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Some Effects of Bottom Trawling on the Availability of Cod Biomass

to an Inshore Longline Fishery: a Discussion

by

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ABSTRACT

A fundamental assumption of fisheries science holds that fishing effort is the only significant variable control on the abundance of typical marine commercial fish resources, such as Atlantic cod, that acts after the age of recruitment. Such effort is supposed to affect the resources only via the fishing mortality that it imposes. This simplified conceptual model is not shared by commercial fishermen, who believe that a much wider range of factors influence abundance. In this paper, a subset of fishermen's views, specifically those advanced by Nova Scotian longline fishermen concerning the effects of bottom trawling on cod abundance, are examined. Most of these ideas have been considered and dismissed in past scientific reviews and, in many cases, those rejections are supported here. I do, however, suggest that trawling may have adverse effects on cod production and availability through either or both of the destruction of specific, prefered bottom habitats off Nova Scotia and the physical disturbance of the fish's behaviour patterns. I therefore suggest that a wider range of mechanisms linking fishing effort to the depletion of cod resources should be considered in fisheries management. Further, while the longline fishermen's arguments against trawling that are based on population dynamics do not bear critical examination, I suggest that there are two mechanisms by which trawling may have a disproportionate effect on the abundance of cod available to longlining. These mechanisms are examined by modelling of the cod fishery in western NAFO Division 4Vn. The first of them, the spatio-temporal concentration of trawling effort on those components of the resource that are available to longlining, does not appear to be significant for this fishery. However, the difference in partial recruitment vectors of the two gears, which allows the trawlers to exploit heavily a year class before it is markedly available to longlining could have important consequences for management. I therefore suggest that, even where fishing effort impacts on the resource via fishing mortality, a more complex view of that mechanism should be incorporated into stock assessments and, particularly, management practises.

INTRODUCTION

Fisheries scientists have long assumed that the predominant controls on variations in the abundance of many exploited marine fishes, such as Atlantic cod (*Gadus morhua*), are exerted by short-term meteorological and oceanographic conditions, acting on the planktonic stages, and by fishing mortality, acting on the recruited age classes Non-scientists, including some fishermen and fishery managers, have often supposed, however, that a much wider range of factors, such as habitat destruction, behavioural disturbance of spawning fish and a lack of prey for adult fish, can contribute to decreases in resource abundance. Most of these latter ideas have been disregarded by the scientific community, either because they lack merit (as many do) or because the data and models available for the generation of management advice are suited only to the consideration of single-species, yield-per-recruit considerations, in which fishing mortality and its distribution across age classes are the only controllable variables. In this paper, I attempt to extend discussion of the factors that control variations in cod abundance beyond the conventional assumptions of fisheries science by examining a sub-set of non-scientists' ideas, specifically those advanced by Nova Scotian inshore longline fishermen concerning the supposed effects of bottom trawling on gadoid resources[1].

During 1990-1, I carried out a survey of the groundfish longline fishermen of Canada's Scotia-Fundy Region, on behalf of the Department of Fisheries and Oceans (Kenchington 1991). This survey was designed to gather information on longline boats, gear and fishing practices but the fishermen also offered comments on many other issues, not least the perceived disadvantages of trawlers, which most interviewees regarded as the most serious problem facing their resources. Some of the points raised on this topic would be familiar to the managers of mixed trawl/longline fisheries, many of whom have long experience of such conflicts between resource user groups defined by fishing gear types. However, the interview-format of this survey made it possible to discuss these issues at length and thus to reach behind the fishermen's attempts to articulate their ideas to discover what they were really trying to say, which was often not quite what it first appeared to be. The final result was a complex of, sometimes mutually contradictory, opinions, of which only the most frequent can be discussed here. After some refinement and translation into the terminology of fisheries science, they included:

> Trawling damages the seabed, destroying the macrobenthos, smoothing out bottom topography and changing the surficial sediment from cobble- or gravel-sized particles to mud, thus reducing the habitat's ability to support the resource (with particularly serious consequences when the spawning grounds are damaged in these ways) or, perhaps, to attract and concentrate the fish,

> Trawling chases the fish, breaking up their schools and altering their behaviour, with deleterious consequences for both feeding (and hence growth) and spawning,

> The damaged seabed and/or the chasing of the fish reduce their

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[1] The fishing method that is internationally-known as "bottom trawling" is always called "fish dragging" by Nova Scotian fishermen. Equally, they usually reserve the term "longlining" for pelagic fishing and demersal fishing by large, specialized boats. Lines of hooks set from inshore, multi-purpose boats are generally called "trawl". To avoid confusion, the internationally-accepted terminology is used throughout in this paper.

tendency to take a baited hook, thus lowering their catchability by longlining.

Trawling wastes the resource by catching small fish before they have had a chance to grow and to spawn, by catching many small fish that cannot profitably be landed (and hence are discarded) and by being unable to take the fish without damaging their quality and their price,

Trawling destroys the spawn on the bottom,

Trawling is not labour intensive and thus creates fewer jobs from the resource than does longlining, and

Trawlers often damage longline gear or, by the threat of such damage, exclude longliners from certain fishing grounds.

The remedy most often suggested, by the longline men, for all of these perceived problems is the exclusion of bottom trawlers from the inshore, hard-bottom grounds, which are the only areas where small longline boats can work.

While most of these claims are known, to a greater or lesser extent, by fisheries scientists and managers, they have generally been ignored both in the development of fisheries management plans and in the framing of research priorities. This is not entirely inappropriate since some of the longline men's claims seem too fantastic to be believable, others are simply wrong and all of them can appear to be an endless repetition of a self-interested position. The claim that bottom trawling destroys cod spawn on the spawning grounds, for example, was advanced before an English Royal Commission in the mid-nineteenth century. Yet, as early as 1865, G.O.Sars showed that some gadoids have planktonic eggs (Russell 1976); a conclusion that had been extended to most of the major commercial species by the end of the century (e.g. M'Intosh and Masterman 1897). Modern longline fishermen's continued ignorance of this early (and conclusive) research adds nothing to the credibility of their other claims.

The suggestion that trawling can make major alterations to bottom topography and sediment type, resulting in significant negative impacts on fish production, seems at first sight to require such support; while Nova Scotian longline men frequently liken the effect of a trawl net to that of a bulldozer on agricultural land, direct studies of otter board and groundrope effects on the seabed suggest a much lighter impact (e.g. Caddy 1973; Main and Sangster 1979; Gibbs *et al.* 1980; de Groot 1984; Van Dolah *et al.* 1987; West 1987).

The claim that trawlers destroy excessive numbers of small fish is another long-standing one and can be traced back as far as a petition to the English king in the mid-fourteenth century (de Groot 1984). Except in extreme cases, however, cod resources are not in danger of recruitment overfishing and, indeed, they do not usually show any marked link between spawning biomass and future recruitment. Increasing the age-at-first capture to some value greater than the age-at-first maturity will not, therefore, usually aid future recruitment. Meanwhile, the complex interactions between age-at-first capture, fishing effort, fish growth and natural mortality have already been optimized for most cod resources (at least in theory) through the use of yield-per-recruit models. In Canadian waters, the Total Allowable Catches (TACs) are based on the $F_{0.1}$ criterion which should ensure that neither recruitment- nor growth-overfishing of cod can occur through the capture of small fish, unless the regulated minimum sizes and maximum catches are evaded by the fishing industry. That such evasion does occur is

an important issue for fisheries managers but not one that is likely to conceal any new scientific insight to which the longline men might contribute.

With these several claims rejected, the objections of longline men to trawling could easily be perceived as no more than a series of inter-human rivalries: the supposed higher quality of hook-caught fish and the greater number of jobs created by a labour-intensive fishing method *versus* the more reliable supply and better profitability of trawling, the desire of each group of men to reserve for themselves as much of the resource and the grounds as they can and so on. Such rivalries are not usually the concern of fisheries science and are relegated to being matters of allocation. In Canada, they are handled by permitting fishing with all conventional gears, dividing the TAC for each stock into gear-specific quotas on the basis of historically-established proportions, and allowing each sector of the fishery to fish its quota throughout the range of the appropriate stock (except that certain gears are excluded from a few, traditional closed areas: Halliday 1988).

With the sole exception of the claimed destruction of spawn, however, the rejection of the longline men's objections has little more rational foundation than do those objections themselves. Only commercial fishermen have made extensive empirical observations of the long-term effects of trawling on the benthos and their evidence should be examined in detail before it is rejected. The effects of trawling on fish behaviour have probably been passed over by scientists for no better reason than the lack of appropriate ethological research on temperate marine fishes that could confirm or refute the hypotheses. Most importantly, the fishermen's lack of understanding of fishery dynamics, which causes them to make improbable specific claims of some effects of trawling, also prevents them from articulating their more general concerns in terms easily comprehendible by scientists. Such ignorance of arcane theory is not, however, grounds to reject the concerns themselves.

In this paper, therefore, I explore two of the longline fishermen's objections to bottom trawling and two possible mechanisms by which trawl fishing might have a disproportionate, though direct, effect on the resources available to longlining. Since these discussions are based on claims made about the effects of trawling, they necessarily accept the conventional scientific assumption that fishing effort (in this case that caused by trawlers) is, after the age of recruitment, the primary control on cod abundance. They lead, however, to the suggestion that that effort may not act exclusively, nor even primarily, through fishing mortality. Even where that is the pathway, more complex relationships than those normally considered in calculating TACs may be active. I therefore suggest that a broadening of conventional assumptions about the controls acting on cod abundance is required.

While some of what follows may be of general relevance, I illustrate my arguments with specific reference to the fisheries for cod in the western part of NAFO Division 4Vn. Those fisheries are a particularly clear example of some of the issues to be considered and thus they can serve as a convenient model. A brief description of them follows.

THE COD FISHERIES OF WESTERN DIVISION 4Vn

The cod resources of Division 4Vn (see Figure 1) have, for many years, been managed in two units. Those fish present in the winter (January to April, inclusive) are considered to be part of the southern Gulf of St.Lawrence

stock [officially 4TVn(Jan.-Apr.) cod], which migrates eastward for the colder months. The fish present in the summer are treated as a distinct, resident, stock [4Vn(May-Dec.)] which is thought to either disperse to the southward for the winter or to remain in Sydney Bight (Sinclair and Smith 1984). In either case, it would represent a minor part of the cod resources fished in Division 4Vn during that season.

The local fishermen have rather different beliefs about the movements of the cod that they catch. Those who work out of harbours on the western shore of Sydney Bight (part of Victoria County, Nova Scotia) claim that their only substantial cod resource comprises a single run of fish which leaves the Gulf of St.Lawrence late in September, moving onto both the inside grounds (along the Victoria County shore) and Smokey Bank, in the centre of the Bight. Those fish are available to the inshore longliners until December, when a combination of bad weather and sea ice closes the small-boat fishery until the spring (Kenchington 1991). While this supposed movement of fish out of the Gulf early in the fall contradicts the assumptions of current management plans, it is consistent with the very limited amount of tagging data available. No cod tagging program has yet been carried out in the western part of Division 4Vn in the fall and so there is no direct evidence as to whether or not the fish in this run spend their summers in the Gulf. Recent tagging studies in Division 4T (with the exclusion of an experiment in late fall, when the supposed run of fish would already have been in Division 4Vn) have seen 11% of the returns being from the 4Vn(May-Dec.) unit, most of those 11% having been taken in the fall. In their review of these studies, Sinclair and Smith (1984) indeed saw this as evidence for a movement of Gulf cod into Division 4Vn in October and November. Similarly, an earlier study, in which fish were tagged off the west coast of Cape Breton in July 1937, led McKenzie (1956) to conclude that cod move from the easternmost part of the Gulf of St.Lawrence into Sydney Bight as early as November; a conclusion that matched the ideas of the fishermen of his day as much as of those who work the grounds now. Thus, it appears that the Victoria County fall cod fishery does indeed exploit an early migratory run of Gulf of St.Lawrence cod.

The cod fishery in the western part of Division 4Vn is composed of a number of semi-discrete units. The smallest boats (10 metres maximum length) work close along the shore, inside the 80 fathom contour, using handlines and longlines. The seaward limit of their grounds is determined by a transition from coarse surficial sediments to mud, since cod will not usually bite a baited hook on the latter type of bottom. A second group of boats, typically rather larger than the first, work the same gears and the same grounds but also extend their activities beyond the mud-floored "Gutter" to fish Smokey Bank and other grounds still further away. A third group of longliners, comprised mostly of larger boats, moves to the grounds off eastern Victoria County, from home ports elsewhere in Canada, specifically to fish the fall run of cod. Finally, a varied group of trawlers (and some Danish seiners) of a range of sizes, pursue these same fish throughout their migrations. It is important to note that, while the differences in seaworthiness of various sizes of longline boats allow them to exploit different grounds, no hook-and-line fisherman can catch cod on areas with "soft" sediments (Kenchington 1991). The grounds potentially-available to longliners are, therefore, limited in extent.

In 1989, the total hook and line catch of cod in all of Division 4Vn during the fall was about 1500 tons, while the trawlers and seiners landed only some 200 tons of cod from this same period and area (Lambert and Smith 1990). The total mobile gear landings from the 4TVn(Jan.-Apr.) cod complex were, however, in excess of 43,000 tons (Choulnard et al 1990) and it may be supposed that the total landings, summed through the year, from the group

of fish vulnerable to the fall fishery off Victoria County greatly exceed 2000 tons. The overall fishing mortality rate on 4TVn(Jan.-Apr.) cod is about 0.25, while that on 4Vn(May-Dec.) cod is above 0.35 (Smith and Lambert 1989; Chouinard *et al.* 1990). The fish vulnerable to the fall fishery off Victoria County therefore probably suffer a fishing mortality, summed through the entire year, of something between 0.2 and 0.4, depending on how intensively that component of the overall resource is targeted relative to other components.

The fall longline fishery in Division 4Vn is clearly very small by international standards. It is, however, of great (if local) social importance in an isolated, mountainous area where the only source of productive employment outside the fisheries is the tourist industry. Within the fishing industry, the only resources available to local fishermen, other than these cod, are lobster and snow crab. Both of those are regulated by short open seasons, such that they do not provide enough weeks of work for the fishermen to qualify for Unemployment Insurance, without which the fishermen's families could not survive the ice-bound winter. Thus, the cod fishery, limited as it is, is vital to the local economy. The sum of similar, local fisheries comprise a substantial fraction of the total fishing industry of Atlantic Canada, even though each alone seems insignificant.

INTRA-MANAGEMENT UNIT DISTRIBUTION OF FISHING EFFORT

Although the longline fishermen's population dynamic-based arguments against the capture of small fish by trawling are not valid in properly-managed gadoid fisheries, there are two mechanisms by which fishing mortality exerted by trawling might have a disproportionate effect on the abundance of cod available to longlining. The first of these relates to the degree to which the trawlers focus their activity on those particular components of the resource that are vulnerable to longlining.

Even if it is assumed that a management unit, such as the 4Vn(May-Dec.) cod, coincides with a genetic stock and hence that pre-recruits are freely exchanged throughout the unit, in the short term it is still inevitable that fish which happen to be on the longline grounds can be caught there, whereas those which happen to be elsewhere cannot be taken by longlining. If trawling were to be forbidden on the longlining grounds, as many longline fishermen have requested, there would be some small increment in the biomass of fish available to the longliners. If, on the other hand, the trawlers chose to fish primarily on the grounds that are also fished by longliners, there would be some local reduction in the latter's available resources. This effect would clearly be magnified if the resource population was spatially structured within the management unit, such that hereditary, environmental or even chance factors encouraged individual fish to reside in particular areas.

The possible magnitude of this effect, as it applies to the Victoria County inshore longline fishery, was investigated by modelling.

A Model
The fishery system comprised of the fall run of cod in Division 4Vn and the fisheries that exploit it can be modelled, at the expense of some simplification, as comprising one resource, two seasons, three fishing grounds and four sources of mortality. In this model, the fish spend most of the year on one ground (representing the Gulf of St.Lawrence, with Sydney Bight in the winter only) where they are vulnerable both to natural mortality and to fishing by boats external to the model [the 4TVn(Jan.-Apr.) fleet]. In the fall, these fish migrate around Cape North and either move onto

the inshore grounds or head southeast onto Smokey Bank. The mud-floored "Gutter" between these two grounds is here treated as being unsuitable habitat for cod (rather than simply unsuitable for cod fishing). During the short fall season, which is here assumed to occupy 30 days, natural mortality is minimal and can therefore be disregarded. There are, however, two fisheries: an inshore one that can only work the inshore grounds and an offshore fishery that can fish on both the inshore and Smokey Bank grounds. To isolate the spatial effects of present interest from other issues, both fisheries are here given the same partial recruitment vectors. In effect, these two fall fisheries are modelled as though they both use the same mix of gears (longlines and trawls) and hence differ only in the grounds fished. To simplify the modelling further, it is assumed that the area of the inshore grounds and the amount of cod present there are negligible, when compared to Smokey Bank and its fish.

If the inshore component of the resource is of negligible abundance, then the dynamics of the Smokey Bank component can be modelled in isolation. Following the conventional exponential model for fish survival, the numbers-at-age on Smokey Bank at the start of any given day of the season, except the first, are :

$$N_{\tau,s,t} = N_{\tau,s,t-1} \cdot e^{-(F_0 \cdot p_\tau)/30}$$

where. $N_{\tau,s,t}$ is the number of fish of age τ on Smokey Bank at the start of day t, F_0 is the fully-recruited fishing mortality exerted by the offshore fishery during the fall season (expressed as an annual rate), p_τ is the partial recruitment for fish of age τ and the divisor, 30, provides the daily mortality rate. (Thus, the fishery is assumed to exert the same effort each day of the fall season.)

The numbers-at-age at the start of the first day of the season are the numbers of survivors from the previous age class at the end of the fall season of the previous year. Assuming static equilibrium conditions and constant recruitment, as in the conventional stable age distribution assumption of yield-per-recruit dynamics :

$$N_{\tau,s,1} = N_{\tau-1,s,31} \cdot e^{-(F_g + M)}$$

where: F_g is the fishing mortality exerted by all fisheries in all areas outside the fall season (the "Gulf fishery") and M is the rate of natural mortality.
In order to express all output in "per-recruit" equivalents, $N_{3,s,1}$ is set at unity; 3 yr being the age-at-first capture in the partial recruitment vector used (see below).

To include the inshore grounds in the model without needing to know the relative areas of the grounds or the abundances of the fish on each one, the various $N_{\tau,x,t}$ can be redefined as the density of numbers-at-age on each ground, rather than the absolute numbers. With that modification, the cod on the inshore grounds can be incorporated in the model, linking them to those on Smokey Bank by three processes: (1) as each fish migrates around Cape North at the start of a fall season, it can either return to the ground that it left at the end of the previous fall or it can go to the other ground, (2) at the start of any day during the season, each fish can remain where it is or can move across The Gutter to the other ground, and (3) the offshore fleet exerts fishing effort on each unit area of the inshore ground that is some fixed proportion of the effort-per-unit-area that it exerts on Smokey Bank, which proportion can be as small as zero or can be greater than unity. The inshore fleet is, of course, confined to the inside grounds.

If it is then assumed that recruitment per unit area is equal on the two grounds (such that $N_{3,i,1}$ is unity), the density of numbers-at-age on the inshore ground at the start of any day of the season other than the first can be represented as :

$$N_{\tau,i,t} = (1-E_i).N_{\tau,i,t-1} . e^{-[(F_i + \phi F_o)p_\tau/30]} + E_s.N_{\tau,s,t}$$

while that on the first day is :

$$N_{\tau,i,1} = \{N_{\tau-1,i,31} . P_i + N_{\tau-1,s,31} . (1-P_s)\} e^{-(F_g + M)}$$

where: i indexes for the inshore ground and fishery (as appropriate), ϕ relates the density of effort by the offshore fleet on the inshore ground to that on Smokey Bank, E_i and E_s are the daily rates of exchange of fish across The Gutter, between the inshore and Smokey Bank grounds, and P_i and P_s are the probabilities that a surviving fish which left the inshore or Smokey Bank grounds, respectively, at the end of the previous season will return at the start of this season to the same ground.

If the probability of an individual fish returning to the near vicinity of its previous location is independent of whether that location is inshore or on Smokey Bank, then the proportion of Smokey Bank fish that return to some part of Smokey Bank should be larger than that for the inshore grounds by the ratio of the areas of the two fishing grounds. Expressed in terms of number density, therefore, P_i and P_s are equal and can both be represented by a single parameter, P. Equally, if the rates of daily emigration from the inshore and Smokey Bank grounds are related as the inverse of the areas of those grounds (fish on the larger ground being more likely to move within that ground than to cross The Gutter, even if the latter is no obstacle), then E_i and E_s can be replaced by the single parameter, E, given that these equations are all in terms of per unit area. This latter relationship is indeed essential if these is to be no net flow of biomass across The Gutter in an unfished, equilibrium condition.

From the density of numbers-at-age on each ground for each day of the fall season, it is simple to calculate the average abundance density across time and, given a vector of weights-at-age, to obtain the average biomass density on each ground during the season (on a per-recruit, equilibrium basis).

This model was implemented on spreadsheet software (using Microsoft Excell™ on a Macintosh™ computer). M was given the conventional value of 0.2 and F_g was also set at 0.2, that being both approximately the $F_{0.1}$ value and somewhere between 50 and 100% of the total fishing mortality experienced by these fish (see above). The vector of partial recruitments and that of weights-at-age were drawn from Smith and Lambert's (1989) recent assessment of the 4Vn(May-Dec.) cod, the latter vector being taken as the average of the weights-at-age across the years 1982-9 (see Table 1). Although it is here supposed that the fall run of cod off Victoria County are actually part of the 4TVn(Jan.-Apr.) complex, data from this fishery are incorporated into the 4Vn(May-Dec.) calculations and the results of the latter are, therefore, a more relevant source for these vectors than Chouinard *et al*'s (1990) assessment would be. The fishing mortality exerted by the inshore fishery was set at the nominal value of 0.01. Since the model incorporates only a 30-day season, this implies that the small longline boats are capable of exerting an effort that, if continued all year, would take half of an $F_{0.1}$ TAC. That seems a not unreasonable rate for an intense season and a concentrated run of fish.

The fishing mortality exerted by the offshore fishery and the three rates

that link the inshore and Smokey Bank grounds were treated as control variables. The model was used to investigate the effects of these four variables on the biomass density-per-recruit of cod on the inshore grounds.

Some Results

Numerical results for selected values of the control variables are given in Table 2. Since the prime interest here is in the possible effects of fishing by offshore boats on cod on the inshore grounds, each output biomass density-per-recruit can be compared with that generated by the same values for the three linking rates but with ϕ set at zero to measure the effect of permitting such fishing.

It is evident that giving the offshore fleet free access to the inshore grounds has only a minor effect on the biomass density available to the inshore fishery. Even if the fish on the inshore grounds constitute an entirely isolated stock (P=1, E=0), a density of offshore effort on the inshore grounds during the 30 day season that would be approximately equivalent to $F_{0.1}$ if continued throughout the year ($\phi F_0 = 0.02$) would only depress the inshore biomass by 4.11%. Only if the offshore fleet fishes inshore at a much greater rate ($\phi F_0 = 0.05$) would that depression approach 10%.

Allowing free interchange of fish between years (P = 0.5) almost eliminates even these biomass depressions; that with $F_0 = 0.02$ (and assuming $\phi = 1.0$) falling to 1.36%. If the high value of $\phi F_0 = 0.05$ is achieved by more moderate offshore fishing ($F_0 = 0.02$) and a relative concentration of offshore boats on the inshore grounds ($\phi = 2.5$), there would only be a 3.26% depression of inshore biomass. If the same level of fishing by the offshore fleet on the inshore grounds is achieved by setting $F_0 = 0.05$ throughout, the depression caused by allowing the offshore boats onto the inshore grounds would be only 3.19%. Even minor inter-annual exchange (P = 0.75) makes these three depressions 2.21%, 5.29% and 5.23%.

It is hardly likely that fish would return to the ground that they left at the end of a previous season if they move relatively freely between grounds during each season. Nevertheless, setting P at unity (perfect annual return) and E at 0.2 [which makes the chance of an individual fish remaining on the inshore ground throughout a 30-day season $(1-0.2)^{30} = 0.001$] allows the effect of near-free daily movement to be examined in isolation. The three scenarios of fishing effort used above then cause biomass depressions inshore of 0.15%, 0.37% and 0.37% respectively. Intermediate levels of intra-season exchange (E = 0.05; i.e. chance of remaining on inshore ground throughout the season about 10%) change these to 0.64, 1.56 and 1.51% respectively.

Thus, only if fishing by the offshore fleet on the inshore grounds is intense and if the inter- and intra-season exchange of fish between the grounds is very small would elimination of the offshore fleet from the inshore grounds have any appreciable effect on the availability of cod to the inshore fishery (within the assumptions of this model, including the conventional assumptions of yield-per-recruit dynamics). This perhaps surprising conclusion is presumably a consequence of the short season of the fall fishery and hence the high out-of-season fishing effort to which potentially-inshore cod are exposed when in the Gulf of St. Lawrence. Were the model applied to a system where some cod could remain on longline grounds throughout the year, exclusion of trawlers from those grounds might be expected to have a greater effect.

PRIOR CAPTURE OF SMALL FISH

The second of the two, possible adverse population-dynamic effects of trawling on cod available to longlining that are considered here depends on the different partial recruitment vectors of the two gears: trawlers can efficiently catch fish that are too small to be readily available to longliners. Intensive trawling will, therefore, reduce the abundance of each year class before the fish can be caught by hook-and-line. The magnitude of this effect was investigated by a second simple model. Both Sinclair (1986) and Fréchet and Chouinard (1987) have previously examined aspects of this effect, including its impact on 4Vn cod.

The Model

If the many complexities of habitats and behaviour are ignored, the biomass of a resource available to a given fishing gear can be represented as the sum across ages of the products of biomass-at-age and partial recruitment-at-age :

$$B_x = \sum^{\tau} p_{x\tau} \cdot W_\tau \cdot N_\tau$$

where B_x is the biomass available to gear x, $p_{x\tau}$ is the partial recruitment for gear x and fish of age τ, W_τ is the weight-at-age for age τ and N_τ is the number of fish of age τ at the start of the year. At equilibrium, N_τ can be found by iterative calculation of the conventional equations :

$$N_{\tau+1} = N_\tau \cdot e^{-Z_\tau}, \text{ where: } Z_\tau = M + \sum^x F_x \cdot p_{x\tau}$$

where M is the rate of natural mortality and F_x is the rate of fishing mortality exerted on the resource by gear x.

This model was also implemented on Excell™ spreadsheet software. To apply it to the fall run of cod in Sydney Bight, the same weight-at-age vector was used as in the first model (Table 1) and M was again given the conventional value of 0.2. In keeping with the principles of yield-per-recruit dynamics, the number of fish at age 3 was set at unity. The outputs of the model are, therefore, available biomasses-per-recruit.

The partial recruitment vectors, which are the key inputs to this model, were derived by dividing the 1989 catch (in numbers)-at-age for all gears and for ages 3 to 12 of the 4Vn(May-Dec.) cod, shown in Smith and Lambert's (1989) Figure 4, by their tabulated estimates of partial recruitment-at-age to produce a vector of numbers-at-age in the population. The catches-at-age for longlines and otter trawls were then divided by these numbers-at-age to obtain age-specific "catch ratios". Those for trawlers were approximately constant (range 0.20 - 0.26) from ages 6 to 12. The gear-specific partial recruitments for these ages were therefore set at unity and those for ages 3 (the age-at-first-capture) to 5 were estimated by dividing the trawler "catch ratio"-at-age by the mean of their "catch ratios" for ages 6 to 12. The "catch ratios" for longlines increased monotonically from ages 3 to 12, with the final value (based on very limited data) being unreasonably high. The partial recruitments for ages 11 and 12 were therefore set at unity and those for other ages found by dividing the appropriate "catch ratio" by that for age 11. The resulting longline partial recruitments lay on a smooth curve, with the sole exception of that for age 8, which was therefore adjusted upwards to lie on that curve. The resulting vectors are shown in Table 1. They differ in detail from the equivalent vectors that Sinclair

(1986) derived by different methods. The only marked distinction between his values and mine, however, is that he found trawler partial recruitment to be strongly domed, declining from unity at age 6 or 7 to 0.45 by age 10. Fréchet and Chouinard (1987), in contrast, found that the partial recruitment vectors of longliners and trawlers were much more similar than is suggested in Table 1. Indeed, for the Divisions 3Pn4RS cod, their vectors suggest remarkably little difference in partial recruitment of most age classes between the two gears.

The model was used to find the relative biomasses available to longlining and trawling under light ($F_L=0.01$) and moderate ($F_L=0.1$) longline fishing and under a variety of levels of trawler fishing, ranging from none ($F_T=0$) to very heavy ($F_T=0.5$). A comparison of the equilibrium longline-available biomass under light longline fishing only with that under both light longline and intense trawl fishing can be a useful indicator of the effects of the development of a trawl fishery. It does not, however, fairly represent the effects of exchanging a given amount of fishing between longlining and trawling. To examine the latter, the longline-available biomasses under a range of intensities of longline fishing (all with $F_T=0$) were also calculated.

Results
The biomasses-per-recruit available to each of the gears, under each fishing regime, are given in Tables 3 and 4. The former also shows the tabulated longline-available biomasses as percentages of (1) the longline-available biomass under the tabulated intensity of longlining ($F_L=0.01$ or 0.1) but in the absence of trawling ($F_T=0$) and (2) the longline-available biomass under an an all-longline fishery that exerts a fishing mortality equal to that exerted by both gears under the tabulated regime ($F=F_T+F_L$). The divisors for the latter standardization are drawn from Table 4.

As expected, the addition of trawl-caused fishing mortality to a management regime that previously permitted only limited longlining would cause a major decline in the biomass of cod available to the longline fleet. Under the assumptions of the model, the imposition of a trawl fishery operating at $F_{0.1}$ (about $F_T=0.2$ for this resource) on a resource previously only lightly fished by longliners would reduce the biomass available to longlining by about 65%. Even if a moderate trawl fishery was added to an existing moderate longline fishery to achieve $F_{0.1}$ ($F_L=F_T=0.1$), the longliners would experience a fall of nearly 30% in the biomass available to them. Some of this decline in biomass is, however, an inevitable consequence of increasing the fishing effort rather than a function of competition between gears with different partial recruitment vectors. Nevertheless, adding the above amounts of trawler effort to pre-existing longline fisheries would cause the biomass of cod available to longlining to fall to 75.9% and 87.0% (respectively) of the level that it would have achieved if the same additional fully-recruited fishing mortality had been exerted by longliners (i.e. if the longline-available biomass at $F_L=0.01$ and $F_T=0.2$ is compared to that at $F_L=0.21$ and if that at $F_L=F_T=0.1$ is compared to that at $F_L=0.2$). Thus, the addition of even an optimally-managed trawl fishery can cause a very severe decline in the abundance of cod available to a pre-existing small-scale longline fishery. This decline is significantly greater than would be the case if the additional effort was restricted to using longline gear.

The present fishery does not, however, appear to be optimally-managed, since the total fishing mortality on the 4Vn(May-Dec.) cod exceeded 0.35 in 1988 (Smith and Lambert 1989). In the model, if the trawler fleet overfishes its quota, the resource available to longlining suffers to a significant degree. Indeed, if the intended fishing mortality was equally divided between the two gears ($F_L=F_T=0.1$) but the trawlers exerted double

the permitted effort (F_L=0.1, F_T=0.2), carrying total fishing mortality to 0.3, the biomass available to the longliners would fall by 34% from its intended, $F_{0.1}$, level. It would then lie at 77% of what its value would have been if the entire fishing mortality (0.3) were exerted by longliners. For a fishery intended to operate at F_L=0.01 and F_T=0.2 but actually experiencing a doubling of trawler effort, the equivalent values are 58% and 62% respectively.

As modelled here and depending on the particular scenario deemed relevant, the consequences of this age-specific depletion of the cod resource for the longline fishery clearly range from serious to devastating. The prior capture of small fish by trawlers may, therefore, go far towards explaining the reported decline, over recent decades, in longline-available cod. It is, however, important to note that, while Sinclair (1986) came to essentially this same conclusion, Fréchet and Chouinard (1987), using their very different estimates of the partial recruitment vectors, decided that this effect was not significant. Thus, the sensitivity of the present results to variations in those vectors clearly needs to be examined.

HABITAT DESTRUCTION BY TRAWLING

In notable contrast to matters of population dynamics, where mathematical modelling is necessary to understand the magnitude of various effects, and to the planktonic nature of gadoid eggs, where scientific sampling equipment is needed to confirm the reproductive biology of the fish, longline fishermen are able to make their own, direct observations of the surficial sediment types on their fishing grounds. For this, they rely on samples of mud brought up on anchors and groundlines or of gravel and stones recovered when the attached macro-epibenthos chances to be caught on their hooks. Indeed, the nature of the benthic substrates is of crucial importance to the catch rates achieved with longline gear, making the fishermen acute observers of sediment type. Furthermore, the frequency with which they "sample" the substrate and the long periods over which they make repeated observations on prefered fishing grounds give them potential access to better data on variations in local surficial sediments than marine geologists can commonly have. It is true that these men "store" and "analyze" their data in their heads and that those "analyses" are based around imperfect understandings of geological processes. It is also true that longline fishermen have strong economic interests in certain conclusions that might be drawn from their observations of sediment change; interests which may colour those observations. Nevertheless, until better data are available on changes in the surficial sediments of the fishing grounds, the fishermen's observations should be seriously examined.

Longline fishermen make many claims about the deleterious effects of bottom trawling on benthic habitats off Nova Scotia, and particularly on the "rocky" bottom of the best cod longlining grounds. These claims include the smoothing of bottom topography (supposedly reducing ridges some metres in height to flat bottom), flattening of rock piles, destruction of macro-benthos (both the deliberate removal of coral "trees" in deep water and the incidental loss of tunicates, echinoderms, coelenterates and others from all areas of hard bottom) and the replacement of "rocky" bottom with "slime" (Kenchington 1991). In short, a hard-bottom benthic ecosystem with pronounced vertical relief is supposedly replaced by a smooth one, dominated by fine sediments. Not only is the latter ecosystem apparently less supportive of cod production (or perhaps less attractive to cod that draw their production from elsewhere), it also greatly reduces the availability of cod to longline fishing since the fish, even if present, will not usually take hooks set on mud.

The edge of Smokey Bank., along the side of the Laurentian Channel, is one
area that is said to have been badly affected in these ways, as have the
grounds around St.Paul's Island (off the northern tip of Cape Breton) and
White Point Bank (near the Victoria County shore). By one fisherman's claim,
the crest of the St.Paul's "Finger" (a narrow ridge west of the island) has
been deepened by several metres by the trawlers.

Studies of the direct effects of otter trawls on the seabed and benthos in a
range of environments, while they show some damage and disturbance, do
not support the extreme claims of the longline men (e.g. Caddy 1973; Main
and Sangster 1979; Gibbs et al. 1980; de Groot 1984; Van Dolah et al. 1987;
West 1987). In several sea areas, including the southern North Sea (de Groot
1984) and the waters off Georgia, USA (Van Dolah et al. 1987), such damage
as does occur seems to recover in a relatively short time. Off Nova Scotia,
however, it appears that more complex, multiplier effects may exaggerate
the consequences of the initial impact of trawling gear on the seabed.
Natural processes may serve to increase, rather than mitigate, that first,
artificial disruption. Different, but analagous, effects have been suggested
as mediating the impact of trawling on fish resources on Australia's
Northwest Shelf (Sainsbury 1987, 1988).

While cod can be caught by trawling over large areas of the Scotian Shelf
and Sydney Bight on sandy bottoms, the prime cod longlining grounds are
individually small and are described by the fishermen as "rocky". This does
not imply that they are bedrock outcrops (the fishermen having no means to
detect bedrock) but rather that the bottom on these grounds is composed of
clean stones of pebble, cobble or boulder size. Off Nova Scotia, such
substrates are modified glacial tills (King 1970; MacLean and King 1971;
Drapeau and King 1972; MacLean et al. 1977). During the last glaciations,
very large amounts of till were deposited there by ice sheets, which
extended as far as the shelf-break. In some areas, principally below 115 m
depth (the level of the last depression of sealevel), these deposits remain in
an essentially-unmodified state known as "Scotian Shelf Drift" (King 1970),
a poorly-sorted, cohesive sediment composed mostly of sand but also
containing abundant silt, clay, gravel and larger particles. The upper surface
of this deposit is characteristically undulating, forming the "peaky bottom"
recognized by the fishermen as ideal for gadoid longlining. At shallower
depths, the till was heavily modified by the erosive effects of wave action
during the marine transgression. The silt and clay fractions were largely
winnowed out, to be deposited in the deep basins nearby. The residue, called
"Sable Island Sand and Gravel" (King 1970) was sorted by wave and tidal
action, with the sand being re-distributed into relatively low-energy areas
and the coarser material left behind as lag deposits. In some areas, the
uppermost surface of Sable Island Gravel can be seen in bottom photographs
to be composed of a pavement of close-set pebbles and cobbles (e.g. plate 6
of MacLean and King 1971). This is probably the type of sediment that is
most often known to the fishermen as "rocky" and, indeed, the distribution
of Sable Island Gravel closely parallels that of prefered longlining grounds
(those with predominantly-gravel-sized sediment being prefered for
haddock and those with larger particles for cod). Thus, the longline
fishermen's claims of the effects of trawling on the bottom are not claims
of its effects on mud or sand in general but specifically of its effects on
the "rocky" lag deposits of Sable Island Gravel.

Sadly, no direct study has yet been made of such effects. It might be that
the stony surface would resist any mechanical damage from trawling,
though it is equally possible that the otter doors would disturb occasional
cobbles (cf. Messieh et al. 1991) and it is likely that repeated trawling

would damage the epibenthos at a faster rate than it can regenerate, leading to its gradual depletion (de Groot 1984; Van Dolah *et al.* 1987). While the loss of the benthos might have a serious effect on the longline fishery (if, as the fishermen suppose, the cod are attracted to "live bottom"), these direct effects cannot suffice to support the fishermen's more extreme claims. The pavement of clean stones that forms good cod bottom is not, however, the topmost layer of a deep stratum of such stones. Rather it is a thin skin, left as a residue of erosion and itself preventing further erosion, over a deep layer of generally-finer sediment. Depending on just how fine that sediment is, once the protective layer of stones has been disturbed, tidal streams and storm wave surge may serve to scour the bottom, spreading soft sediments over the stones and so modifying the micro-habitat as to eliminate the previously-existing hard-bottom epibenthos. I suggest that this combination of factors may be sufficient to produce the scale of bottom modification claimed by the longline fishermen. Whether it can actually do so and whether or not such habitat destruction causes any noticeable loss of cod production are matters for future research.

FISH BEHAVIOURAL DISTURBANCE BY TRAWLING

The one claim of the negative effects of trawling made by longline fishermen for which no rebuttal whatever yet seems to have been advanced is that the noise and physical actions of the trawlers disturb the fish, causing them to feed (and grow) less and to have reduced spawning success, while also reducing their tendency to take baited hooks. The lack of scientific comment on this claim is, perhaps, inevitable, given the lack of ethological research on temperate marine fishes; even their immediate responses to trawl nets are poorly known (e.g. Foster *et al.* 1981; Main and Sangster 1981a,b; Wardle 1983; West 1987; but see McKenzie 1935 for notes on the feeding behaviour of captive cod). Indeed, whereas the effects of bottom disturbance are almost-directly observable by longline fishermen, the sorts of fish behaviour changes that they claim cannot readily be observed by anyone. Thus, these changes can only be matters for speculation. In scientific research, that might be reason enough to ignore them. In resource management, however, a more precautionary approach is appropriate. In terrestrial wildlife, where disturbance is more easily observed, the negative effects of that disturbance on production are frequently of concern. The fact that ethologists have not chosen to study cod in their natural habitats should not be taken as a reason to suppose that trawlers do not disturb the fish, nor that the decline in cod under intensive trawling is not, in part, a result of such disturbance. Nor, of course, should the reverse conclusion be made in the absence of data.

GENERAL DISCUSSION AND CONCLUSIONS

If this discussion has, in common with most scientific comment, tended to reject the longline fishermen's claims of the adverse effects of trawling on cod resources, it has not totally rejected them. The effects of trawling on benthic cod habitats, in particular, while not proven certainly seem to merit both serious management attention and immediate further research (cf. Sainsbury 1987, 1988; Messieh *et al.* 1991). Prior studies, which have led to conclusions of limited impact, have either concerned low intensities of trawling (e.g. Van Dolah *et al.* 1987), have examined the sorts of soft-sediment bottoms that initially appear more vulnerable but which lack the possible magnification effects that may operate on "rocky" lag deposits or have looked at intensively-trawled bottom, where the substrate may be expected to have long since come into equilibrium with that trawling

(reviewed by de Groot 1984). In the latter areas, any hard bottom, longline ground that once existed may have long-since been lost. The effects of trawling on fish behaviour, resulting from the noise and physical disturbance generated by that fishing method, are even more speculative but can no more be rejected than supported with present knowledge. Both of these families of possible effects are important reminders that one of the fundamental assumptions of fisheries dynamics, that fishing mortality is the sole effect on the resource of fishing effort, has no empirical basis whatever. Other pathways, such as habitat or behaviour, may mediate significant, or even predominant, influences of fishing on fish resources.

In the case of habitat modification, it would be appropriate for fisheries science to cease to treat the seabed as simply an invariant, patternless plane across which trawl nets can be dragged, with some statistically-defined distribution, to catch the fish which are distributed there according to some other statistical model. Instead, the seabed sediments and the benthos living thereon (including the macro-epibenthos which is so rarely studied below the immediately sub-tidal zone) should be incorporated into conceptual and (when practical) mathematical models with their full rôles as both important components of the system that supports demersal fish production and as natural "Fish Attracting Devices" that concentrate cod and so make them available to fishing in profitable concentrations. This changed status of the seabed in fisheries dynamic models should include the realization that the sediments and the benthos (and with them the capability of producing fish) are not necessarily stable and, in particular, that they may be subject to modification by fishing effort itself. A similar incorporation of fish behaviour, as something more than an invariant pattern, into management advice may also be merited, once ethological knowledge of temperate marine species has progressed sufficiently.

A current research program directed at the Scotian Shelf cod fishery provides a practical illustration of the change in thinking that may be necessary. Recent efforts have resulted in a design of selective trawl that will capture cod while allowing a high proportion of haddock to escape. This, it is supposed, will allow trawlers to exploit cod in areas that, in an effort to protect the depleted haddock, are currently closed to all gadoid trawling. If fishing mortality is indeed the only consequence of fishing effort that is of concern, this new net will clearly have great value. If, on the other hand, simply towing the otter doors and bobbin gear with no net (or a perfectly selective net) attached would result in a significant loss of haddock through habitat destruction or behavioural disturbance, then the combination of this new net with a regulatory regime centred on single species catch quotas could result in very serious consequences for an already depleted resource.

Even if further research should confirm that fishing mortality is indeed the sole significant effect of fishing effort on the resource, it is clear that conceiving the link between these as comprised of a single partial recruitment vector and a catchability coefficient is insufficient when managing complex fisheries, as Sinclair (1986) has discussed. In the model presented here, variations in the intra-stock spatio-temporal distribution of fishing effort proved to have negligible consequences for resource abundance. Whether that conclusion would hold for other model fisheries must remain moot. More importantly, differences in partial recruitment vectors among gear types have here been shown to have potentially very significant effects on the abundance of some ages classes of cod, with possibly catastrophic consequences for those sectors of the fishery that are dependent on the older fish. Besides Sinclair's (1986) and Fréchet and Chouinard's (1987) prior studies of this effect, O'Boyle et al. (in press) have recently investigated this same issue. They employed a quite different,

bioeconomic modelling approach but still concluded *inter alia* that, with the competitive advantage of prior access to the resource confered by their partial recruitment vector and in the absence of regulatory controls, trawlers fishing for the Divisions 4VsW cod will eventually out-compete longliners and lead to the end of longlining for that resource. The results of the present model are fully consistent with that conclusion, though as noted above, all of these conclusions are dependent on the validity of the partial recruitment vectors employed in the various models. It is at least clear that fine-scale structure in the distribution of fishing effort, in terms of age classes if not also in time and space, must be examined when considering the effects of fishing on the abundance of cod.

Indeed, the modelling results presented here and by both Sinclair (1986) and O'Boyle *et al.* (in press) call the relevance of present Canadian resource allocation methods into question. If changes in the distribution of fishing effort between gear types markedly alter the availability of the resource to one type, there is little virtue in dividing a TAC between those types on the basis of historic shares in the catch. That process presupposes that changes in the TAC are the results of natural fluctuations and hence that the benefits and disadvantages of such changes should be shared between all resource users. The present model shows that not only can an $F_{0.1}$ TAC be strongly influenced by the increased fishing activity of one gear sector, as is expected, but also that the relative diminution in longline-available biomass as a consequence of increased trawling activity exceeds that in trawl-available biomass. Clearly a proportionate decrease in allocations would be inequitable but, more importantly, it may become impossible for the longline sector to catch even such an allocation at economically-viable catch rates. In short, while simplistic conceptual models of the links between fishing effort and available cod biomass might be sufficient for stock assessment purposes, they can still prove seriously suboptimal when used as the foundation for fishery management practices.

ACKNOWLEDGEMENTS

REFERENCES

CADDY, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. *J.Fish.Res.Bd Canada* **30**: 173-180.

CHOUINARD, G.A., G.A. NIELSEN, L.G. CURRIE & J.P. MURPHY 1990. Stock status of the southern Gulf of St.Lawrence cod stock (4T and 4 Vn(Jan.-Apr.)) in 1990. *CAFSAC Res.Doc.* 90/46.

de GROOT, S.J. 1984. The impact of bottom trawling on benthic fauna of the North Sea. *Ocean Management* **9**: 177-190.

DRAPEAU, G. & L.H. KING 1972. Surficial geology of the Yarmouth-Browns Bank map area. *Mar.Sci.Pap.* **2**, *Geol.Surv.Canada Pap.* **72-24**: 6p.

FOSTER, J.J., C.M. CAMPBELL & G.C.W. SABIN 1981. The fish catching process relevant to trawls. *In* W.G. Doubleday & D. Rivard (eds.) Bottom trawl surveys. *Can.Spec.Publ.Fish.Aquat.Sci.* **58**: 229-246.

GIBBS, P.J., A.J. COLLINS & L.C. COLLETT 1980. Effect of otter prawn trawling on the macrobenthos of a sandy substratum in a New South Wales estuary. *Aust.J.Mar.Freshw.Res.* **31**: 509-516.

HALLIDAY, R.G. 1988. Use of seasonal spawning area closures in the management of haddock fisheries in the northwest Atlantic. *NAFO Sci.Counc.Studies* **12**: 27-36.

KENCHINGTON, T.J. 1991. A survey of fishing practices in the Scotia-Fundy Region longline fisheries: Final report of field survey phase. *Confidential report to Department of Fisheries and Oceans from Gadus Associates*

KING, L.H. 1970. Surficial geology of the Halifax-Sable Island map area. *Mar.Sci.Pap.* **1**, *Geol.Surv.Canada Pap.*: 16p.

LAMBERT, T.C. & S.J. SMITH 1990. 4Vn cod (May to December): Status review for the 1989 fishing year. *CAFSAC Res.Doc.* 89/44.

M'INTOSH, W.C. & A.T. MASTERMAN 1897. *The Life-Histories of the British Marine Food Fishes.* C.J.Clay, London: 467 p + 20 plates.

McKENZIE, R.A. 1935. Codfish in captivity. *Biol.Bd Can.,Prog.Rept.Atlantic* **16**: 7-10.

McKENZIE, R.A. 1956. Atlantic cod tagging off the southern Canadian mainland. *Bull.Fish.Res.Bd Canada* **105**: 93p.

MacLEAN, B. G.B. FADER & L.H. KING 1977. Surficial geology of Canso Bank and adjacent areas. *Mar.Sci.Pap.* **20**, *Geol.Surv.Canada Pap.* **76-15**: 11p.

MacLEAN, B. & L.H. KING 1971. Surficial geology of the Banquereau and Misaine Bank map area. *Mar.Sci.Pap.* **3**, *Geol.Surv.Canada Pap.* **71-52**: 19p.

MAIN, J. & G.I. SANGSTER 1979. A study of bottom trawling gear on both sand and hard ground. *Scottish Fish.Res.Rep.* **14**: 15p.

MAIN, J. & G.I. SANGSTER 1981a. A study of the sand clouds produced by trawl boards and their possible effect on fish capture. *Scottish Fish.Res.Rep.* **20**: 20p.

MAIN, J. & G.I. SANGSTER 1981b. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. *Scottish Fish.Res.Rep.* **23**: 23p.

MESSIEH, S.N., T.W. ROWELL, D.L. PEER & P.J. CRANFORD 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. *Continental Shelf Research.*

O'BOYLE, R.N., A.F. SINCLAIR & P.C.F. HURLEY *In press* A bioeconomic model of an age-structured groundfish resource exploited by a multi-gear fishing fleet. *Rapp.Proc.Verb. Reun.Cons.int.Explor.Mer*

RUSSELL. F.S. 1976. *The Eggs and Planktonic Stages of British Marine Fishes.* Academic Press, London: xv+524 p.

SAINSBURY, K.J. 1987. Assessment and management of the demersal fishery on the continental slope of northwestern Australia. *In* J.J.Polovina & S. Ralston, eds. *Tropical Snappera and Groupers: Biology and fisheries management.* Westview Press, Boulder, Colorado: 465-503.

SAINSBURY, K.J. 1988. The ecological basis of multispecies fisheries, and mangement of a demersal fishery in tropical Australia. *In* J.A.Gulland, ed. *Fish Population Dynamics.* 2nd Edition. Wiley, Chicester: 349-382.

SINCLAIR. A.F. & S.J. SMITH 1984. A review of the 4Vn (May-December) cod fishery in 1983. *CAFSAC Res.Doc.* 84/75.

SMITH, S.J. & T.C. LAMBERT 1989. Subdivision 4Vn cod (May to December): Update of stock status for 1988. *CAFSAC Res.Doc.* 89/44.

VAN DOLAH, R.F., P.H. WENDT & N. NICHOLSON 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. *Fisheries Research* 5: 39-54.

WARDLE, C.S. 1983. Fish reactions to towed fishing gears. *In* A.G. MacDonald & I.G. Priede (eds.) *Experimental Biology at Sea.* Academic Press, London: 167-195.

WEST, W. 1987. 1986 Bering Sea trawling impact project. *Oceans '87.* IEEE, New York 2: 626-631.

Table 1 : Partial Recruitment and Weight-at-Age Vectors used in the Models of Sydney Bight Cod[2]

Age (years)	Weight-at-Age (Kg)	Combined Partial Recruitment	Partial Recruitment for Longliners	Partial Recruitment for Trawlers
3	0.553	0.007	0.002	0.016
4	0.843	0.057	0.023	0.120
5	1.161	0.320	0.184	0.604
6	1.465	0.630	0.450	1.0
7	1.894	0.847	0.691	1.0
8	2.330	1.0	0.835[3]	1.0
9	3.030	1.0	0.915	1.0
10	3.908	1.0	0.970	1.0
11	5.165	1.0	1.0	1.0
12	7.128	1.0	1.0	1.0
13	8.454	1.0	1.0	1.0
14	10.039	1.0	1.0	1.0
15	11.594	1.0	1.0	1.0

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[2]The combined-gears partial recruitment vector was calculated by Smith and Lambert (1989) for all 4Vn(May-Dec.) cod fisheries. The gear-specific vectors were derived from the combined-gears one by the method explained in the text. The weight-at-age vector was derived from data published by Smith and Lambert (1989).

[3]Value determined by curve smoothing. Calculated value was 0.708.

Table 2 : Biomass-per-Recruit of Cod on an Inshore Ground : Model Output (see text for explanation)[4]

P	E	φ	Fo:	0.01	0.02	0.05
				Biomass Density-per-Recruit on Inshore Grounds		
1	0	0		4.109	4.109	4.109
1	0	1		4.022	3.940	3.717
1	0	2.5		3.900	3.717	3.285
1	0.01	0		4.109	4.066	3.948
1	0.01	1		4.065	3.980	3.750
1	0.01	2.5		4.001	3.860	3.505
1	0.05	0		4.109	4.035	3.834
1	0.05	1		4.096	4.009	3.776
1	0.05	2.5		4.076	3.972	3.693
1	0.2	0		4.109	4.025	3.798
1	0.2	1		4.106	4.019	3.784
1	0.2	2.5		4.101	4.010	3.764
0.75	0	0		4.109	4.068	3.955
0.75	0	1		4.063	3.978	3.748
0.75	0	2.5		3.996	3.853	3.492
0.75	0.01	0		4.109	4.051	3.894
0.75	0.01	1		4.079	3.994	3.762
0.75	0.01	2.5		4.036	3.911	3.588
0.75	0.05	0		4.109	4.034	3.828
0.75	0.05	1		4.098	4.011	3.777
0.75	0.05	2.5		4.080	3.978	3.705
0.75	0.2	0		4.109	4.025	3.798
0.75	0.2	1		4.106	4.019	3.784
0.75	0.2	2.5		4.102	4.011	3.765
0.5	0	0		4.109	4.050	3.887
0.5	0	1		4.081	3.995	3.763
0.5	0	2.5		4.040	3.918	3.599
0.5	0.01	0		4.109	4.043	3.861
0.5	0.01	1		4.088	4.002	3.769
0.5	0.01	2.5		4.057	3.944	3.643
0.5	0.05	0		4.109	4.032	3.823
0.5	0.05	1		4.099	4.012	3.778
0.5	0.05	2.5		4.084	3.984	3.715
0.5	0.2	0		4.109	4.025	3.797
0.5	0.2	1		4.106	4.019	3.785
0.5	0.2	2.5		4.102	4.011	3.766

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[4] Some combinations of control variable values in this table are unrealistic but have been included for completeness.

Table 3 :   Available Biomasses-per-Recruit under Various Intensities of Trawl and Longline Fishing : Model Output (see text for explanation)

Longline Fishing Mortality		0.01				0.1		
Trawl Fishing Mortality	Trawl Avail. Biom.	Longline Available Biomass	Longline Av.Biom. as %age Longline Av.Biom. at $F_T=0$	Longline Av.Biom. as %age Longline Av.Biom.	Trawl Avail. Biom.	Longline Available Biomass	Longline Av.Biom. as %age Longline Av.Biom. at $F_T=0$	Longline Av.Biom. as %age Longline Av.Biom.
0.00	10.09	8.74	100.0	100.0	7.38	6.09	100.0	100.0
0.01	9.58	8.25	94.4	98.6	7.06	5.79	95.1	98.6
0.05	7.87	6.60	75.5	92.8	5.96	4.74	77.8	93.1
0.10	6.28	5.08	58.1	86.5	4.92	3.76	61.7	87.0
0.15	5.12	3.98	45.5	80.9	4.14	3.04	49.9	81.7
0.20	4.26	3.18	36.4	75.9	3.54	2.49	40.9	76.9
0.25	3.63	2.59	29.6	71.7	3.09	2.08	34.2	72.7
0.30	3.14	2.15	24.6	68.3	2.73	1.77	29.1	69.4
0.35	2.75	1.81	20.7	64.9	2.44	1.52	25.0	66.4
0.40	2.45	1.54	17.6	61.8	2.21	1.32	21.7	63.2
0.45	2.21	1.34	15.3	59.6	2.02	1.17	19.2	61.3
0.50	2.02	1.17	13.4	57.1	1.86	1.04	17.1	59.1

Table 4 : Equilibrium Longline-Available Biomasses-per-Recruit Under Various Intensities of a Longline-Only Fishery

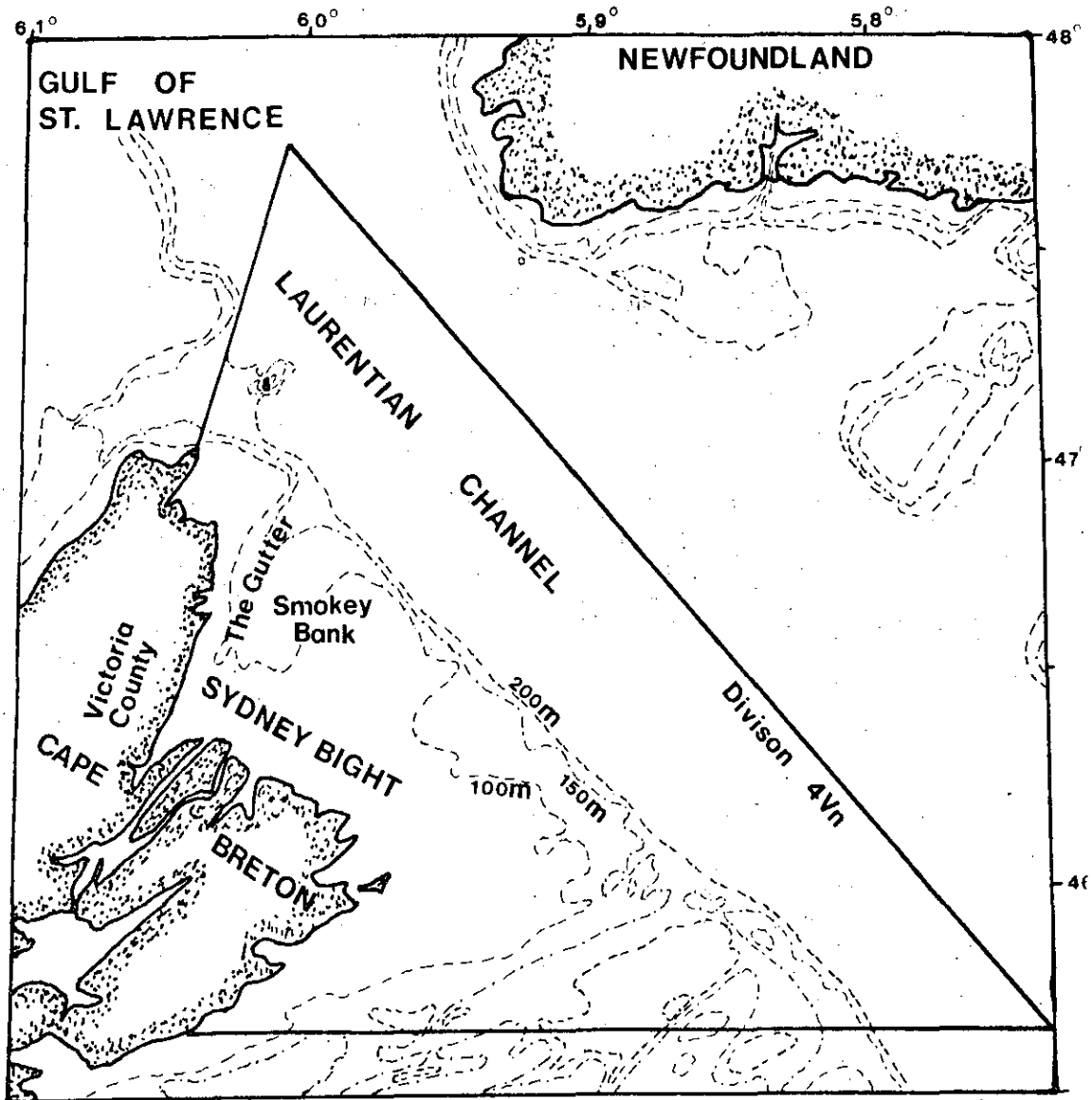| Fishing Mortality	Available Biomass-per-Recruit
0.00	9.12
0.01	8.74
0.02	8.37
0.05	7.40
0.06	7.11
0.10	6.09
0.11	5.87
0.15	5.09
0.16	4.92
0.20	4.32
0.21	4.19
0.25	3.72
0.26	3.61
0.30	3.24
0.31	3.15
0.35	2.86
0.36	2.79
0.40	2.55
0.41	2.49
0.45	2.29
0.46	2.25
0.50	2.09
0.51	2.05
0.55	1.91
0.60	1.76

Figure 1 : **Chart of Division 4Vn and Surrounding Areas showing Places Named in Text, using the Local Fishermen's Names for Underwater Features.** (Points not named on chart. St.Paul's Island is the small island north of Cape Breton, St Paul's Finger extends northwestwards from the island's southern tip at depths of about 200 m, and White Point Bank is the area enclosed by the 100 m contour northwest of The Gutter and east of the northern tip of Cape Breton.)