NOT TO CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N4178 **NAFO SCR Doc. 99/99**

SCIENTIFIC COUNCIL MEETING – SEPTEMBER 1999
(Joint NAFO/ICES/PICES Symposium on Pandalid Shrimp Fisheries)

The Uncertainty of an Assessment Procedure for the West Greenland Stock of Northern Shrimp, *Pandalus borealis* (Krøyer)

by

Carsten Hvingel[1] and Michael C. S. Kingsley

Pinngortitaleriffik—Greenland Institute of Natural Resources
P.O. Box 570, DK-3900 Nuuk, Greenland

Abstract

The shrimp (*Pandalus borealis*) resource off West Greenland was assessed by fitting, to four fleets operating over different periods, separate CPUE models, which were then combined. A logistic model of population dynamics was then fitted to this data and a standard trawl survey series. Uncertainty was estimated by a jack-knife procedure—leaving out one year's data at a time—in several forms: omitting data from all steps in the process or only from the last step of fitting the production model; or omitting data either for one year at a time at each point in the series or for a sequence of years at the start of the series.

Initial results from jack-knifing the entire procedure gave a small scatter (CV 8%) in optimal fishing mortality, but the sustainable catch had a 13% CV and ranged from 9% lower to 52% higher than the value based on all the data. Omitting the first year's data created an outlier with a 47% lower sustainable fishing mortality. When jack-knifing only the input to the logistic population model, the optimal fishing mortality retained a CV of near 8%, but the CV of sustainable catch fell to about 4% (ranging from 8.5% lower to only 9.2% higher). Much of the variation in estimated sustainable catch therefore appeared due to uncertainty in the standardized CPUE series. However, omitting the first year's data continued to give an outlying point, so the effect of leaving out the first year's data was investigated further.

When the experiment was repeated with the first two data points permanently omitted, the CV of MSY remained near 4%, but the variation in sustainable fishing mortality and in standing stock became large. Also, there was little difference whether the jack-knife procedure included the GLM fitting of the CPUE series or whether points were simply omitted from a single series based on all the years' data. I.e. particular properties of the data points appeared to have significant effects.

The jack-knife procedure appears useful for examining the reliability of this standard method of fishery assessment, and these results indicate that the uncertainty of such results may be unpredictable, large, variable between model parameters, and difficult to assign to any particular step in the procedure.

[1] Author to whom correspondence should be addressed, at: Norwegian College of Fishery Science, Dept. of Marine and Freshwater Biology, University of Tromsø, Breivika, 9037 Tromsø, Norway.
Tlf +47 77 64 60 22; Fax: +47 77 64 60 20; carstenh@nfh.uit.no.

Introduction

The northern shrimp (*Pandalus borealis*) occurs off West Greenland in NAFO Divisions 0A and 1A–1F, mostly in water from 150 to 600 m deep. The shrimp fishery started in inshore areas in 1935. Since 1970 an offshore fishery developed and landings increased from about 10 000 tons to a level around 70 000 tons in the 1990s (Fig. 1). Catches were first restricted in 1977 and the fishery has since been managed by the annual setting of a Total Allowable Catch (TAC).

Information available for evaluating the stock status comprises: data from the fishery on catch, effort and standardised catch rates; biomass indices from research surveys; and data on the size composition of the stock (Anon. 1998). No analytical assessment can be carried out and fishing mortality is unknown. Sequential Population Analysis (SPA) has been tried (Savard *et al*., 1991), but older ages cannot be distinguished well enough for these analytical techniques to be reliable. A non-age-structured model must therefore be used. Such models are usually of the stock production type (e.g. Shaefer, 1954) and describe stock dynamics simply in terms of rates of change of total biomass, rather than by the detail of age-specific growth and mortality of individuals (see Hilborn and Walters (1992) for a review of such models). Although simple—which is one of their advantages—they may yet provide as good answers as age-structured models (Ludwig *et al*. 1985; 1989; Prager *et al*., 1996).

Biomass-dynamic models are widely used in marine stock assessments. They have been applied to a broad spectrum of species ranging from whales (e.g. Donovan, 1989 pp. 145–199) through marine fish (e.g. Stevenson *et al.*, 1997; Horbowy, 1996; Mathews and Samuel, 1991) to lobster (Chen and Montgomery, 1999) and sea-cucumber (Bradbury *et al.*, 1996). They are, however, most commonly used in assessments of tuna and tropical fish stocks (e.g. Anon., 1997). Only recently have biomass dynamic models been tried out on stocks of northern shrimp (Cadrin and Skuladottir, 1998; Berenboim and Korzhev, 1997; Stefánsson *et al*., 1994).

For fitting a biomass dynamic-model the minimum data requirements are one or more time series of biomass indices and concurrent catches. Catch rate indices developed by standardizing catch performance(s) of individual vessels or vessel-groups over time (Gavaris, 1980; Kimura, 1981) are assumed to index biomass and may be used as one set of inputs. There may be concerns as to whether this assumption is in general correct (see e.g. Cooke and Caddy, 1984); however, even if it is, there is a further concern as to the effect that uncertainty or error in the input series of catch-effort ratios (or other biomass indices) may have on the estimates of stock-dynamic parameters generated by a biomass-dynamic model. The present article provides one approach to exploring this aspect of the uncertainty of the results arising from stock-dynamic modeling of a stock of northern shrimp.

In order to do this, we fitted a non-equilibrium logistic production model of the Schaefer type to two series of biomass indices for the West Greenland stock of northern shrimp: a standardized catch-rate index from the commercial fishing fleets and a survey series. The commercial catch-rate series was itself a composite of four partly overlapping series. The aim of this study was to determine how reliable were the estimates of biomass-dynamic parameters resulting from this complex process of standardizing four catch-rate series, combining them, and finally fitting a model of population dynamics based on a logistic population growth curve.

Materials and Methods

<u>Input data.</u>

A CPUE (Catch Per Unit Effort) index for 1976-1998 (Hvingel *et al*., in press) and a series of research trawl survey biomass indices (Carlsson *et al.*, 1998) for 1987–98 were used as indicators of stock biomass. Total reported catch in Subarea 0+1 (Hvingel and Folmer, 1998) was used as yield data.

The CPUE data came from four fleets, fishing in different periods and on different grounds. Each fleet biomass index was corrected for the changing composition of the fleet, as vessels of different power entered or left, and for other effects such as the varying distribution of fishing effort through the year, by a General Linear Model (GLM) (SAS, 1988). Then a single series was fitted to the four separate CPUE series, minimizing a sum of squares weighted by the area fished by each fleet (Hvingel *et al*. in press).

Model.

A standard logistic model of biomass dynamics was used, which in its differential form is:

$$dB/dt = rB_t - (r/K)B_t^2 - C_t$$

where $B(t)$ is 'biomass' (tons) at time t, r is 'intrinsic rate of growth' (/yr), K is 'carrying capacity' (tons), and $C(t)$ is 'instantaneous catch rate' (tons/yr). The parameters (r, K, and a series of yearly values for B) were estimated using ASPIC (Prager, 1994). This program fits a trial set of biomass-dynamic parameters and constructs the consequent stock biomass trajectory from the joint action of the supposed dynamics and the observed catches. These calculated annual biomass values are compared with the input index series—scaled by catchability coefficients—and the parameter estimates are adjusted (by simplex optimisation—Nelder and Mead, 1965) to minimise the (sum of squares of the) differences. Parameters, significant for management, that can be derived from the estimates of r and K are: the maximum sustainable catch (MSY=Kr/4) and the associated standing stock (Bmsy=K/2) and fishing mortality (Fmsy=r/2), assuming that the logistic model is appropriate.

Jack-knifing.

We used a standard jack-knife (Efron, 1982) to examine possible error in the estimates of biomass dynamics parameters.

In the first run standardised indices for the commercial catch rate series for 1976–1998 were estimated by the methods of Hvingel *et al.* (in press), but leaving out one year of data at a time; i.e. a CPUE series was computed omitting the data for all fleets active in 1976, then the 1976 data was replaced and another series was computed omitting the data for 1977 and so on. Obviously, there was a missing value for the year whose data was left out, but also, the values for all the other years altered as well. The complete series of reported catch data was included in all runs: for one thing, complete catch data was necessary to calculate the estimated stock trajectory and the catches were in any case assumed known without error. The stock-dynamics model was then fitted to each of the resulting 23 data sets, the same year's value also being omitted from the series of trawl survey biomass indices. The variation of the results so obtained indicated the uncertainty in the overall result.

A second set of runs were carried out in which we used the CPUE series computed from all years' catch and effort data but omitted one year at a time from this unchanging series in the input to the production model. We always kept all the survey and catch data. The variation of the results so obtained indicated the uncertainty in the parameter estimates due only to the uncertain fit of the stock-dynamic model to the series of biomass indices and to the known catches.

In a third set of runs we used all years' catch data as in the second run, but omitted one year at a time of both CPUE and survey data in the production model input. The variation of the results so obtained indicated the uncertainty in the parameter estimates due to the poor fit of both series together.

Influence of the first data point

The results of the first three sets of runs all indicated that the first year had a significant influence on the result; i.e. when the 1976 data point was omitted, the result obtained never lay within the scatter pattern obtained when the other years were in their turn left out. We wished to investigate if this was a special feature of the 1976 data point, or whether it indicated an exceptional influence of the first year's data whatever it was. To do so, we made a 4th run in which we deleted consecutive years of data on catch and effort from the entire computational process including the standardisation of the individual fleet CPUE series, the combination into a single CPUE series, and the fitting of the production model. I.e. the first data series had all the data, the second had data only from 1977, the third only from 1978, and so on. The shortest series we tried had data from 1986 onwards.

As the previous run suggested that both the 1976 and 1977 data had a significant influence on model output we made two final runs like the 1st and 2nd run but with the 1976-77 data permanently deleted.

Results

Running the assessment procedure on the complete data set suggested an MSY of about 96 000 tons at a standing stock of 180 000 tons. Jack-knifing the entire procedure gave variable values for maximum sustainable catch (coefficient of variation (CV) 13%) and for the corresponding standing stock (CV 19%) (Table 1). This variation was positively skewed, and ranged from 9% lower to 52% higher than the MSY value obtained from using all the years' data (Fig. 2). The corresponding values for Bmsy was 16% lower to 78% higher. However, the ratio between MSY and Bmsy, i.e. the sustainable fishing mortality, was less variable (CV 8%) and values were scattered near a central value of 0.5/yr. Omitting the data for the first year (1976) in the catch series gave different results. When this year was omitted, Fmsy was 0.29/yr, and Bmsy was 320 000 t.

In the second and third analyses, jack-knifing was limited to omitting one year's data at a time from the input to the production model; either CPUE data only was treated as missing or both CPUE and survey data were omitted. The results from both runs were similar: CV of MSY was about 4% and of Bmsy about 7% (Table 1). The scatter was evenly distributed around the value obtained from using all the years' data (Fig. 2). Omitting the 1976 data still gave an outlying result with low sustainable fishing mortality.

The results of the 4th run showed that when the data of 1976 and 77 had been omitted, MSY decreased from about 96 000 tons and stabilised around 84 000 tons with a CV of only 1% (Fig. 3). The Bmsy was still very variable with a CV of 31%.

When the 1st and 2nd run was repeated but with the 1976-77 data permanently deleted, the CV of the MSY was reduced to 4.7% and for the Bmsy, 20.1%, when the entire processes were jack-knifed—not very different from when only the input to the production model was jack-knifed (CV for MSY=4.2% and CV for Bmsy=12.3% (Table 1 and Fig. 4).

Discussion

The variation between the estimates from jack-knifing the entire assessment process (Fig. 2+4) is a measure of the uncertainty associated with deductions about sustainable fishing policies based on this kind of model fitting. From the initial investigations about 2/3 of the uncertainty in the estimated MSY and 1/4 of the Bmsy seemed to arise from uncertainty in fitting the CPUE series to the catch and effort data from four fleets. Fitting the production model to the CPUE and survey data was responsible for 1/3 and 3/4 of the uncertainty respectively. The production model appeared sensitive to the first data point in the CPUE series: when this was omitted, very different results were obtained. Further analyses however suggested that this was not a characteristic of being the first point in the data series but rather a special feature of the 1976 and also 1977 data points. In the subsequent analyses where the 1976-77 data were omitted only 1/10 of the uncertainty in MSY and 1/3 of the uncertainty in Bmsy appeared to come from the CPUE-series and the remaining 9/10 and 2/3 were due to model process error.

The uncertainty of the parameter estimates obtained from fitting the production model may originate from various sources. When the fundamental assumption of the data being from a single closed population is fulfilled, the reliability of the estimated parameters are dependent on: 1. the ability of the model to describe the dynamics of the population; 2. the contrast in the data i.e. the historical variation in stock size and fishing effort; and 3. the uncertainty of the stock biomass index. A valid model also requires that all the biomass indices used are linearly related to true stock biomass. The validity of this assumption for the CPUE series used here is discussed in Hvingel *et al.* (in press) and will not be treated further in this paper.

The model assumes a logistic function for unexploited population growth, i.e. a simple quadratic stock-recruitment function. It also assumes that the carrying capacity and maximum intrinsic rate of growth are constant. Some of these assumptions may fail under some circumstances without invalidating all the results. Provided that the data includes a range of stock levels both above and below the true maximum yield level, it will not be serious if the population growth function is not exactly logistic, provided it is continuous and convex upwards. Under such conditions, related errors will occur in both the extrapolated estimate of the carrying capacity and in the estimate of the intrinsic rate of growth, but the estimate of MSY will be nearly correct. However, if the data does not span the true MSY, more serious errors in estimating MSY are apt to result from failure of the model assumptions. For example, if carrying capacity or intrinsic rate of growth, or both, are not constant, performance of the model is hard to predict. Small random variations may not seriously affect the results, but large variations may make the model unstable. If there is a continuing trend in either parameter the model results may be completely confounded. Predation (e.g. Berenboim *et al*., in press; Stefánsson *et al*., MS 1994) is considered to have a significant influence on shrimp population dynamics, and large changes in abundance of a major predator, the Atlantic cod *Gadus morhua*, are well documented within the time span of these data series. In particular, our first two years, 1976–77, were the last two years of a period when cod were abundant in West Greenland waters. The physical environment (e.g. Richards, in press; Anderson, in press) also affect shrimp populations and may be the cause of the rapid changes in abundance seen in some stocks (Anderson, in press; Apollonio *et al*., MS 1986). Over the series of data used in this enquiry, the distribution both of the shrimp fishery and of the catches in the trawl survey has shifted southward (Hvingel MS 1996). It has done so progressively over a number of years. This must imply that the carrying capacity in the northern grounds has fallen, and in the south has increased. However, we cannot automatically suppose that the total carrying capacity has stayed the same, so to that extent, the assumption in this assessment process of a constant carrying capacity seems perhaps questionable.

If the data contains little contrast and much random error, the stock-recruitment curve may not be easily fitted, and may overshoot the data and overestimate the MSY. However, the fishing mortality may be relatively well fixed by the slope at the origin of the stock-recruitment curve, and thus relatively constant. This appears to be what happened in our first set of runs, where the omission of some data points allowed the stock-recruitment curve to greatly overshoot the data and produce elevated estimates of the MSY, although fishing mortality did not change much. The MSY estimated from all the data—96 000 tonnes—is itself greater than the mean catch over the history of the fishery, which has been about 55 000 tonnes, and may indicate that the stock-recruitment curve is not tightly defined by the data.

However, in subsequent runs which used all the data to fit the CPUE series, and only omitted serially the points from the fixed series, the variability was much reduced. This shows that the majority of the uncertainty in these results is due to the fitting of CPUE series to fleets of variable composition.

When the experiment was repeated with the first two data points, viz. 1976 and 1977, permanently omitted, we obtained rather different results. The variation in the MSY was less, and the variation in sustainable fishing mortality and in standing stock was large. Furthermore, there was little difference whether the jack-knife procedure included the GLM fitting of the CPUE series or whether points were simply omitted from a single series based on all the years' data (Table 1). This appears due to two separate effects.

The relative stability of the MSY may be because the data set, without those two years, better fits a quadratic stock-recruitment curve, and the MSY is more stably located. The extrapolation of the quadratic to the carrying capacity, and the concomitant calculation of the sustainable F, then become more unstable. In this connection, we tested the correlation between the catch in one year, and the decrease in CPU from that year to the next. This would be broadly expected to be positive, as large catches should tend to make the resource scarcer. In fact it was negative, indicating that a stock-recruitment model should be difficult to fit. However, when the points for 1976 and 1977—which combined relatively small catches with significant decreases in CPUE—were omitted, the correlation became zero. I.e. the data became more tractable for a stock-recruitment model. These two years were the last of a period in which cod were abundant in West Greenland waters. Cod are predators on small shrimp, and may therefore reduce recruitment. So if cod were abundant, even moderate catches may have exceeded recruitment enough to reduce CPUE in the next year. This illustrates a possible difficulty in fitting a stock-recruitment model to a system in which the parameters are not free of trend.

At the same time, the GLM fitting of the CPUE series may be affected by a poor fit in the two years 1976 and 1977, so that when those years are left out, the CPUE series fits better with less uncertainty. Therefore, including the GLM fit in the jack-knife procedure adds little variability to the results.

The 3-stage procedure used in the model assessment we tested here—fitting CPUE series to fleet data, and then fitting a simple model of stock dynamics to the CPUE data—was not unusually complex in the domain of fishery resource management. The jack-knife procedure we explored is a reasonable one for testing the reliability of such a procedure. Our results indicate enough uncertainty in the output to show that reliability of such procedures needs to be thoroughly checked before their results can accepted for management decision making, and that the reliability may depend on specific local features of the data series used. Under the best circumstances, results may apparently be fairly reliable, but it appears that some parameters of the stock dynamics may be estimated with quite different reliability from others, and it is not always apparent which. The different steps in the process may contribute different degrees of uncertainty, so estimates of the uncertainty accrued in one step may be quite misleading as a guide to the total uncertainty.

Assessment methods based on aggregated stock-production models have an intrinsic problem: a well-managed fishery in a stable environment, in which a sustainable catch close to the maximum is regularly taken with little variability in standing stock or fishing effort, provides little information on the parameters of the stock-recruitment function, which are therefore difficult to estimate reliably. Overcoming this difficulty by relying on long data series imposes a requirement for a stable environment free of significant medium-term (i.e. of the order of decades) drift in the few simple parameters that define the stock-recruitment relationship—a requirement difficult to satisfy for shrimp stocks. Methods that use information on demographic population structure—such as virtual population analysis or delay difference models— can in theory avoid some of these difficulties by relying on details of the age structure of the stock or of the biology of the individual such as mortality, growth and recruitment, but usually have the limitation that they ignore the density dependence that is an important feature of aggregated models.

We thank the organizers of the Pandalid Shrimp Symposium for stimulating us to prepare this study for presentation and publication, and for patiently awaiting its submission. The modeling studies described would not have been possible if we had not been able to use the long series of data carefully assembled and checked by our colleagues at Grønlands Naturinstitut and its predecessor the Grønlands Fiskeriundersøgelser.

References

Anderson, P. J. In press. Pandalid shrimp as indicators of marine ecological regime shift. NAFO/ICES/PICES symp.: Pandalid shrimp fisheries, science and management at the millennium in J. Northw. Atl. Fish. Sci..

Apollonio, S., D.K. Stevenson and E.E. Dunton, Jr. 1986. Effects of temperature on the biology of the northern shrimp, *Pandalus borealis*, in the Gulf of Maine. NOAA Tech. Rep. NMFS 42, 22 p.

Anon. 1997. ICCAT, International Commission for Conservation of Atlantic Tunas. Report for Biennial Period 1996–1997, Vol. 2, 1997.

Anon. 1998. Scientific Council Reports 1998. North Atlantic Fisheries Organisation, Dartmouth, Canada. 257 pp.

Berenboim, B.I., A.V. Dolgov, V.A Korzhev, N.A. Yaragina. In press. Cod impact on the stock dynamics of shrimp Pandalus borealis in the Barents sea and its application in multispecies models. NAFO/ICES/PICES symp.: Pandalid shrimp fisheries, science and management at the millennium in J. Northw. Atl. Fish. Sci..

Berenboim, B., V. Korzhev. MS 1997. On possibility to apply the Stefansson stock production model for assessment of shrimp (*Pandalus borealis*) stock in the Barents Sea. International Council. for the Exploration of the Sea, Baltimore, MD (USA), 25 Sep-3 Oct 1997. Copenhagen-Denmark ICES 16 pp.

Bradbury, A., W.A. Palsson, R.E. Pacunski. 1996. Stock assessment of the commercial sea cucumber *Parastichopus californicus* in the San Juan Islands, Washington State, USA. Int. J. Shellfish Res. 15: 785-786.

Cadrin, S.X. and U. Skuladottir. MS 1998. Surplus production analysis of shrimp in the Denmark Strait, 1977-1998. NAFO SCR Doc. 98/117, 18 pp.

Carlsson, D. M. and P. Kanneworff. MS 1998. Offshore stratified random trawl survey for shrimp (*Pandalus borealis*) in NAFO Subarea 0&1, in 1998. NAFO SCR Doc. 98/118; Ser. No. N4027. 18 pp.

Chen,Y. and S. S. Montgomery. 1999. Modeling the dynamics of eastern rock lobster, *Jasus verreauxi*, stock in New South Wales, Australia. Fish.-Bull. 97: 25-38.

Cooke, J. G. and J. F. Caddy. 1984. The relationship between catch rates and abundance in fisheries. IMA Journal of Mathematics Applied in Medicine and Biology.

Donovan, G.P., (ed.) 1989. The comprehensive assessment of whale stocks: the early years. Rep. Int. Whal. Commn Spec. Iss. 11.

Efron, B. 1982. The jackknife, the bootstrap, and other resampling plans. Soc. for Indust. and App. Math. Philadelphia, Pa. 92 pp.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37: 2272–2275.

Hilborn, R. and C. J. Walters, 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York, 570 pp.

Horbowy, J. 1996. The dynamics of Baltic fish stocks on the basis of a multispecies stock-production model. Can. J. Fish. Aquat. Sci. 53: 2115-2125.

Hvingel, C., H. Lassen, and D. G. Parsons. In press. A biomass index for northern shrimp (*Pandalus borealis*) in Davis Strait based on multiplicative modelling of commercial catch-per-unit-effort data (1976 - 1997). J. Northw. Atl. Fish. Sci. 00: 000–000

Hvingel, C. and O. Folmer. MS 1998. The Greenlandic fishery for northern shrimp (*Pandalus borealis*) off West Greenland, 1970–1998. NAFO SCR Doc. 98/111. Ser. No. N4020.

Hvingel, C. MS 1996. Geographical changes in the fishing pattern of Greenlandic shrimp trawlers in the Davis Strait, 1987-1996. NAFO SCR Doc. 96/110. Serial No. N2807. 5 pp.

Kimura, D. K. 1981. Standardized measures of relative abundance based on modelling log(c.p.u.e.), and their application to Pacific ocean perch (*Sebastes alutus*). J. Cons. Int. Explor. Mer, 39: 211–218.

Nelder J.A. and R. Mead. 1965. A simplex method for function minimisation. Comput. J. 7:308–313.

Prager, M. H. 1994. A suite of extensions to a non-equilibrium surplus-production model. Fish. Bull. 92: 374–389.

Prager, M. H., C. P. Goodyear, G. P. Scott. 1996. Application of a surplus production model to a swordfish-like simulated stock with time-changing gear selectivity. Trans. Am. Fish. Soc. 125: 729–740.

Richards, A. In press. Physical and biological factors influencing recruitment of northern shrimp, Pandalus borealis, in the Gulf of Maine. NAFO/ICES/PICES symp.: Pandalid shrimp fisheries, science and management at the millennium in J. Northw. Atl. Fish. Sci..

SAS, 1988. SAS Institute Inc. SAS/STAT user's guide, release 6.03 edition. Cary, NC: SAS institute Inc., 1988. 1028 pp.

Savard, L., I. H. McQuinn and D.G. Parsons. 1991. Investigating the potential of sequential population analysis for northern shrimp (*Pandalus borealis*) in Division 0A. NAFO SCR Doc. 91/71, Serial No. N1955, 12 pp.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Comm. 1(2): 27–56.

Stefánsson, G., U. Skúladóttir and G. Pétursson 1994. The use of a stock-production-type model in evaluating the offshore *Pandalus borealis* stock of North Icelandic waters, including the predation of Northern shrimp by cod. ICES CM 1994/K:25.

Stevenson D. K., K. Friedland, M. Armstrong. 1997. Managing the U.S. Atlantic herring coastal stock complex for long-term sustainable yield International Counc. for the Exploration of the Sea, Baltimore, MD (USA), 25 Sep-3 Oct 1997. Copenhagen-Denmark ICES 21 pp.

Table 1. Means and coefficients of variation (CV) of maximum sustainable yield (MSY), standing stock biomass (Bmsy) and sustainable fishing mortality (Fmsy) estimated from different jack-knife procedures.

Run	Method	Mean ('000 tons)			CV (%)		
(no.)	of Jack-knifing	MSY	Bmsy	Fmsy	MSY	Bmsy	Fmsy
1	the entire process, 1976-98 data	108	213	0.51	13.3	18.7	8.1
2	the CPUE-input	96	183	0.53	3.9	7.3	7.8
3	both input series	96	183	0.53	3.7	6.5	6.8
4	shortening the input series	85	154	0.61	0.9	31.4	40.3
5	the entire process, 1978-98 data	82	204	0.42	4.7	20.1	21.4
6	the CPUE-input, 1978-98 data	84	241	0.36	4.2	12.3	18.0

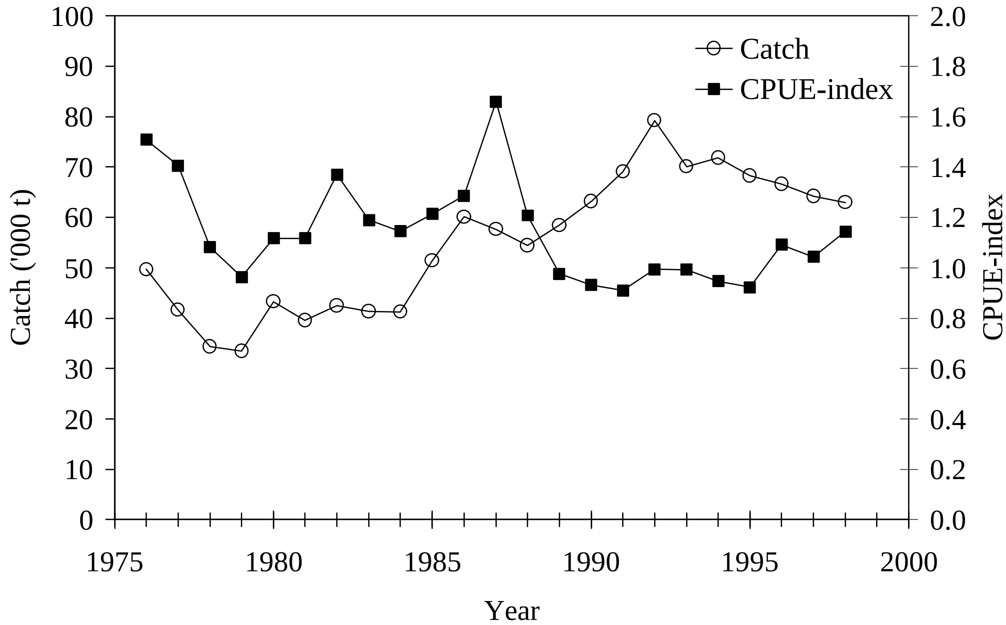

Fig. 1. Catch (thousand tons) and catch-rate index (relative units) in the shrimp fishery off West Greenland 1976–1998.

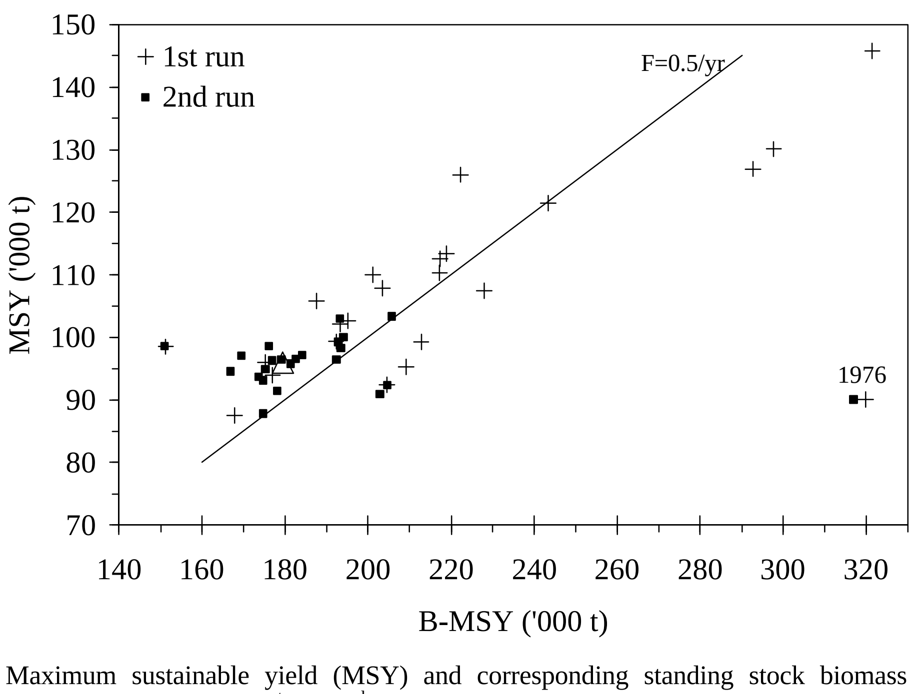

Fig. 2. Maximum sustainable yield (MSY) and corresponding standing stock biomass (Bmsy) in thousand tons from the 1st and 2nd jack-knife runs. The value obtained by including all the 1976-1998 data is shown as an open triangle. The 0.5 isocline of fishing mortality (F) is shown by the straight line.

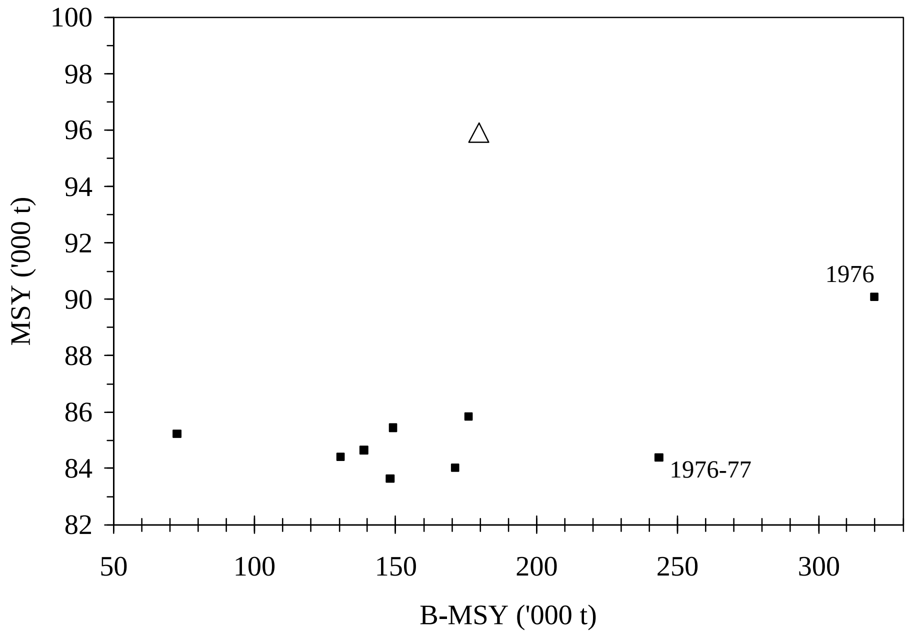

Fig. 3. Maximum sustainable yield (MSY) and the corresponding standing stock biomass (Bmsy) in thousand tons from the 4th run. The value obtained by including all the 1976-1998 data is shown as an open triangle.

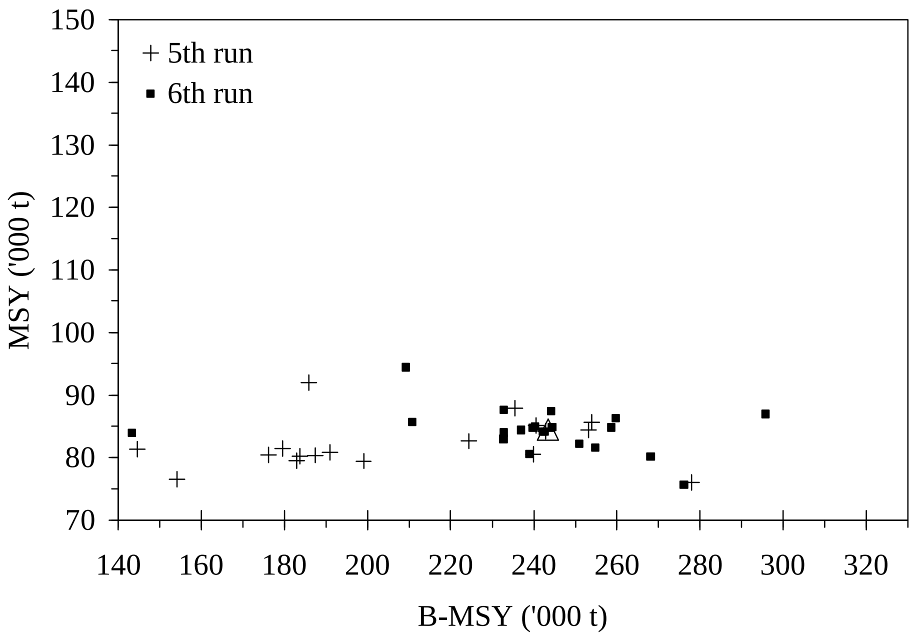

Fig. 4. Maximum sustainable yield (MSY) and the corresponding standing stock biomass (Bmsy) in thousand tons from the 5th and 6th runs. The value obtained by including all the 1978-1998 data is shown as an open triangle.