Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2020/044

Maritimes Region

Eastern Scotian Shelf Shrimp 2016–2017

J. Broome[1], M. Covey[1], K. Nickerson[2], and D. Hardie[1]

[1]Population Ecology Division
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2

[2]84 Old Riverside Road
PO Box 88
Guysborough, Nova Scotia B0H 1N0

November 2020

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Broome, J., Covey, M., Nickerson, K., and Hardie, D. 2020. Eastern Scotian Shelf Shrimp 2016–2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/044. iv + 44 p.

Aussi disponible en français :

Broome, J., Covey, M., Nickerson, K., et Hardie, D. 2020. Crevette de l’est du plateau néo-écossais, 2016 à 2017. Secr. can. de consult. sci. du MPO, Doc. de rech. 2020/044. iv + 47 p.

TABLE OF CONTENTS

ABSTRACT

The DFO-Industry survey stratified mean biomass estimate declined 14% to 25,584 mt (± 5,079 mt, 95% Confidence Interval [CI]) from the 2015 estimate of 29,642 mt (± 7,324 mt, 95% CI). The 2016 Spawning Stock Biomass (SSB, females) point estimate declined 11% to 13,223 mt, and is now below the Upper Stock Reference (USR, 14,558 mt). Based on the precautionary approach as it is applied to Eastern Scotian Shelf Shrimp, this places the stock in the Cautious Zone. A 28% reduction in the 2016 Total Allowable Catch (TAC) (from 4,500 in 2015 to 3,250 mt) was applied to reflect reduced total and Spawning Stock Biomass. The precautionary TAC reduction helped to reduce both total and female exploitation to 12% and 16%, respectively. Commercial Catch Per Unit Effort (CPUE) indices declined by 4% and increased by 3%, for the Gulf and Maritimes (Standardised Nova Scotian) fleets, respectively. The trap fishery CPUE index declined by 22%, relative to 2015. The distribution of catch was consistent with a declining resource, where areas representing all catch rate levels have been reduced. Commercial and survey sample length frequency distributions, combined with modal analysis of survey data, suggest that the fishable stock is currently supported by the less abundant year classes originating between 2009–2012. Trends in shrimp size indices were consistent with expectations based on life history and growth rates for shrimp at moderate abundance (i.e. no evidence of slower growth or delayed sex transition that have occurred for this stock during periods with more abundant cohorts/high density). Similar to 2015, the 2016 belly-bag index of Age 1 abundance was found to be very low. The 2013 year class, which was first identified by high belly-bag index in 2014 (2nd highest in the time series), was evident in 2015 and 2016 main trawl survey and commercial samples, continuing to suggest good survival and growth of this cohort. The 2013 year class is expected to begin recruitment to the Spawning Stock Biomass in 2018. Ecosystem characteristic indices suggest that present conditions on the Eastern Scotian Shelf are not favorable for shrimp. Bottom temperatures derived from the June shrimp survey remained at high levels in 2016. Low or decreasing indices of abundance of sympatric species continue to suggest that the environment is becoming less favourable for coldwater species. The overall mean indicator, summarizing 24 stock indicators, remained yellow for 2016 largely due the ongoing downturn in abundance, combined with declining indices contributing to production and ecosystem characteristic categories. Continued declines in the total and Spawning Stock Biomass indices are consistent with the expectation that the 2007–2008 year classes have reached the end of their life-span, and that the succeeding year classes (2009–2012) are not highly abundant.

INTRODUCTION

The biology of northern shrimp, *Pandalus borealis*, is reviewed in Shumway et al. (1985) for various stocks world-wide, and by Koeller (1996a, 2000, 2006) and Koeller et al. (2000a, 2003a) for the Eastern Scotian Shelf stock. Shrimp on the Eastern Scotian Shelf and in the Gulf of Maine are at the southern extreme of the species' range (concentrated north of 46N), and by inference at the extreme of the species ecological and physiological limits (Koeller 1996a). The rationale for the assessment and management approach used is described in Koeller et al. (2000b). Although there has been some shrimp fishing on the Scotian Shelf since the 1960s, the fishery began to expand toward its full potential only when groundfish bycatch restrictions were overcome with the introduction of the Nordmøre grate in 1991 (Figure 1). The Total Allowable Catch (TAC) was first reached in 1994, when individual Shrimp Fishing Area (SFAs) quotas were removed. Since 1994 the TAC has ranged from 3000 to 5500 mt. Although 24 indicators are considered in the provision of science advice for this stock, the TAC has generally been higher during periods of high survey total and Spawning Stock Biomass and when large year classes are known to be recruiting to the fishery. TAC has generally been reduced to maintain low exploitation rates when biomass indices and/or catch rates are decreasing, or are expected to decrease based on cohort tracking. Details of the history of the Eastern Scotian Shelf shrimp fishery and recent stock assessments are given in Koeller (1996b), Koeller et al. (2011) and Hardie et al. (2011, 2013a, 2013b, 2015).

Science advice was provided on an annual basis with full peer review and industry participation until 2012. The fishery is now fully assessed on a biennial basis, with interim advice provided at a smaller update meeting involving only DFO Science and Resource Management. Interim advice, based on a complete analysis of the data, was first provided in 2013 (DFO, 2014) and again in 2015 (DFO, 2016a).

The organization of this report is based on a "Traffic Light" analysis (TLA), which has been used in shrimp stock assessments since 1999 (Koeller et al. 2000b, Mohn et al. 2001, Halliday et al. 2001). This multiple indicator diagnostic approach analyses and discusses individual indicators grouped under headings representing four summary "characteristics". In this document, the "Methods" section provides a description of the data sources, with reference to past documents for detailed indicator calculation methodology. The discussion of the relevance/interpretation of each indicator to the characteristic that it represents is presented in the "Results and Discussion" section. Note that indicators always represent summary data for the entire area (i.e. all SFAs combined, according to the current practice of managing the fishery as one stock). The indicator series used in the analysis is summarized graphically in Figure 17.

Where appropriate, the interpretation of the indicator time series themselves are supplemented by additional figures and tables. For example, individual SFA data often replicate the indicator trends and thus substantiate them. Supporting data may be quite independent from the data used to derive the main indicator. For example, catch rates in the shrimp trap fishery supported the apparent increasing shrimp aggregation shown by the survey and Catch Per Unit Effort (CPUE) data; anecdotal reports of large numbers of age 1 shrimp found on Cape Breton beaches in 2002 supported survey data indicating a strong 2001 year class, etc. This additional information may be used in the interpretation of indicator trends in the "Results and Discussion," but it is not used in the summary traffic light "scores." In any case, it should be noted that such scoring is not intended to be translated directly into management action (e.g. in the form of rules linked to summary scores). The "Traffic Light" is currently seen simply as a tool for displaying, summarising, and synthesising a large number of relevant yet disparate data sources into a consensus opinion on the health of the stock.

A precautionary approach using reference points and control rules within the framework of the Traffic Light analysis (Figure 2) was last reviewed during the Fisheries and Oceans Canada (DFO) Maritimes 2015 Regional Science Advisory Process (DFO, 2016a; Hardie et al., 2018). In general, the precautionary application of reference points for Eastern Scotian Shelf shrimp includes:

Limit Reference Point (LRP): which is 30% of the average female SSB (5,459 mt) maintained during the modern fishery (2000–2010[1]). The LRP is approximately equal to the average SSB during the low-productivity (pre-1990) period for this stock, characterised by low shrimp abundance, high groundfish abundance, and relatively warm temperatures. The Eastern Scotian Shelf shrimp population previously increased from a low level (approximately 4,300 mt) during the transition from low- to high-productivity, so the working assumption is that shrimp could once again recover from this level given appropriate environmental conditions and fishing pressure (i.e. $B_{recover}$ proxy). Secondly, given the important role of shrimp in the Eastern Scotian Shelf ecosystem, particularly as prey for groundfish, this LRP is set to avoid a decrease in shrimp abundance below the level at which it was previously able to fulfill its ecosystem roles under a situation of high groundfish abundance (i.e. to avoid a scenario in which low shrimp abundance could act as a limiting factor in groundfish non-recovery).

Upper Stock Reference (USR): which is 80% of the average female SSB (14,558 mt) maintained during the modern fishery (2000–2010[2]). The USR has been selected at the default value (80%) and to maintain a sufficient gap between the LRP and USR to account for uncertainty in the stock and removal reference values, and to provide sufficient time for biological changes in the population to be expressed, detected and acted upon.

Removal Reference Point: The removal reference for Eastern Scotian Shelf shrimp is 20% female exploitation (actual female catch/SSB) when in the Healthy Zone (above the USR). This exploitation rate has rarely been exceeded during the modern fishery (2000–present), a period during which high CPUE and SSB have been maintained. Additionally, given that shrimp survive for approximately three to four years after their recruitment to the fishery, it can be approximated that on the order of 25–33% of the fishable biomass would be subject to natural mortality in any given year. Although exploitation scenarios in which fishing mortality equals natural mortality may result in optimal yield (e.g. Gulland 1971) this may be an overly risky exploitation strategy. As a result, the maximum removal reference of 20% for shrimp is on the conservative side of the simplistic approximate range of natural mortality (25–33%).

At SSB levels below the LRP the fishery is closed. A suite of approximately 24 secondary indicators of shrimp abundance, production, fishing effects and environmental conditions provide a scientific interpretation of holistic data to inform the way in which science advises and responds to the stock status and removal relative to reference points.

The SFAs on the Eastern Scotian Shelf are shown in Figure 3. Licensing information for the recent period covered under sharing agreements between the Gulf (midshore) and Maritimes (inshore, Nova Scotia) fleets, and including the number of active vessels, is shown in Table 2. The fishery currently operates under an ‘evergreen’ Integrated Fisheries Management Plan.

The experimental trap fishery was not under quota management from 1995–1998 except for a 500 mt precautionary “cap”. As a result, the total catch tended to exceed the TAC due to the

---

[1] The reference points are set based on data from 2000–2010 to avoid a scenario whereby reference points based on a moving average would become *less* conservative during a period of a biomass downturn. This action does not negate the need to be vigilant for signs of a shift away from the current high productivity regime towards a lower productivity regime in which these reference points may no longer be suitable.

trap fishery. When the trap fishery in Chedabucto Bay was made permanent in 1999, a trap quota was set at 10% of the total TAC, e.g. 500 tons of the 5,000 mt TAC. The reallocation of any uncaught portion of the trap quota late in the year resulted in some fishers being unable to take advantage of the additional quota. This often contributed to an overall catch lower than the TAC. In an attempt to avoid reallocations, in 2004, only 300 mt were allocated to this fishery, which was closer to its capacity. The trap allocation was reduced to 8% in 2005 and trap fishing effort and catch were very low during 2005–2010 due to poor market conditions. Market conditions for trap-caught shrimp remain variable. Total trap landings were 314 mt for 2015, and 106 mt (of 260 mt quota allocation) were landed as of November 15, 2016.

METHODS AND MATERIALS

TRAFFIC LIGHT INDICATORS

Default boundaries between traffic lights for individual indicators, i.e. transition from green to yellow and from yellow to red, were arbitrarily taken as the 0.66 and 0.33 percentiles of the fixed high-productivity 2000–2010 period, respectively (DFO, 2016a; Hardie et al., 2018). Whereas, prior to the 2015 Framework, boundaries were determined relative to the mean of the entire time series for a given indicator (Hardie et al.,2018). If an increase was considered bad for stock health the transition between boundaries was reversed. Note that for commercial CPUE series, the “polarity” of the default boundary should be considered with other indicators for certain years. For example, increased CPUE series coupled with increased aggregation and decreased survey abundance would be viewed as a negative development.

Data series vary in length from 15–35 years depending on the availability of data for each indicator. A detailed description of the calculation of each indicator is not repeated here. Data sources and any methodological changes since the 2015 framework (Hardie et al., 2018) are discussed. Otherwise, the methods used to calculate the 24 indicators that contribute to the Abundance, Production, Fishing Effects and Ecosystem characteristics summarised in the Traffic Light analysis are given in Hardie et al. (2013a) and previous documents.

DATA SOURCES

DFO-Industry Cooperative Trawl Survey

The 22nd DFO-Industry trawl survey, incorporating a mixed stratified random - fixed station design, was conducted in June 2016. Survey design and station selection methods were similar to annual surveys completed since 1995 (Hardie et al. 2013b, Hardie et al., 2018): fishing depths >100 fathoms, randomly selected stations in strata 13 and 15; fixed stations in strata 14 due to the difficulty in finding trawlable bottom; 30 minute tow length; and 2.5 knot vessel speed. Stations in strata 17 (inshore) were selected randomly at all depths having a bottom type identified as LaHave clay on Atlantic Geosciences Centre surficial geology maps. The fixed stations in stratum 14 are assumed to be representative of shrimp abundance throughout the stratum, and as such are not analyzed differently from the random stations in strata 13, 15, and 17. The 2016 survey was completed by marine vessel (MV) *Cody & Kathryn*, which had also conducted the survey in 1995, 1998, 2009–2015. All surveys since 1997 were conducted using the standard trawl (Gourock #1126 2-bridle shrimp trawl and #9 Bison doors). Biomass/population estimates (swept area method) and bootstrapped confidence intervals (Smith 1997) were calculated using the catch/standard tow (17.4 m × 1.25nm), i.e. the actual catch adjusted to the standard by the average measured wing spread (using NETMIND sensors) of the survey trawl during each tow and the actual distance travelled (Halliday and Koeller 1981).

The co-operative DFO-Industry series, begun in 1995, used several different vessel-trawl combinations requiring comparative fishing experiments in 1996–1997 (Koeller et al. 1997), and 2013 (Hardie et al., 2018). In order to obtain a wider range of indicator values for this series, it was extended to include DFO surveys conducted in 1982–1988, a period of low abundance in contrast to the present period of high abundance. There were no comparative fishing experiments that allowed direct intercalibration of the two survey series, consequently, catch data were only adjusted by the difference in the wing spreads of the trawls used. Wing spreads were based on the performance specifications of the trawl used for the earlier series, and from actual measurements for the latter series. However, it is probable that the trawl used during the recent series was more efficient in catching shrimp than during the 1982–1988 series, consequently, the large differences in catch rates between the two series may be exaggerated and should be interpreted cautiously. Since the cod end mesh size in both series was the same (40mm) size selectivity of the two series were assumed to be the same. The Atlantic Canadian Mobile Shrimp Association (ACSMA) oversees professional inspection and necessary maintenance of the survey trawl before (annually) and during (if necessary) the survey to ensure consistent catchability. Survey sets are carried out between 0500–2000hrs (daylight hours) when shrimp are concentrated on the bottom and catchability of the survey trawl is highest.

The chronology of survey vessels, gear changes and comparative fishing experiments are summarized below:

1995: *Cody & Kathryn* – used vessel's commercial net
1996: *Lady Megan II* – vessel's net, comparative fishing with *Cody & Kathryn*
1997: *Miss Marie* – survey trawl (built by Nordsea), comparative fishing with *Cody & Kathryn*
1998: *Cody & Kathryn* – survey trawl
1999–2001: *Carmel VI* (named *Amelie Zoe* in 1999) – survey trawl
2002–2003: All Seven – survey trawl (built by Pescatrawl)
2004–2008: All Seven – survey trawl (new in 2004)
2009: *Cody & Kathryn* – survey trawl (refurbished by Capt. Schrader)
2010: *Cody & Kathryn* – survey trawl (checked by Capt. Schrader and Morgan Snook)
2011: *Cody & Kathryn* – survey trawl (new in 2011)
2012: *Cody & Kathryn* – survey trawl (new in 2011)
2013: *Cody & Kathryn* – survey trawl (weight added to 2011 trawl, comparative fishing with unweighted trawl on 16 stations)
2014–2016: *Cody & Kathryn* – survey trawl (weight added to 2011 trawl)

Commercial Catch Data

Data on catch rates were obtained from fishers' logs required from all participants and provided by DFO Maritimes Region Commercial Data Division. Commercial catch data from Gulf based vessels, which have the longest history in the fishery, provide a CPUE index as an unstandardised mean catch/hour fished from all Gulf-based vessels in any given year. The shorter time series for the Maritimes fleet is used to estimate a standardised CPUE series 1993–2016 derived from commercial catch data for the 24 (<65', Nova Scotia based) vessels that have fished for at least 7 of the 24 years. Standardised CPUE data were limited to April–July inclusive, the months when the bulk of the TAC is generally caught. A generalized linear model was used to standardize commercial CPUEs with year, month, area, and vessel as categorical components. Predicted standardised CPUE values and confidence limits for a reference vessel, month, and area were then calculated for each year using the package *predict.glm* (R Development Core Team, 2005). The data fit best to a Gaussian distribution (lowest Akaike information criterion value). Commercial counts (number of shrimp per pound) are also obtained from commercial logs.

Detailed Shrimp Analysis (Survey and Port Samples)

A random sample of approximately eight pounds of shrimp was collected from each survey set and from the last set of each commercial trip (collected during the fishery in all areas from all fleet components including vessels <65' landing mainly in Louisbourg, and vessels >65' landing mainly in Arichat), and frozen for detailed analysis (i.e. carapace length, individual weight, sex and egg developmental stage). One hundred and twenty survey samples (one each from the main survey trawl and belly bag at each station) and approximately 50 commercial samples (number of samples per month and area approximately allocated in proportion to temporal and spatial distribution of weight of landings) are analyzed annually. Because of the timing of the shrimp assessment relative to the collection and analysis of commercial samples, advice provided during past assessment processes (prior to 2012) may have been based on only a portion of the samples. However, steps have been taken to expedite the analysis of samples such that for 2016, all 120 survey samples and 45 commercial samples were included in this analysis.

Length Frequency Analysis

Survey population estimates (numbers) were determined by the swept area method using individual set length frequencies and weights caught, and a length-weight relationship. Survey population estimates by age group were then estimated by separating total population at length estimates from the swept area method into inferred age groups using modal analysis ("*mixdist*" in R; Macdonald and Pitcher 1979). The data were assigned to seven age bins which are interpreted as corresponding to ages 1–7. Modes corresponding to older ages are binned together as 5+ because the assignment of ages would be highly subjective for ages 6 and older. Fitting the data to seven ages provided a highly significant fit to the 2016 length frequency distribution (Chi-square, $p<0.001$).

Shrimp Size Indicators

Four indicators of shrimp size are considered: mean maximum size, mean size at sex transition, mean female size, and commercial counts (see details in Hardie et al. 2013b). These indices had been presented as simple mean point estimates without any measure of uncertainly prior to 2013. Methods used to calculate size indicators remain unchanged from Hardie et al. (2013b).

Ecosystem Data

Bottom temperature data is recorded during each shrimp survey set with a continuous temperature recorder (Minilog, Vemco Ltd.) attached to the headline of the trawl. Satellite data are used to estimate Sea Surface Temperatures (SSTs) within defined rectangles encompassing the shrimp holes for February–March. Predation, Cod and Greenland Halibut (Turbot) recruitment indices derive from the summer groundfish survey which encompasses the shrimp holes (i.e. strata 443–445 and 459, details in Hardie et al. 2013b). The snow crab recruitment index, as described in Hardie et al. (2013b), derives from the DFO-Industry snow crab survey. This index is now shifted forward by one year in the Traffic Light Analysis (e.g. 2015 value used for 2016 Traffic Light Value) to solve the problem that the current-year value is generally not available in time for the shrimp assessment.

TRAFFIC LIGHT SUMMARY

Twenty-four (24) individual shrimp stock indicators were considered in this analysis. Indicators were assigned a color for each year data was available according to its percentile value relative to the fixed high-productivity 2000–2010 period (Hardie et al., 2018). Default boundaries for individual indicators, i.e. transition from green to yellow and from yellow to red, were arbitrarily taken as the 0.66 and 0.33 percentiles (i.e., >0.66 percentile = green or healthy; 0.66–0.33 percentile = yellow or cautious; and <0.33 percentile = red or critical). However, if an increase in the indicator was considered bad for stock health the transition between boundaries was reversed. Individual indicators were then grouped into stock characteristic categories of Abundance, Production, Fishing Effects and Ecosystem, as well as an overall mean indicator. Regardless of whether or not an indicator time series is presented in an independent figure in the assessment document, red-yellow-green line graphs are presented in Figure 17. Note that indicators are not weighted in terms of their importance, and that the group summary and overall indicator were determined as a simple averages of individual indicators. As suggested by the 2015 framework, the Trap CPUE and Total Effort indices were included in the 2016 analysis (DFO, 2016b; Hardie et al., 2018). The Capelin abundance index and bottom temperature index derived from the R/V *Alfred Needler* groundfish survey were removed from the 2016 analysis (DFO, 2016b; Hardie et al., 2018).

BYCATCH

Introduction of the Nordmøre separator grate in 1991 reduced bycatch and allowed the fishery to expand to its present size. Bycatch information from observer coverage of 41 commercial sets from 2015 (2 trips) and 2016 (1 trip) suggest that the fleet's trawl configurations including the use of the Nordmøre separator grate continue to ensure low total bycatch (2.01%) by weight (Table 7). It is noteworthy that this value is likely over-estimated due to the minimum 1 kg weight recorded by the observers (e.g. a single sand lance would be recorded as 1 kg despite weighing only a few grams). Total bycatch by weight from observed trips in 2015–2016 is similar to that reported in the 2013–2014 summary (Hardie et al., 2015) and the 2012–2013 summary (Hardie et al. 2013b). Two of the observed trips took place during the spring/summer and covered portions of SFA 14. The other trip took place in the fall covering the inshore of SFA 15. There was no observer coverage of SFA 13 during 2015 or 2016. Nonetheless, the Eastern Scotian Shelf mobile shrimp fishery currently poses little risk in terms of bycatch amount or species-composition.

RESULTS AND DISCUSSION

PRECAUTIONARY APPROACH

Spawning Stock Biomass (SSB, females) and female exploitation indices are reported in the Traffic Light Analysis (below), but these indices also define stock and removal reference points for Eastern Scotian Shelf shrimp. In this context, it is worth reiterating that SSB by itself is not a measure of reproductive capacity. Because the relationship between fecundity and size, and the dynamic range of shrimp size in response to fluctuations in density, temperature and growth rate, it is important to carefully consider the "Auxiliary Data" provided by the Traffic Light Indicators when interpreting the reference points depicted in Figure 2.

Traffic Light Analysis

Input data for the traffic light analysis are given in Table 3. Individual indicators are discussed in the sections below, grouped under the following characteristic headings: 1) abundance, 2) production, 3) fishing effects, and 4) ecosystem. Individual indicators are shown in Figure 17, while summary characteristics and the overall mean summary indicator are shown in Figure 18. For additional description of the indicators see: Hardie et al, 2018.

ABUNDANCE

Research Vessel Survey Abundance Index

The DFO-Industry survey stratified mean biomass estimate for 2016, representing a biomass of 25,583 mt (using the swept area method), decreased approximately 14% from the 2015 estimate of 29,642 mt. After two stable years (2013–2014), biomass estimates declined in both 2015 and 2016. The distribution of survey catches during the last two years is shown in Figure 5. Biomass estimates declined by approximately 29% and 20% in strata 14 and 15, respectively. Biomass estimates remained relatively consistent for strata 13 (6% increase) and strata 17 (3% decrease) (Table 6). Relative to the available survey time series, strata 13 and 17 remain at moderate levels of biomass, while strata 14 and 15 are currently nearer the lower end of the historical range (Figures 4, 6; Tables 4, 6). Overall biomass declines were anticipated given several consecutive years of limited recruitment (2009–2012) (DFO 2014; DFO 2015; Hardie et al. 2015; DFO, 2016a).

Interpretation: Decreases in biomass estimates for 2015 and 2016 are consistent with the expectation that less abundant year classes (2009–2012) now support the stock biomass, and any residual shrimp biomass contributed from formerly abundant 2007–2008 year classes has now reached the end of its lifespan. The declining survey abundance index in 2015 and 2016 was observed to be in contrast to the Standardised CPUE index which has increased since 2014.

Gulf Vessels Catch per Unit Effort

The Gulf vessels are the largest in the fleet and although the participating vessels (and fishing gear) have changed considerably since the beginning of the time series, they have always been >65’ in length, compared to the <65’ Nova Scotia fleet. This important time series spans periods of both high and low abundance of the stock. However, since fishing methods and gear have improved over the years (i.e. introduction of Nordmøre grate in 1991), the differences in Gulf CPUEs between the period of low abundance (pre-1993) and the recent high abundances should be interpreted cautiously. The unstandardised Gulf vessel CPUE showed an increasing trend through the 1990’s, peaking in 2004, and has since been relatively stable at a high level.

Interpretation: The 2016 value declined 4% from 2015, but is currently at a high level relative to the available time series (Figure 6A). It is notable that the Standardised CPUE of the Nova Scotian fleet, despite temporal and spatial variation in fishing activity, shows a very similar overall trend to the Gulf CPUE index.

Commercial Trawler Standardised Catch per Unit Effort

In general, the 3 CPUE-based indicators have followed similar trends over the time series. As suggested above, there have been 3 notable divergences between commercial CPUEs and the shrimp survey in the recent time series (i.e. high commercial CPUEs in the face of declining survey CPUE in 2000–2003, 2005–2008, and 2014–2016; Figure 6A). The 2014–2016 divergence can likely be attributed to distributional changes associated with the formerly abundant 2007–2008 year classes reaching the end of their life span.

Interpretation: The 2015 and 2016 standardised CPUE indicator values were found to increase, rebounding from relatively low levels in 2014. The increase in the standardised CPUE, coupled with decreased survey CPUE may indicate that the fishery, under a scenario of reduced TAC may be able to maintain high catch rates on a declining biomass due to increased aggregation of the stock.

Trap Catch per Unit Effort

The trap CPUE (catch per trap hour) index was incorporated following the 2015 framework review. The trap fishery CPUE provides an additional fishery-dependent abundance indicator, but is unique in that it derives from different gear and is spatially and temporally distinct from the trawl fishery catch indices. The trap fishery was made permanent in 1999, and since 2005 the trap allocation has remained at 8% of the total TAC (Table 1). The trap fishery is competitive and consists of 14 licenses (8 active in 2016) which are restricted to Chedabucto Bay (Figure 3). Trap fishing effort and catch were very low during 2005–2010 due to poor market conditions. Market conditions have generally improved, but remain variable year to year. The trap fleet landed 314 mt in 2015, and 106 mt had been landed as of November 15, 2016 (fishing is ongoing).

Interpretation*:* The 2016 Trap CPUE index declined 22% relative to 2015. Reductions in the trap CPUE index may reflect reductions in large female shrimp from the 2007–2008 year classes; however the influence of external factors on this fleet should not be overlooked as variation may be more closely linked to market conditions.

Research Vessel Survey Coefficient of Variation

The survey measure of dispersion (overall CV) has generally remained high. Values in 2013–2015 were very consistent, with a slight decline occurring in 2016 (Figure 7). Declines in CV were found in strata 13–15, but the CV value for strata 17 remains at an elevated level relative to the available time series (Figure 7).

Interpretation: Relatively high CV of survey catches may warn that the fishery is targeting aggregations of a declining resource. This interpretation is substantiated by declining total and Spawning Stock Biomass indices described above. Further, temperatures have increased in all survey strata since 2014 (Figure 16) providing additional explanation for changes in stock distribution.

Commercial Fishing Area

This measure of dispersion is particularly important when survey indices are decreasing while commercial catch rates continue to increase, as in the current scenario described above (Figure 6A). Decreases in the commercial fishing area index indicate concentration of the remaining stock biomass in a smaller area.

Interpretation: The area with commercial catch rates >250 kg/h forms the basis of the commercial fishing area index and has declined in both 2015 and 2016 (Figure 8, top panel). In general, the distribution of catch rates is consistent with a declining resource, where areas of very high to moderate catch rates have been reduced (Figure 8). Despite a significant reduction in TAC in 2016, the overall spatial distribution of effort was similar between 2015 and 2016 (Figure 9). Effort was focused on SFA 14 and the inshore area, with very little effort occurring in SFA's 13 and 15 (Figure 9).

PRODUCTION

Research Vessel Survey Belly-bag Abundance at Age 1

This index has exhibited a dynamic range over the 15 year time series. The index correctly predicted the strength of the 2001, 2007–2008, and 2013 year classes, two years before these began to show up in commercial catches, and as many as five years before they were fully recruited to the fishery (Figures 10–12, Table 5). These significant recruitment pulses provide evidence of recruitment cycles that approximately equal the species' life-span. The appearance of recruitment cycles of different lengths provides evidence that some form of a stock recruitment relationship may exist (i.e. strong year classes' result in large spawning stocks, resulting in strong year classes). The belly-bag index of age 1 abundance was the second highest on record in 2014, subsequently followed by very low values in 2015 and 2016 (Table 5; Figure 11).

Interpretation: Belly bag index values for 2015 and 2016 were consistent and low, suggesting poor recruitment over the past two seasons. The 2013 year class, which was observed in the 2014 survey at very nearly the same level as the 2001 year class, has been monitored closely. This cohort has been tracked into the Age 2 indicator in 2015, and was visible within the 2015 and 2016 survey and commercial catch data (Table 5, Figures 10–12). If continued growth is realized, this cohort will enter the Age 4 abundance indicator next season, and is expected to begin recruiting to the Spawning Stock Biomass over the 2017–2018 seasons. However, it is important to consider that various environmental influences are also understood to strongly influence shrimp recruitment (e.g. spring SSTs and predator abundance, see below).

Research Vessel Survey Abundance at Age 2

Although the length frequency modal analysis tends to clearly define the age 2 mode, it is possible that this size of shrimp is not well (quantitatively) sampled by the main survey trawl. The index of age 2 shrimp declined from 2015 to 2016, indicating that the 2013 year class, as observed in the 2014 belly-bag age 1 index, has now grown into the age 3 size class (Table 5).

Interpretation: Trends between indices of age 1 and age 2 abundance have been somewhat equivocal (i.e. changes in the age 1 index are not always followed by concomitant changes in the age 2 indicator the following year, Table 5). However, this was not the case for the 2015 indicator which detected the abundant 2013 year class. The low value of the 2016 age 2 indicator was consistent with the very low 2015 belly-bag age 1 indicator. The 2016 belly-bag age 1 indicator was nearly identical to the 2015 value, and thus it is expected that the 2017 age 2 indicator will be similarly low.

Research Vessel Survey Abundance at Age 4

The age 4 shrimp abundance index was found to be at a moderate level in 2015, and declined in 2016. This follows on the 2014 value where the abundance of age 4 shrimp was indistinguishable from the large mode associated with the 2007–2008 year classes.

Interpretation: The age 4 modes for 2015 (representing the 2011 year class) and 2016 (representing the 2012 year class) were found at moderate levels that should begin contributing toward the Spawning Stock Biomass over the 2017–2018 seasons.

Research Vessel Survey Spawning Stock Biomass (Females)

A clear stock-recruitment relationship has not yet been described for Eastern Scotian Shelf shrimp, although it has been for some other pandalid stocks (Hannah 1995, Boutillier and Bond 2000). Beginning in the late 1980s, SSBs increased from approximately 4,300 mt to values nearly three-fold higher by the mid-1990's. However, these increases occurred under specific environmental conditions (cold water temperatures and decreasing natural mortality due to reduced predation) and negligible fishing mortalities. As such, 4,300 mt is considered the very lowest that the stock should be allowed to decline, and a more conservative value (5,459 mt) is used as the LRP for this stock. It is important to note that: multiparous females tend not to spawn every year, and as such SSB by itself is not a measure of reproductive capacity. Since fecundity is directly related to size, it should be considered in conjunction with the shrimp size indicators.

Interpretation: Spawning Stock Biomass (SSB) estimates declined 26% and 11% in 2015 and 2016, respectively, following relatively high/stable values in 2013–2014. The relatively high SSB observed in 2013 and 2014 is consistent with the completed recruitment of the abundant 2007–2008 year classes. The subsequent declines in the SSB in 2015 and 2016 are indicative of the limited overall recruitment from 2009–2012 year classes, and therefore low overall biomass of mature females. The SSB estimate for 2016 (13,223 mt) is below the USR (14,558 mt) placing the stock within the cautious zone (Figures 2, 13A).

Average Size at Sex Transition (L_t)

Delayed sex-transition occurs during periods of high population density, and results in extra years of growth, which in turn results in the production of larger females. This indicator was found to decline in both 2015 and 2016 (Figure 14D).

Interpretation: Declines in the size at sex-transition index are consistent with the declines in overall population biomass/density.

Average Maximum Size (L_{max})

The ratio of size at sex transition to maximum size was hypothesized to be constant (invariant) at about 0.8–0.9 for all stocks of *P. borealis* (Charnov and Skúladóttir 2000). This rule was shown to apply to the Eastern Scotian Shelf (Koeller et al. 2003b, Koeller 2006). Consequently, maximum size attained in the population is an indicator of growth (i.e. change in maximum size is probably indicative of a change in growth rate). The relationship between L_t or L_{max} to changes in growth rate is complex due to the influence of other factors including concurrent changes in longevity and natural mortality (e.g. slower growing shrimp tend to live longer). The 2015 and 2016 index values were within the range of uncertainty for these data in recent years (Figure 14B).

Interpretation: The mean maximum size index has been relatively stable over the recent time period. This is consistent with other indicators which suggest, despite recent declines, that the stock remains moderately abundant relative to the available time series.

Predation

Finfish abundance is negatively correlated with shrimp abundance on the Eastern Scotian Shelf and in most other SFAs. This index is used as a proxy of natural mortality, and has varied considerably since 2002.

Interpretation: Following a decline in 2015, the index returned to a relatively high value in 2016 (Figure 15). Relative to the recent time series, natural mortality due to predation is expected to be high in 2016.

FISHING IMPACTS

Effort

The total trawl fleet effort was added as an index following the 2015 framework review, and provides an additional indicator to the fishery impact characteristic. The total effort exerted by the ESS trawl fleet can serve as further information (in concert with the Commercial Fishing Area index) to support inferences regarding stock dispersion/aggregation, and is relevant in reviewing and comparing commercial catch rate index values between successive years. It is important to note that the overall effort exerted in a season is influenced strongly by TAC level, and can also be further affected by fleet dynamics and environmental factors. This index is expected to be most informative in years where there is little to no change in the TAC.

Interpretation: The total trawl effort declined approximately 30% from 2015 to 2016. This decline is consistent with the reduction in TAC adopted for the 2016 season.

Commercial Counts

This indicator is a measure of the ease or difficulty fishers are having in "making the count," i.e. getting the best price for their shrimp. An increase in the count could indicate that a) recruitment is good and there are so many small shrimp it is difficult to avoid them or b) the population of larger shrimp is declining, or a combination of a) and b). Moreover, an increase in this indicator can be considered good (increased recruitment) or bad (growth overfishing) depending on whether it is placed in the production or fishing effects characteristic. Consequently, this indicator must be considered with others including abundance indices of the different age categories. Note that counts may also change considerably during the fishing season, usually starting relatively high, decreasing to a minimum in July, and increasing thereafter, probably due to size specific changes in vertical and\or geographic distribution associated with changes in day length.

Interpretation: Following a decrease in 2014 to the lowest value in over a decade, commercial counts increased in 2015 and remained stable into 2016 (Figure 14A). The return to increased count in 2015 and 2016 is consistent with reduced overall abundance of large mature shrimp contributed by the 2009–2012 year classes, relative to the recent high abundance which had been supported by the 2007–2008 year classes.

Exploitation Index

The research vessel biomass estimate has been shown to be underestimated by as much as 25% because of lack of coverage in shallow areas surrounding the shrimp holes; consequently, the exploitation rate is likely overestimated. This indicator is therefore considered an index of exploitation. Since the survey uses a common commercial trawl with a Nordmøre grate, its selectivity is assumed to be similar to commercial gear. The biomass used to estimate exploitation can be considered a point estimate of "fishable biomass". Assuming the entire TAC of 3,250 mt is caught in 2016 (3,026 mt (93%) caught as of November 15th, 2016) the total exploitation index was approximately 12%, which represents a decrease relative to 2015 (Table 6, Figure 13).

Interpretation: The reduction in total exploitation index for 2016 reflects the precautionary 28% TAC reduction (4,500 to 3,250 mt) applied for the 2016 season, to offset the 23.5% reduction in the 2015 biomass estimate. This precautionary measure was implemented in response to small year classes (2009–2012) contributing to the fishable and Spawning Stock Biomass in 2015 and 2016.

Female Exploitation Rate

Female exploitation is of interest because the shrimp fishery is selective for the larger females. It can be considered one measure of the impact of fishing on the reproductive potential of the stock. Based on preliminary data for 2016, female exploitation (15.6%) has declined from that of 2015, and remains below the removal reference of 20% (Figures 2, 13B).

Interpretation: As was the case for total exploitation, the reduction in female exploitation relative to 2015 reflects the precautionary reduction in the 2016 TAC.

Mean Size of Females in Catch

A decrease in this indicator value can indicate a decrease in the number of larger shrimp in the population due to fishing removals and an increased reliance on smaller animals, i.e. possible growth overfishing and/or recruitment overfishing. The average size of females in the catch has generally declined from the early years of the fishery as the larger animals were selectively and continually removed from the population.

Interpretation: Declines in this index for 2015 and 2016, follow several years of an increasing trend attributed to the growth and maturity of females from the abundant 2007–2008 year class. With the 2007–2008 year classes having now reached the end of their life-span, the female population is now comprised of smaller females contributed by the less abundant 2009–2012 year classes (Figure 14C).

Proportion of Females in Catch

The proportion of females in the catch has been relatively stable at a high value since 2009 (Table 3). Following a decline in 2015, the index rebounded in 2016. The decrease in 2015 can likely be attributed to the significant reduction in large females from the 2007–2008 year classes, and therefore increased catch of larger male shrimp (Figure 10). The 2016 increase likely reflects the reduced TAC, and recruitment of 2011–2012 year classes to the female population.

Interpretation: The relative stability of this index at a high value in recent years reflects the fact that the population has been dominated by older shrimp, mostly female, with relatively poor succeeding year classes (fewer males), which is also apparent in survey and commercial length frequency distributions (Figures 10–12).

ECOSYSTEM

Research Vessel Survey Bottom Temperatures

For some Northern Shrimp stocks near the southern limits of the species' range, abundance is negatively correlated with water temperatures. It is hypothesized that warmer water temperatures have a negative influence on shrimp populations because of the decreased fecundity associated with increased growth rates, decreased size at transition, and decreased maximum size. Recent work has indicated that colder bottom temperatures increase egg incubation times resulting in delayed hatching times, which then align more favorably with optimum spring growing conditions (warmer surface water and the spring phytoplankton bloom) (Koeller et al. 2009). On the Eastern Scotian Shelf, the large shrimp population increase that occurred from the mid-1980's to the mid-1990s was associated with colder surface and bottom water temperatures. Large fluctuations in bottom water temperatures may also be associated with the cyclical recruitment pattern experienced since the early 1990s (i.e. 1993–1995, 2001, and 2007–2008 year classes).

Bottom temperatures on the shrimp grounds were relatively high during the 1980s, when the shrimp population was low, and temperature were low during the population increase of the 1990s (Figures 15–16). Warmer temperatures in 2005, 2006 and 2009–2015 are consistent with the low belly bag index results in 2006, 2007 and 2010–2016, respectively. However, despite warm bottom and spring SSTs in 2013, the belly bag index result from 2014 was found at the 2nd highest value in the time series (Figure 16, Table 5). Bottom temperatures during the shrimp survey have shown an increasing trend since 2009, and are at very high levels relative to the recent time series (>1995) (Figures 15–16).

Interpretation: The elevated values of this index since 2009 highlight the unfavorable overall conditions for Eastern Scotian Shelf shrimp, and the limited prospects for strong recruitment from the 2015 and 2016 year classes under these conditions.

Spring Sea Surface Temperatures

Negative correlations between SSTs and lagged population estimates (four to five years in Gulf of Maine) are common for the southern *P. borealis* stocks, including the Eastern Scotian Shelf. This may be related to water-column stability and the match-mismatch of resulting phytoplankton bloom conditions with hatching times as hypothesized by Ouellet et al. (2007). Accordingly, SSTs used in this index were averages for a period encompassing average hatching times on the Eastern Scotian Shelf (mid-February to mid-March).

Interpretation: Spring surface temperatures declined from 2010–2015, but increased in 2016 (Figure 15). Increased SST combined with very warm bottom temperatures indicates that conditions are currently unfavorable for shrimp.

Cod Recruitment

Cod abundance is generally negatively correlated with shrimp abundance for most North Atlantic stocks, including the Eastern Scotian Shelf. This is probably partly due to large scale environmental influences, such as temperature, which appear to have opposite effects on cod and shrimp population dynamics, as well as a trophic effect of cod predation on shrimp. Cod recruitment (<30 cm) decreased to a very low level in 2014, but returned to values generally consistent with the recent time series in 2015 and 2016.

Interpretation: Natural mortality of shrimp due to cod predation is likely to remain low.

Turbot (Greenland Halibut) Recruitment

Turbot, or Greenland Halibut, is a coldwater species whose abundance is often positively correlated to shrimp abundance. However, it should be noted that Turbot are also known predators of shrimp, and so an increase in this indicator is both positive and negative. Restricting this indicator to juvenile Turbot may decrease the influence of predation and provide more predictive value for shrimp abundance. Greenland halibut <30 cm peaked in abundance on the Eastern Scotian Shelf in 2005–2006, and have since stabilized at relatively low levels.

Interpretation: Although the Turbot recruitment index increased slightly in 2016, it has remained relatively stable at low levels over the past decade. Similar to the other sympatric coldwater species, the recent/current environmental conditions are not thought to be favorable for Turbot recruitment.

Snow Crab Recruitment

As with Turbot, snow crab abundance tends to track shrimp abundance in the long-term. However, snow crab have considerably longer longevities and population cycles. The male pre-recruit index from the snow crab survey off southern Cape Breton has seen gradual declines since 2010.

Interpretation: The decreasing trend in snow crab recruitment in recent years adds further support to suggest that environmental conditions on the Eastern Scotian Shelf may be gradually becoming less favorable for the recruitment of sympatric cold water species.

TRAFFIC LIGHT SUMMARY

Precautionary Note: The overall summary and characteristic summary values are derived by a simple averaging process which does not account for complex interactions between indicators which may be occurring. Consequently, even the interpretation of individual indicators must be approached cautiously with regard to their relationship to stock health. Their placement within characteristics is also open to interpretation.

The summary Traffic Light indicator declined for the 3rd consecutive year, and remains in the yellow zone (Figure 17). The Abundance characteristic indicator declined and remains in the yellow zone due to declines in total abundance, the Standardised CPUE index, and reductions in commercial catch rate area. The Production characteristic indicator declined and remains in the yellow zone due to declines in the abundance of young shrimp associated with poor juvenile recruitment (low belly-bag age 1, and declines in age 2 & 4 abundance indices), reduced SSB, and increased predatory finfish abundance. The Fishing Effects characteristic indicator improved but remains in the yellow zone. The improvement can be attributed to declines in total and female exploitation due to the precautionary reductions in the 2016 TAC that were adopted to reflect reductions in total and Spawning Stock Biomass. The Ecosystem characteristic indicator declined and remains in the yellow zone due to high bottom and spring SSTs, and low/declining indices for sympatric coldwater species (Turbot and snow crab).

SOURCES OF UNCERTAINTY

DFO-Industry shrimp survey results are associated with high variances and biases associated with survey gear changes. Spatial and temporal variability in the distribution of shrimp is a source of uncertainty with regard to the accuracy of survey estimates; the survey is conducted consistently during early June to try to mitigate this effect. In 2007–2008, problems with NETMIND distance sensors and data logging required use of historical average instead of actual wing spread data to calculate swept areas and abundance. Given the inability to accurately age shrimp, modal groups are assigned to age classes; a process that is somewhat subjective, particularly for larger individuals. Growth rates can change dramatically due to density dependence, as happened with the strong 2001 year class. Consequently, recruitment to the fishery can be delayed and spread over a longer time period. Commercial abundance indices are susceptible to logistic, economic, analytical, and other factors that influence index values in ways that may be unrelated to shrimp abundance. For example, periods of bad weather or abundance sea ice can cause low CPUEs, as can fishing areas targeting large shrimp for market reasons. The standardised commercial CPUE index subsamples the data for vessels that meet certain criteria, which can also result in particularly successful or particularly unsuccessful vessels influencing this index in ways that may be unrelated to shrimp abundance in any given year. Unforeseen changes in the ecosystem (e.g. predator abundance), and the environment (e.g. water temperature) together increase the difficulty of making long-term projections for this stock. Finally, because of the timing of the shrimp assessment relative to the collection and analysis of samples, the advice of the Regional Advisory Process has generally been provided based on only a portion of these samples. As previously indicated, 120 survey samples and 45 commercial samples were included in this analysis for 2016.

CONCLUSIONS AND ADVICE

The 2016 DFO-Industry survey stratified mean biomass estimate decreased by 14%, to 25,584 (± 5079 95% CI). The point estimate of the 2016 Spawning Stock Biomass (13,223 mt) decreased 11%, falling below the Upper Stock Reference (USR) point of 14,558 mt, placing this stock within the Cautious Zone. As predicted by recent assessments, these declines are consistent with the expectation of a lag between the complete mortality of the long-lived 2007–2008 year classes, and poor recruitment of 2009–2012 year classes.

Despite declines in the survey abundance index, commercial CPUEs remained at a high level (standardized CPUE increased 3%, Gulf-based vessels declined by 4%). The distribution of areas representing various catch rate levels have all declined since 2014, which in combination with declines in the survey abundance index, is consistent with a declining resource.

Belly-bag Age 1 abundance indices in 2015 and 2016 highlight poor recruitment from the 2014 and 2015 year classes, respectively, which is consistent with the expectation that high temperature conditions lead to poor recruitment. The abundance of Age 2 and Age 4 shrimp also decreased in 2016, which is consistent with the low belly-bag index in 2015 (representing the 2014 year class), and 2013 (representing the 2012 year class). The abundant 2013 year-class increased the index of abundance of Age 3 male shrimp in 2016. Assuming continued growth and survival, this age class will begin recruiting to the Spawning Stock Biomass during 2017–2018.

Size-based indicators (size at sex-transition, average maximum size, female size, count) demonstrate that the size of shrimp has been decreasing in recent years. This is consistent with the end of the expected lifespan of the 2007–2008 year classes which matured as larger than average females, and were replaced by smaller, less abundant shrimp.

Ecosystem indicators, including sustained high temperatures and reductions in the abundance of sympatric species, suggest that conditions are currently unfavourable for coldwater species such as shrimp.

The overall mean indicator, summarizing the 24 stock health indicators, declined and remained in the yellow zone in 2016 due to all four summary characteristics falling within that zone. Despite remaining in the yellow zone, the fishing effects characteristic saw an increase in 2016 based on precautionary TAC reduction which in turn reduced overall effort, and induced declines in both total and female exploitation indices relative to 2015.

Declines in abundance, production, and ecosystem indicators, in combination with the SSB biomass declining below the USR in 2016, provides an unfavorable outlook for 2017. While Age 4+ males will increase in 2017, it is uncertain whether this will translate into an increase in the total biomass index in 2017. The 2013 year-class is not expected to recruit to the SSB until 2018. Continuation of precautionary TAC reductions will help to maintain low exploitation rates and to protect more of the 2013 year-class until it can recruit to the SSB.

ACKNOWLEDGEMENTS

The authors thank Captain Bob Schrader for his co-operation and expert advice on the survey gear, and the entire crew of MV *Cody & Kathryn* for successfully conducting the 2016 survey. Thanks to Scott Bates and Tony DeRoche for their conscientious collection, handling & storage of the shrimp samples for laboratory analysis. Thanks also to the many fishers and buyers who provided fishery data such as counts, catch and effort data, and shrimp samples over the years. The authors thank reviewers David Keith and Daphne Themelis for their constructive comments.

REFERENCES CITED

Boutillier, J.A., and J.A. Bond. 2000. Using a fixed escapement strategy to control recruitment overfishing in the shrimp trap fishery in British Columbia. J. Northwest Atl. Fish. Sci. 27: 261–271.

Charnov, E., and U. Skúladóttir. 2000. Dimensionless invariants for the optimal size (age) of sex change. Evol. Ecol. Res. 2: 1067–1071.

DFO. 2014. Eastern Scotian Shelf Shrimp Stock Status Update for 2013-2014. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/012.

DFO. 2015. Assessment of Northern Shrimp on the Eastern Scotian Shelf (SFAs 13-15). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/004.

DFO. 2016a Eastern Scotian Shelf Shrimp Stock Status Update for 2015-2016. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/001.

DFO. 2016b. Proceedings of the Regional Assessment of an Eastern Scotian Shelf Shrimp (*Pandalus borealis*) Framework; April 14–15, 2015. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2016/002.

Gulland, J.A. 1971. The fish resources of the ocean. Fishing News Books, West Byfleet, UK.

Halliday, R.G., and P.A. Koeller. 1981. A history of Canadian groundfish trawling surveys and data usage in ICNAF Divisions 4TVWX; pp. 27–41. In W.G. Doubleday and D. Rivard (Editors). Bottom Trawl Surveys. Can. Spec. Publ. Fish. Aquat. Sci. 58.

Halliday, R.G., L.P. Fanning, and R.K. Mohn. 2001. Use of the Traffic Light Method in Fishery Management Planning. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/108. 41 p.

Hannah, R.W. 1995. Variation in geographic stock area, catchability, and natural mortality of ocean shrimp (*Pandalus jordani*): Some new evidence for a trophic interaction with Pacific hake (*Merluccius productus*). Can. J. Fish. Aquat. Sci. 52: 1018–1029.

Hardie, D., M. Covey, M. King, and B. Zisserson. 2011. Scotian Shelf Shrimp 2010-2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/102. vi + 76 p.

Hardie, D., M. Covey, M. King, and B. Zisserson. 2013a. Scotian Shelf Shrimp 2011-2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/033. v + 52 p.

Hardie, D., M. Covey, M. King, and B. Zisserson. 2013b. Scotian Shelf Shrimp 2012-2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/034. v + 44 p.

Hardie, D., M. Covey, K. Nickerson, and M. King. 2015. Scotian Shelf Shrimp 2014-2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/062. v + 44 p.

Hardie, D., Covey, M., and Cook, A. 2018. 2015 Eastern Scotian Shelf Shrimp (*Pandalus borealis*) Framework. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/005. vi + 117 p.

Koeller, P. 1996a. Aspects of the biology of pink shrimp *Pandalus borealis* Krøyer on the Scotian Shelf. DFO Atl. Fish. Res. Doc. 96/9.

Koeller, P. 1996b. The Scotian Shelf shrimp fishery in 1995. DFO Atl. Fish. Res. Doc. 96/8.

Koeller, P. 2000. Relative importance of environmental and ecological factors to the management of the northern shrimp fishery (*Pandalus borealis*) on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 27: 37–50.

Koeller, P. 2006. Inferring shrimp (*Pandalus borealis*) growth characteristics from life history stage structure analysis. J. Shell. Res. 25: 595–608.

Koeller, P., M. Covey, and M. King. 1997. The Scotian Shelf shrimp (*Pandalus borealis*) fishery in 1997. DFO Atl. Fish. Res. Doc. 97/125.

Koeller, P., R. Mohn, and M. Etter 2000a. Density dependant sex change in pink shrimp, *Pandalus borealis,* on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 27: 107–118.

Koeller, P., L. Savard, D. Parsons, and C. Fu. 2000b. A precautionary approach to assessment and management of shrimp stocks in the Northwest Atlantic. J. Northw. Atl. Fish. Sci. 27: 235–247.

Koeller, P., M. Covey, and M. King. 2003a. An Assessment of the Eastern Scotian Shelf Shrimp Stock and Fishery for 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/005. ii + 47 p.

Koeller, P., M. Covey, and M. King. 2003b. Is size at transition a measure of growth or abundance in Pandalid shrimp? Fish. Res. 65: 217–230.

Koeller, P., C. Fuentes-Yaco, T. Platt, S. Sathyendranath, A. Richards, P. Ouellet, D. Orr, U. Skúladóttir, K. Wieland, L. Savard, and M. Aschan. 2009. Basin-scale coherence in phenology of shrimps and phytoplankton in the north Atlantic Ocean. Sci. 324: 791–793.

Koeller, P., C. Fuentes-Yaco, M. Covey, M. King, and B. Zisserson. 2011. The Last Traffic Light on the Scotian Shelf: Shrimp 2009-2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/061. viii + 84 p.

Macdonald, P.D.M., and T.J. Pitcher. 1979. Age-groups from size-frequency data: A versatile and efficient method of analysing distribution mixtures. J. Fish. Res. Board Can. 36: 987–1001.

Mohn, R., J. Black, and P. Koeller. 2001. Traffic light indicators. BIO Review 2000. 88 p.

Ouellet, P., L. Savard, and P. Larouche. 2007. Spring oceanographic conditions and northern shrimp *Pandalus borealis* recruitment success in the north-western Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 339: 229–241.

Shumway, S.E., H.C. Perkins, D.F. Schick, and A.P. Stickney. 1985. Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. NOAA Tech. Rept. NMFS 30.

Smith, S.J. 1997. Bootstrap confidence limits for groundfish trawl survey estimates of mean abundance. Can. J. Fish. Aquat. Sci. 54: 616–663.

TABLES

Table 1. Total Allowable Catch (TAC; trawls) and catches (trawls and traps) from the Eastern Scotian Shelf shrimp fishery (SFAs 13–15), 1980–2016. Cells with dashes indicate no data.

Year	TAC Trawl	TAC Trap	Trawl Catch SFA 13	SFA 14	SFA 15	Total	Trap Catch	Total Catch
1980	5021	-	491	133	360	984	-	984
1981	-	-	418	26	10	454	-	454
1982	4200	-	316	52	201	569	-	569
1983	5800	-	483	15	512	1010	-	1010
1984	5700	-	600	10	318	928	-	928
1985	5560	-	118	-	15	133	-	133
1986	3800	-	126	-	-	126	-	126
1987	2140	-	148	4	-	152	-	152
1988	2580	-	75	6	1	82	-	82
1989	2580	-	91	2	-	93	-	93
1990	2580	-	90	14	-	104	-	104
[1]1991	2580	-	81	586	140	804	-	804
1992	2580	-	63	1181	606	1850	-	1850
[2]1993	2650	-	431	1279	317	2044	-	2044
[3]1994	3100	-	8	2656	410	3074	-	3074
1995	3170	-	168	2265	715	3148	27	3175
1996	3170	-	55	2299	817	3171	187	3358
1997	3600	-	570	2422	583	3574	222	3797
1998	3800	-	562	2014	1223	3800	131	3931
1999	4800	200	717	1521	2464	4702	149	4851
2000	5300	200	473	1822	2940	5235	201	5436
2001	4700	300	692	1298	2515	4505	263	4768
2002	2700	300	261	1553	885	2699	244	2943
2003	2700	300	612	1623	373	2608	157	2765
2004	3300	200	2041	755	376	3172	96	3268
2005	4608	392	1190	1392	1054	3636	9	3645
2006	4608	392	846	1997	1111	3954	32	3986
2007	4820	200	267	2633	1678	4578	4	4582
2008	4912	100	349	2703	1265	4317	4	4321
2009	3475	25	298	2450	727	3475	2	3477
2010	4900	100	280	1846	2454	4580	1	4581
2011	4432	168	254	2340	1653	4247	111	4358
2012	3954	246	197	2296	1227	3693	199	3892
2013	3496	304	158	2514	708	3380	224	3604
2014	4140	360	771	2265	1045	4081	250	4332
2015	4140	360	341	2069	1702	4112	314	4426
2016[4]	2990	260	148	2095	676	2920	106	3026
2016[5]			152	2146	693	2990	260	3250

Notes:

[1] Nordmøre separator grate introduced.
[2] Overall TAC not caught because TAC for SFAs 14 and 15 was exceeded.
[3] Individual SFA TACs combined.
[4] Current year to date (November 15, 2016).
[5] Current year prorated to total TAC.

Table 2. Number of active vessels and total licences (in brackets) for the Eastern Scotian Shelf shrimp fishery.

	Trap	Trawl	
Year	**Scotia-Fundy[1]**	**Scotia-Fundy[2]**	**Gulf[3]**
1995	4	24(23)	6(23)
1996	9(17)	21(24)	6(23)
1997	10(17)	18(23)	6(23)
1998	15(26)	17(28)[4]	10(23)[5]
1999	15(22)	19(28)[4]	10(23)[5]
2000	12(21)	18(32)[6]	10(23)[5]
2001	10(28)	18(28)[4]	10(23)[5]
2002	10(14)[7]	15(23)	6(23)
2003	9(14)	14(23)	5(23)
2004	6(14)	14(23)	6(23)
2005	2(14)	20(28)[8]	7(24)[9]
2006	5(14)	18(28)	7(24)
2007	2(14)	20(28)	7(24)
2008	1(14)	18(28)	7(24)
2009	1(14)	17(28)	6(14)[10]
2010	3(14)	18(28)	7(14)
2011	7(14)	15(28)	5(14)
2012	8(14)	12(28)	5(14)
2013	11(14)	13(28)	6(14)
2014	8(14)	10(28)	5(14)
2015	9(14)	10(28)	5(14)
2016	8(14)	11(28)	5(14)

Notes:

[1] All but one active trap licences are vessels <45'. They receive about 8% of the TAC.
[2] These vessels receive about 70% of the TAC according to the management plan. Inactive NAFO 4X licences (15) not included in total.
[3] All licences 65–100' length over all (LOA). Eligibility to fish in Scotia-Fundy for about 23% of the TAC.
[4] Temporary allocation divided among 5 vessels.
[5] Temporary allocation divided among 4 vessels.
[6] Temporary allocation divided among 9 licences.
[7] Nine (9) licences were made permanent for 2002. The reduction in the total number of trap licences is due to cancellation of some non-active exploratory licences.
[8] Five (5) temporary licences made permanent.
[9] One (1) temporary licence made permanent.
[10] The previously reported number of licenses included (10) that were invalid for a number of reasons. The number of valid licenses was updated in 2009.

Table 3. Input data for traffic light analysis.

Indicator	RV_CPUE	G_CPUE	St_CPUE	Trap_CPUE	RV_CPUE	Comm_area	RV_SSB	BB_1	RV_2	RV_4	sex_mm	max_mm	pred	effort	count	Exp_tot	Exp_fem	fem_prop	fem_size	RV_temp	Spring_SST	Cod_R	Turbot	Snow Crab
Action	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile
Indirect																								
RuleAbundance (production == red) +																								
Direct																								
Overwts	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maxwts	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Level_YG	0.66	0.66	0.66	0.66	0.33	0.66	0.66	0.66	0.66	0.66	0.66	0.33	0.33	0.33	0.33	0.33	0.33	0.66	0.66	0.33	0.33	0.33	0.66	0.66
Level_RY	0.33	0.33	0.33	0.33	0.66	0.33	0.33	0.33	0.33	0.33	0.33	0.66	0.66	0.66	0.66	0.66	0.66	0.33	0.33	0.66	0.66	0.66	0.33	0.33
Characteristic	Polarity																							
Abundance	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
FishingM	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
Ecosystem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1

Year	RV_CPUE	G_CPUE	St_CPUE	Trap_CPUE	RV_CV	Comm_area	RVSSB	BB_1	RV_2	RV_4	sex_mm	max_mm	pred	effort	count	Exp_tot	Exp_fem	fem_prop	fem_size	RV_temp	Spring SST	Cod_R	Turbot	snow_c
1982	34.50	128.00	NAN	NAN	89.06	NAN	5040.65	NAN	NAN	NAN	21.46	28.24	179.29	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	2.38	0.00	NAN
1983	71.50	127.70	NAN	NAN	78.52	NAN	7323.05	NAN	NAN	NAN	21.80	28.03	164.05	NAN	NAN	NAN	NAN	NAN	NAN	NAN	2.78	2.42	0.00	NAN
1984	39.00	109.50	NAN	NAN	75.84	NAN	4460.96	NAN	NAN	NAN	22.17	27.69	353.25	NAN	NAN	NAN	NAN	NAN	NAN	NAN	0.48	5.57	0.06	NAN
1985	17.00	75.40	NAN	NAN	83.09	NAN	2417.71	NAN	NAN	NAN	21.77	27.87	236.37	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-0.07	1.71	0.05	NAN
1986	23.00	87.30	NAN	NAN	106.13	NAN	3187.87	NAN	NAN	NAN	23.63	27.94	144.33	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-0.77	0.37	0.09	NAN
1987	25.50	90.70	NAN	NAN	67.53	NAN	3424.46	NAN	NAN	NAN	23.16	27.94	187.04	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.32	0.87	0.16	NAN
1988	31.50	85.10	NAN	NAN	60.14	NAN	4047.02	NAN	NAN	NAN	23.84	28.12	142.81	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-0.92	1.19	0.06	NAN
1989	NAN	133.40	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	66.58	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.07	1.75	0.00	NAN
1990	NAN	134.50	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	67.33	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.02	1.16	0.00	NAN
1991	NAN	197.90	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	46.91	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-0.77	0.17	0.46	NAN
1992	NAN	176.30	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	32.10	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.72	0.17	0.08	NAN
1993	75.00	187.89	142.20	NAN	80.33	31	NAN	NAN	NAN	NAN	23.78	30.45	68.53	1325.4	NAN	NAN	NAN	NAN	NAN	NAN	-2.07	0.29	1.86	NAN
1994	NAN	213.52	188.40	NAN	NAN	48	NAN	NAN	NAN	NAN	NAN	NAN	66.17	1680.9	NAN	NAN	NAN	0.89	26.05	NAN	-1.52	0.30	1.98	NAN
1995	173.02	187.02	181.17	NAN	82.84	71	10912.15	NAN	358.50	875.92	24.05	29.27	66.52	1728.5	55.92	13.44	21.04	0.72	26.03	1.59	-1.17	0.54	1.74	NAN
1996	213.92	244.58	224.35	2.21	64.88	99	13368.38	NAN	307.34	1247.63	24.73	29.99	32.56	1334.3	54.47	11.50	16.11	0.68	26.01	1.72	-0.92	0.16	4.78	NAN
1997	193.00	236.26	218.89	2.26	53.46	146	12100.80	NAN	128.85	1257.47	24.94	29.78	35.85	1538.6	56.35	14.41	19.08	0.64	26.44	2.74	-0.47	0.40	2.91	6588.78
1998	238.38	343.73	298.94	1.69	74.42	209	15707.48	NAN	39.89	1883.71	24.33	29.51	59.87	1321.2	53.22	12.08	14.73	0.60	25.68	1.97	-0.06	0.31	0.41	8446.24
1999	268.40	395.70	325.53	2.02	72.20	258	17607.48	NAN	165.63	3010.18	24.08	29.31	64.13	1483.2	55.30	13.24	16.90	0.63	25.46	3.24	-0.50	1.39	1.67	10482.22
2000	233.36	383.66	365.48	2.58	72.00	242	15893.36	NAN	280.34	0.00	24.74	29.74	76.29	1532.4	55.19	17.06	19.79	0.58	25.57	3.60	0.07	0.79	11.44	5128.69
2001	183.32	428.24	443.46	2.94	126.03	221	14475.58	NAN	174.90	1184.11	24.29	29.19	73.28	1302.6	54.70	19.05	19.56	0.63	25.15	2.36	-0.55	1.58	3.66	4664.29
2002	161.40	572.36	523.48	2.89	111.15	192	14133.20	980.00	134.00	399.17	24.45	29.02	57.30	659.4	52.53	14.17	13.43	0.70	25.61	2.77	-0.09	0.32	3.88	2212.31
2003	204.42	675.41	520.72	2.83	104.48	265	16916.16	196.00	576.74	1411.07	24.31	29.05	100.65	569.9	53.48	9.83	10.91	0.73	25.68	2.69	-1.30	1.03	6.69	1656.46
2004	353.70	793.14	549.32	3.42	78.00	263	26856.47	316.00	354.09	839.46	24.13	29.44	57.46	594.0	54.96	6.75	9.48	0.80	25.41	1.99	-0.43	0.64	3.44	1248.30
2005	312.90	683.25	496.53	2.98	83.01	364	18587.50	198.00	187.02	4502.48	23.63	29.46	99.05	812.0	58.93	8.20	13.05	0.66	25.72	2.41	0.47	0.25	14.00	1500.56
2006	275.20	716.40	614.86	4.33	75.86	296	16288.53	61.00	121.30	0.00	23.39	29.35	77.47	817.3	63.23	10.55	13.57	0.55	25.96	3.62	1.03	0.80	18.92	3012.34
2007	281.20	696.62	507.79	3.60	66.34	389	18345.54	194.00	39.00	0.00	23.67	29.07	51.64	882.8	65.30	11.92	12.28	0.45	25.70	2.30	-0.73	0.29	7.77	5482.42
2008	226.10	664.07	520.17	4.48	72.25	423	12119.42	484.11	134.72	1046.18	23.84	28.57	92.82	838.4	61.52	13.98	20.50	0.52	24.98	1.96	0.03	1.24	6.51	6145.07

Year	RV_CPUE	G_CPUE	St_CPUE	Trap_CPUE	RV_CV	Comm_area	RVSSB	BB_1	RV_2	RV_4	sex_mm	max_mm	pred	effort	count	Exp_tot	Exp_fem	fem_prop	fem_size	RV_temp	Spring SST	Cod_R	Turbot	snow_c
2009	333.10	648.76	628.16	5.15	91.70	324	24853.59	566.52	304.05	463.00	24.21	28.74	55.35	618.7	57.56	7.65	9.37	0.72	25.06	2.59	-0.61	0.57	5.42	4424.86
2010	273.00	536.23	465.57	3.23	105.47	350	21706.69	205.08	188.00	1036.00	24.53	28.87	70.88	997.3	57.77	12.31	15.45	0.74	25.20	2.35	1.54	0.16	2.55	6264.81
2011	223.60	671.18	456.36	3.74	78.89	320	16823.67	97.34	85.22	1044.08	24.27	28.51	149.12	840.0	61.34	14.28	18.61	0.71	25.19	2.99	0.72	0.93	1.96	4912.83
2012	205.30	552.28	496.05	2.96	66.78	294	14762.95	124.76	273.22	1022.00	23.88	29.01	31.80	785.6	59.61	15.01	18.93	0.72	25.22	4.20	0.43	0.65	1.37	4436.99
2013	287.60	626.68	672.22	3.84	91.88	337	20679.51	24.92	302.00	1693.00	23.79	29.11	101.00	612.4	59.30	9.64	13.27	0.74	25.56	3.04	0.40	1.94	1.17	3363.25
2014	284.30	417.43	478.84	3.39	91.86	342	20358.62	789.32	125.00	0.00	24.29	28.97	115.00	912.0	55.54	11.17	15.28	0.70	25.62	3.64	-0.35	0.04	3.27	3214.33
2015	218.40	570.97	614.20	3.51	93.59	299	14939.03	23.03	504.00	922.00	24.46	29.28	63.00	874.8	59.53	15.16	18.65	0.57	25.36	4.72	-0.33	0.57	3.06	3459.18
2016	**186.20**	**549.49**	**632.10**	**2.73**	**79.07**	**227**	**13223.48**	**23.24**	**193.36**	**550.25**	**24.11**	**28.53**	**102.00**	**590.6**	**60.64**	**11.53**	**15.58**	**0.70**	**25.26**	**4.68**	**1.01**	**0.38**	**3.73**	**3309.08**

Note: NAN = not a number.

Table 4. Set statistics from DFO-Industry survey CK1601 conducted by MV Cody & Kathryn from June1–19, 2016.

SET	STRATUM	DATE	LAT.	LONG.	SPEED (kts)	DIST. (n.m.)	DUR. (min)	WING. (m)	DEPTH (fth)	TEMP (°C)	RAW CATCH (kg)	STAND. CATCH (kg)	DENSITY (gm/m2 or m.t./km2)
1	15	01-Jun-16	450023	605728	2.48	1.31	030	16.876294	099	2.2	0107	105.27	2.61
2	15	01-Jun-16	445259	610438	2.38	1.22	030	16.948708	109	5.1	0057	59.96	1.49
3	15	01-Jun-16	444942	605381	2.13	1.05	030	17.041730	116	4.6	0062	75.36	1.86
4	15	01-Jun-16	445584	604634	2.11	1.06	030	17.041730	115	4.3	0210	252.85	6.28
5	15	01-Jun-16	445055	604786	2.35	1.20	030	16.748508	115	4.4	0064	69.26	1.71
6	15	01-Jun-16	444734	604388	2.15	1.09	030	17.433639	122	4.5	0086	98.43	2.44
7	15	02-Jun-16	444922	603205	2.58	1.24	030	17.671464	127	3.5	0195	193.55	4.80
8	15	02-Jun-16	445470	602649	2.46	1.22	030	16.496601	128	3.8	0154	166.43	4.15
9	15	02-Jun-16	445501	602264	2.23	1.11	030	17.431373	115	3.7	0092	103.42	2.57
10	15	02-Jun-16	445106	601611	2.34	1.14	030	17.331608	142	3.9	0195	214.66	5.32
11	15	02-Jun-16	444845	601615	2.31	1.15	030	17.265570	166	4.0	0163	178.55	4.43
12	15	02-Jun-16	444761	601994	2.28	1.20	030	17.521964	159	3.9	0056	57.93	1.45
13	15	02-Jun-16	444442	601661	2.06	0.96	030	17.487522	131	4.5	0062	80.33	2.01
14	15	02-Jun-16	444177	601373	2.26	1.13	030	16.368061	119	6.1	0039	45.86	1.15
15	15	02-Jun-16	444187	600929	2.32	1.15	030	16.449944	108	6.0	0053	60.94	1.51
16	17	09-Jun-16	452237	610124	2.45	1.23	030	16.256560	056	2.1	0043	46.77	1.16
17	17	09-Jun-16	452585	605600	2.36	1.19	030	16.256560	058	2.2	0086	96.69	2.41
18	17	10-Jun-16	452483	604056	2.17	1.08	030	16.240395	077	3.2	0284	352.17	8.71
19	17	10-Jun-16	452845	604517	2.23	1.12	030	16.328178	070	2.7	0111	132.02	3.29
20	17	10-Jun-16	453245	603419	2.11	1.06	030	16.201108	073	3.3	0234	296.36	7.38
21	17	10-Jun-16	452974	601284	2.11	1.10	030	16.339225	088	4.1	0172	208.14	5.17
22	17	10-Jun-16	453127	600770	2.15	1.11	030	16.861341	088	3.7	0048	55.78	1.38
23	17	10-Jun-16	453328	601040	2.27	1.15	030	16.847851	105	3.7	0329	369.33	9.19
24	17	10-Jun-16	453643	600259	2.08	1.03	030	16.805933	085	3.7	0028	35.18	0.87
25	17	10-Jun-16	453658	595472	2.04	1.00	030	17.051663	087	3.8	0005	6.38	0.14
26	13	11-Jun-16	453576	585468	2.33	1.17	030	17.184247	119	5.5	0249	269.37	6.69
27	13	11-Jun-16	454125	590073	2.21	1.11	030	17.598945	144	5.9	0241	268.33	6.64
28	13	11-Jun-16	454295	585633	2.48	1.27	030	16.903000	145	6.0	0221	223.92	5.58
29	13	11-Jun-16	454217	584948	2.45	1.28	030	16.613495	128	5.8	0108	110.46	2.74
30	13	11-Jun-16	454386	584582	2.30	1.21	030	17.627891	140	6.0	0138	140.72	3.48
31	13	11-Jun-16	454704	584698	2.10	1.06	030	17.370603	142	5.9	0186	219.71	5.46
32	13	11-Jun-16	455076	584628	2.19	1.13	030	17.300207	137	6.0	0118	131.28	3.26
33	13	11-Jun-16	455001	583689	2.24	1.14	030	17.520980	145	6.1	0252	274.41	6.82
34	13	11-Jun-16	454740	583746	2.19	1.12	030	17.355456	151	5.9	0074	82.80	2.07
35	17	12-Jun-16	452370	595885	2.37	1.18	030	16.180040	087	4.1	0151	172.02	4.27
36	17	12-Jun-16	452372	600295	2.27	1.12	030	16.881740	111	4.2	0896	1030.70	25.52
37	17	12-Jun-16	451630	601948	2.15	1.21	030	16.120335	093	3.3	0219	244.20	6.07
38	17	12-Jun-16	452107	601567	2.36	1.21	030	16.988830	108	4.0	0306	323.77	8.06
39	17	12-Jun-16	452575	602868	2.32	1.19	030	16.820109	095	3.3	0217	235.80	5.85
40	14	16-Jun-16	445522	595925	2.38	1.21	030	17.282216	102	5.3	0142	147.69	3.67
41	14	16-Jun-16	444822	595834	2.51	1.27	030	17.437970	131	5.9	0118	115.89	2.86
42	14	16-Jun-16	444228	600071	2.39	1.25	030	16.786596	110	5.6	0048	49.75	1.23
43	14	16-Jun-16	444256	594686	2.17	1.06	030	16.225092	135	5.6	0136	171.99	4.24
44	14	16-Jun-16	445199	594356	2.33	1.21	030	17.148307	118	4.6	0121	126.83	3.14
45	14	16-Jun-16	444154	593589	2.60	1.32	030	17.511716	109	5.2	0173	162.78	4.05
46	14	17-Jun-16	445097	592798	2.28	1.16	030	16.796815	133	4.3	0193	215.44	5.35
47	14	17-Jun-16	444791	591163	2.40	1.21	030	17.041730	118	3.4	0153	161.38	4.00
48	14	17-Jun-16	443877	590268	2.02	1.03	030	17.040970	114	3.3	0294	364.31	9.05
49	14	17-Jun-16	444701	585401	2.07	1.04	030	17.424385	137	4.1	0333	399.68	9.89

SET	STRATUM	DATE	LAT.	LONG.	SPEED (kts)	DIST. (n.m.)	DUR. (min)	WING. (m)	DEPTH (fth)	TEMP (°C)	RAW CATCH (kg)	STAND. CATCH (kg)	DENSITY (gm/m2 or m.t./km2)
50	14	17-Jun-16	444777	583849	2.53	1.28	030	17.641315	134	4.9	0232	223.46	5.53
51	14	18-Jun-16	445093	590345	2.13	1.10	030	17.394367	121	3.7	0268	304.64	7.54
52	14	18-Jun-16	445583	584312	2.52	1.26	030	17.786257	136	4.6	0292	283.39	7.00
53	14	18-Jun-16	445080	583360	2.45	1.27	030	17.823370	133	5.0	0267	256.55	6.38
54	14	18-Jun-16	445513	582076	2.19	1.09	030	16.866706	129	5.9	0235	278.02	6.88
55	13	18-Jun-16	453129	582804	2.52	1.29	030	16.773895	115	4.7	0183	183.94	4.57
56	13	19-Jun-16	453174	583610	2.33	1.22	030	17.617665	143	5.0	0171	173.04	4.31
57	13	19-Jun-16	453732	583432	2.44	1.25	030	15.907475	197	5.3	0056	61.25	1.51
58	13	19-Jun-16	454177	582641	2.28	1.16	030	16.114875	205	5.3	0086	100.06	2.48
59	13	19-Jun-16	454689	581907	2.06	1.04	030	16.991859	117	5.2	0000	0.00	0.00
60	13	19-Jun-16	453893	581779	2.16	1.05	030	16.992344	200	4.9	0056	68.27	1.69

Table 5. Minimum survey population numbers at age from modal analysis. Numbers × 10^6. Cells with dashed lines indicate no data.

Age	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
1[1]	-	-	-	980	196	316	198	61	194	484	567	263	97	113	25	790	24	23	289
2	166	280	175	134	616	354	187	121	39	114	304	188	85	348	302	125	504	193	230
3	27	757	362	383	312	3118	652	880	506	396	267	1020	752	1018	1157	628	756	2296	840
4	3010	0[4]	1184	399	1506	839	4502	0[4]	0[4]	1190	463	1036	1044	1022	1693	0[4]	922	550	1368
5+	1952	3374	2110	1847	1727	3324	2224	5106	5506	3017	6020	4109	2488	1666	2398	4980	1956	1534	2827
TOTAL	5155	4412	3831	2763	4161	7636	7763	6169	6244	5201	7622	6616	4467	4167	5574	6523	4162	4596	5145
Age 4+ males[2]	3235	1784	1771	938	1526	1549	4956	3916	2804	3317	4263	3454	1755	1211	1032	3276	427	773	2206
Primiparous[3]	736	728	817	678	551	870	786	771	1739	892	1492	1324	930	281	860	659	399	663	827
Multiparous	991	863	706	630	1188	1698	1183	480	1157	482	1295	630	945	1309	2224	1835	2076	898	1044
Total females	1727	1591	1523	1308	1739	2568	1969	1251	2896	1374	2787	1954	1875	1590	3084	2494	2475	1561	1871

Notes:

[1] Belly-bag.
[2] Total population less ages 2,3 males, transitionals and females, i.e. males that will potentially change to females the following year.
[3] Includes transitionals.
[4] Four year olds of the 1996, 2002, 2003, and 2014 year classes were not distinguishable in the MIX analysis. These year classes appear to be small and are contained in the ages 3 or 5+ categories.

Table 6. Survey biomasses, commercial shrimp catches, and exploitation rates (catch/biomass) by survey stratum (13–15, offshore part), and the inshore area (17), 2000–2016.

Parameter	Strata	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
Biomass (mt)	**13**	5866	4089	3114	7047	12184	9687	6129	7507	4144	6208	2688	4537	6011	7970	8204	5809	6184	6316
	14	9364	12325	12020	12035	20228	20035	18929	15957	12710	20544	16009	14614	10941	17682	11801	11641	8190	14413
	15	7268	2073	2766	3751	4399	4378	5130	5345	4227	7235	4784	4223	4232	2594	3022	3451	2765	4214
	17	9365	6541	2872	5296	11627	10333	7581	9622	9823	11438	13731	7136	6793	11136	15765	8741	8445	9191
	Total	**31863**	**25028**	**20773**	**28130**	**48438**	**44433**	**37769**	**38431**	**30904**	**45424**	**37212**	**30510**	**27978**	**39381**	**38791**	**29642**	**25584**	**34135**
Catch (mt)	**13**	233	432	253	585	2011	1145	630	85	212	11	125	4	0	0	438	101	88	374
	14	1750	1206	1552	1621	752	1372	1998	2640	2696	2026	1844	2342	2526	2259	2283	2060	2094	1942
	15	915	965	264	226	338	613	444	612	534	540	1123	986	805	924	192	40	4	560
	17	2538	2165	874	333	168	515	915	1245	879	900	1490	1026	827	688	1002	2210	840	1095
	Total	**5436**	**4768**	**2943**	**2765**	**3268**	**3645**	**3986**	**4582**	**4321**	**3477**	**4581**	**4358**	**4158**	**3871**	**3915**	**4411**	**3026**	**3971**
Expltn. (%)	**13**	4.0	10.6	8.1	8.3	16.5	11.8	10.3	1.1	5.1	0.2	4.6	0.1	0.0	0.0	5.3	1.7	1.4	5.2
	14	18.7	9.8	12.9	13.5	3.7	6.8	10.6	16.5	21.2	9.9	11.5	16.0	23.1	12.8	19.3	17.7	25.6	14.7
	15	12.6	46.6	9.6	6.0	7.7	14.0	8.6	11.5	12.6	7.5	23.5	23.3	19.0	35.6	6.4	1.2	0.1	14.5
	17	27.1	33.1	30.4	6.3	1.4	5.0	12.1	12.9	8.9	7.9	10.9	14.4	12.2	6.2	6.4	25.3	9.9	13.5
	Total	**17.1**	**19.1**	**14.2**	**9.8**	**6.7**	**8.2**	**10.6**	**11.9**	**14.0**	**7.7**	**12.3**	**14.3**	**14.9**	**9.8**	**10.1**	**14.9**	**11.8**	**12.2**

Table 7. Bycatch of the commercial shrimp fishery from observer data of 27 sets in 2015, and 14 sets in 2016.

	% BYCATCH (# of tows)		**TOTAL OBSERVER ESTIMATED WEIGHT (KGS)**	
SPECIES	**2015 (27)**	**2016 (14)**	**WEIGHT EST. KGS**	**%**
SHRIMP	99.42%	96.07%	73251	97.99%
SILVER HAKE	0.04%	1.95%	642	0.86%
ALEWIFE	<0.01%	0.92%	296	0.40%
GREENLAND HALIBUT (TURBOT)	0.04%	0.61%	213	0.28%
REDFISH, UNSEPARATED	0.02%	0.41%	142	0.19%
ATLANTIC HERRING	0.30%	-	126	0.17%
WITCH FLOUNDER	0.06%	-	25	0.03%
AMERICAN PLAICE	0.04%	-	17	0.02%
SNOW CRAB (QUEEN)	0.02%	0.01%	10	0.01%
EELPOUTS, UNSEPARATED	0.02%	-	10	0.01%
ATLANTIC COD	-	0.02%	8	0.01%
FOURBEARD ROCKLING	0.01%	-	6	0.01%
THORNY SKATE	0.01%	-	4	0.01%
BASKET STARS	<0.01%	-	2	0.00%
CAPELIN	<0.01%	-	1	0.00%
SQUIRREL OR RED HAKE	<0.01%	-	1	0.00%
WHITE BARRACUDINA	<0.01%	-	1	0.00%
STRIPED ATLANTIC WOLFFISH	-	<0.01%	1	0.00%
% BYCATCH	**0.58%**	**3.93%**	**-**	**2.01%**

FIGURES

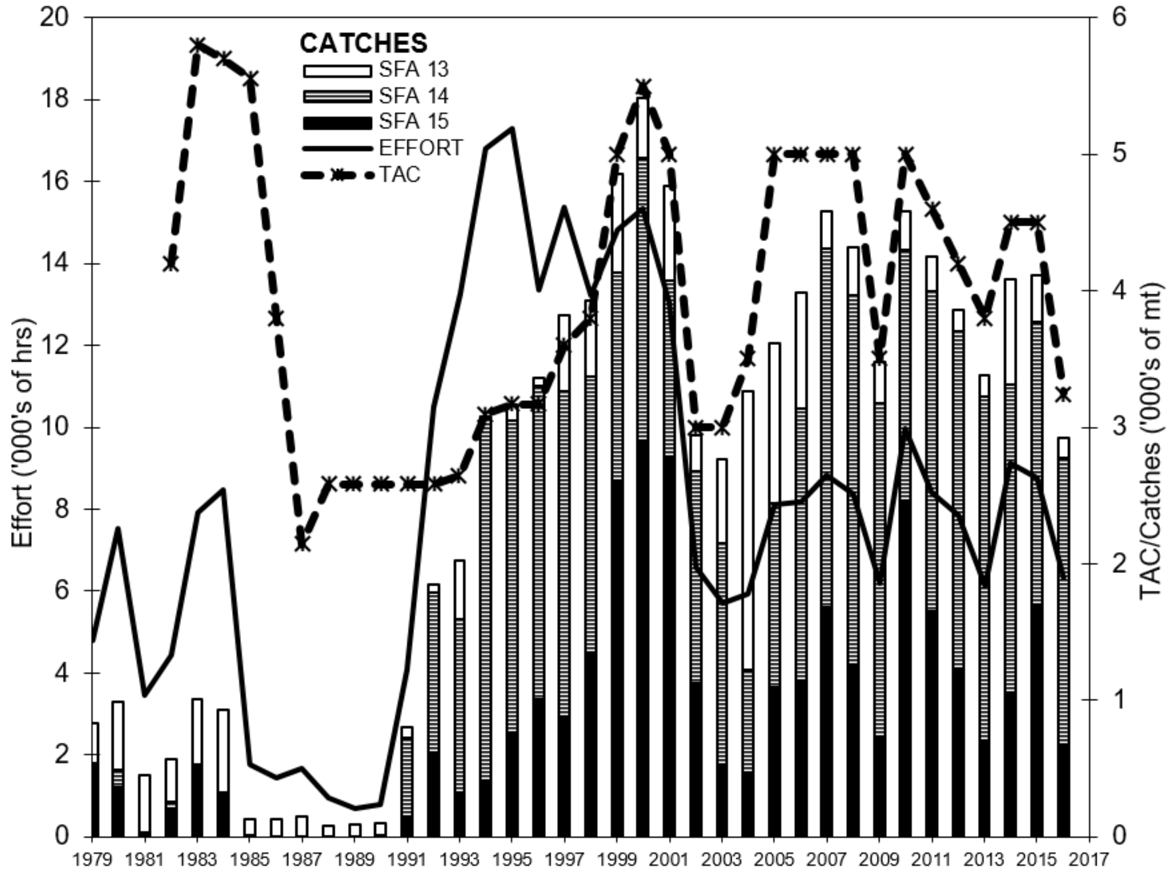


Figure 1. History of Eastern Scotian Shelf shrimp fishery catches per SFA (13, 14 and 15), TAC (thousands of mt) and effort (thousands of hours), from 1979–2016. Effort and catches are those available as of November 15th, 2016.

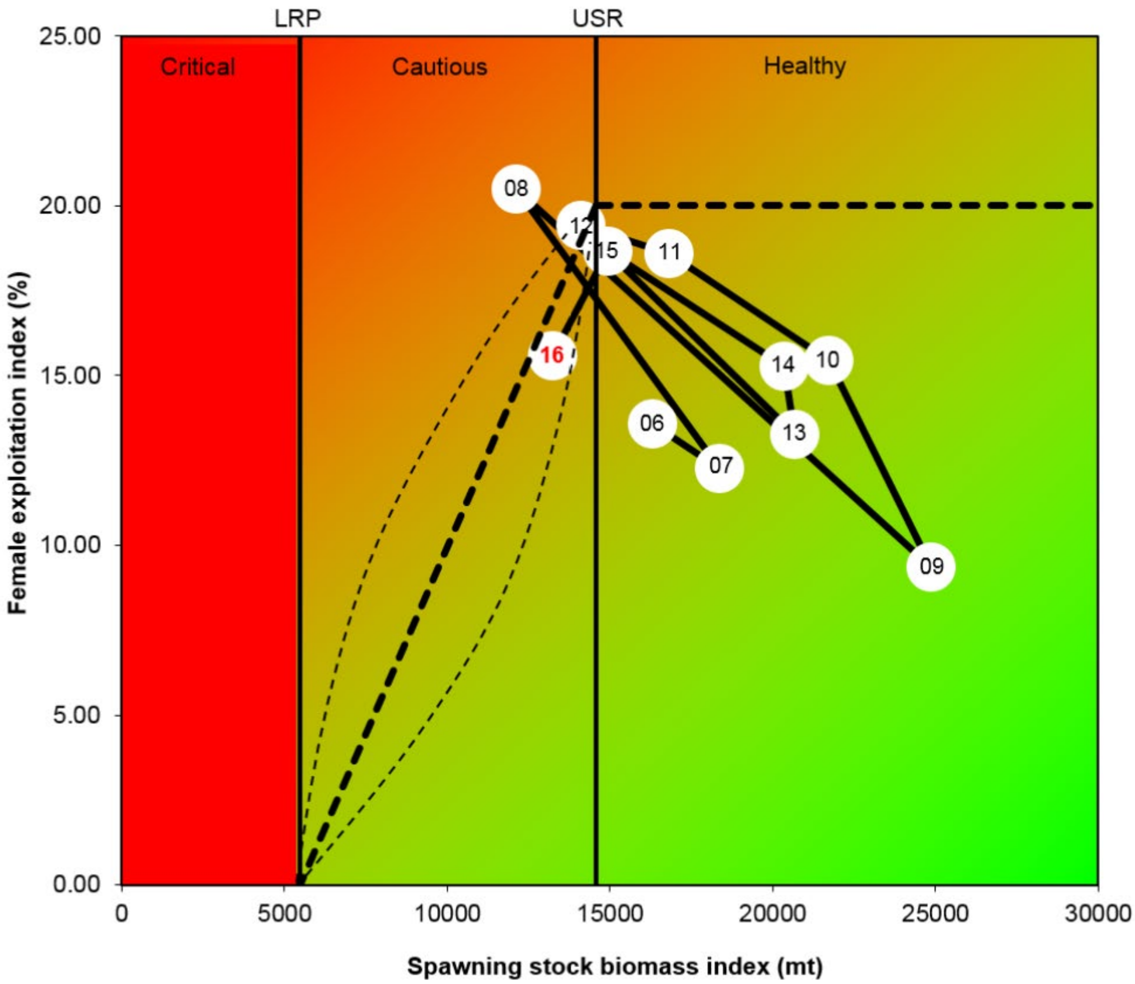


Figure 2. The precautionary approach (A) for Eastern Scotian Shelf Shrimp showing Spawning Stock Biomass index (PA Abundance Index) and female exploitation index (PA Removal Reference 20%, when in the Healthy Zone) point estimates from 2006–2016 relative to lower (LRP, 5,459 mt) and Upper Stock Reference points (USR, 14,558 mt).

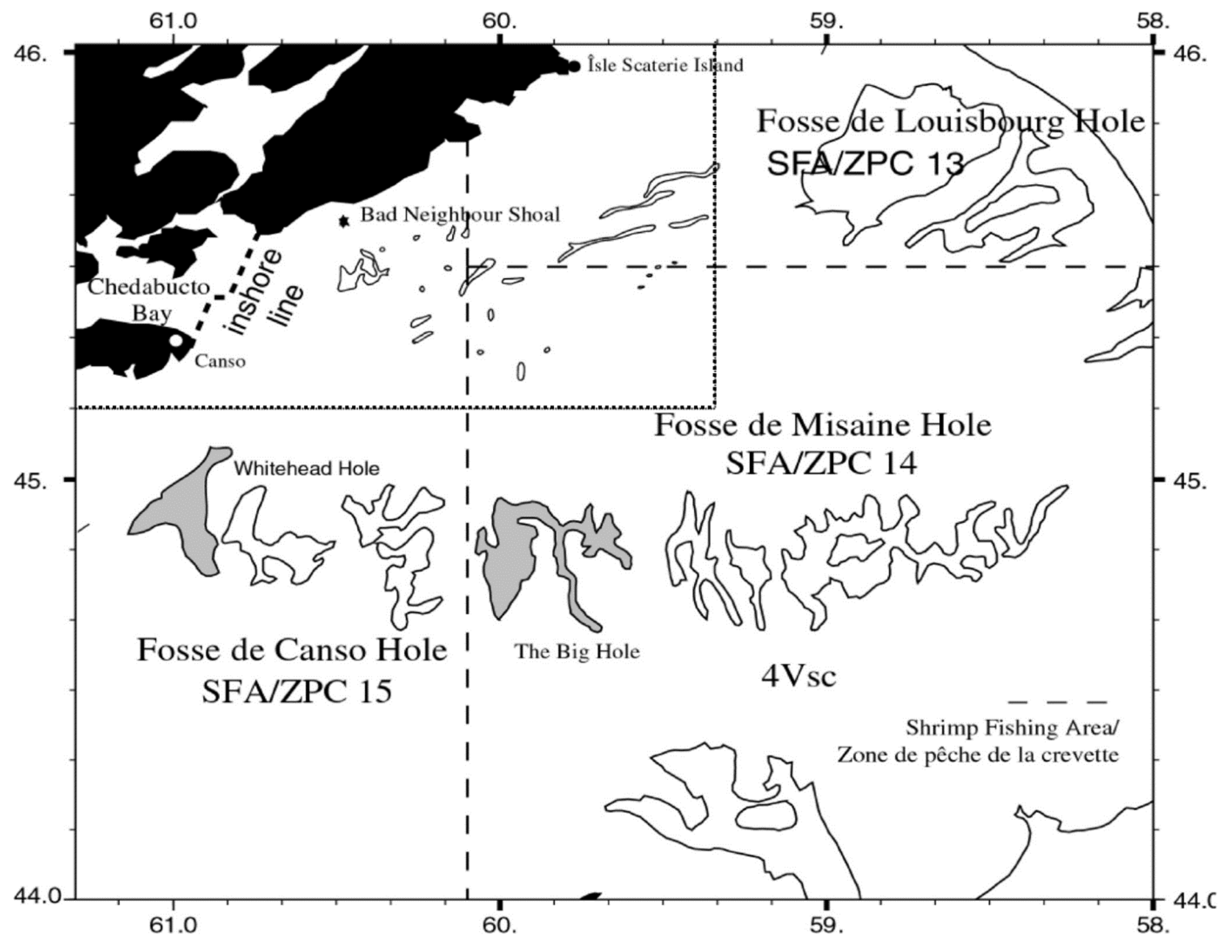


Figure 3. Shrimp Fishing Areas (SFAs) on the Eastern Scotian Shelf. Survey strata approximately correspond to the main shrimp holes and SFAs. Stratum 13 - Louisbourg Hole and SFA 13; Stratum 14 - Misaine Holes and SFA 14; Stratum 15 - Canso Holes and the offshore part of SFA 15. Stratum 17, or the 'Inshore', is comprised of inshore parts of SFA 13–15 denoted by the finely stippled line.

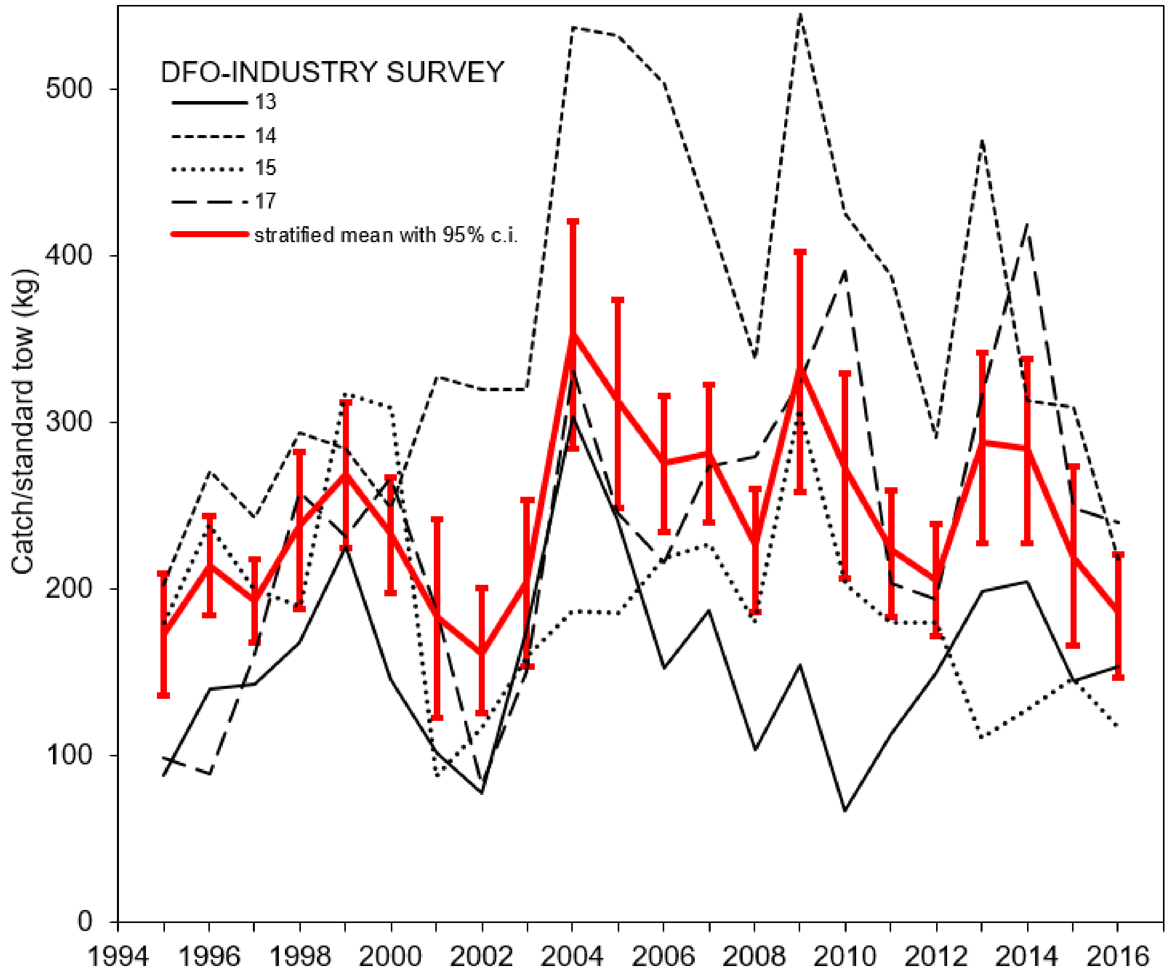
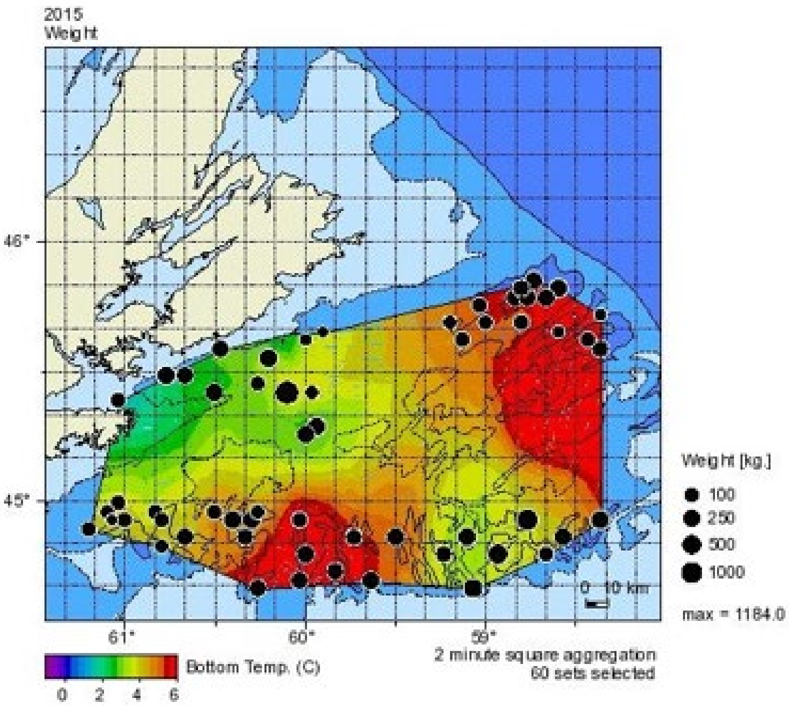


Figure 4. Stratified catch/standard tow for DFO-Industry co-operative surveys from 1995–2016, and estimates for the individual survey strata.



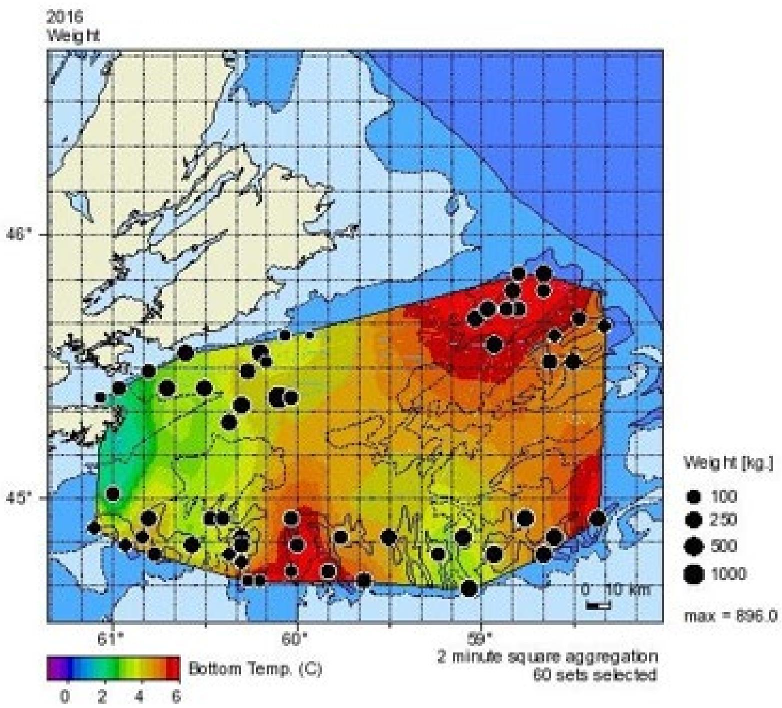


Figure 5. Distribution of catches (kg/standard 30 minute tow) and bottom temperatures from DFO-Industry surveys 2015 and 2016. See previous research documents for distributions prior to 2015 (Hardie et al., 2013b; 2015).

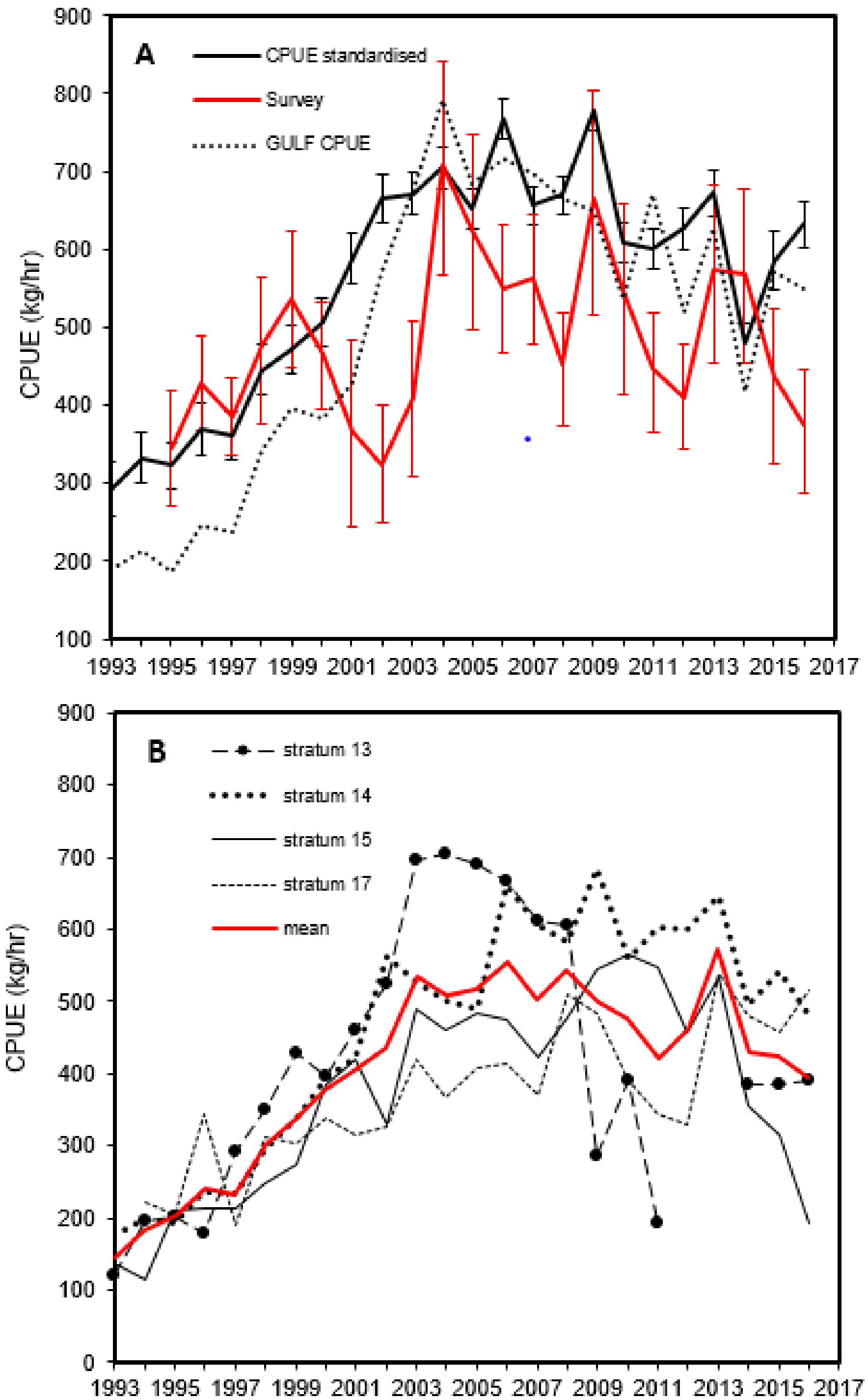


Figure 6. A – Survey stratified CPUE and, standardised commercial CPUE with 95% confidence intervals, and unstandardised Gulf vessel CPUE, and B – unstandardised commercial CPUE for each fishing area, from 1993–2016.

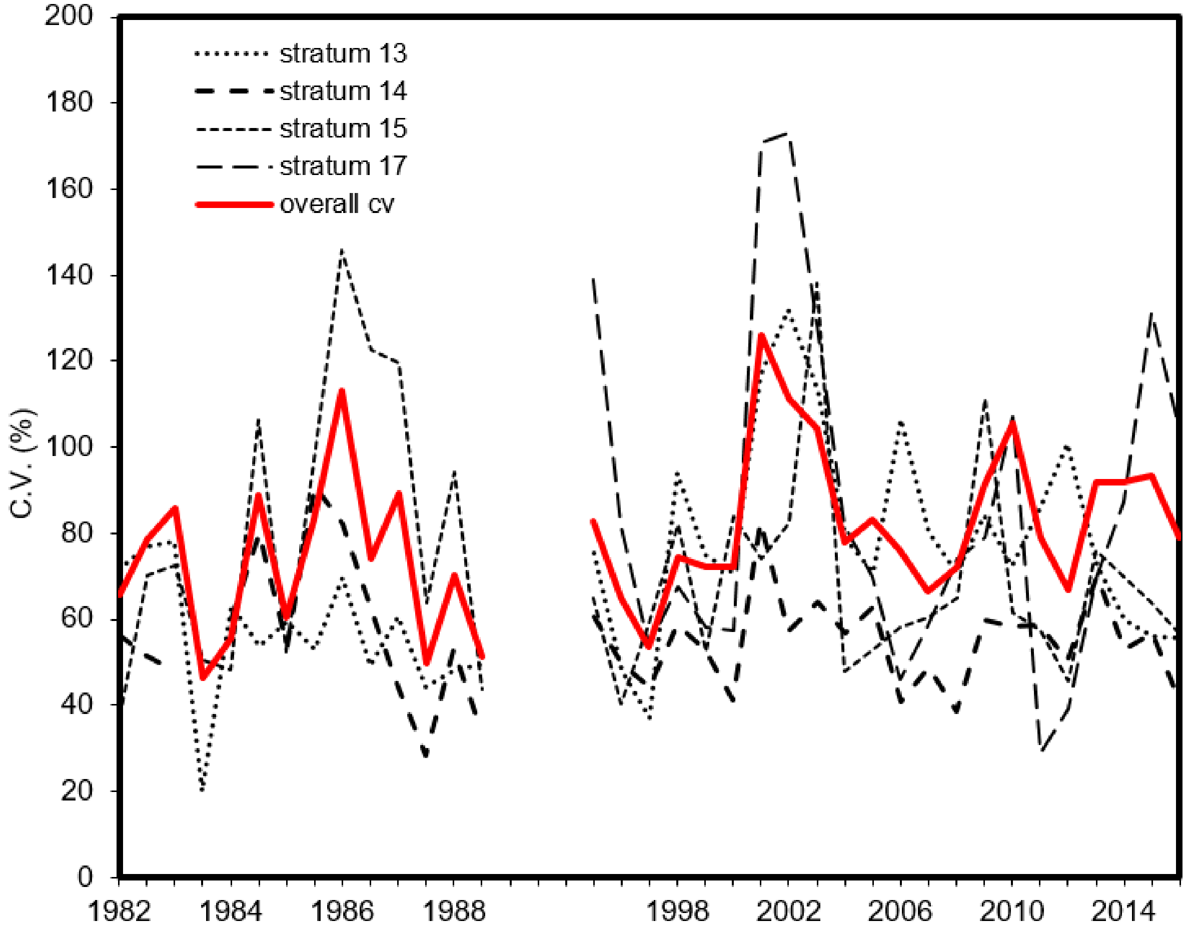


Figure 7. Coefficients of variation (CV) for Shrimp survey strata 13, 14, 15, and 17, from 1982–2016. Note that use of fixed stations in stratum 14 likely acts to constrain interannual changes in CV relative to other areas with randomized stations.

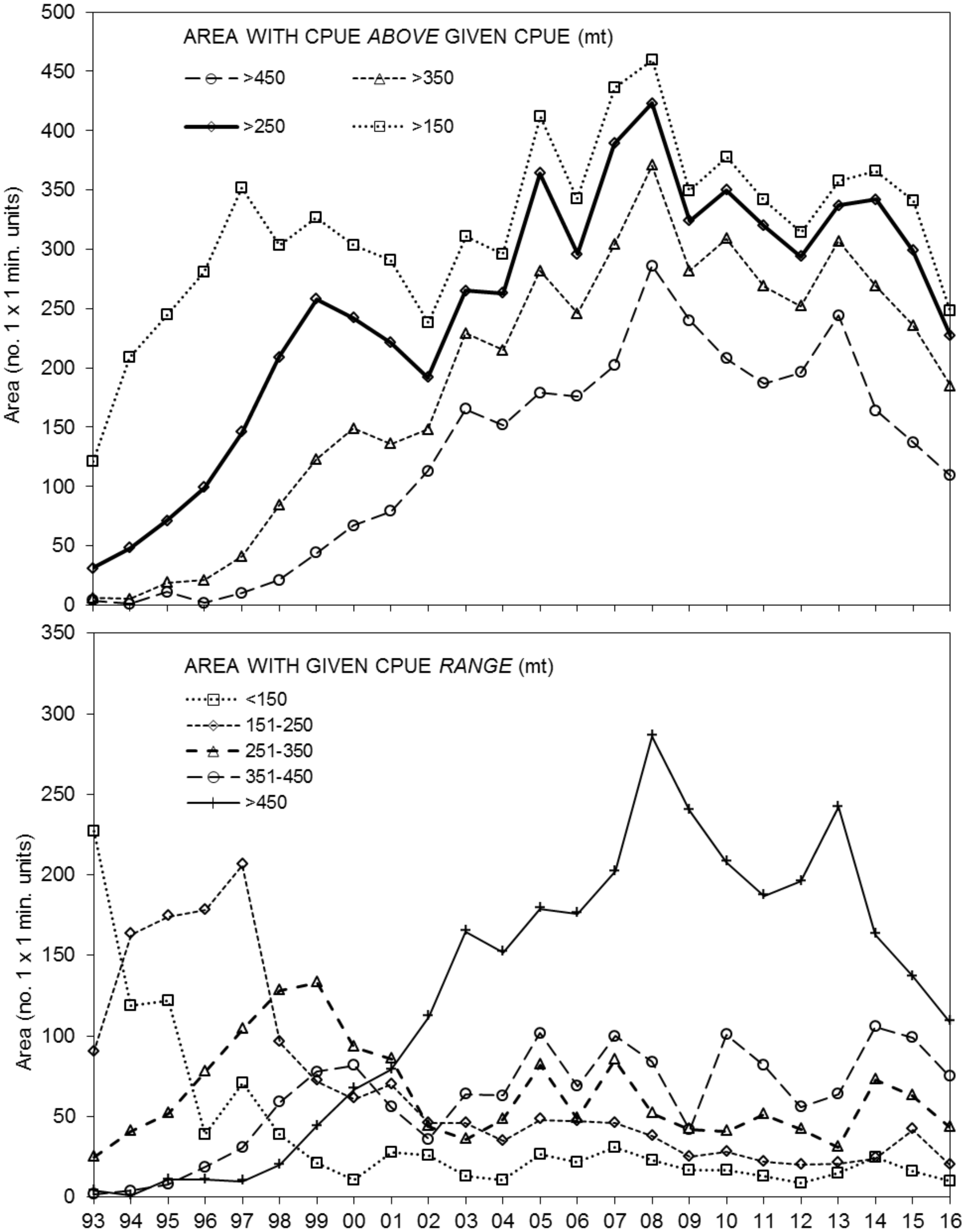


Figure 8. Number of 1 minute square unit areas fished by the Eastern Scotian Shelf Shrimp fleet with mean catch rates above (top) and within (bottom) the values or ranges specified in the legend, from 1993–2016.

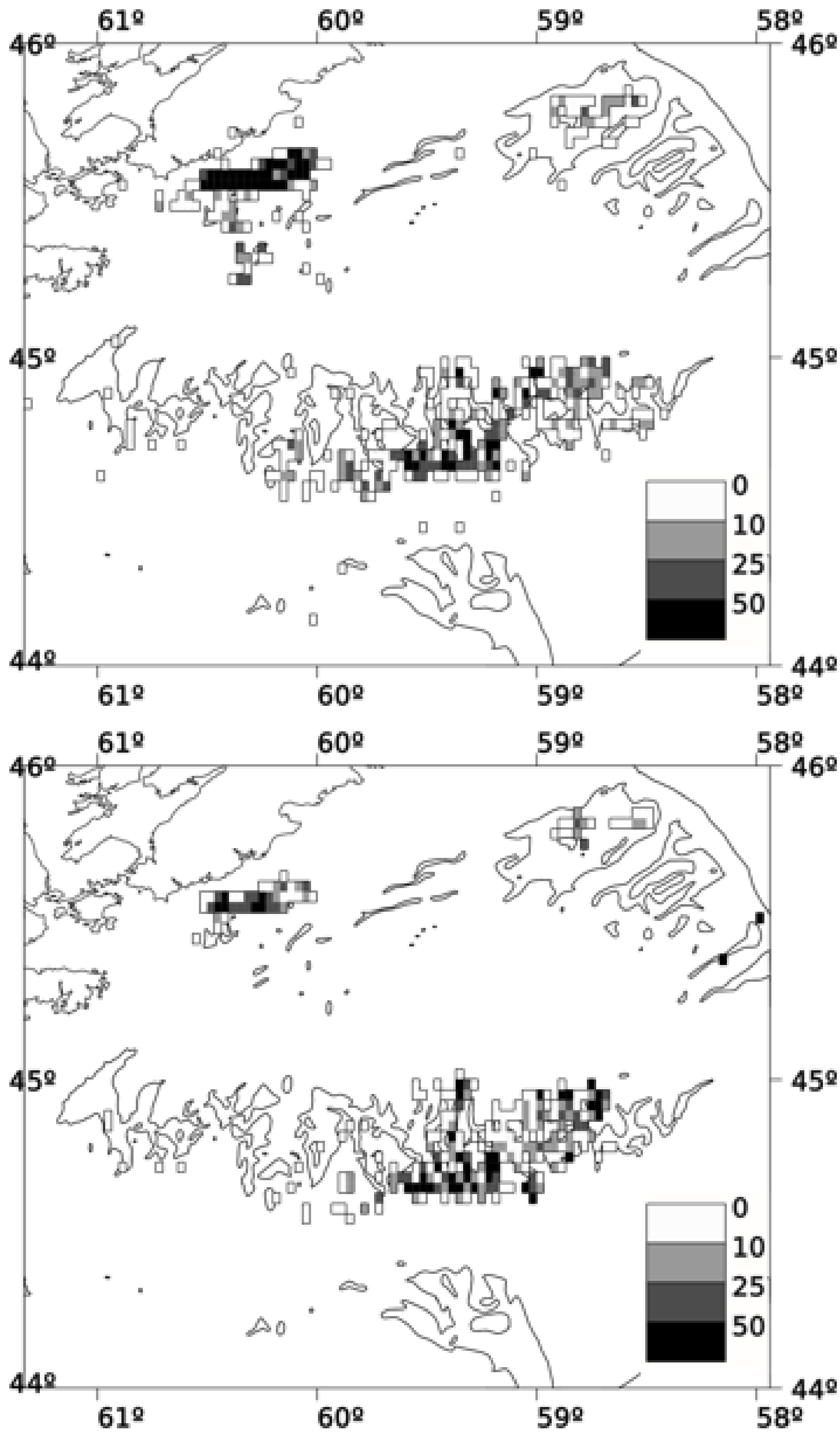


Figure 9. Annual Eastern Scotian Shelf trawl fleet effort (hours) in 2015 (top) and 2016 (bottom), cumulative by 1 minute squares.

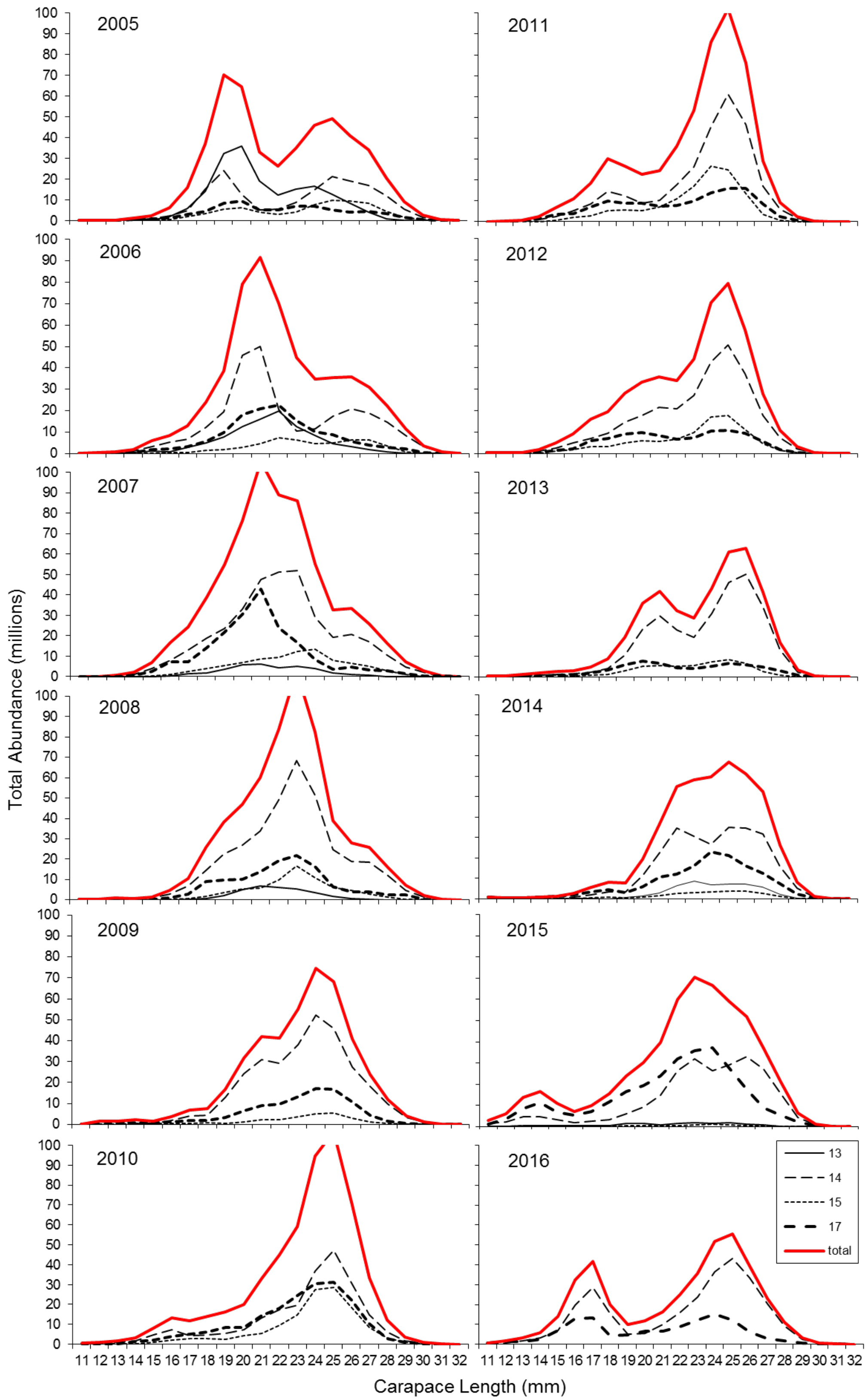


Figure 10. Catch at length from commercial sampling by stratum, 2005–2016.

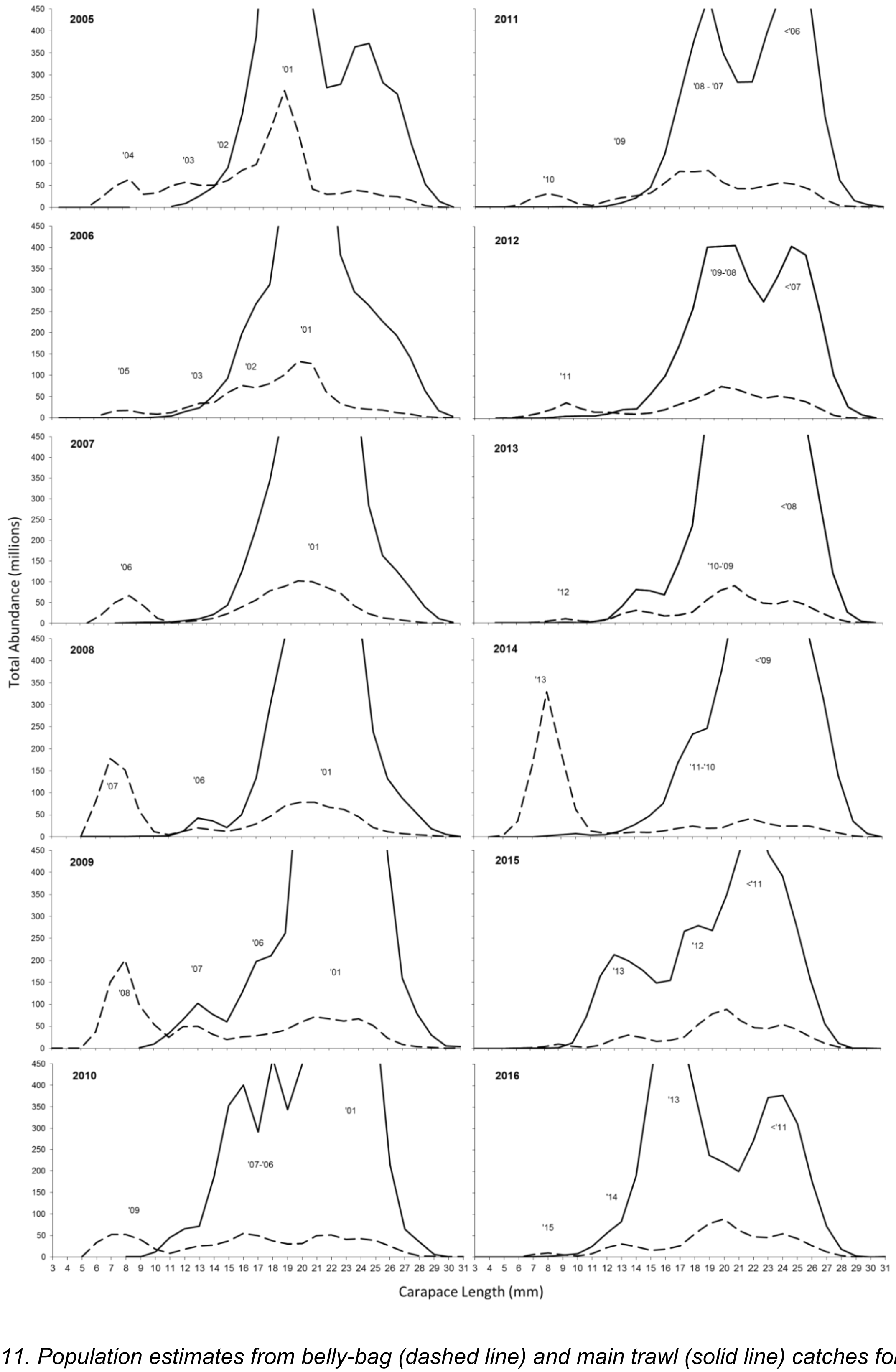


Figure 11. Population estimates from belly-bag (dashed line) and main trawl (solid line) catches for the 2005–2016 surveys.

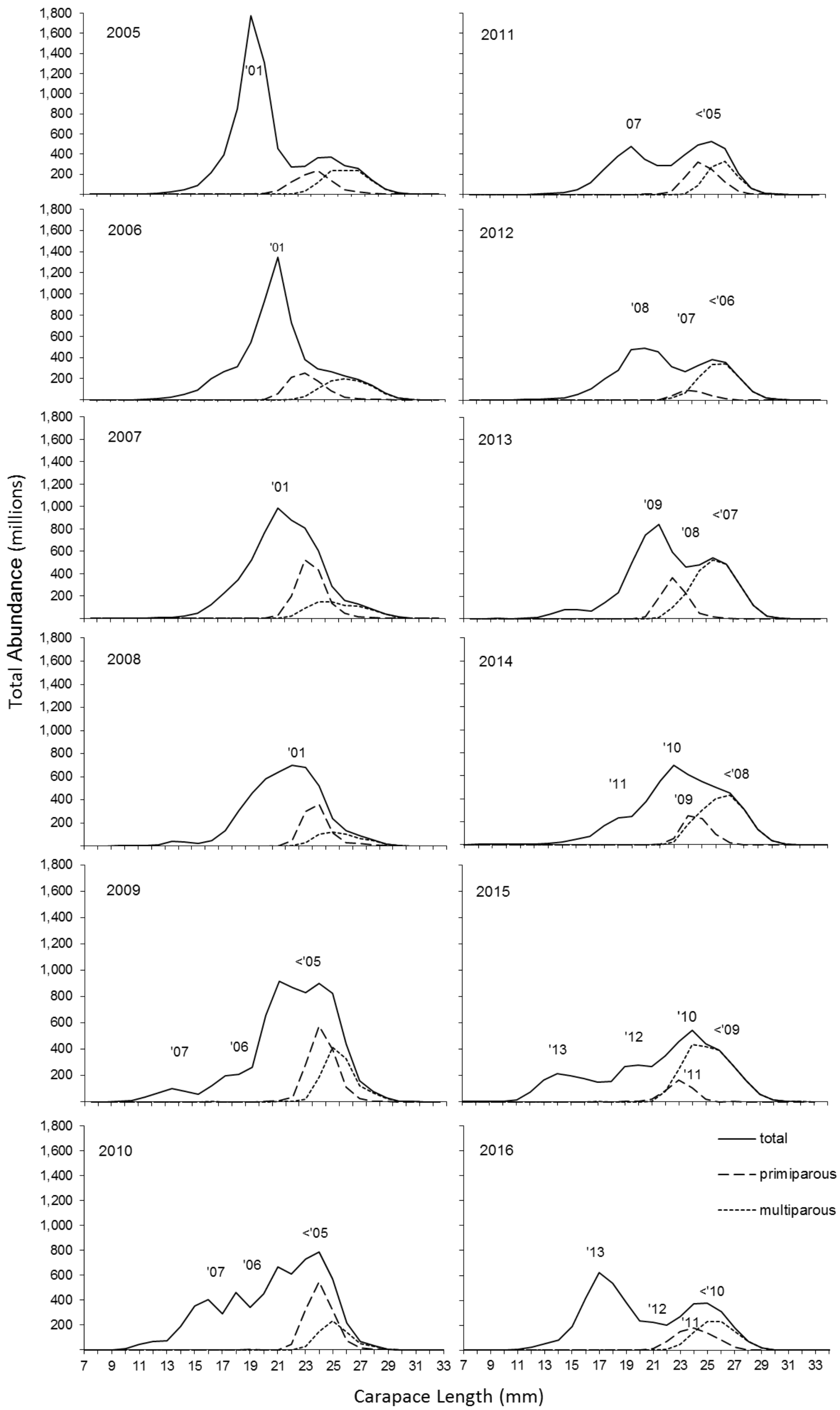


Figure 12. Population estimates at length from DFO-Industry surveys 2005–2016 (solid line). The heavy dotted line in each figure represents transitional and primiparous shrimp, and the stippled line represents multiparous shrimp.

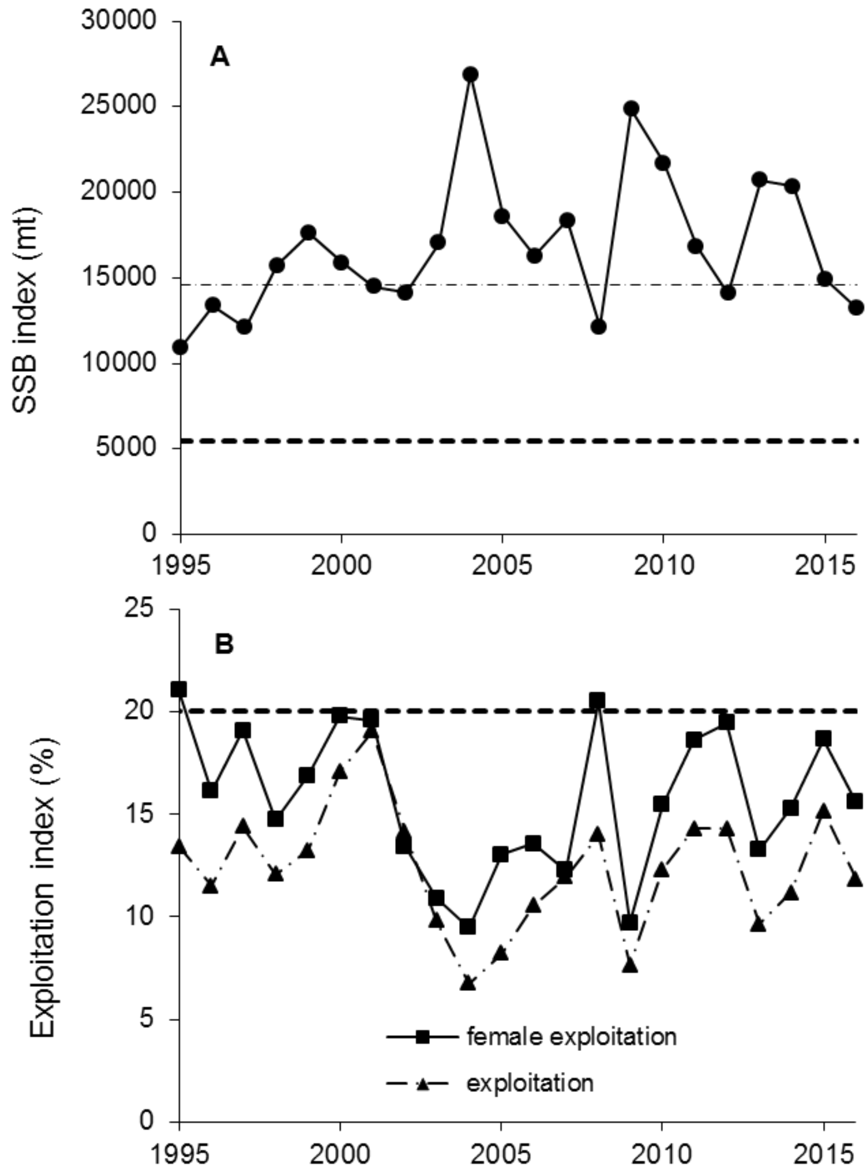


Figure 13. A – Changes in the Spawning Stock Biomass (SSB) index for the Eastern Scotian Shelf Shrimp population. The dashed lines show the Lower Reference Point (LRP) at 30% and Upper Stock Reference (USR) at 80% of the mean SSB during the 2000–2010 high-productivity period. B – Changes in the exploitation indices for the Eastern Scotian Shelf Shrimp fishery. The dashed line shows the removal reference of 20% for the female exploitation index when in the Healthy Zone.

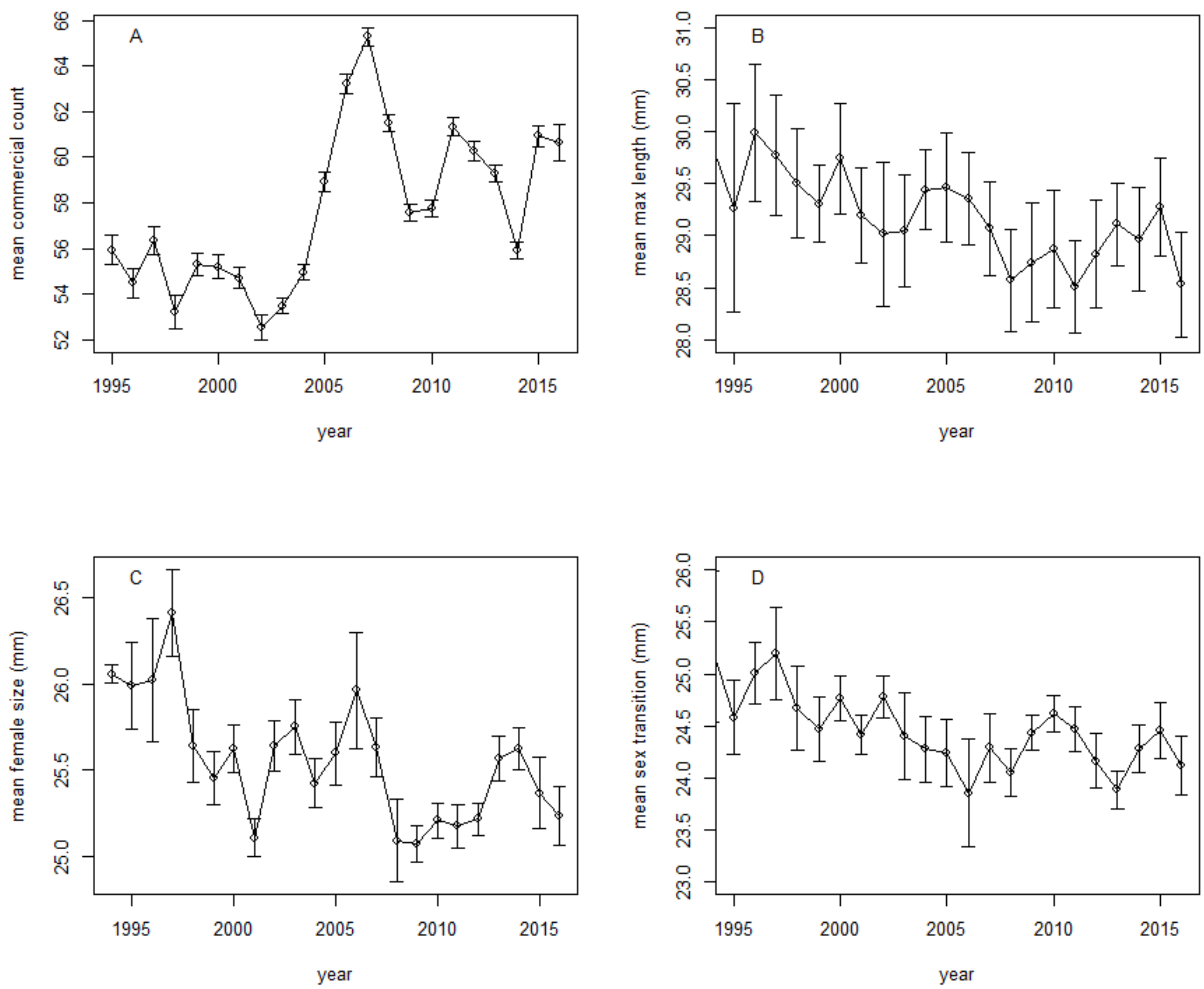


Figure 14. Mean: commercial count (A), maximum length (B), female size (C) and size at sex transition (D) for all Shrimp Fishing Areas (SFAs) combined for 1995–2016 with 95% confidence intervals.

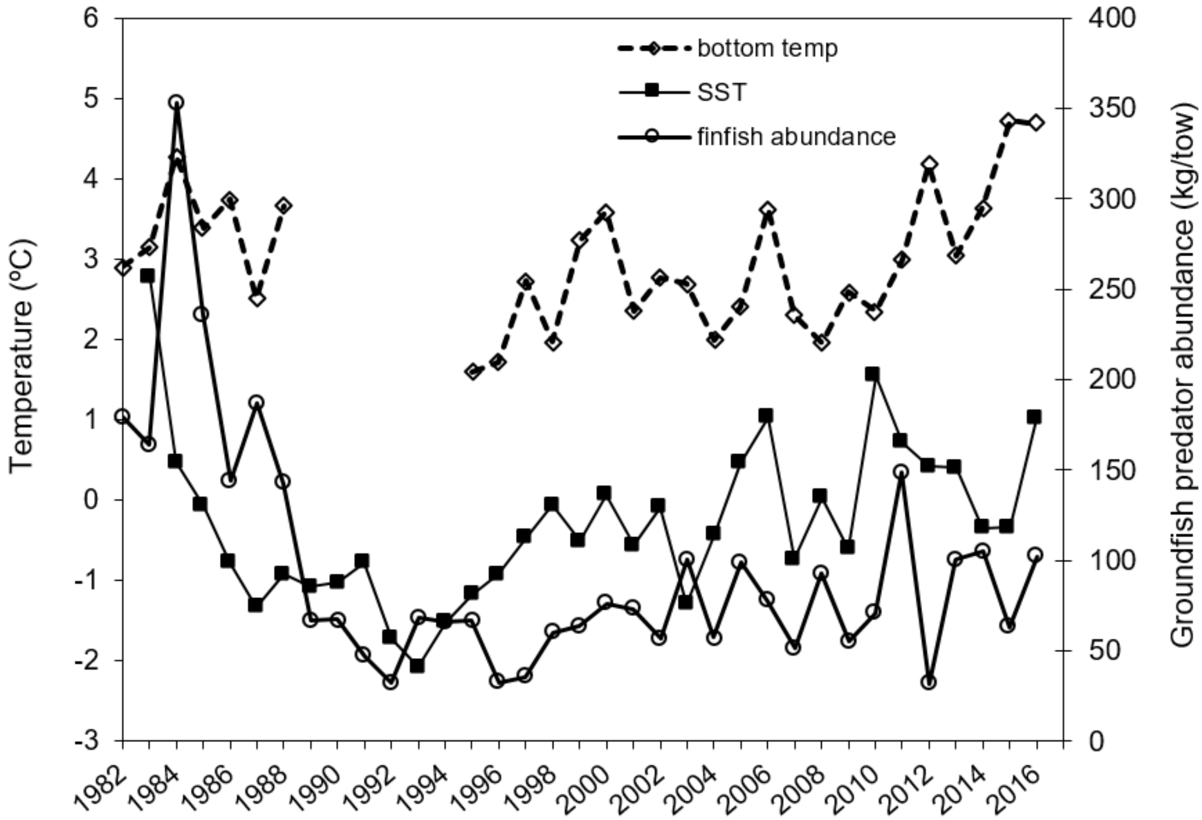


Figure 15. Bottom and spring sea surface temperatures (SSTs) and predator abundance on the Eastern Scotian Shelf Shrimp grounds.

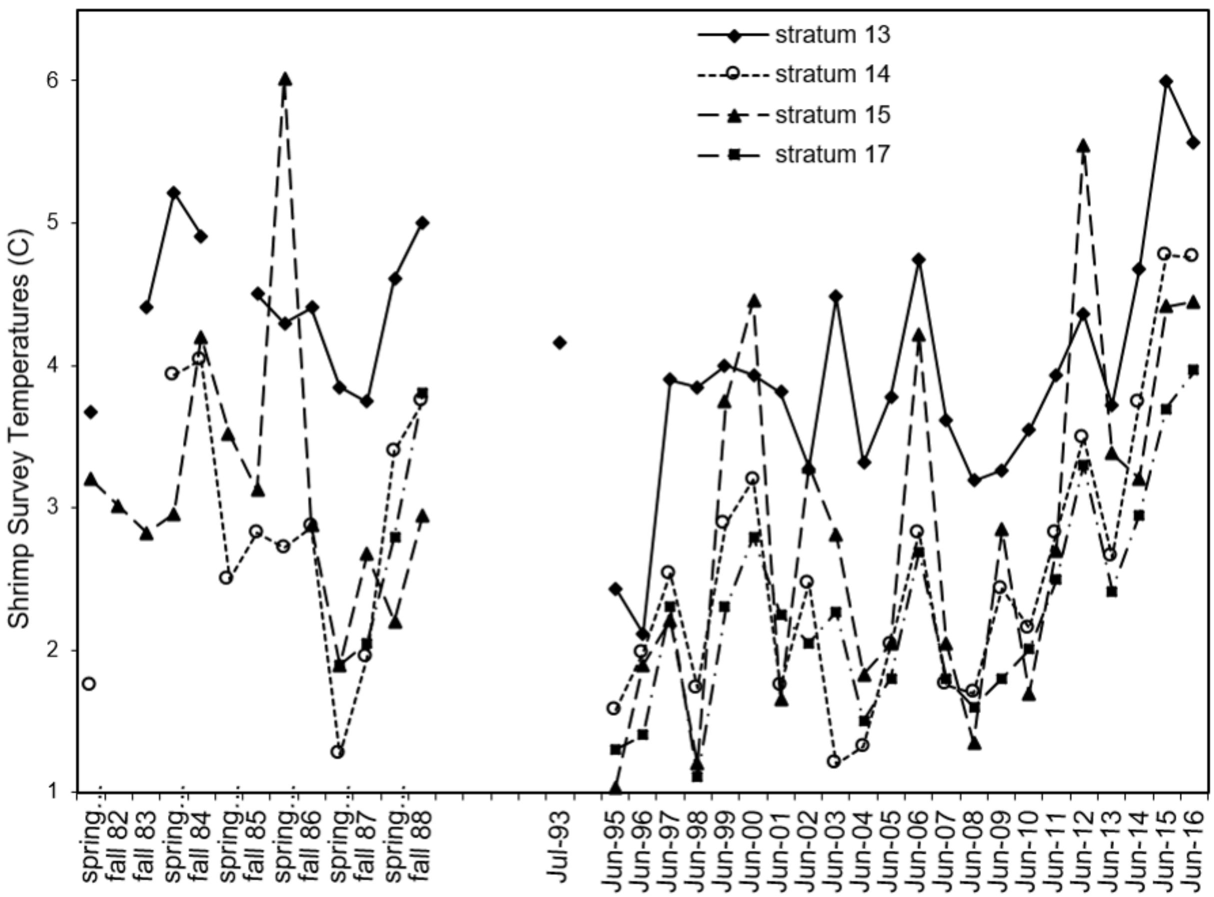


Figure 16. Mean bottom temperatures from Shrimp surveys by stratum (13, 14, 15 and 17). Note that both spring and fall values were available from the earlier series (1982–1988), but only one survey (spring, June) was conducted annually in the recent series.

Figure 17. Time series of all available indicators from 1982–2016. Thresholds between red, yellow, and green are at the 33rd and 66th percentile of the fixed 2000–2010 data series for each indicator. Not all indicators in the summary above are discussed in the text. See Hardie et al., 2013a for detailed description of indicators.

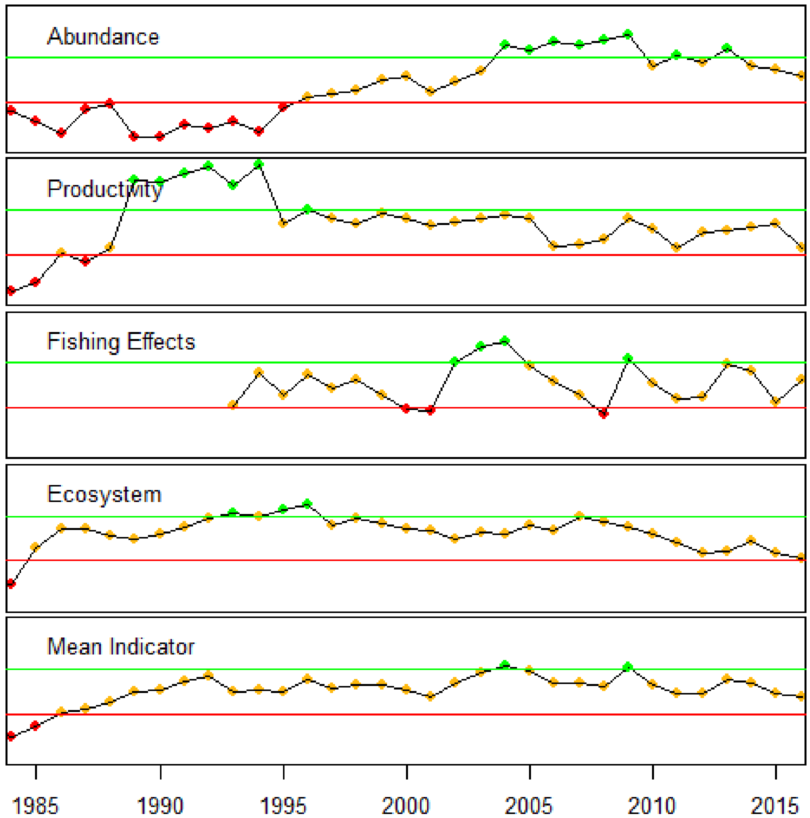


Figure 18. Time series of characteristics and mean (overall) indicator from 1984–2016. Thresholds between red, yellow, and green are at the 33rd and 66th percentile of the fixed 2000–2010 data series for each indicator. Not all indicators in the summary above are discussed in the text. See Hardie et al., 2013a for detailed description of summary characteristics.