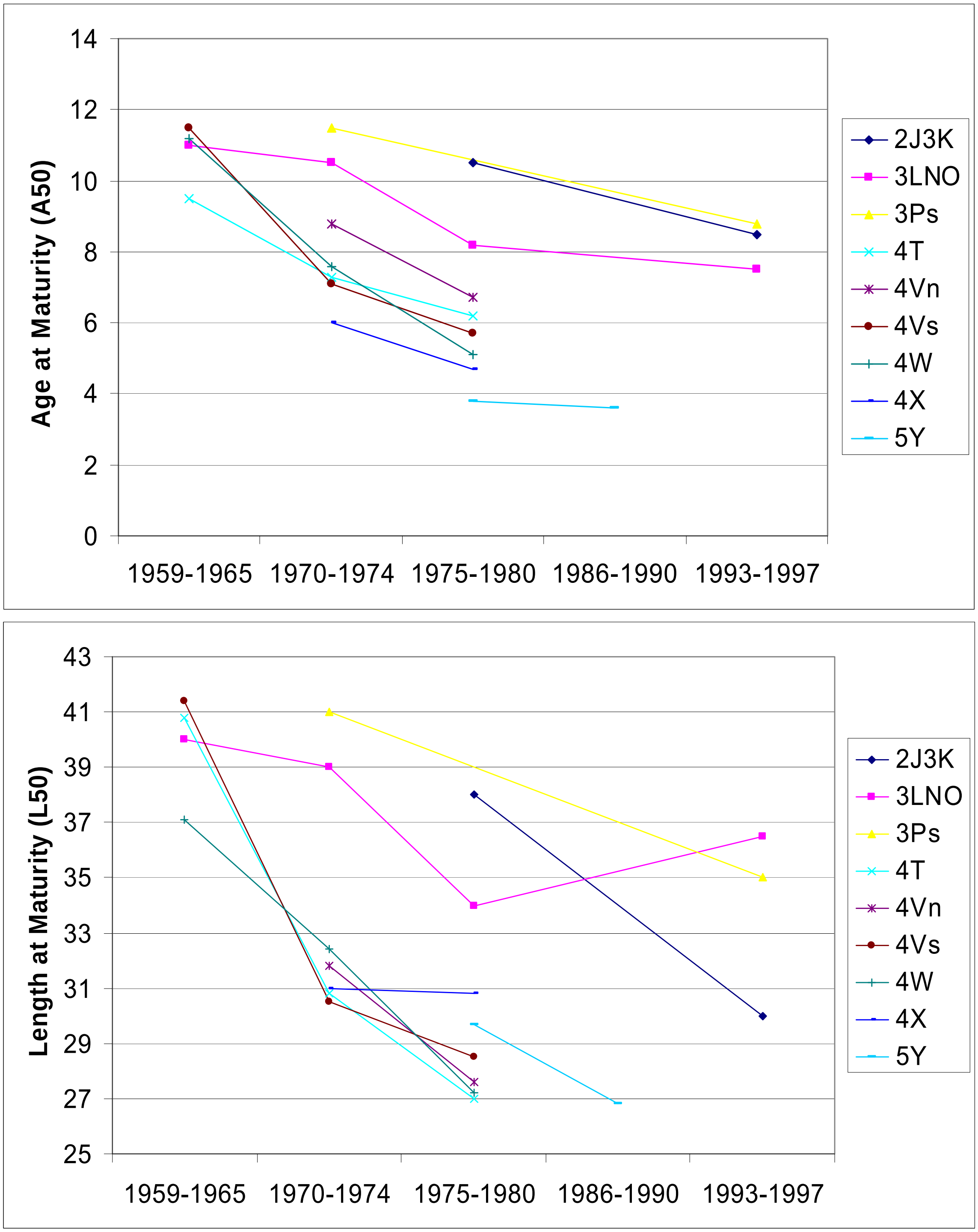

Figure 13. Age and length at 50% maturity for American plaice in different areas in different decades. The areas are listed in the legend in a general north to south order.

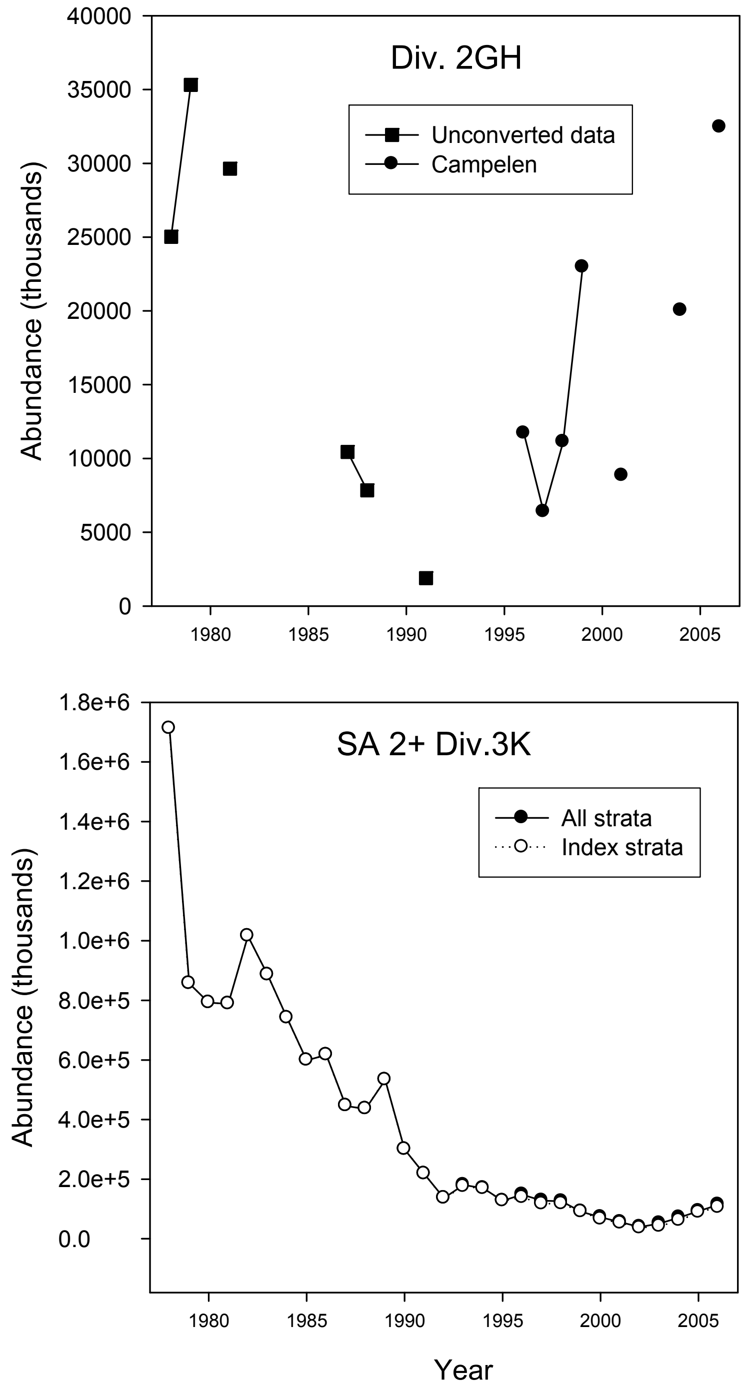

Figure 14. Overall abundance (thousands of fish) of American plaice for Subarea 2+3K over the time series 1978-2006. Top panel shows Div. 2GH, with squares representing non-converted data, and circles indicating Campelen data units. Bottom panel shows Div. 2J3K, and filled circles indicate abundance when all strata are included while open circles indicate abundance when only indexed strata are included.

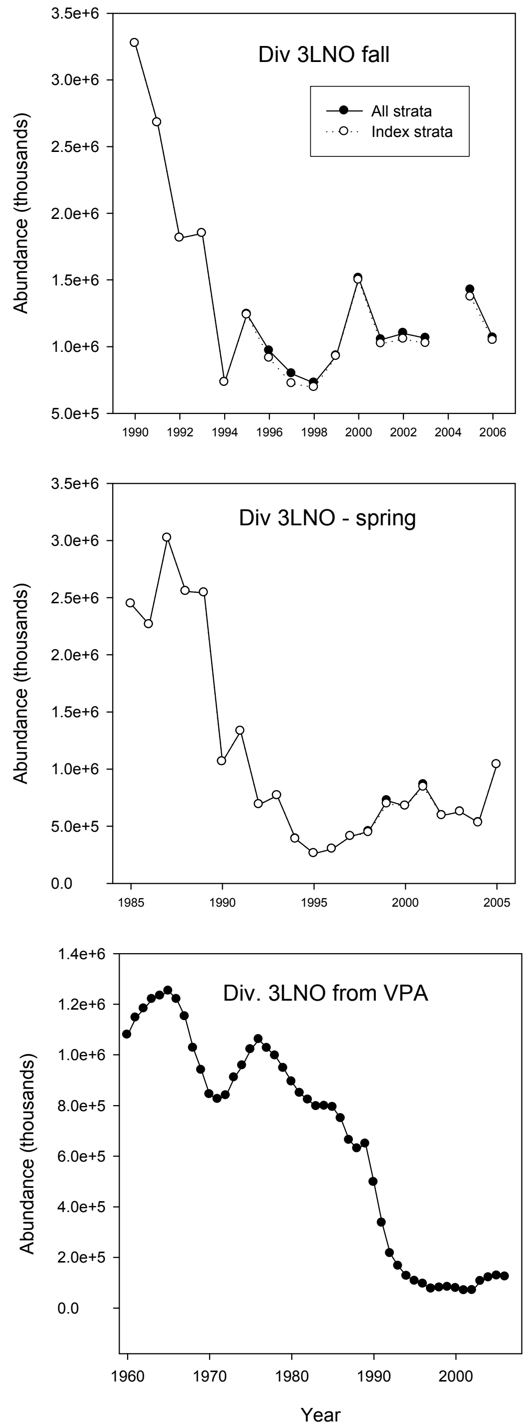

Figure 15. Overall abundance (thousands of fish) of American plaice for Div. 3LNO over the time series. Top panel shows Div. 3LNO from the fall RV surveys from 1990-2006, with filled circles representing abundance from all strata, and open circles representing abundance when only indexed strata are included. Middle panel shows Div. 3LNO from the spring RV surveys from 1985-2005, and the bottom panel shows the total population numbers estimated from the Virtual Population Analysis (VPA) from 1960-2006.

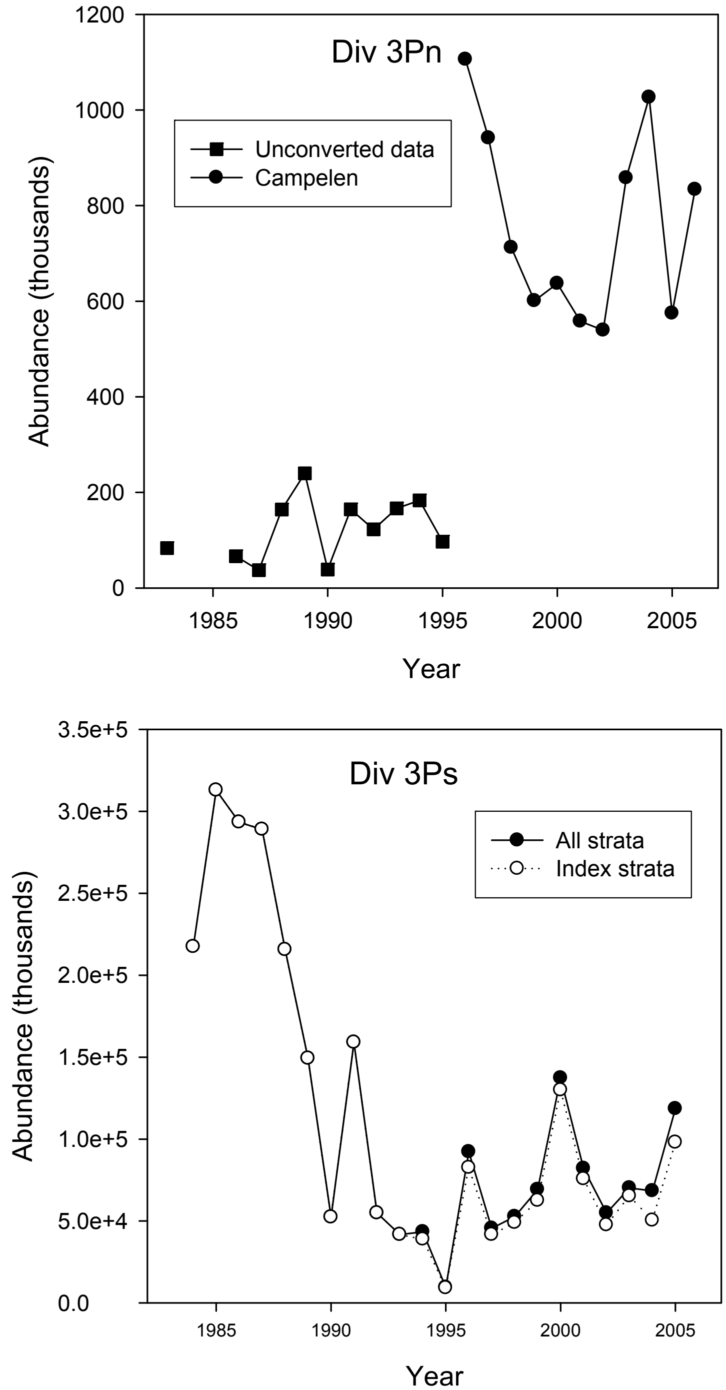

Figure 16. Overall abundance (thousands of fish) of American plaice for Div. 3P over the time period 1983-2005. Top panel shows Div. 3Pn, with squares representing non-converted data, and circles indicating Campelen data units. Bottom panel shows Div. 3Ps, and filled circles indicate abundance when all strata are included while open circles indicate abundance when only indexed strata are included.

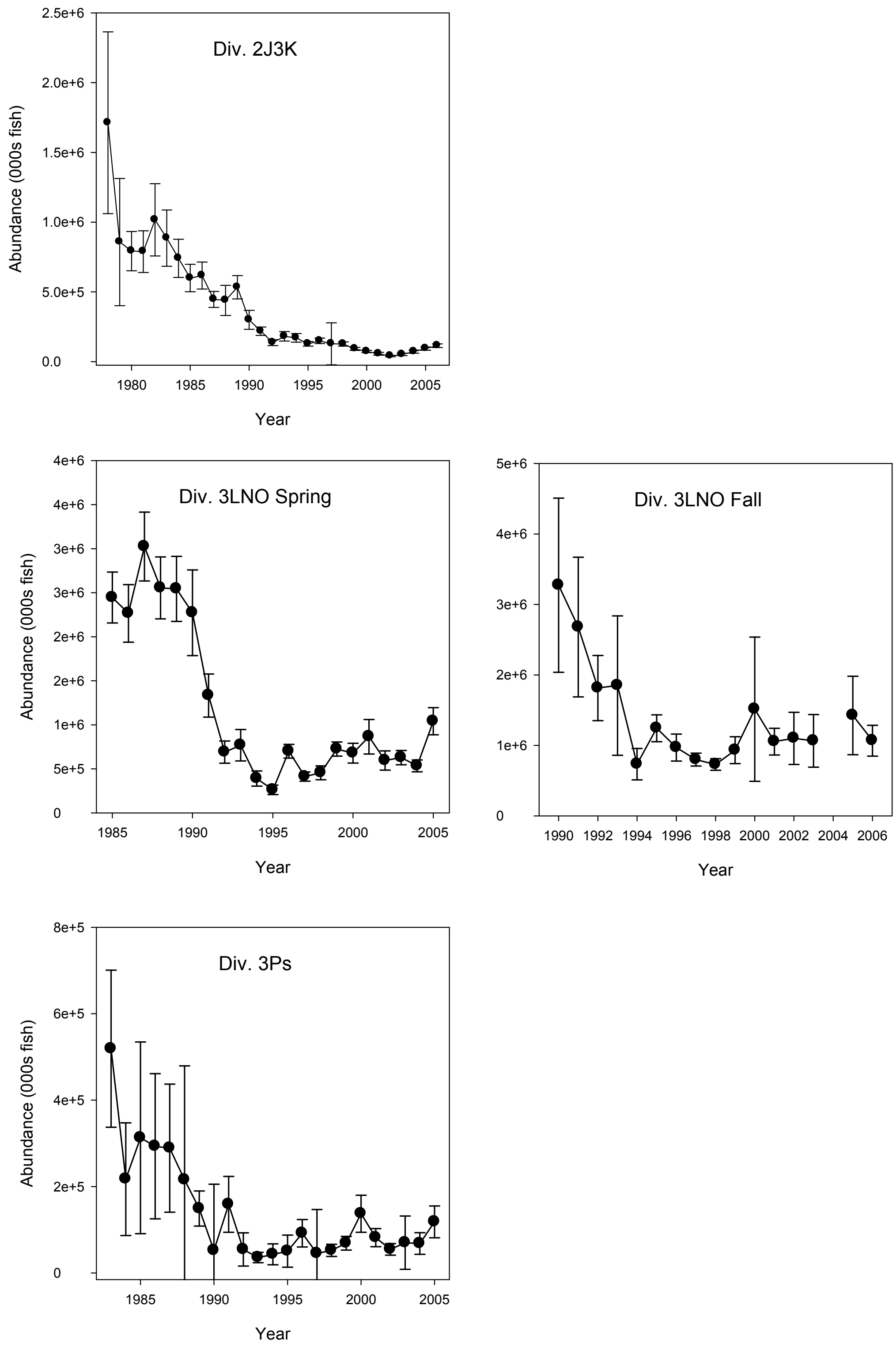

Figure 17. Overall abundance (thousands of fish) of American plaice with associated confidence intervals of Div. 2J3K (top panel), Div. 3LNO spring and fall (middle panels), and Div. 3Ps (bottom panel). Abundance data calculated from all strata surveyed.

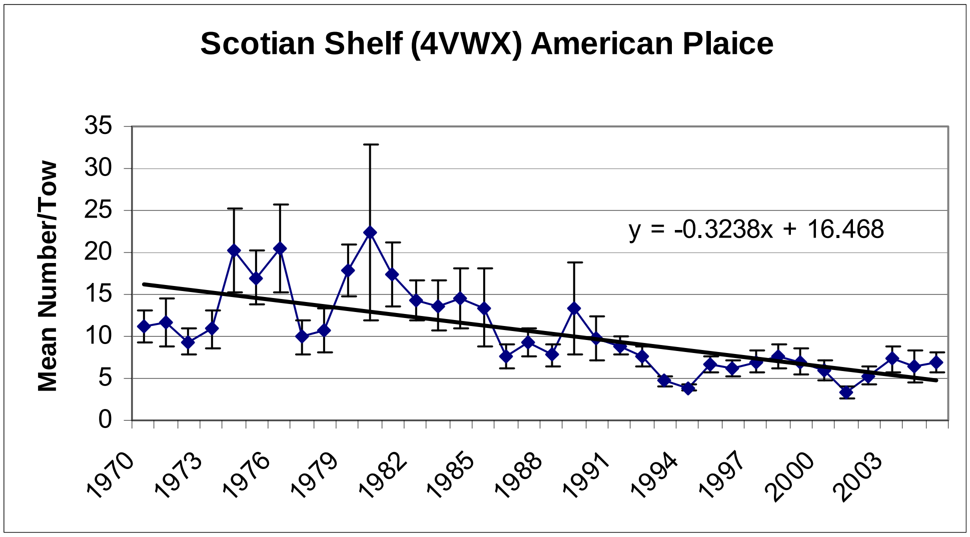

Figure 18. Relative abundance of Scotian Shelf (4VWX) American plaice.

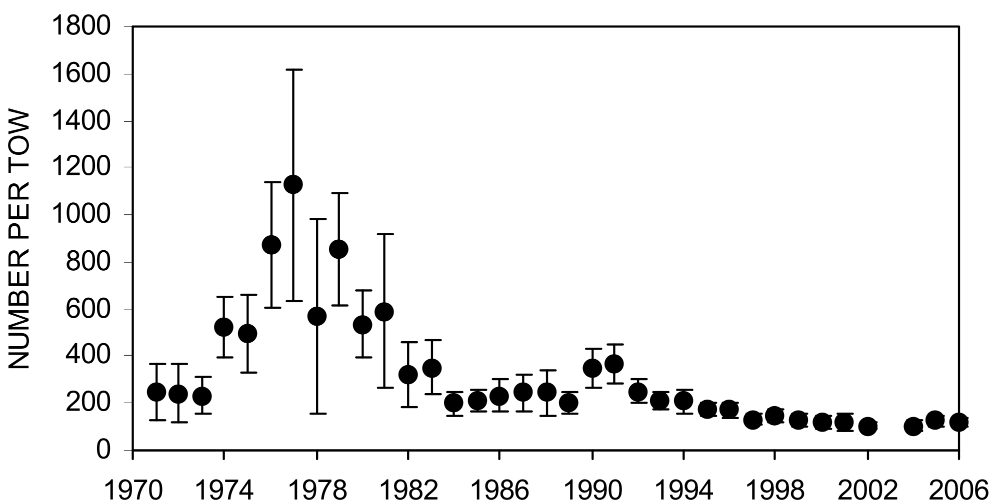

Figure 19. Overall abundance of 4T American plaice as stratified mean number per tow, standardized to a common vessel and trawl. Confidence intervals are represented by ±2 standard deviations.

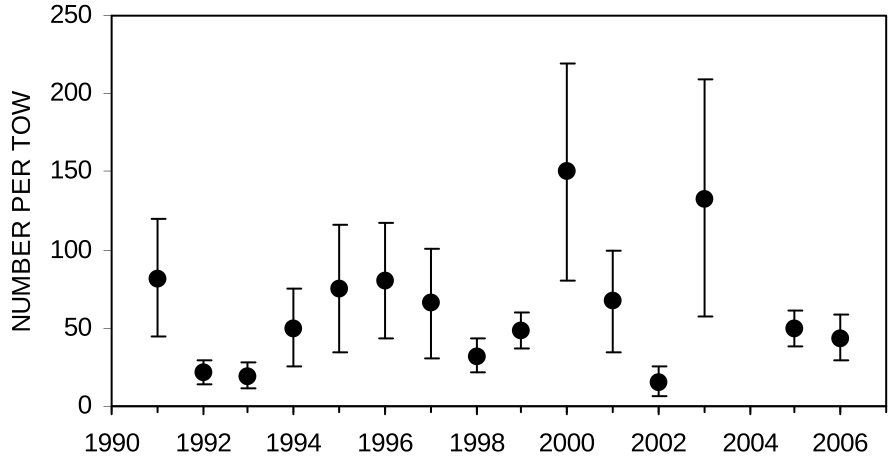

Figure 20. Overall abundance of 4RS American plaice as stratified mean number per tow, standardized to a common vessel and trawl. Confidence intervals are represented by ±2 standard deviations.

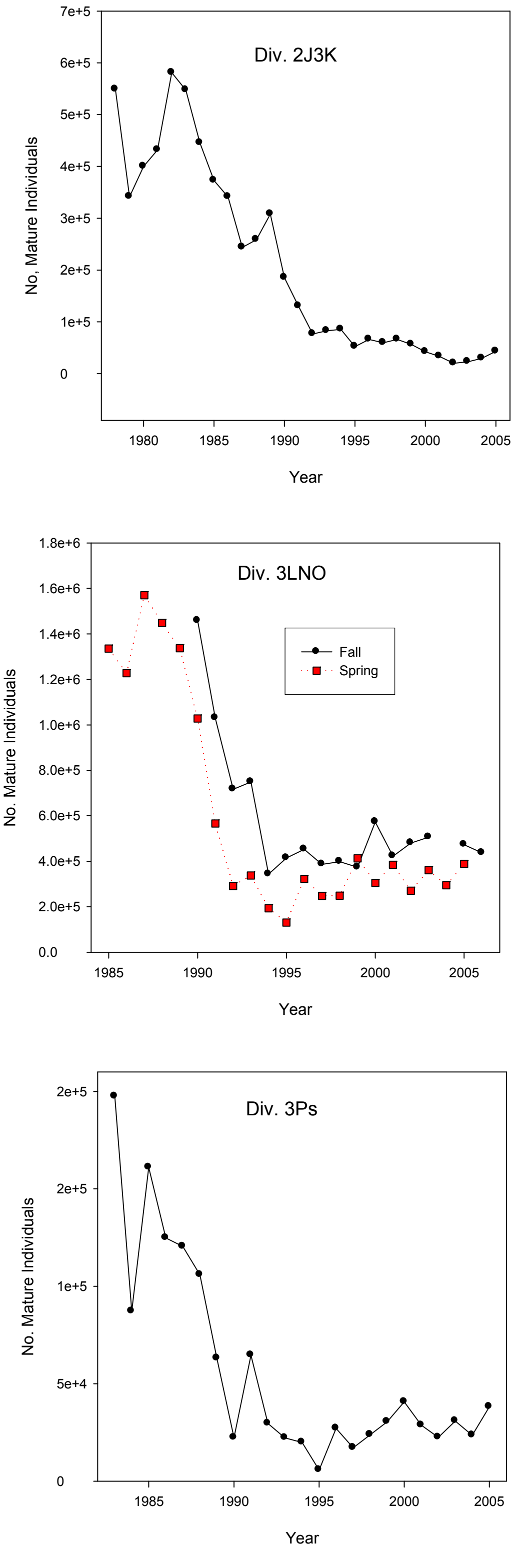

Figure 21. Number of mature individuals (thousands of fish) for Div. 2J3K (top panel), Div. 3LNO Spring (red symbols) and Fall (black symbols) (middle panel) and Div. 3Ps (bottom panel).

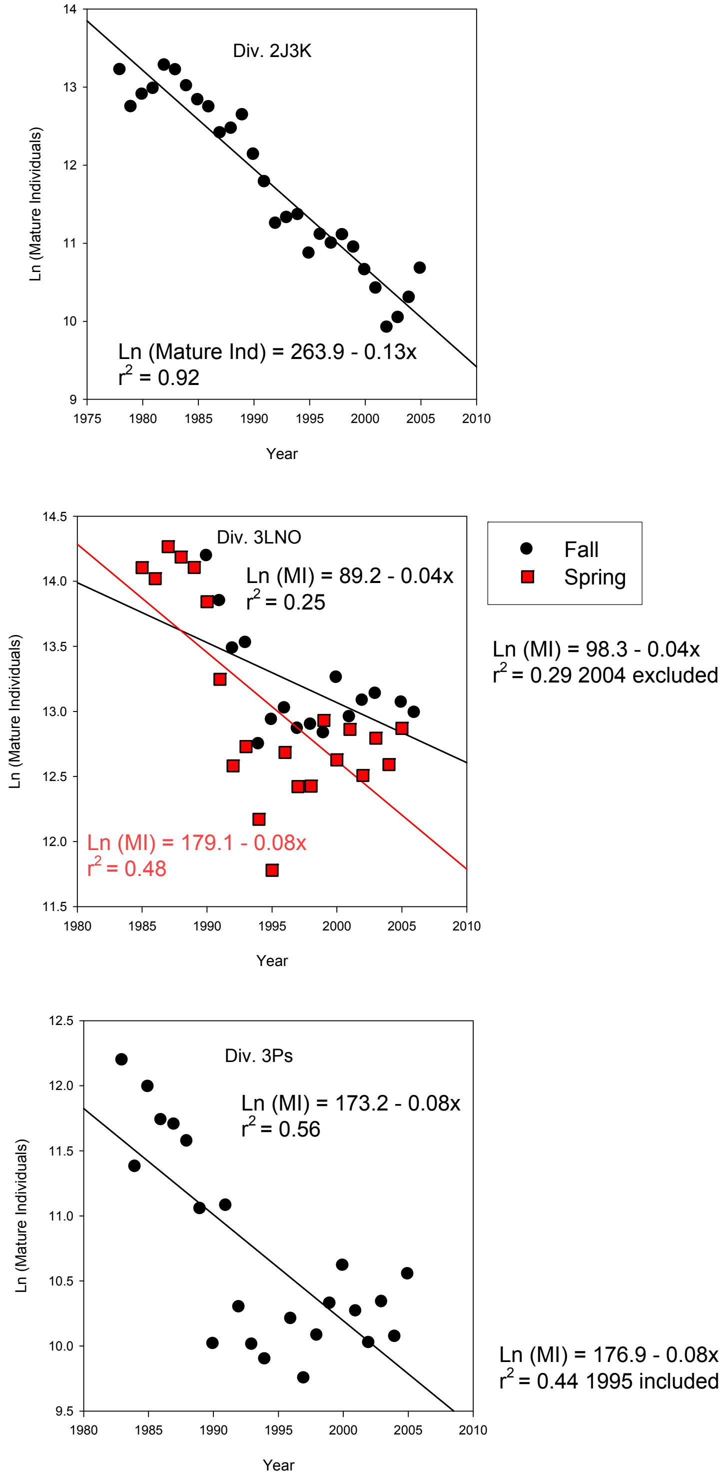

Figure 22. Natural log (Ln) of abundance of mature individuals for Div. 2J3K (top panel), Div . 3LNO Spring (red symbols) and Fall (black symbols) (middle panel) and Div. 3Ps (bottom panel). Linear regression equations are provided for each group. The data point for 1995 has been removed from the 3Ps plot.

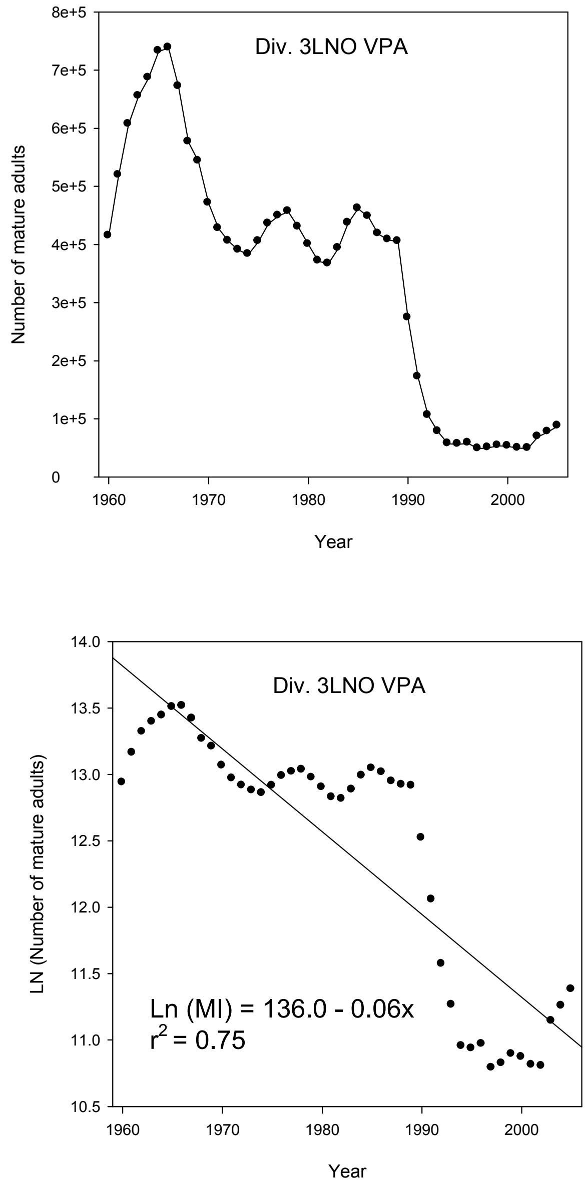

Figure 23. Number of mature individuals (thousands of fish) based on Div. 3LNO VPA estimates (top panel) and natural log abundance of mature individuals (bottom panel) with associated regression equation.

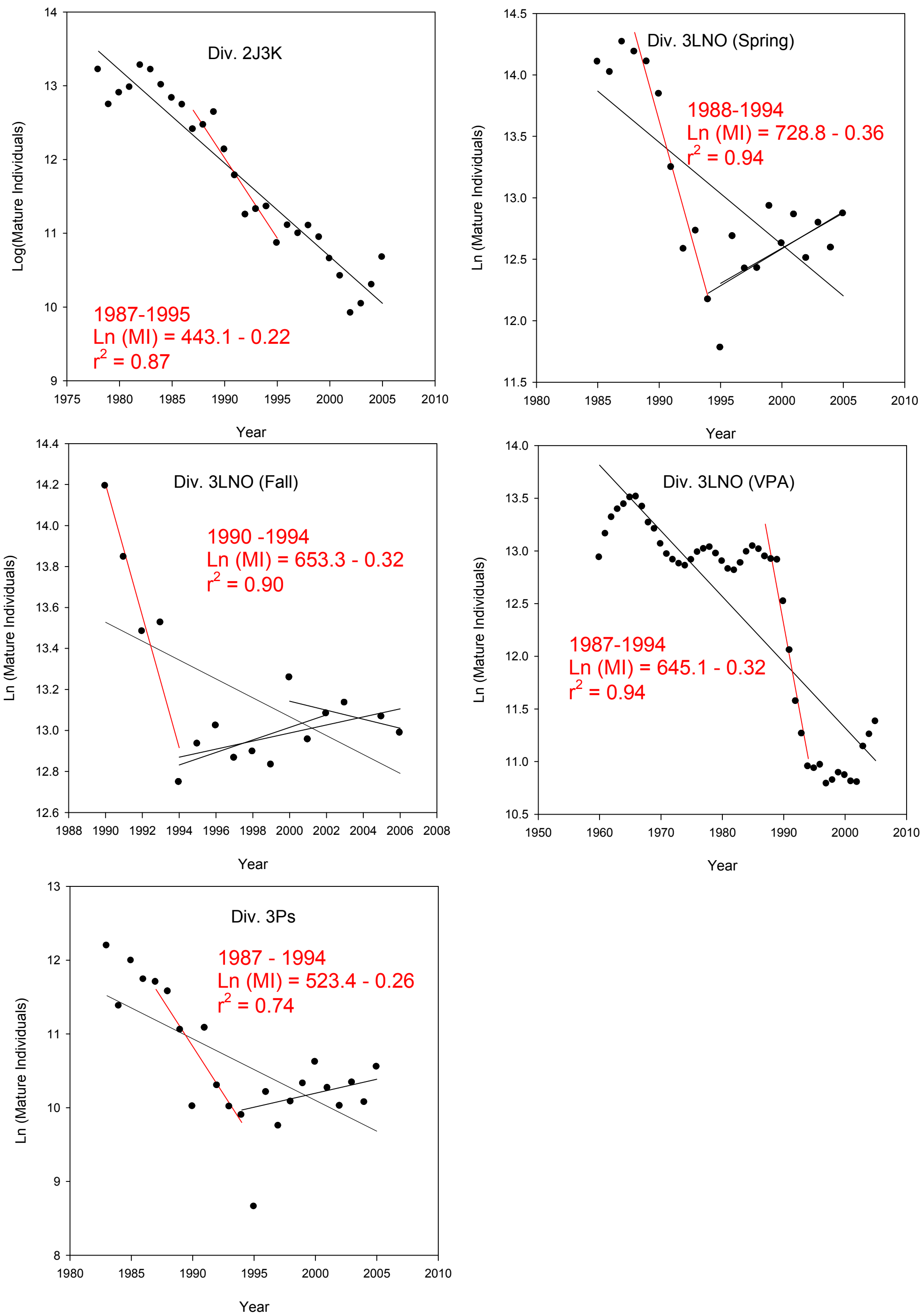

Figure 24. Trends in abundance of mature individuals for Div. 2J3K, Div. 3LNO (Spring), Div. 3LNO (Fall), Div. 3LNO (from VPA estimates) and Div. 3Ps. Lines represent the regression of the natural log abundance versus time over various time periods. The red line is a period of steep decline, and the resulting equation is given in each plot.

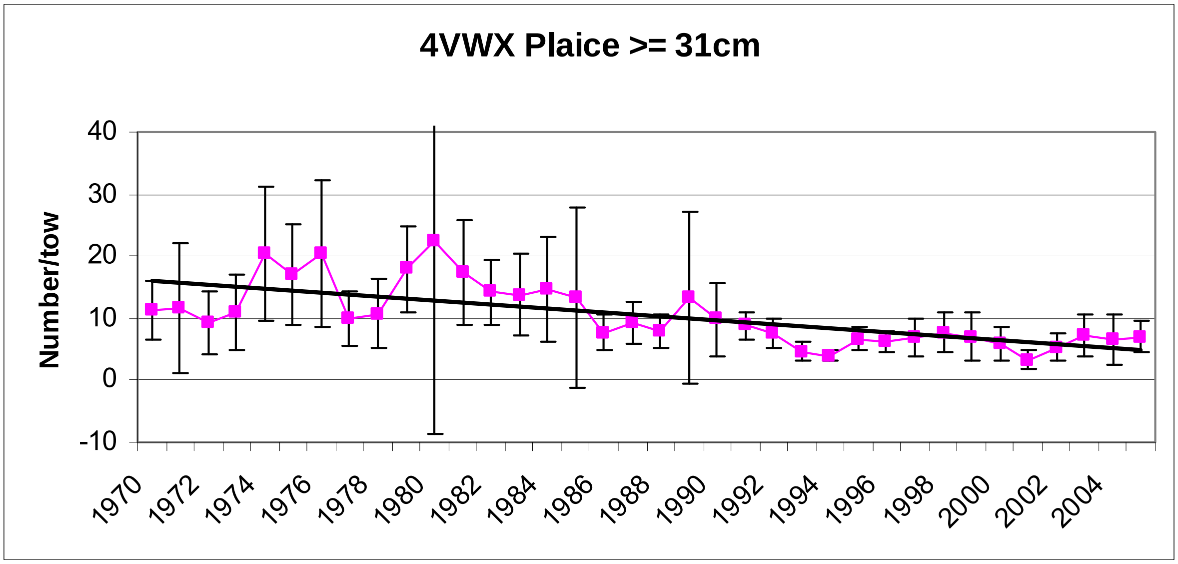

Figure 25. Relative abundance of mature (≥ 31cm) 4VWX American Plaice.

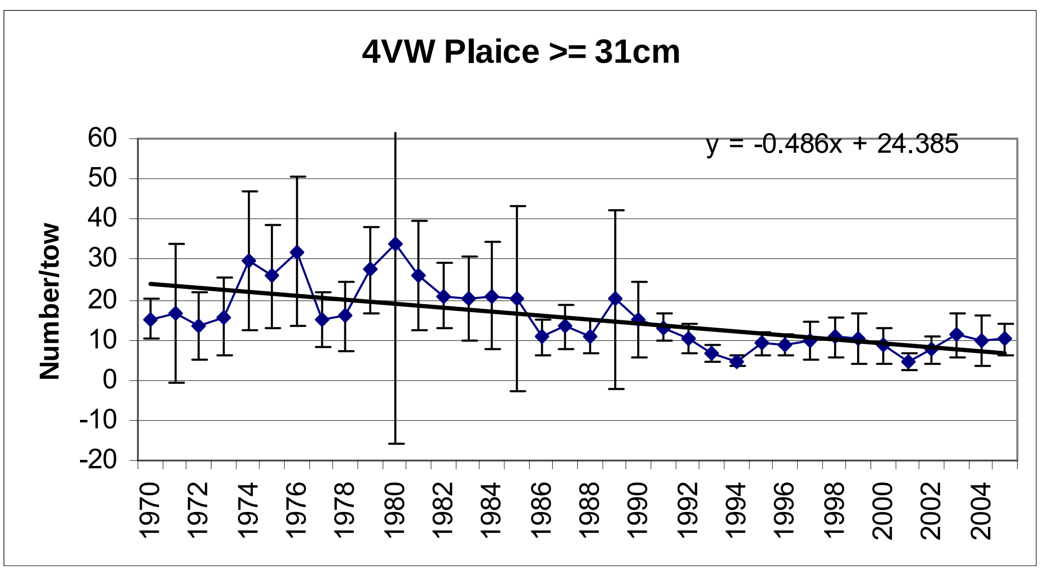

Figure 26. Relative abundance of mature (≥ 31cm) 4VW American Plaice.

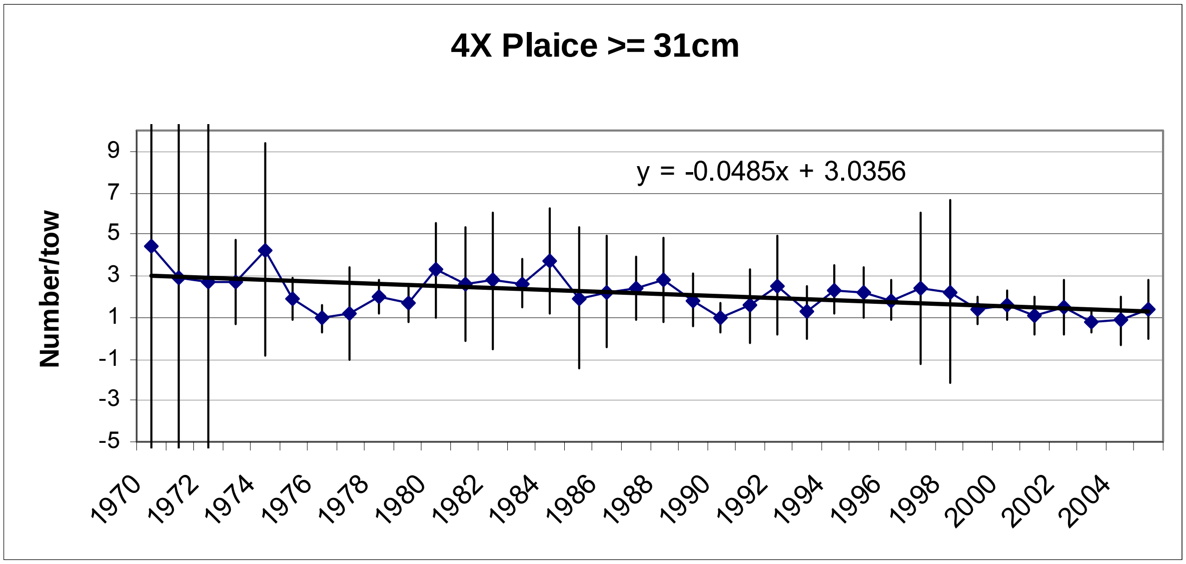

Figure 27. Relative abundance of mature (≥ 31cm) 4X American Plaice.

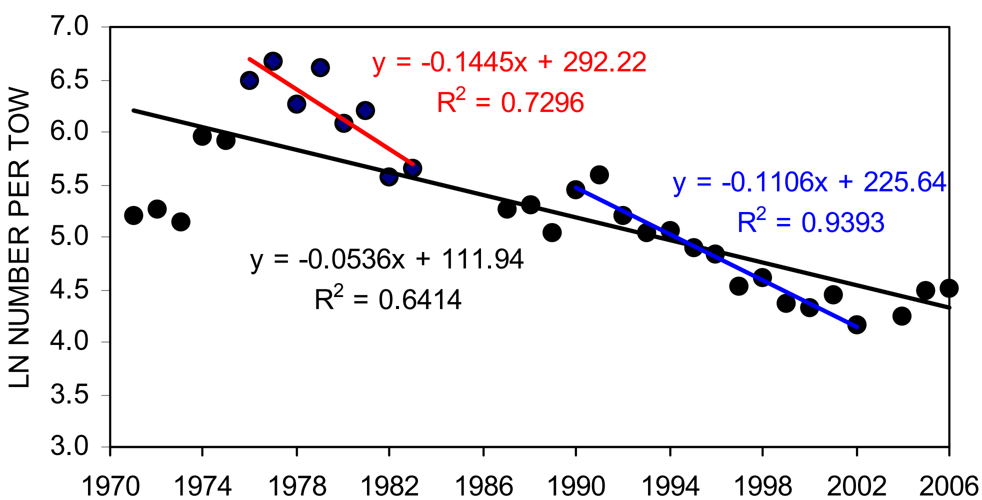

Figure 28. Trends in abundance of mature 4T American plaice (females 26 cm+; males 19 cm+). Coloured lines represent the regression of the natural log of abundance versus time in two periods of decline. The black line is the regression over the 1971-2006 period. Sexed length-frequencies were not recorded in this survey from 1984 to 1986.

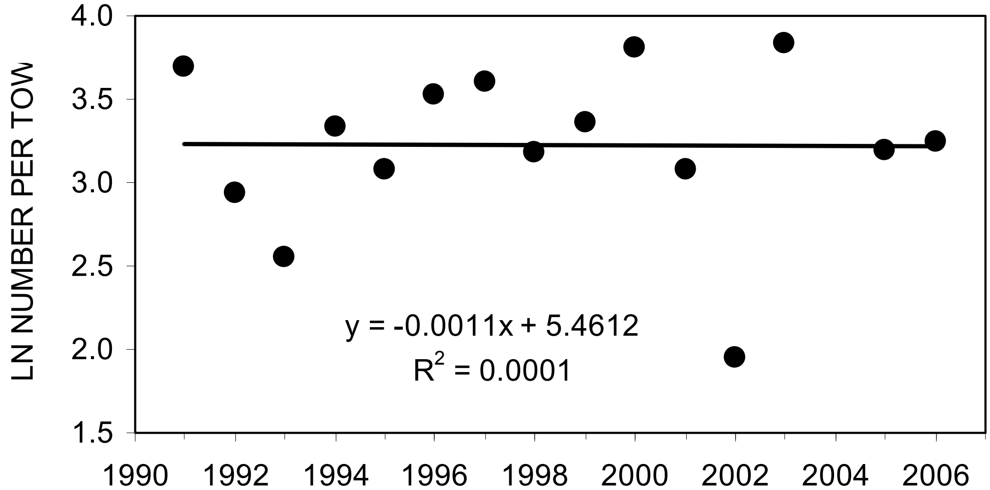

Figure 29. Trends in abundance of mature 4RS American plaice (females 26 cm+; males 19 cm+). The line represents the regression of the natural log of abundance versus time.

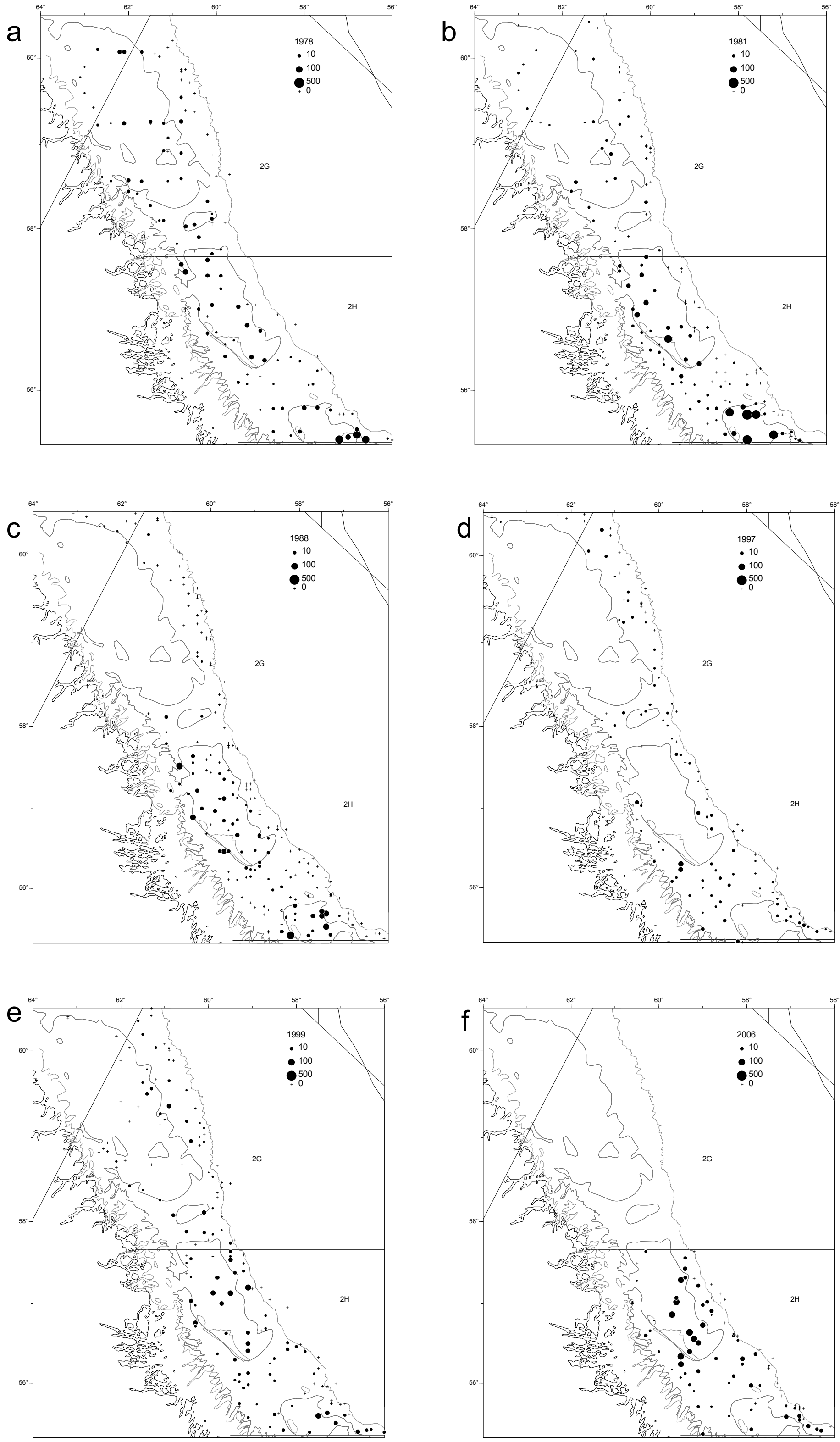

Figure 30. Distribution of American plaice (number per standard tow) from Canadian surveys in NAFO Divisions 2GH. Only select years are shown to illustrate the sporadic nature of the surveys in these Divisions. Figure a) 1978, b) 1981, c) 1988, d) 1997, e) 1999, and f) 2006. For figures a to c, data are from Engel gear and figures d to f, data are Campelen gear.

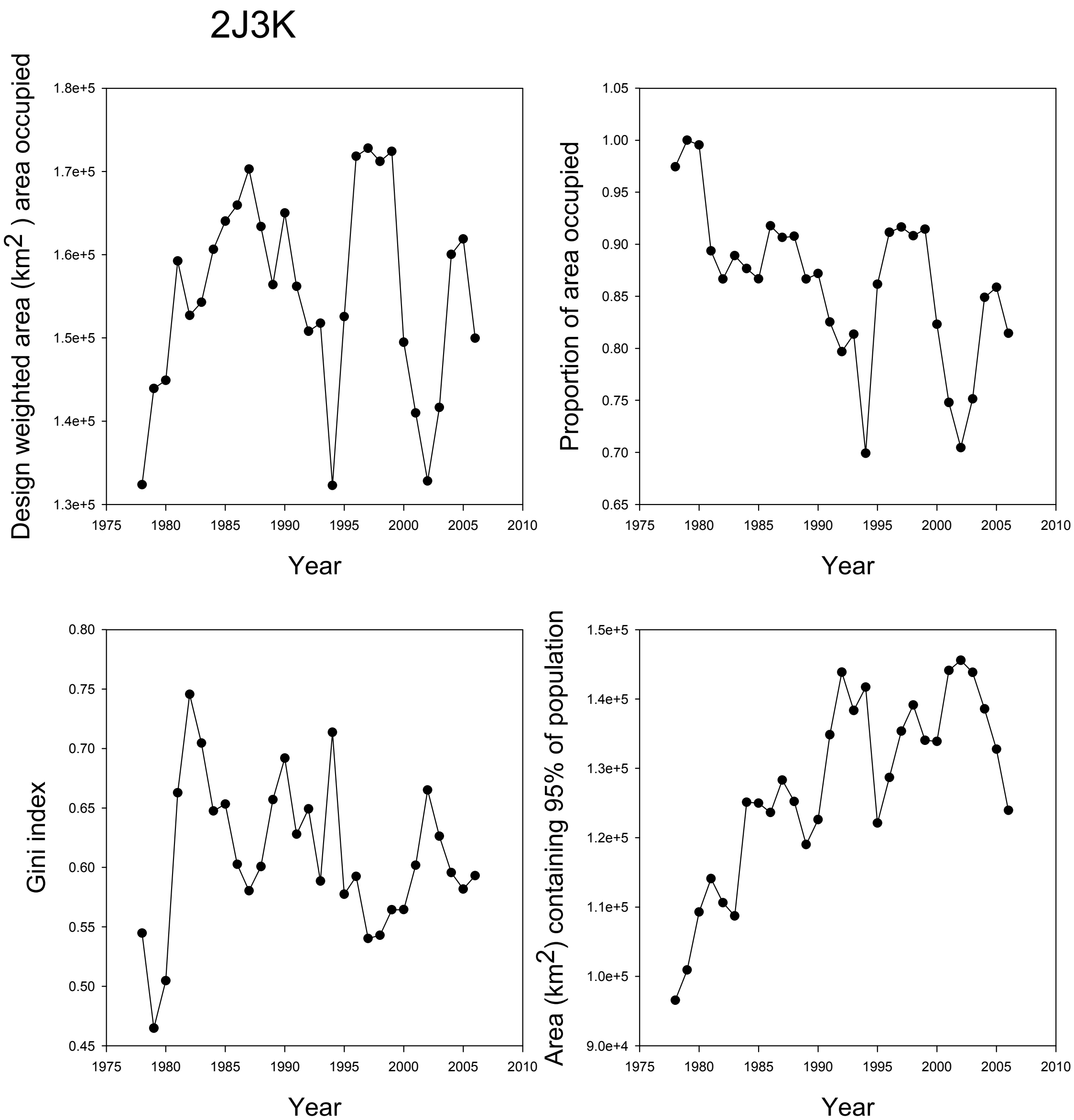

Figure 31. Indices of area occupied by American plaice in Div. 2J3K.

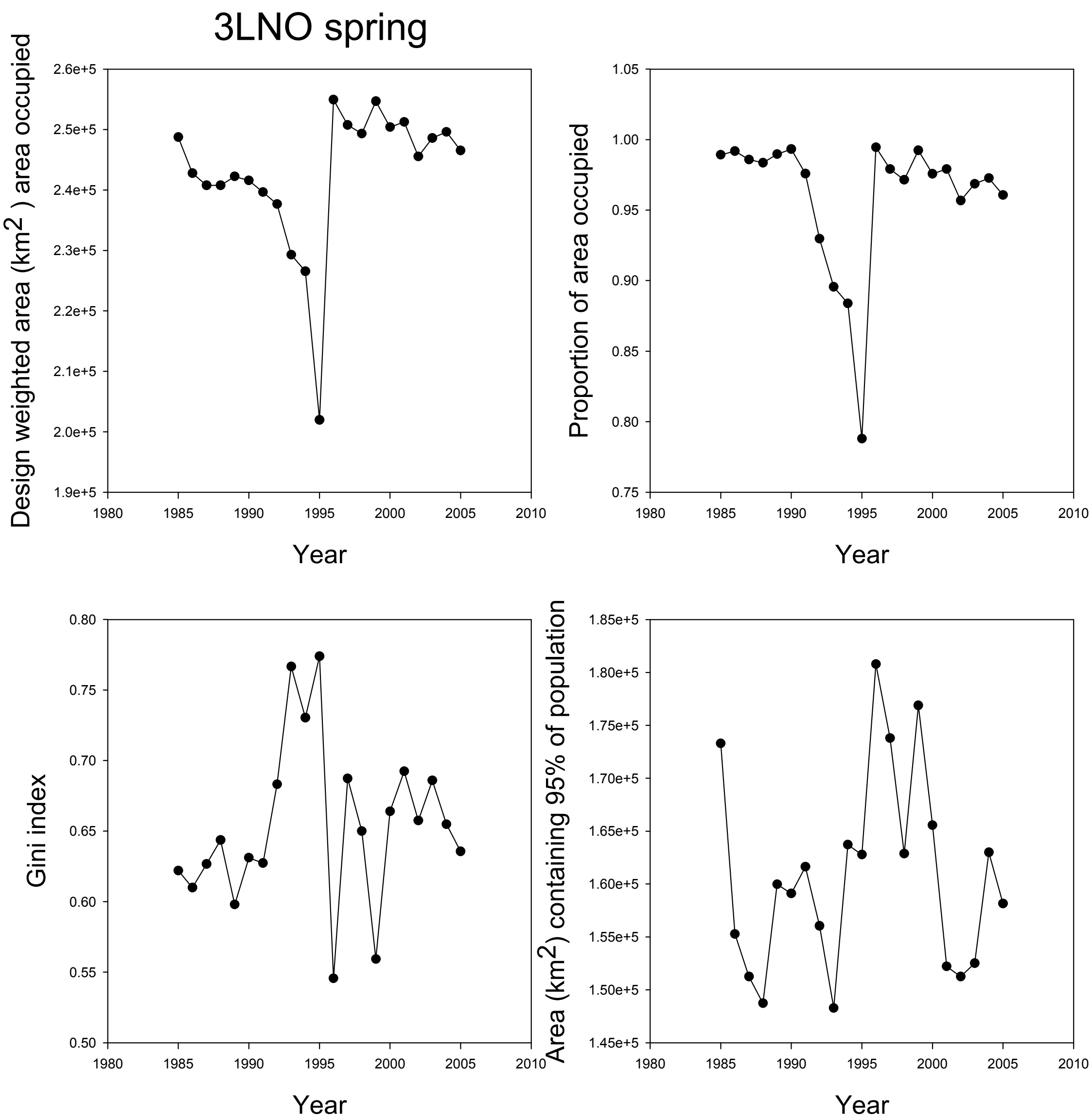

Figure 32. Indices of area occupied by American plaice in Div. 3LNO from the spring survey.

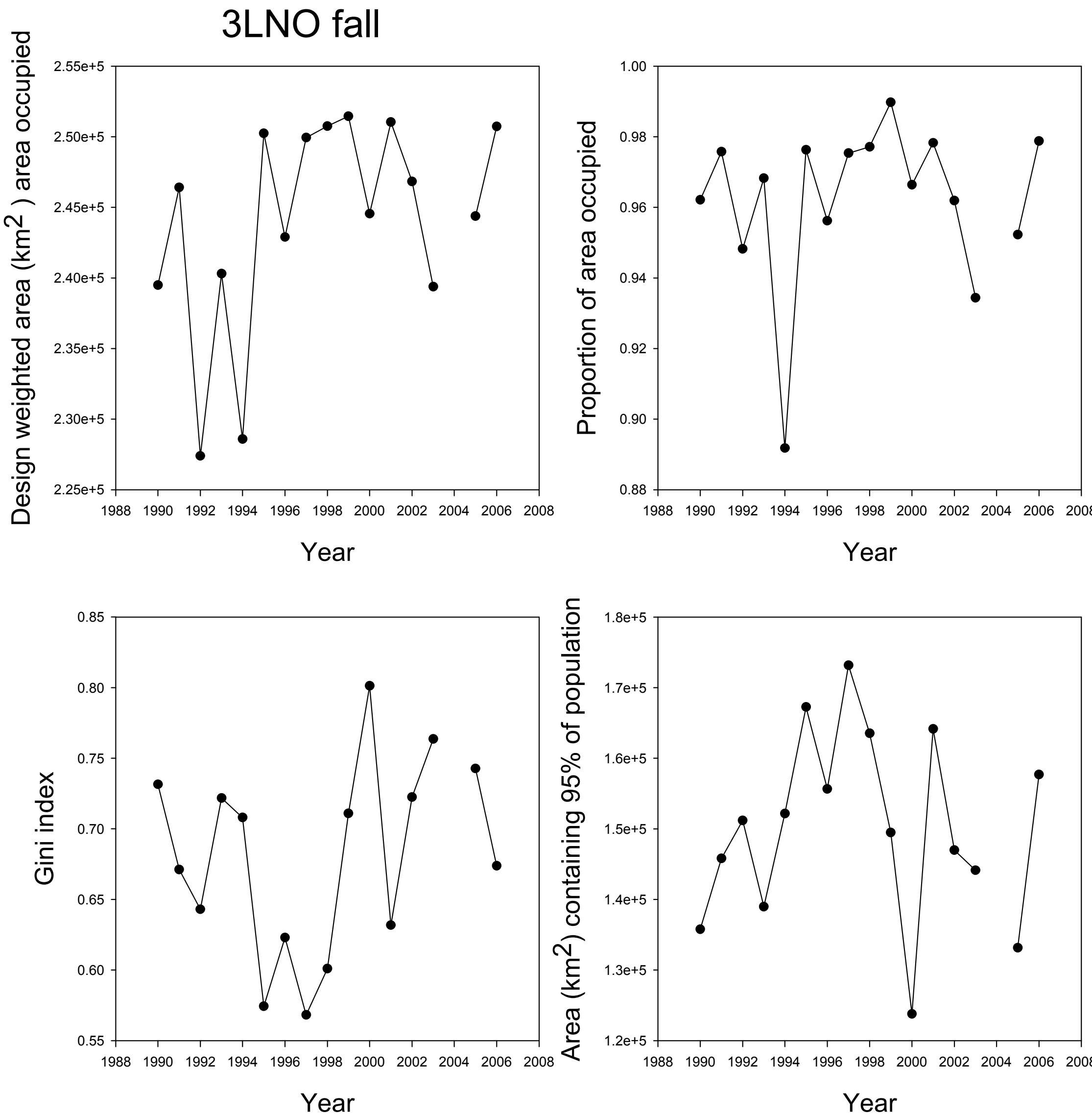

Figure 33. Indices of area occupied by American plaice in Div. 3LNO from the fall survey.

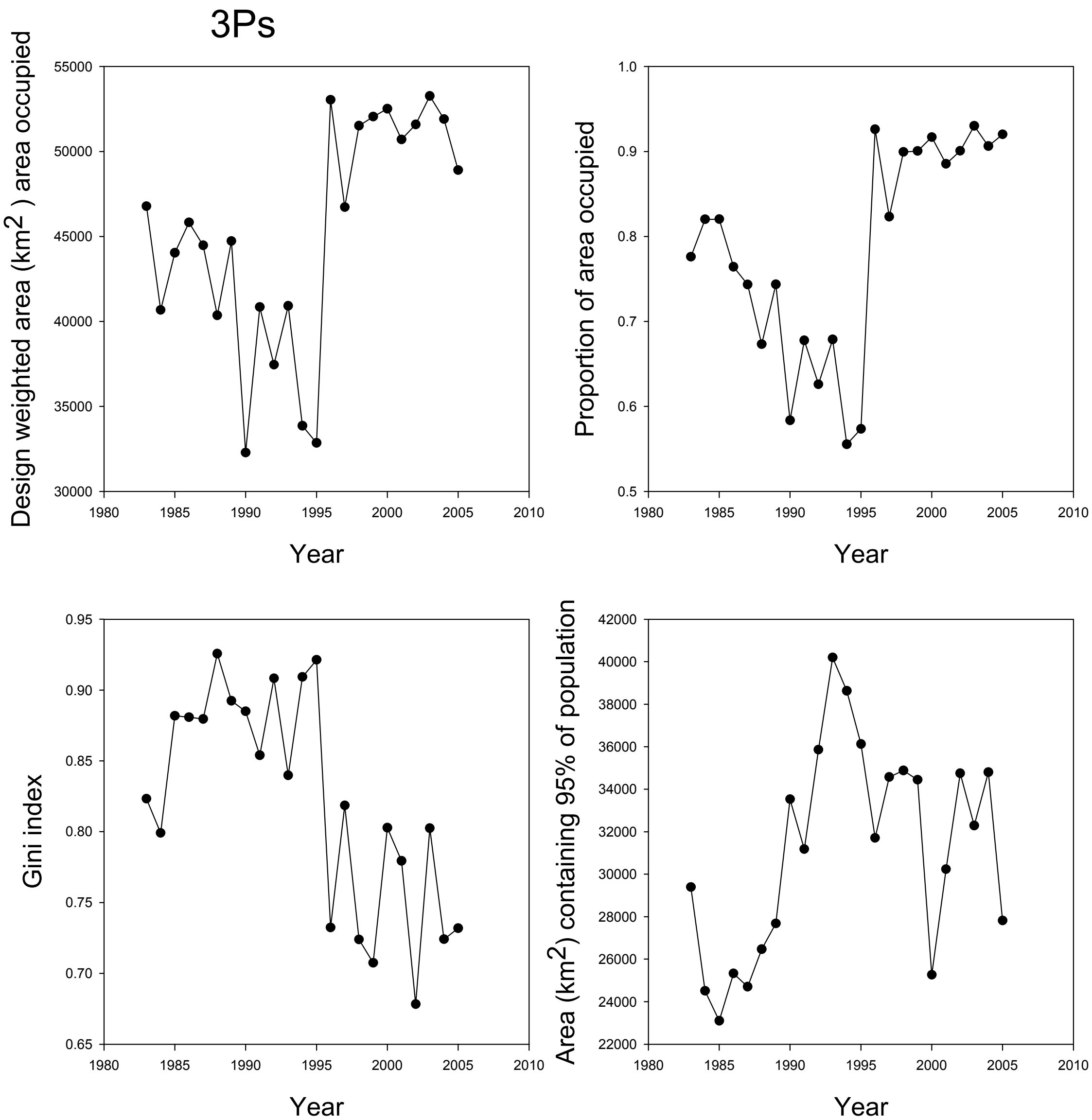

Figure 34. Indices of area occupied by American plaice in Subdiv. 3Ps.

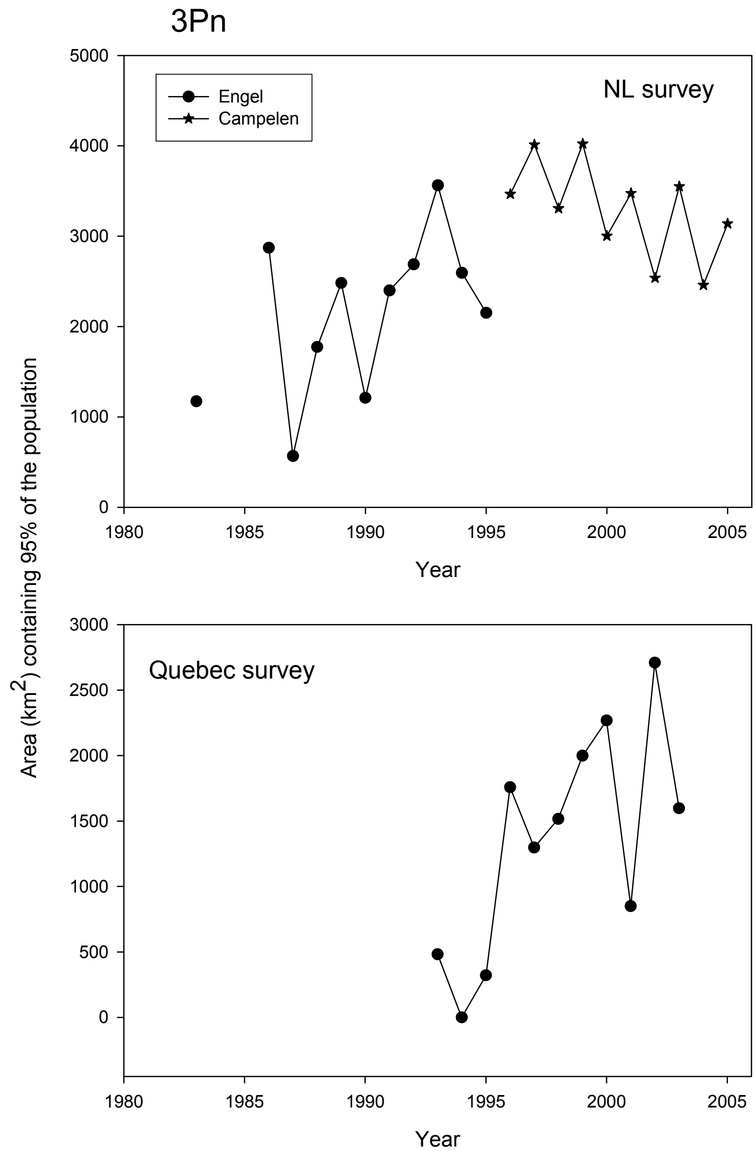

Figure 35. Indices of area occupied by American plaice in Subdiv. 3Pn. Data from the two series from the NL survey are not directly comparable nor are they directly comparable with data from the Quebec survey. However, trends can be compared.

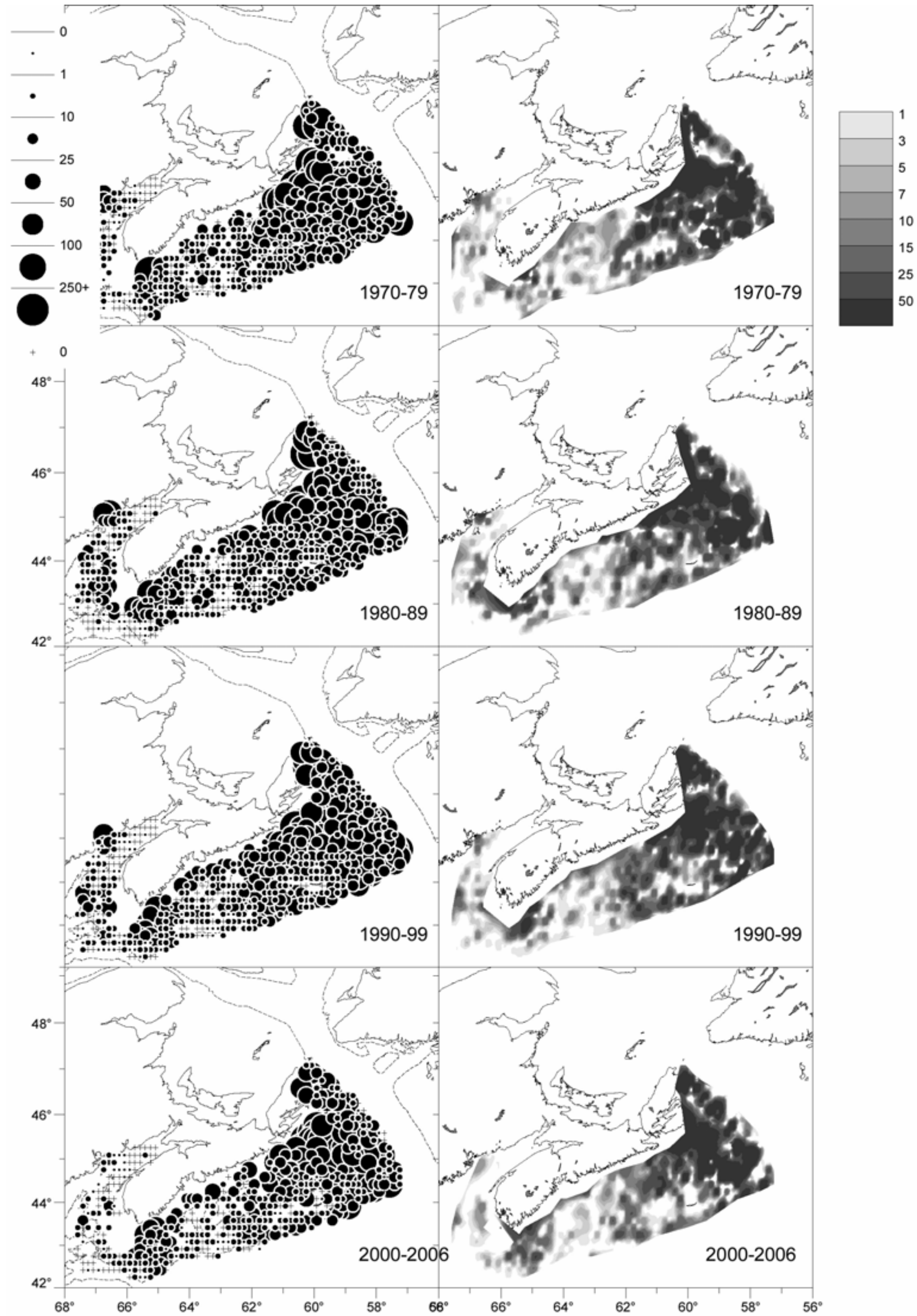

Figure 36. American plaice distributions (catch in kgs) from summer research vessel surveys. Catches are averaged over years within 10 minute squares (left panel) or depicted by Delaunay Triangles (right panel).

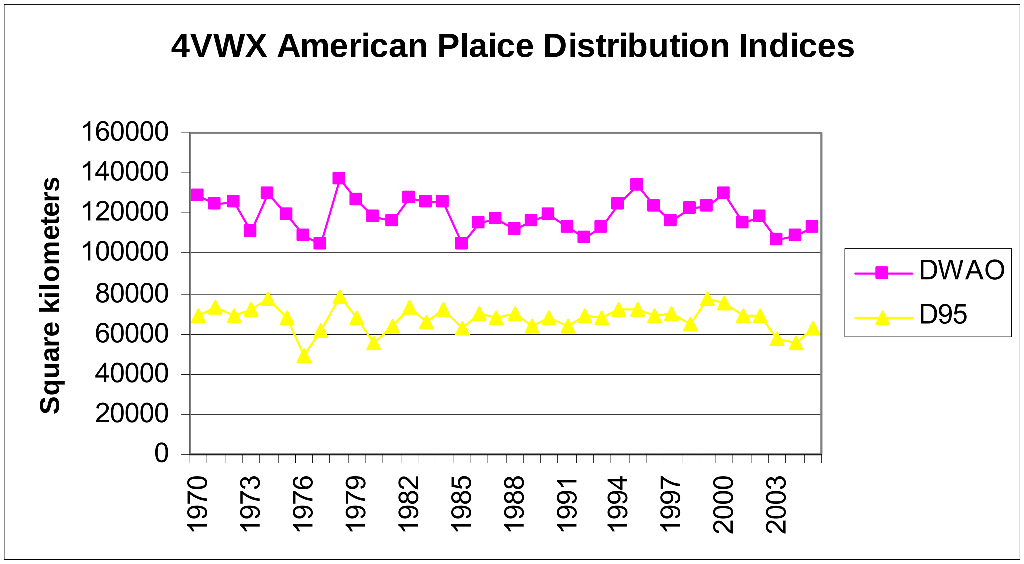

Figure 37. Distribution indices for 4VWX American Plaice.

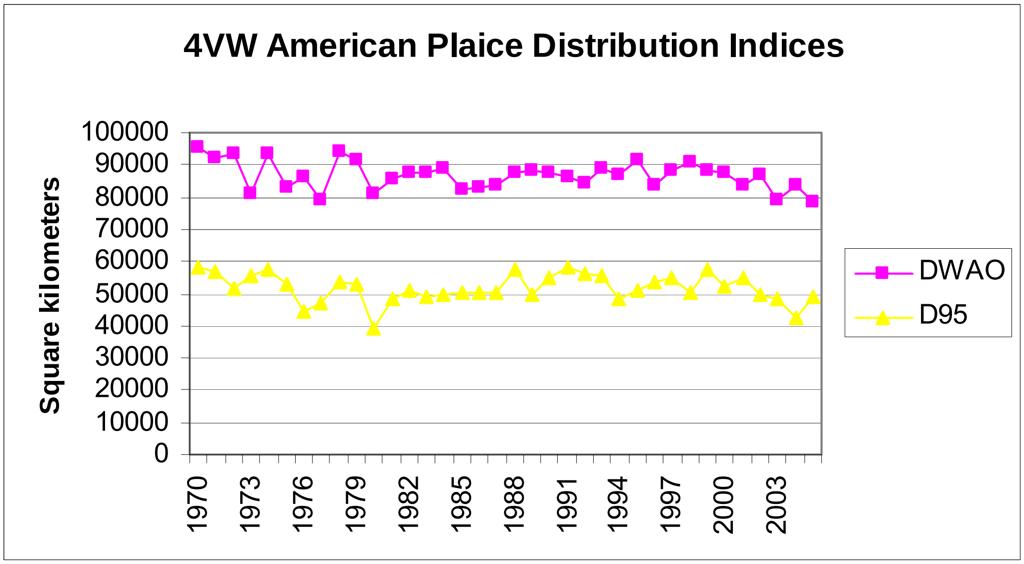

Figure 38. Distribution indices for 4VW American Plaice.

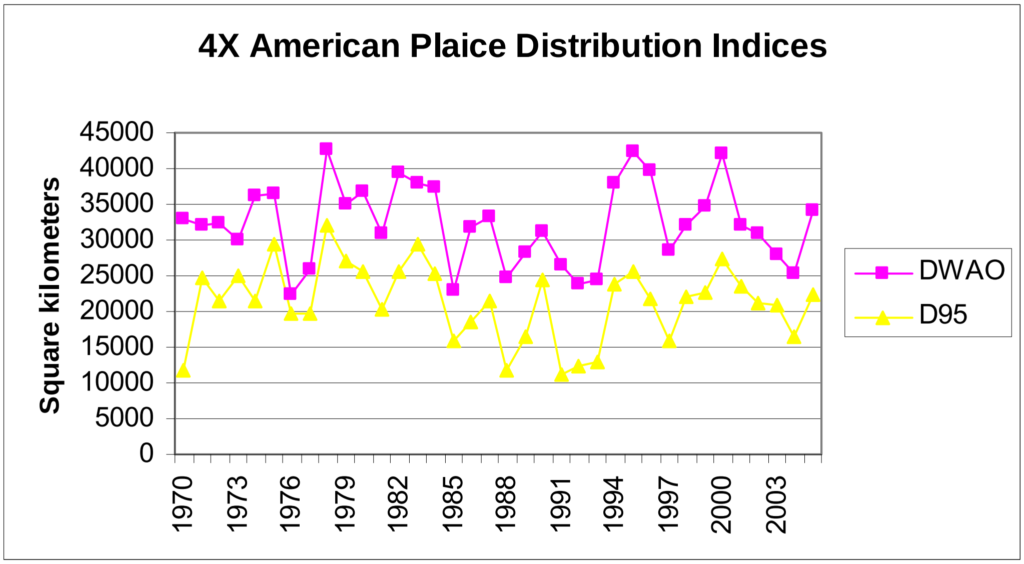

Figure 39. Distribution indices for 4X American Plaice.

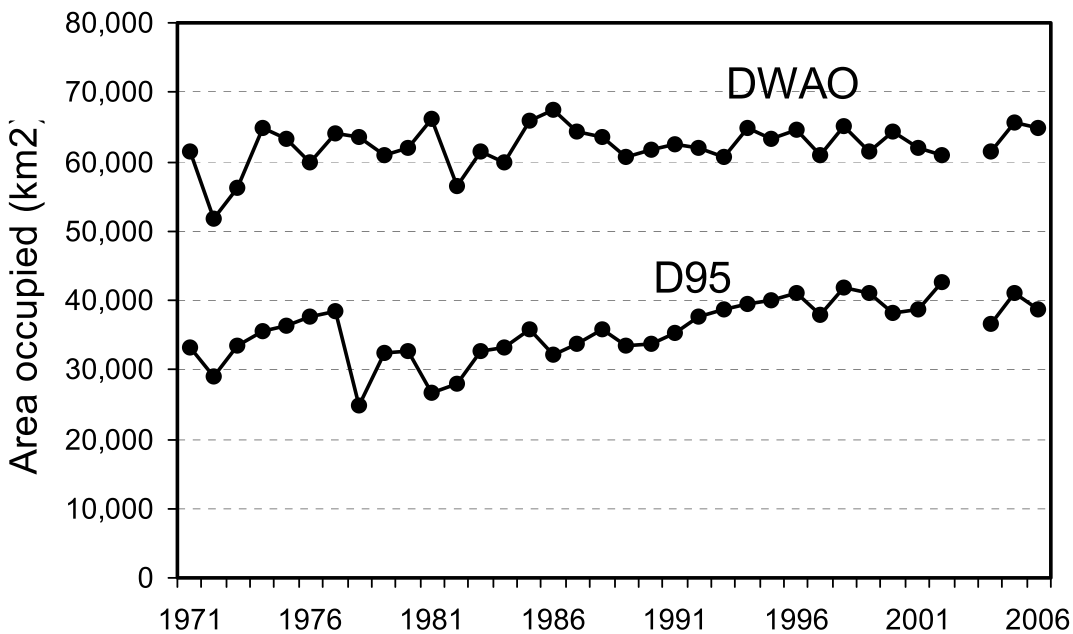

Figure 40. The area occupied by 4T American plaice in research surveys, as the total area occupied or Design Weighted Area Occupied (DWAO) and the area containing the highest density of plaice (the 95th percentile of abundance, D95).

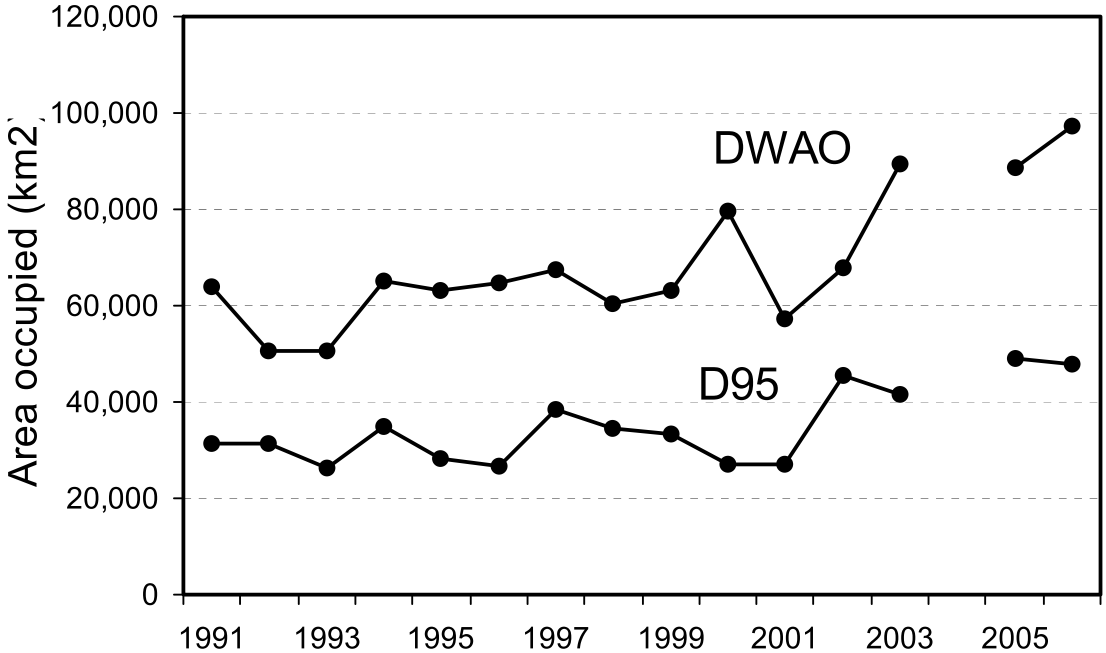

Figure 41. The area occupied by 4RS American plaice in research surveys, as the total area occupied or Design Weighted Area Occupied (DWAO) and the area containing the highest density of plaice (the 95th percentile o