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Maritimes Region
Canadian Science Advisory Secretariat
Science Advisory Report 2008/055

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

(J. Domm 2006)

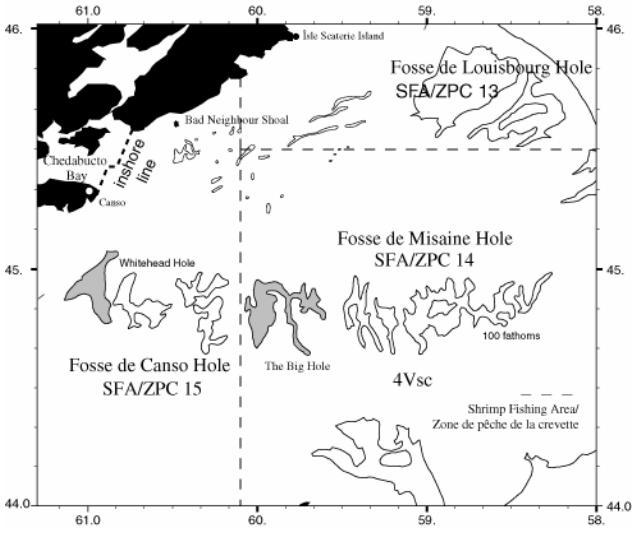

Figure 1. Shrimp fishing areas (SFAs) on the eastern Scotian Shelf.

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 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 2009 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 grate, and a Total Allowable Catch (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 biomass decreased 20% from last year and 36% since the all-time high of 2004. The DFO-industry survey index remains higher than the long-term (1982-2008) average, but is now just below average for the current survey series (1995-2008).
- The SSB (spawning stock biomass of females) has decreased 29% from last year and 50% since the all-time high of 2004. SSB remains higher than the long-term average, but is just below average for the current survey series.
- SSB and total biomass are expected to decrease further as total mortality of the 2001 year-class (yc) females increases and recruitment to the fishable biomass declines due to the weaker 2002-2006 year-classes.
- Commercial catch rates (CPUEs) have been fluctuating at a high level since 2002 and unlike survey results show no signs of a rapid decline. This divergence of survey and CPUE indices was seen as the previous strong group of year classes (1993-1995) declined. However, the area of highest catch rates remains large and the stock is still widely distributed.
- At 15% total exploitation was above average (13%) in 2008. Female exploitation increased to 20%, above the average (16%) and near the maximum (21%) observed. Exploitation rates for SFA 14, which has recently contributed the bulk of the catch, were the highest on record for this area (26%). Exploitation of the smallest (<19mm CL) shrimp continued above average in 2008, which is a conservation concern due to the lower recruitment in recent years.
- Fishers continued to experience difficulty in avoiding small shrimp but this problem declined from last year presumably due to growth of the 2001yc.
- The long-term decreasing trend in length at sex change and maximum size continues. A short-term increase in length at sex change during the last 2 years is probably associated with delayed sex transition and an additional year(s) of growth of 2001yc males.
- Belly-bag results indicate a strong 2007yc, consistent with the establishment of a pulsed recruitment pattern at a frequency about equal to the species' lifespan (6-7yr) in this region.
- Decreasing shrimp sizes and pulsed recruitment may be cumulative fisheries effects that erode population stability and reproductive capacity. These factors should be considered in the development of a long-term harvesting strategy.
- With recruitment of the weaker 2002-2006 year-classes, total and SSB biomass will probably continue to decrease in 2009, the rate of decline depending on the total mortality of the 2001yc. A TAC reduction will be necessary in 2009 to prevent exploitation rates from increasing further.

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 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. They prefer temperatures of 2 to 6ºC, and a soft, muddy bottom with a high organic content.

The Fishery

The fishery currently consists of 28 (20 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 (~2 currently active) restricted to Chedabucto Bay has been almost inactive recently due to low prices. The fishery operates under a 5-year management agreement (2007-2011) 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 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 (000s mt)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008[1]
TAC	5.5	5.0	3.0	3.0	3.5	5.0	5.0	5.0	5.0
Landings	5.4	4.8	2.9	2.8	3.3	3.6	4.0	4.6	4.5

[1]Landings projected to December 31, 2008.

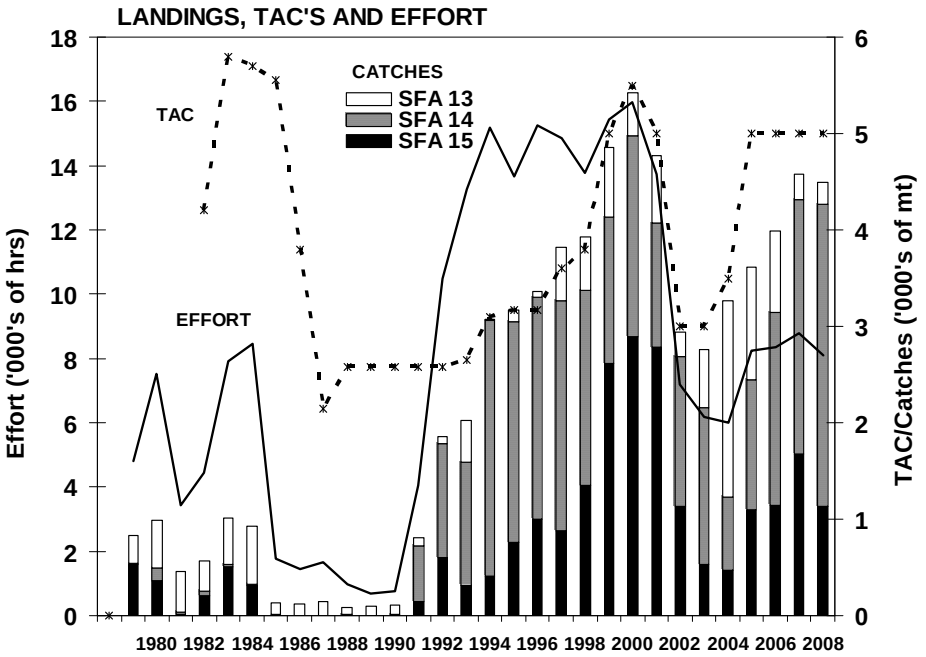

Figure 2. Landings, TACs, and Effort.

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, and again in 2008 (35%). This could contribute to other factors decreasing egg production, such as decreasing size at sex change, female sizes, and spawning stock biomass.

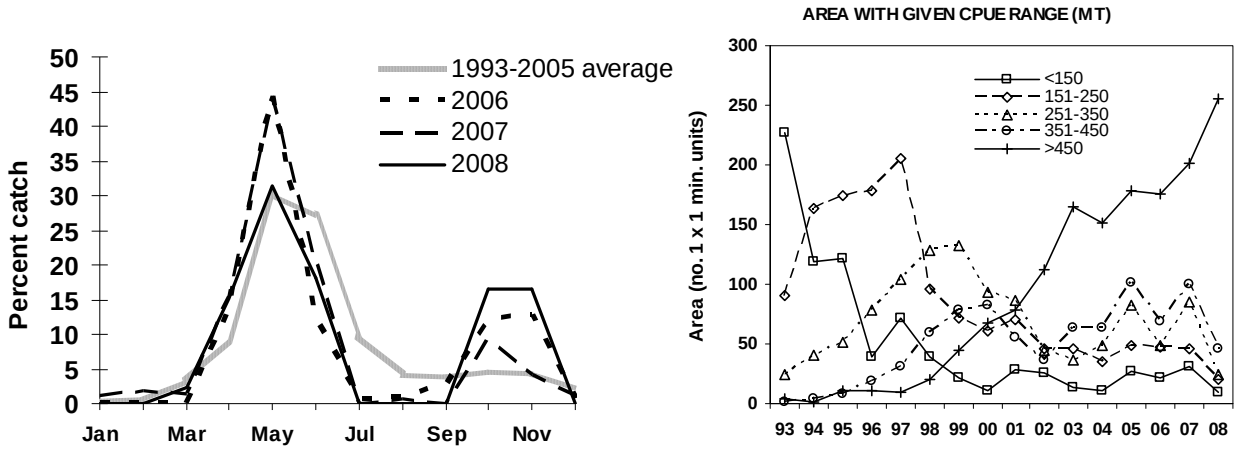

Figure 3. Temporal (left) and spatial (right) patterns in the Scotian Shelf shrimp fishery.

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 only 4% in 2004, and then increased again to 25% in 2007. It decreased to 14% in 2008. In 2004, a large part of the TAC (57%) was taken in SFA 13, but this declined to less than 1% in 2007 (14% in 2008) as effort shifted back to SFA 14 to take advantage of the large accumulated biomass there (approximately 50% of the catch in 2007-2008). In 2008 exploitation rates were not as evenly distributed across areas as in the previous 2 years. In particular, the continued high effort in SFA14 combined with a large biomass decrease here resulted in a relatively high exploitation rate (26%) in 2008. Spatial and temporal changes in the distribution of fishing effort, catch rates, availability to the fishing gear, and the resource itself are complex (Figure 3, right). Consequently, commercial catch per unit effort is not always representative of overall abundance as shown by the occasional (i.e., 1999-2004) divergence of CPUEs from DFO-Industry survey indices. Such a divergence may be occurring again as a result of the decline of the 2001yc (Figure 7). However, the area with the highest catch rates (>450kg/hr) has continued to expand since the late 1990s while areas with lower catch rates have remained smaller.

Decreases in the **average sizes of females** in the catch from 1997-2001 compared to the higher values of the early to mid 1990s (Figure 4, left) is 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 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. 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. **Count** estimates (numbers of shrimp per pound) provided by vessel captains increased significantly in 2005-2007 for the same reason (Figure 4, right). Fishers continued to have difficulty avoiding small shrimp from this year-class and maintaining counts below buyer limits to obtain the best prices; however, this was alleviated somewhat in 2008 presumably due to growth and sex change of 2001yc shrimp. Increased exploitation rates of the smaller sizes (<19mm carapace length) continues as a conservation concern considering the lower recruitment rates since 2001. The catch at length for 1995-2008 is shown in Figure 5.

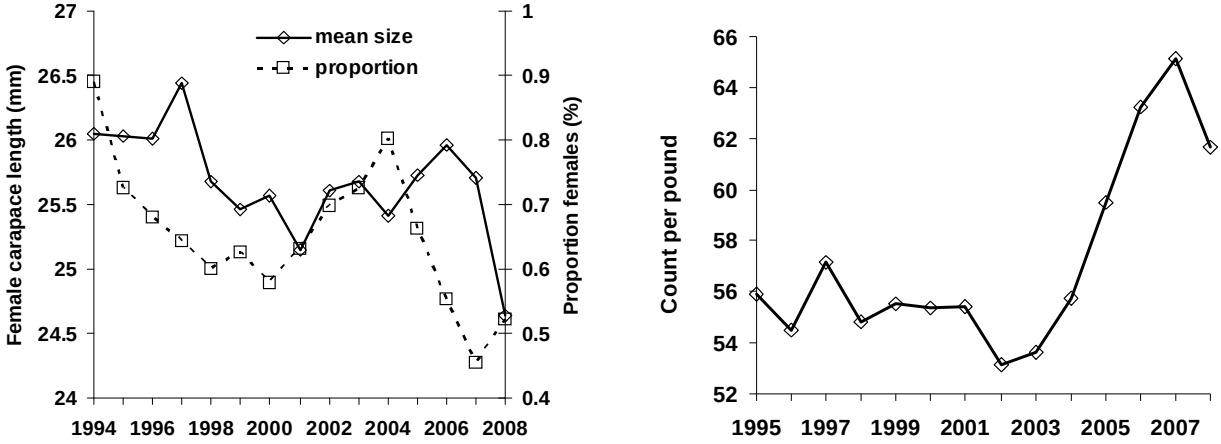

Figure 4. Mean female carapace length, proportion of females (left) and the count per pound (right) in the commercial shrimp trawl fishery.

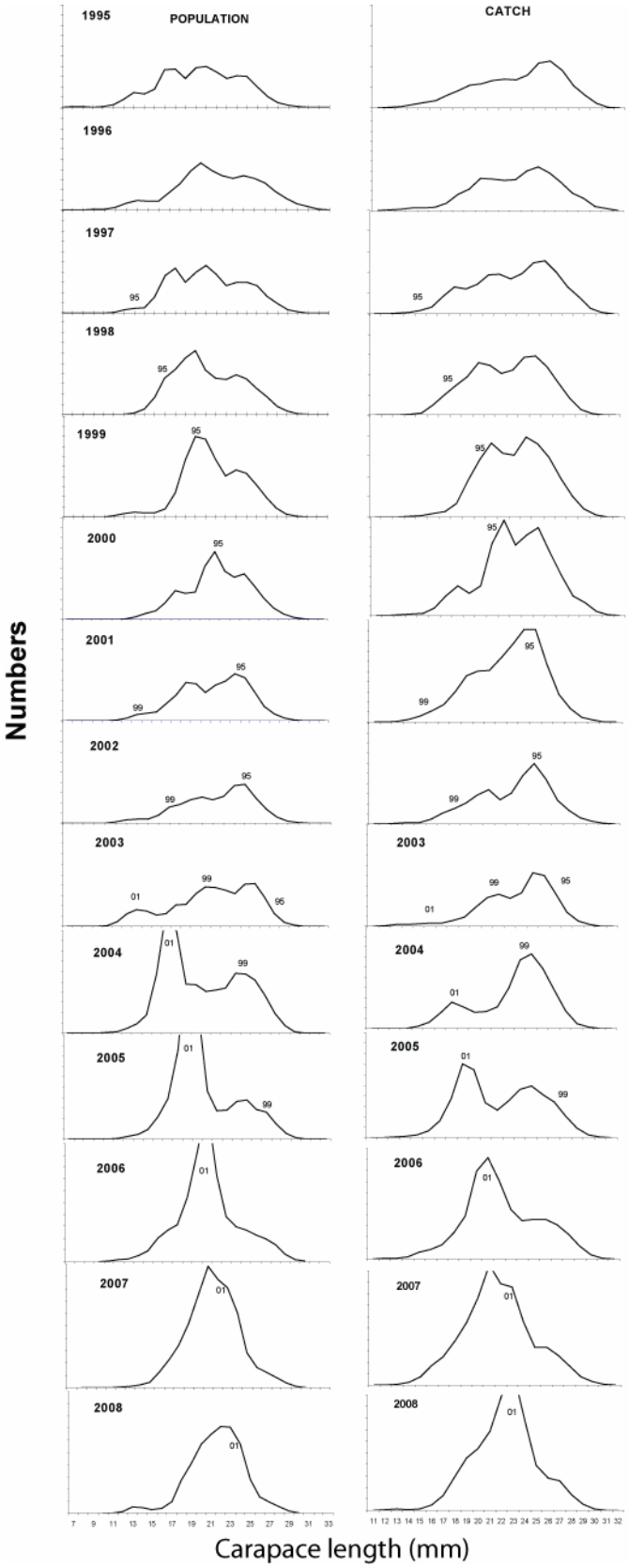

Figure 5. Survey population (left) and catch (right) at length estimates 1995-2008. The maximum value of each panel is $10*10^9$ and $10*10^8$ shrimp for the population and catch figures, respectively. Selected year-classes are identified.

ASSESSMENT

Stock Trends and Current Status

After a sustained long-term increase, commercial **CPUE** indices (Figure 6) leveled off and have been fluctuating at a high level since 2002. As indicated above, these indices do not always reflect overall abundance and have diverged from survey indices due to changes in the spatial distribution of the resource and fishing effort, and in availability to the gear. Such a divergence appears to have been occurring since 2004 as survey biomass decreased but catch rates remained high. However, the area of highest catch rates (>450kg/hr; Figure 3, right) remains large, while the areas of lower catch rates have remained relatively small, which is not consistent with a shrinking (spatially) resource.

The DFO-Industry survey index (Figures 6 and 7) has decreased in 3 of the last 4 years. Total biomass decreased 20% from last year and 36% since the all-time high of 2004. The DFO-industry **survey index** remains higher than the long-term (1982-2008) average, but is now just below average for the current survey series (1995-2008). The largest decreases were observed in Stratum 13 (Louisbourg)) which declined 45% from last year and 66% since 2004, and in Stratum 14 (Misaine) which declined 20% from last year and 37% since 2004. Other areas have not shown comparable declines - Stratum 15 (Canso) has remained about the same since 2004 and Stratum 17 (inshore) has increased since 2006. The **spawning stock biomass** (females) has also decreased from the 2004 record high (27,000mt) to below the average (16,000mt) for the 14-year survey series in 2008 (13,000mt), a decline of 50%. With much of the SSB consisting of the 2001yc, SSB will probably continue to decline as it continues to be targeted by the fishery and its natural mortality increases.

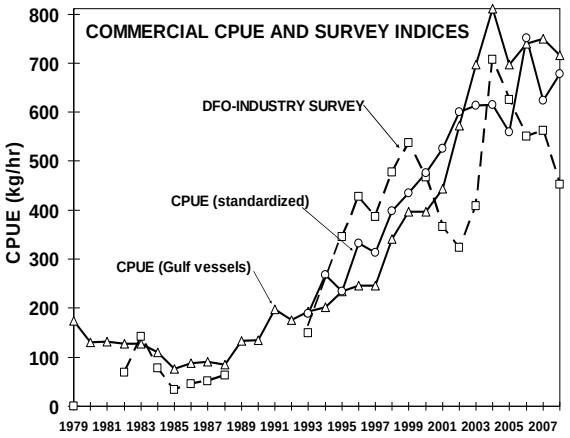

Figure 6. Commercial CPUE and survey abundance indices.

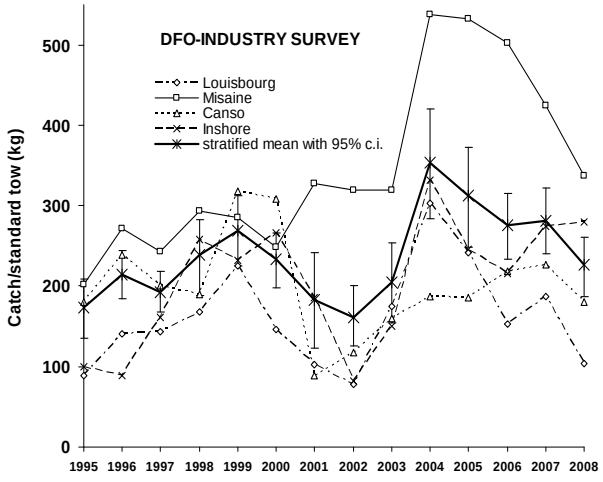

Figure 7. DFO-Industry survey abundance indices by strata.

During the late 1990s, the fishery was supported by a strong group of year-classes (1993-1995), which reached the end of their life cycle in the early 2000s (Figure 5). Lower levels of recruitment in the mid 1990s led to a biomass decrease from 2000-2002 (figures 6 and 7). Good recruitment mainly associated with the 2001yc (Figure 5) 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, increasing natural mortality coupled with relatively high fishing mortality has led to a sharp population decline. Since this year-class comprised up to 70% of the biomass at its peak, and was followed by poorer recruitment as shown by below average abundance of **Age 3 and 4 shrimp** in 2008**,** the decline will continue into 2009 and perhaps beyond. The **abundance of Age 2 shrimp**,

although again below average in 2008, increased from the survey series low in 2007, suggesting that the period of low recruitment has ended. This was supported by belly bag results, which indicated that the 2007yc at Age 1 is the second largest of this series following the exceptional 2001yc. However, this result also supports the theory that the fishery has entered an unstable, pulsed recruitment phase that is at least partly fishery-induced. If the 2007yc stays strong until it recruits to the fishery in about 2011, the fishery will have experienced 3 such pulses, separated by approximately 6-7 years, or the species' life-span in this region, since the survey series began in 1995.

As a result of biomass decreases and continued high TACs, **total exploitation** has increased annually from the all-time low of 7% in 2004 to 15% in 2008, just above the 14-yr average (13%)**. Female exploitation** increased to 20%, near the maximum observed (21% in 1995) and also above the average of the recent series (16%). With effort concentrating in SFA 14, exploitation in 2008 was the highest experienced by this area (26%). **Exploitation of small (<19mm) shrimp** continued to be above average in 2008, which is a conservation concern due to the lower recruitment of recent years.

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 is approaching the small sizes associated with the low population levels of the 1980s (Figure 9). Length at sex change increased during the last 2 years, probably due to late sex change of 2001yc 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). 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.

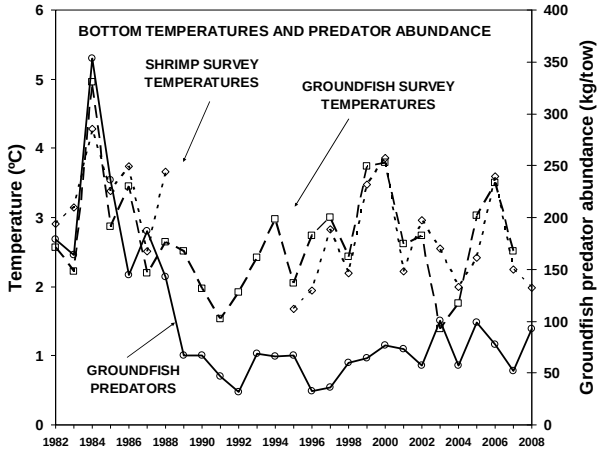

Figure 8. Bottom temperatures and predator abundance on the eastern Scotian Shelf shrimp grounds.

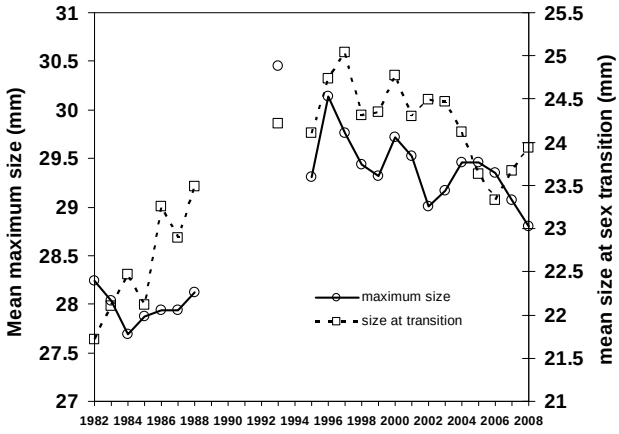

Figure 9. Changes in mean size at sex transition and maximum size.

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 grate in 1991 reduced **by-catch** and allowed the fishery to expand to its present size. Analysis of observer and survey data from 1995-2006 and 2008 confirms that by-catch weight remains very low and probably has little effect on the ecosystem. However, despite low by-catch by weight, most fish caught are small and some commercial species, particularly flatfish, are caught in relatively large numbers. The impact of these removals cannot presently be quantified because the sizes of flatfish populations are not known. Conversely, the impact of **predation** by a relatively large shrimp stock on ichthyoplankton, including eggs of commercially important fish such as cod, is unknown.

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 probably 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 vernal 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 and 2001 and 2007 year-classes). Although temperatures are currently warmer than during the large sustained shrimp population increase in the 1980s, the continued abundance of cold water indicator species including shrimp, capelin, Greenland halibut and snow crab suggests that the regime shift which led to their success is enduring. Nevertheless, a continuing warming trend would be a concern for the shrimp stock.

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 = yellow or cautious, and <0.33 = 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.

In 2008, the overall traffic light summary turned red for only the second time in 20 years. The previous red light (2001) was associated with decreasing biomasses as the strong 1993-1995 year classes passed through the population, analogous to the current situation with the 2001yc. However, the situation is more pressing now in that more of the population is concentrated in this one year class; consequently, subsequent biomass decreases will likely to be more rapid. Note that in the previous cycle, the red summary was derived from 1 red (fishing impacts) and three yellow characteristics. Currently, the fishing impact characteristic is also red and the production and ecosystem characteristics are yellow; however, the abundance characteristic remains green. This is partially due to the continued good (green) commercial catch rates, which are not necessarily representative of abundance, and because the survey biomass estimate is still about average. With survey abundance expected to continue decreasing, this characteristic will probably also turn yellow next year. Although the fishing impact characteristic was red at both instances when the overall summary was red, it is noteworthy that currently all indicators in this characteristic are red, a situation which has not occurred before for any characteristic.

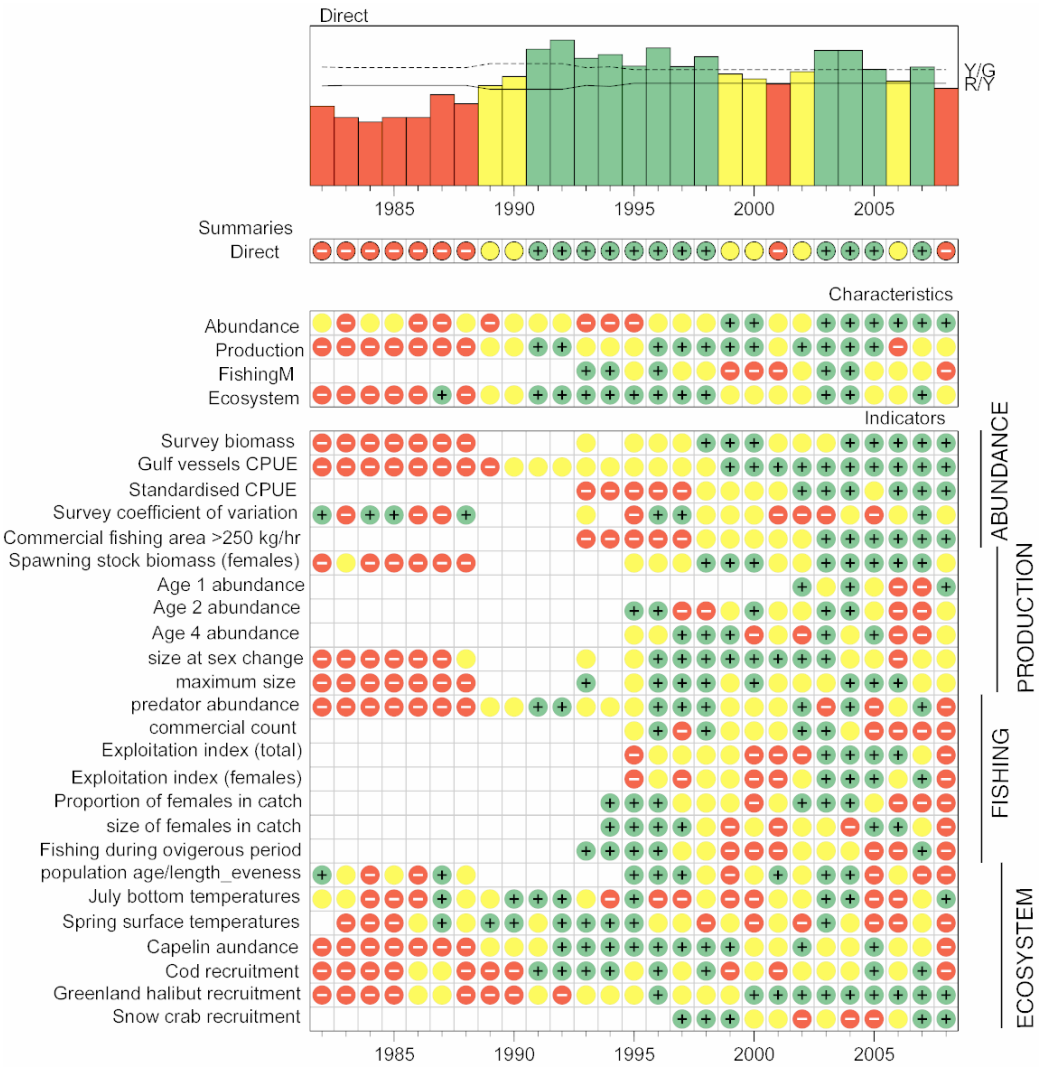

Figure 10. Traffic Light Analysis. Not all indicators in the Traffic Light table are discussed in the text. Please consult the current CSAS Research Document for a detailed description.

Sources of Uncertainty

DFO-Industry shrimp survey results are associated with high variances. The accuracy of estimates can also be biased by temporal changes in availability during the survey period. In 2007-2008 problems with NETMINDER distance sensors and data logging required use of historical average instead of actual wing spread data to calculate swept areas and abundance. Spatial analyses indicate that catch rates do not always represent overall abundance trends. 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 may lead to major regime shifts requiring radically different management strategies.

CONCLUSIONS AND ADVICE

The biomass decrease expected as the 2001yc passes through the population has begun, and is progressing rapidly. This year-class is currently 7 years old and is near or at the end of its life span. Although shrimp from this year-class continued to change sex in 2008, three years later than usual, its natural mortality appears to be higher and longevity lower than might be expected under slower density-dependant growth. Consequently, total biomass and SSB decreased substantially in 2008, resulting in increased total and female exploitation rates under the continued high TAC. With the 2002-2006 year-classes below average, both total biomass and SSB are expected to continue decreasing in 2009 as the 2001 year-class dies off. A substantial TAC reduction for 2009 is recommended to prevent further increases in exploitations rates. Belly bag results, which indicate that the 2007yc is strong, appear to confirm the establishment of a pulsed recruitment pattern with a frequency about equal to the species' life span, effectively concentrating the population in fewer year and size classes. This, together with a continuing decreasing trend in shrimp sizes, may be evidence of cumulative fishing effects that erode population stability and reproductive capacity.

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