Report on assessment and management advice for 2004 of the anchovy fishery in the Yellow Sea

The Bei Dou Fisheries Management Project 2001-2005
Institute of Marine Research
Bergen, April 24-30, 2004

INTRODUCTION

According to the Project Document for the "Bei Dou Fisheries Management Project 2001-2005", a small workshop was arranged in the period April 24-30, 2004 at the Institute of Marine Research (IMR), Bergen. The workshop was arranged within the sub project "Fishery Management based on Scientific Investigations" to evaluate the present state of the anchovy stock and setting and advising on a TAC for 2004. All the input data for the workshop was provided by the Yellow Sea Fisheries Research Institute (YSFRI).

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Similar workshops were held in Qingdao in March, 2001 and April 2002, and workshop reports are available at both IMR and YSFRI. The workshop for 2003 was cancelled due to the SARs epidemics in China. This report thus represent an updating assessment with new data obtained from both 2002/2003 and 2003/2004.

MATERIALS AND METHODS

Data

Data on number, mean weight and biomass by age as well as the total stock biomass of anchovy were available from the acoustic survey in the years from 1987 to 2004, except for the years 1997-1998 (Table 1, Table 2). The surveys were carried out in the winter season from November to early February, the measurements done in November-December one year were however considered as stock estimates at 1 January the following year for obtaining consistency in the data treatment. The total catch by year from the start of the anchovy fishery in 1989, is also available (Table 1).

Basic Methods

As in previous reports, the basic methods used in estimating stock parameters are by comparing stock estimates in number by age in subsequent years. The yearly mortality (Z) is thus obtained by input of acoustic measurements to the formula:

$$\mathbf{N_{t+1} = N_t * e^{-Z}} \quad , \tag{1}$$

where N_t is the estimated number of a year class in year t and N_{t+1} is the corresponding estimate of the year class in the subsequent year.

The abundance of the year classes as one year old recruits (R_1) have been back calculated by the VPA method using the Pope's approximation formula:

$$\mathbf{N_t = N_{t+1} * e^{M} + C_t * e^{M/2}}, \tag{2}$$

where M is the natural mortality and C_t is the catch by age in number in the year t.

The catch in number (the sustained yield) is estimated by the conventional catch equation:

$$\mathbf{C_t = N_t * E*(1-e^{-Z})}, \tag{3}$$

where C_t is the catch in number by age in year t and E the exploitation rate F/(F+M). F is the fishing mortality.

The stock-recruitment relationship was based on the estimates given in Zhao *et al.* (2003), where a Ricker model was used:

$$R = a \times SSB \times e^{-b \times SSB} \tag{4}$$

where a is the recruits per spawner at low stock size, and b describes how quickly the recruits per spawner drop as SSB increases (Hilborn and Walters, 1992). This is one of the major differences in the methods compared to the 2002 report, where a Beverton and Holt model was used.

For the estimation of the model parameters a and b in Equation (4), the number of 1-year-old fish was selected as R and the stock size minus half of the catch in the previous year was used as the corresponding SSB.

The M-output (M_{outp}), i.e., the biomass production corresponding to the natural mortality (Hamre and Tjelmeland 1982), was calculated as follow:

$$\mathbf{M_{outp} = N_t * M/(F+M)*(1-e^{-Z})}, \tag{5}$$

where the stock number Nt was calculated using an iteration procedure according to established stock-recruitment relationship. The corresponding output biomasses of the stock are obtained by multiplying the number by the mean weight by age and summarizing the age groups.

The calculations were executed on Excel spreadsheet, and estimation of the model parameters were performed with Excel's solver function.

As the catch from the fishery was not sampled and the fishing pattern has been changed due to the low fish abundance, new data from the years 2003/03 and 2003/04 was not used for population parameter estimates, instead, the parameter estimates from Zhao *et al.* (2003) based on the data from 1987-2002 were reported here, with the status assessment of the anchovy stock updated according to the new data obtained. The stock number at age and mean weight at age for the year from 1987 up to 2004 are shown in Table 2.

RESULTS AND DISCUSSIONS

The parameters are estimated as in Zhao *et al*. (2003), and the stock-recruitment relationship was re-estimated with the new data included.

Natural mortality

Table 3 shows the estimates of mean natural mortality of each age group. The mortality from age 2 to age 3 in the years 1987 to 1995 was calculated by comparing the measured 2-year-old to the back-calculated 2-year-old derived from the measured 3-year-old in the subsequent years, the differences were squared and the M-value corresponding to the least sum of squares was selected as the average yearly M_2 for the period. The best fit was obtained when M_2 equalled 0.45 and the corresponding stock estimates are illustrated in Fig.1.

Figure 1 shows that the survey data for 2-group and 3-group are consistent and indicates that the estimated M_2 is fairly accurate. The calculated M_1 of 0.09, however, is unrealistic and is probably caused by the incomplete coverage of the 1-year-old by the winter acoustic surveys. A survey in mid December 2000 showed that only young of the year anchovy were still left in the Bohai Sea (YSFRI, unpublished data). This observation supports the assumption that the 1-year-old would not be fully recruited to the measurable stock in the Yellow Sea during the winter acoustic surveys. The M_1 used for further analysis was therefore set equal to M_2 (Table 3). The back-calculated numbers of the 1-group from the observed (measured) 2-group in the subsequent years are shown in Table 4.

Comparing the measured numbers of the 1-group (Table 2) to the back-calculated numbers from the 2-group (Table 4), it is seen that the sum of the former figures is about 25 % lower than that of the latter ones. This figure was taken as an estimate of incomplete recruitment, i.e that only about 75% of the 1-group were covered by the winter acoustic surveys. According to the general knowledge of biology and distribution of the smallest fish, this is a reasonable explanation of the difference in the two estimates.

Figure 2 shows the measured numbers of the 3-group (Table 2) to the back-calculated numbers from the 4-group in the subsequent years. The best fit between the observed and back-calculated data was obtained when M3 equalled 0.92. The figure shows, however that the estimate is due to the very low and fluctuating number left as 4-year old. The estimated natural mortality of 3-group (M_3) is higher than M_2. This may be partly due to an emigration of the oldest fish from the surveyed area; but since anchovy is a short-lived species with a life span of only 4 years, an increase in natural mortality after age 3 is reasonable. M_3 and M_4 were therefore set to the present estimate (Table 3). The error introduced is probably small, due to the low number left in the oldest age groups (Table 2).

Stock-recruitment relationship

As in the 2002 report, the number of 1-year-old back-calculated from the measured 2-year-old in the subsequent year, assuming that M_1 equals to M_2, was regarded as recruit (R_1, Table 4); while the stock biomass measured at the beginning of the previous year, adjusted by substituting the back-calculated 1-year-old for the measured 1-year-old and minus half of the catch in the previous year, was regarded as the corresponding spawning stock biomass (SSB). The loss of stock biomass due to natural mortality from the beginning of the year to and during the spawning season was not taken into account, and**(because)** it was assumed that this loss would be compensated for by the individual growth.

For the calculation of the stock in number and weight for the two years without survey data, reference is made to Zhao *et al.* (2003).

Figure 3 shows the resulting stock-recruitment scatter-plot together with the new stock-recruitment curve:

$$R_1 = 151.1 \times SSB \times e^{-0.299 \cdot SSB}, \quad (6)$$

where R_1 is given in billion individuals and SSB in million tons.

The model implies that under the prevailing conditions, the maximum recruitment of the anchovy stock in the Yellow Sea is about 186 billion individuals, with a corresponding SSB of about 3 million tons. This is close to the average stock measured in the years prior to 1996.

From the data points of 2002-2004 (the 3 small values) it may be concluded that this anchovy stock is self-sustained and independent of other anchovy stocks in the adjacent areas. The very low recruitments in the later years confirm that the stock is grossly over-exploited and my not recover unless the fishing mortality is drastically reduced.

Sustainable yield and M-output

Figure 4 shows the sustainable yield and other stock parameters at various fishing mortalities with recruitment calculated according to Equation (6). For details of the method used, reference is made to Zhao et al. (2003). The virgin stock (F=0) is estimated at about 3.8 million tons, which is slightly higher than the average stock estimates prior to 1995. The maximum sustainable yield (Y_{max}) is about 550 000 tons and obtained at a fishing mortality of 0.4. The corresponding wintering stock size is about 2.2 million tons. This means that fishing more than 550000 tons a year for several years, as being the case in this fishery, the stock is bound for a collapse according to this assessment. The optimum sustainable yield (Y_{opt}) is estimated at about 520 000 tons, corresponding to F_{opt} or $F_{0.1}$ slightly higher than 0.3. This is very close the annual catch recommended by Zhu and Iversen (1990). The corresponding wintering stock biomass and SSB are estimated at 2.6 and 2.3 million tons, respectively. This is also the stock level where the recruitment begins to be adversely affected as indicated by the stock-recruitment curve (Fig. 3).

Anchovy is important both as prey species and as a major plankton feeder in the Yellow Sea ecosystem. In the case of a forage fish it is important to consider its role in the food chain when formulating management plans. In order to quantify this statement the biomass production corresponding to the natural mortality, the M-output (Hamre and Tjelmeland 1982), was calculated and shown in Fig. 4. This clearly demonstrate that anchovy is a very important prey species in the area and that a stock collapse will have serious impact on the food supply for other important commercial stocks in this ecosystem.

State of stock and fishery

The development of stock (measured) and fishery is shown in Figure 5. The 2002 and 2003 catch data represents those fishery within the winter survey area only. A major portion of the total catch in these two year were from the East China Sea and east of the survey area in the Yellow Sea.

The catch-stock development in1995-2004 confirms the conclusion drawn in previous year's report. When the catches approach the F.1 level (0.52 mill. tonnes), the stock is reduced to about 2 mill. tonnes, and is depleted when the yearly catches result in F-values above Fmax (catches > 0.56 mill. tonnes). The stock in 2002-2003 was fished down to some 3% of the estimated virgin stock (3.5 mill. tonnes). The 2004 stock estimate showed a slightly higher abundance mainly due to higher recruitment in relation to the spawning stock (Figure 6).

Fishery management and advices

A work shop for giving scientific management advice for 2000 (YSFRI, 1999) valued the average potential yield of anchovy in the Yellow Sea and East China Sea at 500 000 tons a year (Zhu and Iversen, 1990, Iversen et al.1993). The estimate was considered conservative and regarded as a precautionary catch level. The work shop concluded that since 1996 the catches had been far above the 500 000 tonnes level and warned that if the present fishing effort was carried on in the coming years the risk for stock collapse would be high.

The catches taken after 2000 have been far above the sustainable stock level and the stock has continued to decline. In order to reverse the declining trend, previous workshop recommended limiting the fishing in 2001 to a catch below 100 thousand tonnes. This was not acted upon and the catch in 2001 amounted to about 4 times that level. The measurable stock in 2002 was reduced to below 0.2 mill.tonnes and has later been kept on this low level. Since the anchovy is a fast growing fish which mature at a low age, and the fishery on immature fish is limited, it is possible that the stock will survive on this low level without any direct restriction on the fishery, yielding yearly catches at the 2003 level. (80 thousand tonnes). The consequences of such a management policy is obvious for the anchovy fishery, but an unregulated anchovy fishery may also affect seriously the obtainable yield of other stocks in the region having anchovy as the main food resource.

In the present situation it seems not appropriate any longer to recommend a catch quota regulation of the fishery in order to rebuild the stock. The workshop therefore recommends to ban the direct anchovy fishery in the Yellow Sea until the spawning stock has recovered to the level observed in 2000-2001, i.e. above 0.5 million tones.

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Table 1. Stock sizes and yearly catches in million tonnes in 1987-2004.The 2002 and 2003 catch data was estimated for the survey area in the Yellow Sea only.

Year	Stock	Catch
1987	2.16	
1988	2.82	
1989	2.82	0.04
1990	2.51	0.06
1991	2.46	0.11
1992	2.78	0.19
1993	4.12	0.25
1994	3.74	0.35
1995	3.85	0.45
1996	2.55	0.60
1997		1.10
1998		1.20
1999	0.79	1.10
2000	1.75	0.95
2001	0.42	0.48
2002	0.18	0.15
2003	0.11	0.08
2004	0.26	

Table 2. Stock measurements in number and weight by age. The sum of the number of 1-year-old fish for the period of 1987-1996 and 1999-2004 is also shown.

	Stock in number (billion ind.)				Mean weight in gram			
age:	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1987	102	84.1	32.8	1.4	6.8	12.0	13.0	16.4
1988	210.1	98.9	30.3	0.1	6.8	10.1	12.9	15.7
1989	136.5	105.9	74.6	8.5	3.3	11.1	14.2	15.3
1990	72.9	106.6	67	4.4	5.3	11.0	13.2	15.7
1991	163	94.9	58	17.3	4.8	8.3	11.2	13.5
1992	104.2	161.6	19.9	2.2	6.1	11.3	14.4	15.9
1993	185.6	168.7	80.4	24.1	5.0	10.1	14.1	14.6
1994	122.8	66.4	114.7	43	6.8	11.4	13.0	15.2
1995	198	133.3	58.6	0.6	6.6	12.7	14.6	15.7
1996	113.3	69.1	66.5	5.7	7.3	10.1	13.8	18.8
1997								
1998								
1999	30.1	38.4	14	0.9	4.0	12.0	20.0	24.0
2000	56.6	58.8	36.5	2.4	3.8	11.9	19.6	23.5
2001	18.73	23.24	4.41	0.13	3.2	10.9	20.6	27.3
2002	13.13	7.34	1.56	0.20	3.9	12.2	20.9	25.2
2003	5.67	4.57	1.45	0.18	3.7	12.0	20.0	25.5
2004	24.24	4.80	3.68	0.38	4.3	13.0	22.0	27.0
Sum	**1556.4**							

Table 3. The mean natural mortalities of anchovy in the Yellow Sea.

Mortality \ Age	1	2	3	4
Calculat	0.09	0.45	0.92	
Applied	0.45	0.45	0.92	0.92

Table 4. Back-calculated stock number in billion by age from the corresponding one-year older fish measured in the subsequent years according to the natural mortality given in Table 3 (applied). See text on the calculation of the 1997 and the 1998 data. The number of 1-year-old fish in 2004 is the measured value from survey.

Age	1(R_1)	2	3	4
1987	155.6	47.7	0.2	
1988	166.7	117.4	21.2	
1989	170.2	107.3	12.7	
1990	151.5	94.5	45.7	
1991	263.5	103.4	9.6	
1992	274.4	140.4	62.3	
1993	118.6	193.4	115.1	
1994	224.2	100.0	18.5	
1995	137.8	124.2	25.1	
1996	178.6	76.2	25.0	
1997	*206.2*	*92.3*	*30.9*	*16.7*
1998	*115.1*	*92.8*	*35.3*	*0.1*
1999	139.0	116.8	33.5	
2000	76.6	48.5	32.8	
2001	40.4	38.3	9.1	
2002	21.0	10.0	2.5	
2003	12.7	10.0	2.6	
2004	24.2			
Sum	**2155.2**			

Table 5. Mean weight (g) by age of anchovy for the two exploitation periods and that applied for sustainable yield estimation.

Age	1	2	3	4
1987-1996	5.9	10.8	13.4	15.7
1999-2002	3.7	11.8	20.3	25.0
Applied	3.7	11.3	16.9	20.3

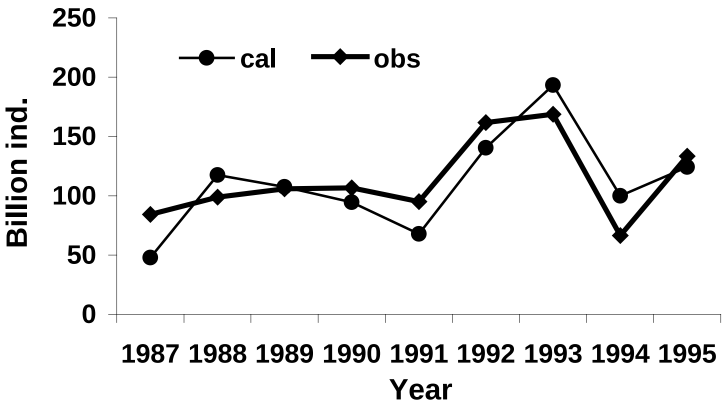

Figure 1. Number of 2 years old anchovies measured (obs), compared to back-calculated (cal) number from measured 3 years old the subsequent year. The 1991 figure is back calculated from the corresponding 4 years old (see Table 2).

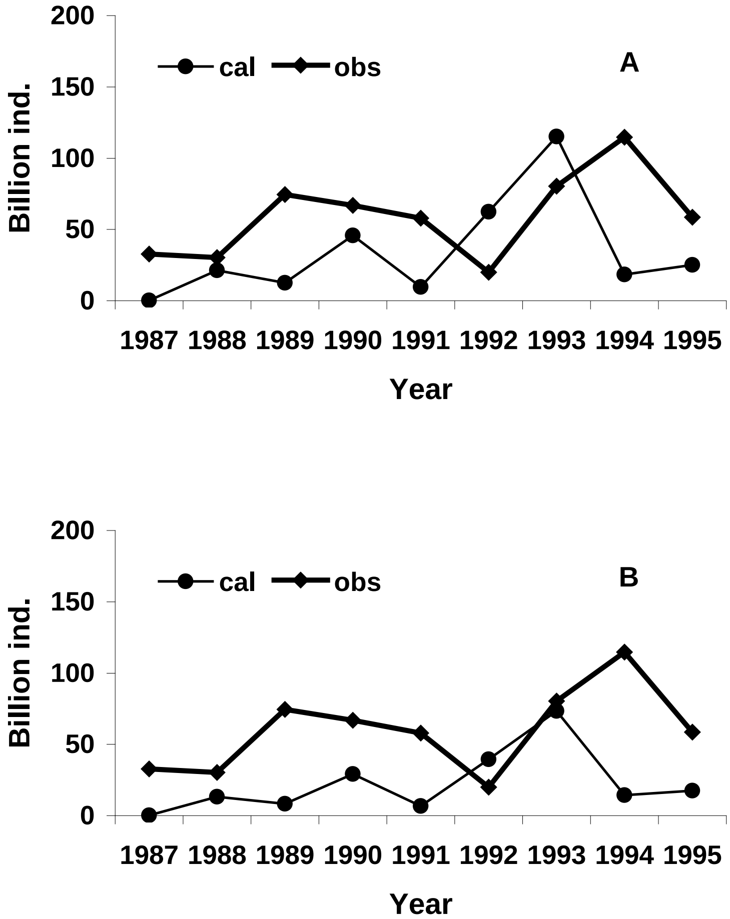

Figure 2. Measured (obs) number of 3-year-old anchovy versus that of back-calculated (cal) from the measured 4-year-old in the subsequent year. A: with M_3 calculated from the 1987-1995, except the 1991 data; B: assuming that M_3=M_2.

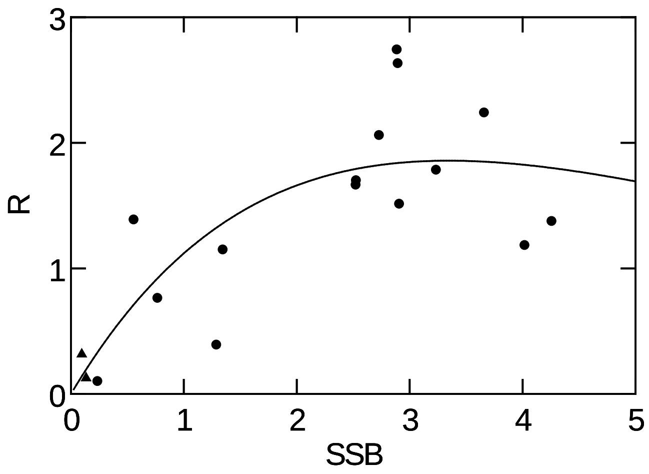

Figure 3. Recruits (R) in 100 billion individuals versus spawning stock size (SSB) in million tons. Solid curve is the estimated Ricker stock-recruitment curve based on the data from 1987 to 2002 (redraw from Zhao et al.,2003) Triangle denote the data points for 2003 and 2004.

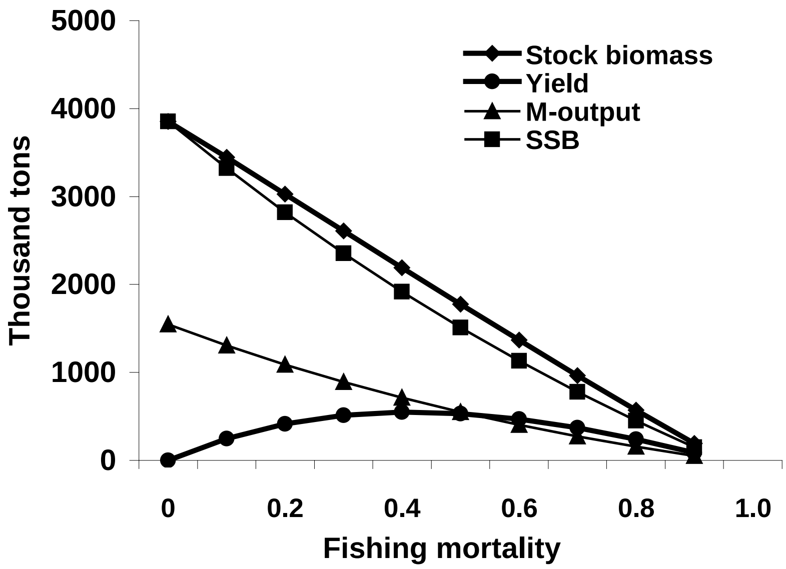

Figure 4. Sustainable yield, M-output, wintering stock biomass and the corresponding spawning stock biomass (SSB) of anchovy versus fishing mortality.

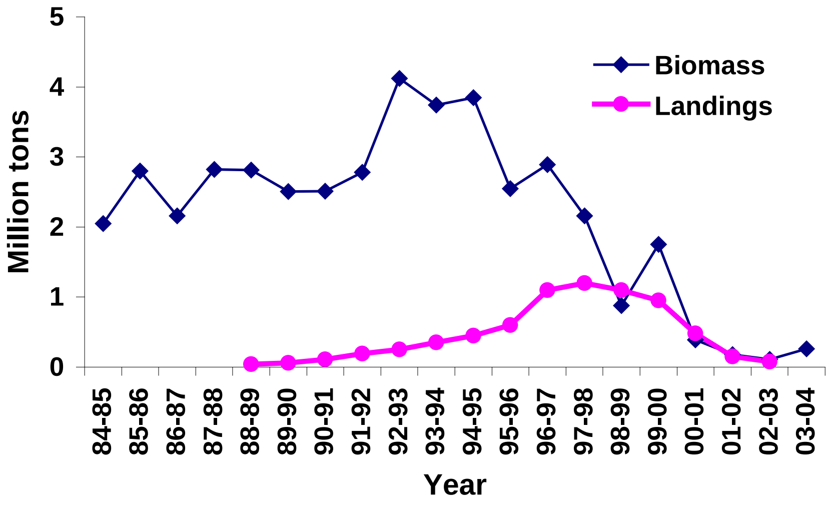

Figure 5. Measured stock biomass and yearly catches. See text for the calculation of the 1996/97 and the 1997/98 stock biomass.

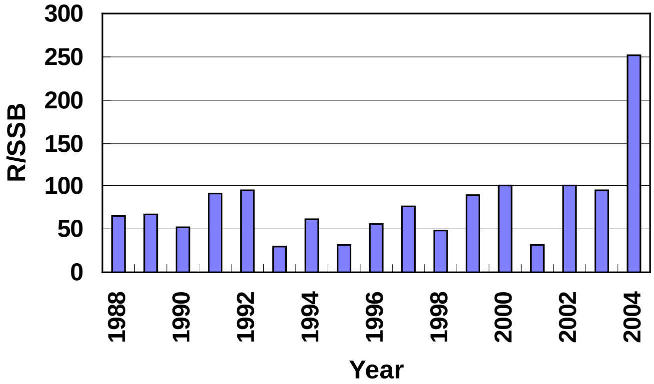

Figure 6. The relative recruitment (R/SSB, billion fish per million ton of spawning biomass). For the 2004 data, the measured instead of back-calculated number of recruits was used.