An evaluation of the Emerald/Western Bank juvenile haddock closed area

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A juvenile haddock (Melanogrammus aeglefinus) closed area was established on the offshore banks (Emerald and Western) of the central Scotian Shelf (NAFO Div. 4W) in 1987. The management objective associated with this measure was to protect incoming recruits and thereby allow the stock to rebuild. Our evaluation of the effectiveness of the closed area revealed that the management objective was not fully met. The expected trend of declining juvenile mortality after, and high mortality preceding its imposition, was not readily apparent. The lack of response may have been due to several factors: (i) the proportion of juveniles within the closed area steadily declined and a majority of year classes during the post-closure period remained unprotected; (ii) the closed area remained open to fishing by fixed gear whose catches inside the closed area and surrounding areas steadily increased; and (iii) the resident haddock stock deteriorated in terms of growth and condition due to a combination of historical over-exploitation and large-scale environmental changes. The closed area does appear to have had some benefit to other groundfish species in terms of increased abundance, notably American plaice (Hippoglossoides americanus) and winter flounder (Pseudopleuronectes americanus).

Key words: recruitment; juvenile survivorship; haddock; closed area; groundfish.

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Introduction

A traditional practice in the management of haddock (Melanogrammus aeglefinus) fisheries in the Northwest Atlantic has been the use of area closures (Halliday, 1988; Fanning et al., 1987). At least two types of closures have been implemented: temporary (seasonal) closures designed to protect spawning fish, and permanent (year-round) closures to protect juvenile fish. The evaluation of the effectiveness of such closures has an important bearing on the emerging use of Marine Protected Areas (MPAs) as an alternative approach for managing fisheries. While spawning area closures should contribute to a reduction in exploitation rates and possibly enhance spawning success through elimination of disruptions during mating, neither of these expectations have been quantitatively evaluated. On the other hand, preliminary evaluations of the year-round protection of juvenile haddock suggested some positive benefits to the resident stock (Zwanenburg, 1992).

Despite the imposition of area closures, haddock stocks in the Northwest Atlantic are in a perilous state. Haddock on Georges Bank have recently collapsed (Brown, 1998), the stock on Browns Bank is severely depressed (Hurley et al., 1997), and the haddock fishery on Western Bank is under a fishing moratorium (Frank et al., 1997). Is it possible that area closures have a limited role in stock conservation? Seasonal area closures offer only temporary relief from exploitation with the fishing fleets compensating by redistributing their effort to other times of the year and in other geographic areas (Fogarty and Murawski, 1998). Permanent area closures would appear to hold greater promise as effective management tools, provided that such areas protect a significant proportion of the stock on a year-round basis (Walters and Maguire, 1996).
The establishment in 1987 of a year-round juvenile haddock closed area on the central Scotian Shelf (Zwanenburg and Fanning, 1988) represents a unique opportunity to evaluate the effectiveness of a permanent area closure on haddock in Canadian waters. The closed area on the central Scotian Shelf is relatively large (~4000 nm²), encompassing two major offshore banks (Fig. 1). The closed area represents about 13% of the total area of the haddock management unit in NAFO Div. 4VW. However, haddock are mainly distributed in Div 4W and the closed area represents about 25% of this subdivision. Unlike the establishment of many closed areas and MPAs, the definition of the closed area boundaries was based on a quantitative analysis of historical data (Fanning et al., 1987). Because the area was associated with a major haddock fishery (Frank et al., 1997), spatial and temporal fishery and scientific data exist that should make it possible to determine the impact of the closed area on the stock and its distribution over the surrounding geographical areas. Furthermore, it has been in existence for over 10 years. Collectively, these features should permit an analysis of the effectiveness of the permanent area closure established for juvenile haddock on the central Scotian Shelf in NAFO Div. 4VW.

Since the same fish may occur inside and outside of the closed area boundaries, and the spatial distribution of haddock appears to be centred inside the closed area, we would expect the measure to have an effect at the population level. Therefore, we analyzed population level changes in recruitment and juvenile survival in the Div. 4VW management unit. Data were insufficient to examine other aspects of the environment such as the benthos or food supply for haddock. Several groundfish species have also been examined for changes in abundance inside the closed area and in relation to adjacent areas, and here we present a brief synopsis of the results.

The fishery and the closed area

The haddock fishery has generally been concentrated on the offshore banks of Div. 4W during late winter and early spring. It is during this time that haddock move up onto the banks (mainly Emerald and Western banks; Fig. 1) to spawn in dense aggregations. These spawning aggregations formed the target of intensive fisheries by

Figure 1. Geography of the Scotian Shelf and associated NAFO statistical divisions in Subareas 4 and 5, with the location of the closed area and topographical names referred to in the text.
both domestic and foreign trawlers and remained the dominant fishing grounds of the domestic fleet after Canada extended jurisdiction to 200 miles in 1977 (Fig. 2).

A succession of strong year classes in the early 1980s resulted in a prevalence of small fish during the mid-1980s. Reports of discarding increased (Angel et al., 1994) and reported landings were less than the Total Allowable Catches (TACs) by a substantial amount (e.g. in 1983 and 1984 there was a 40% and 50% shortfall, respectively). These shortfalls were attributed to the presence of numerous small, unmarketable haddock subjected to appreciable but unknown quantities of discarding at sea (Mahon et al., 1985). In 1984, the management agency attempted to prevent the capture of these abundant year classes by closing Div. 4W to trawlers from May to December. This management measurement diverted landings away from Div. 4W to Div. 4Vs (Zwanenburg et al., 1986) but was not completely effective at reducing the discarding problem.

At a Scotia-Fundy Groundfish Advisory Committee meeting in November 1986, industry representatives unanimously recommended closing the Div. 4W haddock nursery areas to all groundfish fishing activity for 1987 with the objective to protect incoming recruits and thereby allow the stock to rebuild. The areas identified for closure were Western and Emerald banks, which showed persistent and relatively large aggregations of young haddock in annual scientific research vessel surveys. This was also one of two areas within Div. 4W where discarding of small haddock was concentrated, the other being the Gully area (Fanning et al., 1987). It was later decided that fixed gear fisheries could fish inside the closed area (subject to all other regulations in effect) because these gears were believed to catch relatively older fish than mobile gear. The year-round nursery ground closure imposed in 1987 has remained in effect since and in 1993 the area was closed to all fishing (including fixed gear).

Since 1994, the cod and haddock fishery in Div. 4W has been under a moratorium and there has been no directed haddock fishing, even outside of the closed area. For those fisheries directed at pollock, redfish, white hake, cusk, Atlantic halibut and flatfish in Div. 4W, strict haddock by-catch limits exist (Frank et al., 1997). This has generated haddock catches amounting to less than 200 t per year (Fig. 3). No similar fishing restrictions have been in place in the adjacent Div. 4X management unit.

Preliminary evaluations of the closed area on the haddock resource (Zwanenburg, 1992) suggested: (i) the 1987 and 1988 year classes were benefiting from the
effects of the closed area because of higher survey catch rates inside the closed area compared to contiguous areas and; (ii) the closed area appears to encompass the centre of distribution of both juvenile and adult had-dock and therefore could be considered an ef-fective management initiative.

It is important to address the question: how closed has the closed area been since its imposition in 1987? Since fixed gear fisheries were permitted to fish while mobile gear fishing was banned, this has to be taken into account. Also, invertebrate fisheries, particular scallop fishing, have been active inside the area and therefore by-catch and effort distributions are of interest.

Longline landings of haddock from Div. 4W increased from 434 mt in 1987 to a peak of 3382 t in 1992 (Fig. 3). This eightfold increase in landings raised concerns about protection of young haddock in the closed area (Zwanenburg, 1992). As a result, all groundfish fishing ceased inside the closed area in 1993 and outside the closed area a major reduction in effort occurred due to the moratorium on cod and haddock fishing in Div. 4VW. Fixed gear landings in 1993 in Div. 4W were only 20% of the 1992 value and have remained low since.

Scallop fishing in Div. 4W has generally been unrestricted in terms of effort (quotas were first implemented in 1994) and location. Haddock by-catch in the scallop fishery has generally been below 0.3 t during 1989 to 1997 with the exception of 2 t in 1989. Scallop fishing locations have been confined to the shallow, sandy bottom regions of Western Bank with no fishing taking place on Emerald Bank or the western half of Western Bank (Frank and Simon, 1998). Therefore, with respect to the closed area, only the easternmost areas have been subjected to scallop fishing.

Collectively, the available information indicates that the closed area has been only partially closed to fishing since 1987 and has experienced a mixture of fishing activity, albeit at a lower level than surrounding areas that were not under similar restrictions.

Methods

We tested the hypothesis that haddock recruitment and juvenile survival increased after the imposition of the closed area using the before-after-control-impact-pairs (BACIP) procedure. BACIP is a statistical approach developed by Stewart-Oaten et al. (1986) and used to test for environmental effects by controlling for natural variability. Typically, a time series of a population parameter (e.g. abundance) is taken simultaneously in a “control” and an “impact” area, “before” and “after” an intervention in the impact area. The null hypothesis is that the mean difference between Control and Impact before the intervention is not different from the mean difference after the intervention. The hypothesis is tested using a t-test: Control and Impact aras are the test populations, the temporally replicated difference between Control and Impact are the samples (Stewart-Oaten et al., 1986, 1992).

The analogue of an intervention in our study is the imposition of the closed area in 1987. We chose the neighbouring Div. 4X haddock (Fig. 1) stock as a suitable Control based on the fact that this stock exhibits similar population dynamics and because there have never been any permanent area closures to protect juvenile haddock in this management unit. The Div. 4VW haddock stock represented the Impact. Ideally, we would use two or more controls (Underwood, 1992) but the Div. 4X and 4VW haddock populations are the only

Figure 3. Canadian landings of haddock by all gear types combined (a) and by fixed gear (b) in Div. 4VW.
haddock populations on the Scotian Shelf and are ecologically similar. Each year of sampling from 1970–1994 served as a temporal replicate of Before/After, Control (Div. 4X) and Impact (Div. 4VW) treatments. The difference of (Control – Impact) Before and After the closure was compared using a t-test.

The approach taken was to compare trends in recruitment, survival, and distribution of juveniles in Div. 4VW and Div. 4X. The data used were from the July research vessel survey (RV) in the two areas. Recruitment (population number) at age 2 was derived from sequential population analysis and Survival was estimated as (Recruitment at Age 2 at time t/spawning stock biomass of ages 3+(Div. 4X) or 5+(Div. 4VW) at time t-2). Age 2 was chosen to represent juveniles as age 1 is sampled less accurately and part of the age 3 class may have matured.

The use of a two-sample t-test assumes that effects are additive and independent. Additivity refers to the notion that the difference between Control and Impact is similar or additive at each sampling date. In our case, we would expect the differences in recruitment and survival to be constant with respect to the average. We tested for additivity by regressing the differences on the average of the population parameters. If there were no relationship we would expect a slope of zero (Stewart-Oaten et al., 1986; Smith et al., 1993). Independence of observations was examined by testing for significant serial correlation among differences.

Results

Recruitment in Div. 4X and 4VW (Fig. 4a) was significantly correlated (r=0.53, p=0.006, n=25). The difference between Control and Impact recruitment (DR) was related to the average recruitment, violating the assumption of additivity. Although a log transformation of DR achieved additivity, the DR observations were positively serially correlated. Because of the severity of the latter violation, we resorted to the non-parametric analogue of the t-test. The rank sums DR were not significantly different before and after the 1987 imposition of the closed area (Mann-Whitney: U=59; p=0.375). Therefore, the closed area had no effect on recruitment at age 2 in Div. 4VW.

Survival rates (ln R/SSB) were also significantly correlated (r=0.612, p=0.001, n=25; Fig. 4b). The difference between Control and Impact (untransformed) survival (DS) was negatively related to average survival. Logarithmic transformation did not achieve additivity. DS was positively serially correlated and so, as for recruitment, we performed a non-parametric t-test. The rank sums DS were significantly different before and after 1987 (Mann-Whitney: U=15, p=0.001, n=25). However, the pattern would indicate that the 1987 closure resulted in a decrease in juvenile haddock survival in Div. 4VW (Fig. 5).

Thus, the closure had no effect on the average difference between Div. 4X and Div. 4VW recruitment, but average juvenile survival rate in Div. 4VW decreased since the closure. This result was unexpected and we attempted to determine why it occurred. Possible explanations were sought by examining: (i) the size or placement of closed area; (ii) changes in the patterns of the haddock fishery; (iii) large-scale environmental changes; and (iv) biological characteristics of the resident haddock spawning stock.

Size and/or placement of the closed area

Because the intent of the closure was to protect juveniles in their nursery habitat, we would expect that the majority of a year class would occur within the closed area boundaries. Therefore, we compared the proportion of juveniles (age 1 and 2) inside and outside the closed area for each year-class.
The proportion of a year class inside the closed area boundaries exhibited a striking decline from 1985 (60%) to 1993 (<15%; Fig. 6). A better appreciation of the temporal dynamics of the distribution patterns of haddock can be gleaned from Figure 7 where the age-specific catch per tow of juvenile (ages 1–2) haddock is presented before and after the establishment of the closed area. The most consistent features of these geographical data are: (i) high concentrations of juveniles in those areas associated with the closed area (Emerald/Western banks) during the pre and post-closure period; and (ii) appearance of a second centre of abundance or possibly an extension of the primary concentration on Emerald/Western banks during the post-closure period to Sable Island bank. During the post-closure period the eastern boundary of the closed area roughly divided the secondary centre of distribution.

Fixed-gear landings

The closure excluded all mobile gear, but the fixed-gear fleet was declared exempt. Landings and effort increased substantially during the post-closure period in the latter. Catches inside the closed area and surrounding areas in Div. 4W steadily increased from about 1987 to 1992 (Fig. 3).

We examined the possibility that the post-closure, age composition of the fixed-gear catch may have changed, resulting in a relative increase in the catch of juveniles by comparing the relative proportion age-2 fish caught before and after the closure. Landings by age were available for some years during both the pre and post-closure period. For each period, we expressed the total landings by age as a percentage of the total population numbers by age as calculated from sequential population analysis (Frank et al., 1997). Fixed gear landings at age 2 during the pre-closure period were 0.003% and increased to 0.5% during the post-closure period. Fixed gear landings at age 3 were 0.07% pre-closure, which increased to 0.8% post-closure. Although the increase is substantial, the mortality rate is low and would not be expected to suppress an increase in survival as a result of closure.

Large-scale environmental changes

The period since the mid-1980s has been one of significant cooling on the eastern Scotian Shelf. Throughout most of the water column, temperatures remained generally colder than normal and, in 1993, an historical low occurred in the 50-year observational record. The cause of this large-scale cooling appears to be related to downstream advection, as both the Gulf of St Lawrence and southern Newfoundland waters experienced similar trends over this same period (Drinkwater, 1996). The preferred temperature range for haddock on the Scotian Shelf is 4–8°C; temperatures outside this range may be considered detrimental to growth and survival (Smith and Page, 1994). Interestingly, there has been an approximate doubling of the proportion of the bottom area in Div. 4VW with water temperatures less than 3°C (Fig. 8).

Coincident with the changes in the physical environment were dramatic increases in species such as capelin (Frank et al., 1996), shrimp and crab (Zwanenburg et al., 2000). In addition, eastern Scotian Shelf cod collapsed in the early 1990s and a grey seal population

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Figure 7. (a) Pre and (b) post-closure spatial distribution of juvenile haddock (ages 1 and 2 combined) from the July research vessel surveys.
has continued to grow at an exponential rate. Collectively, these changes suggest that a fundamental change in the ecosystem has occurred (Sinclair et al., 1997).

Biological characteristics of the haddock stock

Spawning stock biomass has been below average since 1992 and has declined monotonically since 1986 (Fig. 9a). Although there is no clear relationship with recruitment, low spawning stock biomass may hinder the probability of a good recruitment year. It is noteworthy that the low population during the early 1970s experienced a rapid recovery, in contrast to the current situation.

Condition, the relative weight of the fish at a given length, may be used as an index of fish health. Heavier fish appear to have a greater reproductive potential than do lighter fish. Predicted weight at 45 cm was used as a measure of condition of mature fish. The condition index of adult haddock has shown a 10 to 15% decline since 1970 (Fig. 9b). The trend in condition was correlated with survival \((r=0.42, \ p=0.04, \ n=25)\), suggesting that the condition of spawners has an effect on offspring survival. This result is consistent with other observations that maternal condition affects offspring viability (reviewed in Scott et al., 1999). Condition was not related to recruitment \((r=0.36, \ p=0.08, \ n=25)\) although the trend was in the expected direction.

Once a fish matures, its growth rate slows. Female length-at-maturity has declined from 1979 to 1995 (Fig. 9c). Maturing at such a small size could also be contributing to the reduced growth and reproductive potential of haddock. The mean length-at-age 3 and older has also systematically declined since the mid-1970s. The temporal trend was statistically significant for ages 3–11 (example for age 7 is shown in Fig. 9c). Length-at-age and near-bottom water temperatures were highly correlated \((r=0.82, \ p<0.01, \ n=25)\).

In summary, changes in life history parameters, and declining condition may have resulted in lower egg production and poorer egg viability, resulting in lower offspring survival. These changes have likely hindered
the current and recent past growth potential of the resident haddock stock.

Displacement of fishing effort

An important question not addressed thus far is what happened to the fishing effort displaced from the closed area? We have already shown that the fishing effort of the exempt fleet inside the closed area increased dramatically which eventually necessitated their removal from the closed area. The post-closure geographic distribution of haddock catch rates by large offshore trawlers was concentrated in two areas: (i) around the perimeter of the closed area and extending onto Sable Island bank; and (ii) Banquereau bank (southern half of Div. 4V) and the Gully region (Fig. 10). Overall, catch rates were dramatically lower between the pre and post-closure period (compare Fig. 2 and Fig. 10).

Major changes also occurred in the species that were targeted by the offshore trawlers in Div. 4VW and our evaluation here is restricted to four major species (haddock, cod, pollock and redfish; Fig. 11). Directed effort for haddock (expressed as the number of observed trips relative to the total observed) ranged from 10–38% during the pre-closure period, dropped to below 7% during the post-closure/pre-fishing moratorium period (1987–1993) and was generally less than 1% thereafter.

For cod, the most dramatic decline occurred between the pre and post-fishing moratorium period (22–62% vs. 1–5%). Relative directed effort for pollock varied between 9 and 40% throughout the entire time series. After an extended period of stable directed effort, redfish effort increased dramatically after the imposition of the
fishing moratorium in 1994, reaching a peak of 80% in 1995.

Discussion

The management objective associated with the establishment of the closed area in 1987 on the eastern Scotian Shelf was to protect juvenile haddock and thereby allow the stock to rebuild. Unfortunately, the objective has not been fully met. The expected trend of declining juvenile mortality from a high level coincident with its imposition was not readily apparent. The lack of response could have been due to several factors: (1) the proportion of juveniles within the closed area steadily declined and a majority of year classes during the post-closure period remained unprotected; (2) the closed area remained open to fishing by fixed gear; and (3) the resident haddock stock deteriorated in terms of growth and condition due to combination of over-exploitation and large-scale environmental changes.

The information presented might suggest that there has been no increase in post-closure recruitment or survival because of a change in spatial distribution. However, a significant portion of the juvenile population was still protected within the closed area during the same period as fishing effort was decreasing (Frank and Simon, 1998). Therefore we should have observed increased survival of juveniles. The fixed-gear landings of juveniles increased during the post-closure period but did not represent a significant proportion of the recruitment. We propose that the major reason that the closed area has had no impact on juvenile recruitment and survival is because the reproductive potential of the Div. 4VW haddock stock became progressively lower. Declining mean-length at age, condition and length/age-at-maturity coupled with low SSB all contribute to a decrease in reproductive potential.

Since the early to mid 1980s, the Northwest Atlantic has undergone a significant cooling trend northeast of Emerald Basin (Drinkwater and Mountain, 1997). The collapses of several major Northwest Atlantic cod stocks in the early 1990s precipitated a vigorous debate as to whether these were due to changes in the temperature regime that caused decreased growth, or to over-exploitation (e.g. Hutchings and Myers, 1994). More recently, Dutil et al. (1999) have argued that the cod stock in the northern Gulf of St Lawrence was more vulnerable to fishing pressure when environmental conditions were poor. That is, fishing can exacerbate a decline when conditions are unfavourable to growth and production. Environmental conditions for the Div. 4VW haddock stock have been similarly unfavourable to growth (Drinkwater and Mountain, 1997) during or just after a period of high fishing mortality (Frank et al., 1997). The decline in reproductive potential through size and condition would result in poor recruitment and productivity. This decline might be widespread in fished gadoid populations (e.g. Dutil et al., 1999) and may contribute to the lack of recovery of collapsed stocks in the Northwest Atlantic.

Empirical data were used to define the boundaries of the haddock closure in Div. 4W and were designed to reduced juvenile mortality. In practice, the closure was well designed but ineffective because of large-scale population changes. Processes that influence stock productivity on large spatial and temporal scales can obviously overwhelm any localized measures, such as closed areas, designed to conserve stocks. In the context of marine reserves, this situation is well recognized and has led to the conclusion that marine reserves are necessary but not sufficient for marine conservation (Allison et al., 1998). Our study demonstrates the need for an ongoing evaluation of the efficacy of management conservation measures.

A potential side benefit of the closed area is the protection of non-target species. The possibility that other fish species have experienced increases in abundance due to the imposition of the closed area was
addressed by examining abundance trends in the summer research vessel surveys among the most common groundfish species. Low abundance levels typified many of the species, suggesting that the closed area was not the preferred habitat of these species (Frank and Simon, 1998). However, both American plaice (Hippoglossoides platessoides) and winter flounder (Pseudopleuronectes americanus) were more abundant during the post-closure period inside the closed area relative to adjacent areas (Fig. 12). These species are poorly selected or unavailable to fixed gear directing for haddock and such species would have been protected from fishing inside the closed area for over a decade.

Populations are generally less resilient to perturbation and more prone to extinction when population size is small, due to deterministic and stochastic events. Marshall et al. (1998) modelled the reproductive potential of Northeast Arctic cod based on variable maternal condition. They showed how total egg production based on maternal condition varied with stock size and that total egg production can be near zero at low population sizes. Currently, the Div. 4TVW population is vulnerable because of its size, low condition and low reproductive potential. Maintaining the closed area after the moratorium is lifted could only enhance the recovery of the stock. In fact, the eastern boundary could be extended easterly to encompass the current geographical distribution of juvenile haddock to afford additional protection.

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