ASSESSMENT OF NORTHERN SHRIMP ON THE EASTERN SCOTIAN SHELF (SFA 13-15)

(J. Domm 2006)

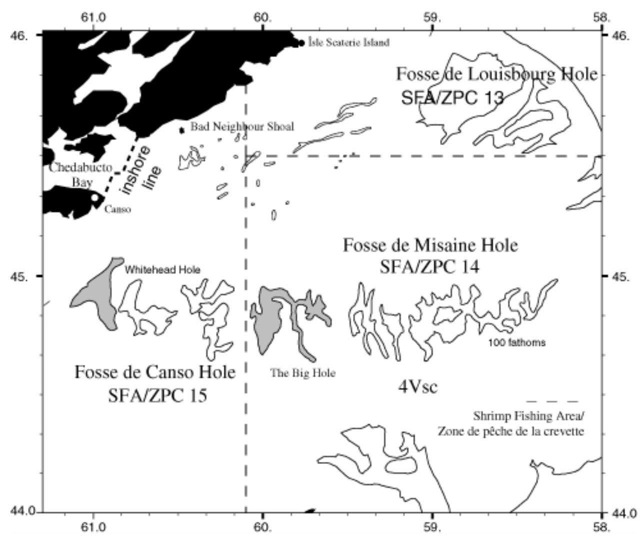


Figure 1. Shrimp fishing areas (SFAs) on the eastern Scotian Shelf.

Context:

Advice on the status of the eastern Scotian Shelf shrimp stock is requested by DFO Fisheries and Aquaculture Management and industry to help determine a Total Allowable Catch (TAC) that is consistent with the management plan. Annual assessments are required because of rapid changes in abundance, variable recruitment to the population and fishery, and changes in the size of shrimp available for harvest. The resource is near the southern limit of the species' distribution where it is thought to be more vulnerable to significant and rapid declines, as has been observed in the adjacent Gulf of Maine stock. The current report provides information and advice for management of the 2010 fishery.

The trawl fishery on the Scotian Shelf currently occurs primarily during late spring and early summer with some fishing during fall, in the deep offshore shrimp "holes", and on an inshore area near the Bad Neighbour Shoal. The main management tools are limits on the number of licenses and size of vessels used, minimum codend mesh size (40mm), use of a Nordmøre separator grid, and a TAC. This fleet (about 20 active trawlers) is divided into two sectors, a midshore sector consisting of about 7 active vessels 65-100' Length Over All (LOA) based in New Brunswick in the Gulf Region, and an inshore sector consisting of vessels mainly <65' LOA based in the Maritimes Region. A trap fishery, currently consisting of 1-2 active vessels is restricted to Chedabucto Bay. All licenses except traps operate under Individual Transferable Quotas (ITQs). Stock assessments are conducted annually based on indicators from commercial, scientific survey, and environmental monitoring data.

SUMMARY

- Total and spawning stock biomasses increased to the second highest on record.
- Total and female exploitation decreased to the second lowest on record.
- Changes in shrimp survey biomass since 2004 were probably due, in part, to survey catchability factors.
- Abundance appears to have remained high since 2004, and the decrease in TAC for 2009 appears to have been premature.
- The area of highest commercial catch rates remains large.
- Count estimates (numbers of shrimp per pound) in the fishery have decreased recently due to the growth of the 2001 year class, and fishers should have no difficulty in the immediate future in avoiding small shrimp.
- The long-term decreasing trend in length at sex change and maximum size has reversed somewhat due to delayed sex transition and an additional year(s) of growth of 2001 year class males.
- Belly-bag results in 2008 and 2009 indicated strong 2007 and 2008 year classes, which coincides with the maturation of the strong 2001 year class. This suggests that large year classes are associated with large spawning stock biomass.
- It is not clear if biomass will decrease before the next recruitment pulse due to uncertainty in the relative strength of succeeding year classes.
- It is likely that average catches higher than those taken during the modern fishery (approximately 4,000mt) are sustainable; however, it is important to accurately monitor the response of the population to increased exploitation.
- A generalized surplus production model suggests that a catch of 5,000mt would result in fishing mortalities that remain well below the fishing rate mortality at maximum sustainable yield (Fmsy) and biomasses well above biomass at maximum sustainable yield (Bmsy).
- An increase in the TAC for 2010 is supported by the current assessment, with cautious increases thereafter if biomass remains high and strong year classes continue to appear.

BACKGROUND

Species Biology

The northern or pink shrimp, *Pandalus borealis*, is the only shrimp species of commercial importance in the Maritimes Region. Shrimp are crustaceans that have a hard outer shell, which they must periodically shed (molt) in order to grow. The females produce eggs once a year in the late summer-fall and carry them, attached to their abdomen, through the winter until the spring, when they hatch. Consequently, shrimp bear eggs, (i.e., are "ovigerous") for about 8 months of the year. Newly hatched shrimp spend 3 to 4 months as pelagic larvae, feeding near the surface. At the end of this period they move to the bottom and take up the life style of the adults. On the Scotian Shelf, the northern shrimp first matures as a male at 2 years of age, and at age 4 it changes sex, to spend another 1 to 2 years as a female. They live on average 6 to 8 years, depending on current environmental conditions and population dynamics. Shrimp concentrate in deep "holes" on the eastern Scotian Shelf (Figure 1), but nearshore concentrations along the coastline closest to the offshore populations were discovered in 1995 by the DFO-Industry survey. In general, northern shrimp prefer temperatures of 2 to 6ºC, and a soft, muddy bottom with a high organic content.

The Fishery

The fishery currently consists of 28 (13 active) inshore licenses mostly <65' LOA and 7 active mid-shore licenses 65-100' LOA. All mobile licenses have been under ITQs since 1998. A competitive trap fishery with 13 licenses (approximately 2 currently active) restricted to Chedabucto Bay has been almost inactive recently due to low prices. The fishery operates under a 5-year "evergreen" management plan (last ratified for 2009-2014), which documents sharing agreements between fleet sectors.

Catches have been close to the TAC since individual SFA quotas were combined into a single TAC in 1994, with minor shortfalls associated with re-allocations of uncaught trap quotas to the mobile fleet late in the season (Table 1; Figure 2). More substantial shortfalls occurred in 2005-2008 unrelated to resource availability. The gap between TAC and catch has narrowed steadily since 2005 as problems associated with market conditions and quota reallocations were resolved. Trap fishing effort and catches have decreased to negligible amounts (2mt in 2009) since 2005 due to low prices. The mobile fleet continues to prefer open access to all areas (i.e., no individual SFA quotas) because of the flexibility this offers in obtaining favourable combinations of good catch rates and counts (shrimp sizes).

Table 1. Recent shrimp TACs and landings ('000's mt)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009[1]
TAC	5.5	5.0	3.0	3.0	3.5	5.0	5.0	5.0	5.0	3.5
Landings	5.4	4.8	2.9	2.8	3.3	3.6	4.0	4.6	4.3	3.5

[1]Landings projected to December 31, 2009.

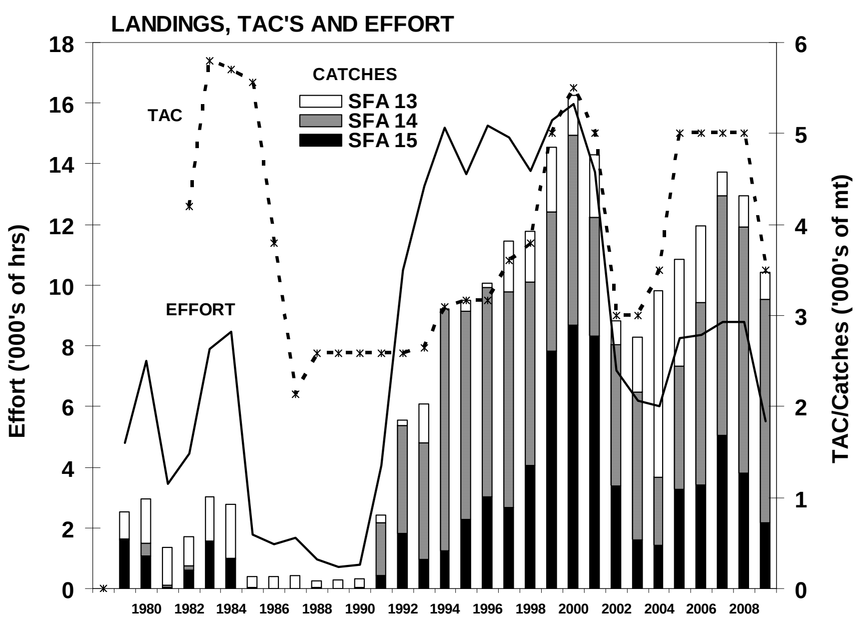


Figure 2. Landings, TACs, and Effort.

The **temporal pattern** of the fishery has changed little over the years (Figure 3, left). Most shrimp are caught during April-June. Effort tends to decrease during summer due to market conditions. Catches during the August-April ovigerous (egg-bearing) period tend to increase when TACs increase as fishers take longer to catch higher quotas. This was the case in 2005-2006 when about 30% percent of the catch was taken during the ovigerous period. However, there was a similar amount (approximately 30%) of fishing during the ovigerous period in 2009 despite a reduced TAC. Fishing during the ovigerous period can contribute to reduced egg production. Other factors that could decrease egg production include decreasing size at sex change, female sizes, and spawning stock biomass.

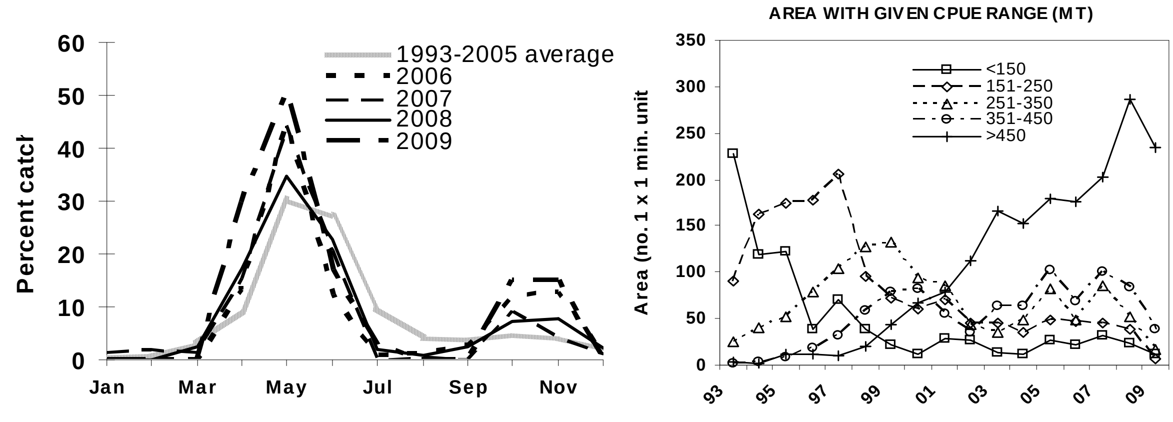


Figure 3. Temporal (left) and spatial (right) patterns in the Scotian Shelf shrimp fishery.

The **spatial pattern** of the fishery has changed significantly over the years, reflecting changing distributions of biomass and size frequencies. Prior to 1999, most of the effort and catch was in the Misaine Hole (SFA 14). In 1998, fishing began along-shore near the Bad Neighbour Shoal, with 44% of the catch taken in this area during 1999. This decreased to between 4-12% from 2003-2005 and then increased to between 20-25% since 2006. In 2004, a large part of the TAC (57%) was taken in SFA 13, but this has declined to less than 1% since 2007 as effort shifted back to SFA 14 to take advantage of the large accumulated biomass there (50-70% of the catch since 2006). Exploitation rates decreased in all areas in 2009 due to the increased biomass and decreased TAC, and none of the fishing areas were subjected to heavy (>20%) exploitation (Figure 2). Spatial and temporal changes in the distribution of fishing effort, catch rates, availability to the fishing gear, and the resource itself are complex. Consequently, commercial catch per unit effort trends may not always represent overall abundance trends. This was suggested by a divergence of Catch per Unit Effort (CPUE) from DFO-Industry survey indices from 1999-2004 (Figure 5), and concurrent changes in CPUE spatial patterns (Figure 3, right). Such a divergence is apparent again after 2004 (Figure 5). However, the area with the highest catch rates (>450kg/hr) has continued to expand, while areas with lower catch rates have remained smaller (Figure 3, right). This, together with the continuing high CPUE temporal trend, suggests that abundance has remained high, rather than decreased as suggested by the survey.

Decreases in the **average sizes of females** in the catch from 1997-2001 compared to the higher sizes of the early to mid 1990s (Figure 4, left) may be due in part to the removal of accumulated older and larger animals in the population by the fishery, but decreased growth rates of the strong 1993-1995 year classes probably were also involved. This trend reversed after 2001 as the survivors of these year classes continued to grow and the weaker succeeding year classes achieved larger sizes. Female size decreased greatly in 2007-2008 as the slow growing 2001 year class changed sex. There are indications that this trend is starting to reverse in 2009. An increasing trend in the **proportion of females** (Figure 4, left) caught from 2000-2004 occurred as males became less abundant and the 1993-1995 year classes dominated the population and catch as females. This trend reversed in 2005-2008 as these year classes died off and the strong 2001 year class appeared in catches as males. This began to reverse in 2009, much as in the previous cycle. **Count** estimates (numbers of shrimp per pound) provided by vessel captains mirror these changes, increasing significantly in 2005-2007 as males from the 2001 year class recruited to the fishing gear (Figure 4, right). They have decreased since as these shrimp changed sex and continued to grow as females. Fishers should have no difficulty in the immediate future in avoiding small shrimp and maintaining counts below buyer limits to obtain the best prices.

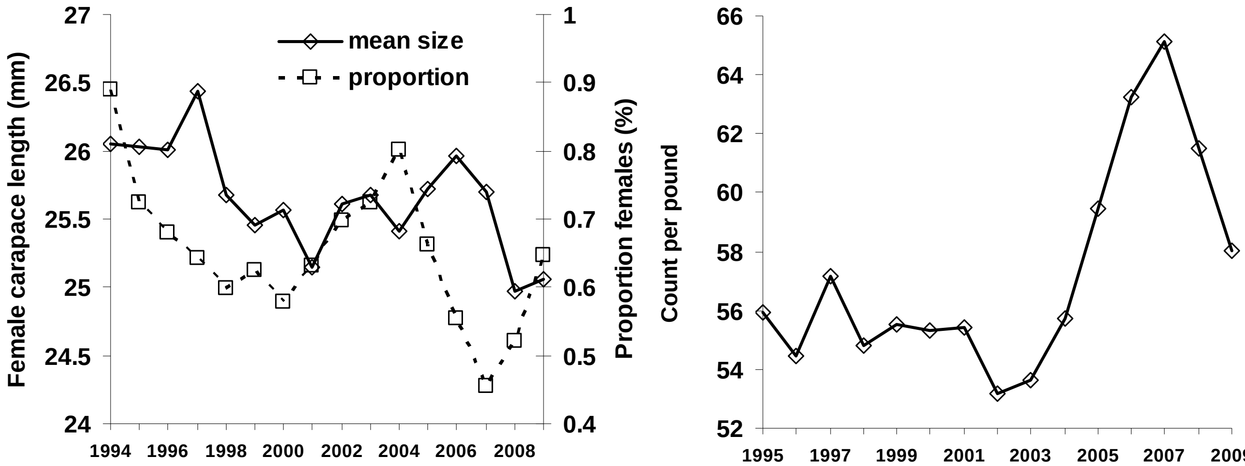


Figure 4. Mean female carapace length, proportion of females (left) and the count per pound (right) in the commercial shrimp trawl fishery.

ASSESSMENT

Stock Trends and Current Status

After a sustained long-term increase, commercial **CPUE** indices (Figure 5) leveled off and have been fluctuating at a high level since 2002. The DFO-industry trawl survey has shown two divergences from CPUE trends (Figure 5). The first, between 2000-2003, was attributed to changing spatial distribution patterns of the relatively large 1994-1995 year classes as these moved through the population and died off, as described above. However, the second divergence (2005-2008) is not consistent with a shrinking, more concentrated resource since the area of highest catch rates (>450kg/hr; Figure 3, right) has continued to increase, while the areas of lower catch rates have remained relatively small. The DFO-Industry survey index (Figures 5 and 6) increased significantly in all areas in 2009, with an overall increase of nearly 50% from the previous year. Some of this increase can be attributed to growth and increased availability to the survey trawl of the 2001 year class. A concurrent increase in the standardized CPUE index is also likely due to this; however, the CPUE increase was only 10% above the previous year, the difference presumably being due to survey-related factors. It is probable that decreases in the attack angles of the Nordmore grid in the survey trawl, discovered and repaired prior to the 2009 survey, were at least partly responsible for this second divergence. Moreover, since the survey index experienced its largest one-year increase in 2004, when the survey trawl was new, the possibility that the first divergence just prior to this was also at least partly due to decreased trawl efficiency cannot be ruled out.

Abundance indices calculated from shrimp catches in the fall snow crab survey covering the shrimp grounds do not show a decreasing trend from 2005 to 2008 (Figure 7, left), which is consistent with the commercial CPUE index. On the other hand, shrimp catch trends from the summer groundfish Research Vessel (RV) survey (Figure 7, right), parallel those in the shrimp survey. However, neither of these surveys were designed for estimating the abundance of shrimp.

In any case, changes in shrimp survey indices may have been given undue weight in formulating management advice, particularly the decreased TAC in 2009. CPUE indices, which indicate sustained increases until the leveling off at high levels after 2004, should be given more weight in the provision of management advice (i.e., are considered more reflective of the biomass trajectory) until issues with shrimp survey have been resolved.

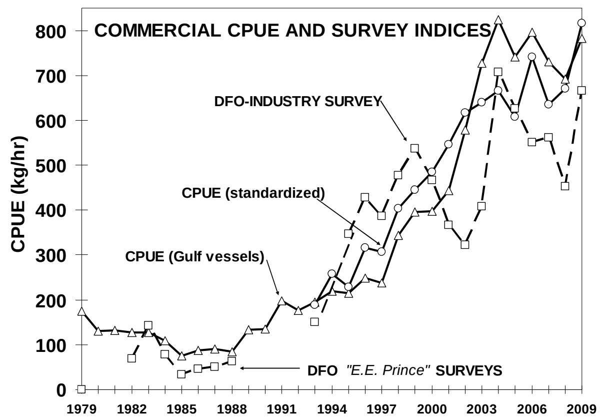


Figure 5. Commercial CPUE and survey abundance indices.

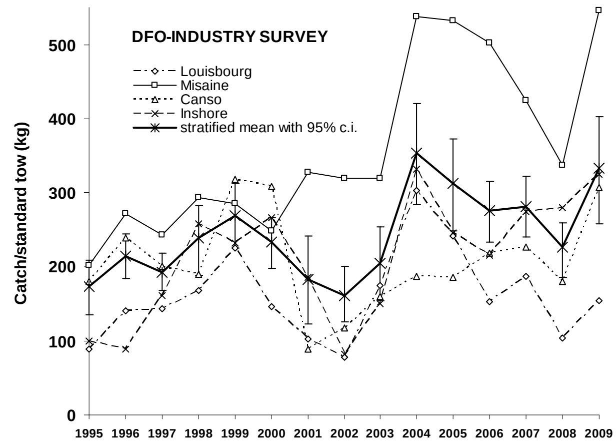
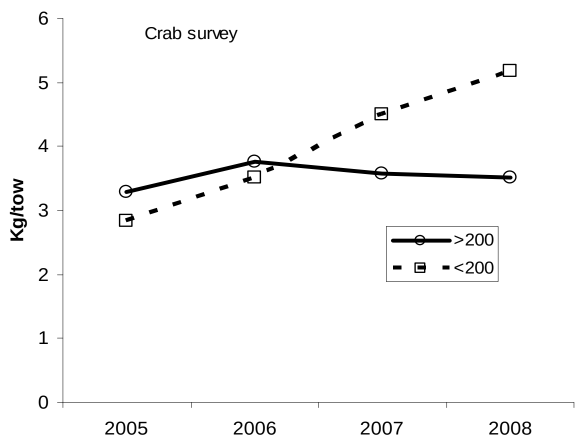


Figure 6. DFO-Industry survey abundance indices by area.

Based on the survey indices, the **total biomass** estimate increased to 45,425mt in 2009, the second highest since the all-time high of 2004 (48,438mt). Biomass estimates increased in all areas to near 2004 levels, due to catchability factors mentioned previously. However, SFA 13 (Louisbourg Hole) has shown a decreasing trend in both survey and commercial CPUEs since 2004. The **spawning stock biomass** (SSB, females) increased to 24,854mt, also the second highest since the 2004 record high (26,856mt).



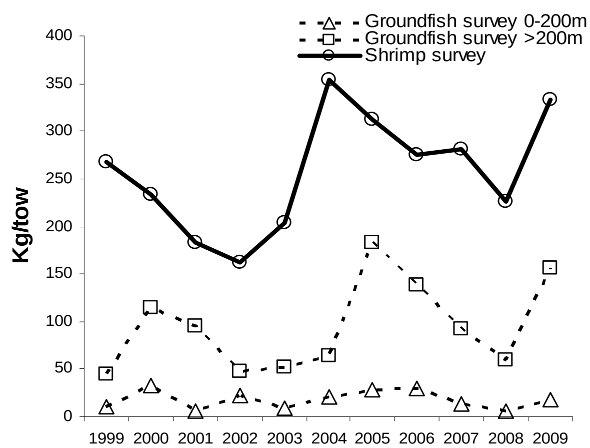


Figure 7. Mean shrimp catch/tow in shrimp strata during fall snow crab surveys from 2005-2008, above and below 200m (left). Mean catch per tow in areas encompassing shrimp habitat from summer (July) groundfish surveys (right).

During the late 1990s, the fishery was supported by a relatively strong group of year classes (1993-1995), which reached the end of their life cycle in the early 2000s (Figure 4, left). Lower levels of recruitment in the mid 1990s led to a biomass decrease from 2000-2002 (Figures 5 and 6) that, however, may have been exaggerated in the survey index by catchability changes as described above. Good recruitment associated with the 2001 year class led to record high biomasses in 2004-2006. In 2008, at age 7, this year class was near or at the end of its life span and its natural mortality was expected to increase sharply. Since this year class comprised up to

70% of the biomass at its peak and was followed by poorer recruitment, biomass was expected to decrease. This appeared to be confirmed by a decreasing survey index; however, this is now considered a false signal. In addition, interpretation of year class strength and longevity is complicated by a number of factors including: the low catchability of shrimp younger than age 4; the strong influence of growth rate on the catchability of age 4 shrimp; difficulty in distinguishing and assessing year classes after age 3; the tendency of a single year class, especially large ones such as 2001, to change sex over a number of years, making it difficult to distinguish them from adjacent year classes; and changing longevities and natural mortalities associated with environmental or density-dependant influences. For example, the abundance of **Age 4 male shrimp**, which normally have changed sex by the following year, was low in 2009. An abundance of age 5+ males, probably representing late sex-changers from the 2001 year class, should provide females to the spawning population in 2010 and possibly 2011. However, their longevity as females is uncertain. The **abundance of Age 2 shrimp**, increased to above average in 2009, apparently confirming the strength of the 2007 year class determined as 1 year old shrimp from belly-bag results in 2008. The strength of the 2008 year class as **Age 1 shrimp** in belly bag results were also above average. Belly-bag catches are not affected by changes to the Nordmøre grid and appear to corroborate the recruitment pulses shown in the main survey trawl results. However, considering the changes in catchability described above, it is likely that the differences in relative year class strengths shown by the survey trawl were also exaggerated. Since the recruitment pulses of 2001 and 2007-2008 coincide with the maturation of strong year classes, i.e. 1993-1995 and 2001, respectively, this is evidence that strong year classes produce large spawning stock biomasses, which in turn produce large year classes.

As a result of the large increase in biomass and decrease in TAC, **total exploitation** decreased to only 7.7%, the second lowest on record**.** For the same reasons, **female exploitation** decreased to 9.6%, also the second lowest on record. Exploitation was well below average in all areas except SFA 14 where, at 11.9%, it approached the overall average exploitation rate of 12.1%, but was still below average for this area (15.5%).

Decreases in average **length at sex change** (L_t) in shrimp stocks may be associated with population downturns due to decreased female fecundity (smaller shrimp produce fewer eggs). On the Scotian Shelf, length at sex change has shown a decreasing trend since the mid 1990s, when monitoring began, and approached the small sizes associated with the low population levels of the 1980s (Figure 8). Length at sex change increased during the last 3 years, probably due to late sex change of 2001 year class males, some of which had an additional year(s) to grow. **Maximum size** (L_{max}) has shown a similar decreasing trend but remains above the mean 1980s values (Figure 8). This indicator increased in 2009, and may continue to do so since changes in maximum size are usually correlated to size at sex change. The observed long-term and continuing decreasing trend in both indicators may be a cumulative fishing effect that may be having a negative impact on the population's reproductive capacity.

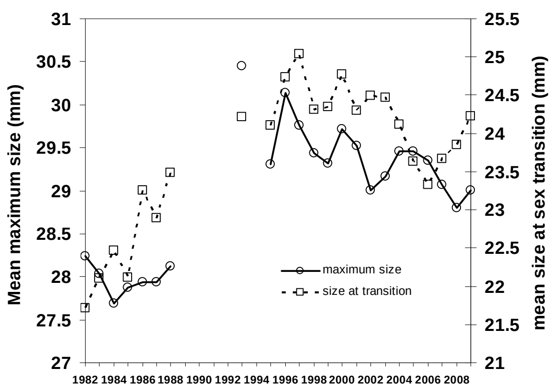


Figure 8. Changes in mean carapace size at sex transition and maximum carapace size.

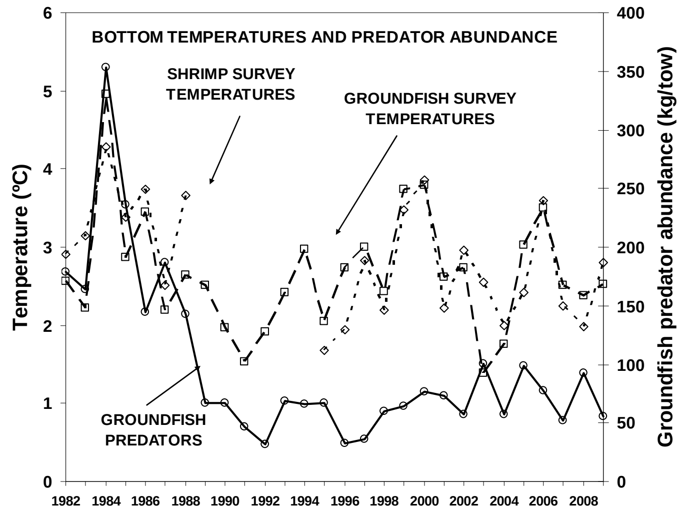


Figure 9. Bottom temperatures and predator abundance on the eastern Scotian Shelf shrimp grounds.

Predator feeding studies have shown that shrimp are important prey for many groundfish species, and significant negative correlations between shrimp and groundfish abundance have been demonstrated from the Gulf of Maine to Greenland. Many groundfish stocks remain at low levels on the eastern Scotian Shelf, and **natural mortality** due to predation is probably below the long-term average (Figure 9). Since shrimp abundance remains higher than the long-term average despite fishing, and because shrimp constitutes only a fraction of their diet, it seems unlikely that this fishery is impacting on the recovery of groundfish species by decreasing available prey. The introduction of the Nordmøre grid in 1991 reduced **by-catch** and allowed the fishery to expand to its present size. Bycatch analysis of observer and survey data (1995-2006, 2008) was last assessed in 2008 (Koeller et al. 2009). Three trips were observed in 2009, but the data was not available for review in time for this assessment. Bycatch analysis should be updated for the next assessment.

For some northern shrimp stocks near the southern limits of the species' range, abundance is negatively correlated with water temperatures. On the Scotian Shelf, the large population increase that occurred from the mid 1980s to the mid 1990s is associated with colder surface and bottom **water temperatures**. This is at least partly because colder temperatures increase the length of the egg incubation period, resulting in later egg hatchings that are closer to the spring phytoplankton bloom and warming of the surface layers where larvae feed and grow. Large fluctuations in bottom water temperatures (Figure 9) may also be associated with the cyclical recruitment pattern experienced since the early 1990s (i.e., 1993-1995, 2001 and 2007-2008 year-classes). The continued abundance of cold water indicator species including shrimp, Greenland halibut, and snow crab suggests that the conditions that led to their success endure. However, the capelin index has been declining and this trend needs further investigation. A continuing warming trend would be a concern for the shrimp stock.

Catches and commercial CPUE served as input to a generalized surplus production model (ASPIC – a surplus production incorporating covariates) used in the Gulf of Maine shrimp stock assessments. Model runs with the standardized commercial CPUE series (1993-2009) resulted in a maximum sustainable yield (MSY) of 11,000mt and carrying capacity (K) of 81,000mt. Five–year projections with a catch of 5,000mt suggest that fishing mortalities would remain well below the fishing rate mortality (F) at MSY (Fmsy) with an F/Fmsy of approximately 0.3 and biomasses well above biomass at MSY (Bmsy) with B/Bmsy of approximately 1.4 under model assumptions. The approach is promising and initial approximations should be refined through further work.

Figure 10 provides a summary of 25 indicators related to the health of the eastern Scotian Shelf shrimp stock. Each indicator was assigned a color for every year there is data according to its percentile value in the series (i.e., >0.66 percentile = green ⊕ or healthy, 0.66-0.33 percentile = yellow ○ or cautious, and <0.33 percentile = red ⊖ or critical). Indicators have been grouped into stock characteristics of abundance, production, fishing effects and ecosystem. Note that indicators are not weighted in terms of their importance, and the summary given at the top of the figure was determined as a simple average of individual indicators.

The summary indicator reverted to green in 2009, mainly in response to improvements in indicators associated with the increase in the survey abundance index (survey biomass, SSB, age 2 abundance, total and female exploitation). Since the evidence suggests that the decrease in the survey abundance index, particularly in 2008, was mainly due to catchabilty factors rather than a real decrease in abundance, the summary red value in 2008 is likely erroneous and was likely more favourable. Other notable improvements for 2009 include the increase in the size at sex change, proportion in the catch, population evenness, and predator abundance. Downturns were recorded for the survey coefficient of variation, proportion of catch taken during the ovigerous period, and bottom temperatures. The abundance characteristic has remained favourable (green) for the last seven years despite the survey downturn, due to the influence of the commercial CPUE indices, which remained strong throughout. The production characteristic turned green in 2009 because of improved SSB, recruitment (age 2), size at sex change and predation indicators. Fishing effects improved due to decreased exploitation indices and proportion of females in the catch. The ecosystem characteristic remained unchanged (yellow) despite changes to individual indicators. Although the snow crab recruitment index was unavailable, recruitment for this stock appears to remain strong – availability of the index would probably not have had a negative affect on the ecosystem characteristic or overall summary.

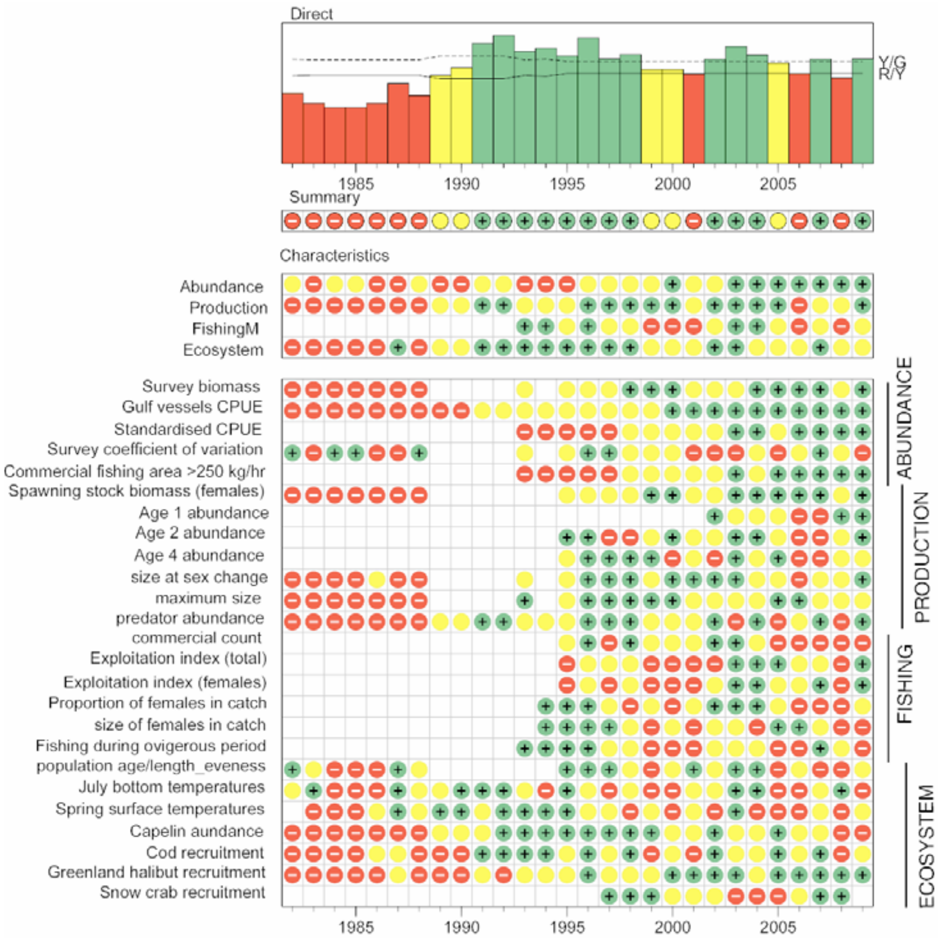


Figure 10. Traffic Light Analysis. Not all indicators in the Traffic Light table are discussed in the text. Please consult the current CSAS Research Document for a detailed description.

Sources of Uncertainty

DFO-Industry shrimp survey results are associated with high variances and biases associated with survey gear changes. 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 the first ten days of 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. The trend in commercial catch rate has not always been consistent with the trend in the shrimp survey index; the possible reasons for these divergences have been discussed previously. There is considerable subjectivity associated with assigning modal groups to year classes; consequently, estimates of year class strength, population numbers-at-age, and projections using these analyses must be interpreted cautiously. Growth rates can decrease dramatically due to density dependence, as happened with the strong 2001 year class. Consequently, recruitment to the fishery will be delayed and spread over a longer time period. Uncertainties associated with the growth rate, sex change, natural mortality and longevity of this year class preclude quantitative projections at this time. Unforeseen changes in the ecosystem (e.g., predators), and the environment (e.g., temperature) together increase the difficulty of making long-term projections but are not expected to influence the advice for the 2010 fishery.

CONCLUSIONS AND ADVICE

The biomass decrease expected with the passage of the 2001 year class through the population, although suggested by survey trends prior to 2009, has not yet materialized. Instead, biomass appears to have remained high or even increased since 2004. Consequently, the decrease in TAC effected for 2009 was premature. Although this year class is currently 8 years old, with high natural mortalities near or at the end of its life span, uncertainties in the relative strengths of succeeding year classes makes it difficult to predict how much, or even if, biomass will decrease in the next 1-2 years before the next recruitment pulse. Belly bag results indicate that the relatively strong 2007 and 2008 year classes will help to ensure continued good productivity of the stock in the longer term (with expected recruitment to the fishery in 2011/2012).

With an exploitation rate less than 10%, the average biomass from the survey in 2002-2009 has been higher than the previous period. It is likely that average catches higher than those taken during the modern fishery (approximately 4,000mt) are sustainable; however, it would be important to have an accurate abundance index to monitoring response of the population to increased exploitation. Further investigation of model-based approaches could assist with exploration of the long-term sustainability of higher catches.

An increase in the TAC for 2010 is supported by the current assessment, with cautious increases thereafter if biomass remains high and strong year classes continue to appear. For example, in 2005, the TAC was increased from 3500mt to 5000mt, based on an increase in the survey index to levels comparable to 2009 and the confirmation that the 2001 year class was strong and would be likely to sustain the fishery for upcoming years.

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FOR MORE INFORMATION

Contact: Peter Koeller
Bedford Institute of Oceanography
Department of Fisheries and Oceans
Science Branch, Population Ecology Division
P. O. Box 1006, Dartmouth, N.S. Canada, B2Y 4A2

Tel: (902) 426-5379
Fax: (902) 426-1862
E-Mail: koellerp@mar.dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice,
Maritimes Region
Department of Fisheries and Oceans
P.O. Box 1006, Stn. B203
Dartmouth, Nova Scotia
Canada B2Y 4A2

Phone number: 902-426-7070
Fax: 902-426-5435
e-mail address: XMARMRAP@mar.dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

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