The United Nations University
FISHERIES TRAINING PROGRAMME
PO Box 1390, Skulagata 4
120 Reykjavik, Iceland

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A comparison of different assessment models for northern shrimp, *Padalus borealis*, in Icelandic waters

Akim Abel Gonzáles Yanez
Fisheries Research Centre,
abel@cip.fishnavy.inf.cu
Havana-Cuba

Supervisors: Björn Ævar Steinarsson, Marine Research Institute and Dr. Gunnar Stefánsson, University of Iceland

ABSTRACT

Two models, an *ADAPT* model similar to the one described by Gavaris (1988) and an Age-structured production model, were compared in the stock assessment of northern shrimp (*Pandelus borealis*) in Icelandic offshore waters in the period 1988-2000. The age-disaggregated data used as input for the models was computed with the simplified version of the Macdonald and Pitcher (1979) method, from commercial landings and surveys based on length frequency data.

Mean weights at age are obtained from a length-weight relationship, which was determined in previous studies, using the mean length at age. The annual rate of sex change was calculated from length maturity ogive and later on the rate of sex change at age was estimated using the mean length at age.

Both assessment models give similar outputs, although the estimated from the Age-structure production model are more optimistic than those from *ADAPT*. The results of *ADAPT* are in better agreement with previous assessments. In general, the results show a slight recovery in the standing stock biomass in the last year, after three years of continuous decline.

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1 INTRODUCTION

The northern shrimp is widespread in the North Atlantic and the North Pacific Oceans and is a very valuable resource. In Icelandic waters it is found in fishable quantities in most Icelandic fishing grounds except off the south coast. Shrimp products accounted for 13% of Iceland's total seafood export value in 1998 exceeded only by cod and capelin products. Twenty years ago, shrimp fishing was restricted to less than 10,000 tons per year, mostly in inshore areas. Another 20 years back, shrimp was frowned upon in the cod fisheries, since cod was often more tempted by this prey than by the fisherman's bait (Information Centre of the Icelandic Ministry of Fisheries 2000a).

1.1.1.1

The shrimp management system has evolved during last decades in accordance with biological and economical sustainable fisheries. The Total Allowable Catch (TAC) for inshore shrimp fisheries was first established in 1973-1974 (Information Centre of the Icelandic Ministry of Fisheries 2000b). At present, inshore and offshore stocks of north shrimp in Iceland are assessed and managed separately. Local stocks of inshore shrimp differ in abundance over time and from one area to another. Each fishing area is therefore a separate management unit (Information Centre of the Icelandic Ministry of Fisheries 2000c). The TACs for inshore and offshore shrimp are provisional, in line with the recommendations of the MRI and pending further research and stock assessment (Information Centre of the Icelandic Ministry of Fisheries 2000d).

The status of shrimp stocks in various areas depends among other things on the fishing effort and cod abundance since shrimp is part of the food of cod, especially small cod. Cod is now more abundant on the shrimp fishing grounds than in recent years and this has adversely affected the shrimp stock, and landings of both offshore and inshore have declined. As a result, the Marine Research Institute recommends much caution pending further surveys. The initial TACs for 2000/2001 have been set at 20,000 tons for offshore shrimp in Icelandic waters and 2,200 tons for inshore shrimp. Stock assessment is presently being revised and further recommendations will be made after a survey in late 2000 (Information Centre of the Icelandic Ministry of Fisheries 2000a).

No standard method is currently in use for the offshore shrimp stock in Iceland waters. Therefore different assessment models need to be tested, compared and evaluated (G. Stefansson, personal communication). The aim of this project is to test two different assessment methods and compare the results.

2 LITERATURE REVIEW

2.1 Northern Shrimp biology

Shrimps of the genus *Pandalus* are found at all depths on continental shelf in the Northern Hemisphere. Nineteen species are recognised within the genus and seventeen of them have been found in the Pacific Ocean. *Pandalus* species are found along the western shore of the North American continent, from the north-western part of Mexico to the Bering Sea off northern Alaska. *Pandalus spp.* occurs in the Chukchi Sea along the Kurile Islands to South Korea and in the East China Sea. There are only three species in the Atlantic and the Arctic Oceans: *P. borealis, P. montagui and P. propinquus.* Of these *P. borealis* is by far the most abundant and widespread species, occurring in all areas where *Pandalus* shrimp are found, except in the English Channel and the Bay of Biscay (Southward et al. 2000). The distribution of northern shrimp extend from southern Greenland to Martha's Vineyard on the western side, and from Novaya Zemlya Franz Josef Land and Spitsbergen in the north to Europe including Britain on the east side of the Atlantic (Dore and Frimodt 1987). *Pandalus borealis* is distributed at various depths around Iceland mainly in the north and north-east. The stock is classified according to distribution in inshore, mixed, offshore and Denmark Strait (Skúladóttir and Pétursson 1998).

The genus *Pandalus* has attracted considerable scientific interest, mainly for two reasons; their commercial value and their reproductive strategy. Most species within the genus are protandric hermaphrodites. Individuals typically change from being functional males to functional females during the course of their lives. *Pandalus* is also an important food item for demersal fish such as cod, and in the Arctic for marine mammals, and thus constitutes an integral part of the marine food webs found on the continental shelves (Southward et al. 2000, Stefánsson et al. 1998). *P. borealis* can best be described as an opportunistic omnivore functioning both as a predator and scavenger. Prey availability, time of day and the developmental stage of shrimp determine the feeding habits (Shumway et al. 1985).

P. borealis was first described as an obligate protandric hermaphrodite. Later studies have shown that the life cycle of *Pandalus borealis* may be more complicated than that. Some authors have reported shrimps, which develop directly into females (primary females). Further studies have demonstrated that age of functional females may vary not only between areas but also between years in the same area (Southward et al. 2000, Shumway et al. 1985). Several factors are known to affect sex change and consequently the age and size at maturity as females including individual size, geographical variation in age and temperature (Shumway et al. 1985). Significant differences in size at sex change (L_{50}) were found among populations in Denmark Strait, the offshore population and inshore populations (Skúladóttir 1998, Skúladóttir and Pétursson 1998).

Growth of shrimp in Denmark Strait is found to be about 2.3 mm per year from age 3 to 6, the change of sex starts at age of 5 but is most common age 6 (Skúladóttir 1995a). Average L_{50} for shrimp off northern Iceland indicates a general trend towards increased L_{50} from shallow to deeper waters. The highest L_{50} are found in the deep cold waters furthest north in the areas Nordurkantur and Kolbeinsey (Skúladóttir et al. 1991). The L_{50} value of the Denmark Strait shrimps is by far the highest, compared to the nearest offshore and inshore areas in Icelandic waters (Skúladóttir 1995b, Skúladóttir and Pétursson 1998).

Females of *P. borealis* spawn once a year. The spawning season is from September to October and hatching takes place in March and April (Shumway et al. 1985). The fertilization is external and occurs just prior to the time of egg laying. The females carry the fertilized eggs on their pleopods from the time of extrusion until hatching. Fecundity generally increases with body size and varies depending on the age of the egg mass. The eggs are over 1 mm wide and 2-mm long, opaque, and quite blue. The opacity and blue colour (yolk) gradually decreases as the embryo consumes the yolk. The developmental rate of embryos is directly related to temperature (Shumway et al. 1985).

The larvae are pelagic and drift with currents. There are seven larval stages. The length of the larval period depends on water temperature. Distributions of adult *P. borealis* depend of size, age, vertical movements and season. Annual differences in distribution of adults occur with changes in abundance. Seasonal changes in distribution occur primarily due to migratory impulses by various sex/age classes. Berkeley (1930) noted that larvae and juveniles were found inshore and in shallower waters than adults indicating a possible spawning migration inshore. As the shrimp mature into males they migrate offshore, possibly reflecting a decrease in thermal tolerance. Shrimp make nocturnal vertical migrations but stay close to the bottom during the day. Ovigerous females do not migrate vertically due to their decreased ability to swim (Shumway et al. 1985).

Temperature, substratum, salinity, currents and depth are also factors affecting the distribution pattern in *P. borealis* populations. Shrimp have been reported in waters ranging in temperatures from –1.6 ^{o}C to 12 ^{o}C. It is generally accepted that *P. borealis* prefers soft mud or sand/silt substrata, though it has also been reported in areas with occasional rocks. *P. borealis* is generally considered a stenohaline species, restricted to waters of fairly high salinity between 34,1 and 35,7 ‰. *P. borealis* is most abundant at depth between 50 and 500 m, but can be found from 9 to 1 450 m (Shumway et al. 1985, Southward et al. 2000).
2.2

2.3 Fishery and stock assessment of northern shrimp

Commercial shrimp fisheries in Iceland began in Ísafjarðardjúp in the West fjords in 1936, and few years later in Arnarfjörður (Sigurðsson and Hallgrimsson 1965). In the following years the fishery was extended to other inshore and offshore areas and in 1978 Icelandic vessels commenced shrimp fishery in the Denmark Strait (East Greenland), after an extensive search for shrimp in far offshore areas northwest of Iceland (Jónsson and Hallgrímsson 1981).

Currently the shrimp fleet is composed of bottom trawlers (wetfish trawlers and freezer trawler). The freezer trawlers are the largest vessels in the demersal and shrimp fisheries. The catch is processed onboard and quick-frozen (Information Centre of the Icelandic Ministry of Fisheries 2000d). The minimum mesh size in the shrimp fisheries is 45 mm in the wings and towards the square but 36 mm beyond that. Sorting grids are obligatory in the deepwater shrimp fisheries, primarily in order to avoid a by-catch of small redfish and Greenland halibut (Information Centre of the Icelandic Ministry of Fisheries 2000e).

The annual shrimp catch in Icelandic waters increased steadily from 10,000 tons in 1980 to 76,000 tons in 1995 but decreased again to 31,500 tons in 1999. There is also some shrimp fishing in international waters. The Icelandic fleet has been fishing shrimp in the Denmark Strait for many years. The catch since 1990 has varied from 500 to 2,900 tons per year, being 800 tons in 1999. In addition, Icelandic ships started catching shrimp in the international Flemish Cap area in 1993, and the catch has ranged from 2200 tons in 1993 to 9200 tons in 1999. The total catch in Icelandic waters in 1999 was 31,500 tons with offshore shrimp contributing 27,100 tons (Figure 1).

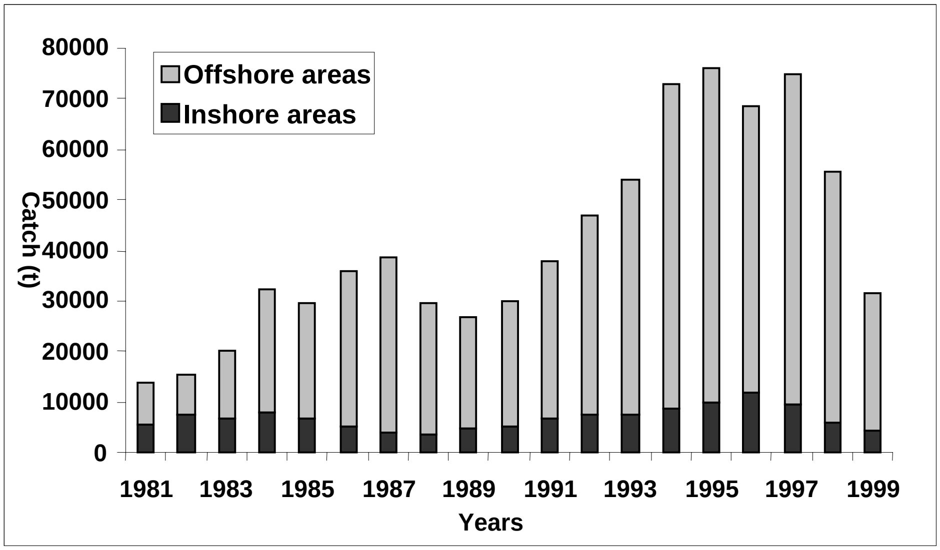

Figure 1: Northern shrimp catches both offshore and inshore (MRI 1986, 1992, 2000).

The age of crustaceans is usually inferred from size distributions, because they do not have hard structures from which age can be estimate as is the case with otoliths in fish. Age distribution is necessary as input data in many assessment models. A method to break down length frequency distribution into age year classes described by Macdonald and Pitcher in 1979 is commonly used, although there are other methods available as described by Skúladóttir (1979), Tanaka (1962) and Hasselblad (1966). The method of Macdonald and Pitcher assumes the total length distribution to be a mixture of normal distributions for each age and reasonable values of mean lengths at age, standard deviation and frequency per age at length. The disadvantage of this method is that it is not easy to discern the modes of the older components of the stock, because there is considerable overlapping (Stefánsson et al. 1994). Some software packages have been developed for this purpose, such as NORMSEP, which uses Hasselblad's analysis and MIX which is based on the Macdonald and Pitcher (1987) (Gallucci et al. 1996).

Methods for assessment of marine living resources can be classified according to the data required. The Virtual Population Analysis (VPA) is used to get a retrospective vision of the stock, based on fishery and survey information, it is based on backwards calculations, assuming the natural mortality rate and fishing mortality rate for the last year and age. Parameters of the model are fitted to minimise the differences between the initial estimation and survey indices. The Cohort Analysis model is equivalent to the VPA. In this model some variations are introduced. A simple variation for example, is to create a model where it is assumed that a given proportion of an age group dies before fishing commences and where the catch is also a specific ratio. On the other hand it also assumes that fishing takes place around the middle of the year and that natural mortality will only affect the stock before and after the fishing season (Nygard and Lassen 1997). The *ADAPT* Cohort Analysis (*ADAPT*) and related or derived methods depend on large data quantities and high quality data. With the analytical methods detailed data from the stock is needed, but they are also believed to give fairly good predictions (Sparre and Venema, 1995, Stefánsson, et al. 1994). Cohort analysis appears to be reliable as it only relies on a few simple assumptions: i) there is no fish alive at some age; ii) the natural mortality rate is known; iii) there is no net immigration or emigration. By fisheries standards, these are rather modest assumptions (Hilborn and Walters 1992).

The holistic model with age-disagregated length distribution is an alternative to VPA. It considers only the change in the exploitable biomass of the fishable stock and it requires fewer population parameters and gives an acceptable assessment. In this case survey CPUE data is used to fit the theoretical model. The dynamic biomass models are still used in the management of many fisheries. This is because the age/size composition of the historic catches is not available or reliable and in some situation it can provide more accurate and precise estimates of management-related quantities than more complex approaches (Polacheck et al. 1993). In order to incorporate the important effect of cod predation on shrimp multi-species surplus production model has been developed (Stefánsson et al. 1994).

3 MATERIALS AND METHODS

3.1 Data sources

Data from landings and surveys including length frequency distributions (Appendix 1 and 2), CPUE indices, annual historical catches, CPUE (Appendix 3) and parameters used in the length-weight relationships for males and females were obtained from the shrimp assessment department of the Marine Research Institute in Iceland. The northern shrimp fishing grounds are divided into 20 strata (Figure 2). In this study the aggregated data from strata 8–17 were used from the period 1988 to 2000. Annual trawl surveys have been carried out at fixed stations in July-August since 1988. A 1400-mesh trawl was used. The mesh size was 37-mm open mesh in codend and belly. The trawl opening is estimated to be 17m horizontally and 7.5 m vertically (Stefánsson et al. 1994).

The shrimp is measured using sliding calipers giving a measurement of the middorsal carapace to the nearest half-mm. The specimens are classified into three main sex groups, males, primiparous females (with a sternal spine) and multiparous females (without sternal spine)(Skúladóttir 1996). The primiparous females are in a transitional stage between males and functional females (Hallgrímsson and Skúladóttir 1986).

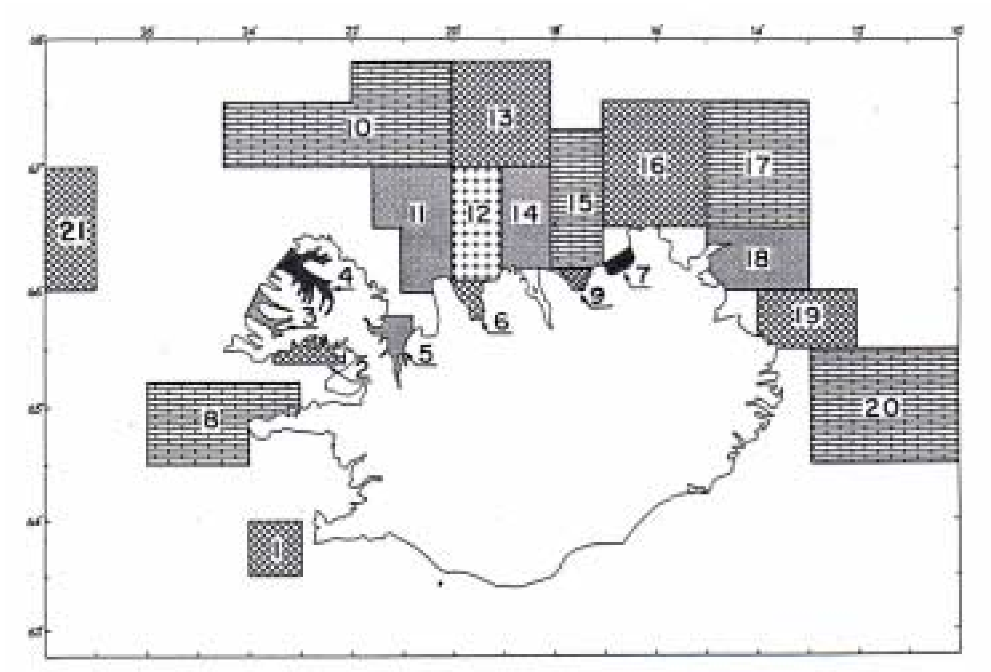

Figure 2: Northern shrimp fishing grounds divided into different strata.

3.2 Methods

Two different assessment techniques were used, an *ADAPT* model similar to the one described by Gavaris (1988), and an Age-structure production model (*ASPM*). The first step was to estimate catch in number and mean length at age from length frequency distribution and further use the result as input data for *ADAPT* and *ASPM*. These models were run in Excel spreadsheets.

3.2.1 3.2.1 Convert length frequency distribution into age

3.2.1.1 The simplified version of maximum likelihood Macdonald and Pitcher (1979) method is used to disaggregate a composite distribution of individual components expressed by individual probability density function $f_a(x)$ of growth in length. The overall probability density function $g(x)$ is appropriate to samples from the mixed populations and can be written as

3.2.1.2

3.2.1.3 (1) $g(x) = \pi_1 f_1(x) + ... + \pi_k f_k(x)$,

where π_a, (a=1,….,k) denotes the relative abundance of the k component as a proportion of total population and must therefore satisfy:

$$1 \geq \pi_a \geq 0 \quad (a = 1......k)$$

$$\pi_1 + ... + \pi_k = 1$$

Where

π_a is the proportion of age a in relation to the total

Each component was taken as a normal distribution, so that $f_{a(x)} = f(x/\mu_a, \sigma_\alpha)$, with

$$f_{(x|\mu,\sigma)} = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$$

Where $f(x/\mu_a, \sigma_\alpha)$, is the function of normal probability density with mean μ and standard deviation σ.

The mean length and standard deviation must satisfy the following constraints,

$$\mu_1 < \mu_2 \ldots \mu_k$$

$$\sigma_1 < \sigma_2 \ldots \sigma_k$$

$$\sigma_k > 0$$

In this project eight age groups (k=8) were used, as recommended by Skúladóttir (personal communication). The smoothing of the landed frequency per age at length was used as criteria for the fit.

3.2.1.4

The mean length at age was compared between years for the survey and landing frequency length distributions using single factor analysis of variance (ANOVA). The t-test assuming equal variances was used to detect significant differences between average of mean length at age from landing and survey (Jerrold 1974). In these tests a 95 % limit of confidence was applied.

3.2.2 Maturity ogive and mean weight at age.

Von Bertalanffy parameters L_∞, K, t_0 were estimated using the average of the mean length at age from survey length distribution, using the Gulland and Holt and Von Bertalanffy graphical method (Sparre and Venema 1995).

The proportions of rate primiparous and multiparous females at length were obtained dividing the frequency of females by the total frequency at length interval from annual survey samples. The parameters a and b from theoretical maturity ogive curve were fitted to the observed values. The point where 50 % of the population had gone through sex-change (L_{50}) was estimated assuming the proportion p=0.5 and solving the ogive equation. The maturity rate at age was computed replacing the mean length at age in the ogive equation, $p_i = 1/(1 + e^{-(\alpha + \beta x_i)})$. The mean weight at age from survey and landing length distribution was computed using the length-weight relationship $W = aL^b$ with mean length at age and two different coefficients sets,

$$a = 0.00083528,\ b = 2.902 \quad (male - ages\ 1\ to\ 4)$$

3.2.2.1

$$a = 0.00185653,\ b = 2.766 \quad (female - ages\ 5\ to\ 8)$$

3.2.3 ADAPT

The input data in this model were age-disaggregated catch in numbers, natural mortality rate (*M=0.3*), mean weight at age from catch and stock and maturity ogive. The natural mortality rate (*M*=0.3) was assumed to be constant and the fishing mortality was assumed for the last year and age. The calculation of the population in number was made in two steps. First, the age structure population in number was computed using the equation,

$$N_{a,y} = \frac{C_{a,y}}{\frac{F_{a,y}}{Z_{a,y}} \cdot (1 - e^{-z})}$$

Where

$N_{a,y}$ is catch in number at age *a,* and year *y*

$C_{a,y}$ is catch at age *a,* and year *y*

$F_{a,y}$ is fishing mortality rate age *a,* and year *y*

$Z_{a,y}$ is total mortality rate age *a,* and year *y,* $Z_{ay} = F_{ay} + M$

Then, the rest of the population in number is calculated using the equation,

$$N_{(a,y)} = (N_{(a+1,y+1)} \cdot e^{\frac{M}{2}} + C_{(a,y)}) \cdot e^{\frac{M}{2}}$$

In this equation it is assumed that fishing takes place around the middle of the year and the natural mortality will only affect the stock before and after the fishing season.

Having estimated the stock size in number, the fishing mortality rate is calculated as,

$$F_{(a,y)} = \ln\left(\frac{N_{(a,y)}}{N_{(a+1,y+1)}}\right) - M$$

The fishing mortality for the last age is estimated as the average fishing mortality for ages 6 and 7. The fishing pattern for the last year is given on the basis of the patterns from the previous year, and an F multiplier (F_{term}). The selection pattern is calculated as $S_a = F_a / \overline{F}_{1-8}$, where the selection pattern average at age between the years 1996 and 1998 was used and an early F_{term} value assumed arbitrarily. It is usual to assume that the annual increase in stock size will lead to a corresponding increase in the index from surveys. The relationships between the index and stock size can be expressed as,

$$U_{ay} = q_a N_{ay}$$

The catchablity coefficient q_a is computed from $\ln(q_{a\bar{y}}) = \ln(U_{ay}) - \ln(N_{ay})$. It is considered constant in time, but is assumed to be variable by age groups. For a stock size estimation and coefficient q_a, the predicted value $\hat{U}_{ay}$ can be computed as $\hat{U}_{ay} = \ln \bar{q}_a \cdot \ln(N_{ay})$. The relationship of the index and the deviation in the forecast concerning indices is given by the sum of squares of the difference between U_{ay} expected and N_{ay} observed,

$$SSE = \sum_{a,y} \left[(\ln(U) - q \cdot \ln(N)) \right]^2$$

Thus, it is simple to compute *SSE* for each value of F_y. Other important model parameters are biomass

$$B_y = \sum_a N \cdot w_s$$

spawning stock biomass

$$SSB_y = \sum_a p \cdot B$$

where p_a is maturity ogive and fishable biomass

$$FB_y = \sum_a N \cdot S_p \cdot w_c \cdot p \cdot e^{-z}$$

3.2.4 Age-structure production model (ASPM)

As a rule, the stock production model considers only changes in the fishable biomass described by the general equation,

$$B_{(t+1)} = B_t - C_t + R_t$$

where the status of biomass in the next year depends on the annual total catch in tons and recruitment in the previous year.

In this model it is assumed that there is a relationship between stock size and catch per towing hour.

Input data for the ASPM is the disaggregated catch at age, natural mortality rate (*M=0.3*), mean weight at age from catch and maturity ogive. The spawning stock biomass was computed as previously described. The Beverton and Holt stock recruitment relationship is used for recruitment predictions.

$$R_y = \frac{\alpha \cdot SSB_y}{(1 + \frac{SSB_y}{K})}$$

$SSB_{(y)}$ is the spawning stock biomass in the year y
α and K are the stock recruitment relationship constants

3.2.4.1 Fitting the commercial landing, the survey catch per towing hour (CPUE index) and the surveys sampling in number at age one as recruitment are considered to be indexes.

The catch estimated was computed after the Baranov (1918) equation.

$$\hat{C}_{(y)} = \sum_a N_{(a,y)} \cdot \frac{F_{(a,y)}}{Z_{(a,y)}} \cdot (1 - e^{-(z_{a,y})}) \cdot w_{(ay)}$$

To predict abundance index $\hat{U}$, it is assumed that there is relationship between stock size and CPUE index

$$\hat{U} = q \cdot B_{\exp.}$$

Where
B_{exp} is exploitable biomass
q is the catchablity coefficient and assumed to be constant every year

$$\bar{q}_y = (1/k) \sum_{y=1}^{k} (U_y / B_y)$$

To predict recruitment, this equation is used

$$\hat{R}_{(y)} = r \cdot R_{(y)}$$

Where
$R_{(y)}$ is the number at age one
r is the coefficient

$$r_y = (1/k) \sum_{y=1}^{k} (U_{1,y} / N_{1,y})$$

3.2.4.2 Different values of α, K, R_0 and one F_{mult} value per year were tried until the lowest *TSSE* value was obtained.

3.2.4.3 $$TSSE = \sum_{a,y} \left[\ln U - \ln \hat{U}\right]^2 + \sum_{a,y} \left[C - \hat{C}\right]^2 \sum_{a,k} \left[\ln R - \ln \hat{R}\right]^2$$

where *TSSE* is the total sum of the least squares.

4 RESULTS

In general, the length frequency distributions from surveys and commercial landings are similar. They are characterised by one or two distinctive modes, which usually correspond to ages 2 and/or 3 (Figures 3 and 4), except for the years 1991 and 1992.

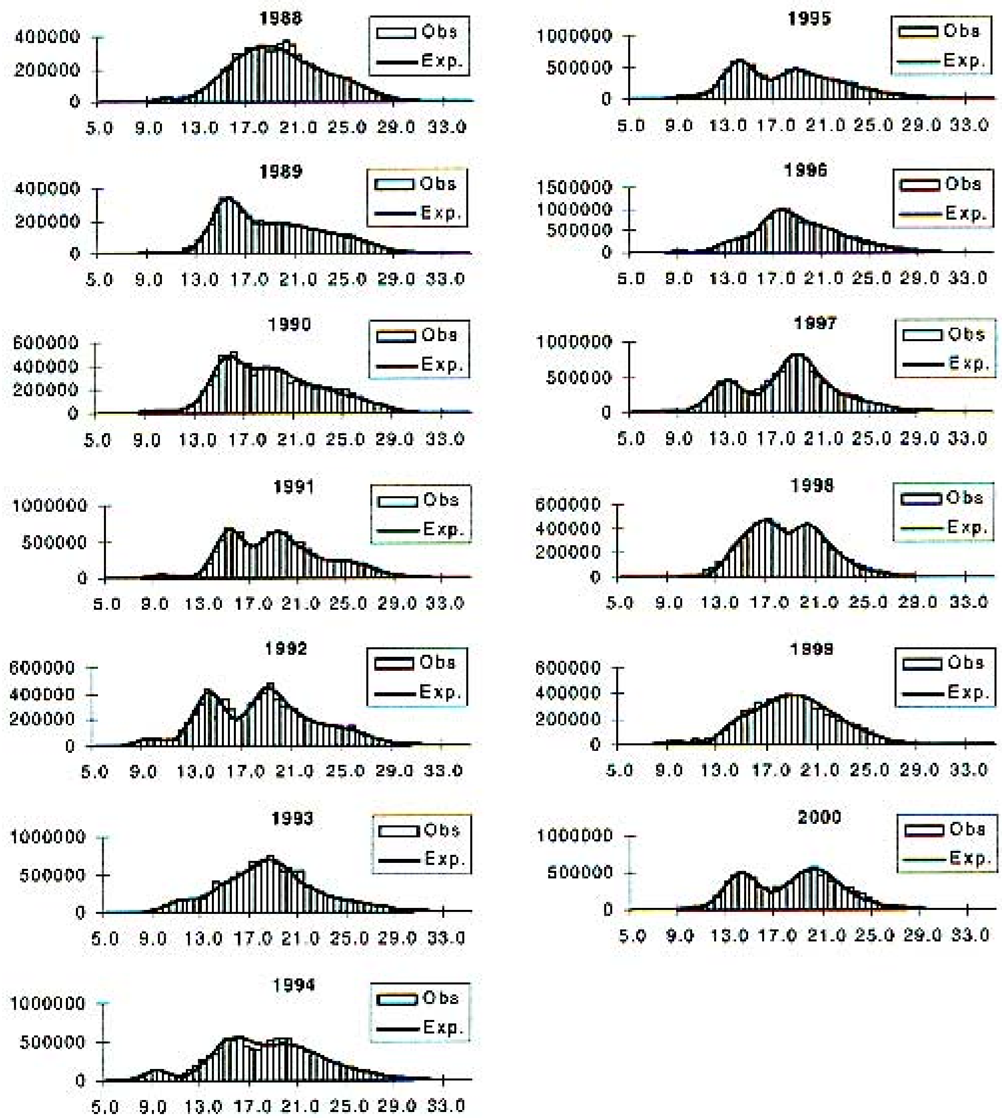

Figure 3: The histogram represents the length frequency distribution from northern shrimp surveys and the line is the fitted curve of the Macdonald and Pitcher method.

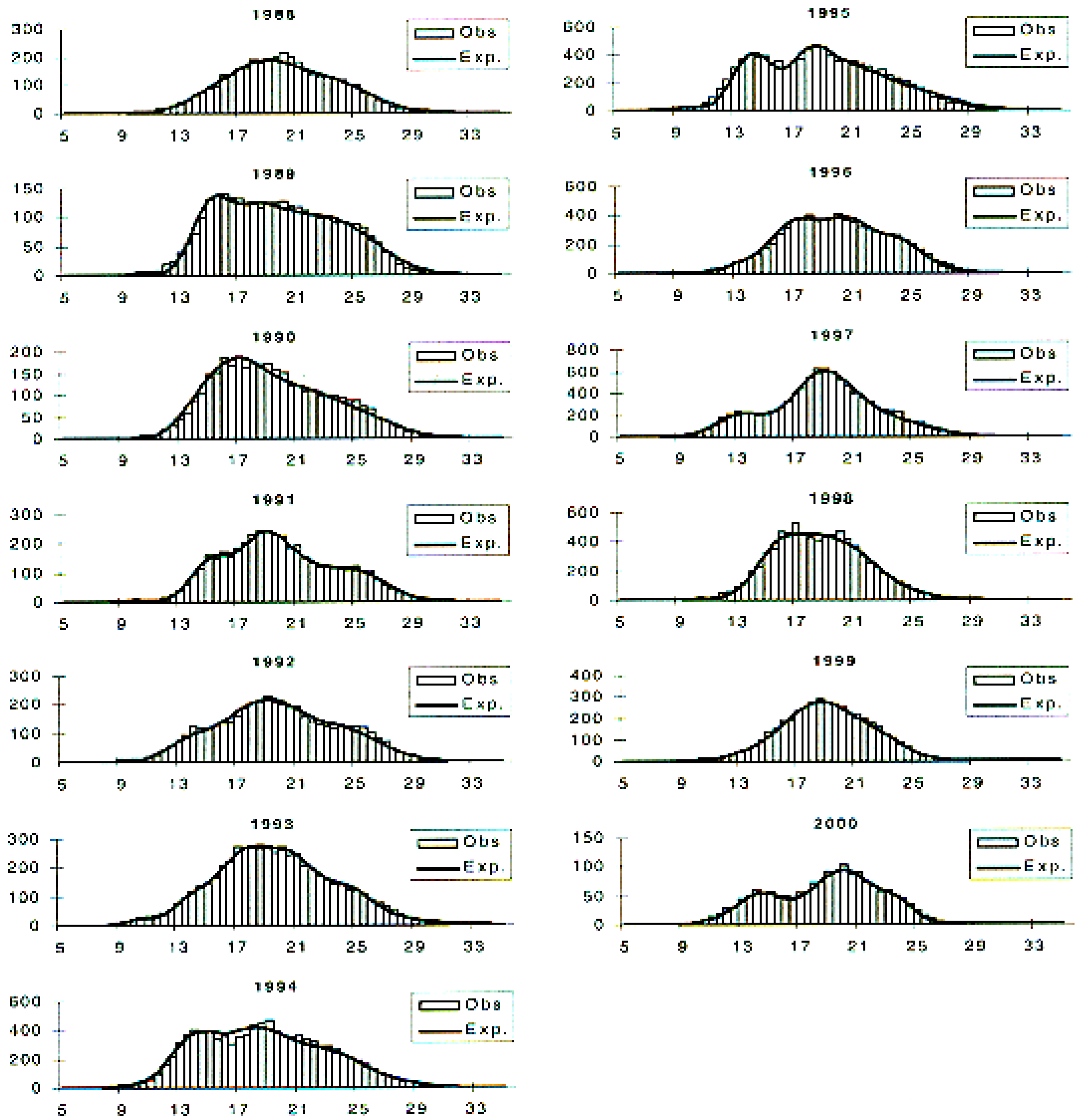

Figure 4: The histograms represent the length frequency distributions from landings and the line is the fitted curve of the Macdonald and pitcher method.

When three modes are observed in the length frequency distribution from survey, they are still relatively smooth in the length frequency distribution. The Macdonald and Pitcher method was run according to the constraints described in the previous chapter. In most of the cases the predicted length frequency distribution did not differ much from the observed. The aim of the fitting model was to contain as much information on the annual length frequency from surveys and landing sampling. The fit process was first run without any constraints to obtain the initial values, the second time with constraints and the third time taking into accounts the logical cohort sequence. The third run was only performed in the cases were the number at age did not follow a cohort logical sequence, i.e. the number at age should increase diagonally in the first ages until arriving at a maximum value and decrease after that (Table 1 and 2).

Table 1: Index of abundance in number by age and year, from northern shrimp surveys (Million ind./nautical miles) (million).

Ages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	66	58	131	225	291	1014	657	215	92	59	32	114	97
2	1099	2095	3401	3827	2710	1861	4770	4245	1706	3182	1388	702	3482
3	2061	1111	2134	3602	2449	4699	3065	2612	6516	6910	2384	1597	4489
4	1197	711	1126	2284	1387	2377	1397	2593	2947	1604	2619	2087	1256
5	1024	686	855	1702	683	1202	1189	560	1909	502	955	1457	682
6	956	566	719	302	635	746	495	323	1258	277	257	516	113
7	20	11	305	121	115	207	227	219	651	7	19	206	1
8	1	0	10	1	0	0	4	3	1	0	6	0	0

Table 2: Northern Shrimp catch in number (million) by age and year, from landing sampling.

Ages	1988	1989	1990	1991	1992	1993	1994	1995	**1996**	1997	1998	1999	2000
1	7	12	6	28	15	94	128	45	**45**	18	15	8	3
2	510	573	340	864	596	608	2575	481	**481**	1687	1106	558	425
3	1185	542	1144	1476	780	1605	2549	2574	**2574**	5073	3826	2581	939
4	823	518	732	937	1460	1607	2400	2716	**2716**	1587	2322	756	168
5	720	442	479	699	747	1047	842	1720	**1720**	863	277	145	76
6	144	378	339	300	517	175	376	99	**99**	327	94	80	14
7	22	193	304	43	60	70	312	23	**23**	29	45	48	10
8	6	40	29	0	11	23	28	7	**7**	8	32	3	1

The cohorts can be tracked as shown in Tables 1 and 2. In most cases the number at age decreases from age four. The numbers at age from surveys indicate that the 1993-year class was particularly strong, getting the highest values in the age groups 1, 2 and 4 over a 12 year period. In 1996 the age classes 4, 5, 6, 7 are particularly well represented. This coincides with the highest shrimp catches. The 1998-year class is the weakest observed. This poor year class may have contributed to the sharp decline of the population.

The predicted mean lengths at age from surveys and landings are presented in Figure 5. In both cases the values are similar, although the mean length estimate from landings are a little higher than from the survey for the older shrimp. The standard error also increases with age. The differences are not significant (t=-0.08, P=0.93). With the mean weight, the behaviour is similar (Figure 6). The growth parameters of the Von Bertalanffy equation computed from survey mean length at age are $L\infty = 35.147$, $K = 0.2217$ and t_0=-0.242.

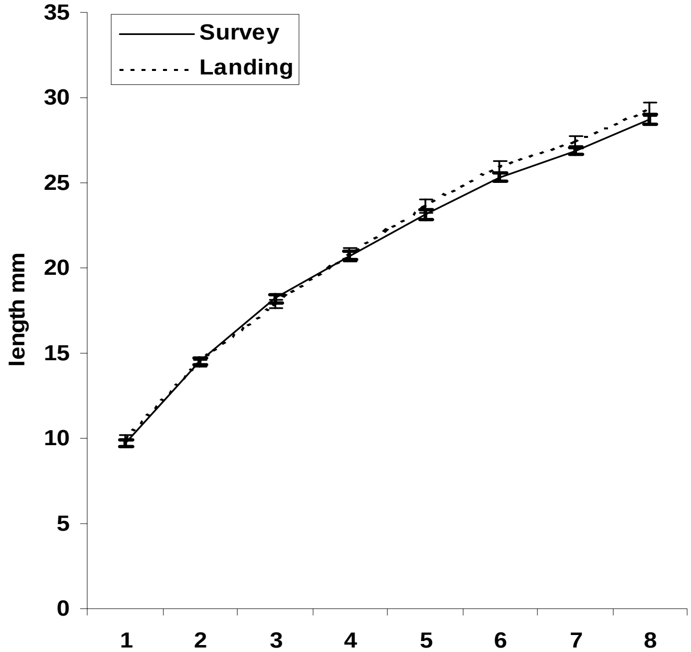

Figure 5: Average of mean length at age from northern shrimp surveys and landings with standard error.

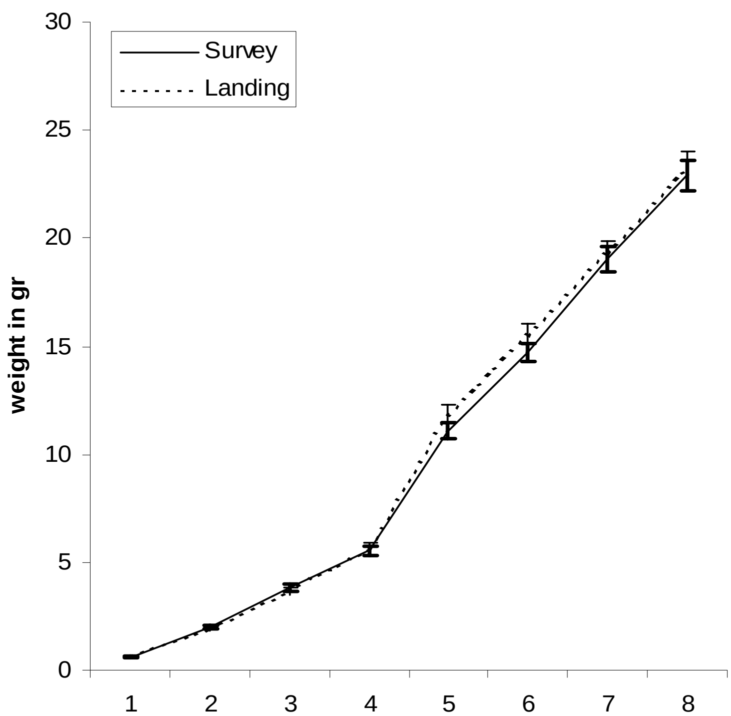

Figure 6: Average of the mean weight at age from northern shrimp surveys and landings with standard error.

The proportions of primiparous and multiparous females at length are computed dividing the frequency of females with the total frequency at length interval from annual survey samples. The parameters a and b from theoretical maturity ogive curve fitting to the observed values are found (Appendix 4). The maturity rate at age is computed and replaces the mean length at age in the ogive equation. The maturity ogive average curve and the standard deviation at age are given in the Figure 7. The interannual variability at age 5 is higher than at others ages. The L_{50} is on average close to age 5. The L_{50} fluctuates between 23.0 mm and 23.5 mm, but declines to 22.2 mm in 1998, and slowly increases again in 1999 (22.4 mm) and 2000 (22.7 mm) (Figure 8).

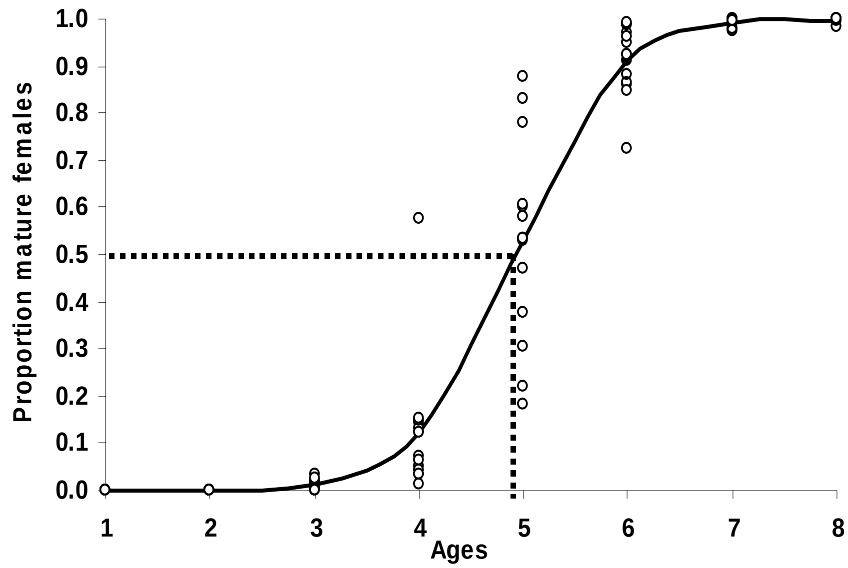

Figure 7: Maturity ogive average curve in the period 1988-2000 at age.

Figure 8: Northern shrimp $L_{(50)}$ in the period 1988-2000.

The age-disaggregated catches in number by year were used for the *ADAPT* and the age-disaggregated abundance indices from surveys for the tuning process. The natural mortality rate used was M=0.3. The reference fishing mortality the average of fishing mortality rate ages 2-7. The selection pattern (S_a) is the average of the years 1996-1998. The methods of least square was used to estimate *F* at age for the last year by minimising the observed sum of square difference error and the model predicted age-disaggregated abundance indices. The *F* multiplier F_{term}=0.23 and the effect of different F_{term} values on the biomass were tested. As is shown in Figure 9, the biomass lines converge in the year 1997 for different F_{term} values and give a notable increase of biomass to low exploitation rate. The outputs are shown in appendix 5.

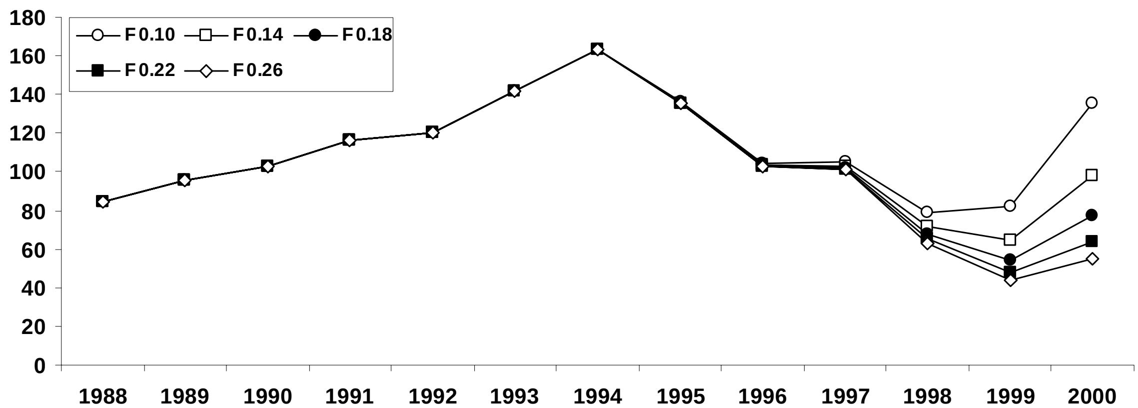

Figure 9: Effect of different F_{term} values on the biomass in the *ADAPT* model.

The natural mortality was M=0.3 as in *ADAPT.* The Beverton and Holt stock-recruitment relationship is used to project the recruitment of the stock for each year. The selection pattern was taken from *ADAPT*. In the *ASPM* the tuning include fit from three indices, the commercial landing, CPUE from surveys and recruitment. It is necessary to find the α, *K,* R_o and F_y to satisfy each processes.

The catches were fit first and the *CPUE* and recruitment was treated to fit. The parameter results were, α=320.5, *K*= 412664342 and R_0=7403176. The Beverton and Holt stock-recruitment relationship estimated parameters that are out of reasonable range, they are considered high, but the output of the model are quite logical and relatively close to *ADAPT* output (Appendix 6).

The $F_{2\text{-}7}$ for both models show a similar pattern, but the $F_{2\text{-}7}$ curve from ASPM is smooth and lower than the *ADAPT* curve. The *ADAPT* and *ASPM* $F_{2\text{-}7}$ results increased steadily from 0.36 and 0.23 in 1988 to 1,14 and 0.99 in 1998 but decreased again to 0.25 and 0.19 in 2000 (Figure 10).

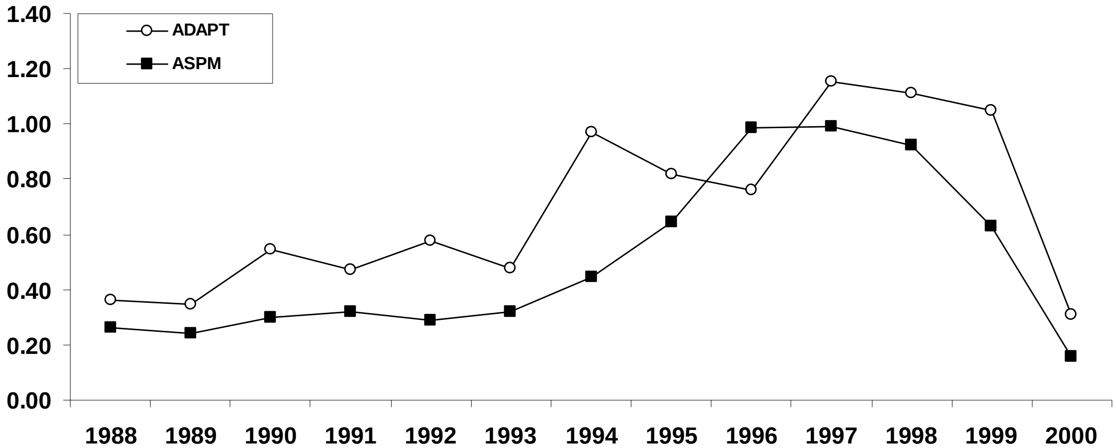

Figure 10: Northern shrimp fishing mortality rate average between ages 2 and 7 from *ADAPT* and *ASPM*.

The biomass estimated by the two models showed the same trends, but *ASPM* gave higher biomass values (Figure 11). The *ADAPT* and *ASPM* values increase steadily from 86,000 t and 136,000 t in 1988 to 163,000 t and 188,000 t in 1994. Then came a continuous decline to 46,000 t and 72,000 t in 1999 with a signal of recovery to 61,000 t and 84,000 t in 2000. Estimates of the spawning stock biomass are more variable but show a similar trend as the exploitable biomass for both models show a decrease in the period and there is a slight increase in the last year (Figures 12 and 13). The recruitment shows the same behaviour but in this case it does not show signs of recovery (Figure 14).

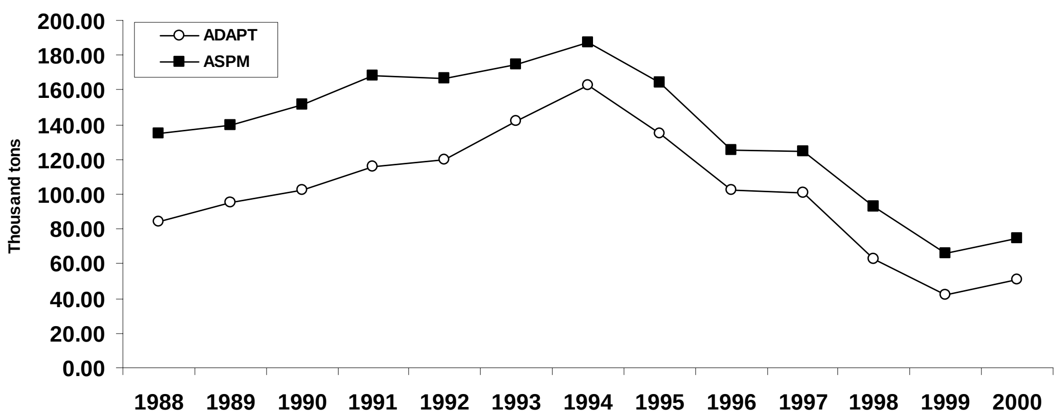

Figure 11: Northern shrimp stock biomass from ADAPT and ASPM.

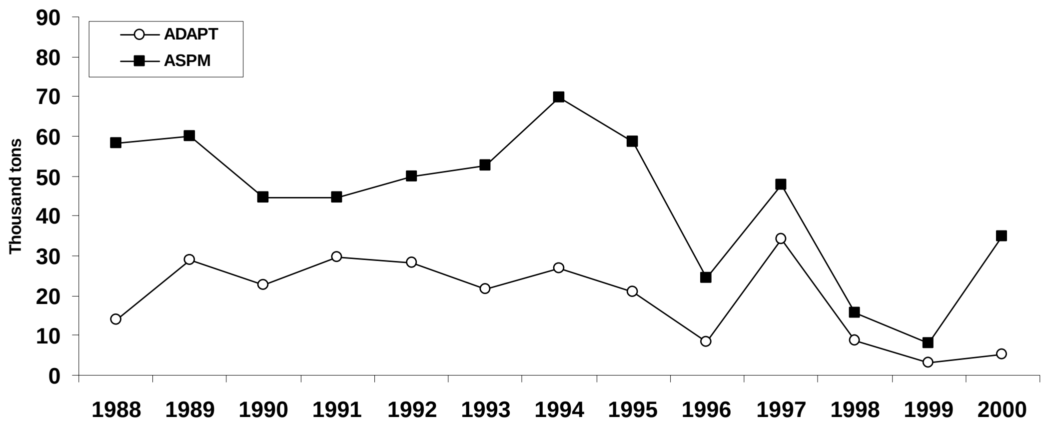

Figure 12:Northern shrimp spawning stock biomass from ADAPT and ASPM.

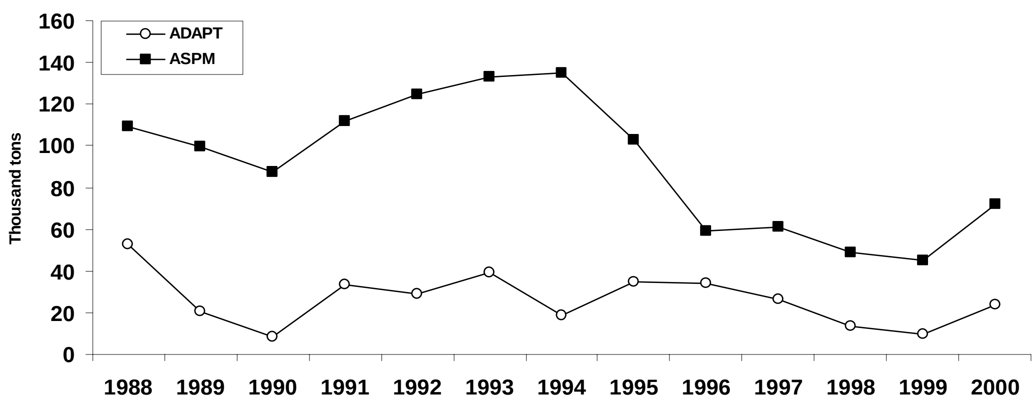

Figure 13: Exploitable biomass form ADAPT and ASPM.

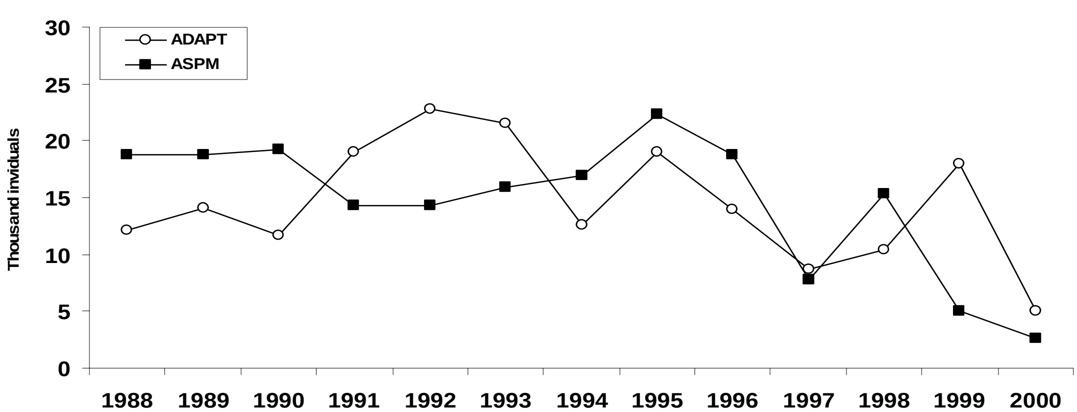

Figure 14: Northern shrimp recruitment from ADAPT and ASPM.

The age composition of the catches is presented in the Figures 15 and 16. According to *ADAPT* results, the ages best represented in the catches correspond to the ages 3, 4 and 5. For the *ASPM* the age best represented is age 4. The age compositions of the stock show similar results as for age proportion (Figure 17 and 18). Possibly because the age composition of catches and stock depend on the stock size, and different assumption are used in *ADATP* and *ASPM*.

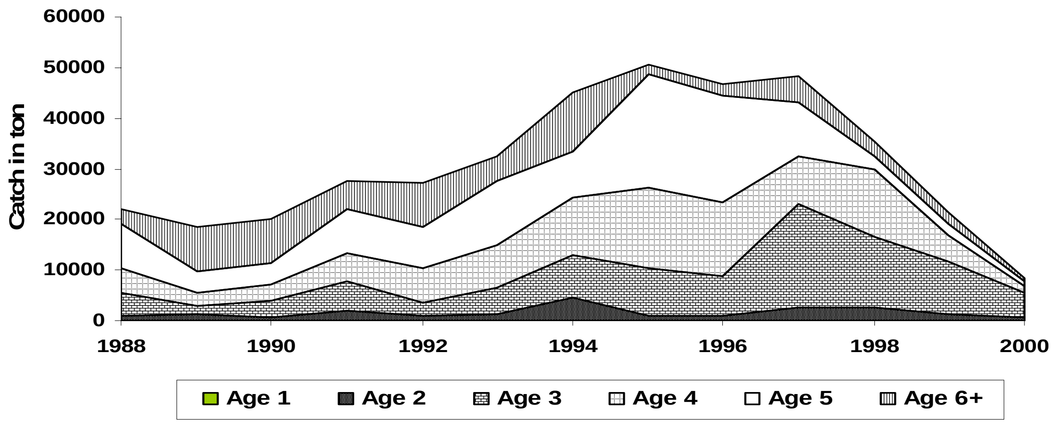

Figure 15: Catch composition by age (ADAPT).

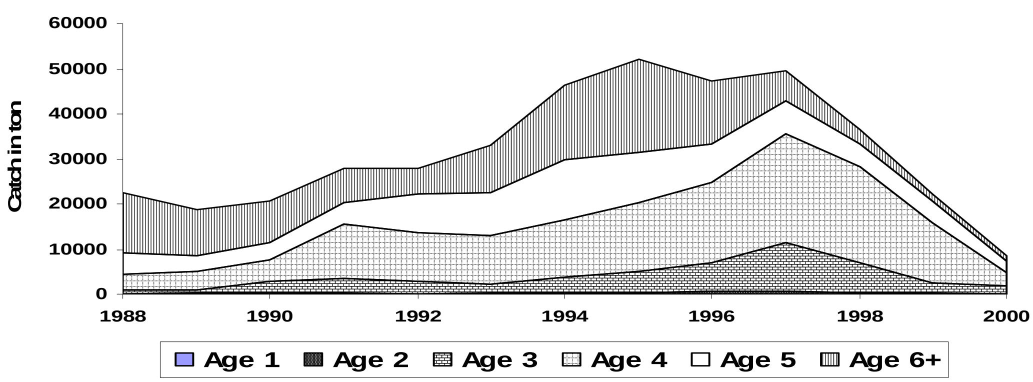

Figure 16: Catch compostion by age (ASPM).

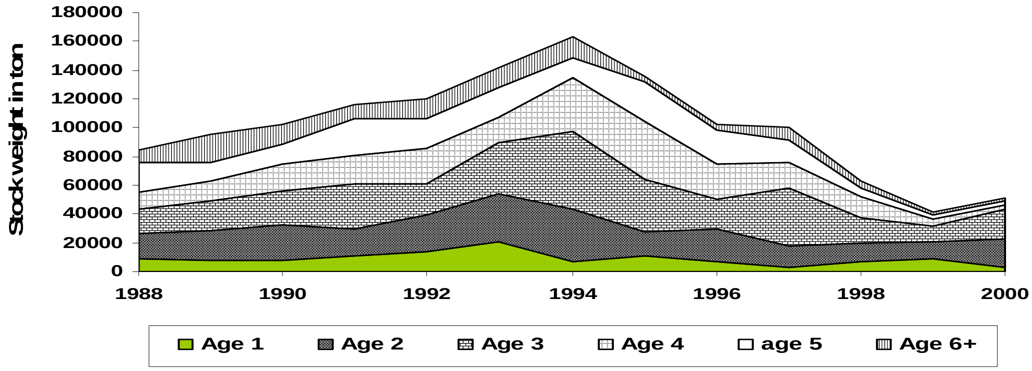

Figure 17: Stock biomass composition by age (ADAPT).

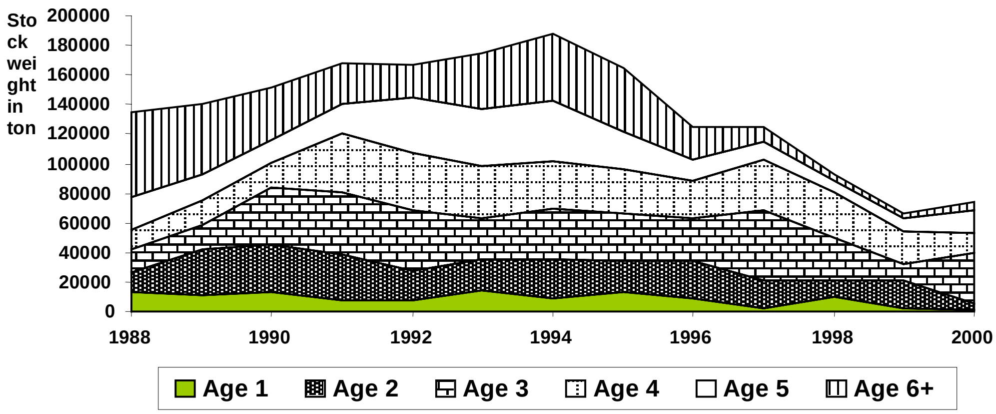

Figure 18: Stock biomass composition by age (ASPM).

5 DISCUSSION

The patterns of the length frequency distribution obtained from surveys and landings are consistent most of the years (Table 1 and 2). The mean length at age estimated from the surveys is comparable with the values published by Skúladóttir et al. 1989 for Ísafjardardjúp. The major differences occur in the age groups 6, 7 and 8 where Skúladóttir reports an average length of 26.47, 29.50 and 31.90 mm respectively, for the period 1978 – 1989. In this study the average lengths for the same ages were of 26.65, 28.14 and 30.09 mm respectively, in 1988–2000. The L_{50} of the northern shrimp Ísafjardardjúp should be smaller than offshore shrimp (Skúladóttir et al. 1991), but the present study is considering a period where the exploitation rate was high. This high exploitation rate probably contributed to an early sex change as a survival strategy for the population. The mean lengths estimated from landing are very similar to the estimates from survey, but the mean length at age 6-8 is closer to the mean length reported by Skúladóttir (1989). This difference can also be explained by a considerable overlap among the larger size classes since the Macdonald and Pitcher method can not distinguish between developmental stages (Stefánsson et al. 1994).

Maximum carapace length reported for Denmark Strait is $L\infty$ = 38 mm (Jónsson and Hallgrimsson 1981). According to Skúladóttir et al. (1989) size at sexual maturity should be low in offshore shrimp population, therefore $L\infty$ = 35,1 is considered a good estimate. The K= 0.2 depends on the growth rate for the species.
Average growth rate for northern shrimp male has been estimated 2.5-2.7 mm per year for Denmark Strait (Skúladóttir 1998), and the growth rate has been computed 2.5 mm in this study.

According to the average maturity ogive curve, an offshore northern shrimp population is reaching maturity close to 5 years old. This age corresponds to 22,96 mm of carapace length. In accordance with the L_{50} values published by Skúladóttir and Pétursson (1998) for all northern shrimp fishing grounds in 1988 to 1995, the L_{50} average for strata 11 to 17 is approximately 23.53 mm. On the other hand she has reported that in Denmark Strait the change of sex starts at age 5 but is estimated on average at age 6. The first spawning will taken place at age 5 for about 18% of year-class and the rest of the year class will spawn at age 6 (Skúladóttir 1997).

The general trend of F_{2-7} is approximately the same for both models in Figure 10. The F_{2-7} curve obtained from *ASPM* is smooth and the values are lower than those from the *ADAPT*. Likewise, the F_{2-7} series follow the same behaviour in the offshore shrimp catches (Figure 1). This indicates a good relationship between catches and the F_{2-7}. The F_{2-7} from *ADAPT* detects the changes in catch better and seems more acceptable than the F_{2-7} values from *ASPM*, which are extremely low, particularly in the period 1988-1994. One of the most important management measures adopted by Ministry of fisheries, when the shrimp fishery collapsed in 1998, was to reduce the fishing effort. This measure has resulting in reducing the fishing mortality rate in the last two years.

The population biomass has shown the same pattern in the time series, according to both models, but the biomass levels estimated by *ASPM* are higher than *ADAPT* (Figure 11). In line with the F_{2-7} analysis, the biomass from *ASPM* appears to be overestimated because this calculation depends upon the fishing mortality rate, among other factors. However, the biomass estimates from *ADATP* in the period 1988-1994 is close to biomass values reported by Stefánsson et al.(1994).

Similar trends can be seen in the spawning stock biomass and the recruitment series (Figures 12 and 14). The recruitment curves of both models overlap, possibly because recruitment is not linked to the fishing mortality rate in the same way as biomass and spawning stock biomass are. The largest difference between these two models was the estimate in exploitable biomass (Figure 13). The observed trends are comparable, but the *ASPM* exploitable biomass series is two or tree time higher than the *ADAPT* series.

It appears that the estimates obtained using *ASPM* are biased. This could also be explained by other reasons, for instance, by the design of the fitting process. The fitting process requires estimates of many parameters, including the stock-recruitment relationship. It is well known that the more parameters a model has the greater the scope for errors. One of the deficiencies in using *ASPM* is the need to estimate a deterministic stock-recruitment relationship, a property that may result in inconsistencies between the estimated level of recruitment and the observed level of catches (Restrepo et al. 1997). On the other hand the important underlying stock-recruitment relationship may be masked by intrinsic variation in the system and by reduced range of observation, which may be the case (Cushing 1979, Hilborn and Walter 1992). Environmental factors have a great influence on the survival rate of fish during the early life history (eggs, larvae, juveniles), high initial numbers of eggs or larvae will not necessary produce high number of recruits. If the environmental effect is strong and variable, one would not expect to see strong relationship between stock size and recruitment (Sinclair 1999).

ADAPT results appear to be quite logical and they are consistent with two previous assessment results for this area (Stefánsson et al.1994). This model has been classified as flexible, the results are generally robust and the model can be applied even with few estimated parameters. This model has been used largely by some institutions such as The International Commission for a Conservation of Atlantic Tuna (ICCAT), Canadian Atlantic Fisheries Advisory (CAFSAC) and The Northwest Atlantic Fisheries Organization (NAFO) (Conser and Powers 1989).

Irrespective of the difficulty caused by the inclusion of stock recruitment relationships in the *ASPM* model, the results are not so different when compared to outputs from the ADAPT model and previous assessments. This is the first time the *ASPM* model is applied to the northern shrimp in Iceland, and the possibility to use it as a reference assessment tool should not be rejected.

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Information Centre of the Icelandic Ministry of Fisheries c. [23-11-2000]<*http:// www.fisheries.is/managem/assessm.htm* >

Information Centre of the Icelandic Ministry of Fisheries d. [23-11-2000]<*http:// www.fisheries.is/ships/fleet.htm*>

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APPENDIX 1: LENGTH FREQUENCY DISTRIBUTION FROM SURVEY MALES AND FEMALES AGGREGATED (NUMBER OF INDIVIDUALS AT LENGTH * NAUTICAL MILES).

Length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6.0	0	0	0	185	0	0	0	0	0	0	0	0	0
6.5	0	0	0	185	0	0	436	0	746	0	0	0	0
7.0	0	0	4988	0	627	635	563	1819	2216	2560	0	130	0
7.5	1400	167	99	1574	1768	1001	10058	7715	15901	8333	479	815	232
8.0	1804	1015	2004	10150	17526	1956	49497	15981	22474	20930	1103	6621	888
8.5	1795	4055	7932	24490	29872	11222	110822	29354	31760	14326	1785	13739	2301
9.0	9592	11624	19831	45784	56000	38871	148438	50149	22980	14215	3695	24308	11414
9.5	17996	15210	22326	48319	65997	60339	142242	52699	24083	21307	5059	21543	18460
10.0	14797	11572	29206	34837	48011	117456	98528	54888	21656	55483	6722	24702	35569
10.5	24603	5162	21828	27422	42460	138933	65594	46934	24618	94416	11336	26454	34642
11.0	20617	7319	26225	22466	55469	178822	53100	65299	63144	159145	12350	38588	71423
11.5	24159	12093	25521	23933	64232	179345	85192	115841	100610	242316	22353	31393	100517
12.0	35467	33254	43934	43510	120304	184815	143721	217896	134251	355935	51628	53615	207057
12.5	42865	51999	73235	83179	181620	184889	197512	333664	187869	423950	73980	57574	243227
13.0	72144	82519	111268	133809	246955	181940	259386	478407	256054	469565	119515	89724	396295
13.5	81684	133682	184852	211639	320730	247864	320747	577333	281141	430170	151215	110080	464979
14.0	115505	179734	245890	356491	438977	392826	345730	633619	335252	345446	231590	147828	515438
14.5	149245	256641	323314	512874	397193	384046	428995	563934	367753	322007	258778	199780	451795
15.0	194757	339617	490977	706215	323487	405957	545873	536429	469839	285496	329049	257288	443881
15.5	208193	338125	456667	619270	357840	470125	513945	405946	502293	332671	378110	271456	320086
16.0	298321	316380	533647	613848	283804	527267	573781	384832	678490	373531	442802	324046	304929
16.5	279401	253491	432877	461200	211067	542550	444053	301576	786685	443435	463125	290264	229636

Appendix 1 (Cont.)

Length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
17.0	331892	231735	425064	454179	248451	679596	408127	326303	953474	553545	474266	344741	308132
17.5	320010	191808	330774	462068	323629	619593	395677	363327	997070	587968	436433	342459	304949
18.0	349239	203903	384831	547176	366353	667396	481780	448361	999906	732103	399202	378727	370579
18.5	312116	187730	395235	623887	407802	738129	522777	463339	821873	813518	368370	394317	422918
19.0	318961	180777	381136	649222	468917	634158	540268	464892	696208	815594	385999	383273	522517
20.0	373823	185752	351452	583855	297452	584967	529784	359720	671770	594663	436892	365170	572861
20.5	348534	165270	261036	452453	288650	553539	455042	345742	632795	505895	423983	285216	471336
21.0	293187	163176	270043	495255	278192	545388	445629	350654	589281	404697	359345	287611	501670
21.5	249327	156301	247616	392414	229513	357737	369973	321892	535053	360620	294553	234276	395524
22.0	227357	149025	239179	322572	201744	309948	331928	308104	467621	309187	224327	215807	350944
22.5	193731	137992	216244	273808	185180	272671	314239	263196	412919	259718	201781	190222	293917
23.0	186690	126322	208575	249584	166527	233136	275710	257856	375911	252449	159584	184568	303268
23.5	160197	122667	219624	245684	149604	220642	258547	228675	359002	237365	134091	161578	249371
24.0	164520	115716	202392	248383	164672	204331	228437	191018	327396	214897	97484	153906	213251
24.5	152889	111130	194807	253312	154128	184013	194560	163654	280202	158685	88049	124160	165543
25.0	141756	116059	195247	241382	130892	162572	177663	148185	256966	141434	66228	96185	114761
25.5	110173	106533	158916	207661	153393	150513	160459	133172	198078	134156	43908	60125	70971
26.0	103167	92574	140710	207896	105943	122400	145733	101185	150130	90274	37687	39834	44804
26.5	75958	76618	101655	152826	92832	103763	117825	64923	106229	69191	30682	21076	25166
27.0	53314	56949	90320	120268	78113	86554	101881	61027	70005	48385	20147	15096	15037

Appendix 1 (Cont.)

Length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
27.5	32704	45403	68033	84552	52665	78834	76943	46508	64851	36786	12450	12403	13653
28.0	18163	26512	44911	72486	30316	67749	55864	34637	36456	22728	7876	8721	8000
28.5	19901	17125	30341	53161	30016	40649	42809	25935	28395	16318	6322	3308	3551
29.0	7693	9151	25403	21168	18770	24652	27564	14029	23543	9063	4462	3142	1836
29.5	6078	7535	12946	21385	9919	16571	24033	12647	12397	6558	2163	1413	836
30.0	2116	4109	4890	11883	5822	10366	15039	7988	12812	3471	2518	931	953
30.5	1907	2515	3830	3351	4476	8448	5046	3993	5990	4427	1210	240	120
31.0	174	1004	2749	1857	2281	4218	3737	1982	2535	948	305	0	0
31.5	0	1292	290	911	2302	785	1717	1963	951	329	871	64	198
32.0	38	0	0	1422	517	938	1223	371	514	932	0	0	164
32.5	0	164	0	261	347	655	250	191	0	505	0	0	133
33.0	0	0	0	0	0	1239	449	0	0	0	0	0	0
33.5	300	0	0	0	65	0	0	0	0	0	0	0	0
34.0	0	0	0	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	106	0	0	0	0	0

APPENDIX 2: LENGTH FREQUENCY DISTRIBUTION FROM LANDINGS, MALES AND FEMALES AGGREGATED.

length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6.0	0	0	0.07	0.08	0	0	0	0	0	0	0	0.09	0.00
6.5	0	0	0	0.08	0.07	0	0	0	0.25	0	0	0.88	0.00
7.0	0	0	0.57	0	0.29	0.44	0.89	0.89	0.5	0.92	0	1.40	0.00
7.5	0.07	0.13	0.07	0.23	0.5	0.53	3.34	3.34	3.22	3.45	0.13	1.23	0.03
8.0	0.21	0.32	0.36	1.74	3.44	1.42	6.23	6.23	5.45	7.12	3.21	2.01	0.10
8.5	0.21	0.83	0.93	2.58	5.58	3.65	12.47	12.47	6.45	6.43	1.07	4.47	0.23
9.0	1.61	2.44	2.49	6.14	10.52	8.27	22.26	22.26	5.33	7.81	3.48	8.76	1.34
9.5	3.65	4.11	2.28	7.58	11.52	12.81	22.71	22.71	5.08	12.64	4.95	9.02	2.08
10.0	6.52	3.92	4.27	7.51	11.95	18.77	31.17	31.17	6.82	25.51	8.97	12.44	5.67
10.5	8.49	3.6	3.42	7.51	12.52	27.48	33.62	33.62	10.04	48.26	10.84	13.31	7.92
11.0	10.52	6.1	7.26	7.66	20.9	33.26	59.22	59.22	19.83	78.13	14.99	18.39	15.00
11.5	15.22	8.35	7.83	9.86	25.48	35.04	95.95	95.95	30.87	116.97	22.09	17.34	17.79
12.0	22.59	18.04	20.94	15.24	42.37	46.69	165.18	165.18	44.75	173.27	45.51	25.57	28.43
12.5	27.64	24.98	30.06	23.51	56.04	57.9	225.29	225.29	59.13	209.35	61.45	32.58	31.18
13.0	42.59	38.91	43.38	37.62	75.36	77.64	311.45	311.45	79.71	236.7	94.51	42.65	44.67
13.5	46.44	55.67	59.47	58.1	92.89	92.94	366.88	366.88	87.27	227.28	125.43	54.39	50.61
14.0	61.81	71.92	83.83	90.25	121.3	119.17	400.94	400.94	109.09	210.96	198.26	73.57	59.33
14.5	72.05	98.57	103.56	117.1	119.01	135.36	385.36	385.36	133.38	215.56	228.51	97.74	54.53
15.0	88.61	128.81	148.58	158.28	116.3	149.32	391.59	391.59	169.71	201.31	325.97	134.70	56.68
15.5	97.66	136.07	150.78	149.87	126.82	164.09	335.93	335.93	204.04	239.91	355.28	152.04	46.95
16.0	133.44	140.11	187.25	170.8	135.12	204.38	357.75	357.75	274.83	270.94	464.79	186.02	51.55
16.5	135.12	133.11	166.6	157	133.61	218.25	305.66	305.66	316.35	319.66	463.58	189.09	43.83

Appendix 2 (Cont.)

length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
17.0	162.48	132.34	187.96	184	160.45	270.72	352.85	352.85	373.5	402.62	523.29	231.47	55.37
17.5	159.96	121.3	165.95	203.18	184.14	265.92	372.22	372.22	388.38	446.51	461.04	247.41	56.51
18.0	188.16	123.03	175.93	229.05	206.97	273.75	438.56	438.56	400.03	547.62	430.25	271.50	71.38
18.5	175.6	115.2	170.66	242.93	210.98	279.79	452.14	452.14	364.33	621.85	407.63	288.40	74.27
19.0	186.83	125.79	172.29	240.5	229.94	275.7	466.83	466.83	370.28	625.98	425.56	274.39	91.89
19.5	200.3	125.21	158.4	231.78	204.89	252.67	390.92	390.92	383.54	595.42	441.63	266.59	92.66
20.0	214.4	127.59	150.14	224.65	199.96	269.21	363.54	363.54	410.44	518.67	464.65	253.72	103.60
20.5	196.72	118.99	122.01	185.36	189.08	244.13	354.41	354.41	373.38	468.57	419	221.23	86.15
21.0	180.58	118.15	121.8	193.63	191.44	247.15	361.54	361.54	353.79	405.37	373.76	220.35	90.17
21.5	150.56	111.09	108.69	156.31	154.94	205.09	334.38	334.38	318.83	359.41	307.09	196.53	74.40
22.0	139.61	106.59	111.97	137.28	138.84	197.88	317.01	317.01	303.21	324.71	256.76	177.61	67.09
22.5	130.63	98.89	96.58	121.2	126.17	174.49	286.51	286.51	285.49	273.47	231.32	157.21	58.49
23.0	126.49	96.06	99.15	117.25	124.67	158.75	289.18	289.18	271.85	253.24	189.82	127.69	60.37
23.5	119.06	91.12	98.22	115.51	113.5	145.05	259.35	259.35	268.75	241.29	157.16	108.95	51.18
24.0	118.35	90.09	95.3	120.51	125.81	140.43	233.08	233.08	265.03	222.22	124.5	88.11	45.00
24.5	103.13	86.94	87.11	119.53	121.3	124.6	204.14	204.14	225.36	162.7	100.27	69.71	34.94
25.0	99.55	89.13	87.61	121.27	123.17	118.73	185	185	207.27	141.1	73.76	45.19	24.77
25.5	71.98	83.16	73.86	106.64	121.09	109.12	164.29	164.29	162.76	127.08	49.4	31.79	16.11
26.0	65.11	66.59	67.66	102.24	101.98	90.89	133.13	133.13	128.3	88.47	40.03	20.23	10.94
26.5	47.57	55.67	50	75.08	82.44	78.53	96.17	96.17	92.72	65.95	29.45	14.19	5.87
27.0	34.8	39.62	40.6	57.87	68.42	64.66	86.15	86.15	73.26	48.72	21.42	10.60	3.62

Appendix 2 (Cont.)

length	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
27.5	21.68	30.24	34.12	43.23	50.1	52.56	62.78	62.78	57.39	34.01	14.06	8.76	2.65
28.0	14.8	18.04	24.72	33.75	33.28	39.93	48.53	48.53	34.83	22.29	8.3	4.99	1.71
28.5	11.65	12.39	16.38	24.04	25.76	29.08	38.96	38.96	21.45	16.09	6.83	3.59	0.94
29.0	5.47	7.9	12.25	12.44	15.89	16.45	23.38	23.38	16.49	7.12	4.69	1.75	0.50
29.5	3.37	4.37	5.98	8.87	8.95	11.38	17.14	17.14	9.17	5.52	2.81	0.96	0.17
30.0	1.26	2.38	2.71	5.46	6.44	8.09	10.46	10.46	9.55	2.99	1.87	0.44	0.34
30.5	1.05	1.35	2.35	2.05	3.44	4.54	7.57	7.57	4.46	2.3	0.94	0.35	0.07
31.0	0.21	0.77	1.21	0.99	2.5	2.49	3.12	3.12	1.49	0.46	0.27	0.00	0.03
31.5	0	0.32	0.21	0.46	1.15	0.98	2.45	2.45	0.62	0.23	0.27	0.09	0.10
32.0	0.07	0.06	0	0.46	0.36	0.53	0.67	0.67	0.5	0.46	0.13	0.00	0.03
32.5	0	0.19	0	0.08	0.21	0.44	0.45	0.45	0	0.23	0	0.00	0.03
33.0	0	0	0	0	0	0.27	0	0	0	0	0	0.00	0.00
33.5	0.07	0	0	0	0.07	0	0	0	0	0	0	0.00	0.00
34.0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
34.5	0	0	0	0	0	0	0.22	0.22	0	0	0	0.00	0.00

APPENDIX 3: OFFSHORE NORTHERN SHRIMP ANNUAL HISTORICAL CATCHES AND CPUE.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Catches	20721	22658	28718	29789	34881	48498	54074	49386	51238	39707	24965	8644	24349
CPUE	91.7	87.6	105.1	120.2	123.7	141.4	154.7	156.5	191.7	179.7	100.0	79.5	86.3

APPENDIX 4: THE PARAMETERS A AND B FROM THEORETICAL MATURITY OGIVE CURVE BY YEAR.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
a	-19.6	-22.9	-20.7	-26.3	-20.7	-23.8	-21.5	-26.7	-24.7	-21.1	-27.7	-30.0	-27.4
b	0.9	1.0	0.9	1.1	0.9	1.0	0.9	1.1	1.1	0.9	1.3	1.3	1.2

APPENDIX 5: ADAPT OUTPUTS

The population in number from ADAPT (million individuals)

Ages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	12095	14113	11646	18977	22822	21555	12649	19051	13920	8740	10377	17941	5005
2	7608	8955	10445	8622	14034	16894	15888	9261	14075	10274	6459	7675	13284
3	4576	5197	6140	7445	5643	9884	11992	9553	6447	10013	6159	3833	5206
4	2583	2370	3383	3564	4245	3509	5941	6690	4861	2560	3051	1269	618
5	2076	1205	1310	1876	1834	1888	1217	2335	2618	1263	531	262	290
6	550	918	512	559	788	716	498	177	250	459	194	155	69
7	171	284	355	88	156	139	380	46	46	100	59	63	46
8	24	108	44	1	28	64	43	13	14	14	49	5	6

Appendix 5 (Cont.)

Fishing mortality rate from ADAPT

Ages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2	0.08	0.08	0.04	0.12	0.05	0.04	0.21	0.06	0.04	0.21	0.22	0.09	0.04
3	0.36	0.13	0.24	0.26	0.18	0.21	0.28	0.38	0.62	0.89	1.28	1.53	0.23
4	0.46	0.29	0.29	0.36	0.51	0.76	0.63	0.64	1.05	1.27	2.16	1.18	0.37
5	0.52	0.56	0.55	0.57	0.64	1.03	1.63	1.94	1.44	1.58	0.93	1.03	0.36
6	0.36	0.65	1.46	0.98	1.43	0.33	2.09	1.05	0.62	1.75	0.82	0.91	0.27
7	0.16	1.56	1.47	0.85	0.59	0.88	3.06	0.90	0.88	0.41	2.13	2.13	0.28
8	0.32	0.54	1.34	0.52	0.57	0.54	1.32	0.83	0.78	1.02	1.27	1.21	0.26

Biomass in tons, from ADAPT

Ages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	8602	8327	7852	11094	13295	20355	6538	11215	6613	3162	7735	10704	3376
2	18190	20239	24609	18895	25767	33827	36791	16386	22626	14619	12933	14062	23635
3	17230	20731	23460	30536	22452	35498	54505	36937	20748	40820	18601	11065	24555
4	12019	13753	19176	20552	23678	17876	37062	40081	24532	18005	15084	5492	3661
5	19863	13498	13984	25634	20768	20458	14283	27408	24405	15865	5388	2330	3519
6	6767	13635	7503	8511	11675	10817	7106	2527	3084	6962	2741	1860	1116
7	2837	5070	6197	1584	2540	2358	6261	752	686	1770	1044	868	836
8	454	2235	875	24	584	1222	826	255	248	298	1040	94	141
Total	85962	97487	103656	116829	120758	142412	163372	135561	102941	101499	64565	46476	60839

Appendix 5 (Cont.)
Spawning stock biomass in tons, from ADAPT

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	32	10	28	1	9	4	22	0	1	2	1	0	1
3	280	262	323	103	388	120	1218	99	35	1387	25	5	615
4	612	1960	2535	868	2860	593	5534	2944	866	10413	943	65	558
5	6018	8097	6571	19959	12060	7725	7620	14617	4405	13904	3260	518	2922
6	4884	12932	6865	7779	10760	9977	6022	2250	2240	6773	2693	1635	1106
7	2735	5024	6072	1559	2447	2295	5950	732	645	1758	1043	847	833
8	448	2230	869	24	582	1212	816	253	246	298	1039	94	141
Total	15009	30515	23263	30293	29105	21926	27182	20896	8438	34535	9005	3164	6176

Fishable biomass in t, from ADAPT

Ages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	14.7	16.3	3.5	33.9	14.0	124.9	56.6	29.1	41.6	9.7	8.6	5.1	8.9
2	3284.2	2133.5	451.5	3325.3	1727.0	1912.7	3000.9	1028.7	1005.7	2213.6	1853.7	1019.7	2924.2
3	11509.6	3091.0	2166.4	9781.1	3893.1	8475.7	5414.5	9422.6	7310.5	12329.2	5402.3	3768.8	15443.1
4	11346.4	3782.7	2041.2	8353.6	9072.4	10217.2	5989.5	13457.5	10445.3	4472.8	2916.3	2369.7	4211.8
5	20617.2	5887.3	2354.1	12302.5	10257.9	13255.5	2710.0	8668.8	11970.9	4165.9	1175.7	1022.6	3441.4
6	5368.0	6211.3	1293.7	5049.7	5639.5	4380.9	1280.1	1032.3	1403.4	1678.2	729.2	742.4	842.0
7	1142.2	2244.4	69.7	916.9	1401.1	1482.2	617.1	302.1	323.6	394.9	177.4	231.4	635.6
8	298.9	931.1	168.9	11.8	280.1	661.5	192.2	94.1	136.4	109.3	226.8	34.9	90.6
Total	55569	26287	10539	41766	34277	42504	21255	36030	34633	27371	14488	11194	29597

APPENDIX 6: ASPM OUTPUTS

The population in number (million individuals), Spawning stock biomass in tons (SSB), Biomass in tons, Exploitable biomass in tons (Expl. Biom) from ASPM.

Ages	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	7403	18713	18713	19109	14025	13910	15548	16455	21686	17911	7204	13503	3751	1602
2	5484	5484	13857	13858	14149	10385	10300	11512	12182	16048	13246	5327	9985	2775
3	4063	4063	4029	10186	10166	10374	7622	7552	8406	8834	11488	9461	3805	7197
4	3010	3010	2801	2793	6941	6891	7100	5171	4945	5190	4885	6232	5138	2231
5	2230	2230	1576	1508	1383	3353	3486	3442	2115	1523	940	807	1035	1235
6	1652	1652	1250	904	809	727	1829	1838	1583	775	365	209	180	311
7	1224	1224	912	707	476	417	390	946	823	558	174	76	44	51
8	907	907	620	477	337	221	204	182	366	234	89	25	11	9
SSB (T)	58	58	60	44	43	49	51	68	56	22	42	12	5	21
Biomass	127	135	140	151	168	167	175	187	165	125	125	93	66	74
Depletion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expl. Biom.	50	109	99	86	110	122	130	130	97	52	51	38	31	50

Fishing mortality rate from ASPM. F multiplier for each year (Fy)

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.04	0.03	0.01
3	0	0.07	0.07	0.08	0.09	0.08	0.09	0.12	0.18	0.29	0.31	0.31	0.23	0.06
4	0	0.35	0.32	0.40	0.43	0.38	0.42	0.59	0.88	1.41	1.50	1.49	1.13	0.29
5	0	0.28	0.26	0.32	0.34	0.31	0.34	0.48	0.70	1.13	1.20	1.20	0.90	0.24
6	0	0.29	0.27	0.34	0.36	0.32	0.36	0.50	0.74	1.19	1.27	1.27	0.95	0.25
7	0	0.38	0.35	0.44	0.47	0.42	0.46	0.65	0.96	1.54	1.64	1.63	1.23	0.32
8	0	0.25	0.23	0.29	0.31	0.27	0.30	0.42	0.63	1.01	1.07	1.07	0.80	0.21
Fy	0	0.20	0.19	0.24	0.25	0.22	0.25	0.35	0.51	0.83	0.88	0.88	0.66	0.17