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Assessment of the status of Div. 4TVW Haddock: 2000

Évaluation de l'état des stocks d'aiglefin dans les divisions 4TVW en 2000

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Abstract

The current evaluation of the Div. 4TVW haddock stock status was derived from reported landings, shore and at-sea based samples taken from commercial landings for size and age composition, research vessel (RV) surveys conducted in March and July, and a fixed-gear Sentinel Survey conducted in the fall. Indicators of abundance revealed that the number per tow (1-29 cm) from the July RV rose dramatically in 1999 and 2000, reflecting the strength of recent incoming year-classes. Intermediate sized haddock (26-41 cm) have been steadily increasing and the highest value in the series occurred in 2001. The summer RV number per tow of haddock 42 cm + has remained very low throughout the 1990s, and the 2001 estimate is among the lowest observed. Spawning stock biomass has been steadily increasing since closure of the fishery and in 2000 exceeded the 1970-2000 average. The sentinel survey catch rate, which selects for larger haddock, exhibited a declining trend since the initiation of the survey in 1995. Some of the production indicators have been increasing since closure of the fishery. Recruitment at age 1 shows that the 1995 year-class is above the 1970-1998 average while the 1998 year-class appears very strong. Survey estimates at age 1 suggest that the 1999 year-class is also strong. Condition factors have generally been below average since the early 1990s. Growth, based on size at age 7, steadily declined throughout the late 1980s/1990s, which was preceded by a more rapid decline during the mid-1980s. Since closure of the fishery, fishing mortality rates have been low. Prior to the collapse of the fishery, exploitation rates were more than twice the $F_{0.1}$ level of 20%. Currently, Div. 4VW haddock is an early maturing, geographically constricted stock plagued by poor growth (both under-weight and under-length) and high natural mortality that has recently produced good to excellent recruitment. The next few years will be pivotal to this stock given recent strong recruitment and improvement in environmental conditions.

Résumé

Les stocks actuels d'aiglefin dans les divisions 4TVW ont été évalués à partir des débarquements signalés, des échantillons prélevés sur la côte et en mer dans les débarquements commerciaux aux fins de détermination de la taille et de la composition par âge, des relevés par navire de recherche (NR) effectués en mars et en juillet et d'un relevé aux engins fixes par pêche sentinelle réalisé à l'automne. Les indicateurs d'abondance ont révélé que le nombre par trait (1-29 cm) lors du relevé par NR en juillet a augmenté énormément en 1999 et en 2000, reflétant la vigueur des nouvelles classes d'âge. Le nombre d'aiglefins de taille moyenne (26-41 cm) s'est accru de façon soutenue et a été le plus élevé de la série en 2001. Le nombre par trait d'aiglefins de 42 cm + lors du relevé d'été par NR est demeuré très faible tout au long des années 1990, et l'estimation pour 2001 compte parmi les valeurs les plus basses observées. La biomasse du stock reproducteur a augmenté de façon soutenue depuis la fermeture de la pêche et, en 2000, a dépassé la moyenne de 1970-2000. Le taux de capture lors du relevé par pêche sentinelle, qui vise les gros aiglefins, est en déclin depuis le début des relevés en 1995. Certains des indicateurs de production sont en hausse depuis la fermeture de la pêche. Le recrutement à l'âge 1 révèle que la classe d'âge 1995 est supérieure à la moyenne de 1970-1998, tandis que la classe d'âge 1998 semble très forte. Les estimations selon le relevé à l'âge 1 suggèrent que la classe d'âge 1999 est également abondante. Les coefficients de condition ont en général été inférieurs à la moyenne depuis le début des années 1990. La croissance, basée sur la taille à l'âge 7, a diminué de façon soutenue dans les dernières années de 1980 et tout au long des années 1990, après avoir subi un déclin rapide au milieu des années 1980. Depuis la fermeture de la pêche, les taux de mortalité par pêche ont été faibles. Avant l'effondrement de la pêche, les taux d'exploitation étaient plus du double du niveau de $F_{0,1}$ de 20 %. Pour l'heure, les aiglefins dans les divisions 4VW forment un stock précoce, géographiquement confiné, affligé d'une croissance très faible (poids et taille insuffisants) et d'un taux de mortalité naturelle élevé qui a récemment produit un recrutement allant de bon à excellent. Les prochaines années seront critiques pour ce stock étant donné la vigueur récente du recrutement et l'amélioration des conditions environnementales.

Introduction

The eastern Scotian Shelf haddock stock is contained within NAFO Div. 4TVW (Figure 1). Historically, the fishery was very productive but this has not been the case in recent times. The fishery was closed in the fall of 1993 and has remained closed since that time. The last full assessment of this stock was conducted in 1997 (see Frank et al. 1997) with annual updates to 2000 (DFO 2000). Little improvement in the status of the adult component of the stock was noted and the stock has been plagued by poor growth.

FRCC has repeatedly recommend: there be no directed fishery, that closure of the haddock box to all groundfish sectors remain in effect, and that restrictive by-catch measures be maintained in all fisheries directed at other species. All of these measures have been adopted. An evaluation of the haddock box (i.e. the Emerald/Western bank closed area) was conducted in 1998 (Frank and Simon 1998) and its performance is under continual scrutiny. Strict by-catch restrictions have been in existence with a 5% overall cap for mobile gear and a 10% overall cap on fixed gear. A small fish protocol also exists and haddock less than 43 cm are considered to be undersized.

The fishing industry has made an increasing contribution to providing primary data inputs to groundfish stock assessments throughout Atlantic Canada and the eastern Scotian Shelf is no exception. Since 1995 a fixed gear sentinel survey of Div. 4VsW has been in place. This survey represents a joint project of the Fishermen and Scientists Research Society and the DFO's Marine Fish Division. The survey results form an integral part of the Div. 4TVW haddock assessment.

This document contains the most up-to-date primary input data for the Div. 4TVW haddock stock assessment. This includes data derived from the commercial fishery and associated sampling (past and present) and at-sea surveys (industry and DFO). The products derived from this include the commercial and survey age composition. Recent research results as well as a virtual population analysis are also presented.

The Fishery

Landings data by division and country for Div. 4TVW haddock extend back to 1954 (Table 1). Total landings peaked in the mid-1960s and were followed by a rapid decline to the mid-1970s. During this period foreign landings frequently exceeded domestic landings (Figure 2). A second peak in landings occurred in the mid-1980s and once again a decline followed, this time in the early 1990s. Foreign landings have been relatively low since extended jurisdiction to 200 miles in 1977 and were associated with by-catch in the silver hake fishery. Total allowable catches were first imposed in 1976. The decadal average landings since 1960 were approximately 25,000t in 1960-1969, 5,000t in 1970-1979, and 11,500 t in 1980-1989. During the 1990s the fishery for haddock collapsed and has been closed to directed fishing since the fall of 1993. By-catches in other fisheries have averaged 128 t since 1994. Throughout the modern history of the fishery, landings have generally been derived from Div. 4W with 4Vs as a secondary area.

Canadian landings of haddock by gear type and division are shown in Table 2. Generally, otter trawlers in both divisions have dominated landings. However, in Div. 4W during 1989 to 1993, fixed gear catches exceeded otter trawlers (Figure 3). This was the result of an exemption for fixed gear in the closed area. Geographic locations of landings data are available since 1990. The fishery distribution patterns, for both mobile and fixed gear, prior to the directed fishery closure are shown in Figures 4 and 5. Mobile gear landings have been concentrated around the perimeter of the closed area, the Gully, and Banquereau bank (Figure 4). Fixed gear landings were concentrated inside the closed area and along the edges of Banquereau bank (Figure 5). Since the closure of the directed fishery in 1994, by-catch has been scattered throughout the management unit with some concentrations around the closed area and to the east (Figure 6). The unusual locations of the some of the landings data, such as those off the continental shelf and on land represent a very small percentage of the total landings (mobile and fixed gear during 1990-1993 was 0.2% and 2%, respectively; 1994-2000 all gears was 1%). The landings reported from inside the closed area since 1994 amounted to 7.7 t. This was a result of by-catch from the Div. 4W scallop fishery and the removals associated with the conduct of the Div. 4VsW fixed gear sentinel survey.

Commercial catch at age

The commercial catch at age was reconstructed from sampling conducted since the last full assessment in 1997 (Frank et. al. 1997). In general, our objective was to create quarterly age length keys by division. When this stratification (or allocation) scheme was not possible, quarters and divisions were combined in order to provide a sufficient number of aged samples. However, sampling intensity has been quite low during 1997 to 2000 necessitating the use of annual age/length keys. Each key was applied to the combined length frequencies from all gears for each year (see Appendix 1-4). Inter-reader age comparisons (also referred to as age-bias analysis) were conducted for 1998 and 1999. The results showed no bias between the primary and secondary age reader and low CV's (5.4-6.3%). These results are considered to be adequate for this stock.

The historical catch at age (1970 to 1984) used in the previous assessment has remained unchanged. However, in the previous assessment the catch at age constructed for 1985-1989 utilized yearly RV age/length keys due to the lack of ageing information from commercial samples. Re-ageing of otoliths from this time period has been completed and age/length keys based on commercial samples have been constructed as per previous assessments (Appendix 5-9). Age-bias analysis of this re-aged material between the primary and secondary agers revealed low CV's and no bias. CV's were 4.1, 3.1, 4.2, 4.7, and 3.5% for 1985 to

1989 respectively. These results are considered to be very good for this stock.

Landings at age from the foreign small mesh gear fishery (since 1985) were estimated by applying summer research vessel survey age length keys to the length frequency estimates derived from samples of haddock by-catch in the small mesh gear fishery.

The resulting catch at age, from 1970 to 2000, is shown in Table 3. Compared to the previous catch at age used in the last assessment (Frank et al. 1997), the current catch at age is identical from 1970 – 1984 and differs from 1985 to 1996 (Table 4). The reasons for this difference include: 1) Canadian landings were revised from 1986 to present using the Zonal Information File Format or ZIFF, 2) commercial ages were applied to the 1985 – 1989 samples which was not the case in the old catch at age when RV age/length keys were used, 3) minor revisions were made to the allocation blocks from 1990 – 1996, and 4) an updated method (known as CATCH) was used to estimate removals at length from the foreign fishery. Collectively, these changes account for the observed differences.

Resource Status

Industry Survey

A fixed gear sentinel survey, involving 6 commercial long-line vessels, has been in place in Div. 4VsW since 1995 (Figure 7). It is based on a stratified, random survey design, utilizing the same stratification scheme as the DFO July RV survey (see Section on Research Vessels surveys for a stratum map). In addition, three inshore strata shoreward of the 50 fathom isobath were added to the design. Approximately 230 pre-selected set locations are occupied, starting in September of each year (Table 5). Each station consists of 1,500 #12 circle hooks baited with frozen mackerel. Detailed biological sampling protocols are also followed, yielding material for age determination. A commercial index phase has been in place but it has not been financially viable and participation has steadily declined. The amount of haddock (t) captured during the sentinel survey was as follows:

1995	1996	1997	1998	1999	2000
6.4	5.6	3.4	3.7	3.1	3.0t

Abundance trends: In all years, haddock catch rates (kg per 1500 hooks) were generally highest in those strata associated with the closed area (strata 463 – 465). Catch rates were also consistently high in the two strata encompassing Sable Island bank (455-456) and the Gully (451). Catch rates were generally low in the three inshore strata (467-469). Low and variable amounts of haddock were caught in the other strata (Table 6). The stratified mean catch rate, with and without the inclusion of the three inshore strata, revealed a declining trend. Catch rates were highest in 1995 (> 25 kg/set), declined in 1996, and have remained low (< 15 kg/set) during 1997 to 2000 (Figure 8).

Distribution: The geographic patterns of haddock catches were remarkably consistent from year to year. In the most recent surveys (1999 and 2000), haddock were concentrated within the Emerald/Western bank closed area and around its perimeter (Figure 9). Smaller catches occurred to the east along the flanks of Sable and Banquereau bank and the Gully. Survey results are also shown from 1995 to 1998 (Figure 10). The annual percentage of haddock inside the closed area for each year was as follows:

1995	1996	1997	1998	1999	2000
69%	59%	71%	86%	68%	53%

Length composition: A uni-modal length composition was evident in 1995 and 1996 with catches peaking around 42-46 cm and falling off rapidly at larger sizes (Figure 11). In subsequent years, catches were lower across most sizes. In 2000, the size composition of the catch was skewed towards smaller sizes.

Survey catch rate at age: The stratified mean catch rate at age from the sentinel survey is shown in Table 7. The progression of year-classes is evident in the matrix – notably the 1992 and 1988 year-class. The 1988 year-class was large and its persistence in the population is quite remarkable. Total numbers show a steady decline each year as do the 3+, 5+ and 7+ components of the population.

Industry consultations: Consultation with industry has revealed a concern for the effect of other fisheries and disturbance associated with oil and gas exploration on the well-being of haddock. Other fisheries associated with offshore clam and herring are a concern as these represent potentially important food resources for haddock. Herring spawn (eggs) has been a traditional seasonal food resource for haddock and clams (bivalves) have been recorded as a diet item in haddock. In addition, the recent removal of significant amounts of shrimp and crab is a concern and some have questioned the Department's commitment to an ecosystem approach. Others noted that lack of eye-bait (or krill) and suggested some changes to the food web have occurred. High numbers of worms have been seen in haddock and some speculated that a high worm burden would reduce haddock growth rates. Seismic activity associated with oil and gas exploration is believed to disrupt the behaviour of haddock and fishers are very concerned that it may be having a negative impact on groundfish. Collectively, this information was given in response to the documented reduction in growth and condition of haddock. It was also noted that a traditional "fall run" of haddock essentially disappeared in the fall of 1991 and has not returned. Other historical groups or "runs" of haddock were also noted such as those that occurred in 4Vn. These fish were considered to be slinky and differed from haddock on the offshore banks and from 3Ps and 3NO. There was no disagreement on DFO's perception of the current status of the stock and that of industry.

Research Vessel Surveys

There are two research vessel groundfish trawl surveys utilizing stratified random sampling designs for this stock: the July or summer series that started in 1970 (Figure 12) and a March or spring series that began in 1979. Haddock collected from the March survey have not been routinely aged. However, efforts are underway to do so and when ageing is completed for the March survey, it will be used as an abundance index for this stock. Detailed sampling of haddock has been conducted during March providing information on length-specific maturity schedules and condition.

Summer (July) RV

Abundance trends: The overall abundance of haddock has remained below the long-term average of 42 fish per tow throughout most of the 1990s. However, abundance estimates in 1999 and 2000 rose dramatically and were greater than twice the long-term average. Numbers per tow in 2001 were also well above average (Figure 13). High numbers of small haddock, <14cm in 1999, 18-23 cm in 2000, and 26-31 cm in 2001, were the main contributors to the increase in overall abundance (Table 8). Weight per tow does not show the dramatic increase in 1999 and 2000 as numbers (Figure 13).

Recent increases in abundance of haddock 30 cm and greater were also evident, with above average numbers per tow from 1998-2001(Figure 13). Weight per tow rose to slightly above average in 1999 and decline to below average in 2001. This size group was considered comparable to the sentinel survey catch rate based on the minimum size of capture. However, the abundance patterns between the two series showed a divergent pattern.

The abundance of haddock 42cm and greater was considered an index of the fishable component of the stock (note: management protocols consider haddock undersized if smaller than 43 cm). Number per tow has remained consistently below the long-term average of 10.6 fish per tow since 1992 (Figure 13). Weight per tow exhibited a near identical trend to numbers.

Length composition: The annual length composition of haddock is presented since the closure of the fishery in 1994. Each year is poly-modal with the entry of new year-classes evident as well as a progression of modal groups through time (Figure 14). Also, a general deficit of larger fish relative to the long-term (1970-2001) average is evident in all years since 1994. There was an unprecedented high abundance of small haddock in 1999 (modal size of 10.5 cm) representing the 1999 year-class. A dominant mode was also evident in 2000 and 2001, presumed to be one and two year-old haddock respectively from the 1999 year-class (Figure 14).

Distribution: Distribution patterns were evaluated for haddock in two size groups from 1995 to 2001: 30cm + and 1-29 cm. Haddock 30cm and greater exhibited consistent annual distribution patterns. Concentrations were evident on Emerald, Western and Sable Island banks. Other important areas included Middle bank, the Gully and edges of Banquereau bank (Figures 15 and 16). This pattern is similar to the September distribution of haddock based on the fixed gear sentinel survey.

Juvenile haddock (1-29 cm group) were concentrated on Emerald, Western, and Sable Island bank similar to the adult distributions. In contrast to the adults, small haddock were more highly concentrated on Sable Island bank and nearer to Sable Island in shallow water. Extremely high numbers per tow were evident in these areas in 1999 –2001. (Figure 17 and 18). In addition, few small haddock were evident in the Gully and areas to the east.

Two indices of spatial distribution were evaluated for each year for all sizes combined: the proportion of non-zero sets and resource concentration. The proportion of annual survey sets where haddock occur is a measure of how widely distributed a stock is throughout the management unit. Peak values (0.6 – 0.7) were evident throughout the 1980s indicating that the stock was widely distributed. This was followed by a decline in the early 1990s (Figure 19). The proportion of non-zero sets has averaged about 0.5 during the past several years. This indicates that the stock is not widely distributed. The proportion of the stock area encompassing 75% of the annually estimated survey abundance is a measure of resource concentration. This index is presently less than the peak values observed during the 1980s, indicating that the resource is somewhat concentrated. It should be noted that the two indices are highly correlated ($r=0.98$, $n=32$, $p<0.001$).

Condition: Predicted weight of haddock at 30 and 45 cm was considered an index of juvenile and adult haddock condition, respectively. Juvenile haddock exhibited no discernable trend in condition throughout the time series, although predicted weights were more variable prior to 1990 reflecting the lower accuracy of spring scales used to weigh haddock (Figure 20). After 1990, electronic scales were in use on the survey resulting in more accurate individual weights. Adult haddock exhibited higher than average weight throughout the 1970s and early 1980s whereas during the remainder of the series weights were generally below average. Since 1993, adult haddock body weight has been below average in seven out of nine years (Figure 20).

Spring (March) RV

Abundance trends: Recent trends in abundance are difficult to discern from the March RV because of missing years (no survey in 1998) and incomplete coverage in some years (1996, 2001). An extremely high level of abundance was recorded in 1981 and this point was omitted when calculating the long-term mean.

The overall abundance of haddock was above average throughout most of the 1980s and somewhat lower and more variable from year-to-year in the 1990s (Figure 21). Numbers per tow in 1999 and 2000 were above average with intermediate (32-39 cm) and small (16-21 cm) haddock being the main contributors respectively (Table 9).

Trends in numbers per tow of 30cm + haddock were nearly identical to the patterns seen among all sizes. The only exception occurred in 2000 when numbers per tow were below average. Numbers per tow of 42cm + haddock were generally above average throughout the 1980s and below average throughout the 1990s to the end of the series in 2001.

Length composition: The length composition from the March survey was distinctly poly-modal with the smallest modal size class occurring between 14 – 21 cm each year. This was the dominant mode in the 2000 survey and was a reflection of the strong 1999 year-class seen as 0-group in the 1999 July survey (Figure 22). This modal size was also above average in 1996 and 1999. In each year since 1994, with the exception of 1999, there was a deficit of fishable sizes (42cm+) relative to the long-term average (Figure 22).

Distribution: Composite distribution patterns of adult (30cm+) and juvenile haddock (1-29 cm) from 1995-2001 were very similar to one another but exhibited a more off-shelf distribution compared to the July RV (Figure 23). Haddock were distributed around Emerald and Western Bank and along the slope edges to the east and in association with the Gully. Few haddock were captured on Sable Island bank and none were collected on Middle bank during this time period (Figure 23). Although not shown, the 1999 distribution was unusual because of the relatively high, on-bank abundance of haddock. This year was unusually warm which may have contributed to the anomalous pattern.

Condition: Similar trends in predicted weights were evident for both juvenile and adult haddock. Generally, length-specific weights were above average during the 1980s and below average throughout the remainder of the time series (Figure 24). The recent pattern of below average adult condition is similar to that seen in the July survey.

Maturities: Maturity at length data has been collected during the March survey since 1979 (Table 10). In most years of the survey, full (100%) maturity was reached by 42 cm. However, 50% maturity has shifted to smaller sizes in the latter years (Figure 25). Adjusting the survey biomass per tow at length data (Table 11) by the proportion mature at length yielded an index of spawning stock biomass, or in the present case, mature female biomass. Mature female biomass has remained below average since 1991 and in 1999 and 2000 rose to near-average levels (Figure 26).

July RV – Age based

The 1997 to 2000 July RV catch at age has been constructed utilizing annual age/length keys. Age bias analyses were conducted for each year. The 1997-1999 analyses revealed no ageing bias and minimal CV's (range: 5.5 – 6.7%). These results are considered to be adequate for this stock. However, the evaluation of primary and secondary ageing information from the 2000 survey revealed an over-ageing by the secondary ager by about 0.5 - 1 year, associated with the younger age groups. In addition, a very high CV of 14.7% occurred. For the present assessment, this discrepancy has not been resolved and the primary agers results are used. The 1970 - 2000 RV stratified mean catch rates at age and biomass per tow at age are shown in Tables 12 and 13.

Recruitment: Number per tow at age 0, 1 and 2 were used to illustrate the development of year-classes in the stock. However, 0-group are not consistently captured by the survey gear and may not provide a meaningful estimate of incoming recruitment. Ages 1 and 2 are considered more reliable indicators of incoming recruitment.

At age 0, numbers per tow were extraordinarily high in 1999 and well-above average in 2000. The 1999 year-class was also extremely abundant at age 1 and the age 1 estimates of abundance for the 1995 and 1998 year-classes were also above-average. (Figure 27). The 1998 year-class, estimated at age 2, was the highest in the time series, and the 1995 and 1997 year-classes were above average as well. A recruitment index, calculated as the average of the abundance estimates at ages1 and 2 for each year-class, suggests that the 1998 is indeed strong, followed by 1995 year-class. The remaining year-classes since 1988 were either near average or below (Figure 27). This age-based description is entirely consistent with the abundance trends presented earlier based on sizes alone.

Abundance trends (numbers and biomass): Stratified mean numbers per tow and biomass for age 3+, 5+ and 7+ are shown in Figure 28. Numbers per tow of 3+ haddock have increased since 1997 with above average levels of abundance occurring during 1998-2000. Biomass of 3+ haddock rose to above average levels in 1999. A similar trend was seen for 5+ haddock with both recent (1999 and 2000) catch rates and biomass either exceeding or near to the long-term mean. Catch rates of 7+ haddock have generally been above the long-term average since the mid-1980s, suggesting lower mortality in recent times.

Cohort tracking: A concern of any survey is its ability to track the progression of a year-class. The approach used to evaluate cohort tracking was to examine the relationship between year-class estimates at successive ages in the survey. A cross section of plots in Figure 29 show the relationship between ages 1 and 2, ages 2 and 3, ages 3 and 4, and so on. A correlation table (Table 14) contains the full matrix of correlations (r^2 in this case) for all ages. The general conclusion is that the survey does well at tracking year-classes. Also, age 1 catch rates appear to give a good indication of incoming recruitment, noting the high correlation between age 1 and ages 5, 6 and 7 in Table 14.

Total mortality or Z: Total mortality estimates for adult haddock derived from the summer survey show high, year-to-year variability, particularly in the first half of the time series. A temporal trend was introduced by smoothing the data using a three-year running mean. This revealed two peaks in total mortality, the latter one immediately preceding the closure of the fishery (Figure 30). After closure of the fishery, total mortality was generally quite low and averaged about 0.35. These estimates take on added significance because in a closed fishery they are an approximation of natural mortality.

Population considerations

Growth (size at age): Length at age for the younger age groups of haddock (1 and 2 year old) has remained close to the long-term average of 22 and 31 cm respectively throughout most of the time series (Figure 31). However, age 3 haddock have shown a declining trend in lengths and recent sizes are about 10% lower than the long-term average of 37 cm. The reduction in length at age is even more pronounced in the older age groups (4 years old and greater). For example, a 6 year old haddock was close to 60 cm in the mid-1970s compared to 41 cm during the past several years. Seven year old haddock are currently near 43 cm – a reduction of nearly 20 cm from a peak size in 1978 (Figure 31). Other, older age groups show equally striking changes (Table 15). Haddock are growing older but not larger in this stock. One implication of this finding is that if slow growth persists in this stock then it will take several years for new year-classes to reach fishable sizes.

Fecundity and total egg production: Recent research (Blanchard 2000) has been completed on the length-specific fecundity of haddock on the eastern Scotian Shelf during 1997-1999. The relationship between egg number (E) and body length (L) was

$$E = 0.2156 * L^{3.5334}, \ r^2 = 0.32, \ n = 404, \ p < 0.001 \text{ (Figure 32)}$$

Relative to other haddock stocks in the North Atlantic, length-specific fecundity of these haddock is quite low and highly variable. This data, in combination with the proportion mature at length, permitted an estimate of total egg production. Total egg production increased two-fold from 1997 to 1999 and the 1999 year-class (estimated at age 1) is the strongest ever-observed (Figure 33). This year-class appears to have benefited for increased egg production as well as favorable conditions for early survival.

Temperature: Bottom temperatures in the area of 4V and much of eastern 4W generally increased in 1999 and 2000 to above their long-term (1961-90) means for the first time in over a decade. From the groundfish surveys, there were no bottom temperatures <2ºC in 4VW by 2000 and the lowest observed area with temperatures <4ºC since the mid- to late 1980s. However, by 2001 temperatures decreased to fall near to or slightly below their long-term means. The deep basins in 4W such as Emerald have generally been warm except during 1998 when an intrusion of cold slope water from offshore penetrated the Scotian Gulf and flushed the Basin. Surface temperatures throughout much of the Scotian Shelf in 1999 to 2000 were also warm and set or were near their long-term maximum records. In 2001, the surface temperatures declined but in the northeastern half of the Scotian Shelf remained above the long-term mean by upwards of 1ºC.

Stock assessment

Estimation of parameters

The traditional age-based population analysis was performed for this stock using ACON software to fit the model, which is described as:

Parameters:

Terminal N estimates -- $N_{i,\ 2000}$, i = ages 1 to 10

Calibration coefficients – $q_{1,i}$ i = ages 1 to 6 for the July RV survey

-- $q_{2,i}$ i = ages 2 to 8 for the September sentinel survey

Structure imposed:

Error in catch assumed negligible
Partial recruitment fixed for ages 11 and 12 in year 2000
No intercept was fitted
M = 0.20 for all ages 1970 to 1984; 0.25 for all ages in 1985; 0.30 for all ages in 1986 and 0.35 for all ages from 1987 to 2000

Input:

$C_{i,t}$ i = 1 to 12; t = 1970 to 2000 Catch at age
$J_{i,t}$, i = 1 to 6; t = 1970 to 2000 July RV index
$S_{i,t}$, i = 2 to 8; t = 1995 to 2000 September sentinel survey

Objective function:

Minimize: $\Sigma\Sigma \{\ln J_{i,t} - \ln q_{1,i} N_{i,t}\}^2 + \Sigma\Sigma \{\ln Si_{,t} - \ln q_{2,i} Ni_{,t}\}^2$

where $N_{i,t}$ is population numbers at age i and year t

Summary:

Number of observations: 228 (186 from July RV and 42 from

Sentinel)
Number of parameters: 23, N's estimated by NLLS, q's algebraically

The main differences between this model formulation and the one used in the previous assessment is the addition of a second tuning index, i.e. the September sentinel survey catch rate at age and the natural mortality assumption. We have now introduced a ramp in natural mortality where M=0.20 from 1970 to 1984, climbs to 0.25 in 1985 and 0.30 in 1986, and remains at 0.35 from 1987 to 2000. The justification for this natural mortality pattern is based on Z's from the survey during the period of fishery closure (Figure 30) and the changes in growth and maturity that broadly characterize the stock as one that exhibited larger size-at-age and later maturity during the 1970s/mid-1980s to one of low size-at-age and early maturity thereafter. Body size and natural mortality are generally considered to co-vary in an inverse manner.

Results

The diagnostics from ADAPT are given in Table 16. The coefficients of variation on the population estimates in the terminal year generally range between 20 and 30% with the exception of ages 1 and 2. High CV's associated with these ages stem from the fact that there are few observations available for estimation of these parameters. The CV's associated with the catchability coefficients or q's for the July RV are generally close to 15% which is quite reasonable. The CV's for the q's from the sentinel survey are generally higher (around 36%) and this due to the short time series. Also shown are the bootstrap bias correction results. It should be noted that other model runs were performed with natural mortality assumed to be constant at 0.35 and 0.2. These runs resulted in poorer model fits, having residual mean square errors of 0.7 and 0.9 respectively. The mean square error for the ramp M model was 0.64 (Table 16). Population trajectories were similar for all fitted models.

Table 17 shows the residual pattern from the model for six ages from the July RV and seven ages from the sentinel survey. No strong time trends were evident in the residuals and in most years the average residual variation was less than 0.2. A graphic display of this data reveals some year effects, e.g. 1988 when a band of positive residuals was evident across all ages. Some cohort effects are also evident (diagonal banding pattern) but overall the residual pattern is well-balanced (Figure 34). The residual pattern from the two surveys shows opposite patterns. Another way to judge the fit of the model to the data is to compare the q-corrected survey estimates of abundance to the population numbers from the VPA. When compared to the July RV q-corrected estimates, a close fit was evident between the model and the data with the exception of a few years during the late 1980s/early 1990s. The model did not fit the sentinel survey abundance estimates as well, in part due to the shortness of the time series (Figure 34).

Past assessments of this stock have shown a strong retrospective pattern, where exploitation is under-estimated and population abundance is over-estimated in the current year, relative to when additional data are available in subsequent years. The retrospective pattern in this assessment is reasonably good and represents a significant improvement over past assessments (Figure 35).

The SPA results associated with population number and biomass are shown in Tables 18 and 19. These data represent beginning of the year population estimates corrected for estimated bias. Bias correction was generally less than 3% with the exception of recent years at ages 1 and 2 in 2000 and age 1 in 1999. Recruitment has been improving since the closure of the fishery. The 1995 year-class is above the 1970-1998 average. The 1998 year-class, which takes into account the age 1 estimate in 1999 and age 2 estimate in 2000 from the July RV, appears to be exceptional, exceeding the largest previous year-class in 1981 by about three-fold (Figure 36). The age 1 estimate in 2000 is not reliable given that only one observation is available for estimation. Recruitment estimates were compared to the estimates from the previous assessment conducted in 1997 and to the July RV survey estimates at age 1. Close agreement was evident in both comparisons (Figure 37).

The biomass of haddock has been slowly increasing since closure of the fishery (Table 19). The biomass of haddock ages 5 and older is close to the 1970-2000 average of 17,000 t. A comparison of the 5+ biomass pattern to the 5+ weight per tow from the July RV revealed a closed correspondence (Figure 38).

We attempted to approximate the biomass of 42 cm + haddock from 1970 to present (i.e. the fishable component). This was done in two ways: by making reference to the length at age data from 1970 to 2000 (Table 15) and examining growth models fit to length at age data from the July RV. During 1994 to 2000, the length of a 43 cm haddock corresponded to age 7. During 1970 to 1976, the length of a 43 cm haddock corresponded to age 4 (Figure 39). Because of declining size at age, the age groups contributing to the fishable portion of the population has changed and included ages 4 and older during 1970-1983, ages 5 or 6 and older from 1984-1992, and ages 7 and older from 1993 to present (Table 20). The biomass of 42 cm+ haddock averaged 17,000 mt during the 1970 to 2000 period. Since closure of the fishery, little change has occurred in the biomass of this size component. On the other hand, 3+ biomass has steadily incrased since the closure of the fishery but currently remains below the 1970-2000 average of 30,000 t (Figure 40).

Fishing mortality at age is shown in Table 21. The patterns in F coincide with the known exploitation history of the stock. For example, high F’s were evident in the early 1970s when the fishery was unregulated and F rose dramatically when fixed gear effort blossomed during their exemption for the closed area (Figure 41). The total mortality patterns from the SPA and July RV show a reasonably good correspondence (Figure 42).

Exploitation rate has generally been in excess of the $F_{0.1}$ target of 20% and frequently exceeded twice this value. Since closure of the fishery, exploitation rates have been very low (Figure 43).

Long-term trends in SSB and recruitment

Spawning stock biomass and recruitment data are available from previous assessments of the Div. 4TVW haddock stock back to 1948. This information is contained in Mahon et al. (1985) and Zwanenburg et al. (1986). We have taken our recent VPA biomass estimates and adjusted them based on the proportion mature at age (Table 22). The recent SSB time series was then combined with the historical data series to produce a long-term view of SSB and recruitment (Figure 44). SSB was generally is excess of 60,000 t up to the early 1960s and started a steady decline to a minimum in the early 1970s. SSB gradually rose to about 60,000 t in the mid-1980s but declined rapidly thereafter. Annual recruitment frequently exceeds 60 million from 1948 to 1965 but did so only a few times since. The 1999 estimate at age 1 (1998 year-class) is the highest ever observed.

Long-term trends in temperature

Temperature anomalies at 100 m (relative to the 1961-1990 mean) are shown for the Misaine Bank region. Temperature variability at this depth has been shown to representative of the thermal conditions in the subsurface waters of the northeastern Scotian Shelf (Div. 4Vs) and eastern section of Div. 4W. Anomalies were relatively high in the 1950s, declined into the 1960s, varied during the 1970s but rose to a peak by the early 1980s. At this time a rapid cooling occurred that reached a minimum in the early 1990s after which temperatures increased gradually to above average values (Figure 45). These temperature anomaly trends have generally paralleled changes in size at age with the exception of recent times, when size at age has either continued to decline or remained low while temperatures have risen.

Traffic Light Analysis

The Traffic Light table summarizes the indicators of stock status shown above (Table 23, Figure 46). This table shows the annual values of each indicator as a combination of three lights depending on whether they are among the best values for that indicator, among the worst or in between. For indicators such as stock biomass and recruitment, high values are good and have a green light and low values are bad and have a red light. However, for indicators such as mortality, high values are bad and are assigned a red light whereas low values are good and receive a green light. Intermediate values (midpoint between red and green) are yellow. A value between red and yellow is expressed as a pie with increasing amounts of red in the pie as the value approaches the red threshold or cut point. Similarly, a value between the midpoint and the green cut point becomes increasingly green in the pie as the green cut point is approached. Empty cells in the table indicate no observation for that year. Uncertainties about the appropriate cut point resulted in a broad yellow zone.

In the traffic light analysis, indicators are summarised into groups that emphasise specific aspects of the resource. These groupings are called characteristics. The following outlook is cast in terms of these characteristics and each is shown in bold.

Indicators of abundance revealed that the number per tow (1-29 cm) from the July RV rose dramatically in 1999 and 2000, reflecting the strength of recent incoming year-classes. Intermediate sized haddock (26-41 cm) have been steadily increasing and the highest value in the series occurred in 2001. The summer RV number per tow of haddock 42 cm +, the historical fishable size limit, has remained very low throughout the 1990s, and the 2001 estimate is among the lowest observed. Spawning stock biomass (based on the SPA) has been steadily increasing since closure of the fishery and in 2000 exceeded the 1970-2000 average. Recent survey estimates of SSB show a similar increasing trend, although the 2001 estimate was below the 1979-2001 average. The sentinel survey catch rate, which selects for larger haddock, exhibited a declining trend since the initiation of the survey in 1995. Area occupied of 30 cm + haddock is largely restricted to closed area. Annual estimates of the percentage of haddock inside the closed area, derived from the sentinel survey, range from 53 to 86%. Local density of 30 cm+ haddock has not shown a trend since the mid-1980s.

Some of the production indicators have been increasing since closure of the fishery. SPA estimates of recruitment at age 1 show that the 1995 year-class is above the 1970-1998 average while the 1998 year-class appears very strong. Survey estimates at age 1 suggest that the 1999 year-class is also strong. Area occupied of 1-29 cm haddock has been increasing since 1995, and the 1999 to 2001 estimates are comparable to the early 1980s estimates when strong year-classes occurred. Local density of 1-29 cm haddock has been increasing since 1992. Condition factors have generally been below average since the early 1990s. Growth, based on size at age 7, steadily declined throughout the late 1980s/1990s, which was preceded by a more rapid decline during the mid-1980s.

Since closure of the fishery, fishing mortality rates, expressed as exploitation, have been low (less than 2% since 1995). Prior to the collapse of the fishery, exploitation rates were more than twice the $F_{0.1}$ level of 20%.

Temperature anomalies from the Misaine bank region were positive during 1999 to 2001 for the first time since 1985. They provide an indicator of the environment of the eastern Scotian Shelf and have coincided with changes in the productivity of haddock and other stocks in the region. Declining productivity (e.g. poor growth and high natural mortality) has been evident in both haddock and cod in the region since the initiation of the cooling trend in the mid-1980s. Recent increases in bottom temperature conditions may change this trend in productivity.

Currently, Div. 4VW haddock is an early maturing, geographically constricted stock plagued by poor growth (both under-weight and under-length) and high natural mortality that has recently produced good to excellent recruitment. The next few years will be pivotal to this stock given recent strong recruitment and improvement in environmental conditions. If growth and survival improve, this could lead to a rapid increase in biomass and recovery of historical productivity. If, however, poor growth, early maturity and high natural mortality persist, there will be a slow or negligible increase in biomass and low stock productivity dominated by small fish. At this time, it is uncertain which production scenario the stock will follow. In either case, minimization of removals continues to be appropriate in the short term.

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