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A Note on a Possible Concept for a Length Based Biomass Model for Assessment of the North-east Arctic Stock of Northern Shrimp (*Pandalus borealis)*

by

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Abstract

For northern shrimp (*Pandalus borealis*) in the Barents Sea and the Svalbard waters (ICES Sub areas I and IIb) the available data for conducting an assessment is limited to numbers, biomass, sex and length. It is possible to construct an age distribution on the youngest age groups from modal length groups. This calls for a length based biomass model in order to perform an assessment on this stock. Based on a detailed demographic model, newly developed for fish and shellfish, a length based biomass model is designed. The model uses natural mortality as the prime source of variation in the model when biomass and recruitment is modelled. The "model variables" are calculated from indices from a bottom trawl survey conducted annually in the areas of shrimp distribution. In addition, the catches and the same variables are calculated from the catch statistics available, although length distribution from the catch is only available from the later years, i.e. since 1999. The detailed demographic model identifies the selectivity pattern in the fishery, and the 50% selection length is used to divide the juvenile from the adults. At the same time this is the length at recruitment. It is further assumed that the reproduction is equal to the numbers at 50% selection length, back calculated and modulated by the changes in natural mortality from eggs to length at recruitment. The model may be used for predictions provided natural mortality can be evaluated based on ecosystem interactions.

Introduction

The two most dominant model concepts in fish stock assessment work are the "Catch analysis with tuning" and the "Surplus production model". Both use a regressional link to survey indices as a major part of the concept and often also a regression link to the catch, although not if a VPA is used for catch analysis. The VPA needs a data set on catches that is resolved on age for a fairly large age range. This concept is not applicable to shrimp, as the possible age range is small and restricted to juveniles. In addition, the catch statistic for North-east Arctic shrimp contains length distributions only for the later years. The "Surplus production model" family are, in their basic versions, multiple regressions of biomass onto a set of variables, usually yield and indices of recruitment and biomass, and in some instances, also indices of predation. The idea of this model family is that this multiple regression resembles a formula for biological performance, where some of the parameters may be set a priori. The experience with the "Surplus production" models is that they may give a fairly good fit to the observed data, but that the parameters do not reflect a reliable biological relation. As such, they perform to describe the development of the observed biomass, but do not give reliable biological explanations to the observations.

The indices of abundance and biomass, calculated from bottom trawl surveys for shrimp, are usually assumed to reflect the underlying stock fluctuations fairly well. Assessing the absolute size of biomasses, being monitored by surveys, is a question of reliable catch selectivity measures of the trawl being used in relation to the stock being surveyed. Calculation of "swept area" abundance values used the "effective trawl width" in order to scale the indices to absolute values. Other information relating to absolute size of the stock is the monitoring of shrimp consumed by other fish stocks in the area, e.g. cod and the factor of natural (predation) mortality related to this consumption. Few, if any, assessments of the natural mortality-at-age for shrimp are made and therefore no reliable demographic description of the shrimp stock is available. This also leads to a slight controversy on the assumed absolute value of the biomass of the North-east Arctic Shrimp stock, varying from about 300 000 tons to about 1 million tons.

Under the assumption that the stock of shrimp may be fairly large, due to high estimates of predation by cod, it is also assumed that the proportion of the stock taken as yield may be fairly low, i.e. around a 10% level. However, if the natural mortality of the young (pre-recruit) shrimp is fairly high and produces the shrimp consumed by cod, this may lead to a rather low exploitable (adult) stock, and a corresponding high exploitation level. Following the harvesting of other fish stocks and the catch efficiency of commercial trawl, it would be reasonable to assume a yield per biomass ratio (Y/B) of the adult stock between 30% and 50%. Applying a newly developed demographic model for fish and shellfish (Appendix I and II) to the shrimp stock yield results pointing at a Y/B of approx. 40% and annual natural mortality rates of shrimp ranging from approx. 1.5 for age 1 down to 0.6 for age 3. This indicate a stock able to produce considerable biomass compared to its standing stock, or what is called a “bottom up type” stock in a system ecological framework. Assessing such stocks, calls for methods that reflect this property of the stock.

Another result from applying the demographic model to the shrimp stock is that the 50% selection length in the catches is fairly large (app 22 mm CL), and that the bulk of the catch is taken at a smaller length. This is due to a fairly broad selection range (SR = 8.5 mm CL) and the fact that the numbers of shrimp at the lower lengths in the stock are so abundant that even a low catch rate produces catch in numbers comparable, and even larger, than the numbers caught at fully recruited sizes.

The intention of this paper is to use the information from the demographic model, together with some ideas of constructing a biomass model, to form an assessment tool that reflects biological relations, and that is not dependant on regressions to the extent that has been common so far.

Material and Methods

The material used in this paper is the data available to the ICES Pandalus Working Group in 2004. The methods description should be regarded as a collection of ideas that is put together in order to initiate a discussion on possible future assessment concepts for shrimp.

Scientific survey and fisheries data

Data from the annual Norwegian bottom trawl surveys in the Barents Sea and the Svalbard waters since 1990 are used. These data are catches in weight and numbers distributed on shell (carapax) length intervals of 0.5 mm and given separately for each of eight sex categories. The stock abundance is calculated as a “swept area” estimate over a pre-stratified survey area.

Catch and yield is available for a number of nations fishing for shrimp in these areas. The main bulk of the catches are made by Norwegian and Russian vessels. Length distribution of the catches is available for a resent, shorter times series than the total surveys, i.e. since 1999.

Data on effort is available through the mandatory log-books from the fishing fleet. These data are processed through the national fisheries authorities and may be used to calculate indices of effort (E) and corresponding catch per unit of effort (CPUE). The introduction of more efficient vessels and gears, i.e. double and triple trawls, has caused some problems of interpretation concerning these time series.

Model description

The assessment model concept is based on a simple biomass model description. Two equations describe the major performance of the biomass model. The first represent the metabolic costs of the biomass and the change of the biomass abundance over a time period. These two variables represent the energy (biomass, B_E) that is retained in the stock, from what is consumed by the stock. This energy, in the next formula, is then the difference between the consumption (H) and the production (P, total natural mortality) or production and yield (Y).

(I) $B*b+\Delta B=B_E$
(II) $H-P=B_E$

Three parameters are needed to conduct calculations on these two equations based on available data. The first parameter is the "metabolic cost rate", (b), which is a constant value to multiply with the biomass to get the annual costs of running the biomass. This parameter is the same as in a traditional von Bertalanffy growth equation describing the metabolic cost. Thus, being able to estimate a growth equation on the early ages will give this factor (b). The second parameter is the "bottom up" factor, or the proportion (p_2) of the consumption (H) that is made available as production (P). In the demographic model this factor is set for the juvenile face of the stock to calculate the predation mortality and this mortality is given by length as p_2*a/L, where $a = b/(1-e^{-b/3})$.

(IIIa) $P/H+B_E/H=1$ $P/H=p_2$ $H=B_E/(1-p_2)$
(IIIb) $(P+Y)/H+B_E/H=1$ $H=(B_E+Y)/(1-p_2)$

If the biomass is not known to scale, a the third parameter, the yield per biomass ratio (Y/B) for the exploited (adult) part of the stock, will allow the two equations of biomass to be calculated if we have only an index of biomass from a survey. The resulting changes from year to year will then be reflected in consumption (H) and production (P, mortality), given that there is a constant relationship between the two.

In order to be able to handle more details of available data than biomass from survey and fisheries, a length distribution is given for both the stock and the catch. A length distribution represents a moment in time, but may also be representing a continuum of the individuals in the stock (or catch) travelling through the life span. It could be represented by formulae where time is substituted with length. In that way growth is not given explicitly, and all changes in the demography is modelled through natural mortality and fisheries mortality (or yield per biomass-ratio).

For such a model concept to be manageable, the stock should be divided in a juvenile part (pre recruit or pre fishable) and an adult part (recruited or fishable). Formula IIIa and IIIb above should then be used on each part, giving different p_2's and with B_r's handling the transfer of recruiting biomass between the two parts, i.e. handling the recruitment to fisheries.

In the length based model the recruitment is not expressed explicitly. One may say that the model implies a continuous, and constant, recruitment at a pre set length and that the mortality acts until this length, and from this length and onwards. It is, however, obvious that the natural mortality will vary from year to year and this will result in variation in recruitment and in the relation (p_2) between production (P) and consumption (H). The reason for this is that the model assumes that predation mortality is inversely proportional to length and consumption is proportional to the surface of the individual (L^2). Then the predation mortality is proportional to the consumption per weight unit and this proportionality is p_2. These considerations are valid for the pre recruit part of the stock, i.e. without fishing.

Monitoring the recruiting year-classes, or length groups, in the survey gives two results. The first is an index of year-class strength and the second is the change in mortality from year to year. These results are obtained through a filtering process that may be described as normalising the logaritmic values of the annual indices ($I_{ycl,a}$) of each year-class (ycl) and length group (i.e. age, a) followed by subtracting the younger from the older in the same year-class.

(IV) $$\Delta m = \ln(I_{ycl,a+1}/\ \bar{I}_{a+1}) - \ln(I_{ycl,a}/\ \bar{I}_a)$$

The average of these values for each year, calculated over the year-classes present in both years, represents the annual variation of natural mortality. Now, these values may be used to correct the annual relative index of abundance for each year-class to obtain a weighted average of year-class strength at the desired year.

Using the factor of variation of annual mortality (Δm) to correct the "bottom up" factor (p_2) will allow the calculation of the three main equations (eq I, II and III) to reflect the changes in the biomass more accurately. Especially useful is the value of consumption H (eq III), as this will reflect the availability of food to the stock, and thus being a measure of production in the sea.

The length distribution of the "swept area" estimate from the survey has now been used for the juvenile part of the stock to calculate natural mortality and recruitment. Now, the length distribution of the adult stock may be used to calculate properties of the fishery, predictions of the stock, and reproduction potential, taking into account the natural mortality and recruitment corrections. Both the length distribution in the survey and the length distribution in the catches may be used. The length distribution in the catch needs to be corrected by the selection pattern.

As mentioned, the main equations are given in two versions, one for the juvenile biomass and the other for the adult biomass. The differences are to include the yield (Y) in the latter. The equations for the whole biomass are then the combination (sum) of the two versions. Also, the natural mortality in the adult version must be given in two parts, one as a function of length to give the observed length distribution, and the other as the annual change in the mortality to adjust the level of the length distribution one year ahead. This is based on the assumption that the traces of the age groups are more or less lost in the adult, exploitable part of the stock, and that there is a fairly constant size distribution that is modulated by annual changes in the mortality and the scaling of recruitment variation over the 50% selection length. This is not a direct biologically based assumption, but an approximation that is assumed to reflect desired biological properties in the model calculation.

The numbers in each length interval (N_L) is used to calculate a smoothed length distribution using a linear regression

$$(V) \qquad \ln(N_L) = \ln(\hat{}N_{L50}) - a(L-L_{50})^2 - b(L-L_{50})$$

Thus the estimate of N_{L50} is then the estimate of reproduction that will reproduce the present adult length distribution. The recruitment potential will thus be calculated applying the sum of annual changes in natural mortality until the time of recruitment.

The recruitment in this model is calculated based on a very simple assumption, namely that the stock reproduces its size in numbers, at any time. Any other recruitment will lead to inconsistencies and the arguments always revert to reproduction of the numbers at any time. The simplest assumption could be to assume that the numbers at the recruiting length interval represents the index of recruitment any year. However, this would not necessary represent the numbers in the stock. Therefore, the smoothed length distribution from formula (V) will be used to give the estimated numbers at the recruiting length interval, i.e.$\hat{}N_{L50}$.

Annual steps, in a projection of the stock, could be to reduce the numbers at length with the annual change in mortality and then add the difference of the assumed recruitment at L_{50} and old abundance at the same length multiplied with the selection pattern over all length groups. The final step would then be to apply the regression equation (V) to calculate the smoothed distribution, if desired. This, then, will give the reproduction potential of the projected adult stock. An ecosystem-based prediction of the variation in natural mortality could then provide the calculation of the future recruitment to the stock.

Results

The results in this paper are partially based on results from the biomass and demography model for fish and shellfish being applied to shrimp (Appendix I and II). The results used are in particular parameters for mortality, growth and living costs.

In Table 1 is given the data from the survey used throughout this paper. It is the numbers at length in 1mm intervals of carapax length. Five length groups are identified to represent the indices of abundance of year-classes at the time of sampling. The length group of recruitment is selected to be 21.5 mm CL.

These indices are also given at the bottom of the table and they will be normalised and used as indices of year-class strength and to calculate mortality and change in mortality over years.

In Table 2 are given indices of year-class calculated as logarithms of the numbers in the selected length groups and adjusted to a zero average. Also given are the same values normalised to the standard deviation. The values are listed by year and age.

In Fig. 1 are shown the logarithmic values and in Fig. 2 are shown the normalised values. The year-classes 1996 and 1997 are excluded from the calculations of the means, and this is due to the abnormal values and trend that they show in development of indices over years. The indices of these year-classes are still shown, although relative to the means calculated without them.

Mortality variation over time

The mortality variation is calculated using formula IV and some calculus alternatives are used. The difference is mainly on the way the calculations are averaged. The results of the calculations are shown in Fig. 3. Here the single values of formula IV are given together with the line representing the smoothed (3 year average) difference of the averages, which is believed to reflect the annual deviation of the mortality fairly well.

The figure also contains a line showing the smoothed deviation of natural mortality (M) obtained from the calculations of Z in the smoothed standardised length distributions in Table 4, and subtracting the deviation in Y/B-ratio (see next paragraph). The series are adjusted to an average of zero. It can be seen that the deviation in mortality is reflected in both lines for the later years, but the large deviation in the juvenile mortality in the earlier years is not shown in the same way in the adult mortality.

The smoothed length distribution is calculated using equation (V) and the results are presented on the top of Table 4. Here Z = b and M_a = a in equation (V), representing total mortality (Z = F+M) at L_{50} and the length dependant natural mortality $M_a(L) = aL$. Then "Z dep onL" is a/b. To calculate the deviation of Z in the smoothed length distribution, a new smooth is calculated by calculating the expected recruits from each length group in the survey by the average regression of equation (V), given un upper right of Table 4. The deviation of Z is then found as the slope of a regression on these values, given as dZ in the middle section of Table 4.

Biomass time series

In Table 5 are shown the calculations relative to a potential model concept. It should be noted that the biomass is visualised using data from the survey and that the variables are calculated based on that the values from the survey are multiplied with a factor of 1.6. This factor is obtained by comparing the biomass of shrimp larger then 21mm CL in the model given in Appendix II with the corresponding biomass from the survey. The smoothed length distribution from the survey times this factor (1.6) is then used as a proxy for the adult biomass.

The reduction of numbers by each length group times the weight is equal to the total production of the adult biomass. The natural production is then found by subtracting the yield. The yield is calculated as the catch of shrimp >21 mm. P_2 for total and natural production and yield is then found by dividing by consumption. The consumption is calculated dependant on length (i.e. weight) to be the consumption needed to increase in size one mm in length times the mean number in the length interval, summed over the length intervals from 21.5 mm upwards. The consumption per length interval is given in Table 4, lower left.

Stock – recruitment relation

In using the Formulae IIIb for only the female part of the shrimp stock, one should note that the recruitment from the juvenile (male) part to the adult part of the stock is in the form of biomass being transferred. This takes the form of writing equations I and II as:

$$\text{(VI)} \qquad B_j{*}b+\Delta B_j=B_{Ej} \quad \text{and} \quad B_a{*}b+\Delta B_a=B_{Ea}$$
$$\text{(VII)} \qquad H_j-(P_j+B_{nr})= B_j{*}b \quad \text{and} \quad (B_{nr}+H_{a)}-(P_a+Y)= B_a{*}b$$

Here, B_{nr} represents the net biomass transferred as recruitment and this is extra production for the juveniles and extra "consumption" for the adult stock. This quantity should, however, be corrected for the net transfer of spawning products from the adult stock to the juvenile part:

$$\text{(VIII)} \qquad B_r=B_{nr}+B_s$$

Here B_r is the biomass recruiting to the adults and B_s is the net wet weight of spawning products that contribute to the year class, i.e. not lost during the egg bearing face of the female.

This (B_r) is shown in the column called "Recruiting biomass" in Table 5. In Fig. 4 and 5 these values are related to the values of estimated recruitment at length interval 21 mm and the observed values for the same interval in the survey. There seem to be a significant relationship between them, although noisy.

Discussion

As the model is made dependant only on length, the growth and variations in this is excluded from the model. Changes in b will also influence growth, but such changes will depend on changes in ambient temperature. Thus, one may say that the model is valid given there are no change in temperature. Further, the effect on b from changes in temperature will probably be linear and may very well be included in the model. The effect of this will be to change the cost of living (B*b) and given an observed length distribution from the survey there will be no other effect on the calculations.

All variations in the model are caused by changes in natural mortality in addition to the effect of fishing mortality. This mortality is predation mortality for the juvenile part. For the adult part there will be both predation and senescent mortality as a result of the onset of maturity and closing up to end of life (being old). Calculating such mortalities from different sources of data in the model and comparing them may give some indication on the consistencies in the model. In Fig. 6 is shown the relationship between total mortality calculated from the smoothed length distributions (Z) and the deviation in p_2 calculated from the variable series given in Table 5. Although noisy, there seems to be a significant relationship between them, indicating a consistent model concept.

Traditionally, proportions and mean values of modal length groups have been used to identify age groups in the juvenile length distribution. When changes in mortality take place, shifts in mean length of modals may be the result. As there is a selectivity pattern in the catchability of the survey, these shifts may result in large fluctuations in index abundance. It was therefore decided to use fixed length groups to reflect year-classes. The advantage is also that these length groups will maintain their predictive ability versus recruitment based on length, even if they fail to reflect the true year-class.

In order to calculate the yield from the model one may use the length distribution together with the selection pattern and a fully recruited Y/B-ratio. This is not done in this paper. In order to perform a prediction, one may also conduct this on a predicted length distribution. In order to do this, some more elaborations may be needed on how to predict the development of a length distribution into the future. Two steps may be defined: To define the change in the slope of the length distribution and to define the change in the level of the length distribution (stock biomass). The change in the slope is closely related to the change in mortality and therefore the ability to predict ecosystem effects and apply these to assessments is crucial. The change in the level is also influenced by the change in fishing mortality and this may be predicted using predictions of effort in the fishing fleet.

In Fig. 4 is seen that the biomass of the adults are increasing even if the recruitment to the stock is declining and the yield is increasing, i.e. the years 1998 to 2002. The reason for this is that the food consumption by the shrimp stock is increasing and the predation (natural mortality) is fairly constant (Table 5). The ability to make such calculations is an advantage of this type of model, i.e. no biomass is lost and all biomass and energy transfer is accounted for in the model. Also, the ability to calculate consumption may give a good indication to the status of secondary production in the ocean and thus be used in regressions on to temperature and other indicators of the environment. Finally, this may be used as a starting pint of including temperature dependency in the model.

Table 1. Data from survey used in calculations. Numbers in millions are given together with length and weight. Rows for year-class groups are selected and the indices are given.

	Total length cm - mid int	Carapax length mm - mid int	Weight g	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Average values
	1.0	2.5	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	1.4	3.5	0.0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	
	1.8	4.5	0.1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	
	2.2	5.5	0.1	0	0	1	14	1	0	0	0	0	7	0	0	0	0	0	
	2.6	6.5	0.2	4	18	15	68	19	1	6	0	4	5	0	0	0	0	0	
	3.0	7.5	0.3	0	93	68	35	43	1	1	0	0	9	7	0	0	1	4	
	3.4	8.5	0.4	5	88	36	65	168	4	1	11	3	36	20	1	7	3	4	
	3.8	9.5	0.6	18	122	61	325	158	55	63	97	32	209	133	38	31	94	13	
	4.2	10.5	0.8	60	305	393	656	378	252	270	299	8	136	406	168	230	147	48	
	4.6	11.5	1.0	144	894	1378	579	362	395	503	343	113	118	517	410	389	488	55	
	5.0	12.5	1.3	156	1462	1746	595	397	422	768	431	324	277	585	383	338	313	143	
	5.4	13.5	1.6	349	1448	2105	1588	996	1021	1100	1134	1186	521	1164	566	569	974	260	
	5.8	14.5	2.0	1090	1424	1608	3368	1996	2384	2780	2972	3112	864	1780	1294	1529	3425	1012	
	6.2	15.5	2.4	2811	2584	3529	5641	2901	4155	6147	5904	6162	2885	1613	2220	3300	4299	1751	
	6.6	16.5	3.0	5133	4557	5912	6887	4500	6077	9967	9992	9719	7856	2796	2851	4314	4930	2416	
	7.0	17.5	3.5	8816	6949	6007	7928	6423	7244	11832	14279	13479	10843	5149	3144	6785	6568	4626	
	7.4	18.5	4.2	8612	11423	6403	7602	5912	6074	10528	13210	14401	11677	8765	3809	6335	6804	5485	
	7.8	19.5	4.9	6508	10828	5633	5153	3815	5222	6220	8014	11068	9915	8904	4001	3588	4985	4177	
	8.2	20.5	5.7	6018	8576	5485	4524	4029	5116	5324	6585	8616	9272	7174	4016	2773	4012	3139	
	8.6	21.5	6.5	6333	7662	6125	4567	3230	4228	5126	5003	6246	7076	5797	4437	3273	4102	3215	
	9.0	22.5	7.5	4306	4815	4293	3124	1544	1830	3089	2530	2740	3257	3341	4389	3403	3147	2293	
	9.4	23.5	8.5	2192	2388	1858	1538	807	679	1193	998	1215	1649	1473	2446	2515	1746	1141	
	9.8	24.5	9.7	819	872	554	606	370	366	487	386	533	637	565	917	1132	799	711	
	10.2	25.5	10.9	294	318	190	272	112	111	207	123	138	200	200	268	521	396	276	
	10.6	26.5	12.2	35	111	43	87	20	27	121	23	19	104	467	100	135	161	107	
	11.0	27.5	13.7	22	4	12	53	29	2	54	11	4	36	18	48	19	45	32	
	11.4	28.5	15.2	9	0	2	16	7	0	26	2	0	13	10	10	3	13	9	
	11.8	29.5	16.9	2	0	0	6	3	0	13	0	0	4	2	2	0	3	2	
	12.2	30.5	18.6	0	0	0	2	1	0	6	0	0	1	1	0	0	1	0	
Length mm CL	cm Total	cm Total																	
0.3	0.3	13.74	Spawn	6289	9783	8594	4947	2571	3390	3936	4255	5271	5054	5400	5412	5663	4154	2920	5408.20
6.25	2.5	3.5< <= 9	1	5	180	103	100	211	5	3	11	3	45	27	1	7	3	9	63
11	4.4	9 < <=13	2	144	894	1378	579	362	395	503	343	113	118	517	410	389	488	55	464
15.5	6.2	13 < <=18	3	2811	2584	3529	5641	2901	4155	6147	5904	6162	2885	1613	2220	3300	4299	1751	4111
19	7.6	17 < <=21	4	15119	22251	12036	12755	9727	11296	16748	21224	25468	21592	17669	7810	9923	11789	9662	14810
			5	6333	7662	6125	4567	3230	4228	5126	5003	6246	7076	5797	4437	3273	4102	3215	4703

Table 2. Logarithmic indices of year-class strength in the years 1990-2004. In the upper part are indices with average equal zero. In the lower part the indices are standardised to normal (scale relative to one standard deviation).

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	Age															
	Spawn	0.22	0.66	0.53	-0.02	-0.68	-0.40	-0.25	-0.17	0.04	0.00	0.07	0.07	0.11	-0.20	-0.55
	1	-1.40	2.17	1.61	1.58	2.32	-1.41	-2.09	-0.65	-1.83	0.77	0.27	-2.75	-1.11	-1.79	-0.87
	2	-0.96	0.86	1.30	0.43	-0.04	0.05	0.29	-0.09	-1.21	-1.16	0.32	0.09	0.03	0.26	-1.92
	3	-0.30	-0.38	-0.07	0.40	-0.26	0.10	0.49	0.45	0.49	-0.27	-0.85	-0.53	-0.13	0.13	-0.77
	4	0.09	0.48	-0.13	-0.08	-0.35	-0.20	0.20	0.43	0.62	0.45	0.25	-0.57	-0.33	-0.15	-0.35
	5	0.33	0.52	0.30	0.00	-0.34	-0.07	0.12	0.10	0.32	0.44	0.24	-0.02	-0.33	-0.10	-0.35
		Normalised														
STD	Age															
0.38	Spawn	0.57	1.72	1.38	-0.06	-1.76	-1.04	-0.65	-0.45	0.11	0.00	0.17	0.18	0.30	-0.51	-1.42
1.83	1	-0.76	1.18	0.88	0.86	1.27	-0.77	-1.14	-0.35	-1.00	0.42	0.15	-1.50	-0.61	-0.98	-0.48
0.70	2	-1.38	1.24	1.86	0.62	-0.06	0.07	0.42	-0.13	-1.73	-1.66	0.45	0.12	0.05	0.37	-2.75
0.45	3	-0.66	-0.84	-0.15	0.89	-0.59	0.21	1.08	0.99	1.09	-0.60	-1.89	-1.18	-0.30	0.29	-1.71
0.40	4	0.23	1.20	-0.33	-0.19	-0.87	-0.49	0.49	1.08	1.54	1.12	0.62	-1.41	-0.82	-0.39	-0.88
0.27	5	1.22	1.92	1.09	0.02	-1.26	-0.27	0.44	0.35	1.17	1.62	0.89	-0.09	-1.21	-0.38	-1.27

Table 3. Logarithmic indices for the year-classes 1988 and 1989, normalised.

Year	Year class	1988	1989
1990		-1.38	-0.76
1991		-0.84	1.24
1992		-0.33	-0.15
1993		0.02	-0.19
1994			-1.26

Table 4. Show the calculation of smoothed length distribution and different estimates of recruitment.

Adult biomass	89	121	107	72	38	44	56	56	67	72	85	86	93	69	55	Mean
N50	6957	6405	7740	4905	3126	2883	4245	4624	4904	5531	4997	5002	3418	3633	2981	4728
Z	-31	1	-23	-27	-37	-16	-36	-33	-21	-34	-19	-17	11	-13	-13	-20
Ma	-89	-375	-175	-56	-15	-250	15	-98	-235	-38	-124	-140	-346	-147	-149	-134
Z dep on L	2.93	-573.60	7.51	2.05	0.42	15.18	-0.41	2.97	11.19	1.13	6.42	8.10	-32.20	11.69	11.42	6.62
Chosen R	**6406**	**9397**	**8277**	**4876**	**2506**	**3210**	**3737**	**4069**	**5266**	**5279**	**5567**	**5168**	**5392**	**3924**	**3104**	
Weight g																
6.5	5392	7776	6848	4285	2757	3528	3753	4296	5351	5359	5534	3950	3507	3534	2998	
7.5	6237	8313	8166	4987	2243	2598	3848	3697	3994	4196	5426	6648	6203	4611	3637	
8.5	6212	8065	6914	4804	2293	1884	2908	2851	3464	4156	4679	7247	8970	5005	3541	
9.7	5222	6629	4642	4259	2366	2284	2669	2480	3419	3614	4041	6112	9084	5152	4963	
10.9	4854	6243	4121	4935	1854	1788	2931	2053	2285	2927	3691	4627	10805	6600	4986	
12.2	1701	6472	2756	4728	984	1318	5112	1120	944	4533	25705	5115	8309	7994	5741	
13.7	3636	739	2590	9867	4862	409	7786	1896	713	5414	3310	8379	4033	7606	5906	
R	6799	12022	8621	4000	2295	3910	2880	4216	6382	4306	4877	5087	5947	3764	3099	5214
dZ	6.29	12.21	8.76	-3.78	0.25	12.31	-4.32	8.08	14.60	0.26	-2.08	-2.00	-1.86	-5.75	-5.14	2.52
dZ annual	0.31	0.61	0.44	-0.19	0.01	0.62	-0.22	0.40	0.73	0.01	-0.10	-0.10	-0.09	-0.29	-0.26	0.13
dZ accumul	0.31	0.51	0.48	0.15	0.02	0.28	0.10	0.23	0.46	0.32	0.07	-0.08	-0.10	-0.19	-0.24	0.16
dF	0.05	-0.14	-0.13	-0.04	-0.06	-0.17	-0.14	-0.13	0.00	0.12	0.07	-0.11	-0.11	-0.13		
dM	0.26	0.65	0.60	0.19	0.08	0.45	0.24	0.36	0.47	0.19	0.00	0.03	0.02	-0.07		-0.75
dZ used	0.31	0.51	0.48	0.15	0.02	0.28	0.10	0.23	0.46	0.32	0.07	-0.08	-0.10	-0.19	-0.24	
R by numbers	6406	9397	8277	4876	2506	3210	3737	4069	5266	5279	5567	5168	5392	3924	3104	
Consum g	Smoothed standardised length distribution															
2.77	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	
3.03	509	465	473	548	583	517	562	529	476	508	568	610	615	642	656	
3.30	225	188	195	261	296	233	274	243	197	225	281	324	328	358	374	
3.58	87	66	70	108	131	91	117	97	71	86	121	150	153	174	186	
3.87	29	20	22	39	50	31	43	34	22	29	45	60	62	73	80	
4.17	8	5	6	12	17	9	14	10	6	8	15	21	22	27	30	
4.49	2	1	1	3	5	2	4	3	1	2	4	6	7	9	10	

Table 5. Show the biomass measured by the survey for females >21 mm CL together with calculated values of variables related to the model concept. Biomass and yield values are in 1 000 tons.

Year	Adult Bio 1 jan	Avg bio	Change	Energy trapped	Yield > 21mm	Energy +catch	Total production	Natural production	Consumption	p2 adult tot	p2 adult natural	p2 adult yield	Recruiting biomass	Delta p2
		B_i	ΔB	B_E	Y_i		P_i+Y_i	P_i	H_i				B_r	
1982					33									
1983	185	205	35	118	54	173								
1984	220	209	-45	40	67	107								
1985	175	132	-75	-21	65	44								
1986	101	86	-24	11	34	44								
1987	76	76	4	35	23	57								
1988	80	89	17	53	25	78								
1989	97	109	27	71	33	103								
1990	124	145	44	103	42	145	75	33	80	0.94	0.41	0.53	74	0.06
1991	168	182	15	89	39	128	106	66	100	1.05	0.66	0.39	104	0.19
1992	183	166	-39	28	36	64	94	59	91	1.04	0.64	0.39	94	0.17
1993	144	116	-55	-8	29	21	60	31	70	0.85	0.44	0.41	53	-0.04
1994	88	72	-23	6	15	21	36	21	41	0.87	0.52	0.36	34	-0.01
1995	66	72	14	43	13	56	43	30	41	1.04	0.72	0.32	41	0.17
1996	79	86	10	45	18	63	49	31	57	0.86	0.54	0.32	39	-0.03
1997	90	93	9	47	19	66	52	33	55	0.95	0.61	0.34	48	0.07
1998	99	106	12	55	29	84	64	35	58	1.09	0.60	0.50	63	0.23
1999	111	117	14	62	39	101	64	25	66	0.97	0.38	0.59	62	0.10
2000	125	133	11	65	43	108	67	24	87	0.78	0.28	0.50	53	-0.12
2001	137	139	6	63	29	92	64	35	94	0.68	0.37	0.31	45	-0.24
2002	143	140	-14	43	30	74	66	36	100	0.66	0.36	0.30	43	-0.25
2003	129	113	-30	16	23	39	51	28	80	0.63	0.35	0.29	32	-0.28
2004	99													

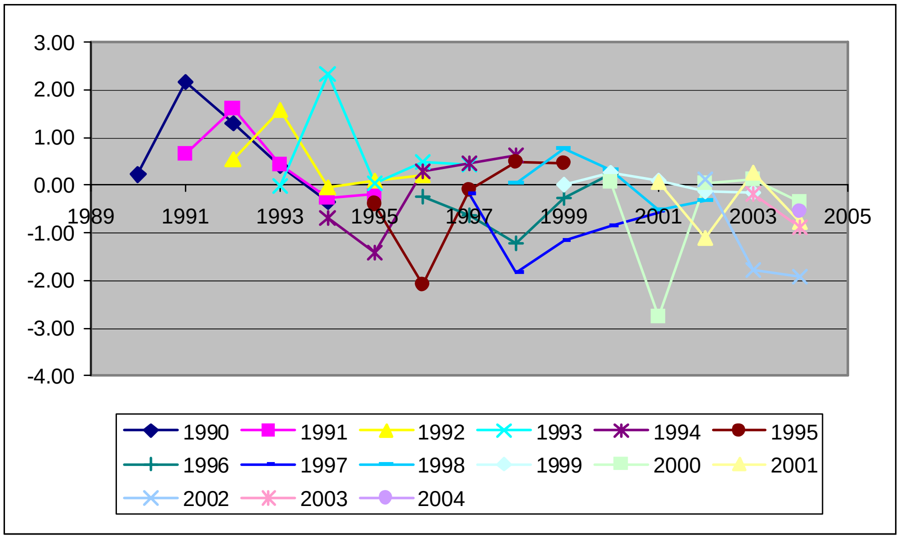


Fig. 1. Showing the indices of year-class strength by year.

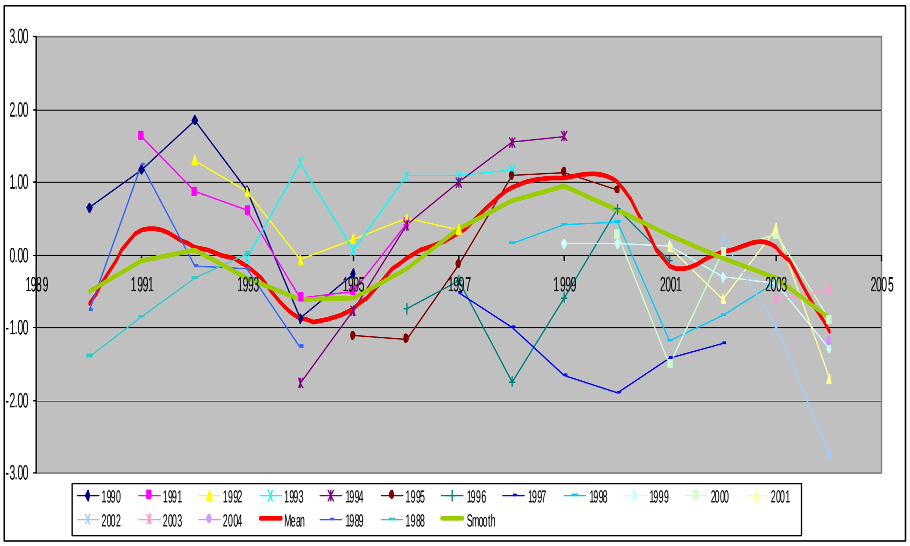


Fig. 2. Showing the normalised year-class indices together with a mean calculated by adding the average difference between years for the year-classes present both years, adjusted t an average value of zero. The smoothed curve is a running 3 year mean of the mean curve. The year classes 1996 and 1997 are excluded from the mean and smoothed curves.

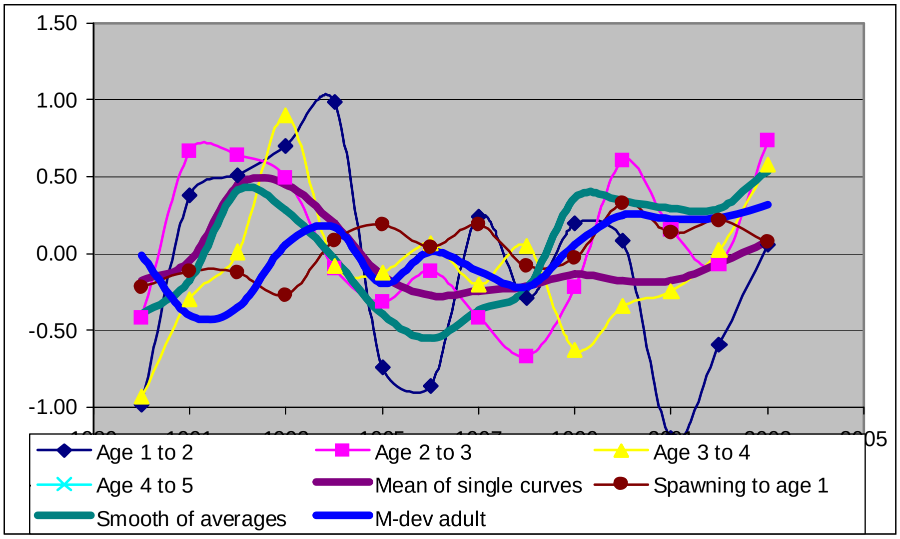


Fig. 3. Show the deviation in annual mortality (+ is increased mortality) plotted on the starting year of the comparison. The smooth of averages is calculated from the smooth line in Fig. 2. The M-dev adults are calculated from the fitting of smoothed length distributions to the survey data.

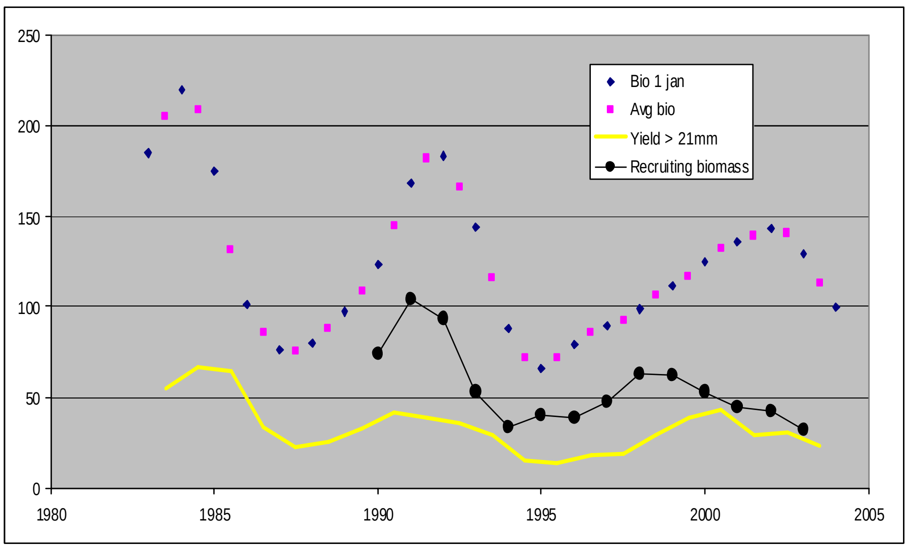


Fig. 4. Showing the development of the adult biomass (>21 mm CL) , yield (>21 mm CL) and recruitment to the adult biomass. The scale is 1 000 tons and year.

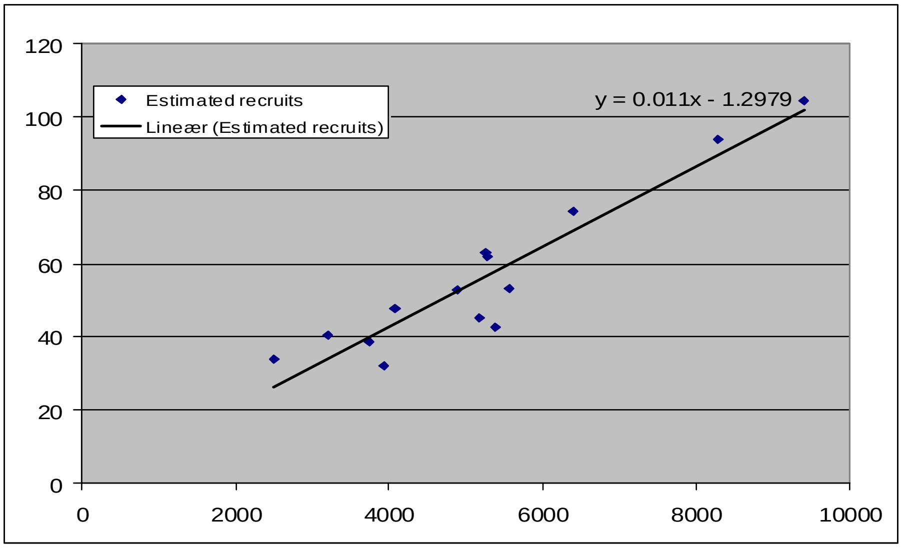


Fig. 5. Show the relation between recruited biomass (Y – 1 000 tons) and estimated indices of recruitment from the survey (X – numbers 10^6).

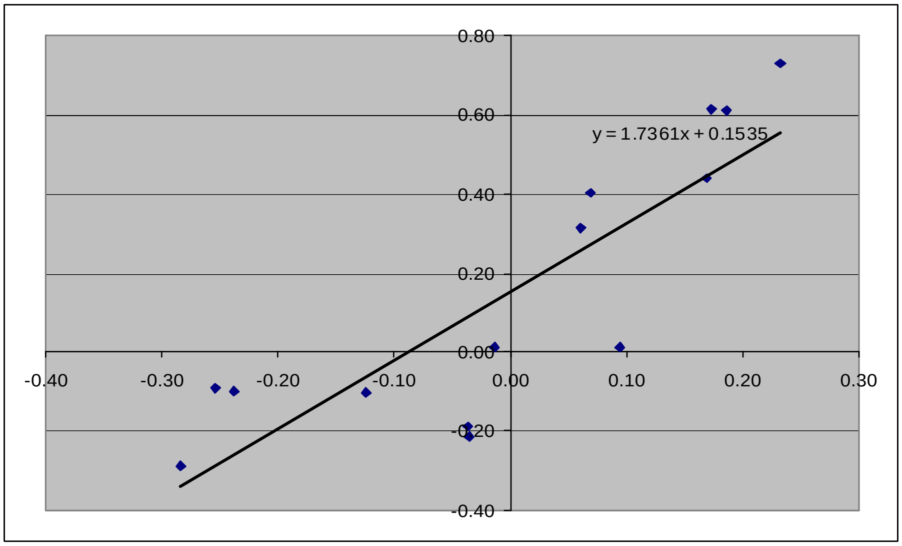
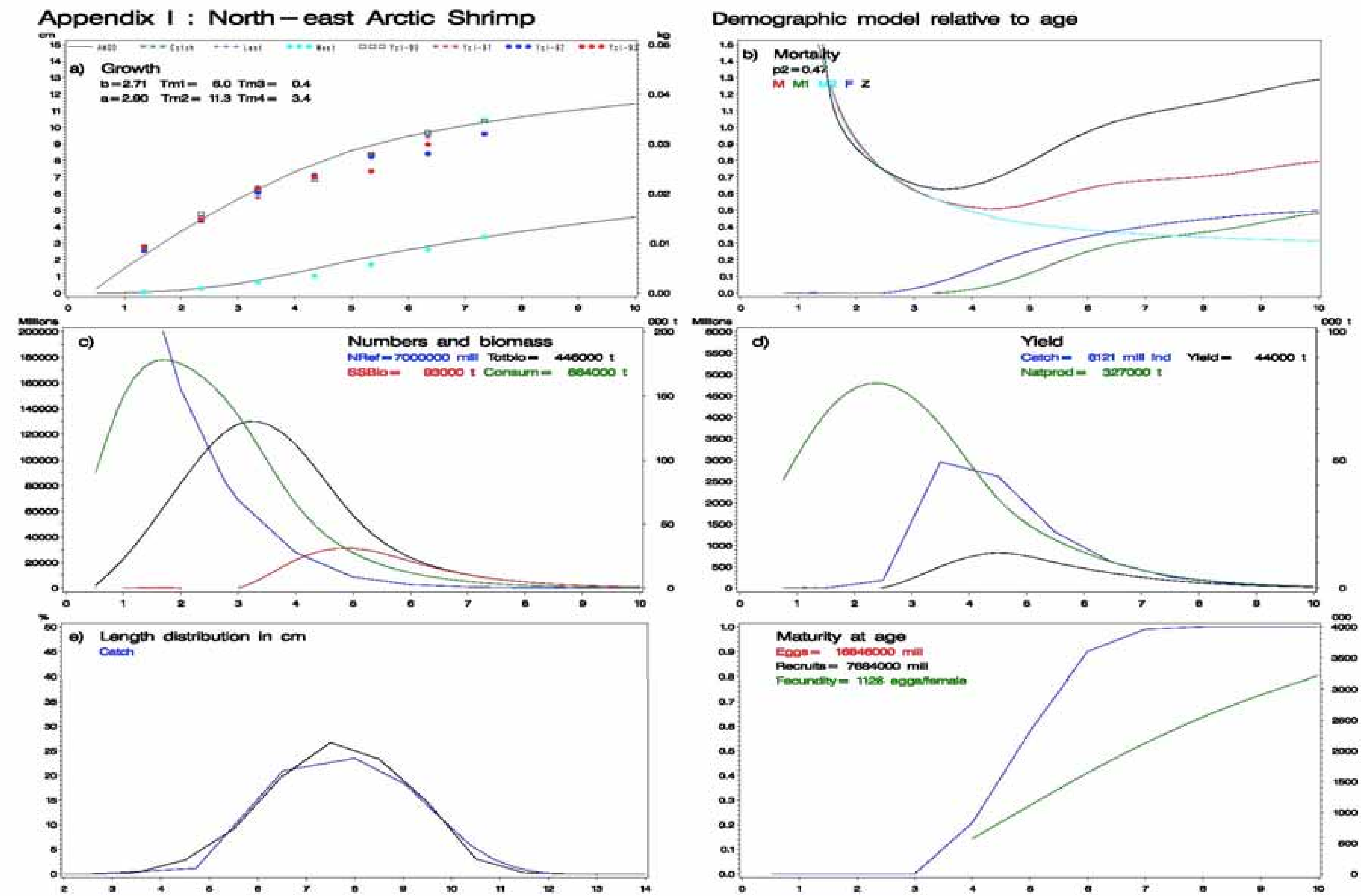
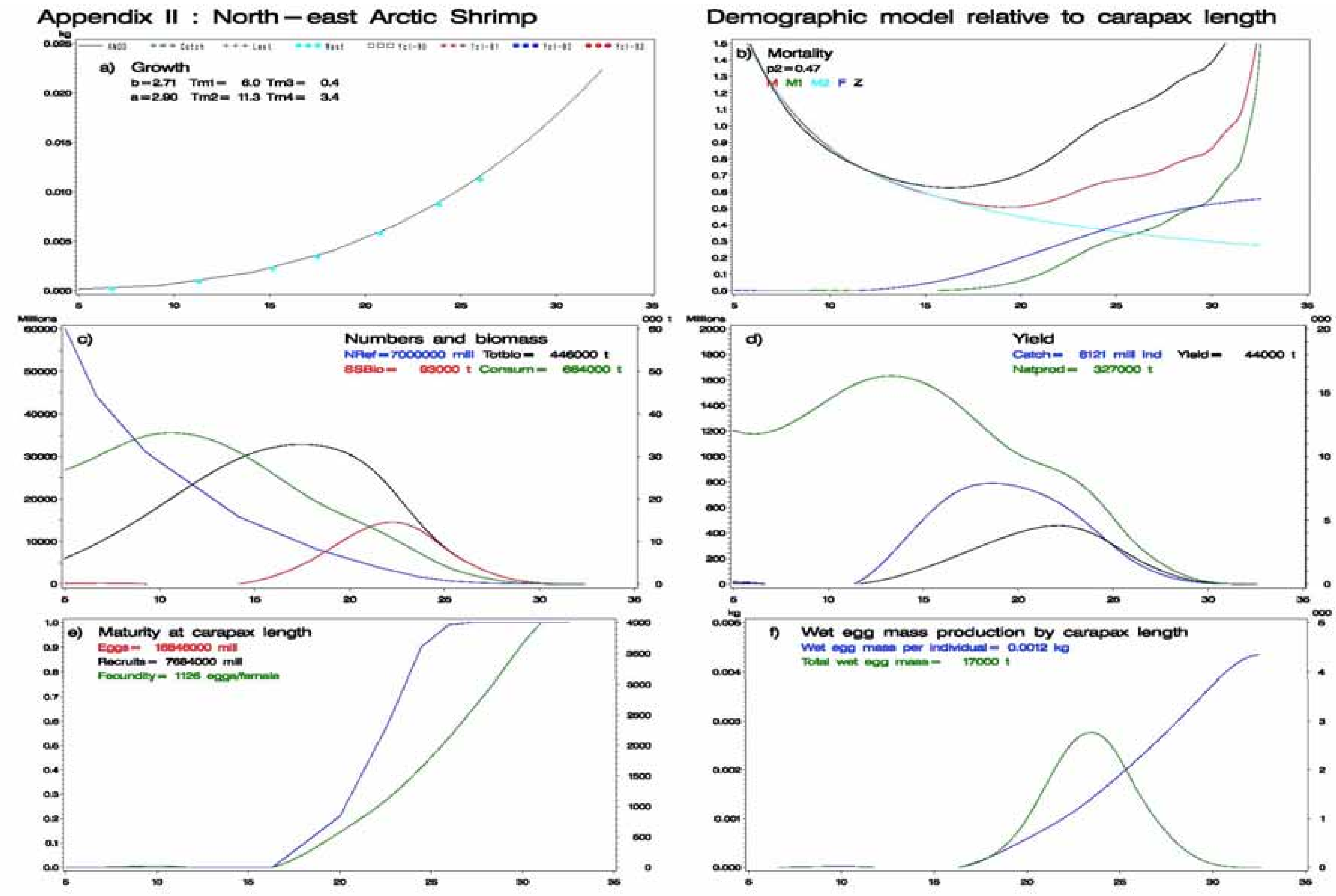


Fig. 6. Show the relation between deviation in p_2 calculated in the model (X) and deviation of Z calculated from the adult part of the survey (Y).



Appendix I : North-east Arctic Shrimp
a) Growth
b=2.71 Tm1= 6.0 Tm3= 0.4
a=2.90 Tm2= 11.3 Tm4= 3.4
cm
kg
Demographic model relative to age
b) Mortality
p2=0.47
M M1 M2 F Z
c) Numbers and biomass
NRef=7000000 mill Totbio= 446000 t
SSBio= 93000 t Consum= 684000 t
Millions
000 t
d) Yield
Catch= 8121 mill Ind Yield= 44000 t
Natprod= 327000 t
e) Length distribution in cm
Catch
%
Maturity at age
Eggs=
Recruits=
Fecundity= 1128 eggs/female


Appendix II : North-east Arctic Shrimp
Demographic model relative to carapax length
a) Growth
b=2.71 Tm1= 6.0 Tm3= 0.4
a=2.90 Tm2= 11.3 Tm4= 3.4
b) Mortality
p2=0.47
M M1 M2 F Z
c)
Numbers and biomass
NRef=7000000 mill Totbio= 446000 t
SSBio= 93000 t Consum= 664000 t
d)
Yield
Catch= 8121 mill ind Yield= 44000 t
Natprod= 327000 t
e) Maturity at carapax length
Eggs= 16846000 mill
Recruits= 7684000 mill
Fecundity= 1126 eggs/female
f) Wet egg mass production by carapax length
Wet egg mass per individual= 0.0012 kg
Total wet egg mass= 17000 t