181872

Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens
Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians

# Biological, Environmental and Fishery Science Considerations for the Management of Atlantic Cod in 4T and 4Vn

G. A. Chouinard, A. F. Sinclair, S.E. Campana[1], T.C. Lambert[1] and J.M. Hanson

Science Branch, Gulf Region
Department of Fisheries and Oceans
Gulf Fisheries Centre
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

[1]Marine Fish Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

March 1995

**Canadian Industry Report of Fisheries and Aquatic Sciences No. 227**

Pêches et Océans    Fisheries and Oceans

Canada

## Rapport canadien à l'industrie sur les sciences halieutiques et aquatiques

Les rapports à l'industrie contiennent les résultats des activités de recherche et de développement qui peuvent être utiles à l'industrie pour des applications immédiates ou futures. Ils sont surtout destinés aux membres des secteurs primaire et secondaire de l'industrie des pêches et de la mer. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports à l'industrie peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports à l'industrie sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 91 de cette série ont été publiés à titre de rapports sur les travaux de la Direction du développement industriel, de rapports techniques de la Direction du développement industriel, et de rapports techniques de la Direction des services aux pêcheurs. Les numéros 92 à 110 sont parus à titre de rapports à l'industrie du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 111.

Les rapports à l'industrie sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

## Canadian Industry Report of Fisheries and Aquatic Sciences

Industry reports contain the results of research and development useful to industry for either immediate or future application. They are directed primarily toward individuals in the primary and secondary sectors of the fishing and marine industries. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Industry reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–91 in this series were issued as Project Reports of the Industrial Development Branch, Technical Reports of the Industrial Development Branch, and Technical Reports of the Fisherman's Service Branch. Numbers 92–110 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Industry Reports. The current series name was changed with report number 111.

Industry reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Canadian Industry Report of
Fisheries and Aquatic Sciences 227

March 1995

# Biological, Environmental and Fishery Science Considerations for the Management of Atlantic Cod in 4T and 4Vn

by

G. A. Chouinard, A. F. Sinclair, S.E. Campana[1], T.C. Lambert[1] and J.M. Hanson

Department of Fisheries and Oceans
Science Branch, Gulf Region
Gulf Fisheries Centre
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

[1]Department of Fisheries and Oceans, Marine Fish Division, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2

Cat. No. Fs 97-14/227E ISSN 0706-3694

Correct citation for this publication:

G. A. Chouinard, A. F. Sinclair, S.E. Campana, T.C. Lambert and J.M. Hanson. 1995. Biological, Environmental and Fishery Science Considerations for the Management of Atlantic Cod in 4T and 4Vn. Can. Ind. Rep. Fish. Aquat. Sci. 227: vii + 45 p.

# Table of Contents

## List of Figures

## List of Tables

**Abstract**

G. A. Chouinard, A. F. Sinclair, S.E. Campana, T.C. Lambert and J.M. Hanson. 1995. Biological, Environmental and Fishery Science Considerations for the Management of Atlantic Cod in 4T and 4Vn. Can. Ind. Rep. Fish. Aquat. Sci. 227: vii + 45 p.

A forum of industry representatives on the management of the fisheries for cod in the southern Gulf of St. Lawrence (NAFO Division 4T) and the Sydney Bight (Sub-division 4Vn) was held October 25 and 26, 1994 in Moncton, N.B. The main objective of the forum was to discuss future management for the cod stocks in the area. This paper was one of the reference documents prepared by scientists of the Department of Fisheries and Oceans. It provides background information on fishery science, biological and environmental issues related to the management of these cod stocks.

**Résumé**

G. A. Chouinard, A. F. Sinclair, S.E. Campana, T.C. Lambert et J.M. Hanson. 1995. Considérations Biologiques, Environnementales et Halieutiques pour la Gestion de la Morue dans le 4T et le 4Vn. Rapp. can. ind. sci. halieut. aquat No. 227: vii + 47 p.

Un atelier de représentants de l'industrie des pêches sur la gestion de la pêche à la morue dans le sud du Golfe du St. Laurent (Division 4T de l'OPANO) et de la Baie de Sydney (Sous-Division 4Vn) a été tenu les 25 et 26 octobre 1994 à Moncton, N.B.. L'objectif de cet atelier était de discuter de la gestion future des stocks de morue dans ces zones. Ce texte constitue un des documents de référence préparés par les scientifiques du Ministère des Pêches et Océans. Il contient une description des considérations biologiques, environnementales et halieutiques relatives à la gestion de ces stocks.

## 1. Introduction

The management of cod in the southern Gulf of St. Lawrence (NAFO 4T) and Sydney Bight (4Vn) was the focus of a forum held October 25 and 26, 1994. A similar forum in April 1994 was aimed at looking at management measures for 1994 whereas the session in October was directed at the long-term management of the fishery. The number of discussions on the cod fishery of 4T and 4Vn that have taken place over the years are an indication that the problems are complex. With the decline in the cod fishery, and the closure that has been in effect since September 1 1993, a biological problem (decline of a resource) has become a social and economic problem of large proportions. In the face of such a decline, fishery management measures that tend to reduce the probability of such events are desirable.

This background document attempts to present simply some basic biological and fisheries concepts which formed a contribution to the discussions. In addition, it presents some history of the early fisheries and the evolution that has taken place over the seven decades or so. The current state of the biological knowledge of the two cod stocks, which are the object of discussion is described including some of the basic biological parameters that should be taken into account when discussing management measures. In preparing the document, we have attempted to provide simple examples or analogies. We recognize that these are a simplification of reality, however; we hope that the examples used can help facilitate understanding.

First and foremost, it has to be clear that any animal population (whether it is exploited or not) is subject to natural fluctuations. An increase may be caused by favourable conditions of food and habitat which promotes survival; conversely, a decrease can be caused by disease, predators or poor environmental conditions. These changing conditions will likely continue. The challenge in fisheries management lies, therefore, in ensuring that the fishery is not the primary source of population fluctuations and that management strategies will be adopted that reduce the impact of natural fluctuations on the fisheries.

Past experience in the fisheries around the world indicates that fishing has been a major contributing factor in the decline of many fisheries. Everyone generally recognizes that there is a biological limit to the resources. However, somehow, it is often perceived that by using specific conservation measures the resources will grow indefinitely. Certainly, sound conservation measures will result in increases in the abundances of presently depressed stocks but clearly it has to be remembered that limits do exist.

In the context of elaborating management measures for a fishery of the future, it is useful to review some basic principles in fishery science and to keep in mind the biological characteristics of individual stock. A discussion of the objectives of a fishery can greatly facilitate the decision making process. This is a difficult step because the objectives desired by the various stakeholders are sometimes competing and not compatible. Nevertheless, establishing objectives for a fishery is an essential process. These objectives also have to recognize that the resource is the base of any exploitation and needs to be maintained for exploitation to continue.

# 2. Fisheries Science

## 2.1 Basic Concepts in Fisheries Science

### 2.1.1 Relationship between fishing mortality (F) and fishing effort, catch and biomass - Some Basic Definitions

This section outlines some basic concepts that underlie the current Canadian approach to groundfish fisheries management. The theoretical relationships between fishing mortality, fishing effort, stock biomass and catch are discussed; and the basis for the choice of the $F_{0.1}$ management strategy is described. A simple analogy is used to help illustrate some of the theory but this is in no way intended to trivialize a complex topic.

Relationship between fishing effort and fishing mortality

Think of a fishery as you would a lawn. Fish are harvested by towing a net; grass is harvested by pushing a mower. The analogy works best if we think of a scallop fishery where the animals don't move much and they are as catchable in all seasons. Some obvious exceptions to this analogy are discussed at the end.

Where one unit of fishing effort may be a set, one unit of lawn mowing effort may be one mown strip. If it takes 10 passes to mow the entire lawn, then one pass will cut 1/10th the lawn and 5 passes will cut half the lawn. It will always take 10 passes to cut the entire lawn. For a fish stock, one unit of effort by the same vessel and in the same season will take on average the same fraction of the fish stock as the next unit of effort. This fraction of the stock taken by one set will be very small. However, when added up over all the active vessels, the fraction may become relatively high. The rate of fishing mortality is equivalent to the fraction of the fish stock that is killed annually by fishing. A higher proportion of the stock will be caught if the total amount of fishing effort is high than if the total fishing effort is low. Fishing effort and fishing mortality vary in direct proportion.

Relationship Between Catch and Stock Size

Let's return to the lawn mowing analogy. The actual quantity of grass cut during one mowing will depend on its length. If the grass is long then you'll have to do a lot more raking than if the grass is short. However, it will always take 10 passes with the mower to cut the lawn, regardless of how long the grass is.

Similarly, the amount of fish caught with one unit of effort will depend on how big the stock is. If the fish are abundant, then more will be caught in an average set than if they are scarce. On the other hand, it will take more effort to catch the same tonnage when fish are scarce than when they are abundant.

Relationship between fishing mortality and catch

Note that one pass with the lawn mower will cut 1/10th the lawn regardless of how long the grass is. In fishing, one unit of effort will take the same proportion (or percentage) of the stock, regardless of the abundance of the stock. Thus, the amount of fish caught for one unit of effort will depend on how abundant the stock is.

Exceptions

Our lawn-mowing example is clearly a simplified analogy, used here only to help explain some of the basic theory of fishing. In reality, fish stocks are migratory and their catchability varies seasonally: many cod stocks become highly aggregated in winter and during spawning, thus, one unit of effort will take a higher proportion of the population than during summer when cod are feeding and more widely dispersed. Large vessels that use large gear will catch more fish per unit of effort than small vessels using small gear. Over time, the efficiency of fishing methods will increase due to improvements in technology. Under these conditions, the amount of fishing mortality caused by one unit of effort would increase over time. Fishermen can also direct their effort at different species. For example, the catch per unit effort of cod will be higher when fishing for cod than when fishing for plaice. It is important to consider these factors when making direct comparisons between the amount of effort expended by a fleet of fishing vessels and the resulting fishing mortality.

### 2.1.2 Objectives, targets and strategies

In broad terms, the objectives of Canadian fisheries management have focused on maintaining the fisheries resources at levels that will generate continuing economic and social benefits while creating conditions necessary for viable and stable commercial fisheries. What harvesting strategies would be compatible with these objectives?

It is well accepted that fish stocks will vary in abundance regardless of the amount of fishing they are subjected to. Many factors will influence the number of young fish that will enter the population each year: the initial number of eggs spawned and successfully fertilized, the extent to which the eggs and larvae drift with ocean currents, the amount of food available to them throughout the time of hatching until they reach a commercial size, how many are consumed by predators, and how many are caught commercially and possibly discarded because of their small size.

Constant Fishing Mortality vs Constant Catch

Given that fish stocks will vary naturally, it could be difficult to provide viability and stability to the industry by keeping catch constant. Bearing in mind the relationships between catch and biomass described above, keeping catch constant would mean fishing harder when stocks were declining and less when stocks were increasing. This would have inherent implications for the stability of the harvesting component. A "safe" constant catch would have to be set fairly low so as not to threaten spawning stock size in poor years.

A constant catch strategy would be like trying to get a fixed yield of grass from your lawn. If there was a good mixture of sun and rain, maybe only half the lawn would have to be mowed to get the target amount of grass. Not only would this be unsightly but it could also result in matting and lower grass production. On the other hand, unfavourable drying conditions could reduce grass growth and it could be difficult to get the target yield. Excessive cutting could result in burning the lawn and lasting damage.

Canada chose a constant fishing mortality management strategy when it extended fisheries jurisdiction over its 200 mile zone in 1977. Since fishing effort and fishing mortality are proportional, this was intended to provide stability to the industry by keeping fishing effort constant while recognizing that catches would vary. Catch would vary with biomass under this strategy, more fish would be landed when stock sizes were high than when stocks were low. The overall yields would be higher than if one safe constant catch level were chosen.

Choosing the target fishing mortality

Once a constant fishing mortality management strategy was chosen, the question became what is the target level. The choice was based on considerations of how quickly individual fish increased in weight as they got older, how quickly their numbers decreased with age, and the age at which the fish were caught. These relationships were summarized in an analytical model called yield-per-recruit.

### 2.1.3 Yield per Recruit

Let's break the yield-per-recruit model into its individual parts.

Growth: Fish tend to increase in weight for most of their lives. However, the rate of growth tends to slow down as the fish become sexually mature since energy is diverted into reproduction. Nonetheless, the weight of an individual fish generally increases throughout its lifetime.

Mortality: We use the term year-class to refer to the group of fish spawned in a given year. The number of fish in a year-class will decrease as the year-class gets older since each year a certain number die of natural causes and some are also caught in the fishery. The total weight of the year-class at any point in time, or its biomass, is the product of the number surviving times the average weight of the survivors.

At some age, the gain in total fish weight is balanced by the loss in numbers of fish due to mortality, and the biomass of a year-class reaches a maximum. This is illustrated in Figure 1 where a cod-like species is used as an example.

Fishing: Several things happen to the year-class as fishing increases (Figure 2). In this example we begin with the same number of age 1 fish. The age 3 fish are only lightly fished while the larger fish are fully available to the fishery. As the rate of fishing mortality (F) increases, there is little effect on the abundance of age 3 fish since they are not caught. However, the abundance of older fish decreases. In addition, the age at which the maximum biomass of the year-class will occur also decreases. If the fish begin to spawn at age 5, the biomass of spawners decreases substantially over a relatively small range of fishing mortality.

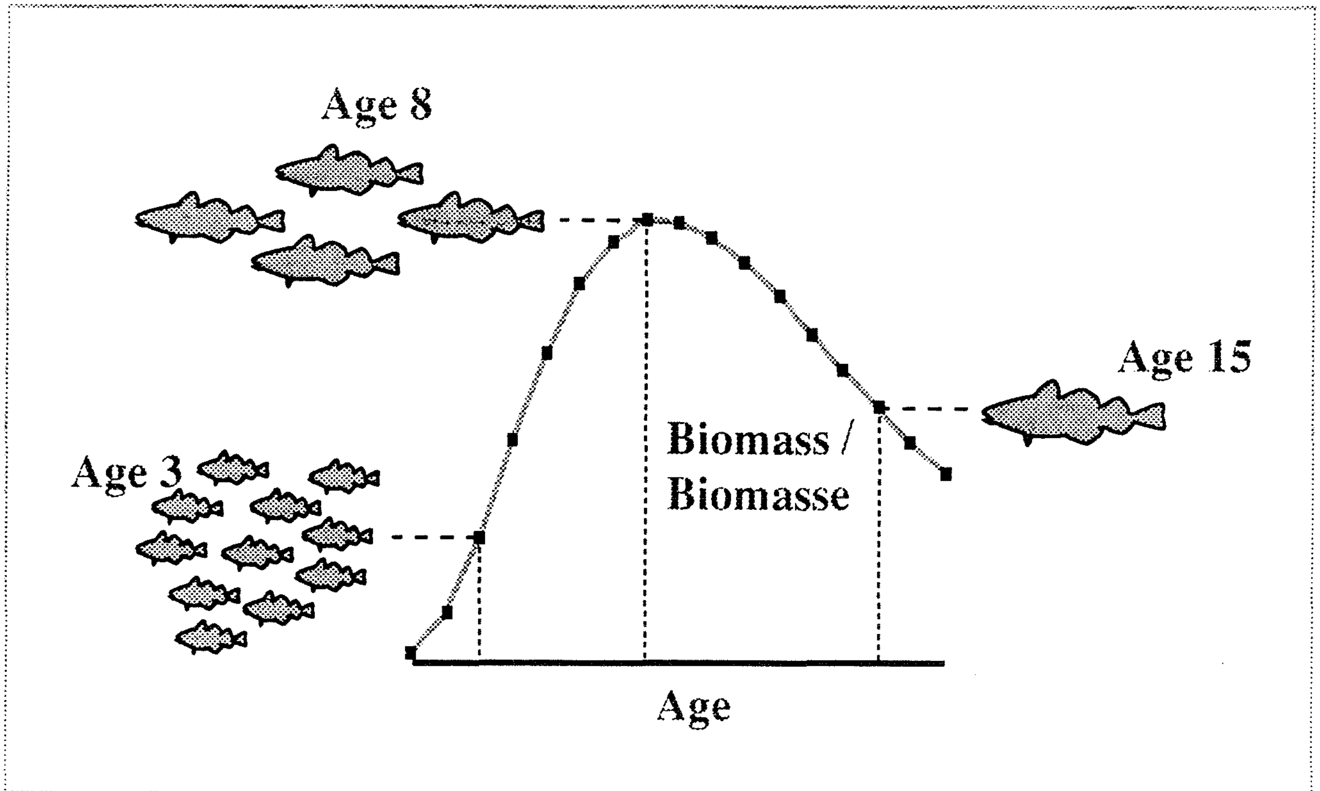


Figure 1: The biomass of a year-class reaches a maximum at a given age due to the trade off between decreasing numbers and increasing average weight.

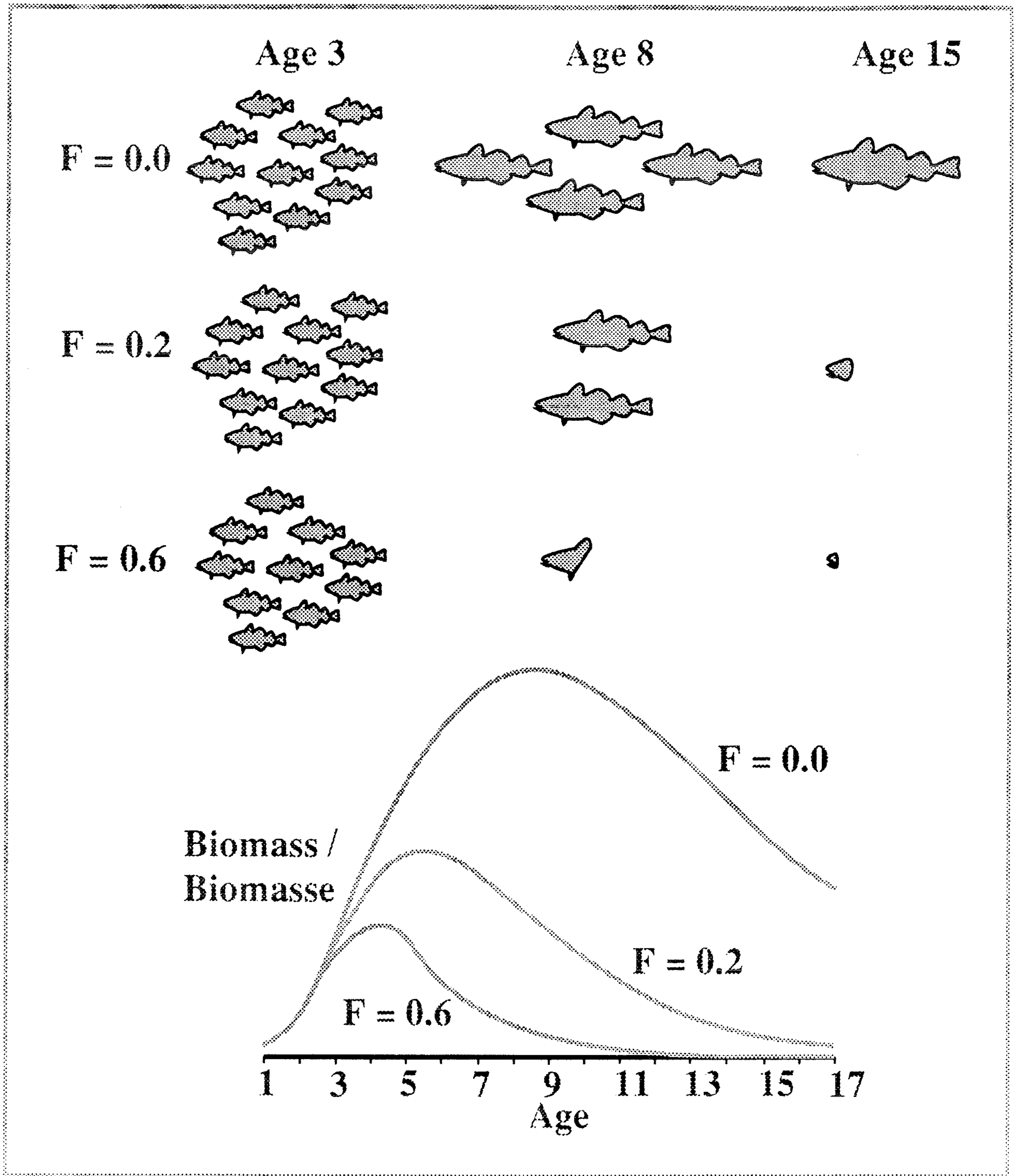


Figure 2: As the rate of fishing increases, the numbers of fish in a given year-class decreases, and more so for the older fish, and the age of maximum biomass of the year-class also decreases.

Several characteristics of the fishery will be affected by the rate of fishing (Figure 3). There is some rate of fishing that will give the most yield from a year-class and we refer to this rate as $F_{Max}$. If we fish below $F_{Max}$, then on average some yield will be lost compared to fishing at $F_{Max}$ because more of the population will be beyond optimal size.

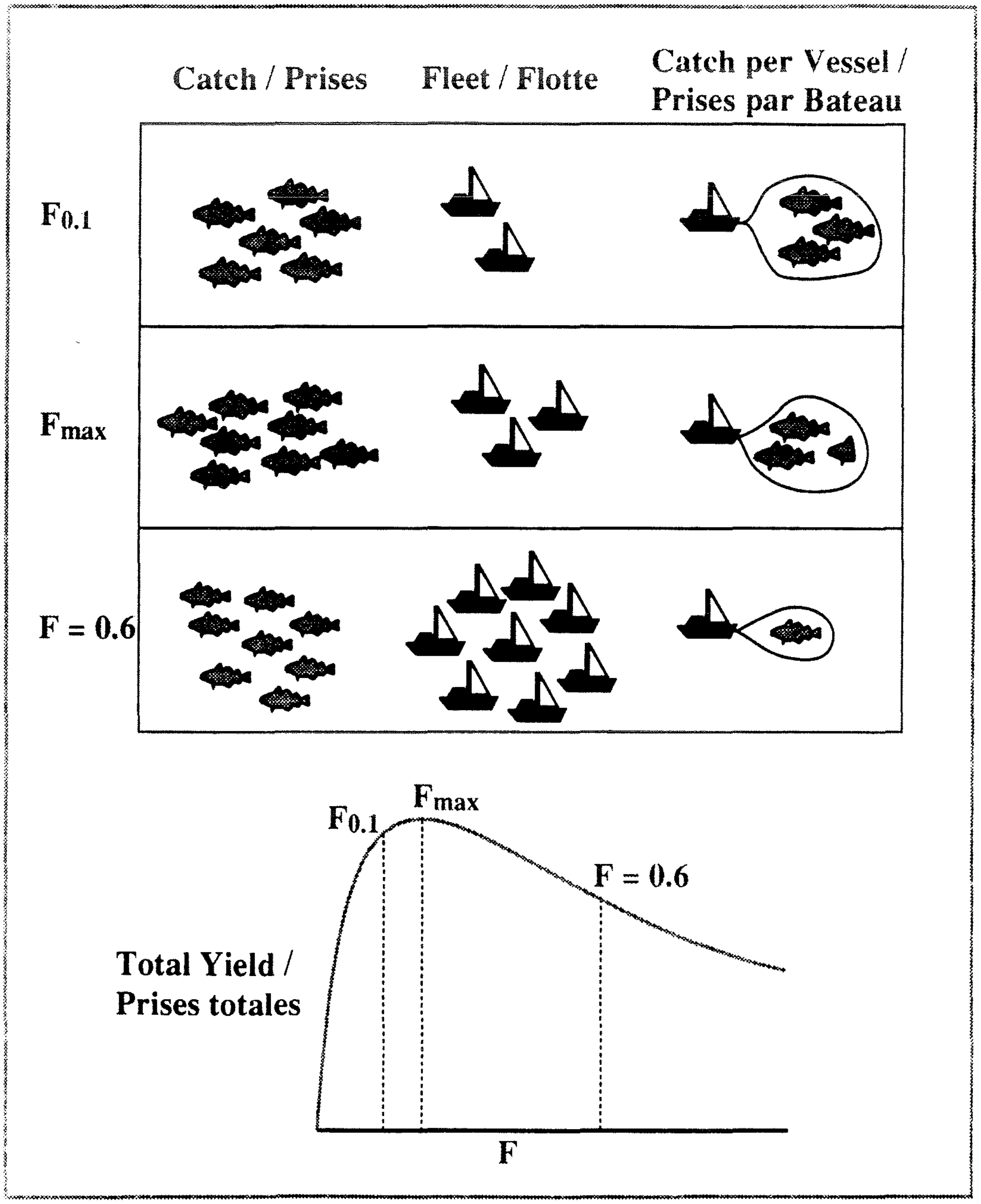


Figure 3: Characteristics of the catch, fishing effort, and catch per unit effort in yield per recruit.

If we fish above $F_{Max}$, then the fish will be caught before they reach the optimal size and some yield will also be lost and more fishing effort will be necessary. The average size of fish in the catch will decline on average as F increases. This is because there will be fewer older fish in the population and the fishery will become increasingly dependent on younger fish. The amount of fishing effort will increase in proportion to the rate of fishing. This will result in decreased catch per unit effort and less profit per vessel.

Canada chose a target rate of fishing below $F_{Max}$. From a conservation perspective, $F_{Max}$ was the upper limit to the rate of fishing since higher levels would give less yield. The target chosen was $F_{0.1}$, which is by definition the rate of fishing at which the addition of one unit of effort would catch 1/10 the amount than if the same effort was applied to an unexploited year-class. The total yield from a year-class was only about 5-10% less than at $F_{Max}$, but the required fishing effort was about 1/3 less. While the yield per recruit model does not explicitly consider possible relationships between spawning stock size and recruitment, it was felt at the time that $F_{0.1}$ would ensure a relatively large spawning biomass and broad age span in the population. These characteristics would help dampen the negative effects of poor recruitment on the fishery.

<u>Considerations of spawning stock size</u>

In the mid-1970's when Canada adopted an $F_{0.1}$ management strategy, little was known about the relationship between spawning stock size and subsequent recruitment. Since then there has been an accumulation of data on many fish stocks in this area and around the world. In general, there is no clear relationship between stock size and the number of recruits produced, but it is clear that low spawning stocks reduce the ability to produce strong recruitment. Considerable research is ongoing in an attempt to develop management models that explicitly consider spawning stock requirements for optimal fisheries. Preliminary results indicate that fishing mortalities in the range of $F_{0.1}$ for cod are likely to ensure adequate spawning biomass. These studies also indicate that fishing mortalities in excess of 0.3 will reduce the frequency of average and above average year-classes.

## 2.2. Groundfish Stock assessments

### 2.2.1 Description of Methods

Stock assessments attempt to provide estimates of the current size of the fish stock under study. The estimates are then compared to estimates of the stock in previous years.

There are several realities with marine fish stocks which tend to complicate the process of counting the fish:

1) Fish stocks occupy large areas.
2) Fish can't be easily counted.
3) Fish taken out of the water die.
4) Fish are not distributed evenly.
5) Fish distribution tends to vary from year to year and seasonally.

Contrary to the census of the Canadian population, which is done every five years or the farmer who can count the number of cattle in his field at any time, it is not possible to count every fish because of the reasons above. Consequently, sampling strategies have to be used to arrive at estimates of the population. Furthermore these estimates have to be seen as "indices" of the population. Because fish can move and some escape being caught by the survey trawl, the estimates obtained are a fraction of the total stock. Calculations for several cod stocks indicate that this fraction is generally between 50 and slightly below 100% .

Another example of an index include the Consumer Price Index (CPI), where the price of a number of specific articles are tracked on a regular basis. The CPI won't tell you the price of a toothbrush; however, it can tell you how much more a variety of articles would cost today relative to the cost in years gone by. Another example of an index is the number of housing starts as an index of construction activity. Again, this index will not tell you exactly how much was spent in the construction sector, but it will give you an indication of whether the situation is improving or worsening. Similarly, the indices derived from groundfish surveys or commercial catch rates provide an indication as to whether the population has increased or decreased and by roughly what proportion.

Providing that we have estimates of the number of fish caught and their ages, the indices of the trends in the population (research survey or commercial catch rates) can then be used to calculate the overall population abundance. This is done using an accounting procedure called sequential population analysis (SPA). Without going into the details, the procedure rests on the principle that if we add all the fish caught by the fishery from a given age-class, take into account how the indices of abundance have changes from year to year and we make an adjustment for the natural mortality, we can calculate how many fish had to be there in the first place.

A few words on each of these indices is warranted at this point.

a) Research surveys

When scientists present the results of groundfish surveys, they are often told " No wonder you say the cod stock is in bad shape....you're fishing where there are no fish!.".

Scientists have designed surveys to try to estimate the size of the stocks; to determine if the stocks are increasing or decreasing. In order to do this, they must fish in all areas where cod could possibly be caught, not just where cod are plentiful. If they fished only where there are lots of fish or only where there are no fish, the estimates would be deceiving. Scientists would say that the results of the survey are *biased.*

For example, if you wanted to know the average height of adults living in Nova Scotia, you wouldn't just measure basketball players. If you did, you would think that people from Nova Scotia are much taller than the average Canadian! To get a better estimate of the average height of adults living in Nova Scotia, you would have to measure a cross-section of the adult population. This means that some of the people measured would be short and others would be tall.

Similarly, if you wanted to know the population of the Maritime provinces, you would not just go to Halifax, Moncton and Charlottetown. An estimate for the entire area based on these three cities would give you a population in the hundreds of millions for the Maritimes ! Everyone knows that the population per square kilometres in the cities is much higher than in the country. A better estimate of the population includes villages as well as unpopulated areas. That is one of the reasons why the survey that is conducted in the southern Gulf of St. Lawrence every September covers areas where there are few cod as well as areas where cod are usually abundant. Secondly, suppose that the survey would only go where fish have been seen in the past and that few fish would be found. Fishermen would be right in saying " Maybe the fish moved this year ! ". To cover this possibility, the surveys have to cover the entire area. There are other reasons as well. The survey is used to obtain abundance estimates of other groundfish species such as plaice, white hake and numerous other species which can be found where there are no cod.

A whole science of statistics has been developed in order to make accurate estimates of the numbers in populations (stock) when you can't count all the individuals (fish). To make an estimate of the number of fish in a stock, you have to *sample* the fish stock, and you have to sample *randomly*. That means that you have to sample in such a way that every location that has a possibility of having cod has an *equal chance of being selected* when you choose where to sample. For example, if there were six sites where fish could be found and you were only able to sample three of them, you could write each of the positions on a separate piece of paper, place them in a hat and draw three of them. Let's say now that the stock is abundant and that fish are plentiful on five of the six sites. In this case, you are guaranteed to have at least two of your three sets in an area where fish are plentiful. On the other hand, if it is a poor year and only one of the six sites has fish in abundance, then you are guaranteed to have at least two poor sets reflecting the lower abundance during that year.

Another frequent comment relating to groundfish surveys is "The locations of the fishing sets are chosen by computers. What do computers know about fishing ? That's the reason why they can't find fish ". The computer is just a tool to ensure that the selection of the stations is done *randomly*. First, someone, had to enter all the possible fishing locations inside the survey area in the computer. The same procedure for selecting stations could be done using a large barrel with the location of each possible fishing station written on ballots.

This is not to say that research surveys are infallible. It should always be recognized that there is a margin of error around the estimates. This is similar to opinion polls which are often presented with a statement like " ... within 3%, 19 times out of 20 ". This means that if you were to repeat your opinion poll 20 times, you would expect your results to fall within 3% of the estimate you just obtained in 19 of the 20 cases. These are called *confidence intervals* because they describe how confident you can be with your results. Small confidence intervals make you more confident, but large confidence intervals make you less confident. Furthermore, scientists would prefer to have several separate indices of abundance. It's a bit like when you have to make a tough decision to make, you're likely to ask the opinion of someone you have confidence in.... and you might ask for a second opinion! Unfortunately, surveys are expensive and it is generally not possible to conduct several. This is why we have to look at other possible indices of abundance.

### b) Commercial catch rates

Commercial catch rates can also provide an index of abundance of a fish stock and it is essential to consider this information closely when looking at stock trends. However, we have to be aware that there can be some pitfalls in using catch rates. First, fishing gear, technology and the knowledge of fishermen constantly improve. This can mean that, for example, even if there is no change in fish abundance, the fishing sets of 1994 might yield more than in 1980 because of a larger trawl, better fish finding equipment or, increasing experience of the skipper. This would mean that the catch rates of a trawler in 1994 may not be directly comparable with the catch rates of 1980. This is essentially saying the same thing as " You can't compare the salaries in 1994 to those of 1980." In this case, a dollar bought more in 1980 than at present. In the case of a fishing vessel, the vessel in 1994 is likely to be more efficient. For the southern Gulf of St. Lawrence mobile gears, our analyses indicate that there has been a steady increase in fishing power (Swain et al, 1994). This information has been taken into account in recent assessments of the southern Gulf of St. Lawrence cod stock.

Secondly, because fishermen tend to fish where catch rates are going to be higher, they will seek the areas where fish are most concentrated. As abundance decreases, cod will disappear from the least preferred areas and gaps will appear on a sounder trace recorded on a continuous steam through the fishing ground. As the decline continues, cod may aggregate in the most preferred areas and as long as these areas can be located, catch rates may not decline too much. At very low abundance, one might still be able to find aggregations where good catch rates can be obtained but these would be few and far between. This means that catch rates could be maintained or could decrease more slowly than the population abundance. This is particularly true for species like herring.

For cod, it is thought to be less of a problem since the fishery used to be spread out over periods of high and low concentration. Although cod are expected to appear at certain locations during certain periods (i.e. 4Vn in winter, Chéticamp in November), there is also some variation in timing and location . This means that some searching and some ' trial fishing sets' have to be made and consequently during periods of lower abundance there will be a reduction of catch rate.

Another aspect of using the commercial catch rates as an index, is that the trends depicted are those over the fishing areas. If there is a significant amount of the population found in un-fishable areas, then the information from catch rates may not be a good index of abundance. Although there is a large area of the southern Gulf that is not fished ( example: around Bradelle Bank), because of the extensive migration of this stock, commercial catch rates in the area generally give a picture of stock abundance that is similar to that from the research survey.

Because we do not have several research surveys to determine the trends in abundance, it is very important that all possible indices of stock trends be examined. The commercial catch rates, when used with an understanding of their limitations, can provide such an index. In addition, as we saw previously, the fishing effort is directly linked with fishing mortality. Therefore, it is crucial that stock assessments not only examine commercial catch rates but also the trends in fishing effort.

<u>Types of assessments</u>

There are different kinds of stock assessments that can be done depending on the amount of information available. Some just look at whether the indices of abundance increase or decrease and make statements on the status of the stock as being low, medium or high based on the value of the index compared to the past. For example, in those cases, a statement such as " The stock has reached the highest level seen since surveys were started " is made. These stock assessments don't tell you the actual biomass, only that the stock is at the highest level seen. They provide a *relative* estimate of the population. These are the kind of assessments that are possible for the 4Vn cod stock. Of course, if the biomass estimated by the survey is 6,000 t then we can conclude that there is at least that much. If we knew that the survey was catching exactly half of the fish the trawl encountered, then we could have an *absolute* estimate of the population simply by multiplying the survey number by two.

Another kind of assessment is called an *analytical* assessment. In analytical assessments for cod, a procedure called *Sequential Population Analysis* (SPA) is used to obtain an *absolute* estimate of the population. (Other analytical assessments can be done using production models). These are the kind of assessments done for the southern Gulf of St. Lawrence. This type of assessment requires detailed information about the catch composition and abundance indices (research surveys, commercial catch rate information). These assessments indicate whether the stock is increasing or decreasing but also give an estimate of the actual population. Once an estimate of the population is known, projections can be made for the coming year assuming different management strategies.

### 2.2.2 Problems

In assessments where SPA is not used, the conclusions will depend only on the precision of the survey estimates or other indices of abundance. Groundfish surveys are not as precise as other types of surveys that can be done such as opinion polls. Opinion polls are generally quite precise in predicting who will win an election. To give you an indication of the precision of the southern Gulf of St. Lawrence groundfish survey, if we could repeat the survey 20 times during the month of September, we would expect that the results would be within about 20% of what we obtained by doing it only once (either above or below) on 19 of these surveys. The results of the surveys done in the southern Gulf of St. Lawrence tend to have narrower confidence intervals or in other words tend to be more precise, compared to groundfish surveys done elsewhere.

In analytical assessments, the problems can be of two kinds: the data and the procedures used. Here, we have to know several components: the total catch in tonnes, the breakdown of this catch in numbers by age group and the abundance indices (research surveys and commercial catch rates). All of these inputs have some error of measurement associated with them as we saw above for the surveys. Like any other calculation, the results will depend largely on the starting numbers. If the wrong numbers are used to start with, then the results may not be close to reality. If there is misreporting, high-grading or discarding, then the total catch will be underestimated and the amount and breakdown of the catch by age group will not be correct. With accurate catches and catch rate data, the precision of our assessments would be improved. Inaccuracies in the data may be detected in subsequent years but it may be too late to take appropriate management actions.

The tendency for vessels to become more and more efficient as time passes has also posed problems in the interpretation of catch rates. There are methods that allow us to calculate the rate at which vessels improve and to include this factor in assessments.

In the late 1980s and early 1990s, we began to observe what is now called "retrospective patterns" in these type of assessments. As we updated the assessments every year, we observed that our estimates of stock abundance from previous years were always being revised downwards (i.e., we had been too optimistic). The causes of this problem are still not entirely clear. They can be caused by problems in the data or by assumptions of the procedure. Simulations of how population abundance changes have showed us that misreporting of catches (including discarding of small fish) can produce these effects. When this occurs, the decline of a population may not be detected right away or may not be seen to be severe. The discrepancies will eventually be detected because the survey and the catch rates will track the population changes, but often at a later date than desired.

The procedures used by Canadian scientists are similar to those used around the world in the assessment of fish stocks. For example, for the southern Gulf of St. Lawrence cod, we have used several procedures including some developed in Europe. There is an advantage to using a variety of methods as they provide a range of "opinions" of the status of the stock. When a majority of analyses point to one solution, it increases the level of confidence in the results. If the various methods give widely different answers, then the confidence in the stock assessment will not be very high.

A number of assumptions are necessary when we use these procedures. Some assumptions can be verified more easily than others. If some of the assumptions made are not appropriate in a given year, then the results can be affected. For example, we assume that natural mortality is constant over time and over most age classes. However, if in a specific year, an epidemic killed a large portion of the population and was not detected, then the assessment results would be affected. Similarly, assumptions have to be made when catch projections are done. If we assume that the weights at age will not be much different than last year, but in reality, the growth decreases by a lot, then our estimates could be too optimistic.

Despite the fact that stock assessments are not as precise as we would want them to be, they still provide a good perspective on general trends in the population and a wealth of information about the stocks themselves. Difficulties identified through assessments often lead to studies which further improve our understanding of the fisheries. For example, stock assessments identified the catch of southern Gulf cod in 4Vs and promoted research on fishing effort and gear interactions.

3. **The Resource**

### 3.1 The environment of the Gulf of St. Lawrence and Sydney Bight

The southern Gulf of St. Lawrence is primarily a shallow shelf (less than 100 m deep) bordered on the north by the Laurentian Channel (Figure 4). Sydney Bight lies immediately east of the southern Gulf and is the northwestern extension of the Scotian Shelf. Although much smaller in area, Sydney Bight is deeper than the southern Gulf: about 1/3 less than 100 m deep, about 1/3 between 100 and 200 m deep, and about 1/3 greater than 200 m deep.

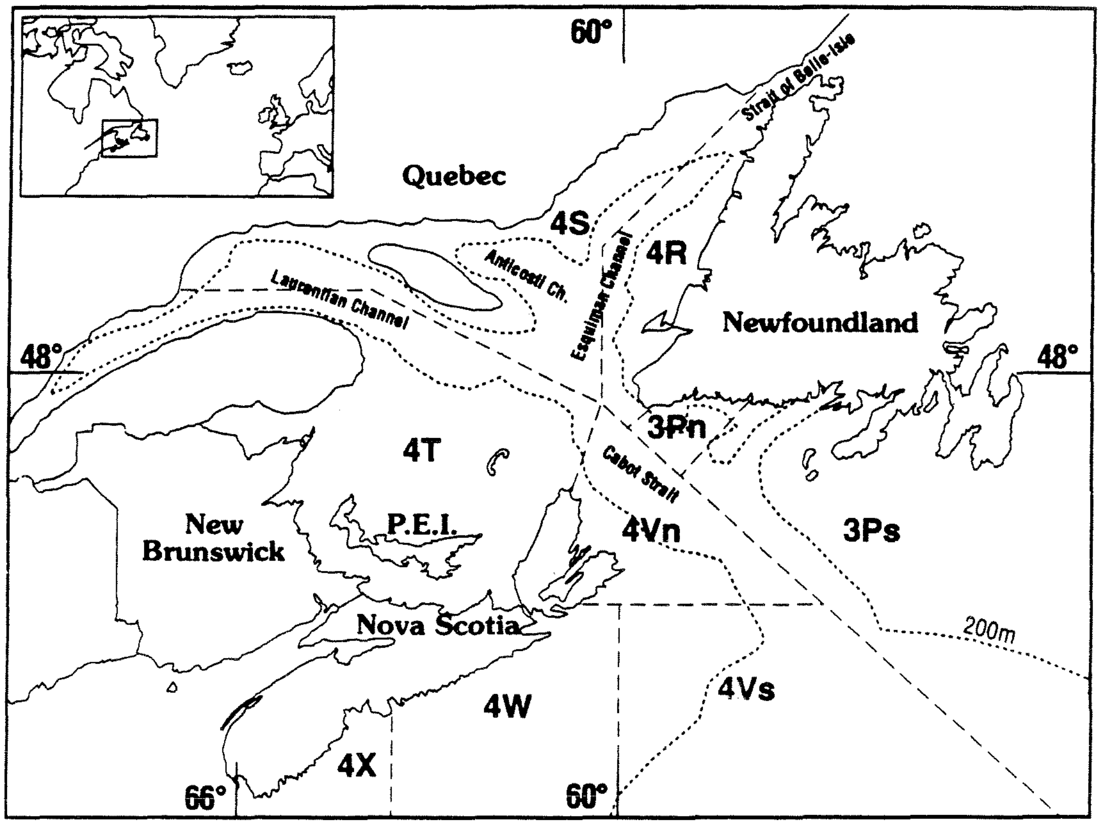


Figure 4: Map of the Gulf of St. Lawrence and the Cabot Strait.

In summer, there are three water layers: a warm surface (0 to 30 m) layer, a cold (-0.5 to 1.0 C) intermediate layer, and a warm (4 to 7 C) deep (150 to 200 m and deeper) layer. Each layer has different characteristics.

The upper layer forms from seasonal warming of seawater and as a result of the freshwater discharge carried by the Gaspé current. Indeed, one of the most important physical features of the southern Gulf is freshwater discharge from the St. Lawrence watershed. It is the prime factor driving the currents in the southern Gulf. There is a seasonal component in river discharge with a maximum during May-June and low levels during September-October. There has been wide variation in the annual mean discharge, with above average values in the early 1950s, low values in the mid-1960s, above average values from 1972 to 1985, average values from 1986 to 1992 and much higher than average discharge in 1993. The Gaspé current enters the southern Gulf at the end of the Gaspé Peninsula and crosses the southern Gulf, part of it moving north of the Magdalen Islands, but most sweeping south between the Magdalen Islands and P.E.I. There is often an eddy in the area of the Shédiac Valley and north end of P.E.I., partly due to the Gaspé current and partly due to prevailing winds. These eddies are favourable areas for retention of fish larvae and their prey. Indeed, the Shédiac Valley area is the principal nursery area for southern Gulf cod in most years. Eddies often occur near the Magdalen Islands, which also serve as an important nursery area for cod in most years. The water then exits the Gulf through Cabot Strait, moving through Sydney Bight, and then onto the Scotian Shelf parallel to the coast of Nova Scotia.

The cold intermediate layer is thought to be the result of seasonal cooling with a small fraction coming from cold Labrador shelf waters. It reaches the bottom over a wide area of the southern Gulf. The area of the southern Gulf covered by this cold water layer during 1990 to 1993 was among the largest ever observed and the previous occurrences lasted only one year rather than the four consecutive years of 1990 to 1993.

The bottom layer within the Laurentian Channel comprises varying proportions of water from the Atlantic Ocean and Labrador current. Its net movement is up the Laurentian Channel; most of the movement occurs on the Newfoundland side of the Channel. Bottom water temperatures (greater than 150 to 200 m) vary very little seasonally but can vary between years by as much as 2 C. Low temperatures were observed in the late 1960s and again in the late 1980s and early 1990s. In 1993, there was evidence that deep water temperatures were again increasing toward more average values in Cabot Strait.

In early winter, the stratification of the upper layers breaks down and there are only two layers: the surface (0 to about 100 m) mixed layer (temperatures near freezing: -1.5 C) and the deep warm (4 to 7 C) layer.

The principal surface feature during winter is the extent and duration of ice cover. Ice forms first in the southern Gulf during late December and the edge of the ice moves out of the Gulf and east and south to the maximum in late February. Ice melt occurs from two directions, from the west (St. Lawrence Estuary) and from the east, such that the area between the Magdalen Islands, Cape Breton, and P.E.I. is the last part of the southern Gulf to become ice-free. The date of ice-melt in this area seems to control the return migration of cod into the Gulf . Fréchet (1990) found that cod during winter tend to be found along the ice-edge in open waters. The median date of ice-melt is 16 April; however, the ice extent was greater than normal in 1990 to 1993 and ice-melt was late (6 May to 24 May), which delayed the onset of the spring fishery in the southern Gulf. Although ice-extent was near record during 1994, April was warm and ice-melt occurred in late April (near normal).

### 3.2 Cod Stock Structure in the area

A stock is considered to be a self-reproducing population that has limited genetic exchange with surrounding stocks. This definition does not prevent migration or mixing of stocks throughout the year, as long as the stock members tend to return to their home stock to spawn.

It will probably never be possible to identify all cod stocks with complete success, because fish from each of the stocks mix with adjacent stocks, and the degree of mixing varies with the stock, the season, and the year. As a result, there is no one geographic line that can be used to permanently separate adjacent stocks. However, by combining the results of different studies, an "average" picture of cod stock structure in 4TVn has emerged. It should be noted that there will be deviations from the "average" picture from time to time. This picture is constantly being improved, and is likely to change in the future both as techniques improve and environmental conditions change.

An early, overall view of 4TVn cod stock structure was presented by Templeman (1962) (Figure 5). Based largely on studies of vertebral counts and early tagging studies, he concluded that there were distinct cod stocks off the Gaspé, off the Baie des Chaleurs, off PEI, off western Cape Breton, and in the Sydney Bight region. He acknowledged that there was considerable mixing between the Gaspé, Baie des Chaleurs and PEI stocks, and indicated that they may not prove to be as separate as was then indicated. He also mentioned the possible existence of a Magdalen Island stock, but seemed doubtful that it was a distinct stock. All of the southern Gulf stocks were known to move east out of the Gulf in winter, although the extent of the migration appeared to vary from between 4Vn and eastern Banquereau.

When quota management was introduced in the early 1970's, two cod management units were defined in this area based upon the results summarized by Templeman (1962) and considerations of the ability at the time to differentiate among biological stocks. One unit comprised the stocks resident in the southern Gulf, most of which also spend the winter in 4Vn or to the east. This unit was referred to as 4TVn (January-April). The second management unit comprised the stock thought to be resident in 4Vn and it included the catches from 4Vn during May to December.

Subsequent tagging studies, summarized by Lambert (1992, 1993), support at least some of Templeman's conclusions. Cod tagged in the summer off the Baie des Chaleurs were largely recovered from the same area in following summers (Figure 6).

Similarly, summer-tagged cod off western Cape Breton returned most often to their general tagging site, although there was some movement both west to the Shédiac Valley and east to 4Vn. Fish tagged in summer in 4Vn were most often caught in 4Vn. Significant numbers were also caught in the western Gulf and in 4Vs. In winter, virtually all cod tags were recovered from 4Vn and east onto the Scotian Shelf as far away as eastern Banquereau.

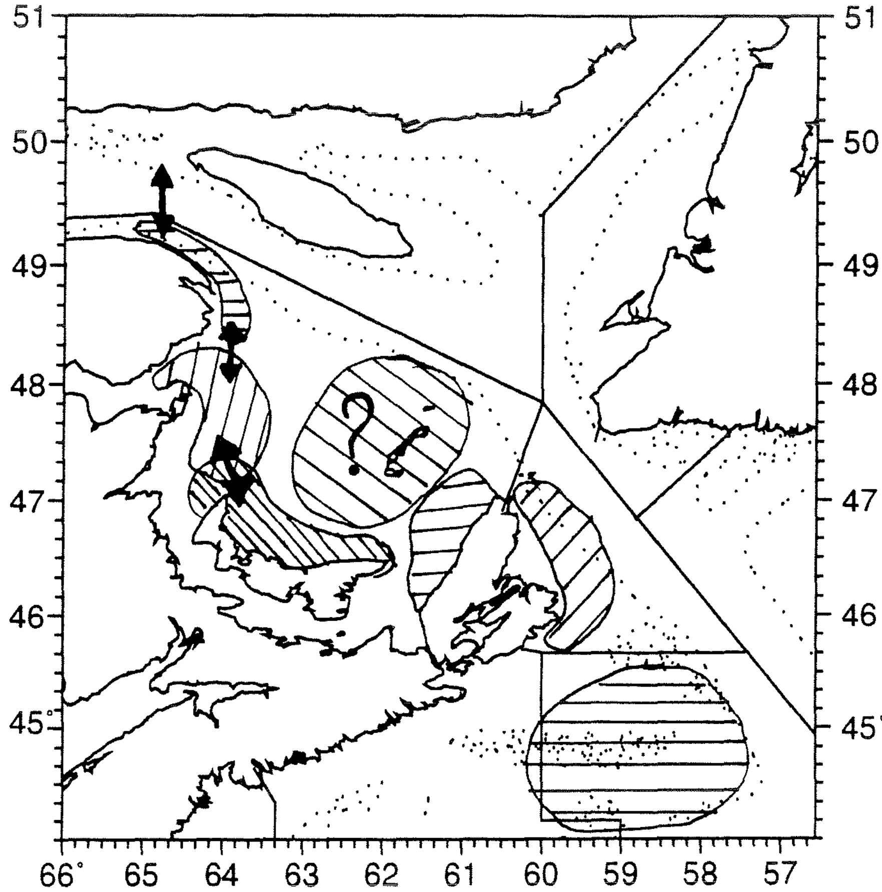


Figure 5 Initial views of cod stock structure in 4T, 4Vn and 4Vs as suggested by Templeman (1962). Arrows indicate areas of known mixing between stocks.

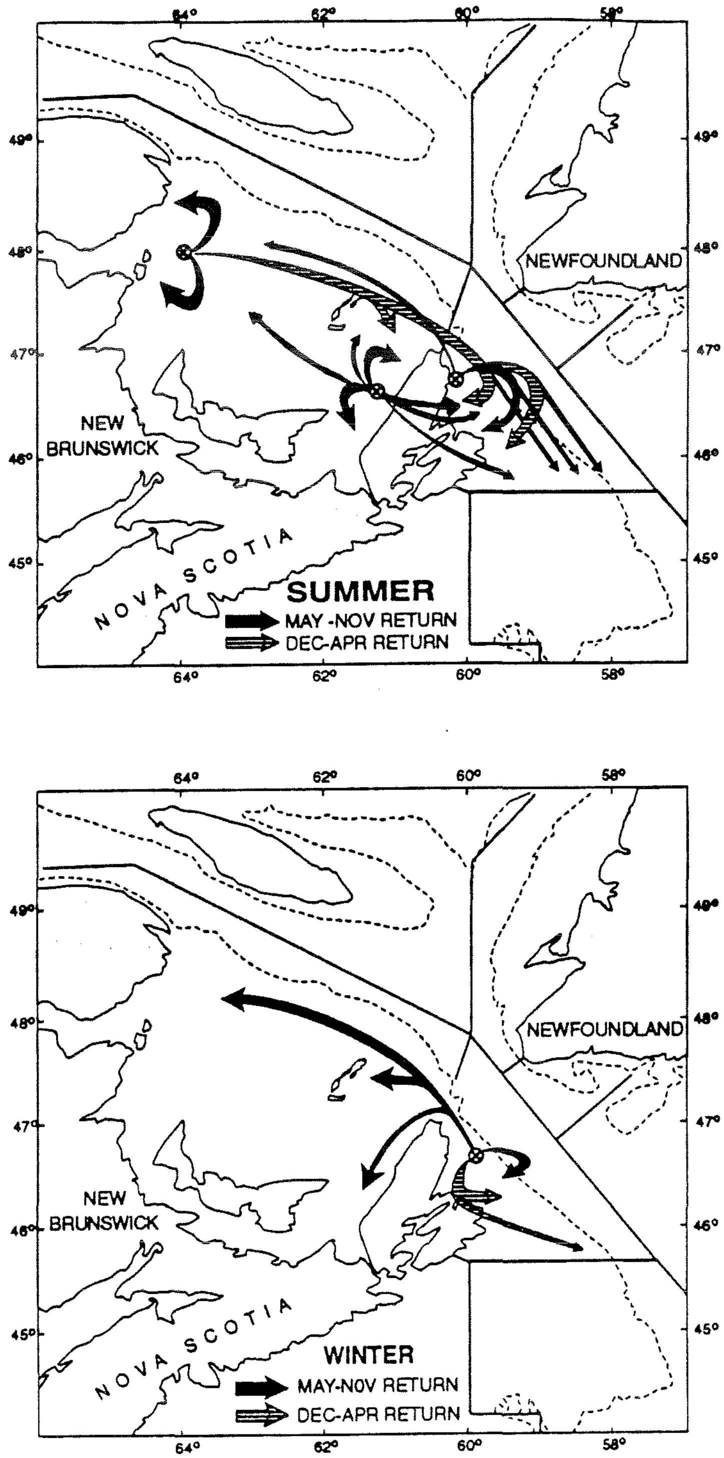


Figure 6: Summary maps of past cod tagging experiments in 4TVn. The top map shows major areas of tag recoveries after summer tagging. The bottom map shows tag recoveries after winter tagging. Tagging locations are indicated by a circled cross. Arrows show general directions of movement only.

The presence of distinct spawning aggregations is normally associated with distinct stocks, although small numbers of spawning cod can often be found throughout the stock area during the spawning period. Ichthyoplankton (eggs and larvae) surveys in the 1960's identified major spawning areas in the Shédiac Valley and off the west coast of Cape Breton near the Magdalen Islands (Lett 1980). In addition, recent surveys in the Sydney Bight region collected cod eggs north of the Bird Islands (4Vn) (Lambert 1992). In general, genetics studies have not been successful in identifying cod stocks, although recent developments in DNA fingerprinting have not been applied in the southern Gulf or in 4Vn.

Recent events in the cod fisheries in 4T, 4Vn and 4Vs indicate that the traditional management units do not fully encompass the winter distribution of the cod stocks in the area. During the late 1980's and early 1990's significant catches of southern Gulf cod were made in the northern part of 4Vs (Hanson and Nielsen 1992, Hanson 1995). It's also generally accepted that cod begin to leave 4T in November. Recent studies have indicated increased fishing effort in 4Vn during November-December, resulting in increased catches of southern Gulf cod (D'Amours et al 1994; Sinclair and Currie 1994; Lambert and Wilson 1994). The most recent assessments of these cod stocks have attempted to account for these overlaps.

One technique which has shown promise for identifying cod stocks in 4T, 4Vn and on the Scotian Shelf is that of otolith elemental fingerprinting (Campana et al. 1994). The technique is based on studies which show that the trace elements in seawater are taken up by the fish otolith (ear bone) as it grows, and that the composition of seawater varies geographically. Using this approach, cod from the western Gulf could be separated from those of 4Vs with almost complete certainty. Cod from the western coast of Cape Breton lay in between, but were different, from both the western Gulf and the 4Vs fish. Very few of the western Gulf cod were found as far east as Artimon Bank in 4Vs, but cod from the eastern Gulf and/or 4Vn migrated as far as eastern Banquereau. Thus these results support the conclusions of the earlier studies using tags.

To summarize, cod in the southern Gulf (4T) form a number of local aggregations, all of which appear to mix with adjacent groups to a greater or lesser extent. These aggregations migrate to 4Vn and parts of 4Vs in winter. The formation of the management unit including 4T and 4Vn (J-A) in the seventies was made in recognition of this large-scale migration. In recent years, adjustments have been made to account for most of the movement of southern Gulf cod in 4Vs in winter and the timing of it's migration in 4Vn in November-December.

## 3.3 Cod in the southern Gulf of St. Lawrence (4T-Vn)

### 3.3.1 History of the fishery

The southern Gulf of St. Lawrence cod stock has been exploited by man to some extent at least since after the $16^{th}$ century voyage of the French explorer Jacques Cartier to the Gulf of St. Lawrence. During that century, French fishermen regularly embarked on fishing expeditions to the Gulf of St. Lawrence and adjacent areas (de la Morandière 1962; de la Villemarqué 1990). It is thought that most of the fishing activity at that time may have been based around Cape Breton Island and to some extent on the Gaspé Peninsula.

The period from the second half of the eighteen to the late nineteen century is sometimes referred to the ""Reign of the Merchants" in the Maritime Provinces. For cod in the southern Gulf of St.

Lawrence, it was the beginning of the domestic commercial fishery. At that time,many merchant families (Robin, Fruing, Loggie, Lawrence) from the Jersey Islands established fish drying facilities around the southern Gulf of St. Lawrence. The fishery at that time was conducted from small vessels fishing relatively close to shore and from schooners offshore. The predominant gear were handlines although towards the end of the nineteen century longlines appeared. With the decline in markets of dried cod at the end of the nineteen century and the increasing competition by other companies, the merchant companies progressively decreased in importance as the twentieth century began.

The beginning of the twentieth century was marked by several technological advances which changed the face of the fishery. The railroad had just been completed and there was demand for fresh fish in central Canada Refrigerated freight cars appeared which facilitated transportation to the United States. Vessels were being equipped with motors. The first trawler to operate in Canadian waters, the "*Active*" started fishing for the National Fish Company (Chaussade 1983) in the early 1900's. Trawlers, which numbered seven on the whole Atlantic coast of Canada by 1919, were seen as a threat by the inshore fishery. The MacLean Commission of 1929 was charged to study the issue. Eventually, a moratoria was placed on the use of trawlers such that only three were active on the entire Atlantic coast of Canada until after the Second World War (Parsons 1993).

Catches declined in the early 20's, then with the deteriorating economic conditions wharf prices decreased dramatically by the early 1930's. After the Second World War, otter trawls were allowed to fish and the level of catches increased dramatically. Starting in 1952, Europeans exerted additional effort on the stock. It was the "race for fish". When the use of trawlers was allowed after World War II, the foreign fishery rapidly expanded and large catches were realized, particularly during the winter in Sydney Bight. When extended jurisdiction was declared in 1977, only France was allowed to continue fishing the stock because of their long standing fishing history in the area.

Landings statistics for the southern Gulf stock were obtained from annual fisheries statistics bulletins for the period 1917-1949 (Anon. 1917-1949) and from Sinclair et al. (1994) since then. Statistics for the period 1917-1950 do not include French catches which may amount to an additional 10% in certain years, but overall the fishery was almost entirely Canadian (Paloheimo and Kohler 1968).

Between 1917 and 1945, landings on the southern Gulf stock varied between 20,000 and 50,000 t averaging 31,000 t per year (Figure 7). After 1945, the fishery expanded and landings increased, peaking at 104,000 t in 1956.

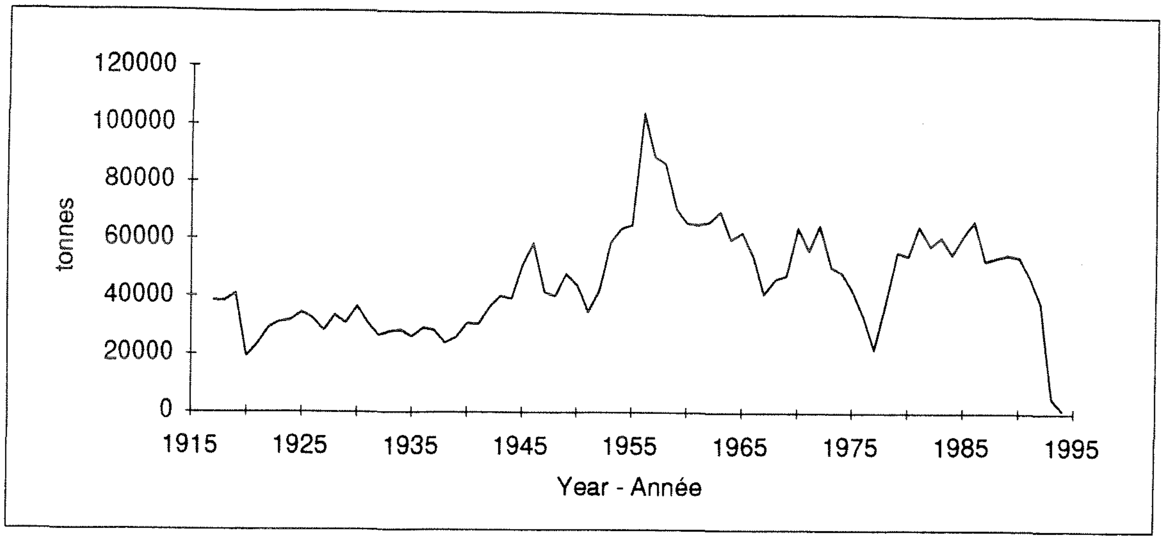


Figure 7: Landings for the southern Gulf of St. Lawrence cod stock (1917-1994).

The average yearly landings for 1946 to 1970 were twice those of the previous 25 years. Between 1960 and 1975, landings fluctuated between about 40,000 and 70,000 t. Landings then declined to their historic low level of 22,000 t in 1977. Landings increased to about 67,000 t by the mid-1980's. Since 1990, landings have declined and reached 39,000 t in 1992. The fishery was closed in September 1993 and the total catch that year reached only 5,200 t, the lowest catch of the twentieth century. Total landings in 1994 will likely be approximately 1000 t.

Gears

Up until the 1940's, the domestic fishery was almost entirely prosecuted with hook and line gears. Trawlers were introduced in the Gulf fishery in 1947 and, in the early 1950's, otter trawls became predominant. Fishing with gillnets started in the early 1960's (Halliday and Pinhorn 1982). At about the same time, Danish and Scottish seines, a gear invented by the Dane Jans Vaever at the end of the nineteenth century were introduced on the Scotian Shelf. Starting in 1965, fishermen from the southern Gulf of St. Lawrence experimented with this gear. Faced with competition from larger trawlers, their profit margin was low and they were looking for ways to increase their fishing power without buying larger vessels. To assist them the Canadian government chartered the British vessel "*Guiding Star*" to determine whether it was feasible to use this gear on vessels ranging from 15 to 20 m (Chaussade 1983). Results surpassed expectations; catch rates were twice to three times those of similar size trawlers. A number of vessels rapidly converted to this gear. Here, it should be noted that although these vessels are invariably referred to as Scottish or Danish seiners; they are all technically Scottish seiners since they all use the "fly dragging" technique which does not require the use of an anchor.

Landings according to gear types are available since 1965. Since the early 1980s, catches by fixed gears (gillnets, longlines and handlines) have declined attaining their lowest level ever in 1992 (Figure 8). Many factors likely contribute to this decline, including smaller size at age of cod, a shift of some fishermen to the more efficient mobile gears and, particularly in most recent years, the decline in the abundance.

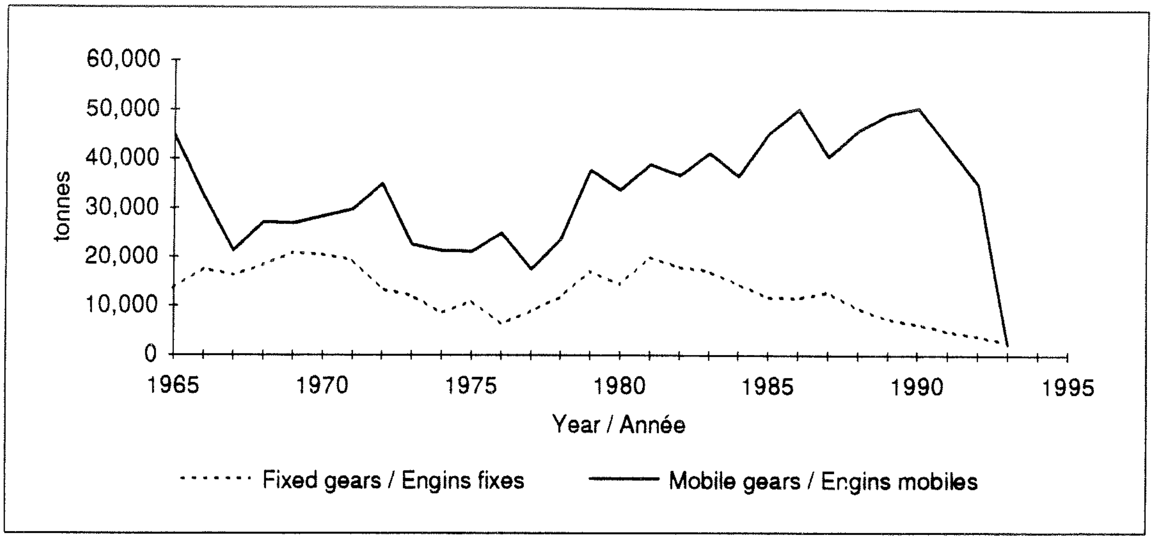


Figure 8: Landings for fixed and mobile gears for the southern Gulf of St. Lawrence cod (1965-1993)

In the mid-1960's catches (and catch rates) declined and many fishermen in the southern Gulf of St. Lawrence searched for new opportunities. Amongst them were the snow crab and shrimp fishery, which were just being developed. Towards the end of the sixties, catch rates of cod increased due to incoming good year-classes produced in the mid-1960's. Within ten years, the stock plummeted because of weak year-classes from the early 1970s and high fishing effort. During the 1960s and early 1970s, there were still some opportunities for the fishermen who wanted to fish other species as licenses were not restricted by the limited entry policy. At about the same time, Canada declared the 200-mile limit. For the southern Gulf of St. Lawrence cod stock, this coincided with good recruitment. Large year-classes produced in the mid-1970's entered the fishery in 1978 and 1979, the stock increased very rapidly and this gave rise to new expectations that the fishery could sustain more effort. With new technologies (e.g.: Loran-C in 1979, improved fish finding equipment) being introduced and the number of licensed vessels, it was realized at the beginning of the 1980's that there was a problem of overcapacity in the fishery (DFO 1980). The problem became even more prominent with the decline of the stock at the end of the 1980's.

### 3.3.2 Biological characteristics

Migration

Southern Gulf cod start to move out of the Gulf long before ice forms. During autumn, southern Gulf cod begin to move out of the Gulf along the edge of the Laurentian Channel and into Sydney Bight in early November. The peak movement is during mid-November, and by late November the majority of cod have left the southern Gulf. In most winters, cod can move as far as Misaine Bank and some as far as Banquereau Bank. However, Fréchet (1990) has showed that in the northern Gulf of St. Lawrence, adult cod seldom occur under ice and move away from the ice-edge as it moves. Thus it is possible that the extent of the southern Gulf cod migration as far as Banquereau Banks will depend on the extent of ice-cover in Sydney Bight and over the Scotian shelf.

The timing of the spring migration back into the Gulf is more variable because the timing of ice-melt in the eastern Gulf varies between late March and late May. In 1992, for example, ice persisted in the eastern part of the Gulf until the end of May and large numbers of cod continued to be landed in Cheticamp until the beginning of July.

Juvenile cod do not migrate as far as adult cod. Research surveys conducted in 1986/87, 1990/91, and January 1994 clearly showed that young cod leave the shallow waters by the end of November but it appears that most of these fish stay in the deep water at the edge of the Laurentian Channel extending in an area from near the Magdalen Islands to just inside of Sydney Bight.

Growth

Based on samples collected during research surveys from 1986 to 1989, southern Gulf cod are much smaller at age than cod caught in Sydney Bight (Figure 9). Furthermore, of all cod stocks in Canadian waters, southern Gulf cod have shown the greatest reduction in average size-at-age when data from the late 1980s are compared to previous years. Indeed, the weight of an age-7 cod has declined 50% since the mid-1970s (Figure 10). A number of factors (changes in abundance, size-selective fishing, length of growing season, changes in water temperature, etc.) acting separately and in combination, are the likely causes of these growth changes (Hanson and Chouinard 1992; Chouinard and Hanson, unpublished data).

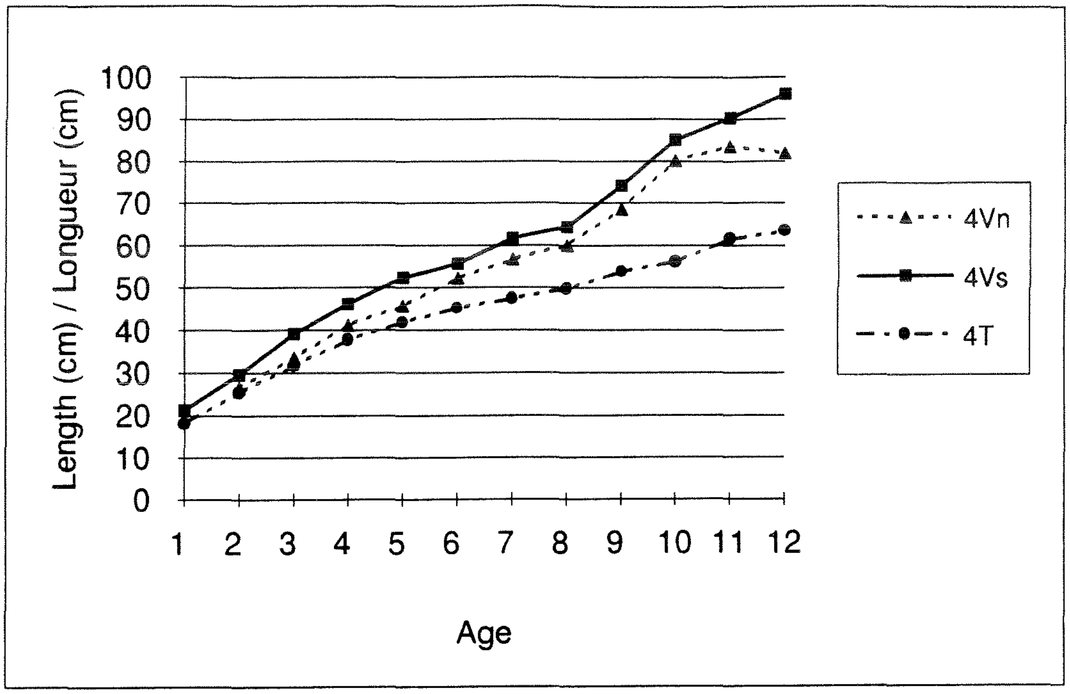


Figure 9: Size at age of cod from 4T, 4Vn and 4VsW.

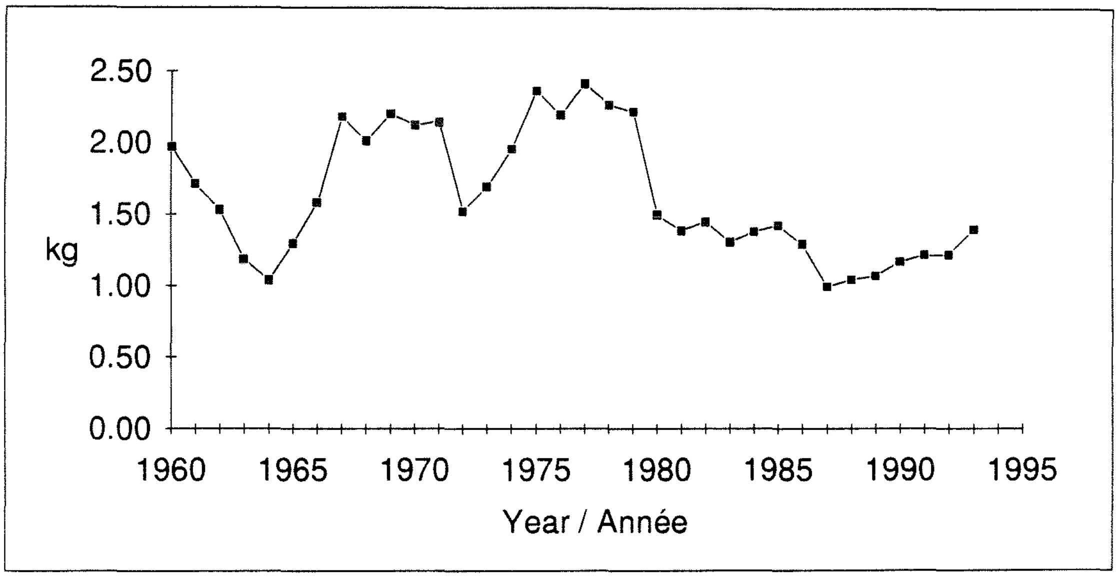


Figure 10: Weight for cod of 7 years of age in the southern Gulf of St. Lawrence (1960-1993).

Feeding

Cod are opportunistic feeders, which is reflected in the wide range of prey items found in their stomachs. Diet studies were conducted on southern Gulf cod from the late 1950s to the present (Powles 1958; Brunel 1962; Kohler and Fitzgerald 1969; Waiwood 1981; Waiwood and Majkowski 1984; Hanson 1994). Although the size of prey eaten increases with fish size, the species eaten varies from year to year dependent on availability. Nevertheless, some general feeding patterns occur.

Very small cod (5 to 20 cm) feed mostly on small crustaceans, especially mysids and euphausiids. The diet of cod 20 to 40 cm long is still dominated by small crustaceans (mysids, shrimp, and euphausiids) and lesser amounts of crabs, polychaete worms, clams, and small fish (e.g., smelt, capelin and juvenile herring). Small snow crab have not represented an important prey in recent years; however, they represented up to 20% of the diet of cod > 50 cm long in the late 1970s but even these amounts were not enough to have a significant impact on snow crab populations (Waiwood and Elner 1982). Fishermen indicate that consumption of lobster by cod occurs during the moulting period although lobsters have never been found in cod stomachs examined in any published studies. Cod predation on lobster, when it occurs, must be a local event involving small numbers of cod and lobster temporarily vulnerable to cod predators during the moult (e.g., when being returned to the water from fishing activities). A recent study of diets of about 100 cod captured in lobster traps found that the cod primarily ate the bait and only one part of a lobster body was discovered .

Fish were the dominant prey of cod larger than 50 cm but the species composition has varied with prey availability. When herring are abundant, they are the principal fish prey; however, capelin and smelt are also eaten in areas where these species are abundant. When herring were scarce, many other prey species were eaten and the total proportion of fish in the diet was reduced (Waiwood and Majkowski 1984). Flatfish (winter flounder, yellowtail, and American plaice) were seldom reported in cod stomachs in any of the published studies.

Reproduction

Southern Gulf cod spawn from May to September with the peak occurring in late-May to early June and, in most years, very few fish are found in spawning condition after mid-July (Powles 1958; Lett 1980). The principal spawning areas are near the Shédiac Valley, just east of the Magdalen Islands, and (in some years) Chaleurs Bay (Powles 1958; Lett 1980; Tremblay and Sinclair 1985). Egg numbers were surveyed from 1965 to 1975 and were correlated with spawning stock size and water temperature (Lett et al. 1975; Lett 1980). Mackerel may be an important predator of southern Gulf cod eggs and larvae (Lett 1980) although a recent diet study failed to find cod eggs or larvae in mackerel stomachs (Grégoire and Castonguay 1989).

Atlantic cod spawn in the water column (Brawn 1962; Solemdal & Sundby 1981). The depth of spawning, however, is limited by water temperature (cod prefer temperatures below 4 to 6 C) and the water depth itself (pressure changes). Female cod do not release all of their eggs at once; rather, they lay batches of eggs about 5 days apart and the number of batches laid appears to depend on the size of the female (Brawn 1962; Solemdal & Sundby 1981; E. Trippel, DFO, St. Andrews, pers. comm.). Because the females mature and shed eggs throughout the spawning period, available estimates of individual fecundity (number of eggs per female) are likely low.

Nevertheless, cod clearly lay large numbers of eggs and the numbers increase with fish size. Estimates for southern Gulf cod range from 231,000 for a female 49 cm long to 8.6 million for one 102 cm long (Buzeta and Waiwood 1982).

Powles (1958) reported that 50% of females were mature at a length of 52 to 57 cm but Lett (1980) found that 50% of females were mature at a length of 45 cm and that some females as small as 35 cm were mature. In recent years, 50% of females were mature at about 38 cm (Hanson, unpublished data). There has been no obvious change in age at first maturity during this time.

Condition

There is a pronounced seasonal cycle of body condition (Figure 11). Peak condition, as measured by muscle mass, occurs from about August to November and condition declines steadily from December to June in response to winter fasting, migration, and maturation of gonads prior to spawning. Muscle mass (equivalent to fillet weight of fish of same size) declines 25 to 40% between December and May (Anonymous 1994;). These data clearly show that a much higher yield per animal would be obtained if the fishery only took place during autumn months.

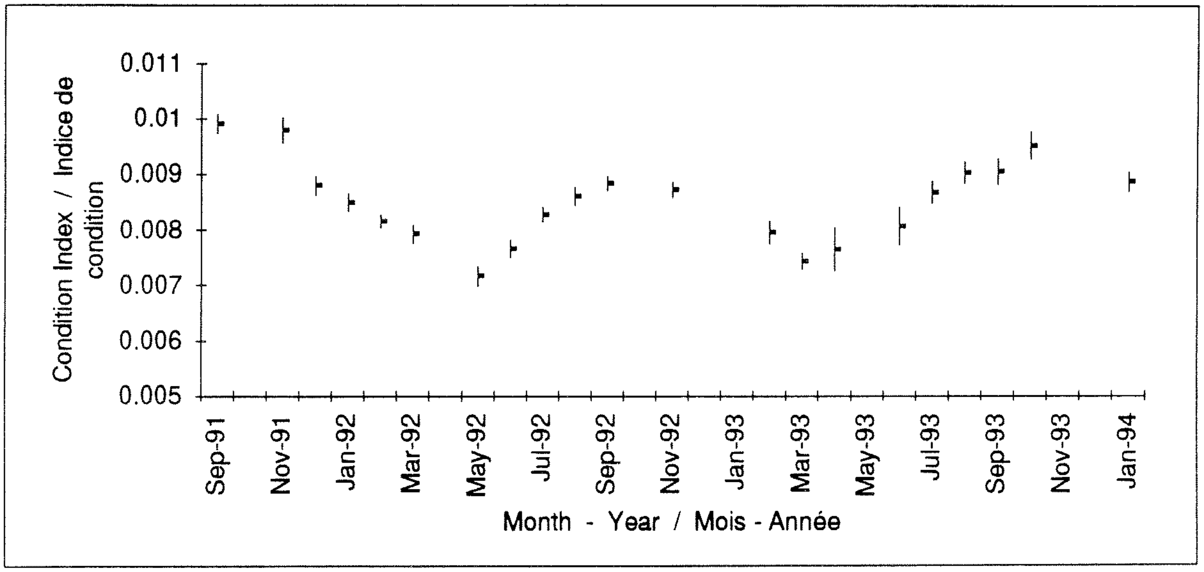


Figure 11: Seasonal cycle in condition (carcass weight in (g) over length (cm) cube) for cod in the southern Gulf of St. Lawrence

Variation in Distribution

The summer distribution of young cod is partly separate from that of the adults. Juvenile cod are usually found in water less than 50 m deep. During summer and early autumn, the greatest numbers of juvenile cod are found in Miramichi Bay - Shédiac Valley, the Magdalen Islands, and at the eastern end of P.E.I. (Tremblay and Sinclair 1985; Chouinard et al. 1991). Much lower numbers are found in Chaleurs Bay. Consequently, a research survey to provide an index of abundance, and to study the biology and ecology, of young cod was begun in the Miramichi Bay Shédiac Valley area in 1990. The time series may still be too short to use in the assessment; however, results to date do not indicate that there has been strong recruitment since 1990 - a pattern consistent with the assessment results.

Although some adult cod are found with the juveniles in water less than 50 m deep, larger and older cod tend to be found in deeper, colder water. The size of the area and depths of water inhabited by adult cod changes with stock size. When cod abundance is high, proportionately more large (old) cod are found in deep water than during periods when cod abundance is low. When stock abundance is low, the highest densities of fish are found in the western part of the southern Gulf (Swain and Wade, 1993; Swain 1993).

### 3.3.3 Summary of recent assessments and advice

Stock assessments have been done on the 4T-Vn stock since 1974. At first, the estimates of the TAC were based on the maximum sustainable yield concept. A few years later, the reference harvest level was set at the $F_{0.1}$ level. The assessments since 1978 have used sequential population analysis using research vessel survey and commercial catch rate information to arrive at estimates of population size.

The CAFSAC advice, the TAC's and the landings estimated from the entire stock since 1980 are documented in Table 1. (Note that this also includes catches from 4Vn made in November and December and the catches estimated from 4Vs).

Until 1987, the scientific advice had been consistently given at the $F_{0.1}$ reference harvest level. In 1987, fishery managers introduced the 50% rule, as a means of reducing the impact of large changes in the assessment of the stocks on the fishing industry. This rule meant that instead of moving directly to $F_{0.1}$ reference catch level, the reference catch level was set halfway between the current F and $F_{0.1}$. For several stocks including the southern Gulf stock, it was noted that harvesting had exceeded $F_{0.1}$ but at the same time, stock size had increased. The 50% rule provided a means of moving to $F_{0.1}$ over a period of several years. Consequently, the advice provided in the late eighties up until 1992 was in most cases above $F_{0.1}$.

Table 1. Summary of recent landings, TAC's and scientific advice for southern Gulf of St. Lawrence cod. The units are thousands of tons.

| Year | Landings (stock) | TAC | CAFSAC Advice |
|---|---|---|---|
| 1980 | 57 | 54 | 54 |
| 1981 | 67 | 53 | 60 |
| 1982 | 62 | 60 | 65 |
| 1983 | 64 | 62 | 62 |
| 1984 | 58 | 67 | 67 |
| 1985 | 64 | 67 | 62 |
| 1986 | 69 | 60 | 60 |
| 1987 | 55 | 45.2 | 24 (45.2 - 50% rule) |
| 1988 | 56 | 54 | 49 |
| 1989 | 57 | 54 | 55 |
| 1990 | 58 | 53 | 53 |
| 1991 | 49 | 48 | 48-53 |
| 1992 | 41 | 43 | 43 |
| 1993 | 5 | 13 (closure Sept 1) | 13-15 |
| 1994 | 1 | 0 | - |

In 1990, CAFSAC was asked to provide advice for multi-year management plans (3-year plans). CAFSAC indicated that there were problems in providing multi-year advice as the outlook in future years depended on year-classes which were not yet in the fishery and for which there was little information on their abundance. CAFSAC indicated that the situation would be monitored and that new advice would be provided if warranted.

The following is a short description of the advice contained in the CAFSAC Advisory Document starting in 1989.

1989 Advice

Data from the research survey and mobile gear catch per unit of effort up to 1988 indicated that the stock was very abundant, close to the highest level in the past two decades. The research survey estimates for 1985 and 1986 were noted in the advice as being highly influenced by a few large sets and therefore likely to be overestimates of the stock size. The 1979 and 1980 year-classes were still contributing significantly to the catches and the 1982 and 1984 year-classes appeared to be strong. Fishing mortality was estimated to be above $F_{0.1}$ , but given the apparent high biomass of the stock CAFSAC advised that the catches at the 50% rule of 53, 000 t would be appropriate for 1990.

1990 Advice

CAFSAC was asked to provide multi-year advice. The stock abundance indices from the research survey and the commercial fishery in 1989 were slightly lower than in 1989, however, not by much. The year-classes in the commercial fishery (1984 and before) were estimated to be above average in abundance. Preliminary indications were that the 1986 year-class was strong; however, because there was not much information as to its abundance, the average was used for catch projections. Different scenarios were evaluated for a multi-year plan. The data available at that time indicated that there would be little difference in stock size if the TAC was kept at 53,000 t. Again, it was indicated that any change in the status would be reported.

1991 Advice

This was the first year that significant catches of 4T-Vn (J-A) cod were noted in catches of 4Vs and a research project was started to estimate the extent of the problem. The research survey estimate of the population declined again in 1990 but was above the long-term average. The commercial catch rates were lower than the peak in the mid-1980's but were well above average. The stock size appeared to be high and the advice in July 1991 was to maintain the multi-year plan.

Several fishermen voiced their concern that the stock was not as abundant as this advice suggested. Consequently, once the 1991 research survey was completed, CAFSAC undertook a review. The survey estimate was slightly lower than in 1990 and the commercial catch rates were about the same. In the final version of the 1991 advisory document, CAFSAC noted that the stock was declining in abundance and that the proposed lower TAC for 1992 of 43,000 t was consistent with this decline in abundance.

1992 Advice

Estimates of past catches in 4Vs from the 4T-Vn cod stock were provided (Hanson and Nielsen 1992). It was also noted that catches in 4Vn in November and December were likely from the 4TVn stock. Management measures were recommended to reduce the unplanned catch of the southern Gulf cod stock. Advice on the stock status was considerably more pessimistic than in 1991. In addition to the decline in the research survey index, the commercial catch per unit of effort also decline during 1991. Year-classes that had been estimated as above average previously now appeared below average. Furthermore, the prospects for the recruiting year-classes (1988-1989) were poor; they all appeared to be well below average in abundance. Based on these indications, CAFSAC advised reducing the TAC to 33,000 t. This was a substantial departure from the multi-year plan.

When the 1992 September research survey was completed, the results indicated a further reduction in stock abundance. Preliminary estimates done using the survey results suggested again a much lower TAC in the order of 13,000 - 15,000 t (Chouinard et al. 1992).

In December 1992, the Minister of Fisheries and Oceans announced the formation of the Fisheries Resource Conservation Council to provide advice on conservation measures and scientific research for groundfish stocks.

1993 Stock Status

The 1993 stock status report indicated that the population was now near the low level seen in the mid- 1970's and that the biomass of the stock was at an all-time low level. This was supported by the research survey results of 1992 indicating that the abundance of the population had continued to decrease. Catch rates in the commercial fishery were now only about half of what they were in the mid-80's. Furthermore, there were indications that year-classes produced after 1987 were all well below average.

In August of 1993, the FRCC recommended to the Minister of Fisheries and Oceans that the fishery be closed effective September 1, 1993.

1994 Stock Status

The research vessel index for 1993 indicated that the decline of the stock appeared to have been arrested. However, both population abundance and biomass remained near the low levels of the previous year. In addition, the estimates of recruitment for the year-classes produced in the late 1980s and early 1990s continued to be well below average.

Preliminary results of the 1994 research survey indicate that population abundance has remained at the low levels seen in the two previous years (see report of preliminary results). The 1991 year-class appears to be slightly larger than the adjoining year-classes but is still well below average.

### 3.3.4 Trends in the Abundance

Population abundance was high in the early 1950's. Given that catches prior to 1950 were considerably lower than they have been since, it is likely that the stock had been previously fished at a lower exploitation level which would have resulted in a build-up of the stock. As the fishery expanded, abundance subsequently declined to reach its lowest level in 1975 (Figure 12).

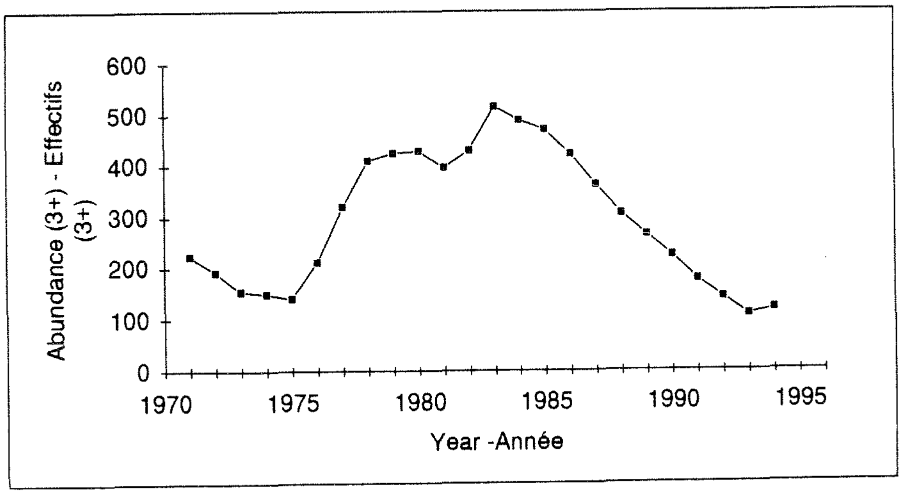


Figure 12: Trends in population abundance (millions of fish) for the southern Gulf of St. Lawrence cod

Population abundance increased dramatically to the mid-1980's and declined rapidly thereafter. Currently, population abundance is estimated to be at the low level observed in the mid-1970's.

The same trends can be seen for total biomass and spawning stock biomass estimated by ages 5 and over  Total biomass is estimated to have been near 500,000 t in 1956.  Total biomass declined to 123,000 t in 1974 then increased  to the mid-1980's and declined after.  Total biomass is currently estimated to be about 90,000 t.  Spawning biomass is also at the lowest level observed around 60,000 t.  Fishing mortality (ages 7+) was high  (> 0.8) in 1958-59 and in recent years (Figure 13).  For the remainder of the period, it varied between 0.4 and 0.8.  Recruitment in the southern Gulf cod has varied by a factor of five over the time period (Figure 14).  Large year-classes were produced in 1956-57, 1974-75 and 1979-80 and recruited to the fishery three years after. The abundance of year-classes produced since 1980 has been continuously declining. The more recent year-classes to have recruited to the fishery (1988-90) appear to be particularly weak.

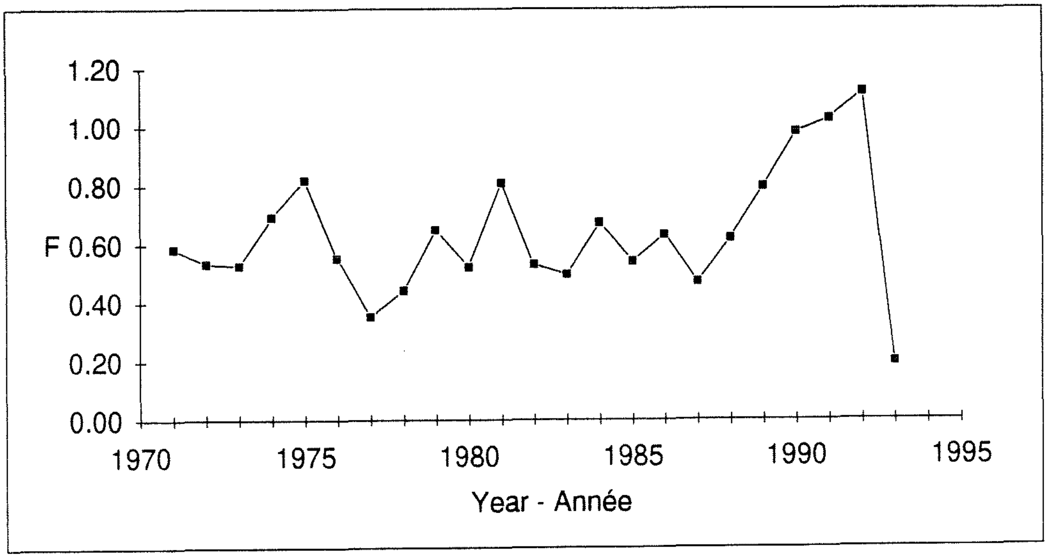


Figure 13:      Fishing mortality on the southern Gulf of St. Lawrence cod stock

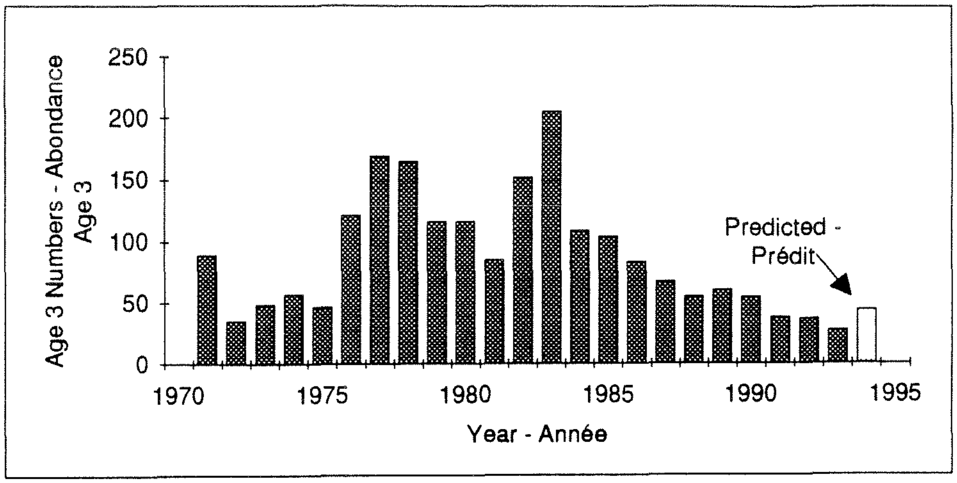


Figure 14: Recruitment estimates (millions of fish of 3 years of age) for the southern Gulf of St. Lawrence cod stock

### 3.3.5 Causes of decline

Several causes can be attributed to the decline in the abundance of the southern Gulf cod stock. The analyses suggest that the decline was first initiated by a decline in growth and in recruitment in the early to mid-1980s but was exacerbated by the high and increasing fishing mortality, which were exerted on the stock (Chouinard and Fréchet 1994) between 1988 and 1992. Given the decline in size at age and the abundance of incoming year-classes, even if fishing would have been stopped completely in the mid-1980's, the decline would still have occurred albeit not nearly as severe. Retrospective patterns in the assessments delayed detection of the decline. The various causes implicated in the decline are described below.

#### 3.3.5.1 Growth

Of all the cod stocks in the Canadian zone, the change in growth rate has been most pronounced for the southern Gulf cod. The average weight of an age 7 cod has been 50% lower in recent years compared to the mid-seventies (see Figure 10 in Biological Characteristics section). This may to be related to a number of factors including fishing, water temperatures and density-dependent causes.

The decline in size at age started in the late 1970s and early 1980s and continued to the late-

1980s. There has been a modest recovery since but weights at age are still well below the values observed in the mid-1970s.

The steady decline in weights at age led to overestimates of TACs. Catch projections assumed average weights at age but the observed weights were lower leading to a higher number of fish caught. The decline also had a very significant impact on the biomass of the stock. If the weights at age of cod in 1994 were similar to those in 1975, the biomass of the population this year would have been larger by a factor of two.

This decline in growth may have also affected the productivity in terms of recruitment. Reduced growth resulted in smaller spawning stock biomass. In general, a higher spawning biomass should increase the chances of more recruits. As spawning biomass decreases, good year-classes tend to appear less often. Since these year-classes will form the spawning stock in coming years, there will be a gradual decrease. In addition, there may be some advantage in having a spawning stock composed of larger fish since the fertility of eggs produced by larger females appears to be higher (E. Trippell, Biological Station, St. Andrews, N.B., pers. communication).

#### 3.3.5.2 Recruitment

There was a large decline in the size of the year-classes produced after 1980 despite the fact that the spawning biomass reached a peak of about 265,000 t in 1985. The average size of the year-classes produced from 1981 to 1990 was about half (63 million) that of those produced from 1971 to 1980 (123 million). Coupled with continuing high fishing effort, the situation is analogous to removing the same amounts from a bank account while only making half the deposits that were being made before. Inevitably, there will be a decline in the account. An increase in growth could have partially compensated for the decline in recruitment but the contrary was observed, which made the decline in biomass worse.

The lower recruitment observed indicates that the survival of young cod produced in the 1980's was considerably lower than that seen in the 1970's. There are no clear causes of this lower survival and it was likely caused by a combination of factors.

#### 3.3.5.3 Fishing Mortality

Fishing mortality remained relatively stable between 1982 and 1988 at around 0.5 to 0.6 (2 to 3 times $F_{0.1}$). As the stock abundance declined, fishing mortality increased substantially to over 1.0 (near twice the levels of the mid-1980's) by 1992. As can be seen in Figure 15, this increase in fishing mortality made the decline worse.

If fishing mortality had remained near the levels seen in the mid-1980's, the decline would have continued at a slower pace such that abundance would be about 50% higher than the present levels. If the $F_{0.1}$ target had been reached in 1986 and thereafter, the population would likely be about twice present levels.

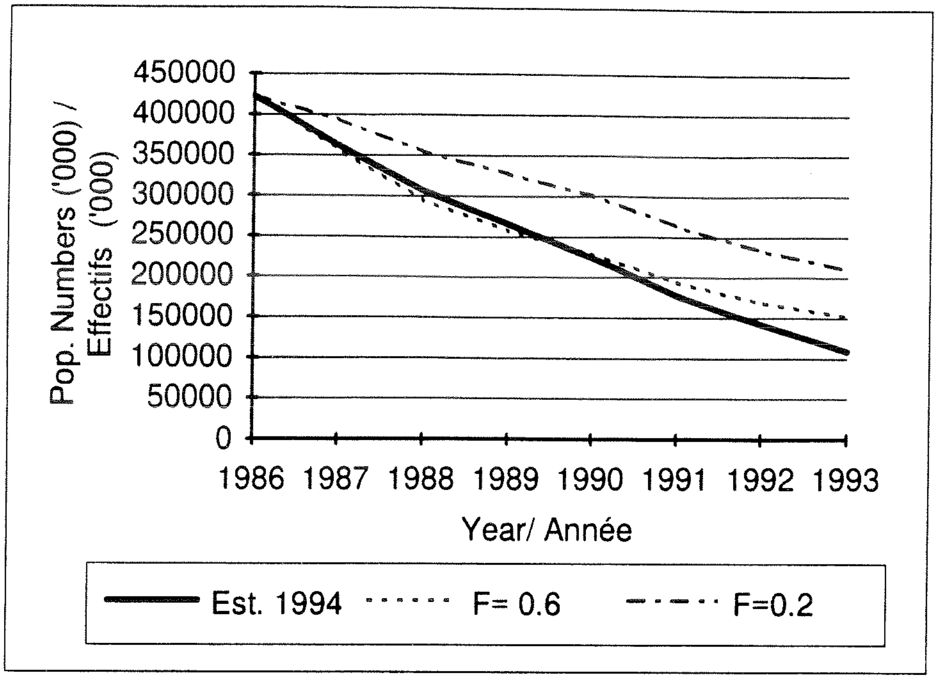


Figure 15: Estimated impact of the increase in fishing mortality on population abundance in late eighties and early nineties. (Est. 1994 is the estimated population at present, F=0.6 and F=0.2 are the estimated populations if fishing mortality had been kept at these levels since 1986

#### 3.3.5.4 Other causes

There are other factors which contributed to the decline. As mentioned above, changes in the environment likely contributed to the decline in growth and recruitment. A weak relationship between the discharge from the St. Lawrence River and an index of survival for cod in the southern Gulf has been reported by Chouinard and Fréchet (1994). In addition, recent cold conditions in the Gulf of St. Lawrence have sometimes been associated with poor recruitment in other areas.

The abundance of grey and harp seal populations has increased significantly recently. These seals prey upon a variety of marine life including cod. It is estimated that grey seals consume about 40,000 t of cod on the entire Atlantic Coast. Estimates of the grey seal consumption of both cod stocks from the Gulf of St. Lawrence (4RST) amounts to 18,000 t. Other species of seals, such as harp seals also include cod in their diets. Part of the harp seal population have their young in the Gulf of St. Lawrence during winter before migrating to Greenland in spring. Research to calculate consumption estimates for this species are underway.

## 3.4 Cod in Sydney Bight (4Vn summer)

### 3.4.1 History of the fishery

The cod fishery in 4Vn has traditionally supported a summer fixed gear fishery and a fall/spring mobile gear fishery, with the latter concentrating on 4T cod migrating through the region. Prior to 1989, the mobile fleet took over 80% of its annual allocation in the May-October period. However, after this date the proportion of annual landings taken during these months fell to less than 40% as catch in November and December became the dominant part of the landings. Based on recent analyses of both commercial and research data, the catch in November-December was mainly 4T cod. Cod caught in 4Vn from May-October are more likely to be resident fish. The longliners who catch these fish and whose fishing pattern, unlike draggers, has not changed over the years, have experienced a drastic decline in landings.

In 1992, the fishery in 4Vn was closed in December due to suspicions that most of the catch was 4T fish. In addition, the 1993 quota was lowered from 10000 to 1800 t in recognition of the serious decline in abundance of all local cod stocks. In 1993, mid-year assessment of stock status indicated no change, and the fishery was closed in September. A "test fishery" carried out in the fall of 1993 documented the movement of 4T cod through 4Vn beginning in November, and in conjunction with analyses of catches of previous years, prompted a change in the stock assessment unit from 4Vn (May-Dec) to 4Vn (May-Oct) in order to reduce the capture of 4T fish.

### 3.4.2 Biological Characteristics

The cod in 4Vn (May-Oct) probably represent a mixture of a small resident stock, 4Vs cod who have moved inshore to feed, and 4T cod who did not fully return to the Gulf during the annual spring return migration. As discussed in the Stock Structure section (3.2), it is not yet possible to discriminate between resident 4Vn fish and those from adjacent areas, particularly given the annual migration of 4T cod through the region each winter. Cod from western Cape Breton and 4Vn may be expected to be closely related, both genetically and morphologically. Any such similarity would complicate both the stock assessment and the study of 4Vn cod. Fishermen from Cape Breton report that they can identify cod from 4T and 4Vn by their length frequency, shape and colour. However, these characteristics have not yet been examined by scientists.

In many respects, 4Vn cod share many of the characteristics of their neighbours. Their growth rate is midway between that of 4T and 4Vs (Figure 16), and as has been observed in the neighbouring stocks, the length of cod of any given age has declined since the early 1980's (Figure 17). The net result of this decline in size at age is a decline in yield to the fisherman - a catch of 8-year old cod in 1990 would weigh slightly more than half that of the same number caught in 1980. The difference is less noticeable for the younger fish.

The inshore to offshore gradient in size of cod is similar to that of other regions. Smaller cod tend to be found in the shallower inshore regions, while larger cod are more plentiful offshore. During several years of inshore surveys, Lambert (1992) consistently found aggregations of juvenile cod in the vicinity of Bird Islands. Evidence of spawning, based on collection of eggs, was found in Bras d'Or Lake and in western Sydney Bight. However, the size of the spawning aggregation which produced these eggs could not be determined.

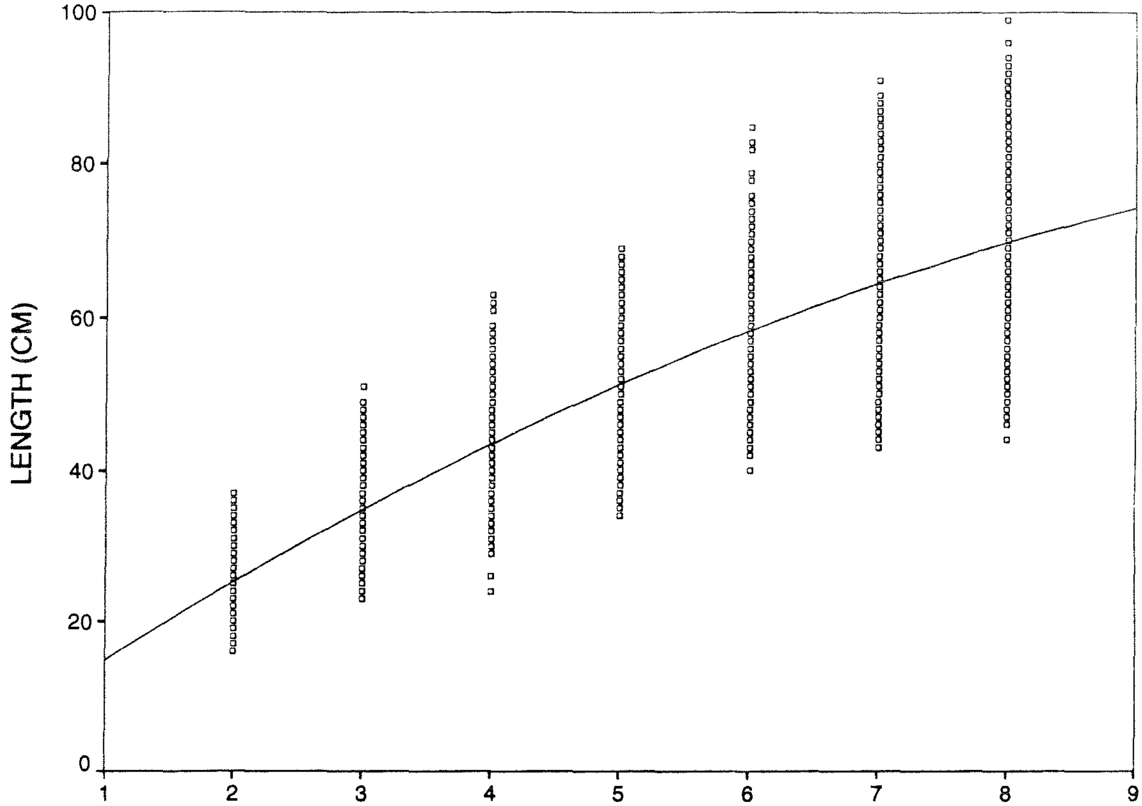


Figure 16: Mean length at age of 4Vn cod based on research surveys between 1970-92

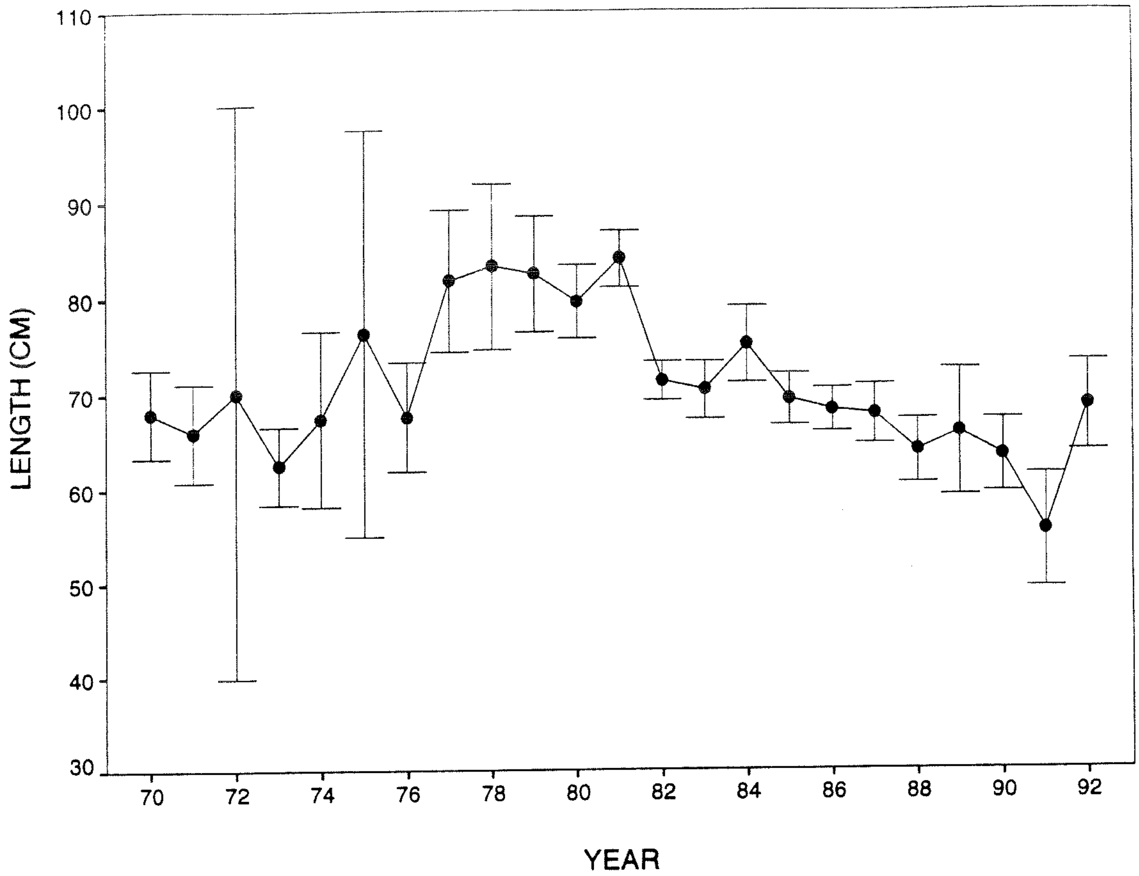


Figure 17: Changes in the average length of an age 8, 4Vn cod between 1970-92. The trend is similar, but less pronounced, for the younger age groups.

### 3.4.3 Summary of recent assessments and advice

Assessments of 4Vn cod are constrained by limited and confusing data: it is difficult to allocate fishermen's catches to stock in periods other than the summer; there is no effort data available for the small vessels making up most of the fixed gear catch; and there is a low number of research vessel stations in the area. As a result, assessments for this stock are considered less reliable than those of 4T or 4VsW.

In the early 1980's, advice on catch levels was based on production models fitted to commercial data. The estimates from these models were in excess of 10,000 t. The first estimates based on $F_{0.1}$ were produced in the mid-1980's, and suggested a reference catch level of about 6000 t. During this period, estimates of fishing mortality suggested that it was about twice the $F_{0.1}$ level. In the late 1980's, there was increasing uncertainty about the underlying data, resulting in a range of $F_{0.1}$ levels being presented. By the 1990's, catches fell significantly short of the TACs, and the fishery was closed.

Table 2. Summary of recent landings, TAC's and scientific advice for 4Vn cod. The units are thousands of tons.

| Year | Landings | TAC | CAFSAC Advice |
|---|---|---|---|
| 1986 | 11.8 | 12 | 10 |
| 1987 | 10.6 | 9 | 6 |
| 1988 | 9.0 | 7.5 | 6 |
| 1989 | 7.5 | 7.5 | 7.5 |
| 1990 | 5.1 | 7.5 | 7.5 |
| 1991 | 4.6 | 10 | 7.5-10 |
| 1992 | 4.5 | 10 | lower than 10 |
| 1993 | 0.7 | 1.8 | 1.8 |

### 3.4.4 Trends in abundance

The abundance of 4Vn cod appears to have declined considerably over recent years. Since 1990, the TAC has not been caught (Figure 18). Traditionally, the longline sector has never had much trouble catching their allocation; however, since 1990 they have caught less than half their allocation (Figure 18). In addition, longline catch rates and landings have declined since 1989 (Figure 18). Results of summer research vessel surveys of the region have been highly variable, so are of limited value in monitoring cod abundance in this region (Figure 18). However, total mortality has increased to very high levels over the past 5-10 years. Inshore surveys have also shown a decline in abundance, particularly of young fish.

### 3.4.5 Causes of decline

There are several contributing factors to the decline of cod in 4Vn, all of which are shared with adjacent stocks:

a) Overfishing - Fishing effort on resident fish probably exceeded what the stock could support; as abundance declined, the cuts in TAC were not sufficient to match what the stock could support. In addition, the increased emphasis on catching the Gulf cod as they migrated through the region almost certainly impacted the resident fish that were present. Any discarding or high-grading that occurred would make this problem worse. Fish that are killed but not landed produce the same effect as overfishing the TAC.

b) Environment - There has been a cooling of bottom water in 4T, 4Vn, and 4Vs since the mid-1980's, which appears to have reduced the survival and abundance of young fish. If the recent increase in water temperature continues, recruitment may eventually improve.

c) Seals - There is no documented impact of seals on 4Vn cod. However, with large grey seal populations in both 4Vs and the Gulf, and given the known predation of grey seals on 4Vs cod (Mohn and Bowen 1994), it appears likely that at least some 4Vn cod are eaten by seals.

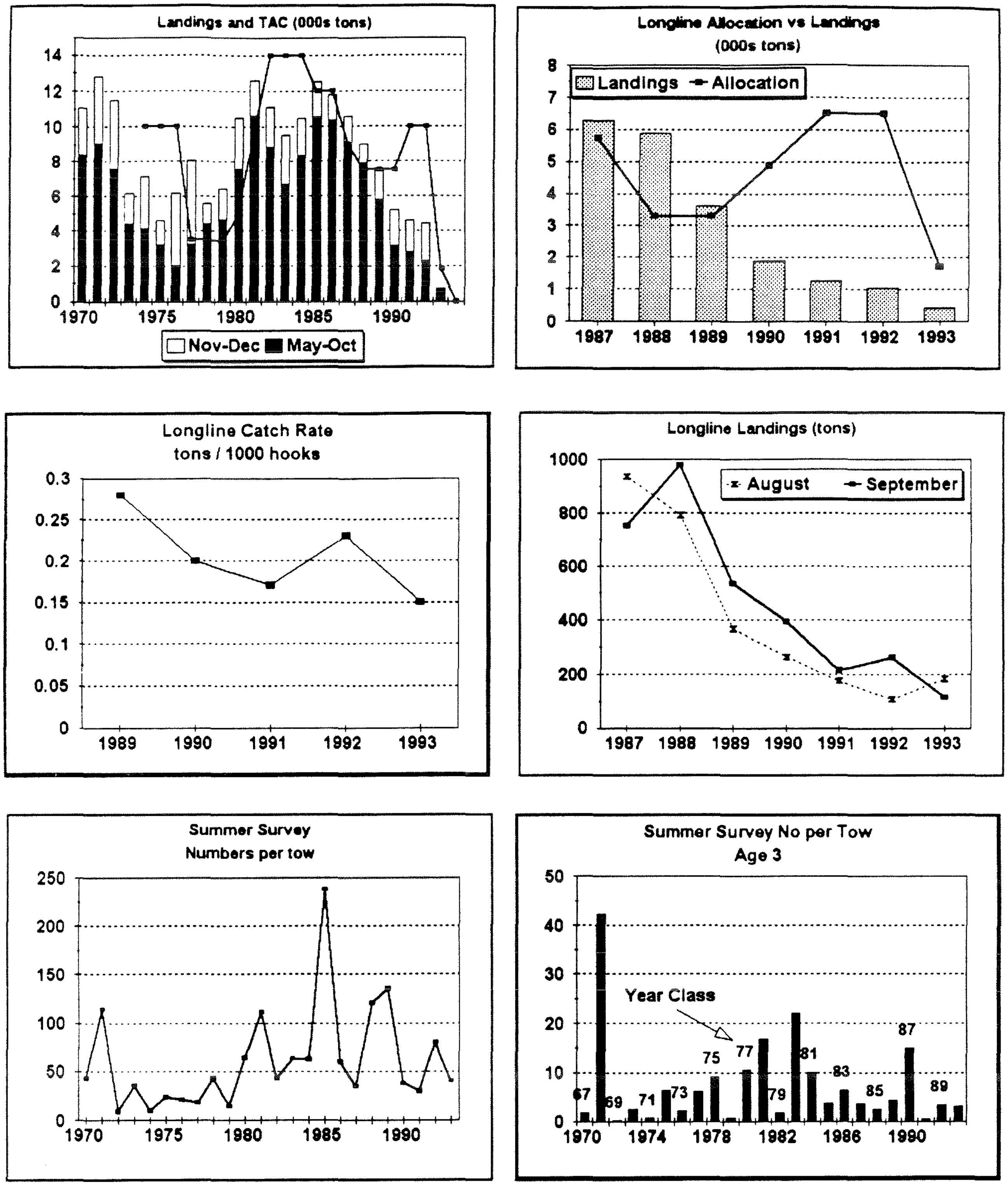


Figure 18: Landings and various indicators of 4Vn (May-October) cod abundance as reported in the most recent stock status report.

## 4. Perspective on the future - Matching fishing effort to stock potential

One of the key elements for an improved management of the fisheries in both the southern Gulf and Sydney Bight will be the ability to tailor fishing effort to the potential of these stocks. As discussed earlier, stocks will continue to fluctuate in response to natural variation in the environment and the parameters affecting fish production. However, if fishing effort is maintained at an appropriate level for the stock, the biomass will be higher on average and the fishery will be more viable in periods of lower abundance. A reduction in effort can be attained in different ways from having a pre-determined number of fishing days for the fleet to removing a number of vessels from the fishery.

It is possible to determine the level of effort that the stock can safely sustain. For a given stock, as we saw earlier, this level will generally be constant (although it may need to be adjusted because of technological improvements). Annual fishing effort could be monitored, much the same as catch, to ensure that over-exploitation does not occur.

The TAC's are established annually and are often based on the most recent assessment of the stock. Suppose that in a given year, an assessment gives an overestimate of stock abundance. If, in addition to the TAC, there is limit on the effort (let's say a season is established), the TAC will not be reached since it was too high relative to the real stock abundance. On the other hand, if the TAC is reached much earlier than the end of the season it is possible that the stock abundance was underestimated or that vessels got more efficient gear. A management strategy that would use both the TAC and the fishing effort restriction at a safe biological exploitation level would be safer than using only one or the other. In addition, an appropriate level of effort make other additional management measures (small fish protocols, strict enforcement of mesh sizes, etc) less critical to the maintenance of the stock.

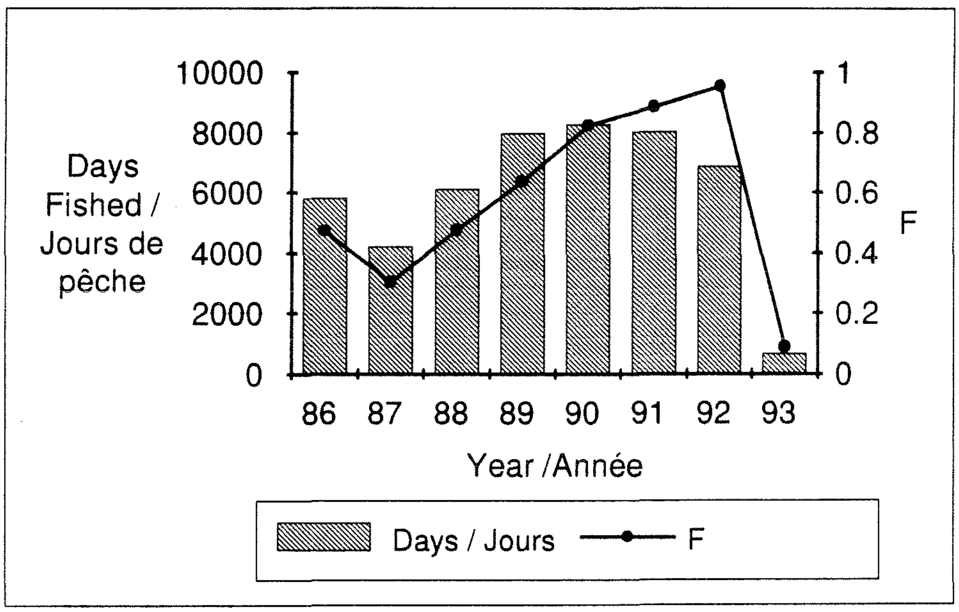


Figure 19: Trends in fishing mortality and nominal fishing effort for the mobile fleet in the southern Gulf of St. Lawrence

The recent decline in fishing effort and the resulting decline in fishing mortality by the mobile gear fleet has provided important information on the amount of fishing effort needed to fish at $F_{0.1}$ for the southern Gulf unit. In theory F and effort are proportional. A significant positive correlation was found between nominal fishing effort and fishing mortality for the mobile gear fleet (Figure 19). The implied relationship suggests that a target fishing effort for the mobile gear fleet may be in the order of one fourth the average of the period 1989-1992, in the order of 1750 fishing days distributed among fleets, areas, and seasons as in the past.

Unfortunately there is little information presently available on the total amount of fishing effort by the fixed gear fleet and it is not possible to estimate a target fishing effort. However, it has been possible to estimate the level of fishing mortality exerted by this fleet. The results indicate that the fixed gear F in the period 1989-92 was, on average, equivalent to that needed to harvest 25% of a TAC set at $F_{0.1}$.

Future yields for the southern Gulf stock will depend on recruitment and growth rates. We are not able to predict these into the future with any degree of confidence. In order to provide a range of possible future yields several scenarios were tested. These included two possible recruitment levels, a short term average (1991-1994) of 36 million at age 3 and a long term average of 87 million (1971-1994). Three sets of weights at age were also used, the 1971-1980 period where the growth rates were relatively high, the 1981-1990 period where growth rates were intermediate, and the recent past (1991-1993) when the growth rates were the lowest. The yields ('000 t) for a fishing mortality of F = 0.2 are summarized below.

| | Weight at Age | | |
|---|---|---|---|
| Recruitment | 1971-1980 | 1981-90 | 1991-93 |
| Recent | 28 | 16 | 13 |
| Long-Term | 67 | 39 | 33 |

If current conditions persist, i.e. that recruitment and growth remain depressed, the long term average yield at F = 0.2 is 13,000 t. This increases to 28,000 t if the weights at age return to the levels observed in the 1970's. If recruitment returns to the long-term average and weights at age remain the same, the long term average yield is 33,000 t. If growth rates improve the yield is 67,000 t.

There is likely to be a trade-off between abundance (determined by recruitment) and growth rates. Conditions of high abundance and high growth rates are unlikely. Similarly, growth rates would be expected to increase at low abundance. However, this has not been observed in the recent past. If we eliminate the extremes in the table above, a possible range of yields, after the stock has recovered, would be 20,000 to 40,000 t in the long term . This is the level of fishing that was sustained during the period 1917-1940.

## 5. References


Anonymous. 1917-1949. Fisheries Statistics of Canada, Ottawa. Canada

Anonymous 1994. 1994 Gulf Region stock status report for groundfish and herring. Can.Man. Rep. Fish. Aquat. Sci. No. 2244.

Brawn, V. M. 1962. Reproductive behaviour of the cod (Gadus callarias L.). Behaviour 18: 177-198.

Brunel, P. 1962. Variations journalières et saisonières de l'alimentation de la morue au large de Grande-Rivière en 1960-61. Rapp. ann. 1961, Sta. Biol. Mar. Grande-Rivière, p. 85-196.

Buzeta, M.-I., and K. G. Waiwood. 1982. Fecundity of Atlantic cod (Gadus morhua) in the southwestern Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. No. 1110. 6 p.

Campana, S. E., J. A. Gagné and J. I. McLaren 1995. Elemental fingerprinting of fish otoliths using ID-ICPMS. Mar. Ecol. Prog. Ser. In press

Chaussade, J. 1983. La pêche et les pêcheurs des provinces maritimes du Canada. Presses de l'Université de Montréal, 303 p.

Chouinard, G. A. and A. Fréchet. 1994. Fluctuations in the cod stocks of the Gulf of St. Lawrence. ICES mar Sci. Symp. 198:121-139

Chouinard, G. A., J. M. Hanson and G. A. Nielsen. 1991. Definition of juvenile areas for the 4T-Vn (January-April) cod stock. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 91/6. 23 p.

Chouinard, G.A., J. M. Hanson and G. A. Nielsen 1992. Examination of the status of the southern Gulf of St. lawrence cod stock following the 1992 fall groundfish survey. CAFSAC Res. Doc. 92/105 , 30 p.

Clay, D. 1991. Seasonal distribution of demersal fish (Osteichthyes) and skates (Chondrichthyes) in the southeastern Gulf of St. Lawrence, p. 241-259. In. J.-C. Therriault [ed.] The Gulf of St. Lawrence: small ocean or big estuary? Can. Spec. Publ. Fish. Aquat. Sci. 113.

D'Amours, D., K. T. Frank and G. Bugden. 1994. Report of the working group on oceanographic effects on stock migration and mixing - reviewed by the Fisheries Oceanography Committee (FOC). DFO Atl. Fish. Res. Doc. 94/54. 52 p.

de la Morandière, C. 1962. Histoire de la pêche française de la morue dans l'Amérique Septentrionale. Tome I, Maisonneuve et Larose, Paris, 507 p.

de la Villemarqué, J. H. 1990. Les pêches françaises du XVI au XVIIIe siècle - relations avec le climat (1 re partie). Equinoxe, 33:35-41

DFO. 1980. Rapporteur's Report (Final version) , Gulf Groundfish Seminar, Memramcook, N.B. September 23-25, 1980

Fréchet, A. 1990. Catchability variations of cod in the marginal ice zone. Can. J. Fish. Aquat. Sci. 47: 1678-1683.

Grégoire, F., and M. Castonguay. 1989. L'alimentation du maquereau bleu (*Scomber scombrus*) dans le golfe du St-Laurent et sur le plateau néo-écossais, avec une application du test de Mantel. Can. Tech. Rep. Fish. Aquat. Sci. 1673F. 23 p.

Halliday, R. G. and A. T. Pinhorn 1982. The Groundfish resource in the Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 1086: iv + 16 p.

Hanson, J. M. 1994. Preliminary estimates of biomass of commercially important species eaten by Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence, 1992 and 1993. DFO Atl. Fish. Res. Doc. 94/45. 16 p.

Hanson, J.M. 1995. Separation of catches of two Atlantic cod stocks in an otter trawl fishery by application of the EM algorithm. N. Am. J. Fish Manage. (in press)

Hanson, J. M. and G. A. Chouinard. 1992. Evidence that size-selective mortality affects growth of Atlantic cod (*Gadus morhua* L.) in the southern Gulf of St. Lawrence. J. Fish Biol. 41: 31-41.

Hanson, J. M. and G. A. Nielsen. 1992. Catches of 4T-Vn (Jan.-Apr.) cod in the 4Vs winter fishery, 1986-1992. CAFSAC Res. Doc. 92/51:31 p.

Jean, Y. Seasonal distribution of cod (*Gadus morhua* l.) along the Canadian Atlantic coast in relation to water temperature. J. Fish. Res. Board Can. 21: 429-460.

Kohler, A. C. 1975. Recoveries from 1969 cod tagging in ICNAF Division 4Vn. ICNAF Res. Doc. 75/91.

Kohler, A. C., and D. N. Fitzgerald. 1969. Comparisons of food of cod and haddock in the Gulf and on the Nova Scotia banks. J. Fish. Res. Board Can. 26: 1273-1287.

Lambert, T.C. 1992. Suddivision 4Vn cod (May-December): update of stock status for 1991. CAFSAC Res. Doc. 92/81.

Lambert, T.C. 1993. The timing of the winter migration of 4T cod into 4Vn. CAFSAC Res. Doc. 93/25.

Lambert, T.C. and S. Wilson 1994. Update on the status of 4Vn cod: 1992-1993. DFO Atl. Fish. Res. Doc. 94/46,26 p.

Lett, P. F. 1980. A comparative study of the recruitment mechanisms of cod and mackerel, their interaction and its implication for dual stock assessment. Can. Tech. Rep. Fish. Aquat. Sci. No. 988. 51 p.

Lett, P. F., A. C. Kohler, and D. N. Fitzgerald. 1975. Role of stock biomass and temperature in recruitment of southern Gulf of St. Lawrence Atlantic cod, *Gadus morhua*. J. Fish. Res. Board Can. 32: 1613-1627.

Martin, W. R., and Y. Jean. 1964. Winter cod taggings off Cape Breton and offshore Nova Scotia banks, 1959-62. J. Fish. Res. Board Can. 21: 215-239.

McKenzie, R. A. 1956. Atlantic cod tagging off the southern Canadian mainland. Bull. Fish. Res. Board Can. No. 105. 93 p.

Mohn, R. and W.D. Bowen. 1994. A model of grey seal predation on 4VsW cod and its effects on the dynamics and potential yield of cod. DFO Atl. Fish. Res. Doc. 94/64.

Paloheimo, J.E., and A. C. Kohler 1968. Analysis of the southern Gulf of St. Lawrence cod population. J. Fish. Res. Bd Canada, 25(3):555-578

Parsons, L. S. 1993. Management of marine fisheries in Canada. Can. Bull. Fish. Aquat. Sci. 225:763 p.

Powles, P. M. 1958. Studies of reproduction and feeding of Atlantic cod (*Gadus callarias* L.) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Board Can. 15: 1383-1402.

Sinclair, A. F. and L. Currie. 1994. Timing of cod migration into and out of the Gulf of St. Lawrence based on commercial fisheries, 1986-1993, DFO Atl. Fish. Res. Doc, 94/47, 18 p.

Sinclair, A, G.A. Chouinard, D. Swain, R. Hébert, G. Nielsen, M. Hanson, L.. Currie and T. Hurlbut 1994. Assessment of the fishery for southern Gulf of St. Lawrence cod: May 1994. DFO Atl. Fish. Res. Doc, 94/77, 116 p.

Solemdal, P. and S. Sundby. 1981. Vertical distribution of pelagic fish eggs in relation to species, spawning behaviour and wind conditions.

Swain, D. P. 1993. Age- and density-dependent bathymetric pattern of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 50: 1255-1264.

Swain, D. P., & E. J. Wade. 1993. Density-dependent geographic distribution of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 50: 725-733.

Templeman, W. 1962. Divisions of cod stocks in the Northwest Atlantic. ICNAF Redbook III:79-123.

Tremblay, M. J. and M. Sinclair. 1985. Gulf of St. Lawrence cod: age-specific geographic distributions and environmental occurrences from 1971 to 1981. Can. Tech. Rep. Fish. Aquat. Sci. No. 1387. 43 p.

Waiwood, K. G. 1981. The predatory impact of cod in the southern Gulf of St. Lawrence ecosystem - a preliminary account. ICES C.M. 1981/g:43. 16 p.

Waiwood, K. G., and R. W. Elner. 1982. Cod predation on crab in the Gulf of St. Lawrence. In. The International Symposium on the Genus *Chionectes*. Alaska Sea Grant Report 82/10. 13 p.

Waiwood, K. G., and J. Majkowski. 1984. Food consumption and diet composition of cod, *Gadus morhua*, inhabiting the southwestern Gulf of St. Lawrence. Environ. Biol. Fishes 11: 63-78.