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Biological Advice for and Management of Some of the Major Fisheries Resources in Greenland Waters

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Abstract

The biological knowledge on, advice for and management of some important fishery resources in Greenland waters are considered.

Sand eel and capelin are considered as a group, since both species are potential resources for industrial fisheries but so far have been very lightly exploited, and both are important prey for commercially important fish species and for marine mammals. Sand eel occurs mainly offshore, capelin mainly inshore. The stocks seem very large, but no good estimates of biomass are provided. To preserve the resource (as prey) and to ensure better background knowledge for management, fisheries for these species, apart from traditional local inshore fisheries for capelin, are restricted to experimental fishing by special permission upon application.

Shrimp is the most important fishery resource for Greenland. Much is known on its biology and distribution, but ageing problems, lack of observations on pre-recruits and uncertainty on actual catch due to unreported discards make biological advice uncertain. Newly started trawl surveys, commercial catch and effort data, and catch samples form the basis for advice. The offshore stock is managed by TAC administered through individual vessel quotas. Greenland now tries to adjust fleet capacity to the estimated yield.

Cod is well studied and the fishery has been regulated by TAC and quotas since 1974. Forecasting of recruitment has generally been good although great uncertainty has occurred round the latest good year-class (1984). Also there is uncertainty in the forecast of weight-by-age. The great uncertainties in advice and management are, however, the varying migration rate which is generally associated with the spawning migration from West to East Greenland and eventually to Iceland, and the inability to fix on a target spawning biomass since stock/recruitment relationship is not very obvious.

Introduction

Most major fisheries and fishery resources in the North Atlantic are regulated in one way or another by laws and regulations. In fact, regulations now are so common that one may state that non-regulation of a North Atlantic fishery (if any such example of a major fishery is found) also reflects a sort of management policy.

Most fisheries regulations are based on biological advice. Non-biological considerations, e.g. economic, social and political issues, usually also influence the establishment and nature of a regulation. After establishment of a regulation the non-biological considerations sometimes increase their role in the management, for instance when the consequences of a regulation were in fact to be felt according to the initial regulation, e.g. when TACs and quotas are reached and further fishing on the resource should have stopped (for the TAC-period) but is allowed to continue either by "special exemption" or simply because no action is taken to enforce the regulation. The excuse, if any such is offered, frequently is the biological uncertainties in the assessment of the stock in question.

The present paper will consider fisheries regulations of three major resources in Greenland waters (sand eel and capelin as a group, shrimp and cod) and the biological advice for these.

Note on the legal background

In 1953, the Danish constitution changed Greenland's status from colony to an integral part of the Kingdom of Denmark. In 1955, the Danish government established a separate ministry for Greenland. Laws and rules for resources in the Greenland fishing zones were thereby set by the minister for Greenland. For decisions on local matters Greenland had a local parliament (Landsrådet).

After a referendum, Denmark joined the European Economic Community (EEC) in 1973. Although the referendum in Greenland showed opposition to join the EEC, Greenland had to follow Denmark according to the new constitution.

Greenland was also an integral part of Denmark in relation to International Commission for the Northwest Atlantic Fisheries (ICNAF) and North East Atlantic Fisheries Commission (NEAFC).

On 1 January 1977 the fishing zone around Greenland was extended from 12 to 200 naut. miles (or to lines agreed with neighbouring nations, although not all questions had yet been resolved). The resources in the extended Greenland fishing zone were then regarded as EEC-resources, and TACs and other fisheries regulations were set by the EEC Council of Ministers.

By 1 May 1979 the Greenland Home Rule Act came into effect whereby Greenland got authority for management of living resources in Greenland waters — except that Greenland was still a member of the EEC and had to make its voice there through the Danish Kingdom's Ministry of Foreign Affairs.

However, a new referendum showed that Greenland still opposed membership of the EEC. After long negotiations and necessary changes of Danish, Greenland and EEC laws, Greenland officially withdrew from the EEC on 1 February 1985. Since then Greenland has had complete autonomy over resources in its fishing zone (but negotiations with other countries on fishing zone delimitation remained a matter of foreign affairs). Thus, the Greenland parliament (Landstinget) makes the decisions and the Greenland Minister for fisheries issues the law and regulations governing management of the resources.

Greenland's membership of NAFO is also a matter of foreign affairs, so that Denmark is an individual member of NAFO in respect of the Faroe Islands and Greenland, but otherwise its voice is through the EEC.

Case Studies

Sand eel (sand lance) and capelin at West Greenland are two species considered to be representatives for which there is limited knowledge. Although it is known that there are very large stocks, virtually no or only negligible fisheries on the species take place. However, large fisheries on these species take place in waters other than those at West Greenland, e.g. sand eel in the North Sea and capelin in the Barents Sea, at Iceland-East Greenland-Jan Mayen and at Newfoundland. Both species are very important prey species for a number of other fish species, e.g. cod (Hansen, 1949, Horsted and Smidt, 1965) and marine mammals (Kapel and Angantyr, MS 1989).

Sand eel at West Greenland

Species identification. The biological uncertainty around this stock is apparent already in connection with the identification of the species. Jensen (1941) considered *Ammodytes lancea* Cuvier divided into three subspecies, *viz. A.1.lancea* Cuvier, *A.1.marinus* Raitt and *A.1.dubius* Reinhardt. Einarsson (1951) adopted Jensen's view but considered *A. lancea* and *A. marinus* as separate species (Einarsson, 1955). Muus (1981) stated that two species occur in Greenland waters, *A. dubius* Reinhardt and *A. marinus* Raitt, the former being by far the most common and occurring mainly offshore, whereas the latter is said to have its occurrence closer to the coast, none of them being common inshore.

Although one should be very careful in considering stocks mixed of species (in this case they are very similar species) as units for single-species assessments, the problem of species identification here may not be that important at the present stage of research in relation to management. Rather, the important uncertainty seems to be the evaluation of stock size and the role of the stock in the food web which contains important predator species. It should also be borne in mind that in a practical fishery no distinction between the species would be made. Catch statistics could be broken down to species level only by sampling and by burdensome analyses of the samples.

Knowledge on biology. The knowledge on the biology of the sand eel species in West Greenland waters is to a great extent based on samples from an exploratory fishing carried out by Danish North-Sea trawlers and fishermen in 1978. The biological material was studied by Andersen (1985). He found that the age distribution ranged from 0 to 16 years and was trimodal, most likely reflecting strong year-class fluctuations. However, the material did not allow for an estimate of total mortality, which in this case would have been equal to natural mortality.

With possible pronounced year-class fluctuations an important element in biological advice would be the forecast of recruitment. Not much is known about the recruitment mechanism. The fish are known to spawn at West Greenland with first spawning at the age of 4–9, mainly 6 years. The larvae are very common in the West Greenland plankton in June–July but scarce in the fjords (Smidt, 1979). However, since no systematic sampling of the mature stock has taken place, it is not clear whether abundance of larvae can indicate fluctuations in recruitment to the fishable stock.

Stock size estimates. In 1967–68, some small-scale commercial fishing experiments were carried out in NAFO Div. 1D. In 1967, the skipper reported that the amount of sand eel was enormous.

In 1974, a Norwegian acoustic survey and sampling by trawl hauls took place over the West Greenland banks and in some of the fjords with sand eel and capelin as the target species (Jákupsstova and Røttingen, 1975). However, no quantitative estimate of sand eel abundance was given due to uncertainty on their acoustic target strength and to the behaviour of the fish which buries itself in sand and gravel during part of the day.

The 1978 exploratory fishing reported by Andersen (1985) did not result in any stock size estimate, but Andersen stated that of the 382 area units (1/8 degree lat. by 1/4 degree long.) covered by the acoustic survey only 25% could be presumed to give a profitable catch, the best areas being on the slopes of some banks in Div. 1D.

Although no accurate stock estimate has been offered, the stock seems very high at least in some years. The fish is recorded as a very common food for cod (Hansen, 1949, Horsted and Smidt, 1965). It seems very likely that cod consume sand eel in quantities which during a year exceed the weight of the predator biomass. Stock size of sand eel would, therefore, be expected to be in the order of hundreds of thousand tons.

Commercial fishery. Occasionally (e.g. in 1967 and 1968) Danish and Greenlandic trawlers have fished for sand eel (industrial fish), but catches never were more than some hundred tons. The most recent attempt to fish commercially was the experiment in 1978 by Danish vessels as reported in the previous sections. No commercial fishing has been carried out in recent years.

Management. This will be considered together with management of capelin.

Capelin at West Greenland

Knowledge on biology. The knowledge on the biology of capelin (*Mallotus villosus* O. F. Muller) is much better than on that of sand eel. With its circumpolar distribution, the species is of great importance for the fishery in many waters. It has been well studied, and some important stocks are assessed regularly by ICES (e.g. the Barents Sea stock) and by NAFO Scientific Council (the stock at Newfoundland).

With its coastal occurrence at West Greenland the species has supported small but locally very important aboriginal fisheries for centuries, and also here the species has been relatively well studied. Jensen (1948) studied systematics and biology, and Hansen (1943) gave basic biological information. Kanneworff (1968) found that the capelin at West Greenland is split into several rather stationary stocks and this was supported by Sørensen (1985) and by Sørensen and Simonsen (1988). Amongst the important facts are:

i) distribution is mainly inshore, although outside the spawning season occurrence on eastern side of offshore banks is also observed. Thus there is not much spatial overlap with sand eel;

ii) age is usually up to 6 years, but many die after first spawning at age 4 or 5;

iii) there is a separation in local stocks, genetically and/or by environment.

Stock size estimates. Although most authors mentioned above have stated that capelin is plentiful at West Greenland, few attempts to estimate the stock size has been made. The first seems to be the Norwegian acoustic survey in 1974 (Jákupsstovu and Røttingen, 1975). They found that the West Greenland stock was 5–10% of that in the Barents Sea. This is to say, that their estimate was between 300 and 600 thousand tons. Sørensen (1985) considered this an underestimate.

Although comparison to other stocks could lead to an estimate of the overall stock and possible yield, it is important to recall that the capelin stock at West Greenland consists of a number of rather well separated local stocks. A TAC management scheme would, therefore, have to operate with a number of local TACs.

Commercial fishery. There is a traditional small-scale fishery in Greenland on spawning shoals of capelin in the tidal zone, mainly for local consumption. Trial fisheries with purse seines have not been very successful, while pair trawling seems to offer possibilities for large catches. So far, however, only small quantities have been landed, mainly for local fish meal production, dried or frozen for human or pet consumption, or bait for long lines. Some experiments to develop a fishery on roe-bearing females (Japanese market) have been made. Indeed, Sørensen's study (1985) was initiated in order to elucidate the possibilities for such a specialized fishery. However, so far no large-scale commercial fishery on capelin has developed at West Greenland.

Management. Although sand eel and capelin at West Greenland show great differences in local distribution and in biology, they can well be considered together since both are examples of stocks for which:

i) the stock size must be very large, although it is not well estimated;

ii) any commercial fishery would need a high minimum catch to be profitable, at least as long as the fish is used as "industrial fish";

iii) they are highly important prey species for other commercially important species, and a high fishing mortality could, therefore, result in adverse effects on such stocks.

The biological uncertainties clearly are connected with (i) and (iii) above.

The Greenland management policy for these resources has been a balance between the wish to extend its fisheries to species other than the traditional ones and the fear of a rapidly expanding industrial fishery which, if not immediately controlled, could be a disaster for the stocks and for predator stocks. In fact, had the Danish exploratory fishing in 1978 given commercially better results, an immediate pressure from a highly specialized large fleet to get access to fish sand eel at West Greenland would no doubt have followed. Plans for transport of catches to Danish plants had already been discussed.

The first regulation of **sand eel** fishing was issued by the Minister for Greenland in March 1978, limiting the right to fish for sand eel in the Greenland fishing zone to persons or concerns registered in Greenland and directly associated with Greenland. Later that year (in November) the Minister changed that paragraph to read "fishing for sand eel in the Greenland fishing zone is not allowed. Experimental fishing for sand eel may take place after permission has been granted by the Minister for Greenland" (author's translation of Danish text, Nal.A, 1978, p. 344).

Clearly, if any such permission would have been granted there would have been conditions to ensure proper sampling and reporting, and may be even regarding planning (e.g. areas to be operated). However, after the 1978 experiment no applications for experimental sand eel fishing have been received. In the meantime, at least from 1985 onwards, the annually issued regulations (TACs and quotas) refer only a zero TAC for sand eel. It is most likely, however, that the Greenland Home Rule would consider an application for experimental fishery positively provided such fishing was conducted and reported to give further knowledge on the species and the stock.

Small-scale fishing for **capelin** is an old tradition for the Greenland population (see above) and no politician would wish (or dare) to change that. However, like for sand eel, one could think of a situation where the use of a modern fishing gear could be promoted. Again, if the fish were to be used for reduction, a high minimum catch would be required. However, recent interest in this fish has been related to production of roe, i.e. a selective fishery on pre-spawning females.

In spite of the above statement that no politician would wish to regulate the aboriginal fishery, the first regulation for fishing capelin at West Greenland issued as late as in November 1981 (for that year!) did, in fact, not allow any catch except in approved experimental fisheries. This strict rule was likely not the intention and was evidently not effective since it came into effect after the season for the local fisheries.

No regulation seemed to be in place during 1982–84, but in 1985 a zero quota was set as for sand eel, but for capelin it did not include waters inside 3 naut. miles from the base line. This has been the regulation also for later years. No applications for experimental fishing outside 3 naut. miles have occurred. Inside 3 naut. miles no large-scale commercial fishing has developed although some experiments on fishing roe-bearing females have taken place.

Summary and discussion. In summary, for sand eel and capelin large stocks are known to occur at West Greenland, the former offshore, the latter mainly inshore where it is split up in a number of local stocks. No good estimates of size of stocks have been provided. Any commercial fishing for these species would require large quantities of fish except in specialized fisheries such as on roe-bearing females of capelin. Since both species are very important prey species for commercially valuable fish and marine mammals, any sound management would have to keep this in mind. It would be necessary also to reflect over minimum spawning biomass, specifically of capelin for which few age groups contribute to spawning. The natural thought that the decreasing stocks of predators (evident for cod through the two latest decades) would leave a high surplus to be taken by man may not prove true.

Under such circumstances the management policy of preventing rapidly expanding fisheries while at the same time keeping open some possibilities for developing the fisheries for these species seems proper. Present rules ensure that biological knowledge for advising managers would increase parallel to a fisheries development.

Shrimp

Although management of shrimp off East Greenland could also serve as a case study of management under biological uncertainty, only shrimp at West Greenland and the adjacent part including some of the Canadian fishing zone in NAFO Subarea 0, will be considered here.

Short review of investigations. The general biology of shrimp (*Pandalus borealis* Kr.), especially its protandric hermaphroditism, was well known from other areas of its circumpolar distribution (e.g. Berkeley, 1930; Rasmussen, 1953) when intensive studies of shrimp at West Greenland started in 1947. Horsted and Smidt (1956) summed up the knowledge of that time of the species and the stocks. Up to then research had been concentrated on inshore stocks, on which a small-scale commercial fishery had started in 1935. The fishery expanded rapidly after 1948 and since then, the species has been one of the high-priority species in the annual research programme of the Greenland Fisheries Research Institute.

Some concern over the major inshore resource, the one in the Disko Bay in Div. 1A, led to expeditions searching for shrimp in the offshore areas in 1963–64 and in some of the following years. From these it soon became clear that the offshore shrimp grounds were much larger than those in the Disko Bay (Horsted, 1969).

The rapidly increasing exploitation of the offshore stocks and the extreme importance of these for Greenland's economy have led to very intensive biological studies of the species and the stock. After a proposal for TAC-regulation was put forward by Denmark to ICNAF in 1976, a very large number of research documents have been presented annually to ICNAF and NAFO. *ICNAF Sel. Pap.* No. 4 (1978) contains 11 such papers, illustrating the knowledge of biology, distribution and stock size at that time. Since then, shrimp at Greenland has been assessed annually by ICNAF/NAFO scientific bodies with quite a number of research documents supplied by scientists from countries interested in this stock.

Knowledge on biology. Two major characters in the biology of this species heavily influence assessments of the stocks, *viz*. the formerly mentioned protandric hermaphroditism and the stepwise growth through ecdysis.

The protandric hermaphroditism means that the spawning stock can be defined as females only, with the fair assumption that there are enough males to mate. In fact, this should make estimation of spawning stock size more easy, although not necessarily so for the advice to managers since the stock-recruitment relationship is not well known. However, due to the limited number of eggs per female and to the protection of eggs by females (at least until the female is fished or dies of reasons other than fishing) it would be expected that a stock-recruitment regression analysis would give a much clearer picture than those found for some fish species, e.g. cod (Hansen and Buch, 1986).

The stepwise growth, together with the fact that the animal has no parts or tissues illustrating individual age, make it very difficult to judge age composition in samples and thereby growth rate. The very long egg-bearing (ovigerous) period after spawning, about 9 months at West Greenland (Carlsson and Smidt, 1978), prevents such females (and that is to say nearly all females) from growing during that period. These may therefore cluster in one size group (Horsted, 1978a).

Although several attempts to solve the ageing problem have been made, most recently in 1989 by a special NAFO working group, this overriding ageing difficulty so far has been a hindrance for developing analytical assessment models such as virtual population analysis (VPA).

In fact, although much is known on distribution, hermaphroditism, spawning and hatching, larval stages, ecdysis, etc., and although numerous samples have been carefully analyzed, it is somewhat frustrating to see one of the conclusions of the above mentioned working group which states that there are "important biological differences between the populations of shrimp from the various areas. It was agreed that the scientific (author's insertion) questions which need to be answered would also vary between populations and that any research or management strategies adopted for one area might not necessarily apply to others." (Parsons, MS 1989). This begs the question: do the shrimp specialists make their advisory job too complicated by trying to solve too many detailed biological questions?

Stock size estimates. Several ways of estimating the stock biomass of shrimp at West Greenland have been attempted. The first was based on the observation that the fisheries in the Disko Bay had developed to, what seemed to be, a stable fishery from which yield-per-unit-area might be deduced. The rough measure for the Disko Bay was 1 ton per km^2 of shrimp ground, defined as fishable ground plus surrounding areas supplying larvae and adult immigrants. Such supplying areas were considered to be three times larger than the trawlable ground (Carlsson and Smidt, 1978). Applying this factor to the newly discovered offshore grounds gave a figure of 17,000 tons at the time (1975) when Denmark prepared a TAC proposal to be presented for ICNAF in June 1976. However, already before the proposal came forward new offshore areas were discovered which led to a new figure of 26,000 tons. This was proposed as TAC (for 1977) in June 1976. No agreement could, however, be reached at that time and the item was postponed to a special meeting in December 1976. At that time further grounds had been discovered, and the estimate of yield by that method now came close to 40,000 tons — at that time an incredible high figure but was in fact what the fishery obtained. Some of the basic assumptions around the supplying areas for the offshore gounds were, however, found to be rather weak and the official Danish proposal was, therefore, 36,000 tons which was agreed.

The rapid change of the estimate of (sustainable) yield from 17,000 to close to 40,000 tons in the course of less than two years, could be interpreted as biological uncertainty. However, the TAC proposed was meant to be a precautionary TAC in a situation when the increase in fishing effort was explosive, and the change in advice must be seen rather as a consequence of the method applied and of the increasing knowledge of shrimp distribution than as a basic biological uncertainty.

The "Disko Bay" method was simple but clearly had its limitation in the assumptions made. More direct observations seemed necessary. Stratified photographic surveys were made in the years 1977–86 after which that method was given up because this method also proved to have some difficulties. They were that only animals right at the bottom and in focus on the camera were seen and more importantly that the size composition seen in the photographs did not agree with that observed by trawl hauls at the same site. Therefore, right through from 1976 ICNAF's STACRES and NAFO's Scientific Council have recommended that stratified random trawl surveys be made.

In fact, a stratified trawl survey had already been conducted in 1976 (Horsted, 1978b), and also some other stock size estimates based on trawl surveys or commercial catch-effect data were presented at the Special Meeting in December 1976 (Klimenkov *et al.*, 1978; Hoydal, 1978; Ulltang, 1978). However, these never were followed up to become a time series of trawl surveys.

What is hopefully resulting in a time series of annual stratified random trawl surveys was started in 1988. The uncertainties connected with this method are discussed below. For the shrimp surveys hitherto conducted, specific difficulties are faced in the material, *viz*. the survey gear has not been comparable between years so that the short time series is not yet a very good index of abundance. The unavoidable variability between trawl hauls in each stratum is also adding to the uncertainty of each year's estimate, being ±39% (95% confidence interval) for the major areas in 1989 (Carlsson *et al.*, MS 1990).

Fisheries data and advice. Parallel to the direct observations (photographs and trawl surveys), the catch-effort database established as time series for some groups of rather uniform trawlers since 1976 has played a major role for the biological advice. Thus, when the index dropped in 1978 (and only 27,000 tons were fished of the 40,000 tons TAC) the TAC for 1979 was lowered to 29,500 tons.

Catch-effort (CPUE) data also have their uncertainties. One is the learning factor, another is gear improvement. Both tend to keep the CPUE index up and, unless some knowledge on gear improvement is available, that factor is very difficult to build into multiplicative models, which have now been applied to the West Greenland catch-effort data.

Having agreed upon a TAC of 29,500 tons for 1979, the advice remained at that figure up to and including 1984 (Table 1). The very precise figure was certainly

TABLE 1. Advised TACs, TACs set and nominal catches (in tons) for the years 1977–90 for the offshore Subareas 0+1 (south of 71° N) shrimp stock (for the period 1977–79 *NAFO Sci. Coun. Rep*., 1982 and for the period 1980–90 *NAFO Sci. Coun. Rep*., 1990).

Year	TAC advised	TAC set	Nominal catch (including estimates of small-vessel catches)
1977	40,000	36,000	34,300
1978	40,000	40,000	26,869
1979	27,200–32,000 (20–32% below 1978)	29,500	27,087
1980	29,500	29,500	36,652
1981	29,500	35,000[a]	37,300
1982	29,500	34,800[a]	36,827
1983	29,500	34,625[a]	39,267
1984	29,500	34,925[a]	35,883
1985	36,000	42,120[b]	42,187
1986	36,000	42,120[b]	44,584
1987	36,000	40,120[b]	46,160[d]
1988	36,000	40,120[b]	43,649[d]
1989	44,000–50,000	40,120[c]	51,134[d]
1990	50,000	44,975[c]	—

[a] Including TAC of 5,000 tons set by Canada in Subarea 0.
[b] Including TAC of 6,120 tons set by Canada in Subarea 0.
[c] Including TAC of 7,520 tons set by Canada in Subarea 0.
[d] Preliminary data.

not reflecting accuracy in the biological estimate. Rather, the figure was the one agreed upon from an advice to lower the 40,000 tons (agreed for 1978) by 20–32% (*ICNAF Redbook*, 1979, p. 19). The philosophy of maintaining that agreed figure as advice was that there was "no significant change in catch rate and stock composition, therefore no change in previous advice". In the meantime actual catch level had already in 1980 increased to about 36,000 tons and remained around that figure in the following years. Consequently, one had to realize that such a fishery did not seem to cause significant changes in commercial stock abundance index or in catch composition, and the advised TAC for 1985 which raised the earlier value of 29,500 tons to 36,000 tons, was not to be interpreted as an increase in stock biomass but as a revised review of the implication of the catch and effort time series.

The advice of 36,000 tons was also maintained over a period, 1985–88. Then again, the effective TAC (sum of that in the Greenland zone and that in the Canadian zone) and actual catches increased above the recommended TAC so that in June 1988, seeing no significant changes in abundance indices based upon commercial data, biologists felt that catch levels of 44,000–50,000 tons could now be advised. The lower limit of 44,000 tons was the average for 1985–86 and the upper limit of 50,000 tons included 1987, for which year the preliminary statistics were 58,811 tons (*NAFO Sci. Coun. Rep.*, 1988, p. 75). Later on, however, it was discovered that about 10,000 tons had been reported twice in the preliminary 1987 statistics. If the Scientific Council had revised the figure, the average for the 1986–87 period would in fact have been 45,000 tons.

The TAC advice for Subareas 0+1 shrimp has thus to a very high extent been based on a gradually expanding fishery's effects (or lack of effects) on stocks. Uncertainties in the advice are, therefore, strongly connected with accuracy and credibility in catch and effort statistics.

Quality of fisheries statistics. Since there has been obligation for vessels above 50 GRT to report haul by haul in logbooks, catch and effort statistics ought to be very good. This seems to be the case for effort but certainly not so as far as catch is concerned, when the figures which actually neglect other components such as discarded shrimp are used as figures for removals from the stock. The figures may be relatively good for "nominal catch" as they are internationally defined (landings converted to fresh weight), but evidence point to a high degree of discarding (with nobody claiming high survival for discarded shrimp). In the way recent advice has been achieved, discarding would not be that great a problem for biological advice (but still important for economical considerations) had the discard rate been constant over all size groups. Additionally, in the most recent report of the NAFO Scientific Council (June 1990) great concern was expressed over the possible increasing discard rate. Great effort is now being made to observe and estimate this factor because when analytical assessment models may be applied on these statistics, the amount discarded and its size composition become important parameters.

The reason for discarding clearly is the economy of the vessel. Large shrimp have much higher value per pound than small shrimp. Since vessel quotas are so low and they can be easily fished, only large shrimp are used while the small ones are discarded. When this became evident and the discard rate seemed to be on the increase, Greenland made a law (from 1979) saying that discarding of shrimp larger than 2 g is not allowed. Without the law some skippers might have been persuaded to record their discard properly (in fact, recording discards is requested by the regulations). However, doing so now would be the same as committing a crime.

The fisheries. The offshore shrimp fishery on shrimp in Subarea 1 and the adjacent part of the Canadian fishing zone (Subarea 0) should be considered well established during the about 20 years it has been operating. Since full licensing is required, the number and characteristics of participating vessels are well known, and the fact that logbooks are mandatory for vessels larger than 50 GRT ought to ensure a good documentation of the fishery. However, severe problems arise due to the discard problem mentioned above.

The inshore fishery, restricted to vessels below 80 GRT, is also well established and rather well documented in terms of landings and major districts fished. However, most vessels in the inshore fishery are below 50 GRT and thus not forced to keep haul-by-haul logbook records. Information on effort and precise fishing ground is therefore scarce.

The TAC regulation does not apply to inshore waters. However, some of the small boats seem to take part of their catches in the offshore area, and such catches do not seem to be counted as part of the TAC. So, although the catch statistics for the inshore fleet may well reflect its actual catch, some uncertainty is found in the breakdown of the offshore and inshore component of the catches by that fleet. Biologists have, however, used some estimates of the offshore component of the catch when comparing TAC to actual catch in the TAC-area. This is one of the reasons for the total catch in the offshore area to usually end up higher than the TAC in force there (Table 1).

A new fishery at West Greenland north of (approximately) 71°N has developed since 1985. This area and its stock so far have been considered as being outside the general TAC area of Subarea 0+1. Greenland has set a specific TAC for that northern area.

Management. *(a) The two national fishing zones.* In the first years of TAC-regulations, Denmark/Greenland (through the EEC) and Canada set a joint TAC for the offshore grounds of Subarea 1 including the adjacent part of Canadian fishing zone, the area for which the biological advice is still given (the boundary between Subarea 0 and 1 was changed in 1980 to follow the Canada-Greenland midline). The TAC was then allocated through negotiations, and there was also some flexibility for the fleets when fishing in either area. However, that cooperation ceased in 1981 (the resources in Greenland fishing zone at that time being EEC resources). Since then, Canada and EEC, and later Greenland, each have set their specific TAC, Canada generally at a level of 17% of the advised TAC. In this paper only the management in the Greenland fishing zone will be considered further.

(b) Spatial breakdown of the TAC. Right from the start of the TAC regulation in 1977 a concern, at least for Greenland, was the possible interrelationship between offshore and inshore stock components, especially in the Disko Bay where a very important local fishery and fishing industry had existed for some twenty years. Also the possible interrelationship between various offshore grounds was of some concern for Greenland with part of its fleet rather immobile and with shrimp producing plants at several cities on the coast.

Lacking detailed knowledge of the offshore-inshore relationship STACRES of ICNAF nevertheless considered that establishment of a "box" with relatively low fishing off Disko Bay would be prudent should managers wish to prevent adverse effects in the bay from offshore fishing. STACRES recommended that catches in the area between 68° 00′N and 69° 30′N east of 59° W not exceed 3,200 tons (*ICNAF Redbook*, 1977, p. 16).

Such a protective area called the "shrimp box" was, therefore, established and has remained part of the management scheme since then although in 1980 it was administratively limited to a smaller area (east of 56° W) and with a higher TAC, thus making it a far less precautionary measure for the Disko Bay fisheries. Only part of the fleet has been allowed fishing in that box, as explained in more detail later in this section.

Apart from the recommendation of the "shrimp box" off the Disko Bay, STACRES really felt unable to advise any specific spatial TAC breakdown, but pointed out advantages and disadvantages for the fisheries by a breakdown. Greenland with its specific circumstances mentioned above found that these warranted some spatial distribution of the TAC. The following four management areas were already established in 1977, although for that year only for reporting of catches, while for 1978 the TAC was allocated to the areas as follows:

Area	TAC
Div. 1A north of 69° 30′N	2,000 tons
The area between 68° 00′ and 69° 30′N (the "shrimp box")	3,000 tons
Div. 1B south of 68° 00′N plus Div. 1C	27,000 tons
Div. 1D–1F	3,000 tons

This represented a total TAC of 35,000 tons for West Greenland. In the Canadian zone a TAC of 5,000 tons was applied, giving an overall TAC of 40,000 tons.

The breakdown on areas south of 68° N was given up in 1980. This, however, does not mean that the present TAC breakdown on areas is more simple. Rather the contrary is the case. For 1990 the following applies (*Hjst. Bek.* No. 9 of 21 February 1990 and No. 20 of 11 April 1990):

— The "Northwest Greenland" area, defined as between 71° and 72° 52.5′N east of 58° W plus 69° 30′–72° 52.5′N west of 58° W, was regarded outside the traditional TAC area and has a specific TAC of 6,775 tons.

— For the "West Greenland" area, defined as offshore (outside base lines) south of 71° N east of 58° W and south of 69° 30′N west of 58° W, a TAC of 37,725 tons is in force, but the following specific regulations apply:

— For an area between 68° and 70° 45′N east of 56° W, no vessel with a license is permitted to produce (i.e. to cook and freeze) 60% or more of their catch on board, and no vessels above 500 GRT are allowed fishing. Furthermore, inside this area between 68° and 69° 30′N east of 56° W (the revised "shrimp box") quotas of 1,500 and 3,500 tons have been set for vessels of 250–500 and 80–250 GRT, respectively.

— In the area 69° 30′–70° 45′N east of 56° W, no vessels above 250 GRT are allowed fishing, while for vessels 75–250 GRT a quota of 3,000 tons is in force.

— All quotas are allocated to individual vessels through the licensing system, probably with the exception of foreign vessels (Faroese and EEC-vessels) who have a total share of 1,000 tons, however these vessels are not allowed fishing north of 68° N.

Certainly, this complicated allocation of quotas on areas and on vessel categories are not established on biological advice but upon internal Greenland economical and political considerations.

(c) TACs and discards. In the light of the discard problem (discussed above) one uncertainty, or rather indistinctness, in the advice should be mentioned.

When the first TAC advice was given, the TAC was meant to include discards (*ICNAF Redbook*, 1976, p. 73). That advice was based on the "Disko Bay" model. It was in fact most likely that discarding was negligible in Disko Bay, hence it was logical that extrapolated yield estimates should include any discards.

The inclusion of discards in the advised TAC was repeated in December 1976 and in November 1977. Also, this was quite a natural approach since the advice was now based on stock estimates and a modified general production model, i.e. on total removals from the stock.

In November 1978 ICNAF, STACRES had total nominal catch and commercial catch rates as its major guidance. The advice was lowered by 20–32% of the November 1977 advice of 40,000 tons, and still it said it included discards (*ICNAF Redbook*, 1979, p. 19).

When advising in November 1979 the NAFO Scientific Council (N.B. NAFO replaced ICNAF and came into force in January 1979) simply advised that the TAC could be advised at the same level as advised in 1978 and took the agreed figure of 29,500 tons as its advice but did not say "including discards" (*NAFO Sci. Coun. Rep*., 1979-80, p. 29). The same was advised through 1980–84.

In January 1985 the advice raised the TAC to 36,000 tons based on "apparent stability of the stock and the fact that higher-than-advised yields have been realized during this period of stability" (*NAFO Sci. Coun. Rep*., 1985, p. 23). The figure of 36,000 tons was based on an average nominal catch during 1979–84. In other words, it was now the reported catch and its effect, or lack of effect, on the stock that became the basis for the advice. Thereby the advice had changed, to an advice for TAC excluding unreported discards on the underlying assumption that discards remained proportionally constant. This assumption was, however, not expressed (or realized?) until the June 1990 Meeting.

This change in the basis for advice, and thereby the nature of the advice, is probably not clear to managers and probably not even to all advisors. The serious uncertainty now is whether the proportion of the catch discarded remained and will also remain constant.

(d) Other regulatory measures. A minimum mesh size of 40 mm in shrimp trawls has been in effect since 1978 at West Greenland. Although this seems a large minimum mesh size compared to what is prescribed in fisheries for shrimp in other areas, this mesh size does not seem to be selective enough to prevent small shrimp in the catch, especially not when catch-per-haul is high. Just to enlarge the mesh size does not seem to be a sure way to prevent the discarding problem mentioned above.

Experiments using special sorting frames in the trawl are now in progress. Square meshes may also prove to be more selective than the presently used diamond meshes.

The regulation meant to prevent discarding of shrimp larger than 2 g, introduced in 1979, is not effective as discussed above. However, there are some obligations in place for fishermen to land part of the catch at shore-based plants. This provides a mechanism to discourage discarding because it is economically less attractive to make that part of the catch consist of mainly larger shrimp.

Other measures to be mentioned is the licensing system. That effectively controls the number of vessels participating as well as providing a rather good knowledge of their fishing power and production capacity. Each vessel in the Greenland fleet further has an individual quota. Such a regulation may eventually lead to effort regulation, as discussed below.

Management policy. Shrimp is by far the most important species in the Greenland fishery and the present basis for Greenland's economy. The management policy is, thereby, bound to be a careful balance between rational exploitation and maintenance of the resource. The interests of the fleet usually are expressed as short-term interests bound to the economy of single vessels (or other economical units) rather than the long-term community considerations. This results in heavy pressure from vessel owners to get a higher share of the TAC; frequently there are pressures for higher TACs and requests for exemptions when quotas are reached. An example of accommodating the wishes of the fleet (or part of the fleet) is the story of the "shrimp box", discussed above. The fleet does also bypass the intended TAC and quota management policy by not adhering to the rules, e.g. by discarding shrimp of sizes above 2 g which are not allowed to be discarded.

On the other hand, the politicians responsible for the management of this resource quite well know the importance of the fishery for the Greenland community and indeed take the biological advice seriously. Nobody would like to be accused of destroying the resource by not listening to biological advice (but it is quite fair to request qualified biological advice). The politicians making final decisions are, so to say, squeezed between economical short-term interests of investors and shipowners (amongst which is a Home Rule dominated company) and uncertain and thereby cautious biological advice. There has, however, been very little tendency to regulate optimistically on biological uncertainty, rather than to take the biological advice.

This latter statement may not seem very evident from Table 1 which lists advised TAC, TACs set and nominal catch for the years 1977-90. What happened in the years 1981-85 was that the EEC set a TAC for Subarea 1 close to the TAC advised for Subarea 1 plus the adjacent part of Subarea 0, while Canada on its side set a TAC close to 17% of the advised TAC. After 1985, when Greenland left the EEC, it has been very difficult for Greenland to reduce its TAC, but in 1989-90 the Greenland TAC was lowered.

The overruns of TAC seen, for instance in 1989, are more the effects of "loose ends" in the practical administration of quotas (because there is no area-restriction or catch limitation on small boats) than of the readiness to manage cautiously. Steps to overcome such difficulties are on their way.

Recognizing that investments in the fleet have increased beyond a rational level, the Greenland Minister for Fisheries now (1990) has taken the first steps to limit or even cut down the fleet so as to ensure better short-term as well as long-term economy in the fishery and hopefully with better chance of maintaining the resource. An important element in the management policy will be transferable quotas.

Such a policy seems proper in the light of the biological evidence that this resource seems to be relatively stable, with the fishery having occurred both before the climatic warming in this century (Jensen, 1939; Horsted and Smidt, 1956) and during periods when cod was plentiful in the area where the major shrimp grounds are found (Horsted, 1969).

A better correspondence between TAC and total amount of effort would most likely also tend to alleviate the discard problem. In fact, it could be the first step towards a management based upon total allowable effort. In practice such effort would have to be expressed in terms of fishing activity by fleet components (a total allowable fishing, TAF), although fishing activity is seldom synonymous with effort when the latter is taken to express fishing mortality.

Cod at West Greenland

Knowledge on biology. Cod is among the most intensively studied species in Greenland waters and the one which has been studied over the longest span of time. Jensen (1939) described its increasing occurrence at West Greenland in the 1920s as one of many biological effects of a circumpolar climatic warming, which also influenced sea surface temperatures. Hansen *et al*. (1935) reported results of the first tagging experiments in Greenland waters, and Hansen (1949) summed up a number of his own and studies by others. Studies based on sampling of commercial and research catches and on tagging experiments, have been carried out and reported annually since then by staff members of the Greenland Fisheries Research Institute, primarily as research documents to ICES, ICNAF and NAFO. Also many scientists from other countries have frequently made valuable contributions to the biological knowledge of cod at Greenland. A list of such contributions could well exceed the number of pages of this chapter.

Through these studies a very good knowledge has been obtained of the ever changing spatial distribution, age composition, growth, spawning, migrations, but less so on mortalities. The age distribution varies considerably between years reflecting high variability in year-class strength. Occurrence of cod larvae in the plankton and of young fish reveals some possibilities for early estimation of year-class strength (Hermann *et al*., 1965; Hansen and Buch, 1986), and together with studies of abundance of age-groups I-III (pre-recruits) gives a reasonably good possibility for forecasting recruitment to the fishable stock, at least in qualitative terms (see below).

One factor which sometimes contributes much to the uncertainty on the prognoses of stock biomass and catch is the mean weight of fish by age. This is known to fluctuate between years and year-classes. The method usually used for this stock is to use the most recently observed values for the prognosis. An approach suggested to be better is to follow the growth of each year-class in the stock and extrapolate the growth as a curve by fitting the von Bertalanffy growth equation. To give an idea of the uncertainty around this factor, Table 2 lists the values used over the last 10 years.

Another factor contributiong to uncertainty in the biological advice is migration, primarily of (first-time) spawners, from West to East Greenland and for some eventually to Iceland as evidenced by tag/recapture data (Hansen, 1949) and more recently by otolith type studies (Rätz, MS 1990). When such a migration occurs, the emigration and immigration rates become important parameters for assessing stocks and stock components between which the migration takes place.

TABLE 2. Mean weight (kg whole fish) by age of cod at West Greenland as calculated from observations in the year given and used next year for projections of stock biomass and catches in the following years (Horsted, MS 1981 and MS 1982, *NAFO Sci. Coun. Rep.*, 1983-90).

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.87	0.70	0.83	0.78	0.78	0.50	0.65	0.90	0.55	0.52
4	1.33	1.24	1.11	0.98	0.91	0.76	1.04	1.07	1.08	0.72
5	2.06	1.97	1.70	1.38	1.37	1.04	1.86	1.80	—[a]	1.27
6	3.00	2.85	2.35	2.08	2.00	1.60	2.09	2.12	—[a]	1.67
7	4.28	3.95	3.20	2.95	2.75	2.22	2.71	2.61	—[a]	2.31
8	5.84	5.10	4.20	3.85	3.50	3.03	3.16	3.24	—[a]	3.71
9	6.40[c]	6.40[c]	6.50	4.78	3.94	3.96	4.59	4.30	—[a]	4.21
10	7.80[c]	7.80[c]	9.02	5.58	4.92	4.39	4.71[b]	4.70[b]	—[a+b]	4.72[b]

[a] Few fish of these age groups were weighed. The 1984 figures were used since size at age was rather similar in 1984 and 1988.
[b] For 10+ fish.
[c] Taken from the 1979 figures.

Stock size estimates. Although some attempts to estimate stock size have been made on the basis of catch statistics, mortality studies and tag/recapture data, stock size estimates in recent years are based mainly upon direct observation through stratified-random trawl surveys carried out by the Federal Republic of Germany at West Greenland since 1982 and at East Greenland since 1980 (see *NAFO Sci. Coun. Rep.* since 1983).

As is well known, several factors contribute to the uncertainty around results of trawl surveys. The most critical one probably is the catchability coefficient. Lacking experiments to get a good estimate of this factor the NAFO scientists have used a factor of 1 to be "on the safe side", i.e. to accommodate the biologists' traditional fear of overestimating stock by a "blow-up factor". However, it seems questionable whether the factor could not be below 1 for otter trawls when wing spread and not distance between otterboards is used to calculate the swept area (Hovgård, MS 1989). This possibility is now taken into account in the Scientific Council of NAFO.

Another uncertainty is the unavoidable variability between trawl hauls inside each stratum. The statistical 95% confidence interval of biomass estimates from the trawl surveys at West Greenland is usually at a level of ±30% or even higher.

Recruitment and stock/recruitment relationship. As stated above, the forthcoming recruitment can to some extent be judged through observations of environmental factors at spawning time, by studies of larvae and by observations on pre-recruits (age groups 0–III). Forecasts of year-class strength were also made prior to 1973, when absolute figures for recruitment became essential for analyses leading to TAC-advice. Before that time qualitative expressions such as "good", "fair", "poor" were used, and these forecasts generally showed up to be right.

There is, of course, bound be be uncertainty around an estimate of year-class strength given in absolute numbers. Table 3 shows figures used for recruiting year-classes of West Greenland cod at age 3 in projections of stock size and catches since 1974 (*ICNAF Redbook*, 1974-79, *NAFO Sci. Coun. Rep.*, 1979-90). These figures are compared to the most recent values found by VPA (Riget, MS 1990). Broadly speaking, the table shows that at least the level of forecast figures has been reasonably good, although for some year-classes this statement deserves comments.

The 1973 year-class was underestimated when the fish were 0-3 years old. The year-class probably immigrated as young fish, and its actual magnitude was recognized after its first years in the commercial fishery (*ICNAF Redbook*, 1978, p. 55).

The first forecast of the 1982 year-class, which was forecast as a good one based upon environmental factors and abundance of larvae, showed up to be a complete failure. The year-class was a disaster to the fishery. What happened is not quite clear, but it should be noted that the two coldest winters seen over West Greenland since regular meteorological observations started there in 1874 occurred in 1982/83 and 1983/84 leading to severe cooling of sea water and to wide and heavy ice formations (Rosenørn *et al.*, 1984). Evidently, what seemed to be a promising year-class nearly vanished. When the next good prospective year-class seemed to occur in 1984, the history of the 1982 year-class was still so much in the minds of biologists that none of those advising for that stock dared to promise more than a poor year-class, and in the next couple of years just a moderate one (smaller than the 1973 year-class). The abrupt upgrading of the estimate of that year-class in 1988 did, of course, not contribute to managers confidence in biological advice.

The dependence of recruitment on spawning stock size is, unfortunately, not very well known. Attempts to

TABLE 3. Strength (numbers × 10^6) of cod year-classes at West Greenland as estimated at various stages of their life and as they occur in the most recent VPA. All values refer to the strength at the beginning of age 3 (e.g. year-class 1984 values are by 1 January 1987). Twenty million fish has been used as a conventonal figure for poor year-classes. See text for references.

Year-class	Larvae and/or 0-group	I-group	II-group	III-group	VPA
1972	small	30	25	25	27
1973	40	40	85	85	272
1974	40	40	30	40	56
1975	50	40	75	75	56
1976	20	20	20	20	38
1977	20	50	90	200	146
1978	20	20	20	20	10
1979	40	90	75-150	150	91
1980	75	75	75	75	17
1981	20	20	20	20	13
1982	200	150	20	20	4
1983	20	20	20	small	11
1984	20	200	200	500	569
1985	100	50	125	100	80
1986	small	20	20	20	
1987	20	20	20		
1988	20				
1989	20				

correlate the two are heavily disturbed by many other factors influencing the survival of each year's progeny (Hansen and Buch, 1986). Furthermore, it seems evident that the varying, but sometimes large, proportion of recruits stems from spawning elsewhere (at East Greenland or even Iceland). It has, therefore, not been possible for biologists to advise managers on specific target levels of spawning stock. This is not to say that stock-recruitment relationship has been ignored. In fact, on several occasions when spawning stock has been at a low level, biologists have advised that rebuilding or maintenance of the spawning stock should be the consideration when managers consider the various management options.

Connection between cod at West and at East Greenland. A factor contributing much to the uncertainty in the biological advice is the well known migration of some of the adult, mainly mature cod, from West to East Greenland waters with little reverse migration. Some of the migrants eventually reach Icelandic waters and never seem to return.

This fact causes more trouble when advising than it probably ought to, because up to this year West and East Greenland were separate management areas for the cod fisheries. Although as early as in 1976 ICNAF's STACRES proposed that the two North Atlantic fisheries commissions (ICNAF and NEAFC) should consider combined regulation of the West and the East Greenland cod stocks (*ICNAF Redbook*, 1976, p. 70–71), it was not until this year (1990) that some but not full flexibility between the West and the East Greenland TACs has been made.

Since biologists still have to advise on the two stocks (or stock components) separately, the emigration from West to East Greenland needs to be quantified and projected. This parameter is known to vary between years and year-classes. NAFO has had several approaches to this, the latest being otolith type studies (Rätz, MS 1990). But still great uncertainty exists in projecting emigration, the coefficient from West to East Greenland suggested to vary from 0.05 to 0.30 in recent year' analyses, influencing also input F-values for VPA.

The fisheries. The fishery for cod at West Greenland is partly an offshore fishery by large trawlers and partly a coastal and fjord fishery by gears other than trawls, primarily by pound nets and hand lines. Apart from a small local fishery at Ammassalik, the East Greenland cod fishery is almost exclusively by large trawlers.

The fisheries are well established and reasonably well documented; logbooks being mandatory for vessels larger than 50 GRT. However, since many vessels smaller than that take part in the inshore fisheries, the catch statistics are not very informative on catch-by-gear category, nor on fishing side for that part of the fishery.

Management. Cod fishing was a free fishery for many years, except that trawling for cod was not allowed (and apart from minor exemptions it is still so) inside the 3 naut. mile boundary (foreign fishing is not permitted in the fisheries territory). Minimum mesh size regulations for trawls were set through ICNAF in 1966 (130 mm, effective from 1969), and a domestic rule of minimum size for landed fish of 42 cm reasonably well corresponding to the 50% retention length of the prescribed trawls, was introduced in 1969 (Nal. A., 1969. p. 336). The minimum size was changed to 40 cm in 1973 (Nal. A, 1973, p. 123).

Based on the fact that Store Hellefiske Bank in Div. 1B usually (at that time) contained relatively many small fish, and on results of tagging experiments (Horsted, MS 1966), Denmark in 1965 proposed that ICNAF consider this area to be a nursery area and prohibit trawl fishing there. However, this proposal was never adopted or introduced.

After TACs were introduced by ICNAF in 1969 (for 1970 as unallocated TAC for haddock in Subarea 5 and Division 4X, see *ICNAF Ann. Proc*., Vol. 19, p. 26–27) and seeing what could be regarded as overfishing of the West Greenland cod stock (*ICNAF Redbook*, 1968, p. 45), Greenland saw a TAC regulation as the way to manage the fisheries on that stock. Already in 1969 STACRES had begun predicting catch levels by various F-values and providing comments on those. This developed into a 'one-figure' TAC advice in 1973, while since 1976 the analyses have again considered various options for TAC.

The first TAC at West Greenland came into force in 1974. Since then the West Greenland cod fishery has been regulated by TACs allocated amongst ICNAF/NAFO members (in ICNAF with an estimate of non-member catches). Table 4 lists recommended TACs, agreed TACs and total nominal catch for the years 1974–89. Unfortunately, stock size and catch level during that period have been much lower than in the years prior to that, when catches were some hundred thousand tons. Biologists have not had a chance to estimate stocks or recommend TACs at such a level, and the response from the managers to such a situation is therefore not seen either. Rather, the scientific advice has been cautious, incorporating considerations around rebuilding of the stock or at least maintaining of the spawning stock level. Also considerations around yield-per-recruit in years when relatively good year-classes were recruited to a depleted stock, were part of the biological advice (year-class 1973 in 1977, year-class 1984 in 1987–89).

Generally, the TACs have been set with great consideration of the biological advice but naturally also with political and socio-economic considerations.

When the first TAC was agreed the biological advice was 80,000 tons. The proposal put forward by Denmark was, however, 90,000 tons. The increase in the proposal as compared to the recommendation was argued as "a justifiable increase in TAC in view of the conservative nature of the quantity recommended by the scientists" (*ICNAF Meet. Proc.*, June 1973, p. 127). Evidently, there was a political consideration to present a proposal more digestible to the other ICNAF members, who in 1972 alone (the last year of known data available at the meeting in 1973) had reported catches of nearly 90,000 tons, and even higher in preceding years. The fact that the agreed TAC was 95,000 tons **plus** an estimate of 12,000 tons for non-regulated fisheries inshore (i.e. outside the ICNAF Convention Area) supports the view that it was politically important to get a TAC such as that introduced.

The total catch of that year (1974) of 48,000 tons clearly shows that the quotas had no limiting effect. No quota holder except Portugal came near its quota. Portugal evidently keep its catch level due to the newly introduced dory gillnets (*ICNAF Stat. Bull.*, Vol. 24, p. 241). All other fisheries decreased simply because of

TABLE 4. TACs as recommended by ICNAF/NAFO scientific bodies for cod at West Greenland. TACs in force and total nominal catch by year (all figures in '000 tons).

Year	TAC recommended for the year	TAC in force	Nominal catch
1974	80	107 (12)[a]	48
1975	55 for $F_{0.1}$ but lowest possible recomm.	60 (9)[a]	48
1976	45 or lower	45.1 (9)[a]	32
1977	0	31	73[b]
1978	lowest possible	—[h]	73[b]
1979	26	—[h]	99[b]
1980	49–54[d+g]	20 + inshore[i]	54[b]
1981	40[g]	50	53
1982	62[g]	62	56
1983	52–56[e]	62	58
1984	49[g]	68.5	33
1985	22.4–37.1[f+g]	28.3	15
1986	9.3[g]	12.5	7
1987	5.8[g]	12.5	16[c]
1988	33[g]	53[j]	62[c]
1989	135[g]	90	103[c]
1990	112	110	

[a] For some years the agreed TAC includes an estimate of inshore fisheries (outside the Convention Area). For such years the inshore catch expected when the TAC was agreed is given in parenthesis. The difference between the agreed TAC and the inshore estimate was allocated between participants in the fishery.
[b] Estimates used for assessment.
[c] Provisional data (*NAFO Sci. Coun. Rep.* 1990, p. 45).
[d] Range due to range in estimates of the 1973 year-class.
[e] Range due to range in estimates of the 1979 year-class.
[f] Range due to range in emigration rate and survey stock estimate.
[g] The $F_{0.1}$ value is shown but several options were analyzed and for the years 1986–89 a more cautious approach than the $F_{0.1}$ option was advised.
[h] No TAC was set but catches were limited to Greenlandic fishery and to by-catches, Greenland's catch was 37,000 and 46,000 tons for 1978 and 1979 respectively.
[i] The TAC of 20,000 tons was for areas outside baseline only.
[j] Initially (in Dec 1987) set at 40,000 tons. Raised in 1988.

the rapidly decreasing stock which thereby decreased catch rates and created less interest in fishing there. Practically, however, the TAC management had then been introduced to stay as the regulatory measure, at least up to now.

For the years 1975–78, the advice really could and should be read as a recommendation for a total closure of the fishery, and for 1977 it was directly stated so (*ICNAF Redbook*, 1976, p. 70). Clearly, however, the social and thereby the political situation in Greenland did not allow for such a drastic regulation. For 1978, a quota (TAC) of 25,000 tons was set for Greenland while non-Greenlandic fishermen were restricted from fishing cod in directed fisheries.

For the years 1986–87 Greenland again did not find it possible to go as low as the scientific advice, although the full stop for trawlers and poundnet fishermen was an unheard and a politically daring, restrictive step. Several exemptions for pound-nets were, however, given during that period.

It is interesting to compare actual catches to the TACs (Table 4). The 1974 situation has already been commented on. Also the shortfall of catches in 1975–76 was probably not a result of quota restrictions as much as of over-optimism in the TAC agreement. The overrun in 1977–80 in the unofficial figures used by scientists in their assessment was due to legal and administrative difficulties when some trawlers misreported the species composition of their catch.

The reason for the shortfall in 1984 was not quite clear, but was probably due to the fact that some of the assumptions underlying the scientific projections failed. The emigration of cod from West to East Greenland was evidently higher than assumed, and the growth rate of cod remaining at West Greenland decreased at the same time. Also, fleet capacity, a term which has become a key in discussions leading to the TAC decision, is usually set unrealistically high ignoring the fact that decreasing abundance of fish usually means decreasing catch rates and introducing the necessity of increased fishing activity to maintain a given catch level. Quotas therefore tend to be set higher than practically obtainable when stock is decreasing.

Discussion. Some discussion on management of cod at Greenland has already been incorporated. A number of uncertainties around advice for TAC is also pointed out in previous sections. In general, the uncertainties can be grouped as uncertainties on data themselves and uncertainties on assumptions. Whereas many of those in the first group, to a certain extent, can be analyzed and quantified, e.g. variability between hauls in trawl surveys, the latter are more "diffused". Two of the major uncertainties in advice fall in this group, *viz*. stock-recruitment relationship, and migration, more specifically emigration from West Greenland.

The fact that the biologists have been unable to advise on a target spawning biomass, and that good year-classes have also occurred sometimes when spawning stock was very low, has made recommendations of cautious fishing less strong than they would have been had a clear stock-recruitment relationship been evident. Only in very recent years has TAC been set at or even below the $F_{0.1}$ level (Table 4, footnote g). However, Greenland policy has not been so much as specific levels of F but as a wish of a steady and reasonably high level of fishing on the 1984 year-class over as many years as possible (prognoses by 1988 promised up to 1992, *NAFO Sci. Coun. Rep*., 1988, Table 7). In considerations of this, fleet capacity has been taken as being rather constant although the prognoses showed the necessity of increasing F over these years to maintain a steady catch level of about 90,000 tons (the 1989 TAC).

Table 4 also seems to indicate that TAC was never really a limiting factor for fishing except in the years 1986–87 when trawlers and pound-net fishermen were not allowed fishing, although with some exemptions for the latter. What has not been seen is a stop of fishing for all fishermen due to the TAC being reached. Instead the contrary has been the case. For instance, the initially set TAC of 40,000 tons for 1988 was raised to 53,000 tons in August that year when it became clear that the TAC of 40,000 tons would be reached. It must, however, be admitted that managers had the very good excuse that biologists had just upgraded their estimate of the 1984 year-class in June that year from 200 to 500 million and, although yield-per-recruit considerations still spoke for a low TAC, the biologists could not say that the increased TAC could not be taken.

With respect to yield-per-recruit, it also had to be remembered that biologists have not incorporated economical parameters, for instance neither the interest of investments in vessels, nor the price differentiation by size of fish (these two parameters will act in opposite directions). Furthermore, although the Y/R calculations tries to incorporate the emigration "mortality", fishermen and managers pose the question: "Why not fish the fish while they are available?". Admitting that cod may leave not only West Greenland waters but also all of Greenland waters to go to Icelandic waters, biologists only have very vague answers.

In summary, for cod at West Greenland the biological uncertainties do not seem to have had great influence on the short-term (annual TAC) management process, although they did on the TAC level. However, they may have affected planning. Several managers expressed great dissatisfaction with biologists' wavering over the various rather different estimates of the size of the 1984 year-class. Greenland's very late investment on large trawlers (starting 1968/69) was to an extent influenced by the knowledge of the cod resource being an unstable resource for which nobody dared predict its size over the number of years a trawler usually is in operation.

General Discussion and Summary

The description of the three case studies (the first containing two species) in this paper happens to be more voluminous than anticipated by the author (when the paper was proposed for the Special Session). The amount of information on the biological uncertainties around these stocks was found much higher than anticipated, and so was information on management.

It has been far less evident how the uncertainties have influenced managers' decision process. The most clear example is probably the case study on sand eel and capelin. With no present stock size estimate and with no political pressure from investors, a clear management or resource policy has evolved, *viz*. that fishing can be allowed to expand gradually provided it is under control and supplies data for stock assessment.

In the case of cod the uncertainties do not seem to directly influence the decision process. The valuable part of the advice on this stock probably is the possibility and reasonable success of forecasting trends in stock and fisheries. With (i) a lag time of about 3 years from first prognosis of year-class strength to first recruitment of a year-class, (ii) individual year-classes usually staying in the fishery over some years, and thereby with several year-classes (although of very different size) in the exploited stock, and (iii) a relatively flat yield-per-recruit curve, the possibility of adjusting inaccuracy in initial predictions while a year-class is still available, is good.

In fact, cod at West Greenland seems to be a stock for which assessment is of a relatively high quality. Short-term management (TAC level) can be based reasonably well on biological advice. Due to the large fluctuations in stock size, long-term management is, however, not that easy, especially in planning of investments on vessels and fish plants and their production.

For management of the shrimp fisheries the biological uncertainties seem to play a greater role than for cod management. The shrimp resource is so valuable, probably also relatively stable from nature's own side, that the management becomes a delicate balance between exploitation and conservation. No serious thoughts, like for cod, of "fishing while the fish is here" occur. The biological uncertainties thereby really come to influence the level at which the balance between exploitation and conservation is sought. Too low an advice compared to what the stock may really support means loss of much income, while too high a fishing may be a disaster to the stock and thereby to the community depending on the stock. But it has to be pointed out that one of the most serious uncertainties stems from the fishery itself: What quantities are really removed from the stock and what is their size composition? Probably with that question in mind, managers (politicians) now seem to operate cautiously and at the same time to look for ways to combine TAC management with regulations of fleet capacity and fishing power.

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ICNAF and NAFO reports are referred to in the text as follows:

ICNAF Annual Proceedings (ICNAF Ann. Proc.)

ICNAF Redbook (Reports of STACRES)

ICNAF Statistical Bulletin (ICNAF Stat. Bull.)

ICNAF Meeting Proceedings (ICNAF Meet. Proc.) (not publications)

ICNAF Selected Papers (ICNAF Sel. Pap.)

NAFO Scientific Council Reports (NAFO Sci. Coun. Rep.)

When special references are made to these, year and page number are given in the text.