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Assessment of Thorny Skate (*Amblyraja radiata* Donovan, 1808) in NAFO Divisions 3LNO and Subdivision 3Ps

by

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Abstract

Available information on the fishery, management, biology, and assessment of thorny skate in NAFO Divisions 3LNO and Subdivision 3Ps were reviewed to determine the status of this stock. Recent Canadian research surveys indicate that, since the mid1990s, biomass and abundance of thorny skate were fairly stable at low levels. In recent years, there was a slight indication of an increase in the biomass of thorny skate in NAFO Div. 3LN. This trend is apparent in both Canadian spring and autumn research surveys. However, a 2007 survey conducted by Spain in the NRA of Div. 3NO did not indicate a similar increase in thorny skate biomass relative to 2006. ASPIC surplus production models that incorporated current and historical survey and catch indices were investigated as a tool to quantitatively assess relative biomass and fishing mortality rates.

Introduction

Thorny skate (*Amblyraja radiata* Donovan, 1808) is a widely distributed species in temperate and arctic waters of the North Atlantic. In the western Atlantic, thorny skate are distributed from Greenland to South Carolina, with the centre of distribution on the Grand Banks (Fig. 1) in NAFO divisions 3LNO. Commercial catches of skates consist of several skate species, however, thorny skate dominates the catch composition. In Canadian commercial catches, about 95% of the skate catch are thorny skates (Kulka and Miri 2007, Kulka and Mowbray 1999); similar to the proportion of thorny skate in EU-Spain research survey catches in NAFO Div. 3NO (Gonzalez *et al.* 2006). Thus, the skate fishery on the Grand Banks can be considered as a directed fishery for thorny skate.

Fishery and Management

TAC Regulation

Thorny skate came under quota regulation in September 2004, when the Fisheries Commission of the Northwest Atlantic Fisheries Organization (NAFO) set a Total Allowable Catch (TAC) of 13 500 tons for 2005-2007 in Div. 3LNO, and Canada set a TAC of 1 050 tons for Subdivision 3Ps. A 3 000-ton quota for Canadian waters in 1997-2004 was generally underfished; resulting in relatively stable removals inside Canada's 200-mile limit. Unregulated until 2004, catches in the NAFO Regulatory Area (NRA) have been more variable and substantially higher.

Catch Trends

On the Grand Banks, Kulka and Mowbray (1998) reported that significant bycatch of skates have been taken since commencement of offshore fishing in the late 1940s, initially by non-Canadian fleets and later by Canadian vessels. Prior to the mid1980s, non-Canadian fleets comprised the largest component of offshore fisheries on the Grand Banks, and took several thousand tons of skate as bycatch each year. The bycatch derived primarily from the Greenland halibut fishery and from the Canadian mixed fishery for thorny skate, white hake and monkfish (Kulka and Mowbray 1999).

Kulka and Mowbray (1998) estimated that approximately 5 000 tons on average were discarded annually by the Canadian fleet during the 1980s and early 1990s, although only a few hundred tons were recorded in Canada's annual landings statistics during that period. Commercial landings data for skates are not specific to species.

Catches for NAFO Divisions 3LNO (Table 1, Fig. 2) increased in the mid-to-late 1980s with the commencement of a directed fishery for thorny skate. In 1985, Spain began targeting skate in a non-regulated fishery in the NRA (Junquera and Paz 1998; del Río and Junquera 2001). During the period from 1985-1991, catches averaged 17 000 tons and peaked at about 28 400 tons in 1991. This fishery was mainly prosecuted by Spain, Portugal, USSR, and the Republic of Korea. Non-Canadian catches significantly declined to only 5 059 tons in 1992 (Table 1). In 2000, Russia joined the directed fishery for thorny skate. Due to a new directed fishery that began in 1994, Canadian catches increased during 1994-2000 to an average of 1 430 tons (Table 1). Since 2000, total catches by all countries of skate in Div. 3LNO have declined. In 2005-2007, an average of 4 545 tons of thorny skate was reported.

STACFIS-agreed catches of thorny skate in Div. 3LNO was 3640 t in 2007. Over the period 2000-2007, STACFIS estimates averaged approximately 9 050 tons (Table 2, Fig. 4).

In NAFO Subdivision 3Ps, Canadian fleets report the majority of thorny skate catches in recent years; while St. Pierre and Miquelon (EU-France) annually reports small catches of thorny skate (Table 3, Fig. 3,4). Prior to 1994, Canadian catches of thorny skate in 3Ps rarely exceed a few hundred tons. From 1994-1999, Canadian catches averaged 1 200 tons, which is similar to the average Canadian catch from 2000-2006. The reported 2007 Canadian catch in NAFO divisions 3Ps is 1151 tons.

Size

Sampling of Canadian commercial catches by at-sea Fisheries Observers was limited in 2006, and almost non-existent in 2007; thereby precluding a detailed comparison of skate lengths in 2007 with length distributions from previous years. In 2006, Canadian gillnetters directing for monkfish in NAFO Div. 3O caught a size range of skates similar to that of previous years: 55-97 cm Total Length (TL) with a mode of 75 cm (Fig. 5a; Kulka *et al.* 2006). In 2006, Canadian trawlers directing for redfish in Div. 3O caught a wider range of sizes: 41-100 cm; while those directing for Atlantic cod in Subdiv. 3Ps caught 43-89 cm skates. The only observed trip in 2007 entailed a trawler directing for skates in Subdiv. 3Ps; catching 41-87 cm skates.

For 2006-2007, length distributions from Canada, EU-Portugal, EU-Spain, and Russia in the directed skate (280 mm mesh size) and bycatch (130-135 mm mesh size) trawl fisheries of the NRA indicated that the range of sizes caught did not vary and were similar to those reported in previous years (Fig. 5b; Kulka *et al.* 2006). One exception was the distribution of skates caught by Russia as bycatch in Div. 3LO during 2006: 12-15 cm young-of-the-year were reported. A comparison of length distributions between countries shows that EU-Portugal consistently caught an abbreviated range of smaller skates at 18-47 cm TL (modes of 38-40 cm); while EU-Spain usually caught 30-90 cm skates (modes of 56-58 cm), and Russia caught 24-96 cm fish (modes of 60-63 cm).

Research Survey Data

Spring Surveys

Stratified-random surveys have been conducted by Canadian research vessels in the spring (April-June) of each year from 1971 to 2007. A summary of the stratified-random survey design adopted by the DFO - NL Region can be found in Doubleday (1981). While survey design has remained constant, additional strata have been included in recent years, along with modifications to some of the original strata (Bishop 1994). A significant change in the surveys is the addition of shallower and deeper strata after 1993. The spring survey can be split into 3 time periods, based on the trawl used in each period: 1971-1982 (Yankee), 1983-1995 (Engel), and 1996-2007 (Campelen; see McCallum and Walsh 1996). Conversion factors exist for the Engel to Campelen gear change (Simpson and Kulka 2005); however, data from the Yankee series have not been converted.

Historical biomass and abundance indices from Canadian spring surveys in NAFO Division 3LNOPs are provided in Table 4a. In 2006, biomass estimates for thorny skate in Div. 3L, 3N, and 3O were 16 193, 56 698, and 25 252 tons;

respectively. However, due to mechanical difficulties with Canadian research vessels, only shallow strata in Div. 3NO (<78 m in 3N; <104 m in 3O) were surveyed in 2006; while most of Subdivision 3Ps was not. In 2007, biomass indices were 25 044, 54 188, and 48 369 tons for thorny skate in Div. 3L, 3N, and 3O. In Subdiv. 3Ps, biomass was estimated at 21 080 tons in 2007; with no comparable data for 2006.

Biomass and abundance indices for thorny skate in Div. 3LNOPs declined from the mid1980s to mid1990s (Fig. 6a,b,9). These declines were most apparent in Div. 3L, and to a lesser extent in Div. 3NOPs. Partitioning of the Grand Banks by the northeast (3LN) and southwest (3OPs) Divisions illustrates that the biomass and abundance in the southwest, although fluctuating, was more or less stable over the entire time series; whereas biomass in the northeast declined by nearly 95% between the 1970s and the mid1990s (Fig. 17b,c; Kulka and Miri 2007). Ratios of 3LN/3OPs biomass and abundance were stable during the 1970s, but then declined steadily during the 1980s to late 1990s. Since then, an increasing trend in this ratio was observed (Fig. 11a).

Since the mid1990s, spring biomass and abundance indices for thorny skate in Div. 3LNOPs were relatively stable at low levels. In recent years, there appears to be a small indication of an increase in the biomass of thorny skate in Div. 3L and 3N (Fig. 6a,b).

Relative mean weight of thorny skate in Div. 3LNOPs decreased from ~2 kg in the early 1970s to 0.83 kg by 1994; with most of the decline occurring during the late 1980s and early 1990s (concurrent with the decline in biomass; Fig. 8,10). Since the mid1990s, average size showed an increasing trend to 2.12 kg by 2007.

Autumn Surveys

Stratified-random autumn surveys have been conducted by Canada in NAFO Division 3L from 1981 to 2007. In 1990-2007, autumn surveys also extended onto the southern Grand Banks in Div. 3NO. Canadian surveys from 1983-1994 were conducted with an Engel trawl, and from 1995-2007 with a Campelen trawl. It must be noted that Canada does not survey Subdivision 3Ps in autumn, and did not survey Div. 3NO before 1990. Therefore, autumn survey data are not directly comparable to spring indices (which extend over the entire stock area and time period; except for certain Divisions and years). Furthermore, autumn surveys reach deeper maximum depths (~1 400 m in recent years) than those in spring (~750 m). Because the autumn series is not spatially complete over the designated stock area, spring surveys are used as the primary estimator of biomass and abundance trends for this stock. However, autumn indices are still considered in assessments of this stock, because this survey is conducted when a greater proportion of thorny skate is available to survey trawl gear. During autumn, thorny skates are concentrated on the shelf; whereas in spring, part of this population has moved to the shelf edge, and a proportion apparently moves outside of the spring survey area (Kulka *et al.* 2004). While using spring estimates of biomass and abundance to examine trends in this stock, it is assumed that the proportion of skate that moves outside of the surveyed area remains consistent between years. Survey variation due to other reasons are discussed in detail by Brodie (2005), and Kulka and Miri (2007).

Historical biomass and abundance indices from Canadian autumn surveys in NAFO Division 3LNO are provided in Table 4b. In 2006, biomass estimates for thorny skate in Div. 3L, 3N, and 3O were 18 610, 54 372, and 50 605 tons; respectively. In 2007, biomass indices were 30 089, 70 198, and 56 976 tons; respectively. Indices from both years indicate increases in the biomass of thorny skate on the Grand Banks.

Autumn biomass and abundance indices for thorny skate in NAFO Div. 3L declined during the 1980s (Fig. 6c). Since the mid1990s, this population remained stable; with a possible increase in 2007.

Comparison of Canadian Spring and Autumn Surveys

For comparable years and areas (1981-2007 in NAFO Div. 3L; 1990-2007 in Div. 3LNO), spring and autumn biomass indices indicate similar trends (Fig. 6a,b,c); despite autumn estimates showing more variation between years, and being higher within NAFO Division. The decline observed in the spring survey series during the early 1990s also appeared in the autumn series. After 1995, the autumn index fluctuated without pattern; but 85-90% of the skate biomass in Divs. 3LNO was concentrated in 3NO (Table 4b).

A comparison of spring and autumn biomass indices (a ratio of estimates in Divs. 3LNO; the three Divisions surveyed

during both seasons) indicates that autumn estimates are consistently higher (Fig. 7). From 1990-1997, concurrent with a period of decline for this stock, the ratio averaged about 50%; afterwards declining to about 20-25%, then remaining relatively stable.

Spanish Survey

Spain initiated a survey of the NAFO Regulatory Area (NRA) of Div. 3NO in 1995. Initially the survey was carried out in spring with the C/V *Playa de Menduiña* using a Pedreira bottom trawl. Since 2001, the R/V *Vizconde de Eza* replaced the C/V *Playa de Menduíña* and a Campelen net replaced the Pedreira (Gonzalez-Troncoso *et al.* 2007).

Abundance and biomass of thorny skate were calculated from Spanish surveys in the NRA of Div. 3NO from 1997-2007. The survey biomass index showed a consistent increase from 5 000 t in 1995 to a peak of 50 000 t in 2000. Since 2001, this index fluctuated on a yearly basis; averaging 38 000 t in 2001-2006. In 2007, the Spanish biomass index from the NRA declined relative to that of 2006.

A comparison of the Canadian Campelen spring biomass indices to those of the Spanish 3NO survey in 1997-2007 indicated similar overall trends (Fig. 11b). It should be noted that the Canadian survey covers the entire area of Div. 3NO; whereas the Spanish survey is limited to the NAFO Regulatory Area of Div. 3NO.

In the NRA of Div. 3L, Spain initiated a survey in 2003 with the research vessel "Vizconde de Eza"; configured with a Campelen bottom trawl. Recent biomass estimates are higher that those in 2003 and 2004 (Fig. 11b).

Index of Fishing Mortality

A relative index of fishing mortality (commercial catch/Canadian spring survey biomass index) was calculated for thorny skate in Div. 3LNO and Subdiv. 3Ps for 1985-2007. The fishing mortality index for Div. 3LNO increased from the late 1980s to late 1990s; then stabilized around 20% during 1997-2004 (Fig. 12). Relative F was greatest in Div. 3LNO during 1997 at nearly 30%. Since 2004, the mortality index has declined to 4%. This corresponds to a period of reduced commercial catches of thorny skate, and a potential increase in the spring biomass. Fishing mortality for Subdiv. 3Ps was relatively constant; remaining below 5% in most years.

Size

Lengths of thorny skates captured in the Canadian Campelen surveys of Div. 3LNO and Subdiv. 3Ps from 1997-2007 ranged from 5-105 cm TL (Fig. 13). For most areas and years, a peak of young-of-the-year skates (5-20 cm TL) was observed, and averaged 15 cm TL. A dominant peak of immature skates can be observed in spring survey data, with the following modes: 32 cm in 1997; 35 cm in 1998; 40 cm in 1999 and 2000; 44 cm in 2001; 46 cm in 2002; 48 cm in 2003; 55 cm in 2004 and 2005; 62 cm in 2006; and 66 cm in 2007.

Stages

Numbers of thorny skate at length (spring, Div. 3LNOPs) were partitioned into young-of-the-year (YOY), immature, and mature (Spawning Stock Biomass, or SSB) components (Fig. 14). The various stages of thorny skate underwent different changes in abundance over time. In 1996-2007, thorny skate YOY appeared to be relatively stable in abundance. However, both male and female immature skates showed trends of decreasing abundance; while the abundance of mature skates appeared to be increasing.

The ratio of males to females in the sampled population remained relatively constant over time; with some fluctuations in the three components (Fig. 15): YOY averaged close to 1:1 males to females; ratio of immature males to females was generally below 1:1; while the mature abundance ratio was greater than 1. This pattern suggests that there may be some difference in the catchability of male and female thorny skates at different life history stages; potentially due to differential migration in and out of the sampled area.

The relationship between mature female abundance and thorny skate YOY is illustrated in Figure 16. This recruitment index declined from relatively high levels observed in 1996 and 1997 to an average of 0.75 since 1999.

Distribution

Within Div. 3LNO and Subdiv. 3Ps, the distribution of thorny skate changed significantly since the 1980s. In the early 1980s, skates were widely distributed over the entire Grand Banks in moderate to high concentrations (Kulka and Miri 2003, 2007). By the late 1990s, much of the biomass was concentrated in the southwest (Fig. 17c). In 2001-2005, the area of high concentration expanded northward and along the Bank edge (Fig. 17b,c; Kulka and Miri 2003, 2007). In 2006-2007, the distribution of thorny skate in Div. 3LNOPs continued to be concentrated on the southwest Grand Banks, Subdiv. 3Ps, and northward along the edge of the Bank (Fig. 17a).

Area Occupied

The Design-Weighted Area of Occupancy (DWAO) index (Swain and Sinclair 1994), was used to calculate area occupied indices:

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

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. Strata with less than two sets have not been considered.

The DWAO index was calculated using all strata (Fig. 18) and indexed strata (Fig. 19) from Canadian research surveys; where indexed strata are those strata in which at least two successful survey trawls were completed in each year of the time series. DWAO indices were calculated for the spring surveys in Div. 3LNO and Subdiv. 3Ps, and for autumn surveys in Div. 3L and Div. 3NO.

Declines in the area that thorny skate occupy in Subdiv. 3Ps were apparent from the mid1980s, where the proportion of area occupied decreases from approximately 0.80 to 0.70 by 1996. Since then, the proportion of area occupied varied from 0.80 to 0.50; but maintained an average of 0.68 (Fig. 20).

The Canadian spring survey in Div. 3LNO showed a similar trend to that of Subdiv. 3Ps; but the declines were more dramatic. The proportion of survey area occupied averaged above 0.80 through the 1970s; but underwent a decline to ~0.70 through the late 1980s, and further to an average of only 0.50 in 1996-2007. Although the area occupied was very low in the latter period, it remained fairly constant (Fig. 20).

A comparison of area occupied in autumn surveys of Div. 3L and Div. 3NO suggested that the reduction of area occupied in Div. 3LNO spring surveys may be attributable to dramatic declines observed in Div. 3L. There, the proportion occupied decreased from ~0.90 in the early 1980s to only 0.40 by 1996. Since 1996, the area occupied remained stable. In comparison, the area occupied in Div. 3NO remained constant; with proportions of area occupied averaging 0.85 through the time series (Fig. 20).

Assessment Results

Surplus Production Modeling

A non-equilibrium surplus production model incorporating covariates (ASPIC Version 5.24; Prager, 1994, 2005) was applied to catch and survey biomass indices, in order to investigate this method in quantitative assessment of the thorny skate population. Several model formulations were explored. Indicators of model suitability included: the fit of data to the model (R-squared values in the CPUE), residual patterns, correlation between biomass indices, and consideration of the estimated parameters.

The model formulations and parameter estimates are illustrated in Table 5. The run that produced the best fit for the stock in Div. 3LNO used observed catch and Canadian spring survey Campelen equivalent data for Div. 3LNO (1985-2007), tuned with the Canadian autumn survey Engel series (1990-1994) and Campelen series (1995-2007; Run 4, Table

5). This model estimated an MSY of 12 140 t; with a B_{MSY} of 30 110 t, and F_{MSY} of 0.434. However, each of the model formulations was very similar. In addition, it should be noted that, when added to this model, catch data prior to 1985 and earlier survey indices using the Yankee time series do not greatly affect the estimated parameters; nor do they add to the goodness of fit of the model. However, examination of the model diagnostics and fits after repeated removal of initial states found that this model is highly dependent upon starting values. Estimates of B relative to B_{MSY}, and F relative to F_{MSY}, are shown in Figure 21.

Six-year series of projections were produced with this model using: A) average catch of thorny skate in the most recent years (4 545 t in 2005-2007; Fig. 22, Lower Panel); and B) the TAC for 2007 (13 500 t; Fig. 23, Lower Panel). Projections were also made on the basis of the 2007 catch level (3 640 t; Fig. 22, Upper Panel) and on the MSY projected by the model (12 140 t; Fig. 23, Upper Panel). Biomass ratios based on catches at MSY produced stable biomass projections for the population at a B/B_{MSY} level just above 1.0. Should catches in subsequent years remain at the 2007 level, this model predicts a substantial increase in thorny skate biomass with B/B_{MSY}.

Catch at the MSY-estimated level of 12 140 t represents ~15% of B_1 estimated by the model (80 380 t), and a B_{MSY} at 30 110 t is ~37% of the estimated B_1. Comparison of these estimates with similar species suggested that these values may be higher than expected, and caution should be exercised when interpreting the model. Agnew *et al.* (2000) found that MSY for a fished skate and ray species complex in the Falkland Islands was in the range of 6.5-7.6 % of the unexploited biomass; depending on which model was used to estimate B_0. Similarly, Anderson (1990) compiled estimates for sharks, in which the range for MSY was 4.5-7.5%, and B_{MSY} was 35-48% of the B_1 level.

ASPIC model results should be taken as a first and preliminary assessment. There is an observed systematic pattern in the model residuals (Fig. 24) that indicates a problem with the underlying model. As well, there is the potential violation of the model assumptions, in particular the assumptions that the catch statistics are accurate, there is a single stock unit, and r responds instantaneously to changes in B. . ASPIC models do not incorporate time delays between reproduction and recruitment which would be especially important for species such as thorny skates.

Precautionary limit reference points

In addition to potential reference points from ASPIC modeling, preliminary proxies for precautionary limit reference points can be calculated as 15% of the highest observed biomass estimate (Maddock-Parsons 2007; NAFO LRP Study Group 2004). Based on biomass estimates from the Canadian converted spring survey in Div. 3LNO, this proxy for B_{lim} is 45 000 tons; and current biomass estimates for Div. 3LNO are 127 602 tons. For thorny skate, autumn survey estimates were often higher than spring estimates in the same year (Fig. 7); indicating a difference in catchability between seasonal surveys. As previously discussed, skates are concentrated on the shelf in autumn, whereas in spring, part of the population moves to the shelf edge, and a proportion apparently moves outside of the Canadian spring survey area (Kulka and Miri 2003, 2007). Therefore, reference points based on the spring survey should be considered conservative estimates. However, since Canadian survey coverage increased during recent years (i.e., relative to the early years of this time series), current biomass estimates may be overestimated relative to the proxy B_{lim}. Similar estimates of B_{lim} and current biomass levels for the spring 3LNO time series, based on a standardized survey series (only including strata sampled in all years), are 40 000 tons; relative to the current estimate of 113 000 tons. Further research and simulation of limit reference points are required and presently in progress.

Summary

Thorny skate underwent a decline in the late 1980s to early 1990s; followed by a slight increase in the late 1990s. The Index of Fishing Mortality (commercial catch/Canadian spring survey biomass index) increased from approximately 5% in the mid1980s to about 20% in 2001-2005. An average catch of 11 200 t during 2001-2005 resulted in a flat biomass trajectory. The current TAC of 14 550 t for skates in Div. 3LNOPs (13 500 t in Div. 3LNO; 1 050 t in Subdiv. 3Ps) greatly exceeds the average catch during a period when minimal or no rebuilding of this stock occurred. The exploitation ratio declined over the past three years to an average of 5%. This lower level of exploitation resulted in a slight increase in biomass observed recently by Canadian surveys in Div. 3LN. During recent years, average catch was approximately 4 800 tons; which is a third of the current TAC in Div. 3LNO.

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Table 1. Catches (tons) of skates in NAFO Divisions 3LNO, 1960-2007 (STATLANT-21A).

Year	Canada	Other	Total
1960	0	73	73
1961	0	119	119
1962	0	99	99
1963	0	65	65
1964	0	145	145
1965	17	199	216
1966	75	347	422
1967	212	188	400
1968	128	31	159
1969	68	1123	1191
1970	99	539	638
1971	125	77	202
1972	64	487	551
1973	10	413	423
1974	638	1690	2328
1975	180	2535	2715
1976	260	1006	1266
1977	551	1266	1817
1978	816	1015	1831
1979	382	657	1039
1980	351	1027	1378
1981	244	1467	1711
1982	52	756	808
1983	4	1277	1281
1984	0	2013	2013
1985	9	10390	10399
1986	52	14277	14329
1987	195	18301	18496
1988	91	18675	18766
1989	15	14222	14237
1990	44	14726	14770
1991	18	28390	28408
1992	78	5059	5137
1993	78	5992	6070
1994	1554	6601	8155
1995	2412	4912	7324
1996	1314	4804	6118
1997	2165	9903	12068
1998	1013	8501	9514
1999	1081	10864	11945
2000	498	17779	18277
2001	354	14507	14861
2002	1107	10648	11755
2003	671	13592	14263
2004	352	11476	11828
2005	685	2853	3538
2006	248	5255	5501
2007	92	4841	4933

Table 2. Thorny skate STACFIS estimates, recent STATLANT-21A reported catches, and Total Allowable Catch quotas (000 tons) for NAFO Divisions 3LNO.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Div. 3LNO:											
TAC[3]									13.5	13.5	13.5
STATLANT 21A	12.1	9.5	11.9	18.3	14.9	11.8	14.3	11.8	3.5	5.5[1]	5.4[1]
STACFIS	12.1	9.5	11.9	14.1	10.4	11.5	13.4	9.3	4.2	5.8	3.6
Subdiv. 3Ps:											
TAC									1.05	1.05	1.05
STATLANT 21A	1.5	1.5	1.2	1.0	2.0	1.5	2.0	1.2	0.9	1.2	0.2[1, 2]

[1] Provisional for 2006-2007

[2] Based on Canadian Statistical landings data (STATLANT 21A not available)

[3] TAC for Div. 3LNO applicable to 2005-2007

Table 3. Catches (tons) of thorny skate in NAFO Subdivision 3Ps, 1960-2007 (STATLANT-21A).

Year	Canada	Other	Total
1960	0	11	11
1961	0	17	17
1962	0	11	11
1963	0	58	58
1964	0	145	145
1965	0	85	85
1966	0	126	126
1967	0	162	162
1968	86	67	153
1969	0	353	353
1970	35	229	264
1971	303	213	516
1972	8	184	192
1973	7	231	238
1974	122	641	763
1975	9	490	499
1976	91	230	321
1977	521	360	881
1978	454	256	710
1979	545	121	666
1980	554	609	1163
1981	558	520	1078
1982	117	395	512
1983	0	516	516
1984	21	602	623
1985	21	944	965
1986	7	1576	1583
1987	52	787	839
1988	2	781	783
1989	0	1685	1685
1990	5	549	554
1991	1	639	640
1992	13	46	59
1993	22	11	33
1994	1566	3	1569
1995	1866	4	1870
1996	603	2	605
1997	829	3	832
1998	1251	6	1257
1999	1102	4	1106
2000	935	21	956
2001	1769	39	1808
2002	1413	238	1651
2003	1705	82	1787
2004	1190	87	1277
2005	967	0	967
2006	910	78	988
2007	1151	0	1151

Table 4a. Campelen equivalent biomass, abundance, and mean weight of thorny skate from Canadian spring research vessel surveys, 1971-2007. Surveys were conducted with a Yankee bottom trawl (1971-1983), an Engel trawl (1984-spring 1995), and a Campelen trawl (spring 1996-2007). Spring surveys: NAFO Subdiv. 3Ps was not surveyed in 1971, 2006; NAFO Div. 3O was not surveyed in 1972, 1974, 1983; and NAFO Div. 3N was not surveyed in 1983. Note that deep strata in Div. 3NO were not surveyed in spring 2006.

Canadian research vessel spring surveys															
	Biomass (000s of tonnes)					Abundance (000,000s)					Mean weight (kg)				
Year	3L	3N	3O	3Ps	3LNOPs	3L	3N	3O	3Ps	3LNOPs	3L	3N	3O	3Ps	3LNOPs
Yankee series - unconverted data															
1971	35,100	11,307			46,408	11,533	3,921			15,454	3.04	2.88			3.00
1972	23,391	36,084		16,422	75,897	11,037	15,634		5,615	32,285	2.12	2.31		2.92	2.35
1973	17,993	27,241	23,288	13,417	81,940	12,114	11,033	12,830	6,822	42,800	1.49	2.47	1.82	1.97	1.91
1974	40,252	21,823		22,428	84,503	26,621	11,627		11,136	49,383	1.51	1.88		2.01	1.71
1975	31,191	21,579	25,328	5,719	83,817	24,762	8,273	12,183	1,654	46,871	1.26	2.61	2.08	3.46	1.79
1976	40,242	39,416	80,235	29,506	189,399	28,294	21,419	28,595	19,118	97,427	1.42	1.84	2.81	1.54	1.94
1977	63,601	44,092	19,632	12,326	139,651	25,240	16,375	7,518	8,840	57,973	2.52	2.69	2.61	1.39	2.41
1978	37,944	16,394	17,803	10,266	82,407	21,879	10,117	7,578	11,911	51,485	1.73	1.62	2.35	0.86	1.60
1979	44,377	23,877	19,820	10,094	98,168	23,370	13,859	7,496	8,310	53,034	1.90	1.72	2.64	1.21	1.85
1980	41,247	26,141	21,488	21,149	110,025	19,206	15,847	16,788	12,200	64,041	2.15	1.65	1.28	1.73	1.72
1981	55,274	17,293	12,311	11,450	96,329	33,223	9,694	5,912	12,195	61,024	1.66	1.78	2.08	0.94	1.58
1982	37,768	30,161	22,868	7,363	98,161	21,391	23,623	11,055	3,562	59,632	1.77	1.28	2.07	2.07	1.65
1983				13,704	13,704				12,249	12,249				1.12	1.12
Engel series - Campelen equivalent data															
1984	17,269	57,720	61,026	20,318	156,333	7,574	25,226	24,615	9,417	66,832	2.28	2.29	2.48	2.16	2.34
1985	102,351	86,438	110,322	36,954	336,065	63,081	45,278	50,123	55,214	213,697	1.62	1.91	2.20	0.67	1.57
1986	69,864	110,325	46,634	47,728	274,551	51,231	53,395	21,134	36,152	161,913	1.36	2.07	2.21	1.32	1.70
1987	82,037	60,535	51,007	40,697	234,276	39,151	33,539	34,040	28,113	134,842	2.10	1.80	1.50	1.45	1.74
1988	70,143	49,686	87,375	29,993	237,197	35,030	26,475	42,991	19,043	123,539	2.00	1.88	2.03	1.58	1.92
1989	73,291	49,142	40,172	44,271	206,875	40,349	30,030	17,678	25,863	113,919	1.82	1.64	2.27	1.71	1.82
1990	45,312	47,479	61,946	24,264	179,002	43,938	71,656	40,119	21,344	177,057	1.03	0.66	1.54	1.14	1.01
1991	22,197	28,925	99,003	61,534	211,659	34,780	44,550	35,194	50,254	164,778	0.64	0.65	2.81	1.22	1.28
1992	11,945	23,047	57,929	38,693	131,615	36,886	20,645	35,567	21,511	114,609	0.32	1.12	1.63	1.80	1.15
1993	8,546	18,550	35,113	16,256	78,465	27,765	17,068	15,026	16,001	75,860	0.31	1.09	2.34	1.02	1.03
1994	3,920	10,193	28,874	16,539	59,526	15,999	17,564	19,106	19,222	71,891	0.25	0.58	1.51	0.86	0.83
1995	2,798	2,824	32,323	24,924	62,869	9,319	7,018	26,782	19,493	62,613	0.30	0.40	1.21	1.28	1.00
Campelen series															
1996	4,993	11,010	35,529	21,851	73,382	10,418	10,636	22,731	25,591	69,376	0.48	1.04	1.56	0.85	1.06
1997	3,969	9,703	28,293	20,705	62,669	6,804	13,554	25,635	18,379	64,372	0.58	0.72	1.10	1.13	0.97
1998	5,807	13,186	42,351	28,629	89,972	7,764	10,140	34,130	22,781	74,815	0.75	1.30	1.24	1.26	1.20
1999	7,266	26,254	54,045	32,062	119,626	8,263	15,967	36,042	20,212	80,484	0.88	1.64	1.50	1.59	1.49
2000	14,011	27,861	40,917	22,528	105,317	12,512	16,027	28,525	18,574	75,638	1.12	1.74	1.43	1.21	1.39
2001	10,383	29,197	59,078	24,566	123,223	8,521	16,276	33,321	17,606	75,724	1.22	1.79	1.77	1.40	1.63
2002	8,580	13,986	38,025	22,127	82,718	5,920	8,469	32,902	17,560	64,851	1.45	1.65	1.16	1.26	1.28
2003	8,411	18,216	49,707	37,072	113,406	6,737	9,645	34,734	24,615	75,732	1.25	1.89	1.43	1.51	1.50
2004	7,806	20,425	39,740	38,354	106,325	4,762	8,925	21,153	24,256	59,095	1.64	2.29	1.88	1.58	1.80
2005	19,266	33,757	46,515	32,702	132,240	11,011	15,986	26,621	26,399	80,016	1.75	2.11	1.75	1.24	1.65
2006	16,193	56,698	25,252		98,143	8,450	23,618	17,778		49,846	1.92	2.40	1.42		1.97
2007	25,044	54,188	48,369	21,080	148,682	11,357	24,065	23,317	11,440	70,180	2.21	2.25	2.07	1.84	2.12

Table 4b. Biomass, abundance, and mean weight of thorny skate from Canadian autumn research vessel surveys in Div. 3LNO, 1981-2006. Surveys were conducted with a Yankee bottom trawl (1981-1983), an Engel trawl (1984-autumn 1994), and a Campelen trawl (autumn 1995-2006). Some deep strata were not sampled in 2005.

Canadian research vessel autumn surveys												
	Biomass (000s of tonnes)				Abundance (000,000s)				Mean weight (kg)			
Year	3L	3N	3O	3LNO	3L	3N	3O	3LNO	3L	3N	3O	3LNO
Yankee series - unconverted data												
1981	36,467				33,523				1.09			
1982	65,293				36,223				1.80			
Engel series - Campelen equivalent data												
1983	165,500				103,303				1.60			
1984	149,061				70,979				2.10			
1985	141,054				86,070				1.64			
1986	113,170				75,424							
1987	87,843				80,879				1.09			
1988	107,910				86,633				1.25			
1989	67,877				76,793				0.88			
1990	95,586	67,459	97,496	260,540	116,758	43,855	53,191	213,803	0.82	1.54	1.83	1.22
1991	52,655	103,959	75,526	232,141	73,576	61,128	29,680	164,384	0.72	1.70	2.54	1.41
1992	40,289	52,980	42,383	135,652	94,058	33,854	24,675	152,587	0.43	1.56	1.72	0.89
1993	24,096	35,528	64,294	123,918	61,501	31,073	41,382	133,957	0.39	1.14	1.55	0.93
1994	16,212	50,950	31,929	99,090	44,205	50,141	30,748	125,094	0.37	1.02	1.04	0.79
Campelen series												
1995	11,306	40,775	44,653	96,734	23,299	37,322	30,582	91,203	0.49	1.09	1.46	1.06
1996	14,459	28,629	36,969	80,057	23,483	22,694	45,145	91,321	0.62	1.26	0.82	0.88
1997	7,534	43,075	58,160	108,770	13,448	30,540	50,047	94,035	0.56	1.41	1.16	1.16
1998	9,205	34,279	39,280	82,764	8,917	21,132	29,785	59,834	1.03	1.62	1.32	1.38
1999	13,614	32,609	42,608	88,831	10,448	25,116	31,847	67,411	1.30	1.30	1.34	1.32
2000	17,722	61,202	40,861	119,786	12,536	31,419	39,918	83,873	1.41	1.95	1.02	1.43
2001	16,420	34,311	62,156	112,886	12,655	21,352	42,095	76,103	1.30	1.61	1.48	1.48
2002	11,068	52,855	40,593	104,517	7,541	30,925	24,488	62,954	1.47	1.71	1.66	1.66
2003	14,463	36,829	46,123	97,416	9,363	19,203	34,556	63,121	1.54	1.92	1.33	1.54
2004	11,327	45,678	26,361	83,366	6,369	21,068	32,343	59,780	1.78	2.17	0.82	1.39
2005	20,107	37,442	61,595	119,143	11,346	20,027	30,553	61,927	1.77	1.87	2.02	1.92
2006	18,610	54,372	50,605	123,587	8,888	23,211	27,688	59,787	2.09	2.34	1.83	2.07
2007	30,089	70,198	56,976	157,263	13,372	36,453	29,768	79,594	2.25	1.93	1.91	1.98

Table 5. Model format and estimates for four non-equilibrium production model runs in NAFO Divisions 3LNO (refer to Prager 1994, 2005).

	Run 1	Run 2	Run 3	Run 4
Model	3LNO Spring	3LNO Spring	3LNO Spring	3LNO Spring
Tuning 1	None	3LNO Fall 1990-2007	3LNO Campelen Fall 1995-2007	3LNO Campelen Fall 1995-2007
Tuning 2	None	None	None	3LNO Engels Fall 1990 1994
Tuning 3	None	None	None	None
R^2 Model	0.791	0.627	0.736	0.783
Tuning 1		0.162	0.297	0.245
Tuning 2				0.259
Tuning 3				
B1/K	1.554	1.773	0.938	1.335
MSY	11,970	8,903	12,180	12,140
K	59,360	141,500	65,590	60,210
q(1) model	3.922	0.9465	3.914	3.965
q(2)		1.338	4.422	4.256
q(3)				4.419
q(4)				
Bmsy	29,680	70,740	32,790	30,110
Fmsy	0.4	0.126	0.372	0.4034
B/Bmsy	1.253	1.207	1.18	1.32
F/Fmsy	0.27	0.349	0.283	0.2514

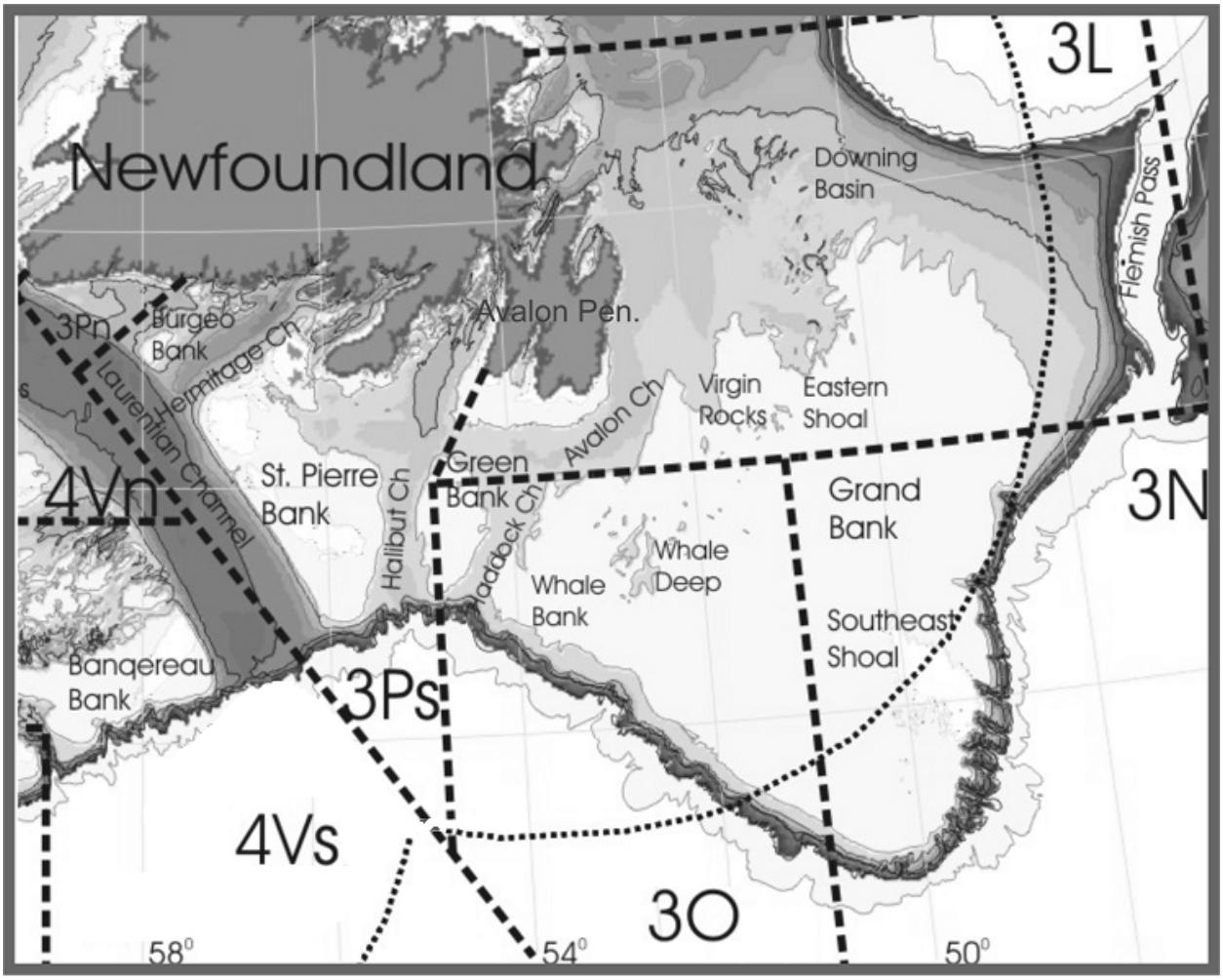

Figure 1. Map of NAFO Divisions 3LNO and Subdivision 3Ps in relation to Canada's 200-mile limit.

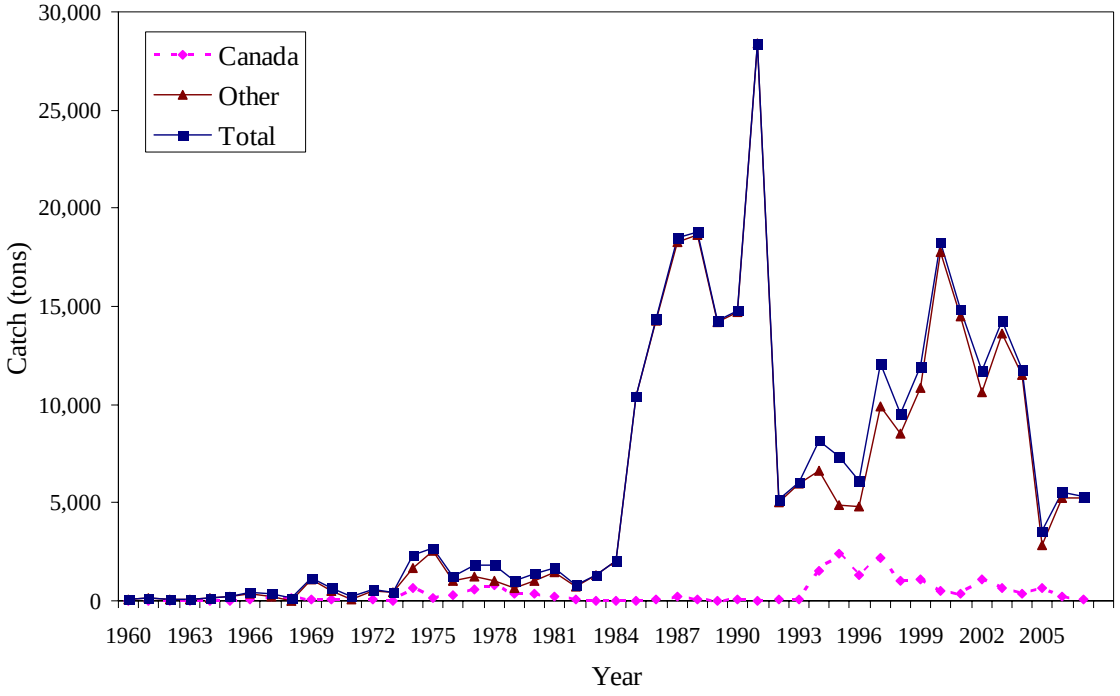

Figure 2. Reported catches (tons) of thorny skate by Canada and other countries in NAFO Divisions 3LNO in 1960-2007 (NAFO STATLANT-21A).

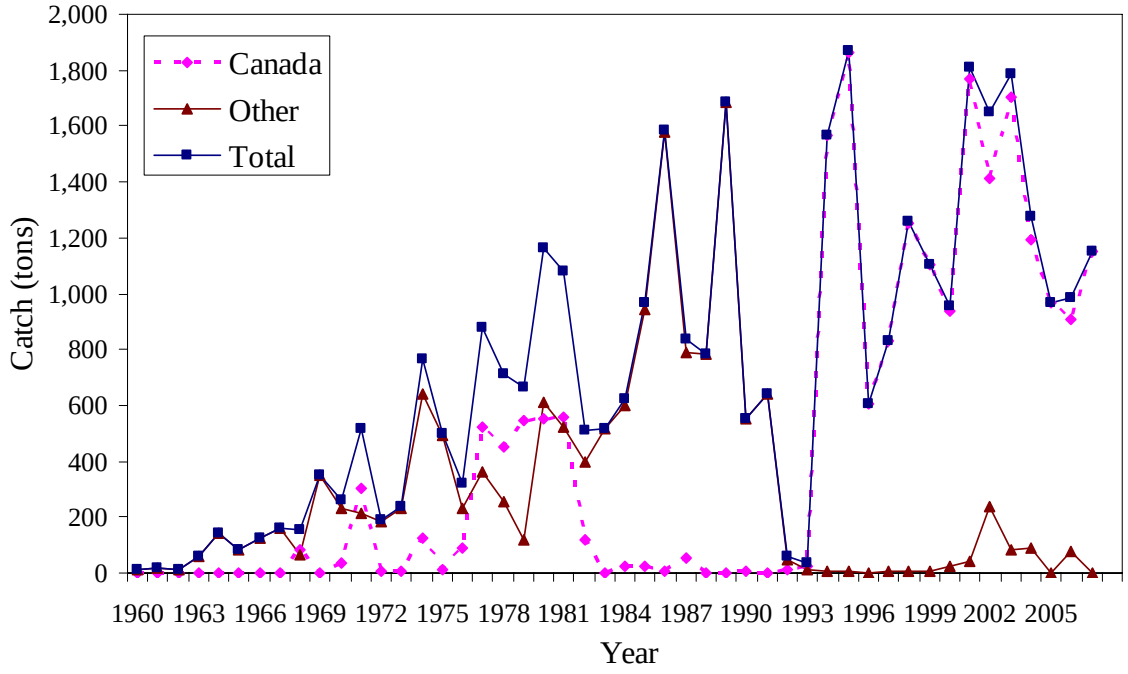

Figure 3. Reported catches (tons) of thorny skate by Canada and other countries in NAFO Subdivision 3Ps in 1960-2007 (NAFO STATLANT-21A).

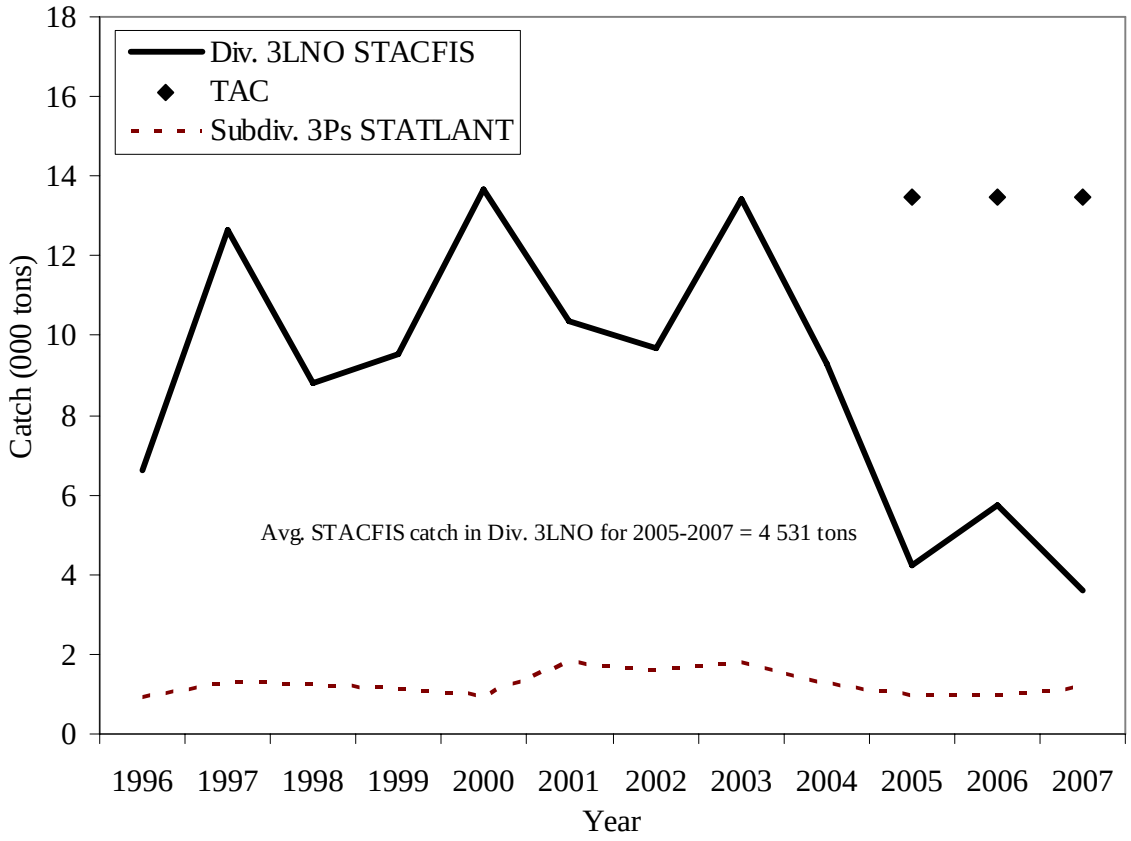

Figure 4. Total reported catch of thorny skate and Total Allowable Catch (TAC) in Div. 3LNO (STACFIS) and Subdiv. 3Ps (STATLANT-21A), 1996-2007.

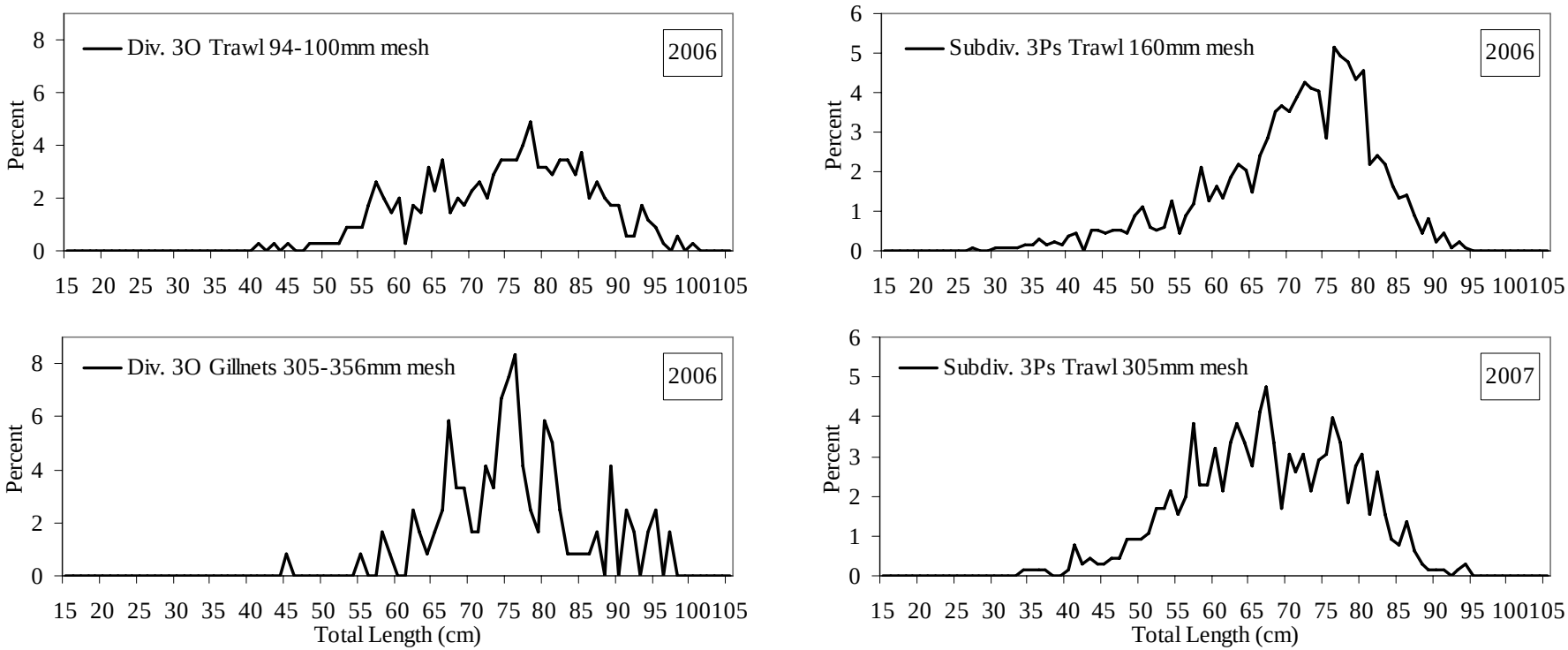

Figure 5a. Length distributions of Canadian commercial catches (sexes combined) in NAFO Div. 3O and Subdiv. 3Ps for the directed skate (gillnet) and bycatch (trawl) fisheries in 2006, and 2007 (Lower Right Panel). Data are from Canadian Fisheries Observers.

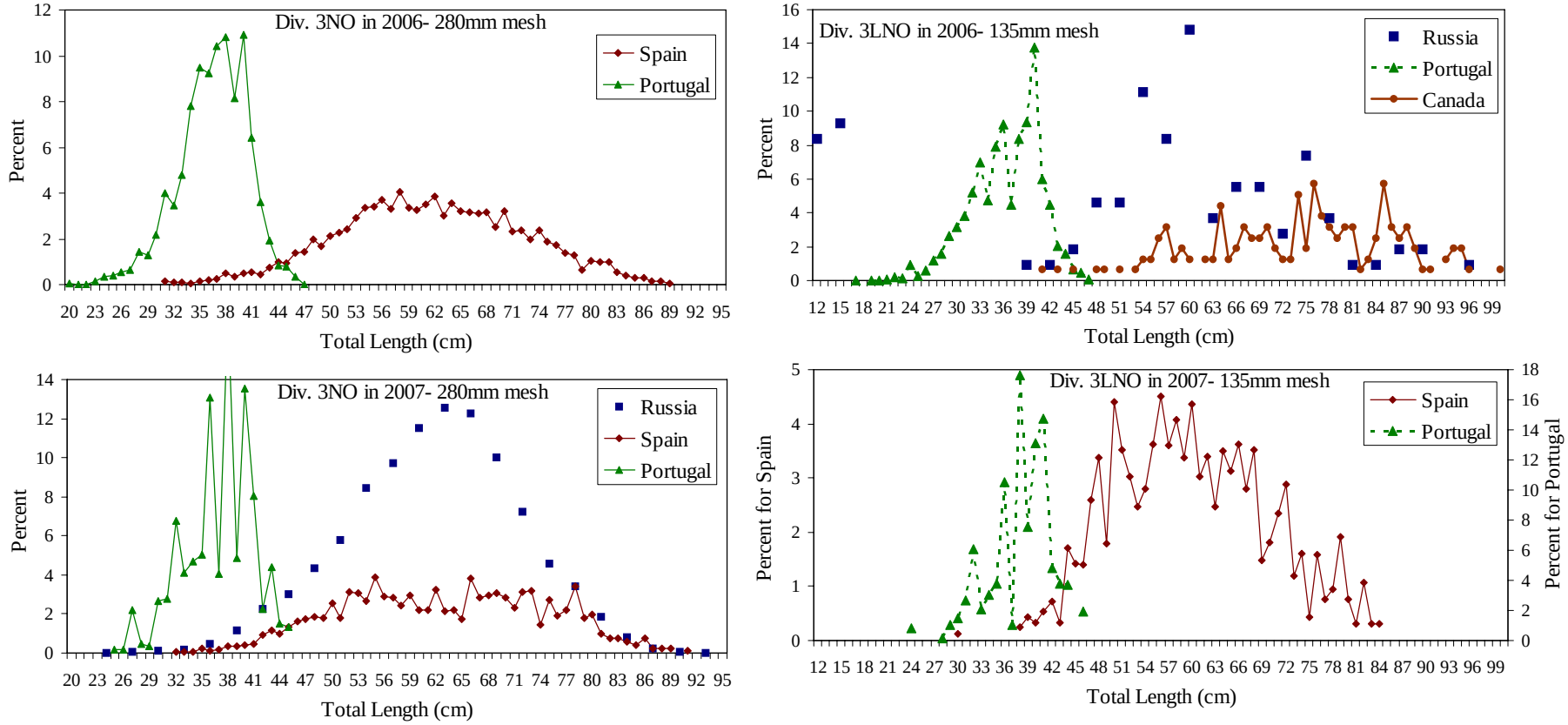

Figure 5b. Length distributions of commercial catches (sexes combined) in NAFO Div. 3LNO by country for the directed skate (280 mm) and bycatch (135 mm) trawl fisheries in 2006 (Upper Panels) and 2007 (Lower Panels).

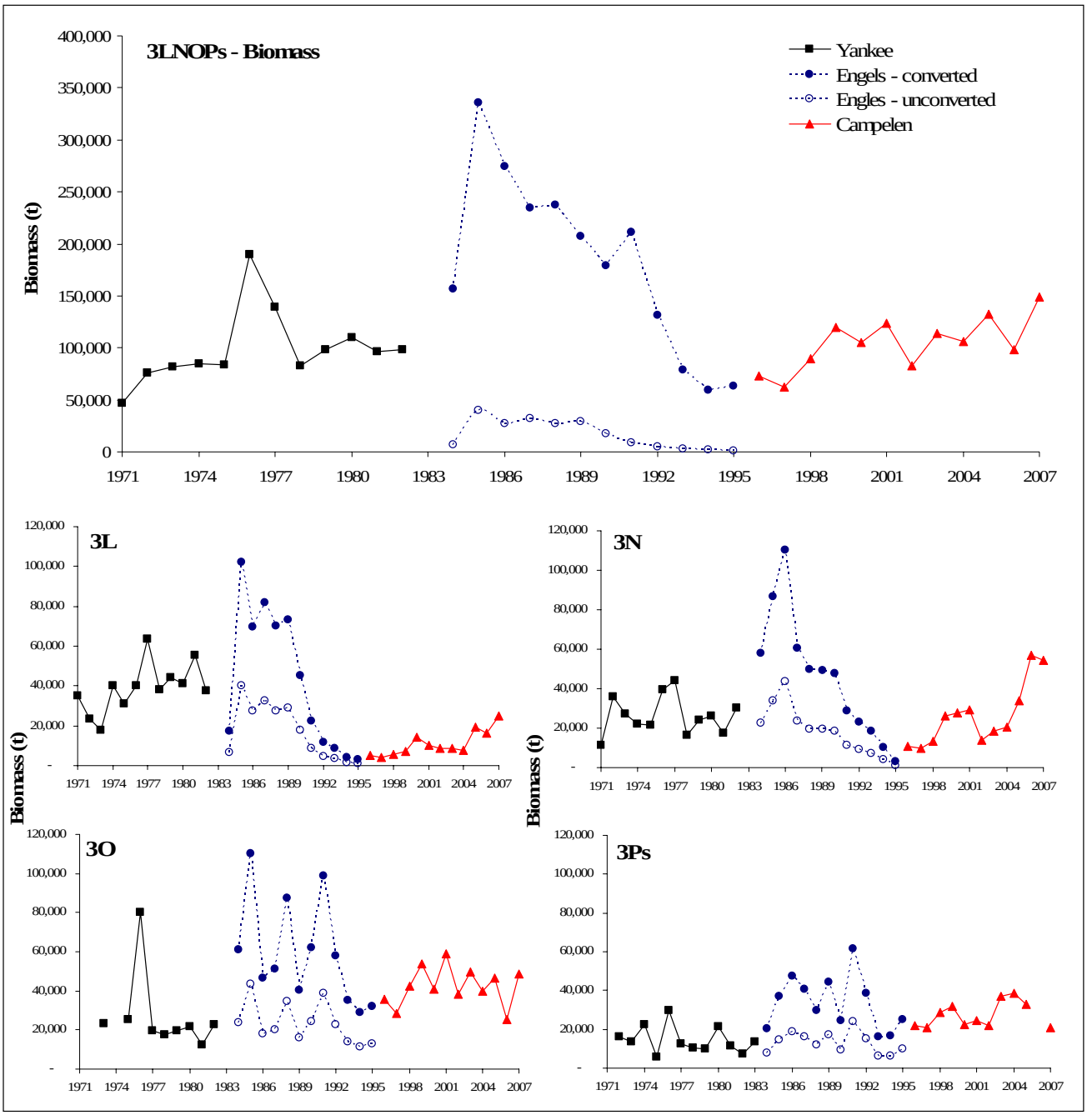

Figure 6a. Canadian spring research survey biomass indices for thorny skate in NAFO Divisions 3LNO, and Subdivision 3Ps, 1971-2007. Note that Div. 3LNO were not surveyed in 1983; Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

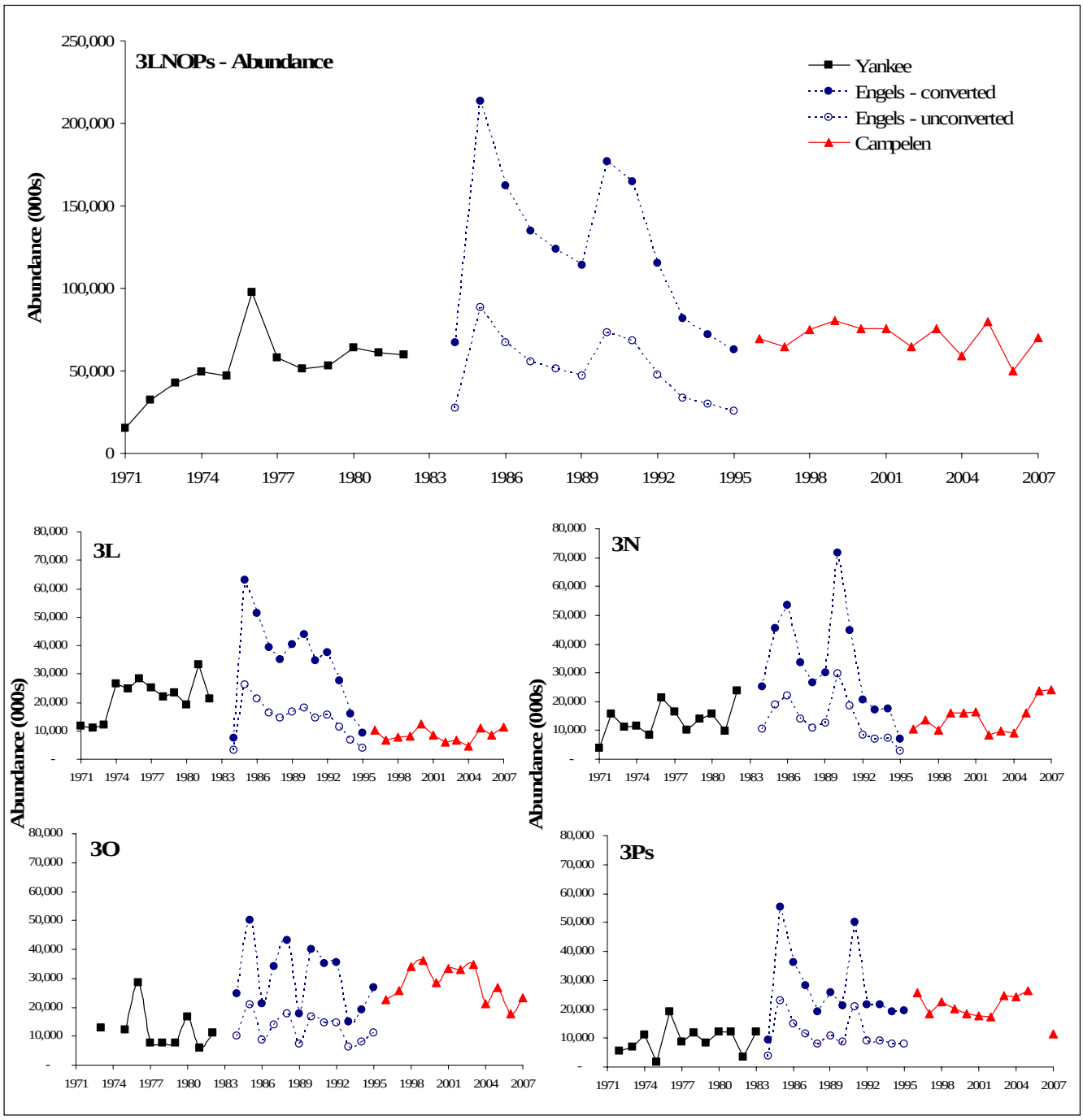

Figure 6b. Canadian spring research survey abundance indices for thorny skate in NAFO Divisions 3LNO, and Subdivision 3Ps, 1971-2007. Note that Div. 3LNO were not surveyed in 1983; Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

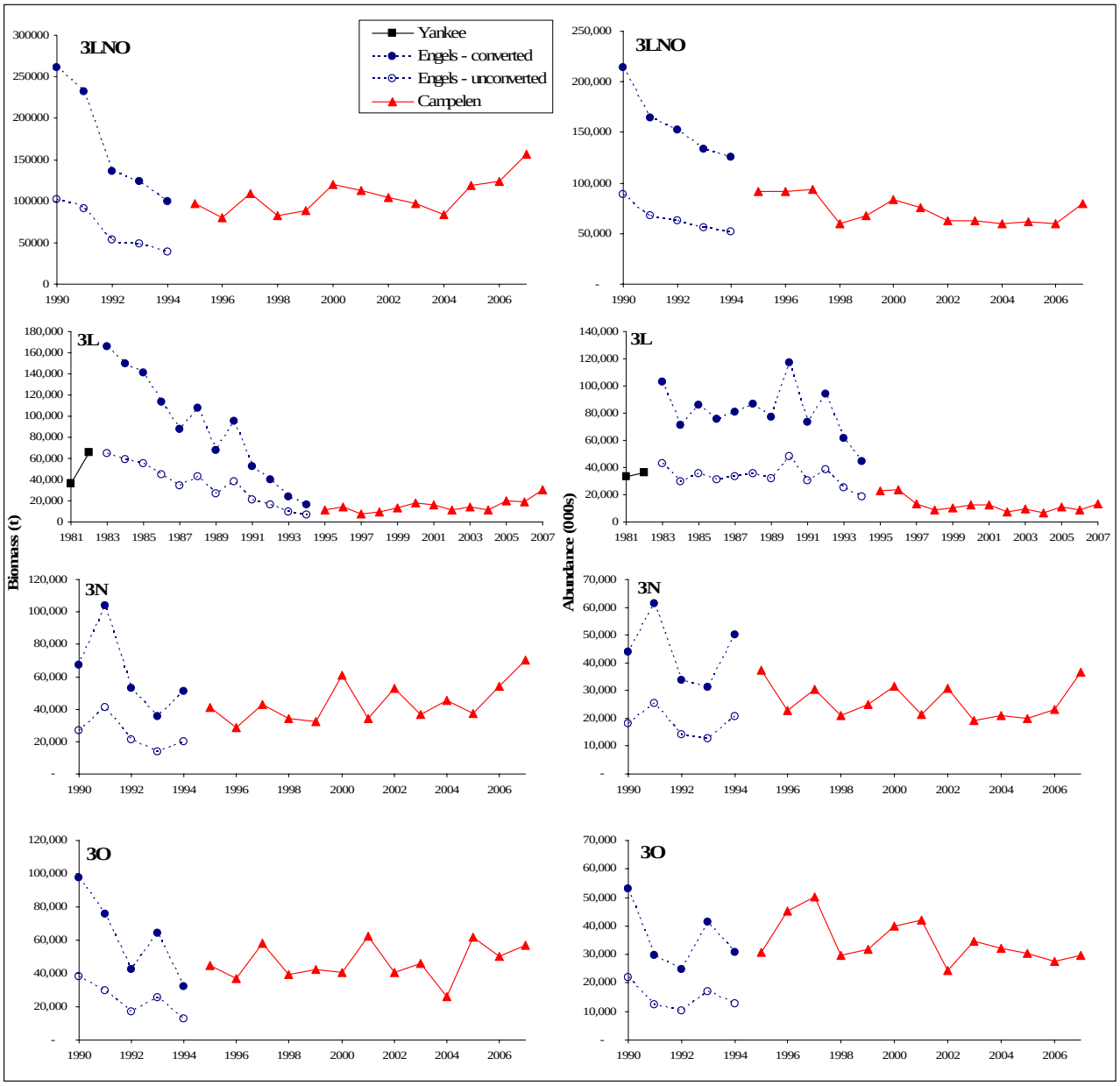

Figure 6c. Canadian autumn research survey biomass and abundance indices for thorny skate in NAFO Divisions 3LNO, 1990-2007. Note that Div. 3L was surveyed in 1971-2007 (except in 1983); Div. 3NO were surveyed in 1990-2007 (except in 1983, and only the shallow portion (<104 m) of Div. 3NO in 2006).

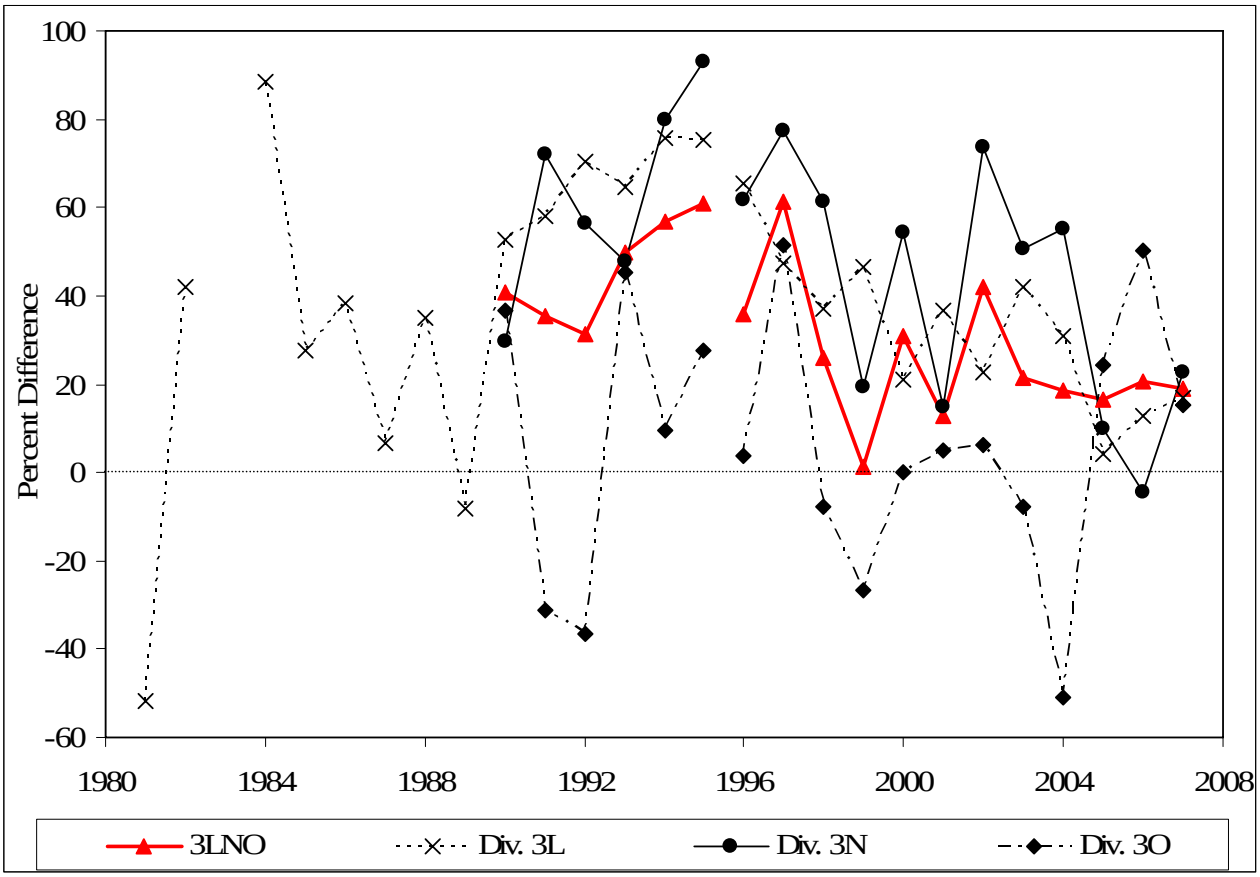

Figure 7. Percent difference between Canadian spring and autumn survey biomass estimates for thorny skate in NAFO Divisions 3LNO (Div. 3L: 1981-2007, no 1983 data; Div. 3N, 3O, 3LNO: 1990-2007). Breaks in data series indicate changes in survey gear: Yankee in 1981-1982; Engels-Campelen equivalent in 1984-1995 (spring); Campelen in 1995 (autumn) and 1996-2007.

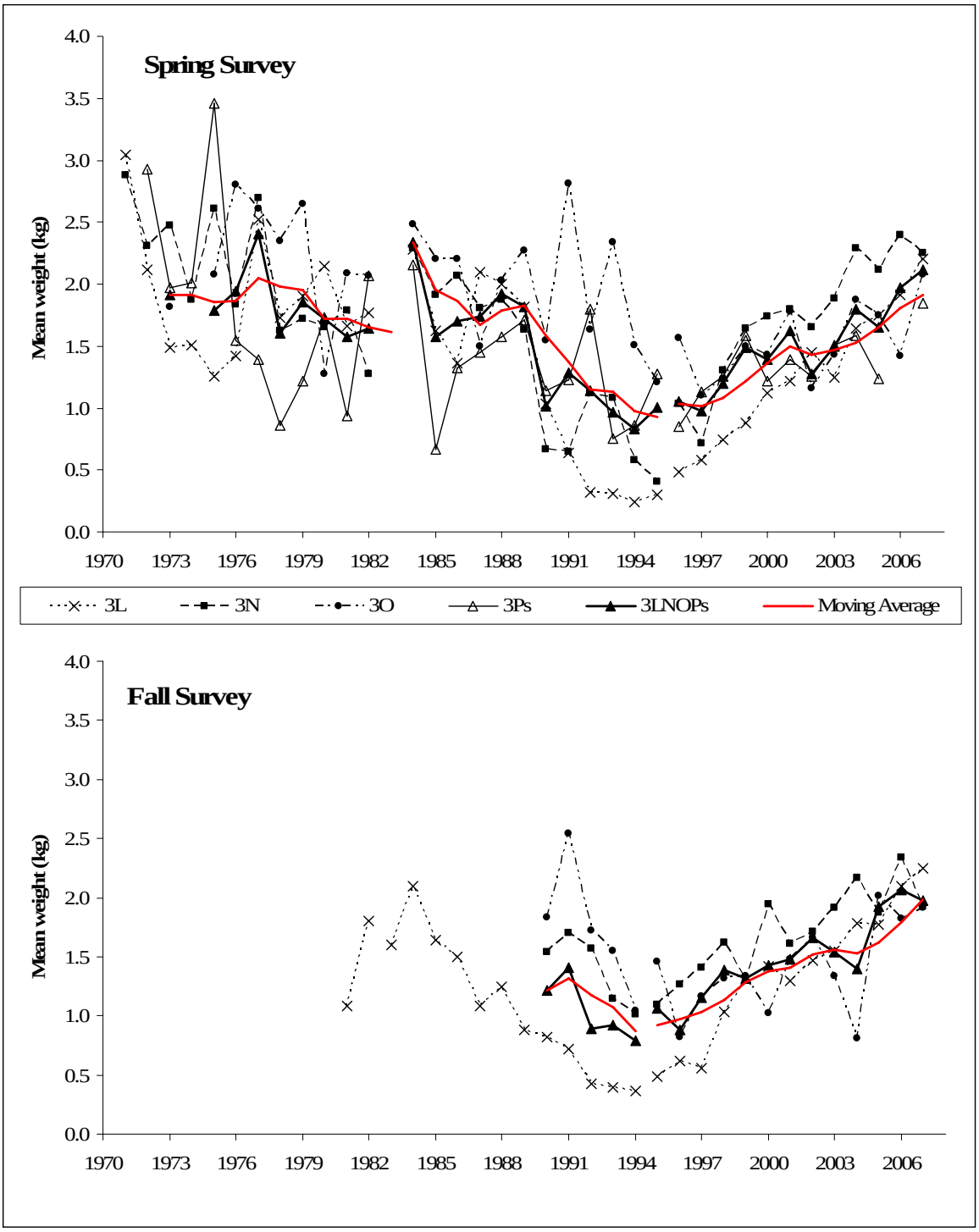

Figure 8. Mean weight (kg) of thorny skate in Canadian spring (1971-2007) and autumn (1981-2007) research surveys in NAFO Divisions 3LNO and Subdivision 3Ps.

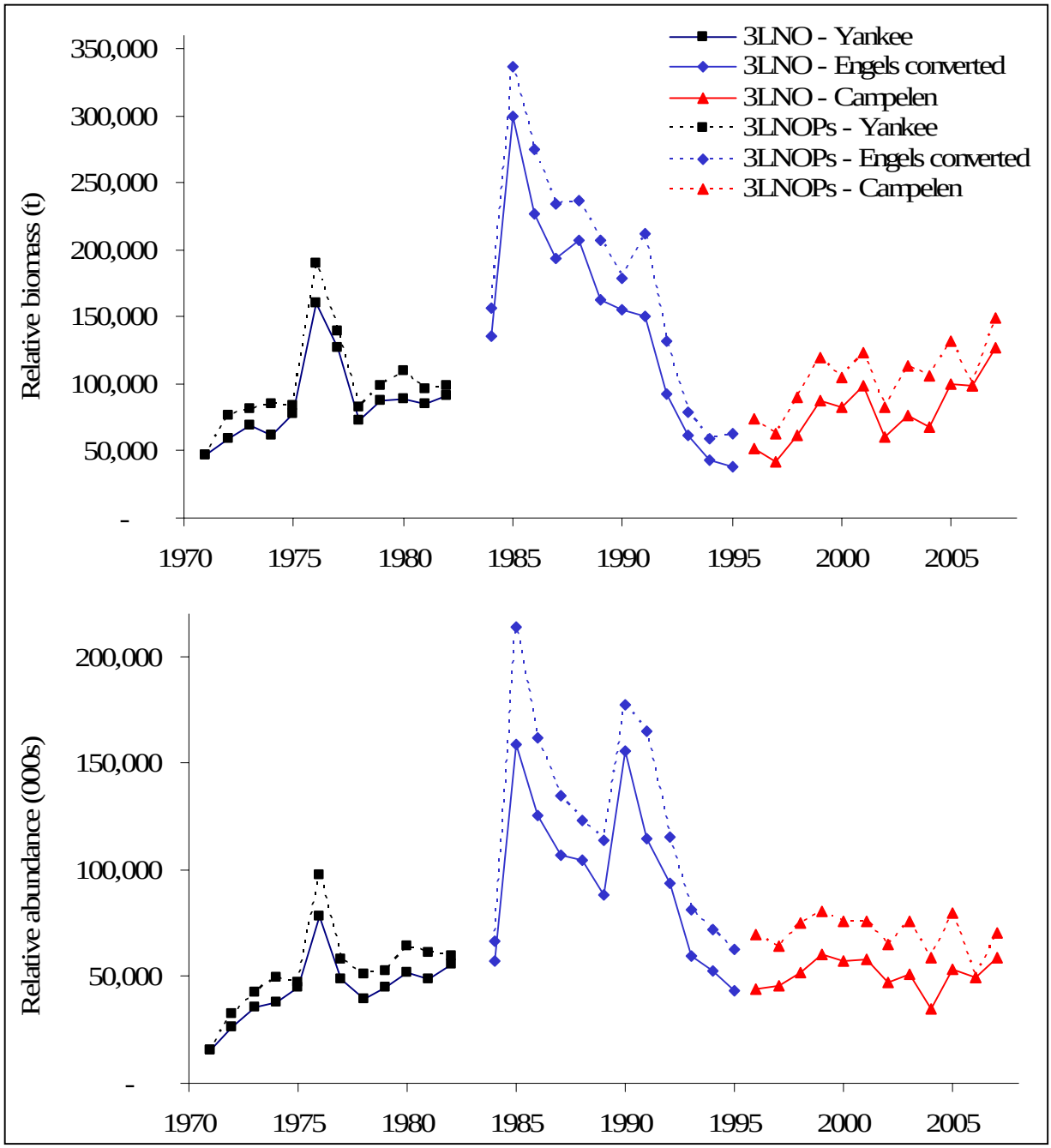

Figure 9. Relative biomass and abundance indices of thorny skate in NAFO Div. 3LNO and Subdiv. 3Ps in 1971-2007 from Canadian spring research surveys; with Engel estimates converted to Campelen equivalents. Note that Div. 3LNO were not surveyed in 1983; Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

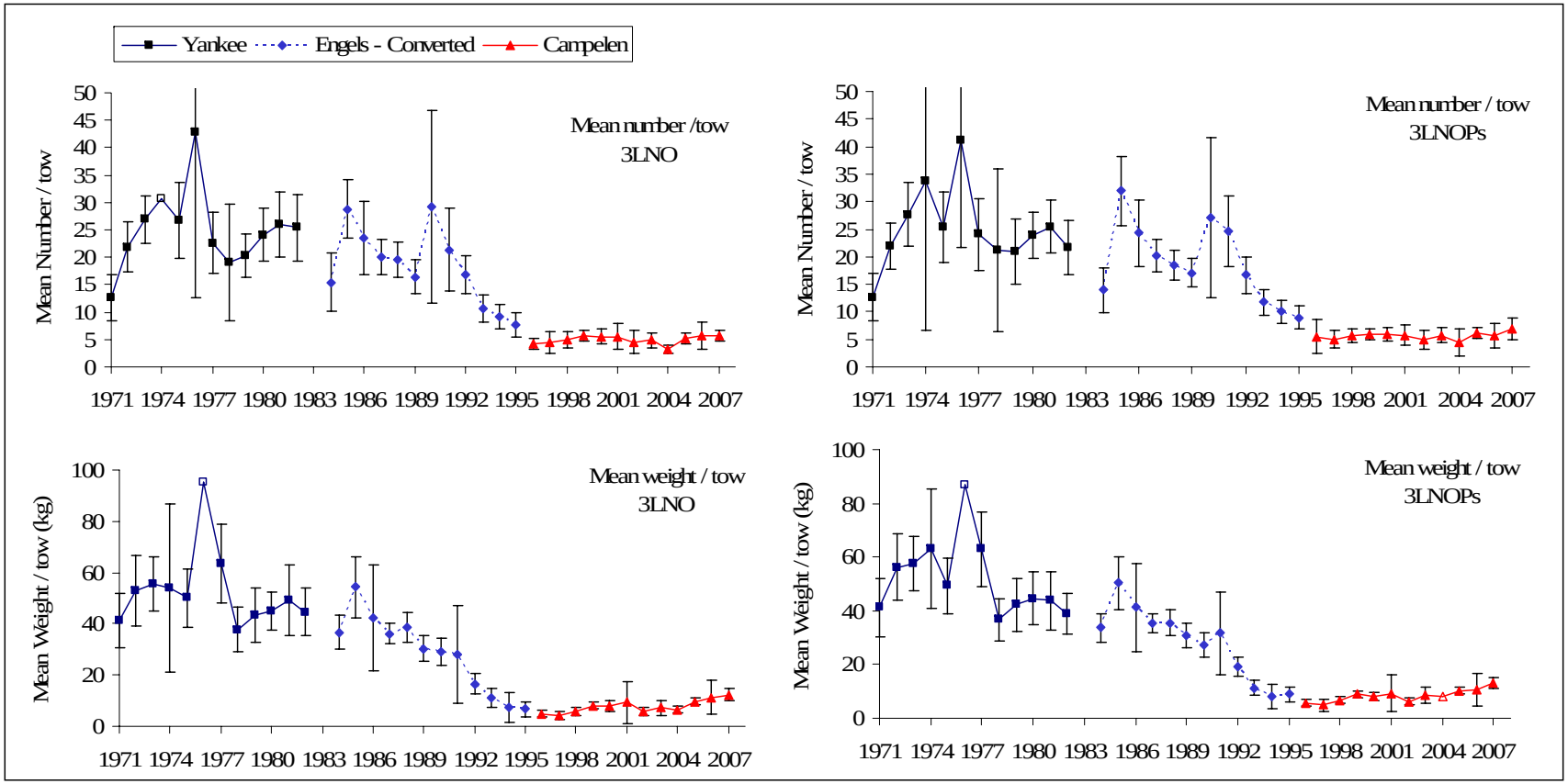

Figure 10. Mean numbers and weights (kg) per tow of thorny skate from Canadian spring surveys in NAFO Divisions 3LNO and 3LNOPs, 1971-2007. Note that Div. 3LNO were not surveyed in 1983; Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels. Where lower confidence limits were negative, error bars were omitted (hollow symbols).

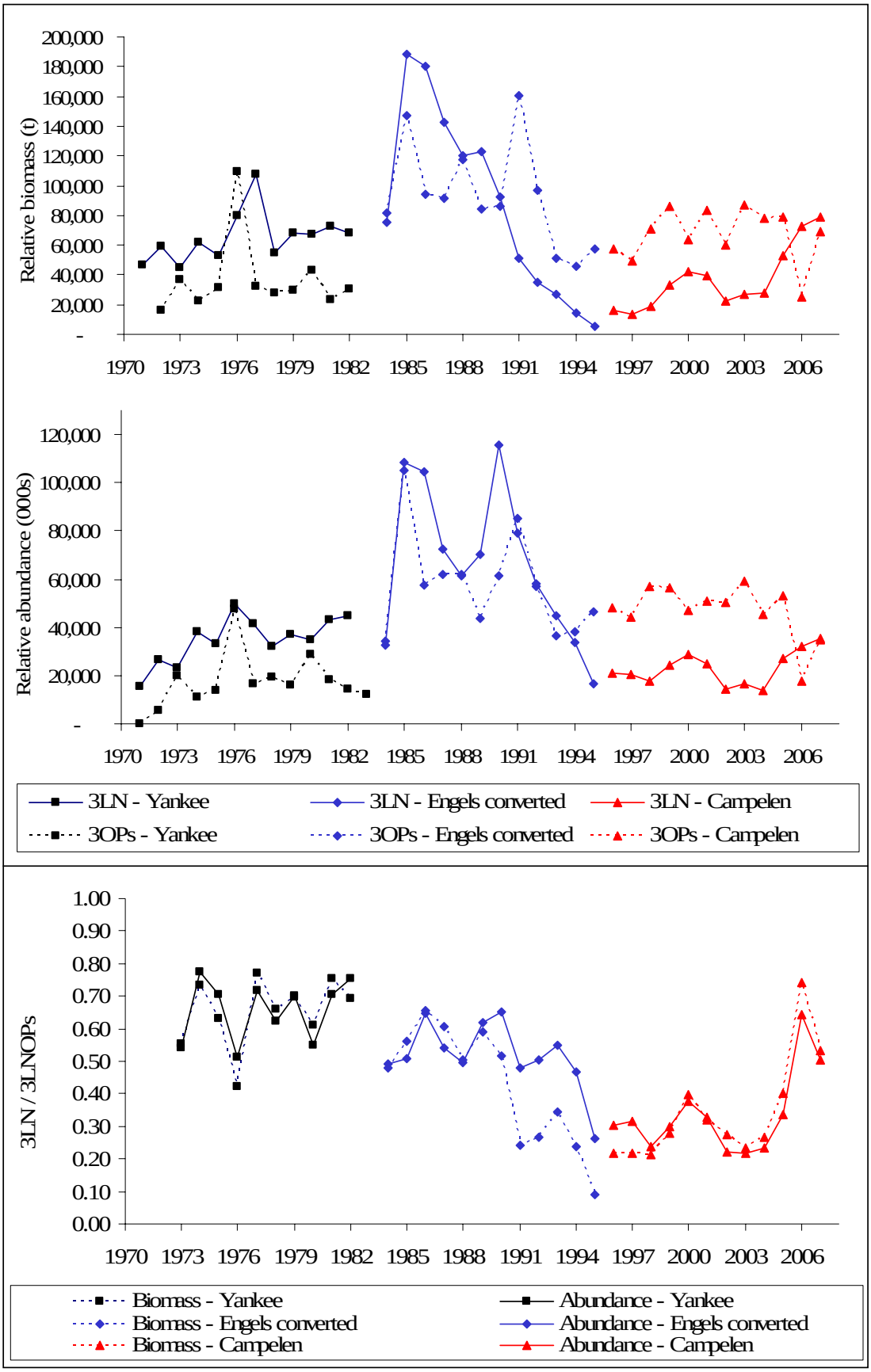

Figure 11a. Relative biomass and abundance indices of thorny skate in Div. 3LN *versus* Div. 3OPs from Canadian spring research surveys in 1971-2007 (Upper Panels); ratio of Div. 3LN/3LNOPs biomass and abundance indices in 1973-2007 (Lower Panel). Note that Div. 3LNO were not surveyed in 1983; Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

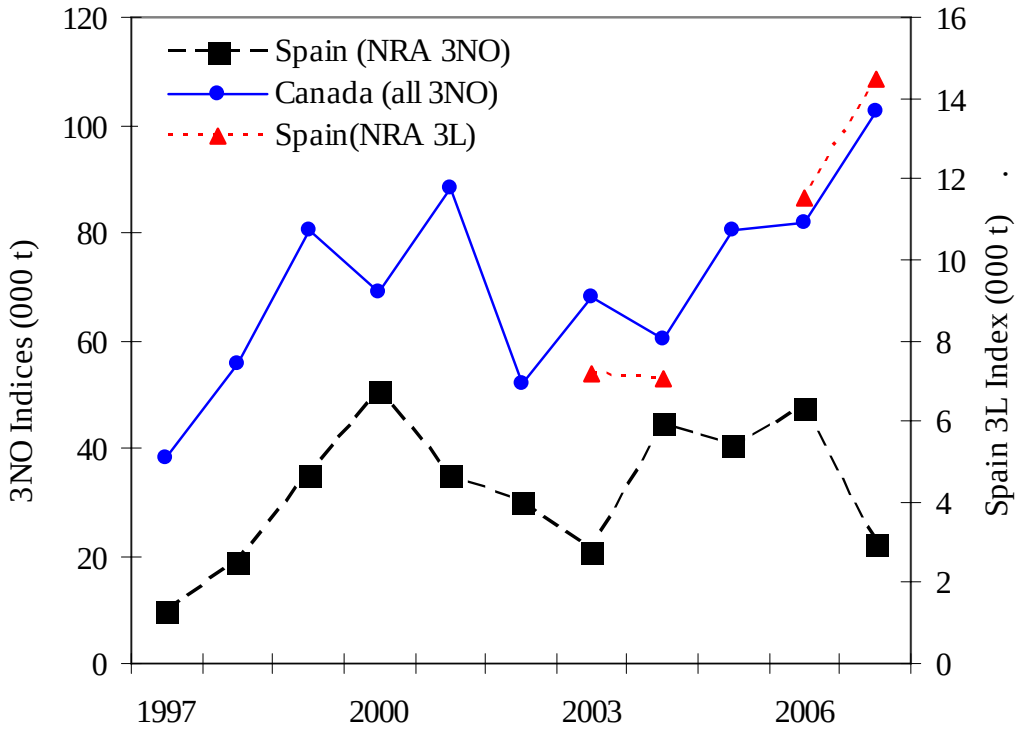

Figure 11b. Comparison of thorny skate biomass indices in 1997-2007 from the Canadian Campelen spring survey in Div. 3NO, the Spanish 3NO, and the Spanish 3L (2003-2007) surveys. Note that Spanish surveys occur only in the NAFO Regulatory Area of Div. 3NO.

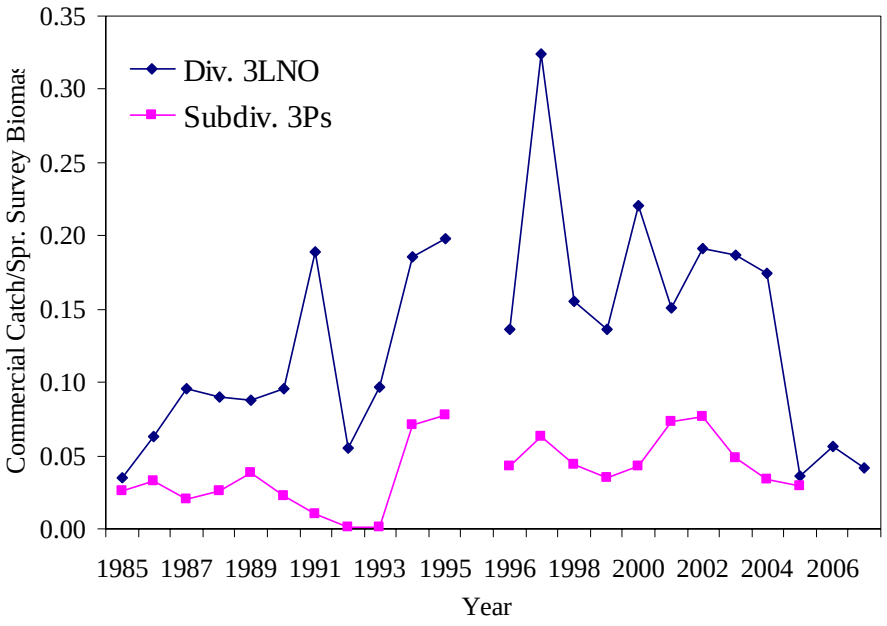

Figure 12. Catch/Biomass Ratio in Div. 3LNO and Subdiv. 3Ps, 1985-2007. Note that catch estimates are from STATLANT-21A; biomass indices are from Canadian spring research surveys; survey gear was changed to Campelen trawl in spring 1996. In the 2006 spring survey, Subdiv. 3Ps was not surveyed; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels..

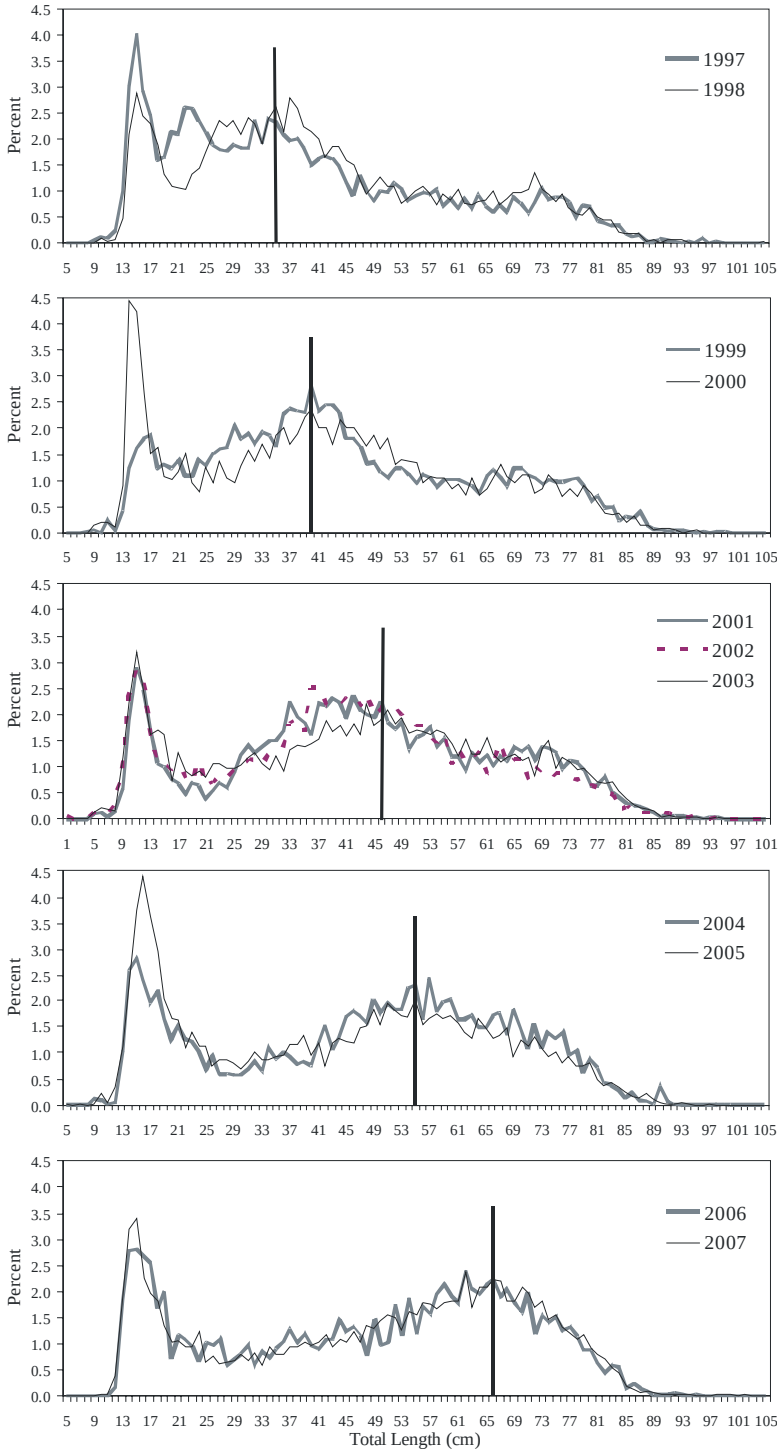

Fig. 13. Length distributions of thorny skate from Canadian Campelen spring surveys in NAFO Div. 3LNO and Subdiv. 3Ps, 1997-2007. Vertical bars represent dominant modes of immature skates (excluding YOY): 35 cm in 1998 (Top Panel); 40 cm in 1999-2000; 46 cm in 2002; 55 cm in 2004-2005; and 66 cm in 2007 (Bottom Panel). Note that Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

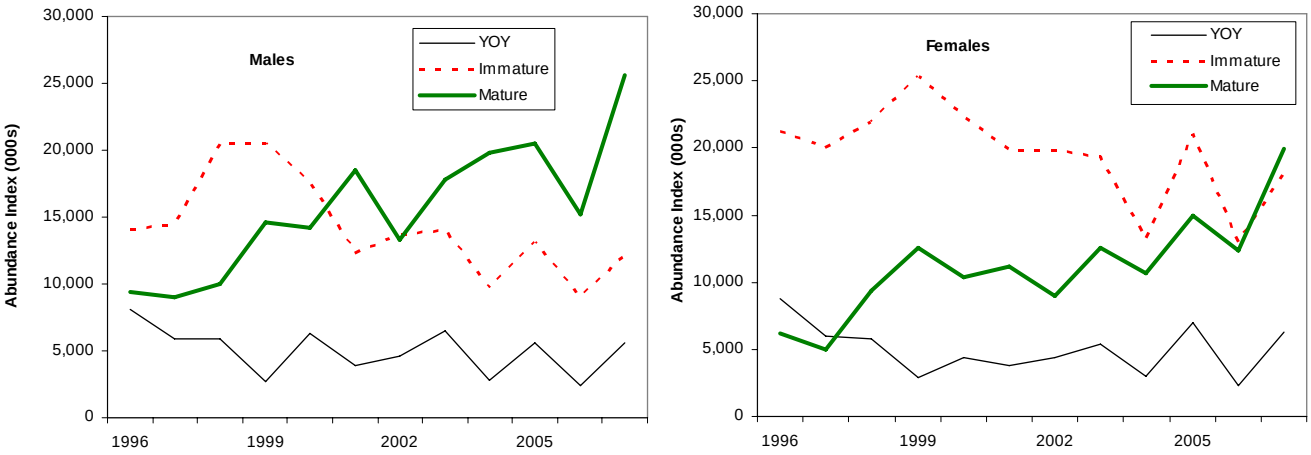

Fig. 14. Estimated abundance, by stage, of male and female thorny skates in NAFO Divisons 3LNOPs from spring Campelen surveys. Note that Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

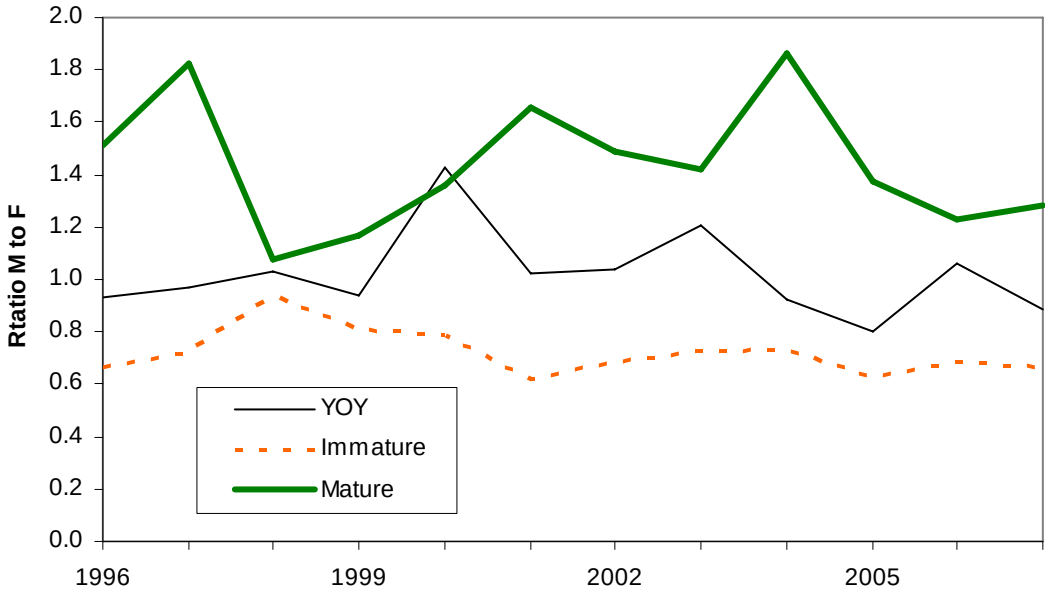

Figure 15. Ratio of staged male *versus* female thorny skates in NAFO Divisons 3LNOPs from spring Campelen surveys. Note that Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

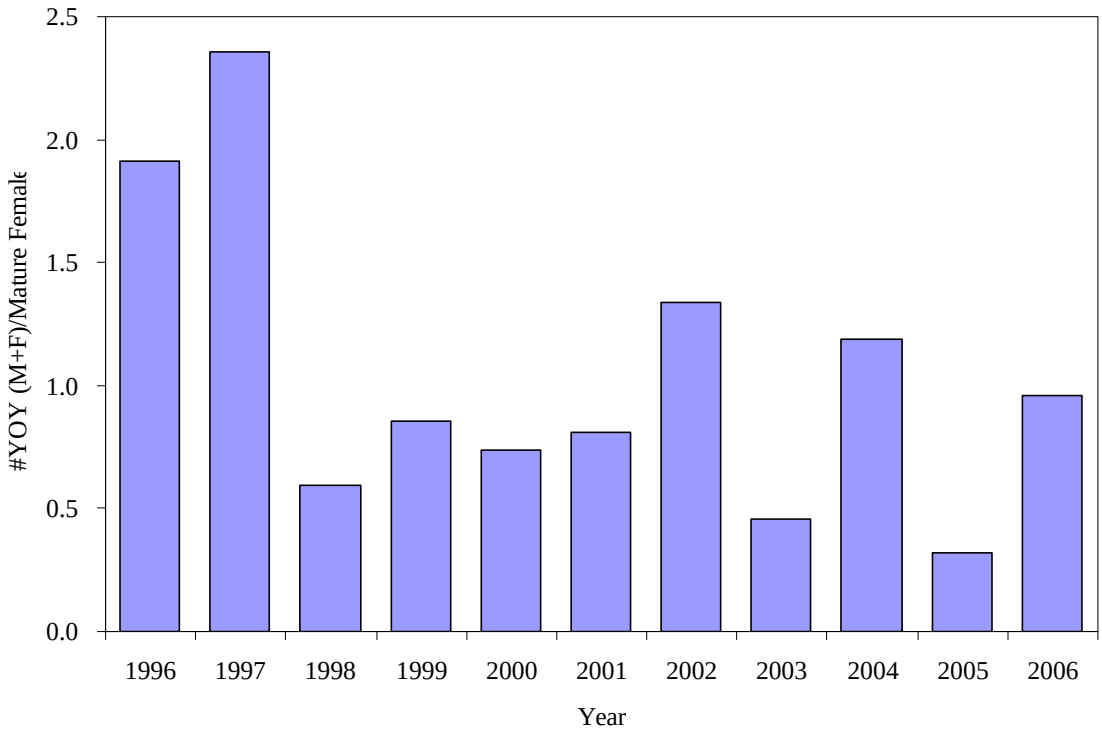

Figure 16. Recruits per spawner expressed as number of young-of-the-year males and females (1-year-olds produced per female in year -1) from Canadian Campelen spring surveys in NAFO Div. 3LNO and Subdiv. 3Ps, 1996-2006. For the 2005 point, one-year-olds in 2006 are only from the shallow (<104 m) portion of Div. 3NO; due to incomplete survey coverage in that year.

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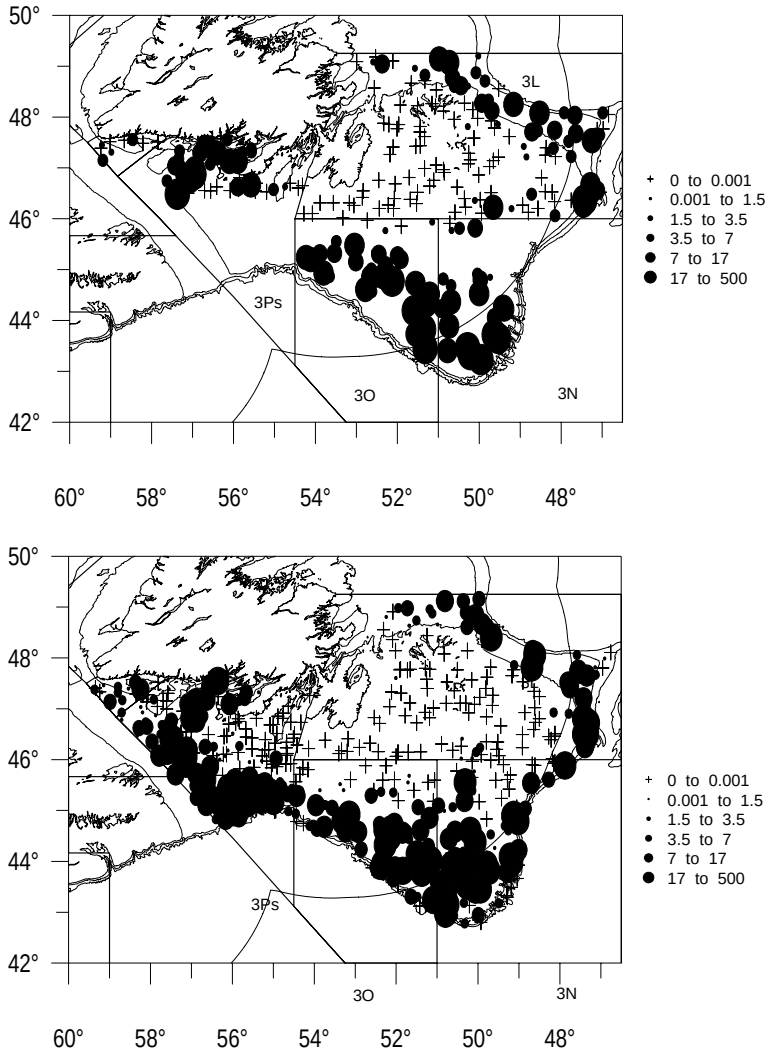

Upper panel: Thorny skate catch (number/tow) DFO 3LNO & 3Ps spring survey, 2006. Standardized to 0.8nm tow.
Lower panel: Thorny skate catch (number/tow) DFO 3LNO & 3Ps spring survey, 2007. Standardized to 0.8nm tow.

Figure 17a. Distribution of Thorny skate on the Grand Banks (NAFO Divisions 3LNOPs), based on Canadian spring surveys in 2006 (Upper Panel), and 2007 (Lower Panel). Note that Subdiv. 3Ps was not surveyed in 2006; neither the deeper portion (>103 m) of Div. 3NO in that year, due to mechanical difficulties on Canadian research vessels.

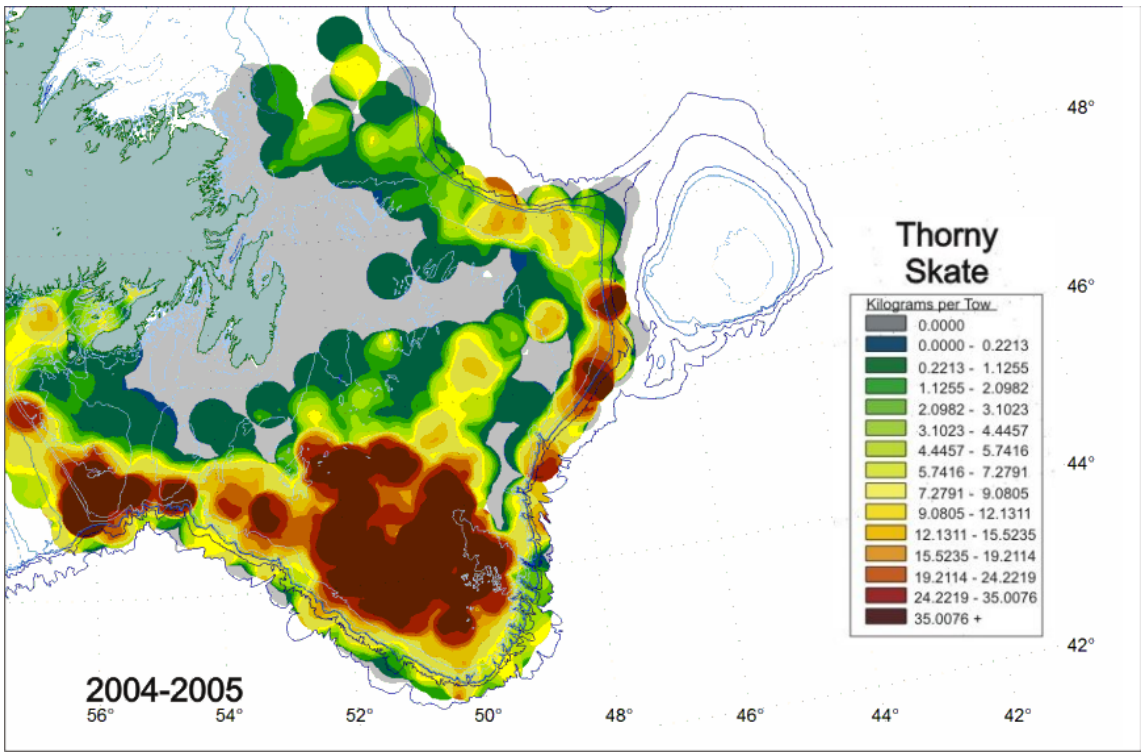

Figure 17b. Distribution of thorny skate on the Grand Banks (NAFO Divisions 3LNOPs), based on Canadian spring surveys in 2004-2005 (years combined). Green represents low catch rates (in kg per tow). Red represents high catch rates. Grey denotes sampled areas with no skate catches. White depicts unsampled areas.

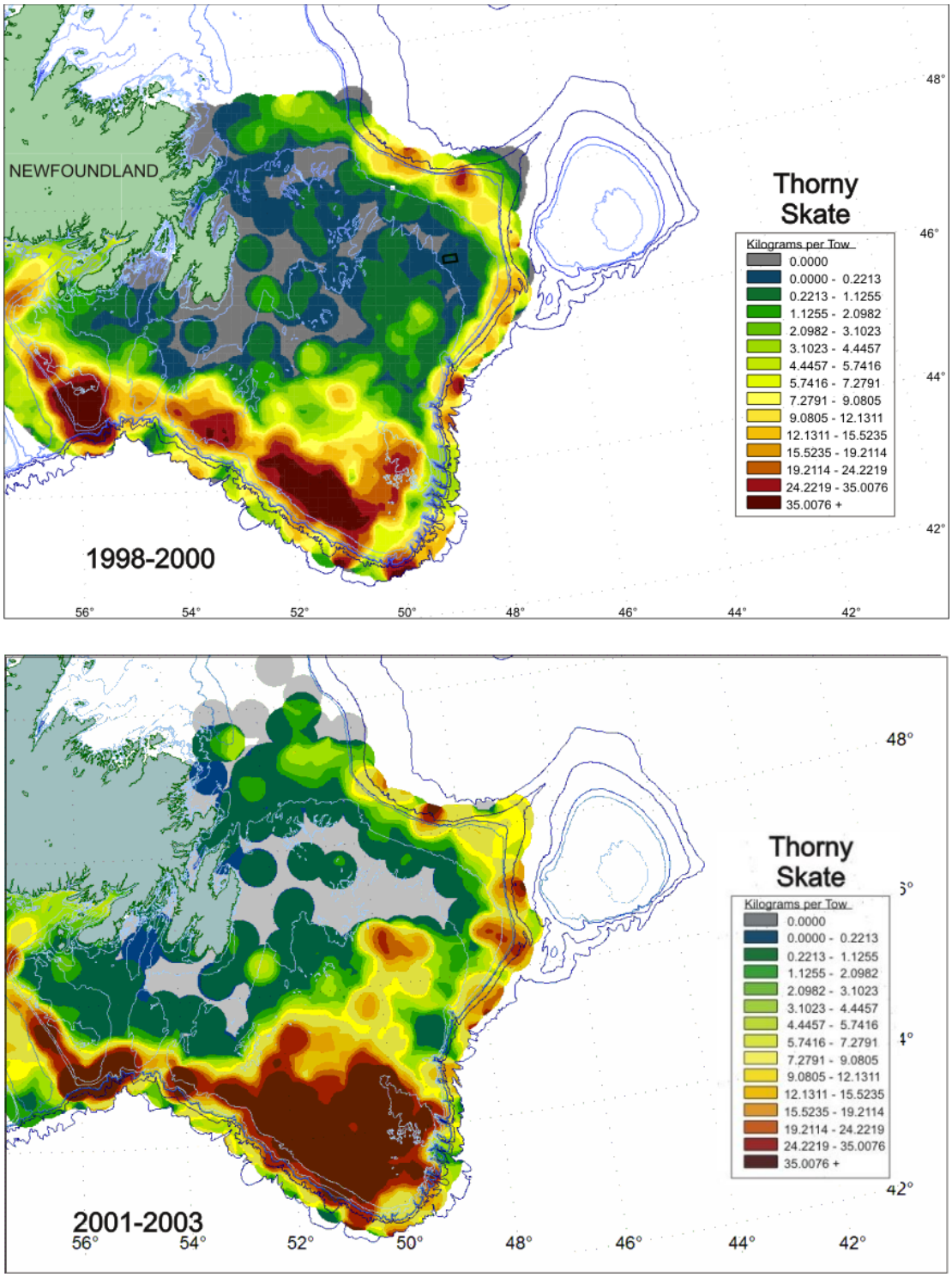

Figure 17c. Distribution of thorny skate on the Grand Banks (NAFO Divisions 3LNOPs), based on Canadian spring surveys in 1998-2000 and 2001-2003 (years combined). Green represents low catch rates (in kg per tow). Red represents high catch rates. Grey denotes sampled areas with no skate catches. White depicts unsampled areas.

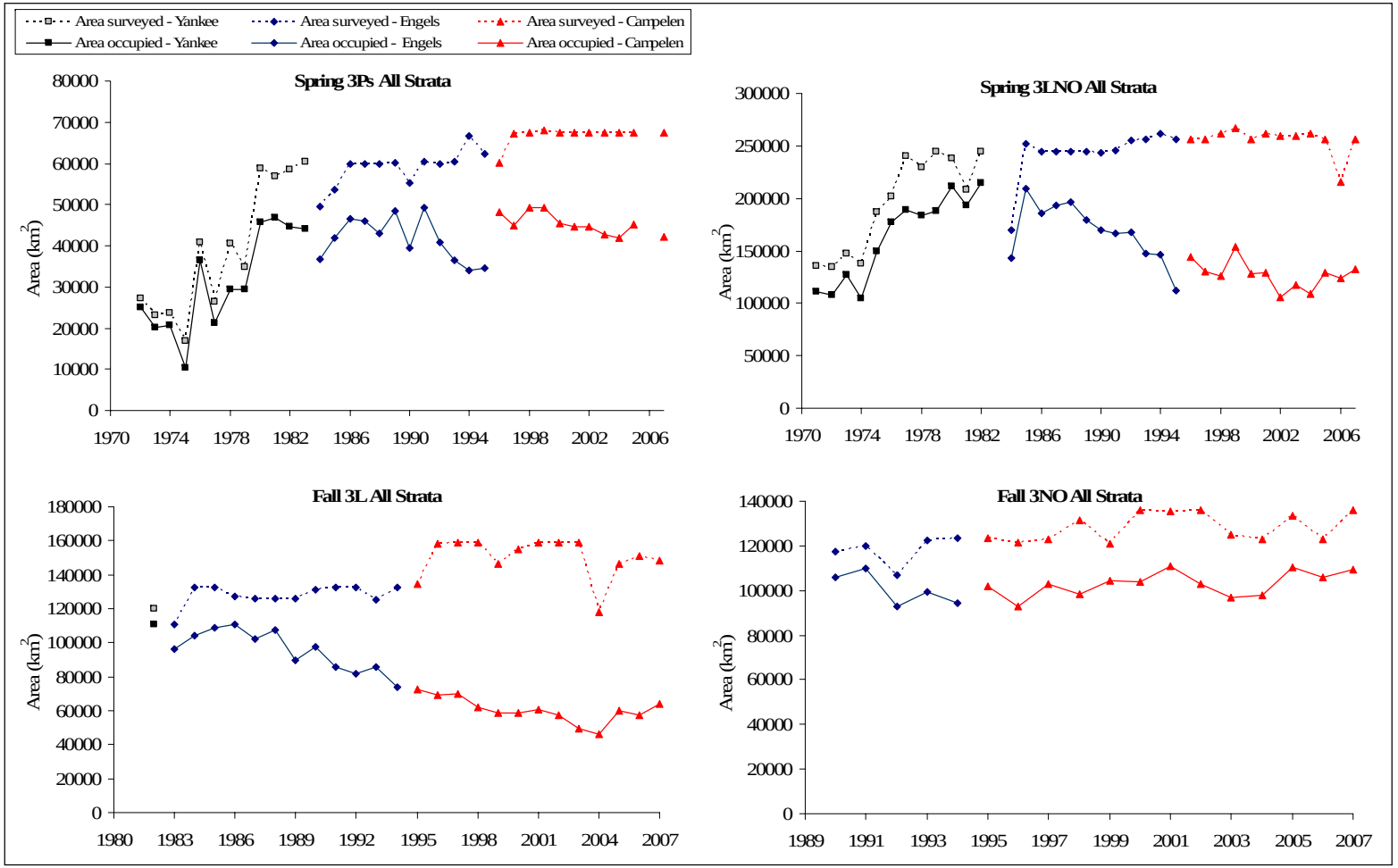

Figure 18. Design-Weighted Area of Occupancy for thorny skate in NAFO Divisions 3L, 3NO, 3LNO, and 3Ps; using all Canadian survey strata. Note that Div. 3L was surveyed in autumn 1982-2007 (no 1983 data); Div. 3NO in autumn 1990-2007; Div. 3LNO in spring 1971-2007 (no 1983 data); and Subdiv. 3Ps in 1972-2007 (no 1996 data). Breaks in data series indicate changes in survey gear: Yankee in 1971-1983 (spring); Engel (unconverted data) in 1983-1994 (fall), and 1984-1995 (spring); Campelen in 1995-2007 (fall), and 1996-2007 (spring).

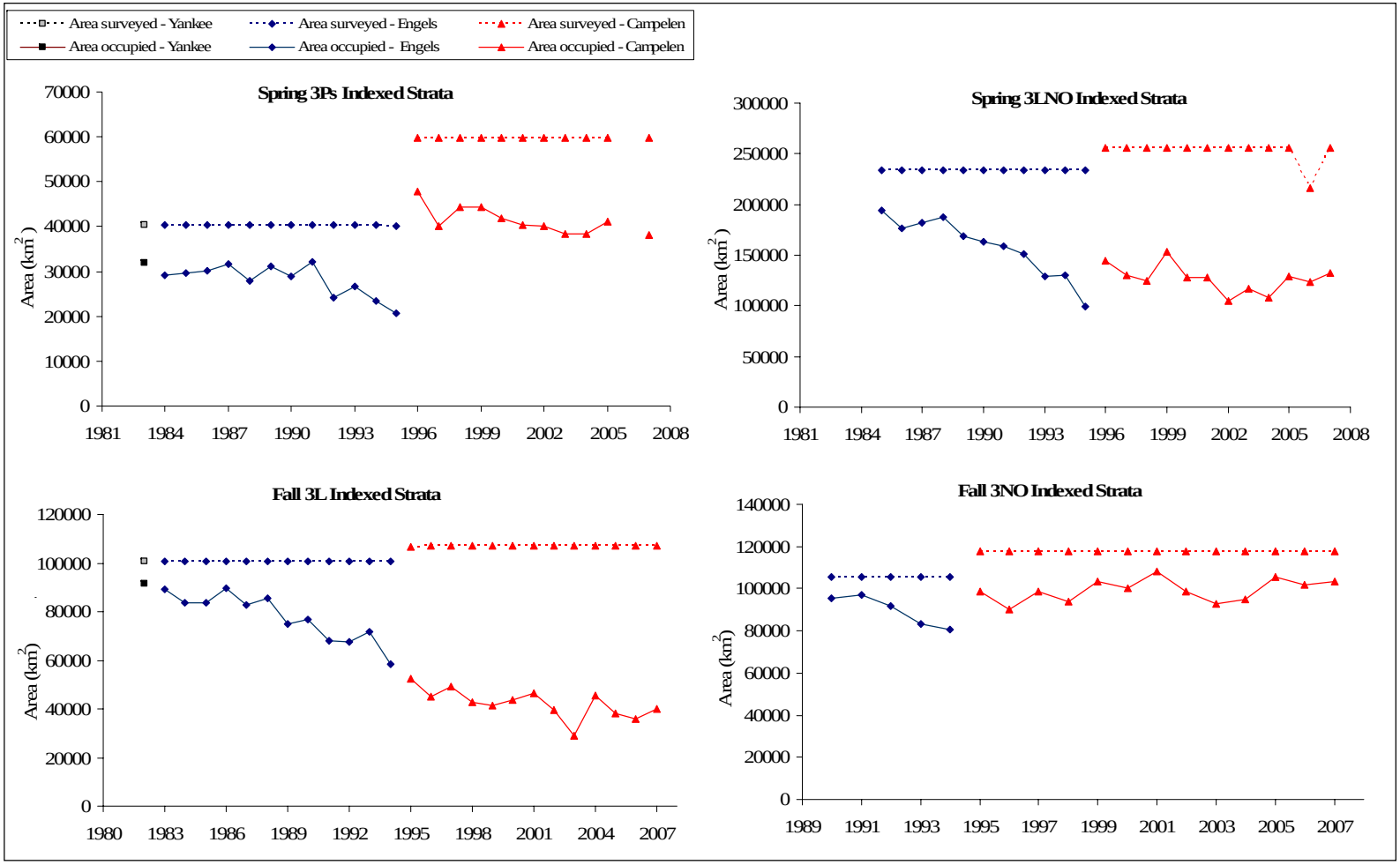

Figure 19. Design-Weighted Area of Occupancy for thorny skate in NAFO Divisions 3L, 3NO, 3LNO, and 3Ps; using indexed Canadian survey strata. Note that Div. 3L was surveyed in autumn 1982-2007; Div. 3NO in autumn 1990-2007; Div. 3LNO in spring 1984-2007; and Subdiv. 3Ps in 1983-2007 (no 1996 data). Breaks in data series indicate changes in survey gear: Yankee in 1982 (fall), and 1983 (spring); Engel (unconverted data) in 1983-1994 (fall), and 1984-1995 (spring); Campelen in 1995-2007 (fall), and 1996-2007 (spring).

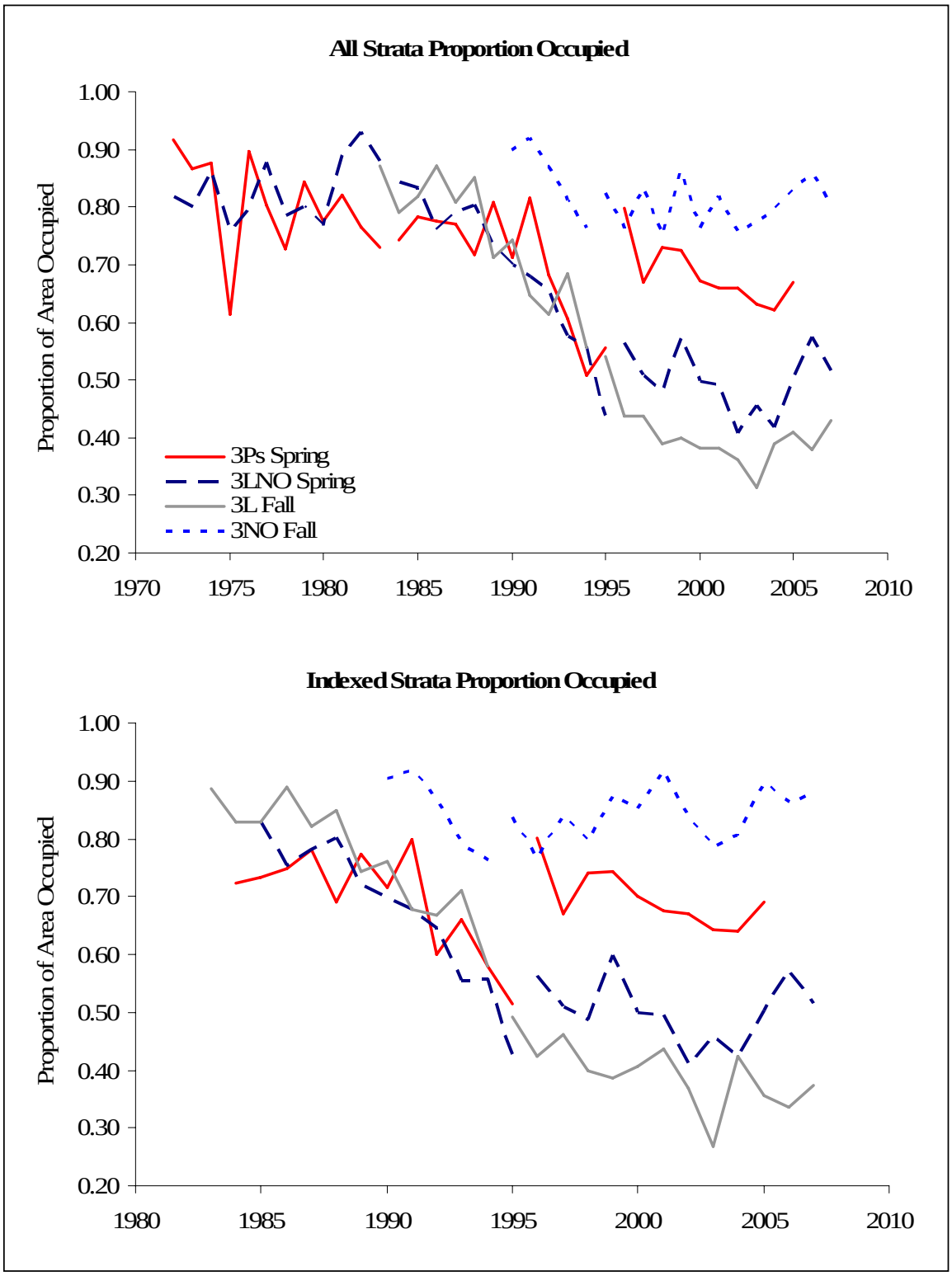

Figure 20. Proportion of area occupied by thorny skate based on DWAO indices for all strata (Upper Panel) and index strata (Lower Panel) in Div. 3LNO and Subdiv. 3Ps spring surveys, and in Div. 3L and Div. 3NO fall surveys.

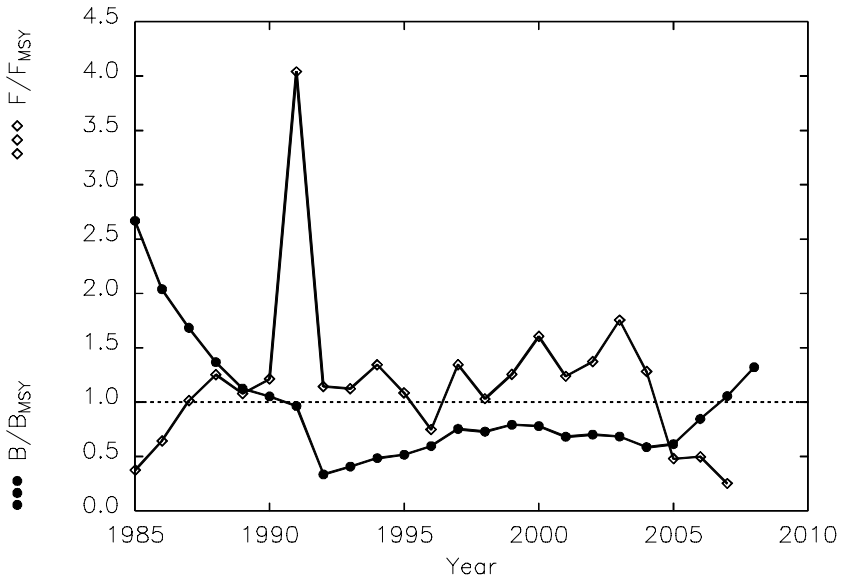

Figure 21. Estimated population trajectory based on the ASPIC model for thorny skate in NAFO Divisions 3LNO. Biomass is shown relative to B_{MSY} and fishing mortality relative to F_{MSY}.

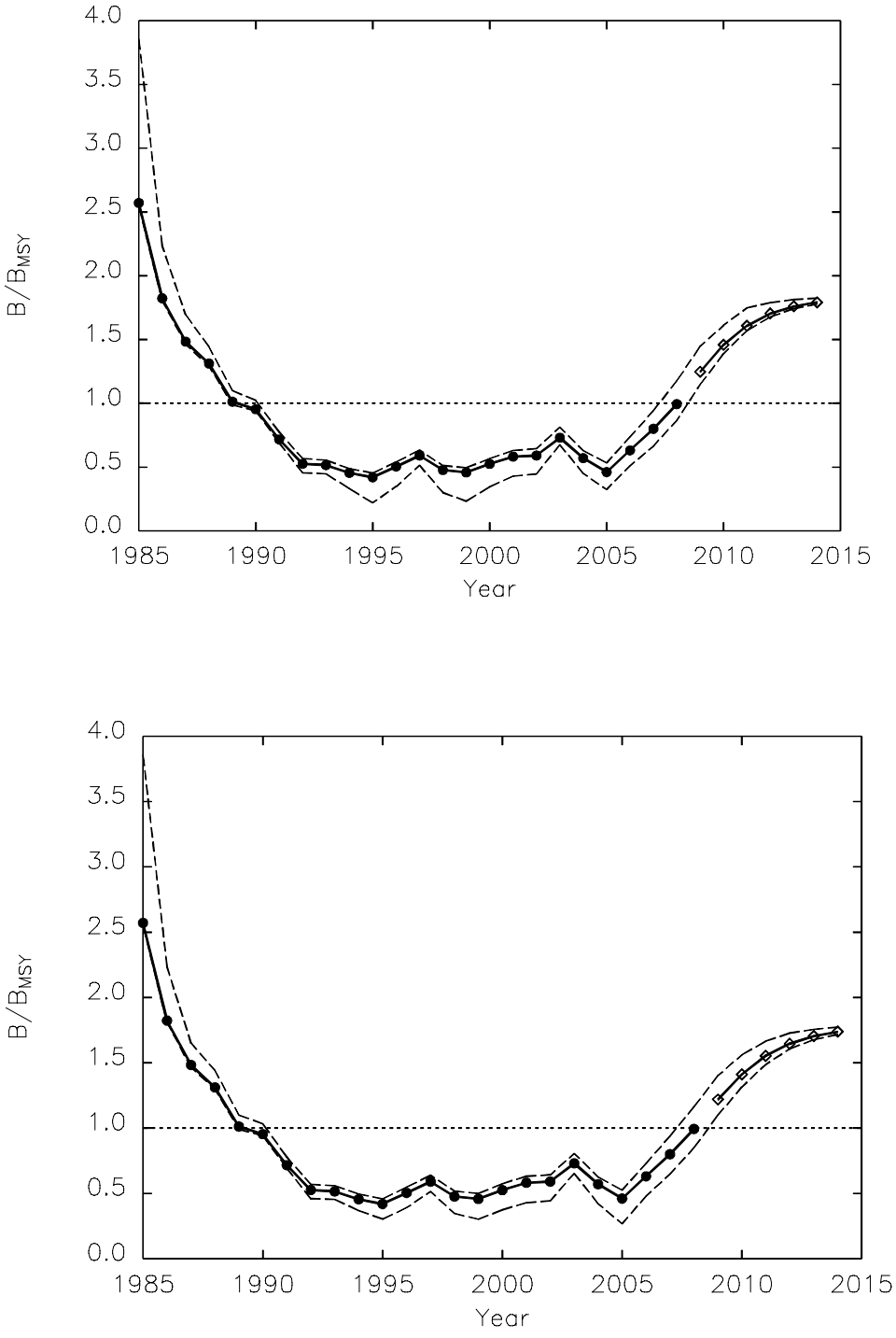

Figure 22. Estimated population trajectory based on the ASPIC model for thorny skate in NAFO Divisions 3LNO. Biomass is shown relative to B_{MSY}. Projections forecast six years based on: recent catch of thorny skate (3 650 t in 2007; Upper Panel), and average catch for previous three years for Div. 3LNO in 2007 (4 545 t; Lower Panel).

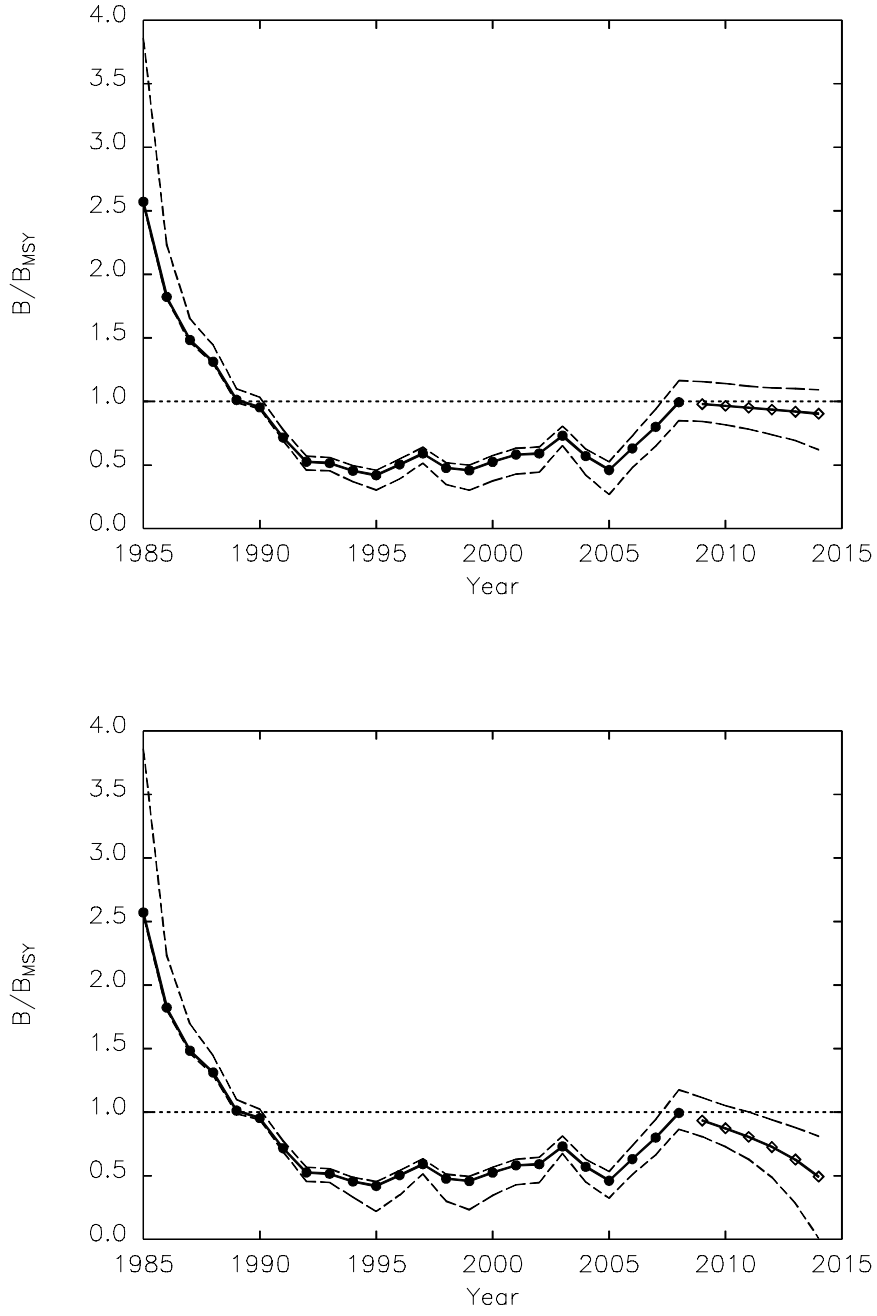

Figure 23. Estimated population trajectory based on the ASPIC model for thorny skate in NAFO Divisions 3LNO. Biomass is shown relative to B_{MSY}. Projections forecast six years based on: estimated MSY (12 140 t; Upper Panel), and the current TAC for Div. 3LNO in 2007 (13 500 t; Lower Panel).

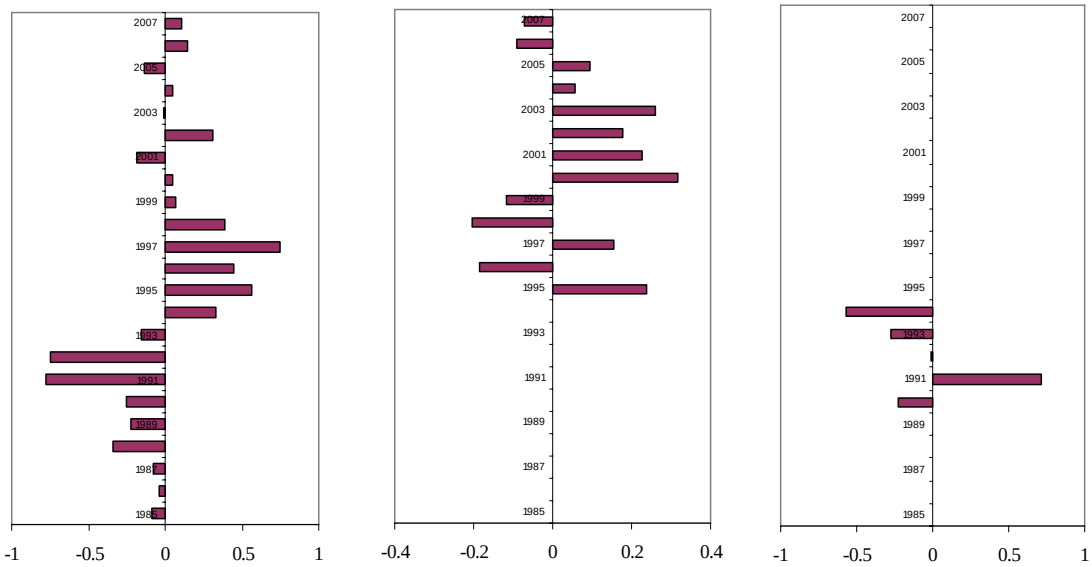

Figure 24: Residuals from ASPIC model for the spring (left panel), fall campelen (middle panel) and fall engel (right panel) series..