Report on assessment and management advice for 2005 of the anchovy fishery in the Yellow Sea

The Bei Dou Fisheries Research and Management Project (CHN 025) 2001-2005
Institute of Marine Research, Bergen, May 19-24, 2005

INTRODUCTION

According to the Project Document for the "Bei Dou Fisheries Research and Management Project 2001-2005"and the Work Plan for 2005, a small workshop was arranged in the period May 19-24, 2005 at the Institute of Marine Research (IMR), Bergen. The workshop was arranged within the sub project "10023-5 Assessment of Anchovy Stock (TAC)" to evaluate the present state of the anchovy stock and advising on a TAC for 2005. 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 November 1998, November 1999, March 2001 and April 2002, and workshop reports are available at both IMR and YSFRI (Anon. 1998, 1999, 2001, 2002). The workshop for 2003 was cancelled due to the SARs epidemics in China. The workshop for 2004 was held in Bergen, with data obtained from both 2002/2003 and 2003/2004 (Anon. 2004). The present assessment is an updated version of the 2004 workshop report, with new data obtained from the winter survey of 2004/2005.

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 2005, 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 on 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). The survey area is shown in Fig. 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:

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

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:

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

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:

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

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 (Anon., 2002), 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:

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

where the stock number $\mathbf{N_t}$ was calculated using an iteration procedure according to established stock-recruitment relationship. The corresponding output biomasses of the stock were obtained by multiplying the number by the mean weight by age and summarizing over 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 2003-2005 was not used for population parameter estimates. Instead, the parameter estimates from Zhao *et al.* (2003) are reported here, with the present status of the anchovy stock and catch updated according to the new data obtained. The stock number at age and mean weight at age for the year from 1987 up to 2005 are shown in Table 2.

RESULTS AND DISCUSSIONS

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 catches were subtracted by converting the total catch to catch in number by age using the age composition in the stock from the survey data. 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. 2.

Figure 2 shows that the survey data for 2-group and 3-group are consistent and indicates that the estimated M_2 is fairly accurate. The correspondingly calculated M_1 of 0.09 is however unrealistic (Table 3) and is probably caused by the incomplete coverage of the 1-year-old by 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 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.

Stock-recruitment relationship

As in previous reports, 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 and during the spawning season was not subtracted assuming that this loss would be compensated 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 with the new data points added (2003 to 2005). The stock-recruitment curve is as follow (Zhao *et al.*, 2003):

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

where R_1 is the 1-year-old recruits in billion individuals and SSB in million tons.

The model indicates that the maximum recruitment of the anchovy stock in the Yellow Sea (top of the curve) is about 180 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.

The data points of 2003-2005 in Fig. 3 indicate 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 may not recover unless the fishing mortality is drastically reduced.

Figure 4 shows the recruitment trend of the anchovy stock in the Yellow Sea. As expected from Fig. 3, the absolute recruitment went down as the stock decreased. The reproductive rate however remained stable in general and kept at relative high level in the last three years. This might have saved the stock from further decline since 2002.

Sustainable yield and M-output

Figure 5 shows the sustainable yield, M-output and the corresponding stock biomass 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. 5. In the virgin state of stock (F=0), the M-output is estimated to about 1.5 million tons, which clearly demonstrate that anchovy is a very important prey species in the area and that a stock collapse may have serious impact on the food supply for other commercial important stocks in this ecosystem.

State of stock and fishery

The development of stock (measured) and fishery is shown in Fig. 6, and the development of the total mortality is shown in Fig. 7. In the last three years an additional catch of anchovy has been landed from the East China Sea and east of the survey area in the Yellow Sea.

Figure 6 confirms the conclusion drawn in previous year's report. When the catches approach the level of 0.5 million tonnes, the stock is reduced to about 2 million tonnes, and is depleted when the yearly catches result in F-values above F_{max} (catches > 0.55 million tonnes). The stock in 2001-2002 was fished down to some 5% of the estimated virgin stock (3.5 mill. tonnes), and has remained at low level in later years yielding catches of less than 100,000 tonnes a year. It should be noted that this development of stock and yield is in accordance with the prediction made by the workshop in 2001 (Anon 2001).

Fishery management and advices

A work shop for giving scientific management advice for 2000 (Anon., 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 workshop concluded that since 1996 the catches had been far above the 500 000 tonnes level and warned that if the high fishing effort was carried on in the following years the risk for stock collapse would be high.

So far no direct restriction has been placed on the anchovy fishery and the stock is reduced to a level below 400,000 tonnes. Since 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 present level (about 100 thousand tons). 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 the workshop therefore recommends to ban the direct anchovy fishery in the Yellow Sea until the spawning stock has recovered above 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 1987-2005. Since 2002, the 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	0.08
2005	0.33	

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 1999-2005 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
2005	16.42	9.03	5.42	0.41	5.9	12.7	19.6	26.2
Sum	**1572.8**							

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

Age / Mortality	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 Zhao *et al*. (2003) for the calculation of the 1997 and the 1998 data. The number of 1-year-old fish in 2005 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	23.7	10.4	2.8	
2005	16.4			
Sum	**2171.1**			

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

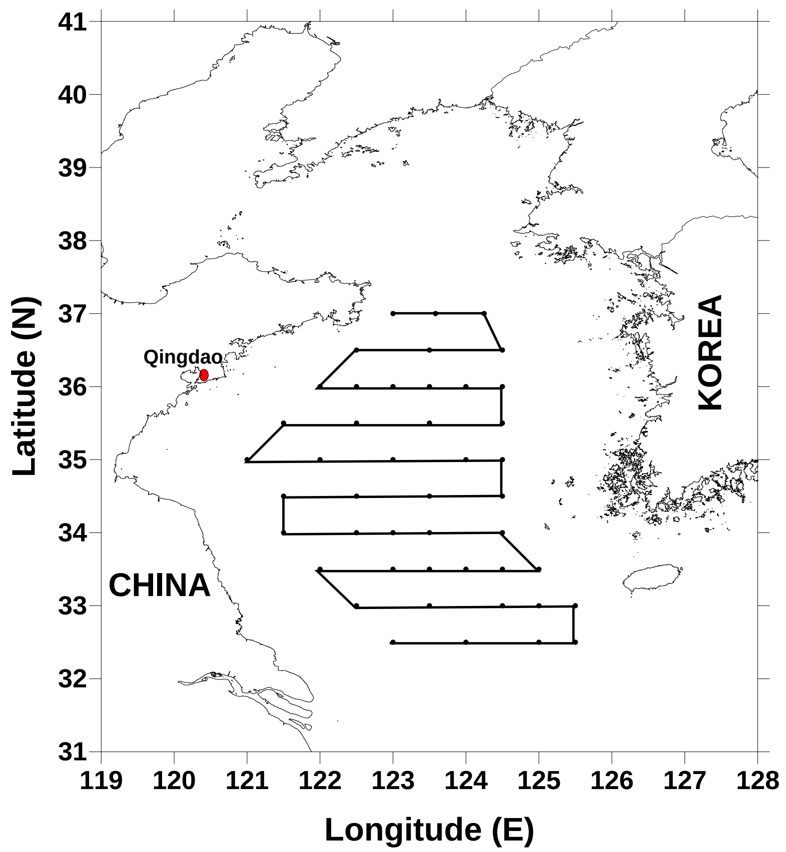

Figure 1. The survey track line and sampling stations of the winter acoustic survey in the Yellow Sea.

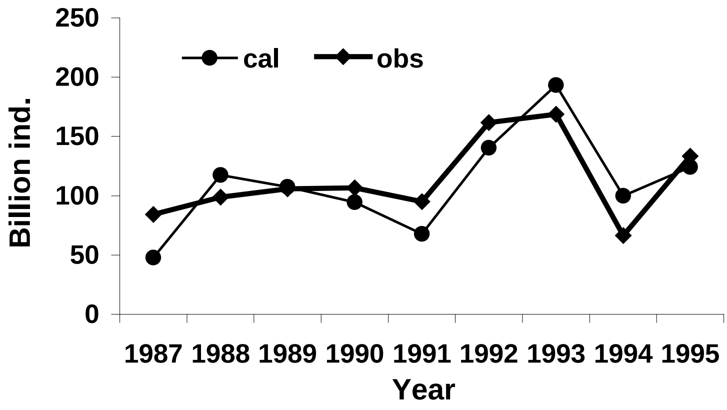

Figure 2. Number of 2 years old anchovies measured (obs), compared to back-calculated (cal) number from measured 3 years old the subsequent year. The 1991 figure is back calculated from the corresponding 4 years old (see Table 2).

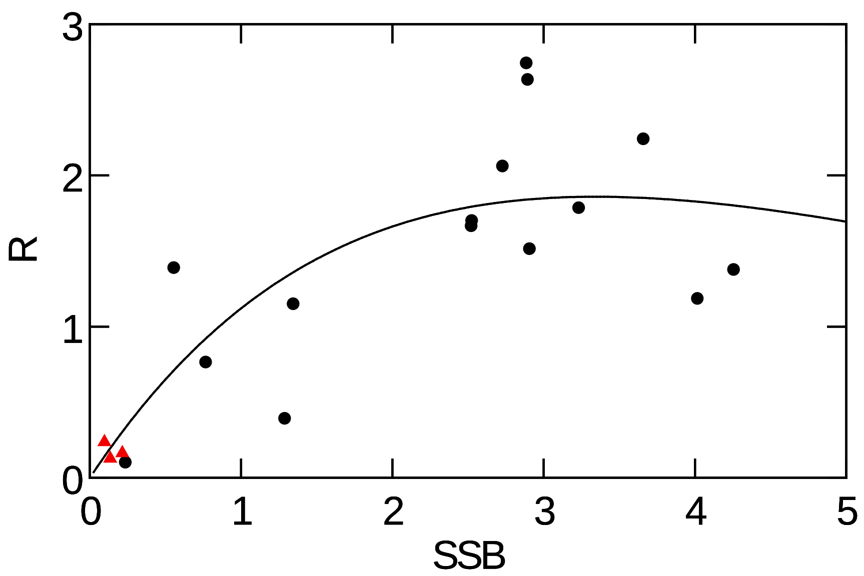

Figure 3. Recruits (R) in 100 billion individuals versus spawning stock size (SSB) in million tons. Solid curve is the estimated Ricker stock-recruitment curve based on the data from 1987 to 2002 (redraw from Zhao et al.,2003) Triangle denote the data points for 2003 through 2005.

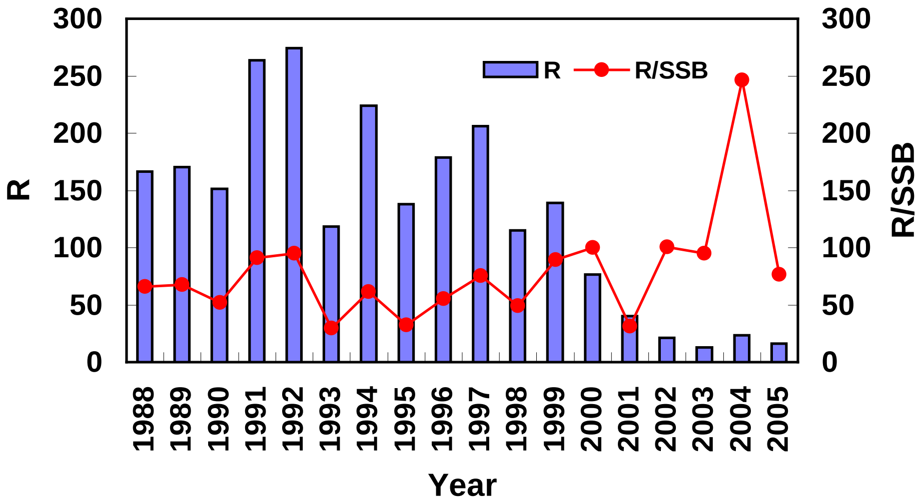

Figure 4. Development of the absolute recruitment (R in billion fish) and the reproductive rate (R/SSB, billion fish per million ton of spawning biomass). For the 2005 data, the measured instead of back-calculated number of recruits was used.

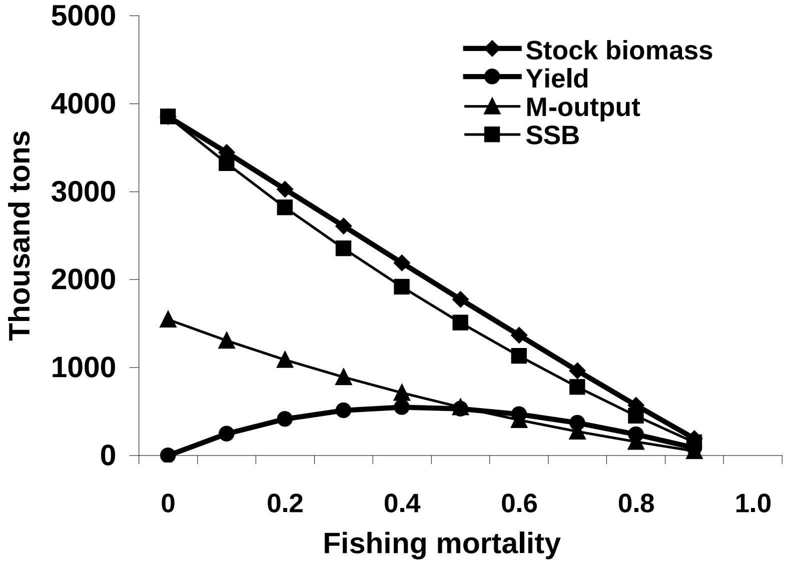

Figure 5. Sustainable yield, M-output, wintering stock biomass and the corresponding spawning stock biomass (SSB) of anchovy versus fishing mortality.

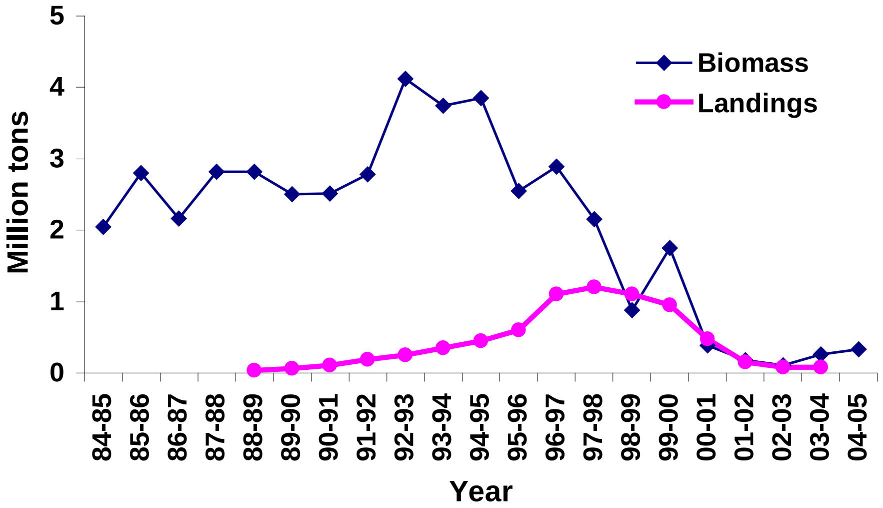

Figure 6. Measured stock biomass and yearly catches. See Zhao *et al.* (2003) for the calculation of the 1996/97 and the 1997/98 stock biomass.

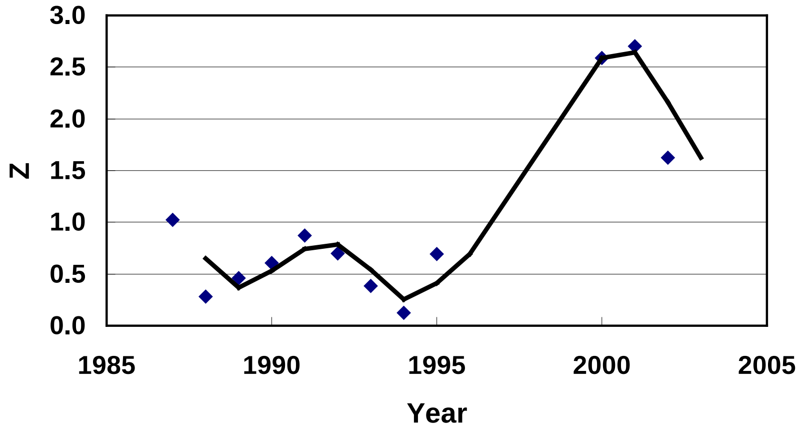

Figure 7. The total mortality rate (Z) of the 2 years old anchovy based on acoustic estimates in the winter acoustic surveys. The running-average smoothed trend line (Excel model) shows a dramatic increase in the total mortality after 1995.