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2019 Assessment of Northern Shortfin Squid (*Illex illecebrosus*) in Subareas 3+4

by

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Abstract

This assessment pertains to the northern component of the Northern shortfin squid (*Illex illecebrosus*) stock, in Subareas 3+4, which is managed by the Northwest Atlantic Fisheries Organization (NAFO). Research survey relative biomass indices and nominal catch data are also presented for the southern stock component in Subareas 5+6, which is managed by the United States of America, because the species constitutes a single stock throughout its range in Subareas 2-6. Two general levels of productivity have been identified for the Subareas 3+4 stock component based on trends in relative biomass indices and squid mean body weights derived from Canadian research bottom trawl surveys conducted in Division 4VWX during July. A period of high productivity (1976-1981) occurred between two low productivity periods (1970-1975 and 1982-2017). During the high productivity period, the Div. 4VWX relative biomass indices averaged 13.2 kg per tow and squid mean body weights averaged 150 g. During the 1982-2017 low productivity period, relative biomass indices averaged 3.0 kg per tow and squid mean body weights averaged 81 g. Trends in the biomass indices for fall bottom trawl surveys conducted in Division 4T and Subarea 5+6 were compared with those for Division 4VWX because all three time series are correlated.. Since 1999, there has been no directed fishery in Subarea 4 and the majority of catches from Subareas 3+4, during most years since 2000, were from the Subarea 3 Canadian inshore jig fishery. This jig fishery has no annual quota and is not managed. During 2018, relative biomass indices and mean body size for the Div. 4VWX surveys were unknown because much of the Northern shortfin squid habitat was not sampled, and therefore, the survey indices were not computed. However, the 2019 biomass index and mean body size were the second highest of the time series and above the high productivity period average, respectively. The 2018 relative fishing mortality index remained very low in relation to the 1982-2017 low productivity period average. As a result, the productivity state of the Subareas 3+4 stock component of Northern shortfin squid was unknown for 2018, but appeared to be moving toward a high productivity state based on the 2019 biomass index and mean body size. However, the 2019 indices were not available for all of the survey indices and previous spikes in the Div. 4VWX biomass indices have been followed by low values in the subsequent years. The existing 34 000 t quota for Subareas 3+4 is the higher of the two potential yields computed by Rivard et al. (1998), yet the highest percentage of the quota harvested since its adoption in 2000 was only 20.5%. Given the lack of 2018 productivity state metrics and the appearance that the northern stock component may be moving toward a high productivity state, maintaining the existing quota is recommended for 2020, with a re-evaluation of the productivity state in 2021.

1.0 Introduction

Northern shortfin squid (*Illex illecebrosus*) is a species with a lifespan of less than one year (Dawe and Beck, 1997; Hendrickson, 2004). *I. illecebrosus* is a nerito-oceanic squid species that seasonally inhabits the continental shelf and upper slope of the East Coast of the USA and Canada, where fisheries occur, but the species is also found farther offshore in oceanic waters and on seamounts (Hendrickson and Holmes, 2004; Arkhipkin et al., 2015).

The population constitutes a single stock throughout its broad latitudinal range in the Northwest Atlantic Ocean, from Southern Labrador to Florida (Dawe and Hendrickson, 1998; Hendrickson, 2004). Although this transboundary resource is continuously distributed between Cape Hatteras, North Carolina and Newfoundland, it has been managed as two stock components since 1977 due to regulatory jurisdictional boundaries of the squid resource. The northern stock component includes the portion of the resource located in Subareas 3+4 (very small amounts of the resource also occurred in Subarea 2 during several years), and the southern stock component includes the portion of the resource located in Subareas 5+6 (Fig. 1).

Legal establishment of the 200-nautical mile jurisdictional boundaries (Exclusive Economic Zones, EEZs) of the USA, Canada and France (St. Pierre and Michelon, a portion of 3Ps and 4Vs) occurred in 1977, and since then, the portion of the resource located within each of the EEZs has been managed by each respective country. The portion of the northern stock component (Subareas 3+4) located within the EEZs of Canada and France are managed by these two countries and the portion of the southern stock component (Subareas 5+6) located within the EEZ of the East Coast of the USA is managed in the USA by the Mid-Atlantic Fishery Management Council. Since the establishment of the Northwest Atlantic Fisheries Organization (NAFO) in 1979 (Anderson, 1998), the portion of both stock components located seaward of the EEZ boundaries, and within the NAFO Regulatory Area (NRA, Fig. 1), have been managed by the NAFO Contracting Parties which include the USA, Canada, France and 11 additional Contracting Parties. During 1951-1978, the forerunner of NAFO, the International Commission for Northwest Atlantic Fisheries (ICNAF), had fisheries jurisdiction throughout all Subareas.

Prior to 1977, international fleets fished for squid in all Subareas. In Subarea 3, research survey data indicate that the species is found seasonally off Newfoundland, in nearshore waters and on the Grand Banks, including NRA waters on the “tail” and “nose” of the Grand Bank and on the Flemish Cap in Division 3M (Fig. 1). In Subarea 4, the northern stock component includes the portion of the resource that inhabits waters overlying the Scotian Shelf and slope, in the Bay of Fundy and Gulf of St. Lawrence and farther offshore in the NRA. In Subareas 5+6, the research survey data indicate that the southern stock component is distributed from the Gulf of Maine to central Florida.

Fishery and research survey data are presented for both stock components because of their relationship to one another as a unit stock. However, the focus of the subject assessment is the SA 3+4 stock component that is managed by NAFO. Details about the fisheries that occur in each Subarea and management of the resource are described in Arkhipkin et al. (2015) and details about the habitat and life history of the species are described in Hendrickson and Holmes (2004).

The onset and duration of the fisheries in each Subarea generally reflect the timing of squid migrations through each of the three fishery regions (Subarea 3, Subarea 4 and Subareas 5+6). Subarea 3 catches are primarily from a small-boat jig fishery that occurs in the shallow, nearshore waters of Newfoundland during July-November, but an offshore bottom and midwater trawl fishery also occurred during 1974-1984 (Dawe, 1981; SCS 19-08REV). During 1987-1998, Northern shortfin squid were harvested in Subarea 4 by an international, mixed-species, bottom trawl fishery for silver hake (*Merluccius bilinearis*), *I. illecebrosus* and argentine (*Argentina* sp.) that occurred on the Scotian Shelf (Hendrickson *et al*., 2002). International midwater and bottom trawl fleets began directed fisheries for Northern shortfin squid in Subareas 5+6 during 1967 (Lange and Sissenwine, 1980). Since 1987, catches from Subareas 5+6 have been solely from a USA bottom trawl fishery that occurs along the edge of the continental shelf and upper slope, primarily in the Mid-Atlantic Bight but also on Georges Bank and in Southern New England (NEFSC, 1999).

The Northern shortfin squid stock in Subareas 3-6 was initially managed by ICNAF beginning in 1974 with the establishment of a pre-emptive Total Allowable Catch (TAC) of 71,000 t for *I. illecebrosus* and *Doryteuthis* (*Amerigo*) *pealeii* (formerly *Loligo pealeii*) combined (Table 1). There is no TAC or fishery management plan for the either the commercial or recreational Northern shortfin squid fisheries that occur within the Canadian EEZ in SA 3 (Krista Baker, pers. comm.). Beginning in 1975, ICNAF established separate TACs of 25,000 t and 71,000 t for SA 3+4 and SA 5+6, respectively, for both squid species combined. During 1977-1979, TACs for Northern shortfin squid in SA 3+4 were increased by ICNAF and NAFO from 25,000 to 120,000 t, respectively, each time the TACs were exceeded (Lange, 1978). Despite a rapid decline in the catches from both Subarea 3 and Subarea 4 (following a 1979 time series peak catch of 162,092 t), which was followed by a collapse of the northern stock component in 1983, a TAC of 150,000 t remained in place for Subareas 3+4 during 1980-1998. The TAC was reduced to 75,000 t in 1999, and since 2000, the TAC has been 34,000 t.

The Subareas 5+6 stock component has been managed by the Mid-Atlantic Fishery Management Council since 1977 based on a Fishery Management Plan and annual fishery specifications that include establishing a TAC each year based on an Allowable Biological Catch (ABC). The southern stock component is not assessed annually. In contrast to the TACs for SA 3+4 since 1978, the TACs for Subareas 5+6 were set much lower (Table 1). The SA 5+6 TAC was set at 30,000 t during 1978-1995 based on the results from a yield-per-recruit model which is no longer valid because it is now known from aging studies that the species has a lifespan of less than one year. During 1996-2010, TACs for Subareas 5+6 consisted of the catches associated with either MSY-based biological reference points, or proxies thereof (e.g., %MSP) and were computed using several different methods. During 2000-2019, the SA 5+6 TAC ranged between and 22,915 t and 24,825 t. The TACs for Subareas 5+6 were exceeded during 1998, 2004, 2018 and 2019 (Table 1).

After 2002, assessments of the SA 3+4 stock component were conducted by the NAFO Designated Expert (DE) for Norther Shortfin Squid in Subareas 3+4 and reviewed by the NAFO Scientific Council on a three-year basis rather than following the previous annual assessment schedule. In the interim years, data sufficient for the Scientific Council to update the NAFO Commission with respect to TAC advice are provided in the form of Interim Monitoring Reports. However, there was no NAFO DE available to conduct the squid assessments during 2007-2009. Therefore, the Scientific Council used trends in the nominal catch data from SA 3+4 and the Div. 4VWX survey indices during 2006-2008 to assess stock status. As of 2010, the NAFO Squid DE has conducted stock assessments every three years and prepared Interim Monitoring Reports during the interim years. The most recent assessment was conducted in 2016 and included data through 2015 (Hendrickson and Showell, 2016). The subject assessment provides an evaluation of the status of the Subareas 3+4 stock component based on trends in commercial fishery data, research survey biomass indices and relative fishing mortality indices through 2018 as well as the 2019 survey biomass indices that were available as of the September 2019 assessment review of the Scientific Council.

2.0 Materials and Methods

2.1 Fishery Data

All catches presented herein represent nominal catches. Northern shortfin squid catches have been recorded from the Subarea 3 fishery since 1911 (Dawe, 1981) and from the Subarea 4 fishery since 1920 (ICNAF, 1973). Catches from the SA 5+6 fishery have been recorded since 1963. During the early 1970's, most Flag States reported their squid catches to ICNAF (i.e., the STALANT 21 Database) by species. However, squid catches in Subareas 5+6 from some Flag States were not reported by species (as either *I. illecebrosus* or *Doryteuthis pealeii*) during 1963-1977. Therefore, *I. illecebrosus* catches from Subareas 5+6 during this period were estimated based on prorated catch compositions for Flag States that reported their squid catches by species (Lange and Sissenwine, 1980). Nominal catches are presented for 1953-2018 from Subarea 3 and Subarea 4 and for 1963-2018 from Subareas 5+6. The three most recent years of all catch data are considered preliminary by the NAFO Scientific Council and were updated as needed.

Subareas 3+4

Northern shortfin squid catches from Subarea 3 include Canadian commercial fishery catches obtained from the Fishery Statistics Division of the Newfoundland Region of the Canada Department of Fisheries and Oceans (DFO, Krista Baker, pers. comm.) and catches reported in the NAFO STATLANT 21 Database for international squid fleets that fished in the NRA. The total catches from SA 3 are underestimated because reporting of the recreational catches within the Canadian EEZ, which can be greater than the commercial fishery catches during some years, is not required by the DFO (Krista Baker, pers. comm.)

Subarea 4 catches of *I. illecebrosus* were obtained from the NAFO 21 STALANT Database for international vessels that fished in the NRA and from the MARFIS Database maintained by the DFO (Maritimes Region). The MARFIS Database contains squid catches from Canadian vessels and international vessels with Canadian catch allocations. During 1987-1998, the Subarea 4 catches also included the kept fraction of Northern shortfin squid catches from the international mixed-species fishery for silver hake, *I. illecebrosus* and argentine that occurred in Canadian waters on the Scotian Shelf. These catches were obtained from the Maritimes DFO Observer Program Database during a period of 100% observer coverage of international fisheries and are considered highly accurate because the catch data were collected on a tow-by-tow basis by independent, trained scientific fishery observers (Showell and Fanning, 1999). Since 1999, Canada has not issued licenses for foreign-flagged vessels to fish in Canadian waters.

Subareas 5+6

Catches from Subareas 5+6 were obtained from the Commercial Fisheries Database (CFDBS) maintained by the Northeast Fisheries Science Center (NEFSC) of the U.S. National Marine Fisheries Service (NMFS). The source of the catch data are fishery dealer reports of the amounts of Northern shortfin squid purchased. Dealer reporting of squid landings became mandatory beginning in 1996. Prior to 1996, landings were recorded by NMFS port agents located at the major fishing ports and then entered into the CFDBS.

2.2 Research Survey Data

Fishery-independent indices of relative abundance and biomass were derived for Northern shortfin squid using data from seven stratified, random multi-species bottom trawl surveys; four conducted in Subarea 3 and three conducted in Subarea 4. All of the surveys incorporated stratified-random sampling designs with stratification based on depth. Surveys have been conducted by the Canada DFO in: Div. 3LNO (covering most of the Grand Banks) during the fall (mainly during October-December, since 1995) and spring (mainly during April-June, since 1996); in Div. 4T (southern Gulf of St. Lawrence) during September (since 1971); 4RS (northern Gulf of St. Lawrence) during August (since 1990); and in Div. 4VWX (Scotian Shelf and Bay of Fundy) during July (since 1970). Swept-area minimum biomass and abundance estimates were also derived from bottom trawl surveys conducted by the EU-Spain/Portugal in Div. 3M (Flemish Cap), during July (since 1988), and minimum biomass estimates in Div. 3NO (southern Grand Banks) primarily during June (since 2002).

Relative abundance and biomass indices were also derived for the SA 5+6 stock component using data from stratified random, multi-species bottom trawl surveys conducted by the NEFSC, between Cape Hatteras, North Carolina and the Gulf of Maine, mainly during September-October (since 1967). Sampling during all surveys was conducted around-the-clock with the exception of the Div. 3M and Div. 3NO surveys and the Div. 4T surveys, during 1971-1984, which were conducted during the daytime (between sunrise and sunset).

Subarea 3 – Divisions 3LNO

Relative abundance and biomass indices (stratified mean number and kg per tow, respectively) were derived for the spring (1996-2018) and fall (1995-2018) DFO bottom trawl surveys conducted in Div. 3LNO using data from the strata within which Northern shortfin squid were consistently caught (Hendrickson, 2006). Although the spring and fall surveys were also conducted prior to 1995, catches of *I. illecebrosus* were not consistently quantified (Earl Dawe, CA DFO, pers. comm.). The strata set used to compute the spring survey indices included: 328-337, 340, 344, 351-358, 361, 385-386, 392, 717-722, 724-727, 730, 734-736, 761,765, 769, 771, 773, 775, 784, 786, 789, 790, 792-793 and 800 (Fig. 2). The strata set used to compute the fall survey indices included: 332-337, 345, 348, 355-360, 364-366, 368-370, 374, 376-383, 385-392, 712, 717-718, 720-733, 735-736. For both spring and fall surveys, these strata sets cover a depth range of 30-731 m. Survey sampling designs, protocols and coverage are provided in Doubleday (1981), Healey et al. (2012) and Rideout and Ings (2019). Since 1995, a Campelen 1800 shrimp trawl has been used to conduct both surveys, but various survey vessels have been utilized. The Div. 3LNO spring surveys were conducted by the CCGS *Wilfred Templeman* during 1996-2008, but have since been conducted by the CCGS *Alfred Needler* (Healey et al., 2012). Both vessels are of the same design and are characterized as “sister” ships (Healey et al, 2012). Nevertheless, there are no vessel conversion factors available for *I. illecebrosus* for either of these vessels or the CCGS Teleost. In addition, length composition data were not collected for *I. illecebrosus* during either survey. In the future, length composition and maturity data collected during both surveys would be useful for stock assessment purposes. During 1995-2008, the Div. 3LNO fall surveys were conducted by the CCGS *Wilfred Templeman,* which sampled depths of 30-731 m. The CCGS *Teleost* sampled the deeper stations (depths of 732-1,460 m), as well as some of the shallow stations, but the CCGS Teleost data for tows greater than 731 m were not included in the fall survey indices for squid. The CCGS *Alfred Needler* also sampled some of the fall survey stations during 1996, 2001, 2005 and 2008. Since 2009, the fall surveys in Div. 3LNO have solely been conducted by the CCGS *Alfred Needler* and the CCGS *Teleost* (Healey et al., 2012).

Subarea 3 – Divisions 3NO

Swept-area biomass indices were derived for the NRA portion (“Nose” and “Tail” of the Grand Bank) of Div. 3NO (Fig. 2) using data from bottom trawl surveys conducted by the EU-Spain during June (2002-2019) and assuming a catchability factor of 1 (Gonzalez-Troncoso et al., 2019). The 2019 data are preliminary. The surveys were conducted in June by the R/V *Vizconde de Eza* using a Campelen 1800 shrimp trawl towed at 3 knots for 30 minutes (González-Costas et al., 2019a); the same trawl design that is used to conduct the CA DFO bottom trawl surveys in the Div. 3LNO (Walsh et al., 2001). Survey design and sampling protocols are described in Vázquez (2010) and Vázquez et al. (2013).The biomass indices were derived using data from strata 353-360, 374-382, 721-728 and 752-767 (Fig. 2), which include depths ranging from < 55-1,460 m. Swept-area abundance indices could not be computed because length composition data are not collected for *I. illecebrosus* during these surveys.

Subarea 3 – Division 3M

Survey abundance and biomass indices were also derived for the Flemish Cap, in Div. 3M, using data from bottom trawl surveys conducted by the EU-Spain/Portugal during 1988-2019. The 2019 data are preliminary. Survey design and sampling protocols are described in Vázquez (2010) and Vázquez et al. (2013). Strata 1-19 (depths of 120-730 m) were sampled during 1988-2002 and strata 1-25 and 28-34 (depths of 730-1,460 m) were sampled from 2003 onward (Fig. 3). All surveys were conducted during the daytime (0600-2200) and occurred primarily during July, but some sampling also occurred during June. A Lofoten bottom trawl was consistently used to conduct the surveys with a codend mesh size of 35 mm during most years (exceptions were the use of mesh sizes of 40 mm in 1994, 25 mm in 1998 and 30 mm in 1999; Vázquez, 2010). Different vessels have also been used to conduct the survey. During 1988 and 1991-2002, the surveys were conducted with the R/V *Cornide de Saavedra*, but two other vessels were used during 1989 and 1990. The R/V *Vizconde de Eza* replaced by the R/V *Cornide de Saavedra* in 2003 and has been used to conduct the surveys since then (Vázquez, 2010). Indices used in the assessment included swept-area biomass and abundance indices, derived for 1988-2019 with data from strata 1-19, which included the majority of *I. illecebrosus* catch data, and allowed for maximization of the length of both time series. Abundance indices could not computed for years when *I. illecebrosus* length data were not collected. Vessel conversion factors were computed using data collected during comparative fishing experiments between the two survey vessels during 2003 and 2004 (González-Troncoso, 2016). These conversion factors were applied to the *I. illecebrosus* biomass and abundance indices for 1988-2002 to standardize the entire time series.

Subarea 4 - Divisions 4VWX

Relative abundance and biomass indices (stratified mean number and kg per tow, respectively) for Div. 4VWX were derived, for 1970-2018, using survey catches from strata 440-495, encompassing a depth range of about 50-400 m on the Scotian Shelf and Bay of Fundy (Fig. 4). The survey design, gear characteristics, and sampling protocols are provided in Halliday and Koeller (1981). The surveys were conducted by the RV *A.T. Cameron,* with a Yankee 36 bottom trawl, during 1970-1981. A Western IIA bottom trawl has been used to conduct the surveys since 1982, but with several different vessels, including: the RV *Lady Hammond* (1982); CCGS *Alfred Needler* (1983-2003 and 2005-2015) and the CCGS *Teleost* during 2004 (Clark and Emberley, 2011). There are no gear or vessel conversion factors available with which to standardize the *I. illecebrosus* survey indices prior to 2004 (Fanning, 1985). However, during July of 2005, a comparative fishing study was conducted with the CCGS *Alfred Needler* and the CCGS *Teleost*. For Northern shortfin squid, Fowler and Showell (2009) found that the catchabilities of the two vessels were not significantly different at an α level of 0.05 (p = 0.095).

Subarea 4 – Divisions 4RS and Northern 4T

Relative abundance and biomass indices (stratified mean number and kg per tow, respectively) were derived using data from the Div. 4RS and Northern 4T bottom trawl survey (which also covered the northern part of Div. 4T), during 1990-2018, from all survey strata (Fig. 5A). The survey encompasses a depth range of 20-274 m in the northern Gulf of St. Lawrence. The survey was conducted using the *CCGS Teleost* rigged with Campelen 1800 shrimp trawl equipped with rockhopper footgear (McCallum and Walsh 2002). Standardized tows were conducted at 3.0 knots for 15 minutes. Details of the sampling design, gear characteristics and survey sampling protocols are provided in Bourdages et al. (2018).

Subarea 4 – Division 4T

Relative abundance and biomass (stratified mean number and kg per tow, respectively) indices for Div. 4T were derived, for 1971-2018, using data from offshore survey strata 415-439 (Fig. 5B), which encompass a depth range of 20-274 m in the southern Gulf of St. Lawrence. The sampling design, gear characteristics, and survey sampling protocols are provided in Halliday and Koeller (1981) and Hurlbut and Clay (1990). Surveys were conducted by the R/V *E.E. Prince* using a Yankee 36 trawl from 1971 to 1985, by the R/V *Lady Hammond* using a Western IIA trawl from 1985 to 1991 and by the CCGS *Alfred Needler* using a Western IIA trawl during 1992-2005. The survey has been conducted with the CCGS *Teleost* and a Western IIA trawl since 2006 (2008). The Div. 4T survey indices were adjusted for diel and vessel catchability differences for 1985-2002 (Benoît and Swain, 2003). During 2003, there was a reduction in the number of strata sampled and the CCGS *Wilfred Templeman* was used to conduct the survey, but there were no data available with which to adjust the 2003 indices for vessel catchability differences (Hugues Benoît, CA DFO, pers. comm.). During 2004-2005, comparative fishing experiments were conducted between the CCGS *Alfred Needler* and the CCGS *Teleost* (Benoît, 2006). However, there was not enough catch and length data available from these studies to determine whether there was a significant diel effect on *I. illecebrosus* catches between the two vessels (Hugues Benoît, pers. comm.).

Subareas 5+6

Relative abundance and biomass indices (stratified mean number and kg per tow, respectively) were derived for Subareas 5+6 using data from the fall bottom trawl surveys conducted by the Northeast fisheries Science Center. All offshore survey strata (depths of 27-366 m) located between the Gulf of Maine and Cape Hatteras, North Carolina, with the exception of strata 31-33 because these strata were not consistently sampled (Fig. 6). Survey design, sampling protocols and gear characteristics are described in Azarovitz (1981), for bottom trawl surveys conducted during 1963-2008, and in Politis et al. (2014) for bottom trawl surveys conducted since 2009. Indices for 2009 onward were adjusted for catchability differences between the RV *Albatross IV* and its replacement vessel, the RV *Henry B. Bigelow*, based on comparative fishing studies (Miller *et al*., 2010). Diel catch rate differences of *I. illecebrosus* were not significant at an α level of 0.05 for pre-2009 fall survey catches of *I. illecebrosus*, and therefore, diel conversion factors were not applied to the indices (Brodziak and Hendrickson, 1999).

2.3 Relative Fishing Mortality

Relative fishing mortality indices for Subareas 3+4 were computed, for 1970-2018, as the sum of the annual catches from Subareas 3+4 (in tons) divided by the annual biomass index from the July Div. 4VWX survey (in kg/tow) and the resulting value was then scaled by dividing it by 10,000.

2.4 Limit Reference Points

For data-poor stocks such as the Subareas 3+4 stock component, the NAFO Study Group on Limit Reference Points recommended that 85% of the maximum observed biomass index be used as a proxy for B_{lim}, assuming that the highest index is equal to B_{MSY} (SCS Doc. 04/12). For all NAFO stocks, F_{lim} is considered as F_{MSY} or a proxy thereof. However, like most squid species, *I. illecebrosus* is a sub-annual, semelparous species for which recruitment overfishing rather than growth overfishing is of most concern because annual stock size is dependent on the amount of recruitment that occurs within the same year. As a result, proportional spawner escapement is recommended for squid stocks (Basson et al., 1996), because like *I. illecebrosus*, most show high inter-annual variability in stock size because recruitment is strongly influenced by environmental conditions (Dawe et al., 2007).

Following record high relative fishing mortality indices in SA 3+4, during 1977-1982, this stock component collapsed in 1983 and remained in a low productivity state through 2017. Since the onset of the low productivity period, the magnitude of the Div. 4VWX July biomass index has not consistently reflected the magnitude of annual fishery removals in SA 3+4. Given this inconsistent biomass index response and the lack of a stock-recruitment relationship, limit reference point proxies for fishing mortality (F_{lim}) were developed for the SA 3+4 stock component (Rivard et al., 1998).

Management advice for the SA 3+4 stock component is provided by the Scientific Council Chairman to the Commission in September of each year, but for Northern shortfin squid, the advice is for three years and is based on benchmark assessment data The advice is based on whether the stock was in a low or high productivity state two years prior to the terminal year of data included in the stock assessment. The method used to compute potential yield only applies to a low productivity period (e.g., 1982-2017) and does not account for the effects of environmental conditions on yield. Furthermore, the yield estimate assumes that the 1976-1981 period of highest catches (and highest relative fishing mortality indices during 1977-1982) are appropriate for the low productivity period. Potential yields for the low productivity period were computed as: 1.) the average of the combined catches in SA 3+4 during 1976-1981*(average Div. 4VWX biomass index during 1982-1997/average biomass index during 1976-1981) = 19,000 tons and 2.) the sum of the catches in SA 3+4 during the 1979 peak*(average Div. 4VWX July biomass index during 1982-1997/the same biomass index during 1979) = 34,000 tons (Rivard et al. 1998). Both potential yields were assumed to represent limit reference points.

The current TAC of 34,000 t is the maximum potential yield associated with an F_{lim} proxy which the northern stock component may be able to sustain under the low productivity regime that followed the collapse of the SA 3+4 stock component in 1983 (Rivard et al., 1998; Hendrickson and Showell, 2016). However, this TAC does not account for the underlying stock dynamics (e.g., effects of environmental conditions on stock size and migration rates between Subareas) and also assumes that the high relative fishing mortality indices that occurred during 1977-1982 were appropriate for the low productivity regime.

Real-time management is advisable for sub-annual squid stocks, but this such an assessment is not possible for the *I. illecebrosus* stock due to assessment data limitations, the shared transboundary nature of the stock (between the USA, CA and NAFO Contracting Parties) and the requirement to provide stock status advice to fishery managers for the subsequent three years beginning two years after the terminal year of data from the benchmark assessments (e.g., provide stock status advice in 2019 for 2020-2023 based on data from 2018).

3.0 Results and Discussion

3.1 Catches

Subarea 3

Northern shortfin squid catches from Subarea 3 are underestimated because Canadian recreational catches of squid harvested off Newfoundland, which can be much greater than Canadian commercial catches of squid during some years, are not recorded in the DFO landings database and the fishery is not managed (Krista Baker, pers. comm.). Although Canadian commercial jig fishery catches are recorded in the DFO landings database, the fishery is not subject to annual quotas and is not managed (Krista Baker, pers. comm.). Consequently, commercial squid catches may also be underestimated. For example, the 2018 catch from Subarea 3 was very low, 1,476 t (Table 1), despite the fact that the 2018 spring survey abundance index for Northern shortfin squid in Div. 3LNO was the highest on record (Fig. 9).

Since 1953, catches in Subarea 3 have been predominately from the Newfoundland inshore jig fishery, which expanded during the 1950's as a result of new markets and again after 1964, with the use of Japanese mechanized jigs (Dawe, 1981). Although international bottom and midwater trawl occurred offshore in Subarea 3 during 1970-1979, the peak catch from these fisheries, 5,700 t in 1978, only comprised a small percentage (14%) of the total catch from Subarea 3 (Dawe, 1981). Small amounts of *I. illecebrosus* bycatch have occurred in Div. 3M (average = 12 t during 1976-2015) but there has never been a directed squid fishery there. Total catches from Subarea 3 increased rapidly during the 1970's, from 3,751 t in 1975 to a peak of 88,833 t in 1979. Thereafter, catches decreased rapidly to 5 t in 1983 (Table 1, Fig. 7). Since 1983, catches from Subarea 3 have been highly variable and predominately from the inshore jig fishery. During 1987-1997, catches ranged from 48 t in 1995 to 12,748 t in 1997; the highest level since 1981. However, catches were much lower since then, with the exception of 2006. During 1998-2005 catches were highly variable and averaged 699 t. The largest catch from Subarea 3 since 1997 occurred in 2006 (6,957 t). During 2009-2012, catches declined from 676 t in 2009 to no catch during 2012-2015. Thereafter, catches increased from 134 t in 2016 to 1,476 t in 2018; the highest level since 2006. Such a low catch in 2018 is odd because the spring Div. 3LNO abundance and biomass indices reached record highs during 2018 (Fig. 9). High abundance of squid on the Grand Banks during 2018 was also supported by the fact that directed fishing was conducted by a Spanish vessel in Div. 3O (catch = 145 t) during 2018 (González-Costas et al., 2019b). During 2018, the ex-vessel value of Canadian commercial squid catches was $1.94 CDN/kg ($0.88 CDN/lb) and a total value of $2.3 million CDN (http://www.nfl.dfo-po.gc.ca/publications/reports_rapports/Land_All_Vessels_Debarquer_Tous_Les_ Navires_2018_eng.htm).

Subarea 4

Catches in Subarea 4 increased rapidly, from 13,945 t in 1975 to a peak of 73,259 t in 1979, with the development of international bottom trawl and midwater trawl fisheries on the Scotian Shelf (Amaratunga et al., 1978). However, the 1979 peak in catch was followed by a rapid decrease to 1,744 t in 1982 and a collapse of the fishery in 1983 with catch of only 421 t (Table 1, Fig. 7B). During 1983-1998, catches in Subarea 4 were primarily from the international mixed-species fishery for silver hake, argentine and *I. illecebrosus* and ranged between 110 t and 6,535 t. Since 1999, there has been no directed fishery for *I. illecebrosus* in SA 4 (NAFO, 2003). Since 2000, SA 4 catches have been primarily from bycatch in the Canadian small-mesh bottom trawl fishery for silver hake and have generally totaled less than 50 t (Table 1). Small amounts of *I. illecebrosus* bycatch by international vessels have also occurred; 12 t in 2000 and 4 t in 2003 by Russia (NAFO, 2003) and 13 t in 2005 by Korea (T.-Y. Oh, National Fisheries Research and Development Institute, Korea, pers. comm.). During 2000-2010, catches from the NRA averaged 29 t, and following a slight increase to 38 t in 2011 catches decreased to the lowest level of the time series; 14 t in 2015 (Hendrickson and Showell, 2016). The 2018 catch was 70 t.

Beginning in 2004, a majority of the squid catches in the STATLANT 21A Database, from the Scotia-Fundy Region, were listed as either *Loligo pealeii* (now known as *Doryteuthis pealeii*) or "unspecified squid" (i.e., the latter designation represents either "Ommastrephidae sp. or Loliginidae sp. of squid"). The *D. pealeii* catches totaled 102 t in 2004 and 240 t in 2005. The "unspecified squid" catches were very high during 2008 (2,154 t), 2009 (1,821 t), and 2011 (1,110 t). However, these catches were not recorded in the official Canadian database (MARFIS) for the Scotia-Fundy Region and did not appear in the STATLANT 21B Database. Discussions with the MARFIS Database staff from the Maritimes Region, as well as the NAFO database staff, did not resolve the issue. Catch data from the MARFIS Database were included in this stock assessment because they were considered more accurate because, since 1999, there has not been a directed fishery in Subarea 4 because foreign-flagged vessels have not been licensed to fish within the Canadian EEZ. Based on the fact that very small catches of *D. pealeii* occurred infrequently in the July Div. 4VWX surveys, and that small amounts of *L. pealeii* were reported as such in the MARFIS Database, the small amounts of "unspecified squid" catch included in the MARFIS Database (0.001-22 t during 2006-2015) were considered to be *I. illecebrosus* catches.

Subareas 3+4

During 1975-1979, Northern shortfin squid catches increased rapidly in Subareas 3+4 with the development of an international offshore fishery and increased catches in the inshore jig fishery in Subarea 3 (Dawe, 1981) and international offshore fisheries in Subarea 4 (Amaratunga et al., 1978).

Catches in Subareas 3+4 increased during the 1970s and reached a peak of 162,092 t in 1979 (Table 1, Fig. 7A). With the exception of 1979, the period of highest catches in SA 3+4 (1975-1980) were from SA 4. During 1976-1981, total catches from the stock (Subareas 3-6) were predominately from Subareas 3+4; averaging 80,645 t in Subareas 3+4 and 19,661 t in Subareas 5+6. Following the 1979 peak, Subareas 3+4 catches declined rapidly and the Subareas 3+4 fishery collapsed in 1983. Catches in Subareas 3+4 totalled less than 1,000 t during 1983-1988 (Table 1, Fig. 7B). Catches during 1989-1996 averaged 4,984 t then reached their highest level since 1981 in 1997 (15,614 t) and were primarily from the Subarea 3 inshore jig fishery (12,748 t). Partially due to the lack of a directed fishery in SA 4 since 1999, catches during 1999-2017 were low and highly variable, averaging 770 t. the highest and lowest catches during this time period were 6,981 t in 2006 and 14 t in 2015 (Table 1, Fig. 7B). The SA 3+4 catch in 2018 was 1,546 t.

Subareas 5+6

During 1964-1966, the Russian fishing fleet began landing Northern shortfin squid in Subareas 5+6. Directed bottom and midwater trawl fisheries, by international fleets (mainly Japan, Spain, Italy, Russia, and Poland), developed in 1967 (Lange and Sissenwine 1980) and occurred through 1986 (NEFSC, 1999). During this time period, total catches for Subareas 5+6 increased rapidly to a peak of 24,936 t in 1976 (Table 1, Fig. 7A). Since 1987, the directed fishery has consisted solely of domestic bottom trawlers (NEFSC 1999). During 1987-1997, catches were generally in the range of 10,000-18,000 t. Domestic fishery catches reached a peak of 26,922 t in 2019, but the fishery was closed on August 21 because 95% of the TAC (24,825 t) was harvested and the TAC was exceeded. During 1999-2003, catches from Subareas 5+6 ranged from 2,750 t in 2002 to 9,011 t in 2000. The fishery was also closed early during 1998 and 2004 when 95% of the respective quotas were harvested (Table 1). During 2005-2012, catches averaged 14,453 t, but were much lower during 2013-2016 and averaged 5,416 t. During 2017-2019, catches were very high and increased from 22,526 t in 2017 to 26,922 t (preliminary) in 2019. The 2019 catch was the highest on record for the domestic fishery and was, in part, attributable to an increase in the quota from 22,915 t to 24,825 t. The fishery was closed early during 2017-2019 due to harvesting 95% or more of the respective annual quotas Table 1).

3.1.4 Subareas 3-6

The timing and duration of the Northern shortfin squid fisheries vary by Subarea, mainly due to availability and a regulatory fishery start date of July 1 for Subareas 3+4 beginning in 1979 (NAFO, 1999). During 1992-2001, most of the catches in the Subarea 4 and Subareas 5+6 fisheries occurred during June-October, with peak catches during July. During this same time period, the Subarea 3 fishery has generally occurred about one month later, during July-November, with peak catches during September (Hendrickson *et al.*, 2002).

Total catches from Subareas 3-6 increased rapidly from 4,211 t in 1970 to a time series peak of 179,333 t in 1979, but then declined rapidly to 6,788 t in 1985 (Table 1, Fig. 7A). Total catches declined further to 2,769 t in 1988, but then increased to 28,970 t in 1997. Since 1998, catches in Subareas 3-6 have been predominately from the Subareas 5+6 fishery. During 2004, the Subareas 3-6 catches (28,671 t) reached the second highest level since 1982. During 2008-2012 and 2013-2016, total catches averaged 16,439 t and 5,470 t, respectively. Catches reached their highest levels since 2004 during 2017 (22,881 t) and 2018 (25,663 t).

3.2 Survey Abundance and Biomass Indices

Of the three research surveys with the longest time series (i.e., surveys in Div. 4VWX, Div. 4T, Div. 4RS; Tables 2 and 3, Figs. 8-10), the Div. 4VWX survey represented the best indicator of Northern shortfin squid biomass in Subareas 3+4 because the survey occurs within Subarea 4 during July, when the species is most available in the continental shelf survey area. In addition, the Div. 4VWX survey occurs prior to the Subarea 3 fishery and nearest to the start of the fisheries in Subareas 4-6. The Div. 4VWX survey also covers a large portion of the shortfin squid habitat in Subareas 3+4. Although the Div. 4RS survey also occurs during a time of high availability to the survey, it covers a smaller area and occurs later (August) than the Div. 4VWX survey. Indices for the surveys conducted in Div. 3M (July) and Div. 3LNO (April-June) can also be considered as measures of pre-fishery biomass for the Subarea 3 fishery, these time series are shorter than the Div. 4VWX biomass indices. Indices for the autumn surveys conducted in Subareas 5+6 (Sept-Oct), Div. 4T (Sept) and Div. 3LNO (Oct-Dec) can be considered as measures of post-fishery biomass because they occur near the end or after the directed fisheries in Subareas 3-6, particularly since 1998, when the total catches from all Subareas have been predominately from the Subareas 5+6 fishery (which ends in October during most years).

3.2.1 Subareas 3+4

The Div. 4VWX biomass indices and the precision (%CVs ranged from 17-72%) of these estimates showed a high degree of variability. However, some trends were evident. A period of high productivity occurred during 1976-1981, averaging 13.2 kg/tow (average %CV = 31%), followed by low productivity periods during 1970-1975 and 1982-2017, averaging 2.0 kg/tow (average %CV = 35%) and 3.0 kg/tow (average %CV = 36%), respectively (Table 2, Fig. 8). During the 1982-2017 low productivity period, the biomass index was highest in 2017 (16.1 kg/tow) and second highest in 2004 (12.9 kg/tow). However, spikes in the biomass indices (e.g., during 2004 and 2006) were followed by very low indices during the subsequent year; 0.7 kg/tow in 2005 and 1.5 kg/tow in 2007. The estimate of the 2004 biomass index was very imprecise (%CV = 65%), but the 2006 index was not (%CV = 29%). This post-1981 trend of infrequent, single-year spikes in the biomass indices has been occurring for the past 35 years and it is difficult to determine whether the spikes represent a true signal or are simply noise in the time series. During the 2018 interim assessment, it was assumed that this same pattern would be repeated and that the high 2017 biomass index would be followed by a low biomass index in 2018. Consequently, the conclusion of the interim assessment was that the SA 3+4 stock component remained in a low productivity state during 2017. Biomass indices generally declined after 2004 and were below the 1982-2017 low productivity period average (3.0 kg per tow) during most years for 2007-2016. However, during 2018, the CA DFO survey vessel had mechanical problems and the Div. 4VWX survey was only conducted in Div. 4X (the westernmost portion of the Scotian Shelf). As a result, the 2018 biomass index was not computed because a large portion of *I. illecebrosus* habitat was not sampled. However, the 2019 biomass index was computed and was the second highest value of the time series (32.1 kg per tow, %CV = 22%).

Biomass indices for the Div. 3LNO spring and fall surveys were very low compared to the biomass indices from all of the other surveys, and during 1996-2017, averaged 0.032 kg per tow and 0.049 kg per tow, respectively (Fig. 9). Only the fall survey indices for Div. 3LNO were presented because they were the higher of the two time series (Table 3). The low biomass indices for both Div. 3LNO surveys were likely due to low availability of the species to the spring and fall surveys because of migrations on and off the Grand Banks, respectively (Hendrickson, 2006). The species is distributed primarily in Div. 3O, along the southwest flank of the Grand Banks, during both spring and fall (Fig. 10). The biomass indices from both surveys were considered as good indicators of relative biomass in Subareas 3+4 only during high abundance years, such as during 2018, when the biomass indices from both surveys reached record high levels (Fig. 10). The Div. 3LNO biomass indices were also highly variable, and during 2019, the spring biomass index returned to a very low level similar to the 2017 value.

The Div. 3M bottom trawl survey of the Flemish Cap is also conducted primarily during July, but the survey covers a smaller area of *Illex* habitat than the Div. 4VWX survey. In addition, the Flemish Cap is more isolated from the continental shelf *Illex* habitat in Subarea 3 due to its location farther offshore and its separation from the Grand Banks by the deep waters of the Flemish Pass. An analysis of *Illex* catches in the 2003 and 2004 comparative fishing studies between the R/V *Cornide de Saavedra an*d the R/V *Vizconde de Eza* was indicated that the fit of the vessel conversion factor for relative biomass (1.279) was very good (R^2 = 0.8225, $p <$ 0.00001), but it was very poor (R^2=0.0113) for relative abundance (González-Troncoso, 2016). Consequently, *Illex* relative abundance indices could not be standardized, and therefore, were not presented here. The biomass indices from 1988-2002 were standardized by multiplying *Illex* catch weights from the R/V *Cornide de Saavedra* by 1.279. With respect to biomass, the R/V *Vizconde de Eza* was 28% more efficient at catching *Illex* than the R/V *Cornide de Saavedra* (González-Troncoso, 2016). The Div. 3M biomass indices were very low (< 100 t) during 1988-2018, with the exception of 1990-1991, 2006, 2008-2009 and 2018 (Table 4, Fig. 11). Only the strata < 730 m were included in the derivation of the biomass indices because catches of Northern shortfin squid at depths between 730 m and 1,460 m were low during most years and only accounted for an additional 1.5% in biomass on average during 2004-2015. Biomass indices were highest during 2006-2009, reaching a peak of 5,137 t in 2008 then declining to 1,363 t in 2009. However, these high biomass indices were not attributable to high squid biomass in strata deeper than 730 m, because the latter comprised only 0 to 0.4% of the annual biomass indices during this same time period. There were no catches of *Illex* during 2013 and 2015 and only 3 t in 2014. It is possible that the magnitude of the 3M survey indices are influenced by the timing of the annual inshore migration of the species which generally occurs during July (Dawe, 1981), however, the residence time of the species on the Flemish Cap is unknown. Trends in the Div. 3M biomass indices were similar to the trends in the Div. 4VWX biomass indices only during periods of high biomass in Div. 3M. This suggests that the Flemish Cap represents marginal *Illex* habitat in July during most years, but that the survey indices are useful biomass indicators for Subareas 3+4 when squid biomass is high on the Flemish Cap (Fig. 11). A similar *Illex* range expansion occurs in U.S. waters.

Similar to the Div. 4VWX survey biomass indices, the Div. 4T biomass indices were much higher during 1976-1981 than thereafter (Table 3, Fig. 8). There were no *Illex* catches in the Div. 4T survey during 2015 and biomass indices during 2013 and 2014 were very low, similar to the 2013-2015 biomass indices for Div. 4VWX. However, the 2018 biomass index was the second highest index of the low productivity period. Biomass indices for the Div. 4T and Div. 4VWX surveys were correlated with those for the Div. 4VWX surveys during 1970-1997 (Dawe and Hendrickson 1998), despite the fact that the 4T survey area covers only a small portion of Northern shortfin squid habitat in Subarea 4. The August survey conducted in Div. 4RS occurs one month earlier than the Div. 4T survey and both occur in the Gulf of Saint Lawrence. As expected, the biomass indices for these two surveys show similar trends (Fig. 12).

3.2.1 Subareas 5+6

Similar to the Div. 4VWX biomass indices, the Subareas 5+6 biomass indices were much higher during 1976-1981 (average = 5.7 kg per tow) than thereafter (1982-2017 average = 1.0 kg per tow), and since 1982, the biomass indices have been highly variable (Table 3, Fig. 8). Since 1982, the biomass indices have exhibited two general rise-and-fall periods. The first period included an increase to a peak of 3.3 kg per tow, in 1989, which was followed by a general decline through 1999. The second period included a biomass increase to the second highest level since 1982. The second peak occurred in 2006 (2.8 kg per tow), but it was followed by a decline to 0.5 kg per tow in 2010 and subsequent biomass indices have generally remained at this level. With respect to recent relative abundance indices, the 2003 (28.5 squid per tow) and 2006 (29.5 squid per tow) spikes were due to large catches at one or two stations. In contrast, during 1981 (a year during the high productivity period), the abundance index (27.1 squid per tow) was similar to the indices for 2003 and 2006, but the 1981 catch rates were high at many stations. The inter-annual variabilities of these post-fishery biomass and abundance indices are also affected by the timing of the species' annual off-shelf migrations (Hendrickson, 2004).

3.5 Mean Body Weight

Trends in squid mean body weight reflect the combined effects of emigration/immigration, recruitment, growth and mortality of these semelparous species (NEFSC, 1999; Hendrickson, 2004). For *I. illecebrosus*, environmental conditions have major influences on these factors (Dawe et al., 2007). Mean body weights were highest during the high productivity period (1976-1981 average = 150 g) and lower during the 1982-2017 low productivity period (average = 81 g) in the Div. 4VWX July surveys (Fig. 13A). Similarly, mean body weights in the Subareas 5+6 autumn surveys were highest during 1976-1981 (average = 295 g) and lower during 1982-2017 (average = 101, Fig. 13B). During 1982-1994, the mean body weight of squid caught in the Subareas 5+6 survey averaged 131 g and was generally above the low productivity period average, but then gradually declined through 2015 (average during 1995-2015 = 83 g) and was mainly below the average during 2000-2018 (Fig. 13B). Trends in mean body weights from the Div. 4VWX survey did not show the same gradual decrease. Since 1982, mean body weights fluctuated widely around the 1982-2017 low productivity period average, but were generally at or below the average (although increasing) during 1982-1996 and were generally above the average during 2002-2016 (Fig. 13A). During 2017 and 2019, the Div. 4VWX mean body weights reached the second highest and highest levels of the time series, respectively.

3.6 Relative Fishing Mortality Indices

Relative fishing mortality indices for Subareas 3+4 were highest during 1977-1982 and reached a peak of 4.20 in 1978. During 1976-1981, relative fishing mortality indices averaged 1.69 but were much lower during 1983-2014; averaging 0.12 with a peak of 0.96 in 1996 (Table 5, Fig. 14). The indices have consistently been below 0.12 since 2004, and during 2009-2018, were at the lowest levels of the time series.

3.7 Limit Reference Points

Potential yields during the low productivity period were previously computed as: 1.) the average of the combined catches in Subareas 3+4 during 1976-1981*(average Div. 4VWX biomass index during 1982-1997/average biomass index during 1976-1981) = 19,000 t and 2.) the sum of the catches in Subareas 3+ 4 during the 1979 peak*(average Div. 4VWX July biomass index during 1982-1997/the same biomass index during 1979) = 34,000 t (Rivard et al. 1998). Both potential yields were computed based on F_{lim} proxies of were assumed to represent limit reference points. Since 2000, the SA 3+4 quota has been set at 34,000 t; the highest of the two low productivity period potential yields, yet only 2.5% of this quota was harvested on average during 2000-2018 (Table 1). The highest percentage of harvested quota occurred in 2006 and only totalled 20.5%.

4.0 Summary

Two general levels of productivity have been identified for the Subareas 3+4 component of the Northern shortfin squid (*Illex illecebrosus*) stock based on trends in relative biomass indices and squid mean body weights derived from the July Div. 4VWX bottom trawl surveys and relative fishing mortality indices (Rivard *et al*., 1998; Hendrickson, 1999). A period of high productivity (1976-1981) occurred between two low productivity periods (1970-1975 and 1982-2017). During the high productivity period, relative biomass indices averaged 13.2 kg per tow and squid mean body weights averaged 150 g. During the 1982-2017 low productivity period, relative biomass indices averaged 3.0 kg per tow and squid mean body weight averaged 81 g.

During 2018, indices of relative biomass and mean body size for the Div. 4VWX surveys were unknown because much of the Northern shortfin squid habitat was not sampled, and therefore, the survey indices were not computed. However, the 2019 biomass index and mean body size values were the second highest of the time series and above the high productivity period average, respectively. The 2018 relative fishing mortality index remained very low in relation to the 1982-2017 low productivity period average. As a result, productivity state of the Subareas 3+4 stock component of Northern shortfin squid was unknown for 2018, but appeared to be moving toward a high productivity state based on the 2019 biomass index and mean body size. However, the 2019 indices were not available for all of the survey indices and spikes in the Div. 4VWX biomass indices have been followed by low values in the subsequent years. The existing 34 000 t quota for Subareas 3+4 is the higher of the two potential yields computed by Rivard et al. (1998), yet the highest percentage of the quota harvested since its adoption I 2000 was only 20.5%. Given the lack of 2018 productivity state metrics and the appearance that the northern stock component may be moving toward a high productivity state based on the 2019 biomass index and mean body size value, maintaining the existing quota is recommended for 2020, with a re-evaluation of the productivity state in 2021.

With respect to stock sustainability, unless quotas are established for the Canadian commercial inshore jig fishery, which is the primary source of catches in Subareas 3+4, the risk of overrunning any quota during years of high inshore squid abundance in Subarea 3 cannot be prevented. In addition, the total catches for Subarea 3 are underestimated because catches from the Canadian recreational jig fishery are not recorded.

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Table 1. Nominal catches (t) of *Illex illecebrosus* in NAFO Subareas 3 and 4 during 1953-2018 and Subareas 5+6 during 1963-2018. TACs (t) for Subareas 3+4 and Subareas 5+6 are shown for 1974-2018.

Year	Subarea 3[1] (t)	Subarea 4[2] (t)	Total Subareas 3+4 (t)	Subareas 5+6[3] (t)	Total Subareas (3-6)[4] (t)	TAC (t)[5] 3+4	TAC (t)[5] 5+6	% of TAC Harvested 3+4	% of TAC Harvested 5+6
1953	4,460	51	4,511		4,511				
1954	6,700	115	6,815		6,815				
1955	7,019	269	7,288		7,288				
1956	7,779	450	8,229		8,229				
1957	2,634	335	2,969		2,969				
1958	718	84	802		802				
1959	2,853	258	3,111		3,111				
1960	5,067	24	5,091		5,091				
1961	8,971	50	9,021		9,021				
1962	482	587	1,069		1,069				
1963	2,119	103	2,222	810	3,032				
1964	10,408	369	10,777	360	11,137				
1965	7,831	433	8,264	522	8,786				
1966	5,017	201	5,218	570	5,788				
1967	6,907	126	7,033	995	8,028				
1968	9	47	56	3,271	3,327				
1969	21	65	86	1,537	1,623				
1970	111	1,274	1,385	2,826	4,211				
1971	1,607	7,299	8,906	6,614	15,520				
1972	26	1,842	1,868	17,641	19,509				
1973	622	9,255	9,877	19,155	29,032				
1974	48	389	437	20,628	21,065		71,000		
1975	3,751	13,945	17,696	17,926	35,622		71,000	70.8	25.2
1976	11,257	30,510	41,767	24,936	66,703	25,000	30,000	167.1	83.1
1977	32,754	50,726	83,480	24,795	108,275	25,000	35,000	333.9	70.8
1978	41,376	52,688	94,064	17,592	111,656	100,000	30,000	94.1	58.6
1979	88,833	73,259	162,092	17,241	179,333	120,000	30,000	135.1	57.8
1980	34,780	34,826	69,606	17,828	87,434	150,000	30,000	46.4	59.4
1981	18,061	14,801	32,862	15,571	48,433	150,000	30,000	21.9	51.9
1982	11,164	1,744	12,908	18,633	31,541	150,000	30,000	8.6	62.1
1983	5	421	426	11,584	12,010	150,000	30,000	0.3	38.6
1984	397	318	715	9,919	10,634	150,000	30,000	0.5	33.1
1985	404	269	673	6,115	6,788	150,000	30,000	0.4	20.4
1986	1	110	111	7,470	7,581	150,000	30,000	0.1	24.9
1987	194	368	562	10,102	10,664	150,000	30,000	0.4	33.7
1988	272	539	811	1,958	2,769	150,000	30,000	0.5	6.5
1989	3,101	2,870	5,971	6,801	12,772	150,000	30,000	4.0	22.7
1990	4,440	6,535	10,975	11,670	22,645	150,000	30,000	7.3	38.9
1991	1,719	1,194	2,913	11,908	14,821	150,000	30,000	1.9	39.7
1992	924	654	1,578	17,827	19,405	150,000	30,000	1.1	59.4
1993	276	2,410	2,686	18,012	20,698	150,000	30,000	1.8	60.0
1994	1,954	3,997	5,951	18,350	24,301	150,000	30,000	4.0	61.2
1995	48	1,007	1,055	13,976	15,031	150,000	30,000	0.7	46.6
1996	8,285	457	8,742	16,969	25,711	150,000	21,000	5.8	80.8

Year	Subarea 3[1] (t)	Subarea 4[2] (t)	Total Subareas 3+4 (t)	Subareas 5+6[3] (t)	Total Subareas (3-6)[4] (t)	TAC (t)[5] 3+4	TAC (t)[5] 5+6	% of TAC Harvested 3+4	% of TAC Harvested 5+6
1997	12,748	2,866	15,614	13,356	28,970	150,000	19,000	10.4	70.3
1998	815	1,087	1,902	23,568	25,470	150,000	19,000	1.3	124.0
1999	19	286	305	7,388	7,693	75,000	19,000	0.4	38.9
2000	328	38	366	9,011	9,377	34,000	24,000	1.1	37.5
2001	23	34	57	4,009	4,066	34,000	24,000	0.2	16.7
2002	230	30	260	2,750	3,010	34,000	24,000	0.8	11.5
2003	1,087	46	1,133	6,391	7,524	34,000	24,000	3.3	26.6
2004	2,540	34	2,574	26,097	28,671	34,000	24,000	7.6	108.7
2005	548	30	578	12,013	12,591	34,000	24,000	1.7	50.0
2006	6,957	24	6,981	13,943	20,924	34,000	24,000	20.5	58.1
2007	230	16	246	9,022	9,268	34,000	24,000	0.7	37.6
2008	523	11	534	15,900	16,434	34,000	24,000	1.6	66.3
2009	676	42	718	18,418	19,136	34,000	24,000	2.1	76.7
2010	102	18	120	15,825	15,944	34,000	24,000	0.4	65.9
2011	88	50	138	18,797	18,935	34,000	23,328	0.4	80.6
2012	18	29	47	11,709	11,756	34,000	22,915	0.1	51.1
2013	0	27	27	3,792	3,819	34,000	22,915	0.1	16.5
2014	0	21	21	8,767	8,788	34,000	22,915	0.1	38.3
2015	0	14	14	2,423	2,437	34,000	22,915	0.04	10.6
2016	134	18	152	6,684	6,836	34,000	22,915	0.4	29.2
2017	313	52	365	22,516	22,881	34,000	22,915	1.1	98.3
2018	1,476	70	1,546	24,117	25,663	34,000	22,915	4.1	105.2
2019				26,922		34,000	24,825		108.4
AVERAGE									
1976-1981	37,844	42,802	80,645	19,677	100,322				
1982-2017	1,682	768	2,450	12,046	14,497				

[1] During some years, SA 3 catches include small amounts from Subarea 2.

[2] SA 4 catches from 1987 onward include catches recorded in the Canadian Observer Program and MARFIS Databases.

[3] During 1963-1977, squid catches that were not reported by species (as *Doryteuthis pealeii* or *Illex illecebrosus*) by Contracting Parties (CP or country) that fished in Subareas 5+6, including the USA, were prorated based on the ratio of the two species, by CP and year, for CPs that reported catches by species (Lange and Sissenwine, 1980).

[4] Catches from each Subarea are provisional during the last three years of the time series.

[5] TACs during 1974 and 1975, for Subareas 5+6, included *Doryteuthis (Amerigo) pealeii* and *Illex illecebrosus,* and during 1975-1977, 15,000 t and 10,000 t of *I. illecebrosus* were allocated to Russia and Canada, respectively. Countries without allocations were permitted to land 3,000 t from Subareas 3+4 (Dawe, 1981).

Table 2. Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow), and CVs (%), for *Illex illecebrosus* derived using data from the Div. 4VWX bottom trawl surveys conducted during July in Div. 4VWX during 1970-2018. Indices were derived using data from strata 440-495, with the exception of the 2018 indices.

Year	Number per tow	CV (%)	Kg per tow	CV (%)
1970	5.8	37	0.4	39
1971	27.6	39	2.8	38
1972	6.6	20	0.7	22
1973	10.9	57	1.5	61
1974	12.4	16	1.6	18
1975	44.8	35	5.0	34
1976	247.2	40	45.6	38
1977	50.9	28	9.5	31
1978	16.1	27	2.2	30
1979	94.2	20	14.6	22
1980	23.3	34	2.2	28
1981	35.5	34	4.9	36
1982	25.5	54	2.1	53
1983	77.0	60	2.1	55
1984	14.1	42	1.5	48
1985	81.0	70	2.7	55
1986	7.7	43	0.4	43
1987	4.9	33	0.4	37
1988	47.2	34	2.7	36
1989	25.4	26	2.5	28
1990	41.3	32	4.3	33
1991	27.1	22	1.8	21
1992	121.7	69	7.3	72
1993	79.0	42	5.4	29
1994	45.3	28	4.2	14
1995	34.5	36	2.5	35
1996	12.2	28	0.9	26
1997	53.5	34	5.0	38
1998	10.0	24	0.9	21
1999	17.0	38	2.1	36
2000	4.0	40	0.1	23
2001	3.3	31	0.2	35
2002	13.0	50	1.1	53
2003	12.1	39	0.9	36
2004	119.3	61	12.9	65
2005	9.6	38	0.7	38
2006	74.4	31	10.2	29
2007	15.4	28	1.5	31
2008	28.7	38	3.0	40
2009	69.9	39	6.0	38
2010	19.6	28	1.8	34
2011	23.4	31	1.9	27
2012	16.9	20	1.5	19
2013	1.4	23	0.1	17
2014	10.1	28	1.1	30
2015	2.4	31	0.2	39
2016	10.9	58	0.4	37

Table 2. (cont.)

Year	Number per tow	CV (%)	Kg per tow	CV (%)
2017	119.9	35	16.1	34
2018[1]	-	-	-	-
2019	196.1	20	32.1	22
AVERAGE				
1976-1981	77.9	30	13.2	31
1982-2017	35.5	38	3.0	36

[1] The 2018 indices were not computed because vessel mechanical issues prevented sampling a large portion of the *I. illecebrosus* survey strata set.

Table 3. Fall indices of relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow) for *Illex illecebrosus* based on data from bottom trawl surveys conducted in Subareas 5+6 (mainly Sept.-Oct., 1967-2018), Div. 3LNO (mainly Oct.-Dec., 1995-2018), and Div. 4T (Sept., 1971-2018). Relative abundance and biomass indices were not computed for the fall surveys conducted in Div. 3LNO during 2014 and in Subareas 5+6 during 2017 due to inadequate sampling of *I. illecebrosus* habitat because of survey vessel mechanical problems.

	Subareas 5+6		**Div. 3LNO**		**Div. 4T**	
Year	**Number per tow**	**Kg per tow**	**Number per tow**	**Kg per tow**	**Number per tow**	**Kg per tow**
1967	1.6	0.2				
1968	1.6	0.3				
1969	0.6	0.1				
1970	2.3	0.3				
1971	1.7	0.3			0.72	0.20
1972	2.2	0.3			0.05	0.02
1973	1.5	0.4			0.08	0.03
1974	2.8	0.4			0.06	0.02
1975	8.7	1.4			2.47	0.54
1976	20.6	7.0			30.77	8.29
1977	12.6	3.7			25.74	7.62
1978	19.3	4.5			52.83	15.04
1979	19.4	6.1			28.47	8.19
1980	13.8	3.3			18.05	4.61
1981	27.1	9.3			5.76	1.70
1982	3.9	0.6			0.39	0.13
1983	1.7	0.2			0.09	0.02
1984	4.5	0.5			0.04	0.02
1985	2.4	0.4			0.32	0.12
1986	2.1	0.3			0.12	0.01
1987	15.8	1.5			0.22	0.05
1988	23.2	3.0			1.33	0.42
1989	22.4	3.3			0.97	0.24
1990	16.6	2.4			1.37	0.29
1991	5.2	0.7			0.17	0.03
1992	8.2	0.8			0.65	0.11
1993	10.4	1.6			0.83	0.13
1994	6.8	0.9			0.79	0.18
1995	8.0	0.7	0.1342	0.0049	0.32	0.03
1996	10.8	0.9	0.1584	0.0183	1.09	0.19
1997	5.8	0.5	0.9824	0.1333	0.89	0.14
1998	14.6	1.4	0.4045	0.0851	1.34	0.30
1999	1.4	0.2	0.0079	0.0018	0.47	0.11
2000	7.4	0.7	0.3186	0.0303	0.27	0.03
2001	4.5	0.3	0.1669	0.0281	0.08	0.01
2002	6.4	0.4	0.6145	0.0879	0.11	0.02
2003	28.5	1.9	0.6964	0.1281	0.22	0.05
2004	5.1	0.4	0.0752	0.0178	1.61	0.37
2005	11.0	0.7	0.0923	0.0169	0.46	0.10
2006	29.5	2.8	0.5678	0.1704	2.33	0.54
2007	15.7	1.3	0.2196	0.0600	7.27	1.43
2008	10.4	1.0	0.1139	0.0275	0.53	0.10
2009	8.7	0.9	0.0142	0.0042	0.88	0.18
2010	10.0	0.5	0.0048	0.0002	0.86	0.18
2011	6.3	0.5	0.0032	0.0001	0.42	0.10

	Subareas 5+6		Div. 3LNO		Div. 4T	
Year	**Number per tow**	**Kg per tow**	**Number per tow**	**Kg per tow**	**Number per tow**	**Kg per tow**
2012	8.0	0.5	0.2162	0.0275	0.64	0.12
2013	4.7	0.4	0.0098	0.0017	0.11	0.01
2014	8.3	0.6	-	-	0.28	0.06
2015	9.5	0.5	0.0886	0.0062	0.00	0.00
2016	7.6	0.7	0.1117	0.0185	0.39	0.03
2017	-	-	0.9072	0.1616	1.35	0.28
2018	15.8	1.3	1.6480	0.2794	5.07	0.89
Average						
1976-1981	18.8	5.7			26.94	7.58
1982-2017	9.9	1.0			0.81	0.17
1996-2017			0.2750	0.0488		

Table 4. *Illex illecebrosus* minimum biomass (t) estimates derived from EU bottom trawl surveys conducted on the Flemish Cap (Div. 3M) during July, 1988-2018. Catches in survey strata 1-19 (depths ≤ 730 m) were used to derive the indices. Minimum biomass estimates for 1988-2002 were converted from R/V *Cornide de Saavedra* units to R/V *Vizconde de Eza* units. Minimum abundance estimates are not presented because a vessel conversion factor for abundance is not available.

Year	Biomass (t)	SE
1988	6	4
1989	9	4
1990	2,107	604
1991	1,483	395
1992	83	18
1993	1	1
1994	269	33
1995	1	1
1196	113	15
1997	81	12
1998	92	12
1999	22	4
2000	3	1
2001	10	3
2002	8	3
2003	222	60
2004	470	55
2005	79	8
2006	3,541	1,244
2007	411	64
2008	5,137	2,392
2009	1,688	346
2010	43	7
2011	89	19
2012	38	8
2013	<1	
2014	3	1
2015	< 1	
2016	3	1
2017	2,359	490
2018	49	6
2019	363	50
Average 1988-2017	612	

Table 5. Relative fishing mortality indices (SA 3+4 nominal catch/Div. 4VWX July survey biomass index) of Northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 during 1970-2018. Indices were divided by 10,000 to scale the values.

Year	SA 3+4 Nominal Catch (t)	Div. 4VWX July Survey Biomass Index (kg/tow)	Relative Fishing Mortality Index
1970	1,385	0.4	0.34
1971	8,906	2.8	0.32
1972	1,868	0.7	0.29
1973	9,877	1.5	0.65
1974	437	1.8	0.03
1975	17,696	5.0	0.36
1976	41,767	45.6	0.09
1977	83,480	9.5	0.88
1978	94,064	2.2	4.20
1979	162,092	14.6	1.11
1980	69,606	2.2	3.21
1981	32,862	4.9	0.67
1982	12,908	2.1	0.61
1983	426	2.1	0.02
1984	715	1.5	0.05
1985	673	2.7	0.02
1986	111	0.4	0.03
1987	562	0.4	0.14
1988	811	2.7	0.03
1989	5,971	2.5	0.24
1990	10,975	4.3	0.26
1991	2,913	1.8	0.17
1992	1,578	7.3	0.02
1993	2,686	5.4	0.05
1994	5,951	4.2	0.14
1995	1,055	2.5	0.04
1996	8,742	0.9	0.96
1997	15,614	5.0	0.31
1998	1,902	0.9	0.20
1999	305	2.1	0.01
2000	366	0.1	0.28
2001	57	0.2	0.02
2002	260	1.1	0.02
2003	1,133	0.9	0.13
2004	2,574	12.9	0.02
2005	578	0.7	0.09
2006	6,981	10.2	0.07
2007	246	1.5	0.02
2008	534	3.0	0.02
2009	718	6.0	0.01
2010	120	1.8	0.01
2011	138	1.9	0.01
2012	47	1.5	< 0.01
2013	27	0.1	0.05
2014	21	1.1	< 0.01
2015	14	0.2	0.01

Year	SA 3+4 Nominal Catch (t)	Div. 4VWX July Survey Biomass Index (kg/tow)	Relative Fishing Mortality Index
2016	152	0.4	0.04
2017	365	16.1	<0.01
2018	1,546	11.6	0.01
Average			
1976-1981	80,645	13.2	1.69
1982-2017	2,450	3.0	0.11

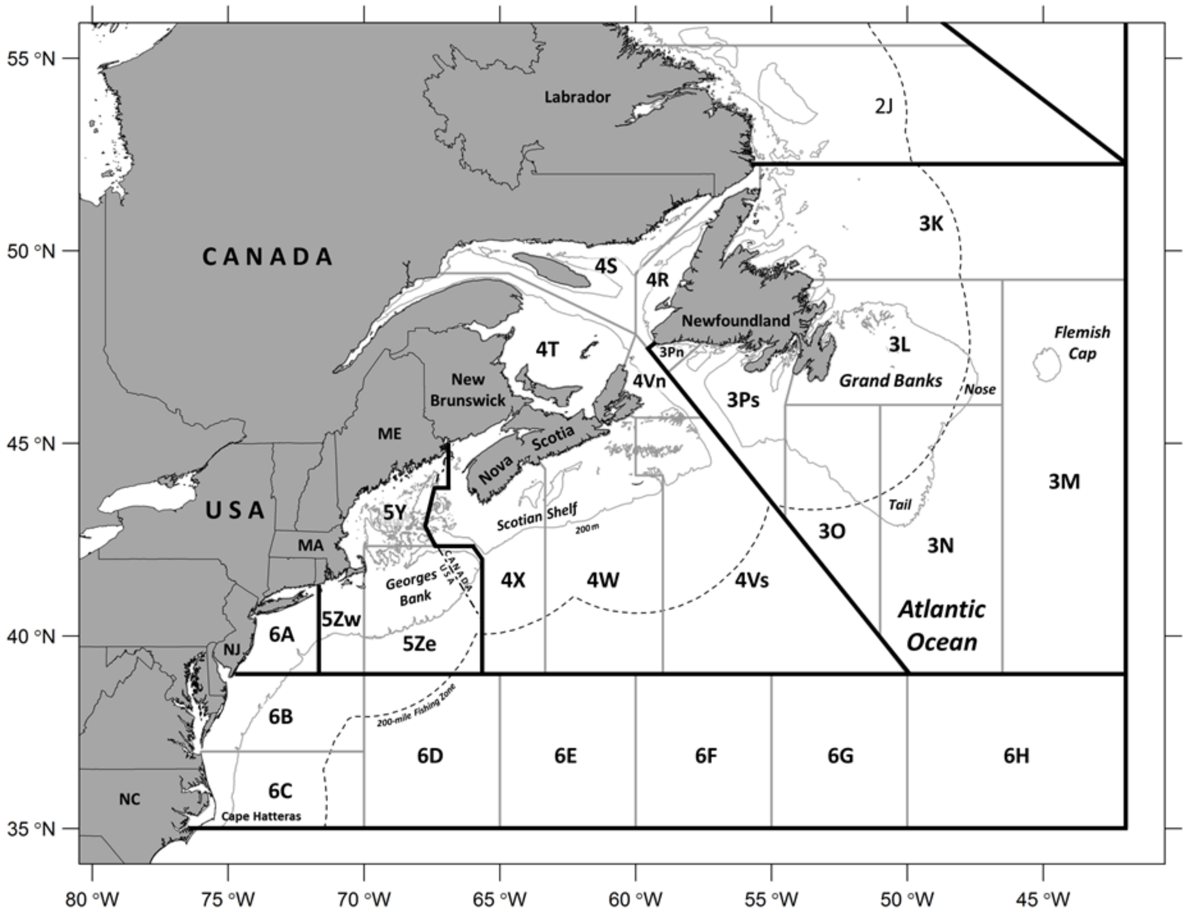

Figure 1. Northwest Atlantic Fisheries Organization (NAFO) nominal catch reporting areas, Subareas 3-6 (thick black lines) and associated Divisions (grey lines), for fisheries operating in the Northwest Atlantic Ocean. Fishing that occurs in portions of Divisions located seaward of the 200-nautical mile Exclusive Economic Zones (EEZs, dashed line) of the USA and Canada are regulated by NAFO.

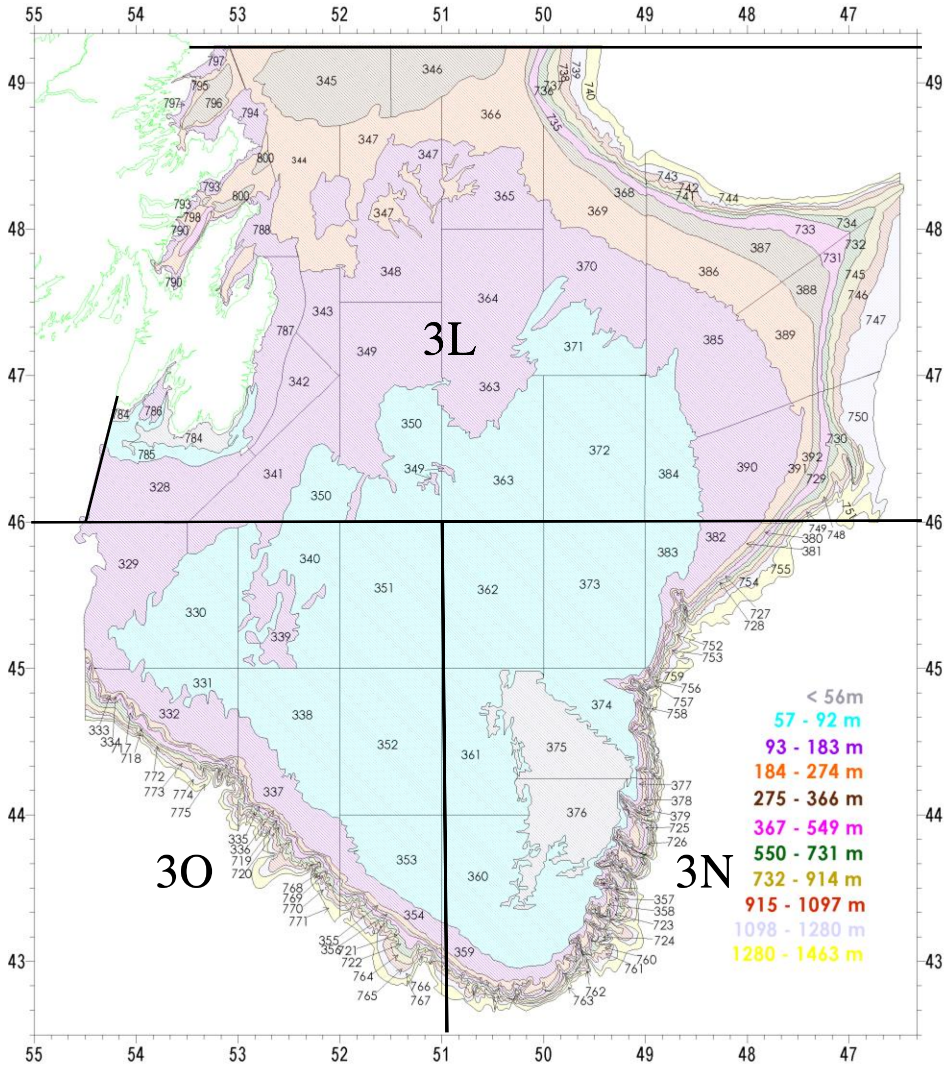

Figure 2. Depth strata sampled during spring and fall bottom trawl surveys conducted in Divisions 3LNO by the Canada Department of Fisheries and Oceans and during summer bottom trawl surveys conducted in Divisions 3NO by the EU-Spain (from Rideout and Ings, 2019).

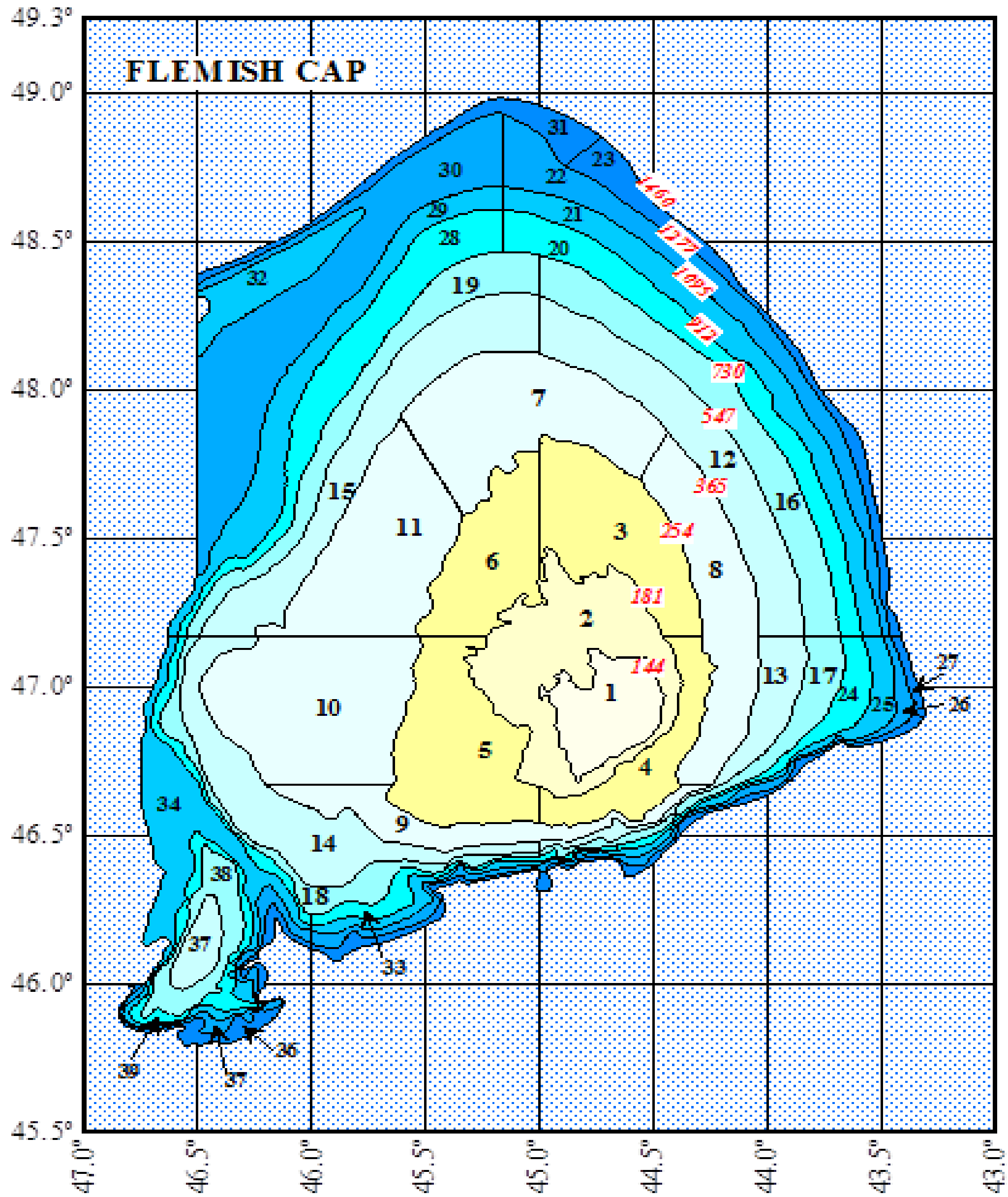

Figure 3. Depth strata sampled during bottom trawl surveys conducted by the European Union (EU-Spain/Portugal) on the Flemish Cap, in Division 3M, primarily during July. Strata 1-19 (depths of < 44-730 m) were sampled during 1988-2003 and strata 1-25 and 28-34 (depths of < 44-1,460 m) were sampled from 2004 onward.

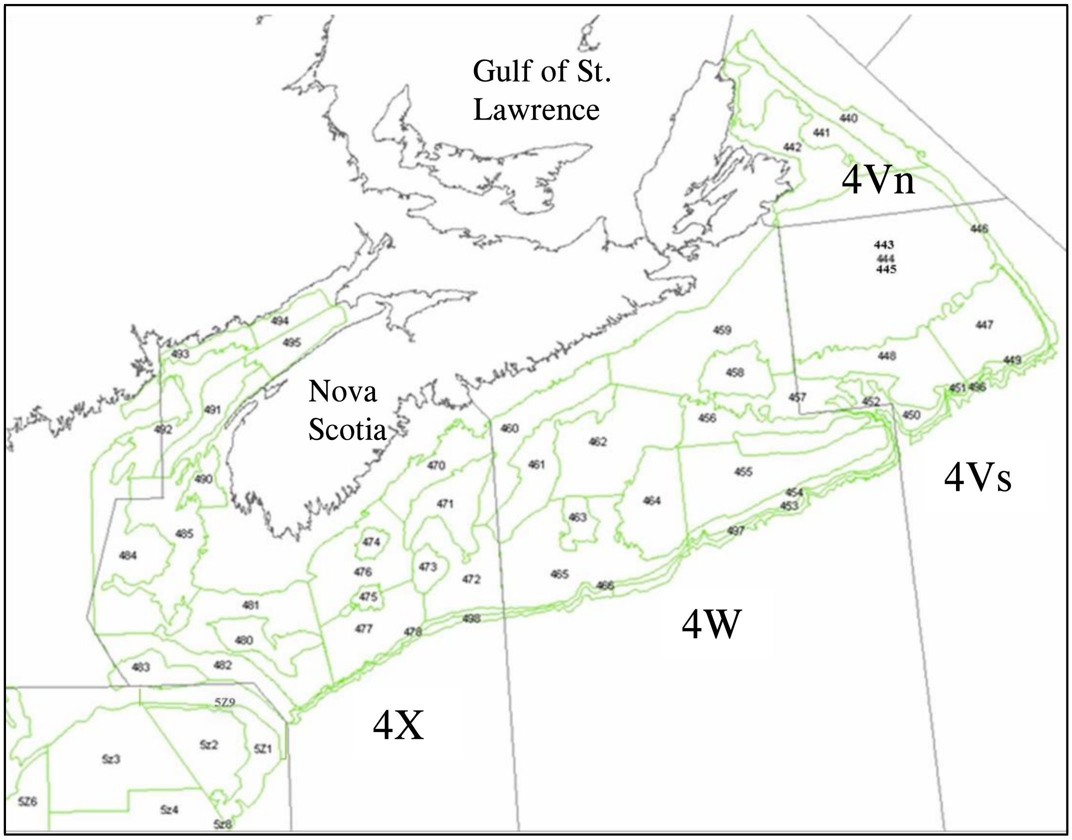

Figure 4. Depth strata sampled during bottom trawl surveys conducted in Division 4VWX (the Scotian Shelf and Bay of Fundy), by the Canada Department of Fisheries and Oceans, during July, 1970-2018.

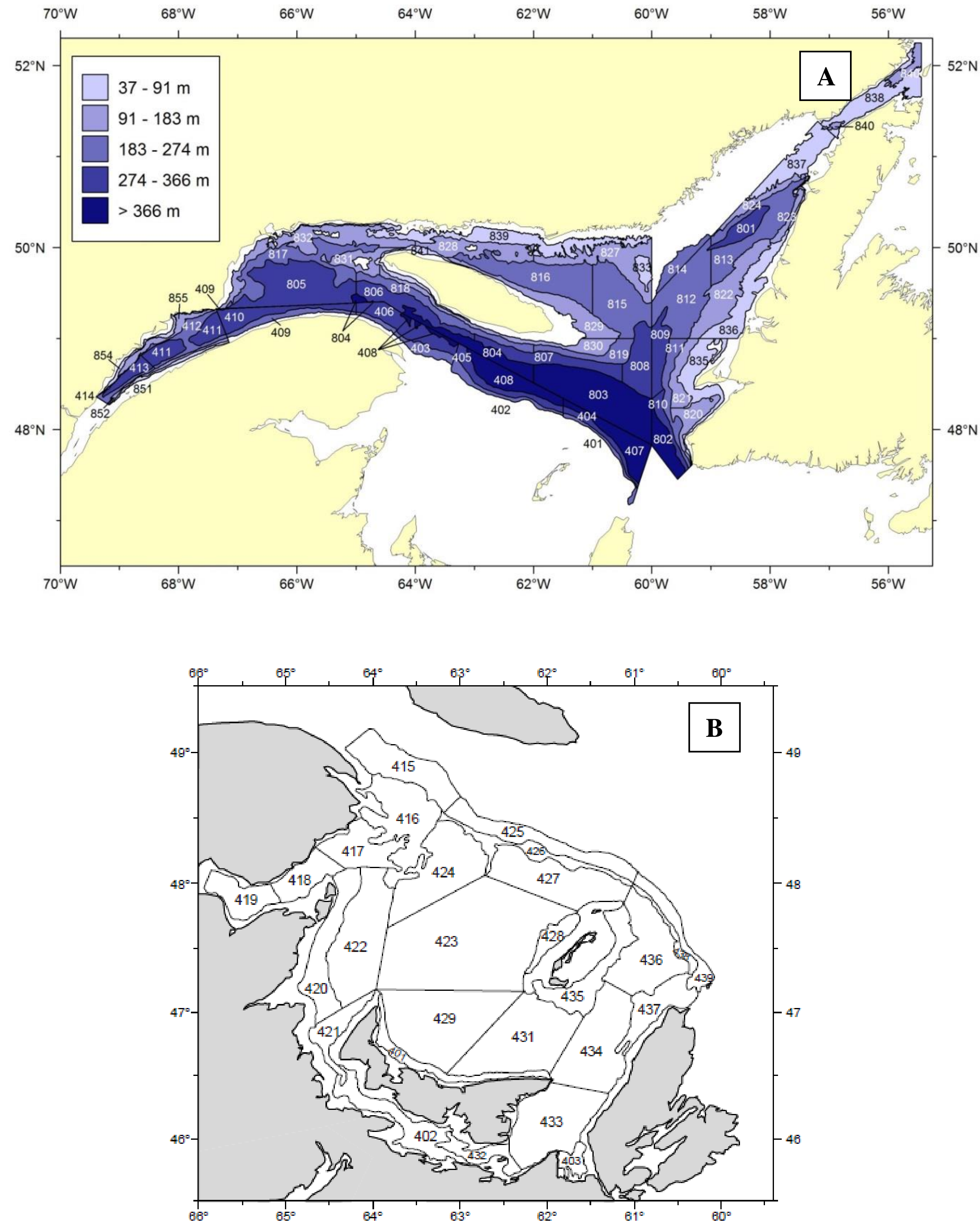

Figure 5. Depth strata sampled during bottom trawl surveys conducted in (A) Division 4RS (northern gulf of St. Lawrence and northern part of 4T) during August (from Bourdages et al., 2018) and in (B) Division 4T (southern Gulf of St. Lawrence) during September by the Canada Department of Fisheries and Oceans.

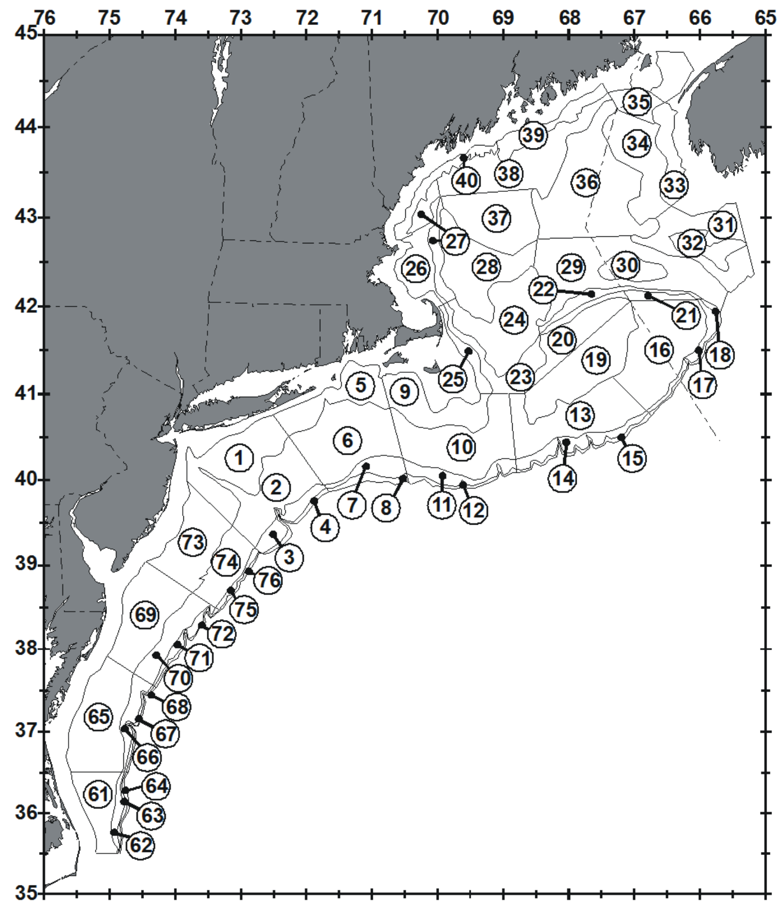

Figure 6. Offshore depth strata (27-366 m) sampled during fall bottom trawl surveys conducted off the East Coast of the USA, in NAFO Subareas 5+6, by the U.S.A. (Northeast Fisheries Science Center).

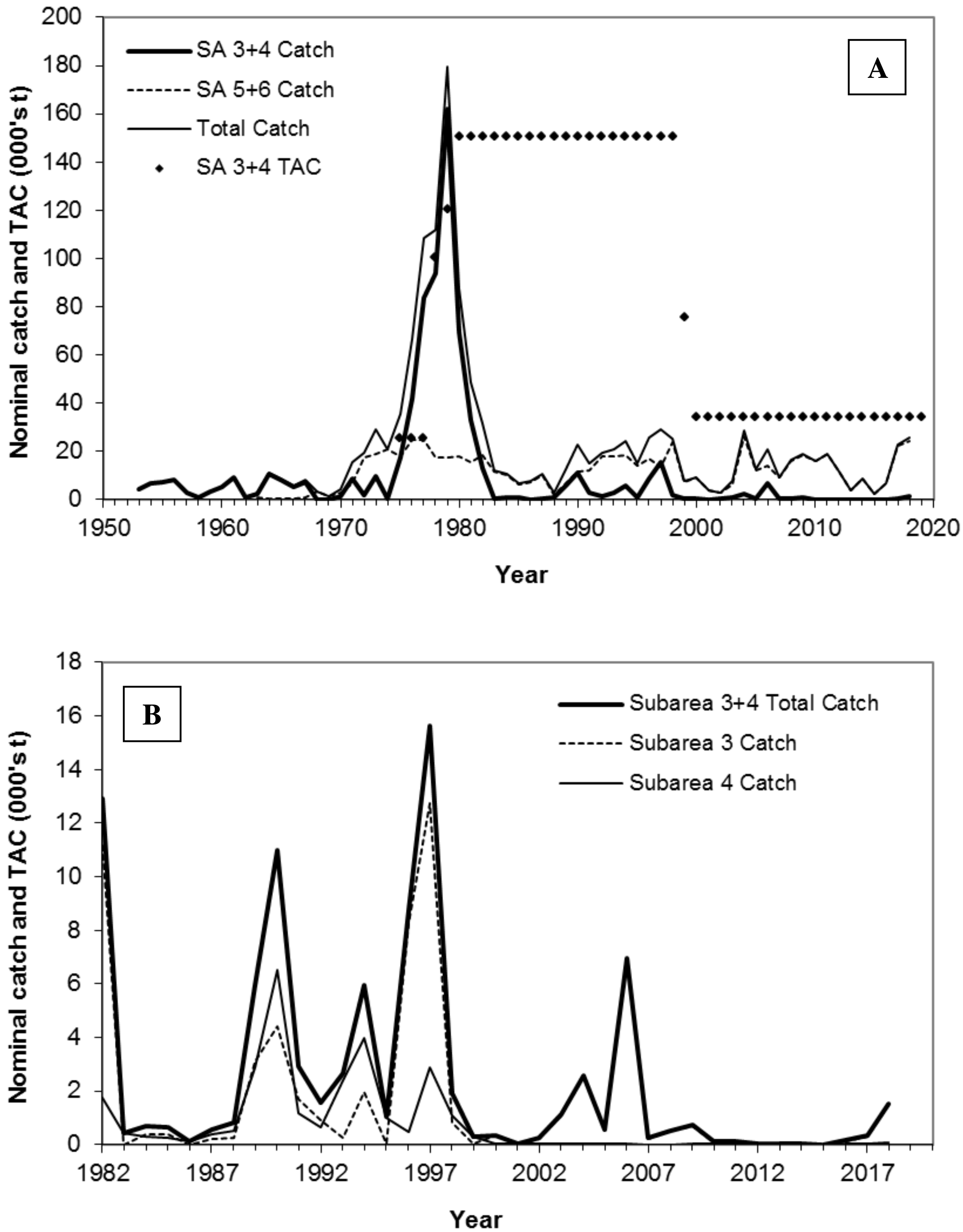

Figure 7. Nominal total catches (000's t) of *Illex illecebrosus* and TACs (000's t) in (A) Subareas 3+4 (SA 3+4) during 1953-2018, and in Subareas 5+6 (SA 5+6) during 1963-2018, and nominal catches in (B) Subarea 3 and Subarea 4 during 1982-2018.

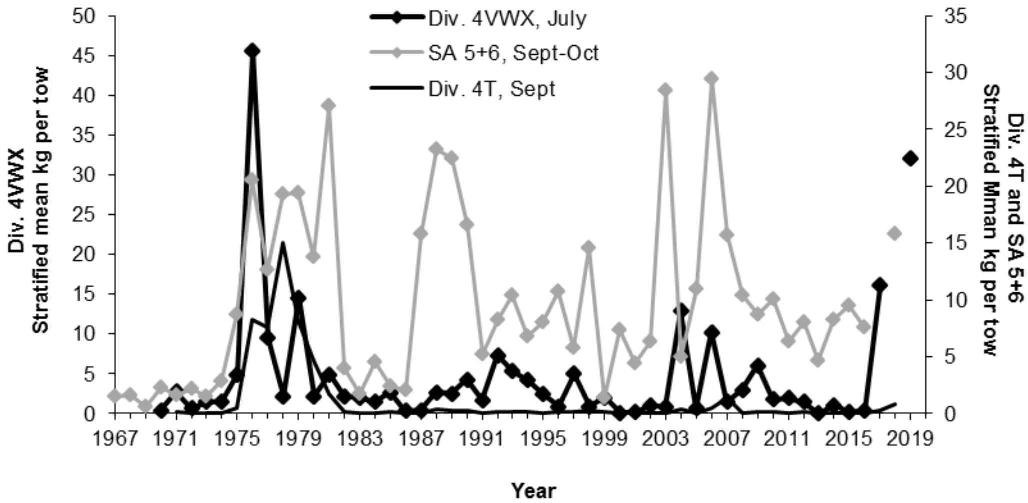

Figure 8. *Illex illecebrosus* relative biomass indices (stratified mean kg per tow, bottom) derived using data from the Canadian bottom trawl surveys conducted in Div. 4VWX (July, 1970-2019) and Div. 4T (September, 1971-2018) and from bottom trawl surveys conducted by the USA in Subareas 5+6 (September-October, 1967-2018).

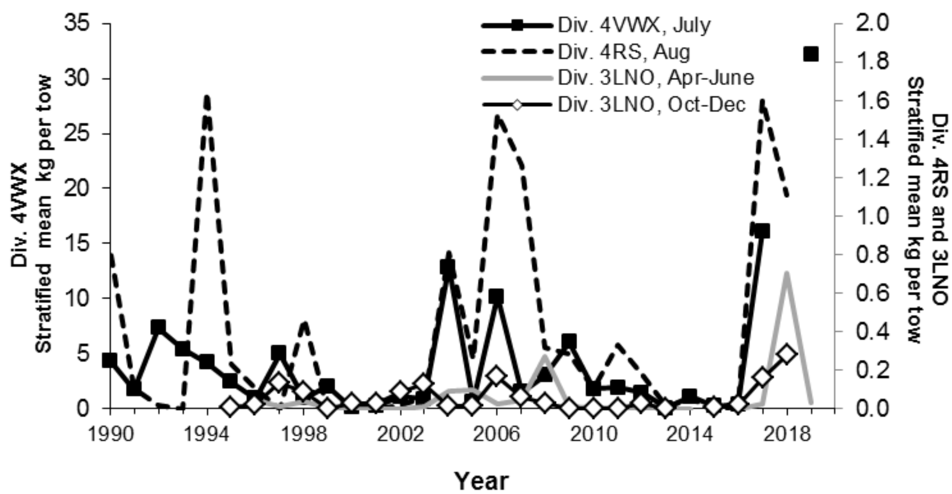

Figure 9. *Illex illecebrosus* relative biomass indices (stratified mean kg/tow, bottom) derived using data from the Canadian bottom trawl surveys conducted in Div. 4VWX (July, 1990-2019), Div. 4RS (August, 1990-2018) and Div. 3LNO during spring (April-June, 1996-2019) and fall (Oct-Dec, 1995-2018).

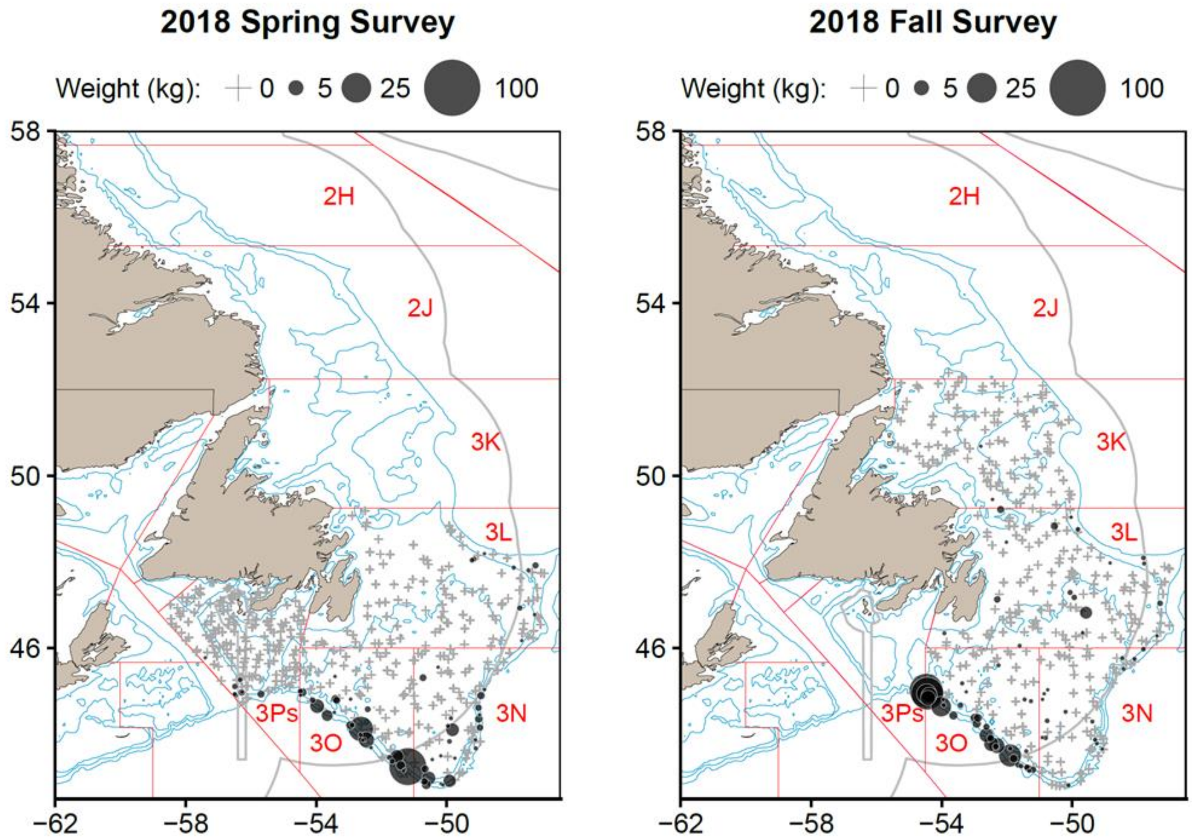

Figure 10. Distribution of *Illex illecebrosus* (kg per tow) in the 2018 spring and fall bottom trawl surveys conducted by the Canada Department of Fisheries and Oceans.

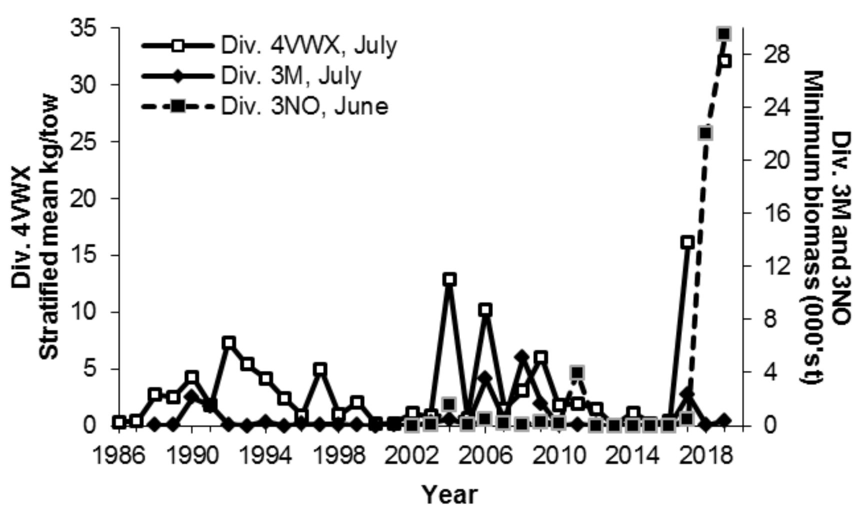

Figure 11 *Illex illecebrosus* relative biomass indices (stratified mean kg per tow, bottom) derived using data from the Canadian bottom trawl surveys conducted in Div. 4VWX (July, 1986-2019, indices are only shown for 1986 onward) and from the Div. 3M and 3NO bottom trawl surveys conducted by the EU-Spain in Div. 3M (July, 1988-2019) and Div. 3NO (June, 2002-2019).

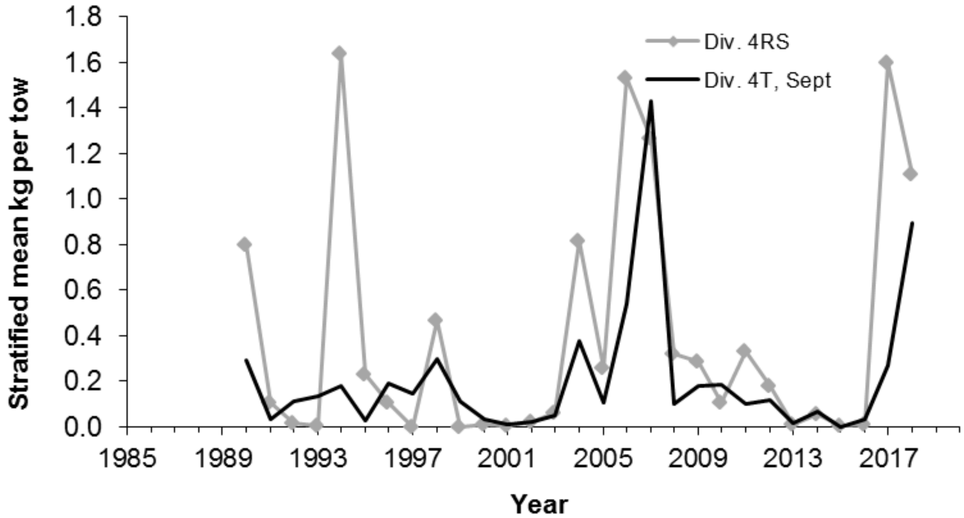

Figure 12. *Illex illecebrosus* relative biomass indices (stratified mean kg/tow) derived using data from the Canadian bottom trawl surveys conducted in Div. 4T during September and in Div. 4RS during August, 1990-2018.

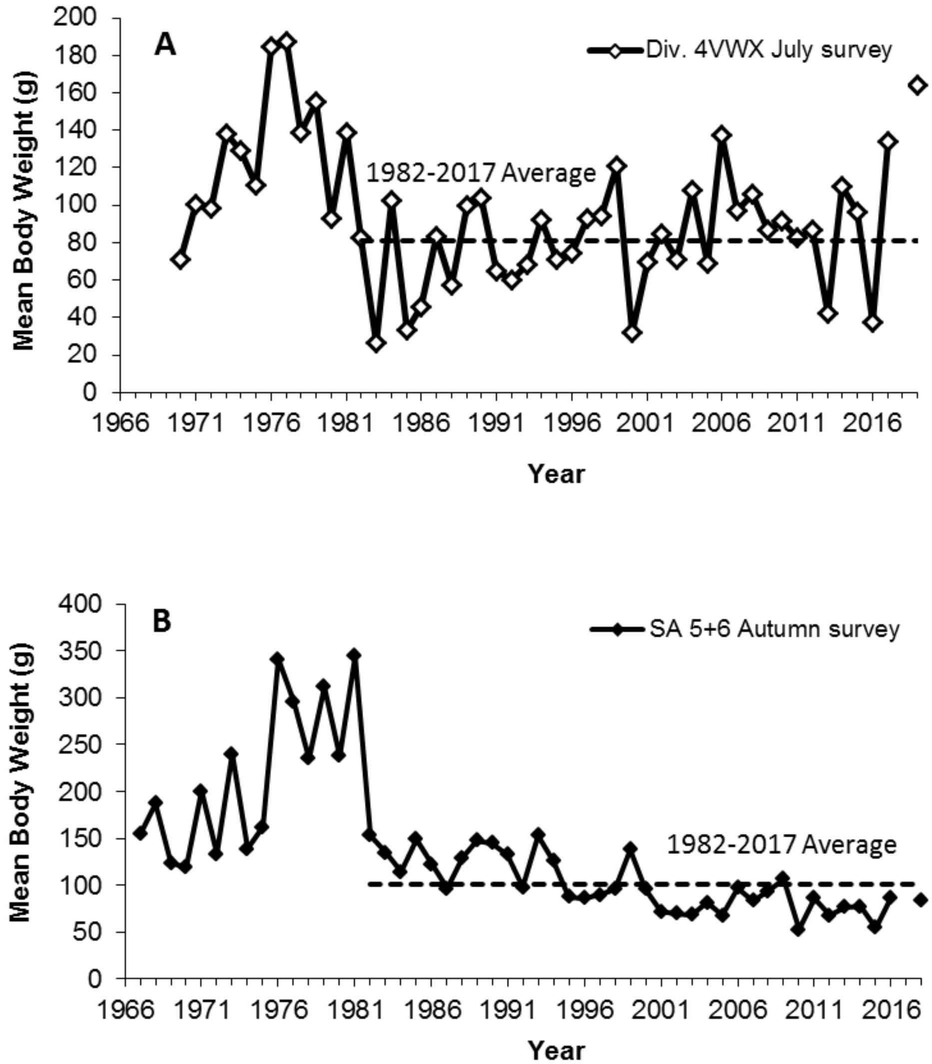

Figure 13. Stratified mean body weight (g) of *Illex illecebrosus* caught in the (A) Canada Div. 4VWX July bottom trawl surveys (1970-2019) and the (B) Subareas 5+6 autumn bottom trawl surveys (1967-2018).

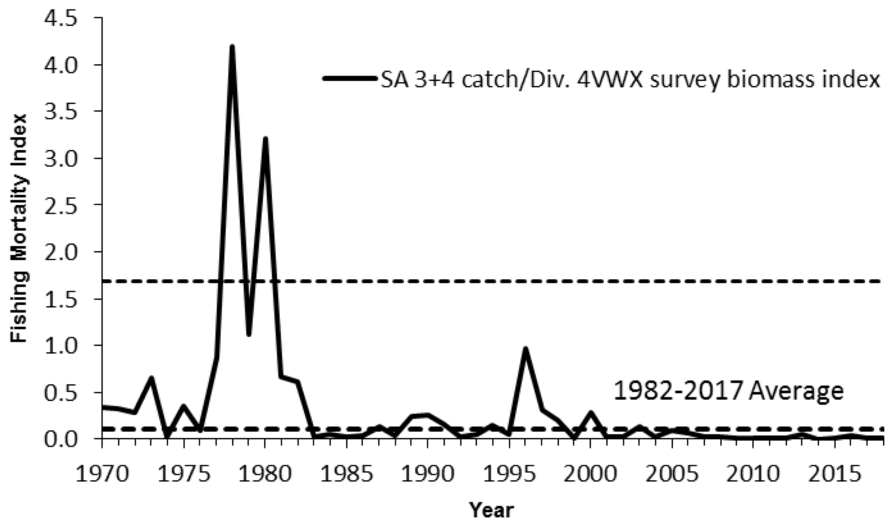

Figure 14. Relative fishing mortality indices (SA 3+4 nominal catch/Div. 4VWX July survey biomass index) in Subareas 3+4 during 1970-2018, and averages during the high (1976-1981) and low (1970-1975 and 1982-2018) productivity periods. Indices were divided by 10,000 to scale the values.