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Once More on the Stock-recruitment Relationship as one of the Factors Determining the Abundance Dynamics and Fisheries Management Strategy for Some Commercial Fish Species in NAFO Area

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Abstract

The stock-recruitment relationship (SRR) was researched in 13 stock units of commercial fishes in NAFO area, and for this purpose the retrospective estimates of recruitment abundance and spawning biomass were used. The results obtained were analyzed in view of the interpretation of the above said relationship as one of the factors determining the abundance dynamics and fisheries management strategy for commercial fish populations. The effect of SRR was most evidence in 8 populations (3Ps cod, 5Ze, 5Zw+6 silver hake, 5Ze red hake, 2+3 Greenland halibut, 3LNO yellowtail flounder, 3LNO American plaice and 3-6 Atlantic mackerel).

Certainly, the environment factors affected recruitment abundance formation to different extent in all cases. The results of the study allowed proposing some general recommendations on the ways of the researched stock unit's management. The probable mechanism of SRR effect in the periods when the spawning biomass considerably differed from the optimal level was considered and within the discussion the opinion was expressed concerning further development of the precautionary approach strategy.

Introduction

The current fisheries management based on the precautionary approach (PA) strategy makes high demands of the precision level of the spawning biomass (SSB) and recruitment estimates stipulated by the need to estimate such biological reference points as B_{lim}, B_{buf}, B_{tr}, the latest estimates of which are presented in Barkova *et al.* (2003). Earlier I have made an attempt to analyze the extent of the spawning biomass and recruitment data correspondence in 11 stock units of commercial fishes in the Northwestern Atlantic Ocean with the curves described by equations by Ricker, Beverton and Holt, Cushing and Chapman (Rikhter, 1990). However, the correlation between observed and estimated recruitment values appeared significant only in three stocks. In the rest stocks the estimated curves remained purely theoretical being far from the actual data. The points scatter caused apparently by the environment factors impact on the fish survival at the early stages of development (eggs, larvae, young-of-the-year) was rather considerable in all cases. In general the results obtained were of little use in preparation of scientific advice on the fisheries management.

In this work the attempt is made to obtain more definite evidences of the required relationship existence in order to approach solving the problem of SSB levels being optimal to the formation of strong year-classes of the stock units considered and to outline the ways of fisheries management taking into account the stocks abundance dynamics.

Materials and Methods

The subject of study became 13 stock units from NAFO Subdivisions 2-6. The recruitment data (abundance of the first age group, represented in the analytic estimates), spawning biomass (SSB) and total biomass (TB) were obtained from the following sources:

Species	NAFO Subareas, Divisions and Subdivisions	Information source
Cod	2J+3KL	Baird and Bishop, 1986
Cod	3NO	Healey *et al*., 2003
Cod	3Ps	Bishop and Baird, 1985
Silver hake	4VWX	Showell, 1997
Silver hake	5Ze	Almeida and Anderson, 1979a
Silver hake	5Zw+6	Almeida and Anderson, 1979b
Red hake	5Ze	Almeida et al., 1979a
Red hake	5Zw+6	Almeida *et al*., 1979b
Greenland halibut	2+3	Darby *et al*., 2003
Yellowtail flounder	3LNO	Brodie, 1985a
American plaice	3LNO	Brodie, 1985b
Beaked redfish	3M	Avila de Melo *et al*., 2003
Atlantic mackerel	3-6	Isakov *et al*., 1976

This time another simplified approach has been selected to analyze the stock-recruitment relationship (SRR) not requiring the above equations application. SSB value by years was compared to the respective year-classes abundance. Then the years were chosen when strong year-classes appeared. Deviation from the long-term average level exceeding 20% was used as a criterion, and further the mean abundance of these year-classes and respective spawning biomass (SSB_{opt}) were estimated. In the same way the mean values of high biomass (SSB_{high}) were obtained. The above said data were used to estimate relationships between SSB_{opt}, SSB_{high} and TB. In most cases the size of the spawning stock was estimated as the sum of age groups biomasses starting from the specified age:

Species	Subareas, Divisions and Subdivisions NAFO	Age
Cod	2J+3KL	7+
Cod	3NO, 3Ps	6+
Silver hake	4VWX, 5Ze, 5Zw+6	2+
Red hake	5Ze, 5Zw+6	2+
Greenland halibut	2+3	10+
Yellowtail flounder	3LNO	7+
American plaice	3LNO	8+
Beaked redfish	3M	Estimated from maturity ogive
Atlantic mackerel	3-6	Estimated from maturity ogive

It should be noted that recruitment and biomass estimates obtained from the above sources have been interpreted as the relative indices reflecting the dynamics of the stocks considered sufficiently closely. This was made taking into account the fact that operating with absolute values the reliability of which is often doubtful (some estimated were made 15-20 years ago and should be revised applying the advanced tuning methods, while others have been corrected, sometimes very seriously, actually every year), is hardly reasonable and may result in erroneous conclusions.

Results of Researches

The pattern of curves of biomass-recruits relationship shown in Fig.1-13 is very hard to interpret. Almost each case can be explained individually. Nevertheless, some general conclusions seem possible. Thus, one common feature is observed in 3Ps cod, 5Ze and 5Zw+6 silver hake, 5Ze red hake, 2+3 Greenland halibut, 3LNO yellowtail flounder, 3LNO American plaice and 3-6 Atlantic mackerel (Fig. 3, 5, 6, 7, 9, 10, 11, 13), i.e. during the period considered strong year-classes appeared, as a rule, in the years when SSB was notably below the maximum level. A horizontal line in the figures indicates the average value of SSB_{opt}. At the same time in 2J3KL cod (Fig.1) the apparent positive relationship is traced between recruits abundance and the spawning biomass. It is hardly possible to reveal any optimal level of SSB in 4VWX silver hake, 5Zw+6 red hake, 3NO cod and 3M beaked redfish (Fig. 2, 4, 8, 12). However, some doubts may exist in the case of beaked redfish because the observation series does not cover the initial period of this species fishery (the late-1950s to early-1960s), when its biomass seems to be at the highest level.

Judging from the figures, the periods of different duration, when the effect of the direct relationship between recruitment and spawning biomass was evident, appeared almost in all stock units.

Now we proceed from the qualitative to quantitative estimates, initially determining the years of the strongest year-classes and high SSB (Table 1) for the stock units considered.

As can be seen from the data presented, in most cases the correspondence between the years selected was only partial (to the more or less extent), and was not observed at all for yellowtail flounder and American plaice. Then the data on SSB and TB in the years, listed in Table 1, were used to estimate the mean values (Table 2). The data from this Table need not be commented, since they are intermediate and are intended to determine the relationships presented in Table 3.

The data obtained confirm the preliminary observation concerning 8 stock units, where SSB_{opt} was considerably lower than SSB_{high} (by 36.7% on average, and more than by 50% in flatfishes). At the same time SSB_{opt} and SSB_{high} were actually similar in Div. 2J+3KL cod and Div. 3NO cod. As regards the correlation between SSB and TB, the proportion of spawning biomasses of the stock units considered, as expected, varied depending on the age of maturity (life span), and SSB_{op}t proportion for these stocks appeared lower than that of SSB_{high}. This allow to conclude that the highest spawning biomass proportion of the total biomass for the whole observation period is not always the reference point taken as the guideline in developing measures for the stock recovery.

Discussion

The results of researches presented in the form of figures allows to assume the strong impact of environment factors on the year-classes abundance formation in the most species considered in couple with the effect of stock-recruitment relationship became apparent to different extent in different populations. Sometimes fishery might distinctly affect the stock dynamics. Frequently all these factors act simultaneously.

Let us begin discussion with Div. 2J+3KL cod. The pattern of the curves in Fig. 1 suggests that almost direct relationship between recruits abundance and SSB, and the results of the previous researches confirm this (Rikhter, 1990). This means that SSB reduction as a result of high fishing mortality, on the contrary, the increase after a sharp reduction of exploitation rate (Baird and Bishop, 1986) has to affect respectively the recruitment dynamics. However, in some years extremely unfavorable conditions to young fish survival may occur, and in such case poor year-classes will appear even at relatively high SSB level and relatively low fishery pressure. It is likely that in particular this was the reason of the cod stock collapse in the early-1990s (Bishop *et al*., 1994). The above considerations evidence that super-favorable environment conditions for juvenile fish survival and hence formation of at least one strong year-class are the necessary conditions of the stock recovery. Otherwise, the process of recovery will extend to a long period even if the fishery is ceased and this is actually observed in practice. Exactly this conclusion was made by Canadian scientists (Lilly *et al*., 2003). And it seems that the reasons are very specific, other than any abstract period of low productivity, i.e. extremely low current SSB and the absence (until now) of necessary environment conditions for strong year-class formation in Div. 2J+3KL. The above considerations are probable true for cod in Div. 3NO also.

As regards management of these stocks fishing, in the years of depression the only recommendation could be the ban of specialized fishery followed by expectation for strong year-classes appearance. During periods of high abundance the maintenance of these stocks spawning biomass at the maximum high level evidently being the target from the precautionary approach (PA) point of view. Such reference points as B_{buf} and B_{lim} are hardly applicable to the populations with above said stock-recruitment relationship.

Silver hake in Div. 4VWX is the illustrative example of the case when the abundance within the observed SSB range was determined mainly by the environment factors without any evidences of SRR impact (Rikhter *et al*., 2001). The results of this study, not contradicting this conclusion, nevertheless allow assuming that SSB_{opt} in this case is slightly lower than SSB_{high}. However, it seems impossible to estimate reliably any limiting reference points here. This stock management should above all take into account the environment factors, affecting year-classes abundance, and should regulate the exploitation rate in compliance with the trends in respective population abundance dynamics.

In 8 stock units (3Ps cod, 5Ze and 5Zw+6 silver hake, 5Ze red hake, 2+3 Greenland halibut, 3NO yellowtail flounder, 3LNO American plaice and 3-6 Atlantic mackerel) with considerably lower SSB_{opt} level as compared to SSBhigh, the effect of stock-recruitment relationship undoubtedly existed and was the most distinct in two flatfish species. However, even in this case the role of environment factors in year-class abundance formation should not be underestimated. For the stocks group considered SSB_{opt} level may be assumed as the target biomass and it seems possible to estimate approximately the limits of B_{lim} and B_{buf}.

In addition, the results obtained allow to assume that considerable exceeding of the spawning biomass optimal level will reduce the ability of the above said 8 populations to produce strong year-classes increasing the risk of so-called low productivity period. From the fishery management point of view, such type of abundance dynamics implies application of right-side limiting reference points for respective stock units, i.e. SSB increase above estimated optimal level is undesirable. The idea of the necessity of B_{lim} upper limit estimation in the cases when the pronounced SRR of Ricker's type is available, has been expresses in 1998 (Rikhter, 1998). Later on the same thought appeared in the paper considering the application of precautionary approach in pelagic fishery management in the Central-Eastern Atlantic Ocean (Barkova *et al*., 2003).

Evidently that in the terms of stocks collapse this supplement to PA strategy is of theoretic importance only. However, as the history of researches and fishery shows anything may happen on the long-term basis: depressions are replaced with abundance growth; stocks recover and sometimes even approach the level when some reduction of the spawning biomass is required.

Undoubtedly, for scientifically grounded fishery management the periods when SSB considerably deviates from the optimal level to any side and, as is assumed, there is the direct relationship between recruitment and the spawning biomass exists, and are of great interest. Now we consider briefly probable mechanism of the above said relationship effect. As a rule, following the depression period the process of the stock recovery begins, and the first in this cycle relatively strong year-class appearance is likely to become the start of this process. After several years SSB increases and SRR begins to act towards further stock growth until it reaches the optimal level. Certainly, to provide further recovery of the stock the environment conditions should not be too bad for young fish surviving at the first year of their life. In its turn, the stock depression seems to begin with the first poor year class appearance. The spawning biomass decreases below the optimal level and then the mechanism of the stock-recruitment relationship is switched on. During this period the environment conditions do not promote a strong year-class formation. It is evident that we could not speak about any SRR manifestation in pure form.

Within the discussion on PA advantages and disadvantages (Shelton *et al*., 2003) a certain restriction should be noted of the latter interpretation as a tool intended to regulate fishery on the basis of biologic and fishery reference points estimated sometimes formally without any profound scientific background. The attempts to determine at any price the limits of reference points for each stock unit, divert scientists from the deep study of populations abundance dynamics determined by both general and specific for each of them factors (abiotic and biotic). The relationship between recruitment and the spawning stock size is only one of them and not always the key one.

It is quite evident that the necessity to include ecosystem elements into the fishery management is the challenge of the times. It is hardly necessary to search for any alternative to the precautionary approach. However, the efforts should be made to turn the latter into the universal fishery management tool, based on the knowledge of the true trend of fish population abundance dynamics. Such strategy may be, for example, defined as the ecosystem-based precautionary approach (EBPA).

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TABLE 1. Years of strong year-classes and high spawning biomass in 13 unit stocks of commercial fishes in NAFO area.

Stock units	Strong year classes	High biomass
2J+3KL cod	1962-67	1962-68
3NO cod	1959, 1961, 1962-66	1959, 1961, 1963-68, 1971-72, 1986
3Ps cod	1962-64, 1978, 1980-81	1959-64, 1970
4VWX silver hake	1981, 1983, 1985, 1995	1983-85
5Ze silver hake	1959-63	1961-65
5Zw+6 silver hake	1961-64	1963-67
5Ze red hake	1968-69, 1974	1971-72
5Zw+6 red hake	1968-69, 1970	1969, 1971-72
2+3 Greenland halibut	1983-86, 1993-95	1987-94
3LNO yellowtail flounder	1968-69, 1977-78, 1980	1970-72, 1984
3LNO American plaice	1974-76, 1970-71	1964-68, 1983-84
3M beaked redfish	1989-90, 1998	1989-92
3-6 Atlantic mackerel	1968-69, 1973	1969-72

TABLE 2. Mean spawning biomass and total biomass (thous.t) in 13 stock units of commercial fishes in NAFO area.

Stock units	Mean SSB		Mean TB	
	SSB opt	SSBhigh	TB corresponding SSBopt	TB corresponding SSBhigh
2J+3KL cod	865	841	1912	1846
3NO cod	115	114	242	245
3Ps cod	77	107	145	186
4VWX silver hake	163	203	205	251
5Ze silver hake	325	476	484	639
5Zw+6 silver hake	201	294	304	372
5Ze red hake	52	78	73	85
5Zw+6 red hake	101	116	124	134
2+3 Greenland halibut	31	73	128	170
3LNO yellowtail flounder	10	20	69	88
3LNO American plaice	156	331	242	391
3M beaked redfish	69	73	223	227
3-6 Atlantic mackerel	982	1375	2020	2123

TABLE 3. Spawning and total biomass ratio in 13 stock units of commercial fishes in NAFO area.

Stock unit	SSBopt/SSBhigh	SSB/TB	
		SSBopt	SSBhigh
2J+3KL cod	1.028	0.453	0.454
3NO cod	1.008	0.475	0.465
3Ps cod	0.720	0/531	0.575
4VWX silver hake	0.803	0.795	0.809
5Ze silver hake	0.683	0.671	0.745
5Zw+6 silver hake	0.684	0.661	0.790
5Ze red hake	0.667	0.712	0.918
5Zw+6 red hake	0.871	0.814	0.866
2+3 Greenland halibut	0.653	0.242	0.262
3LNO yellowtail flounder	0.475	0.139	0.231
3LNO American plaice	0.471	0.645	0.846
3M beaked redfish	0.942	0.309	0.461
3-6 Atlantic mackerel	0.714	0.486	0.648

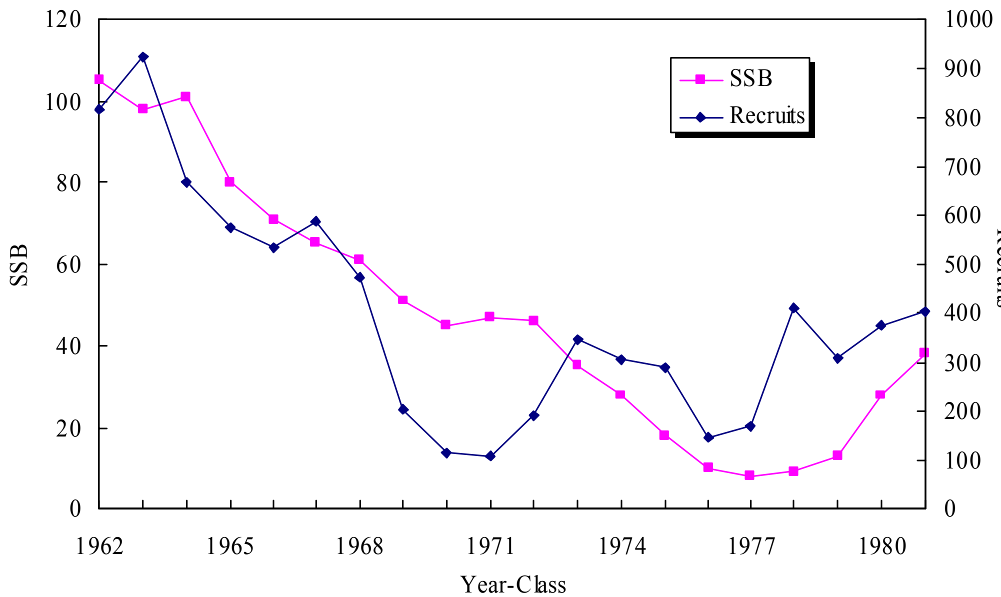

Fig. 1. Dynamics of recruitment and biomass of the spawning stock 2J+3KL cod in 1962-1981.

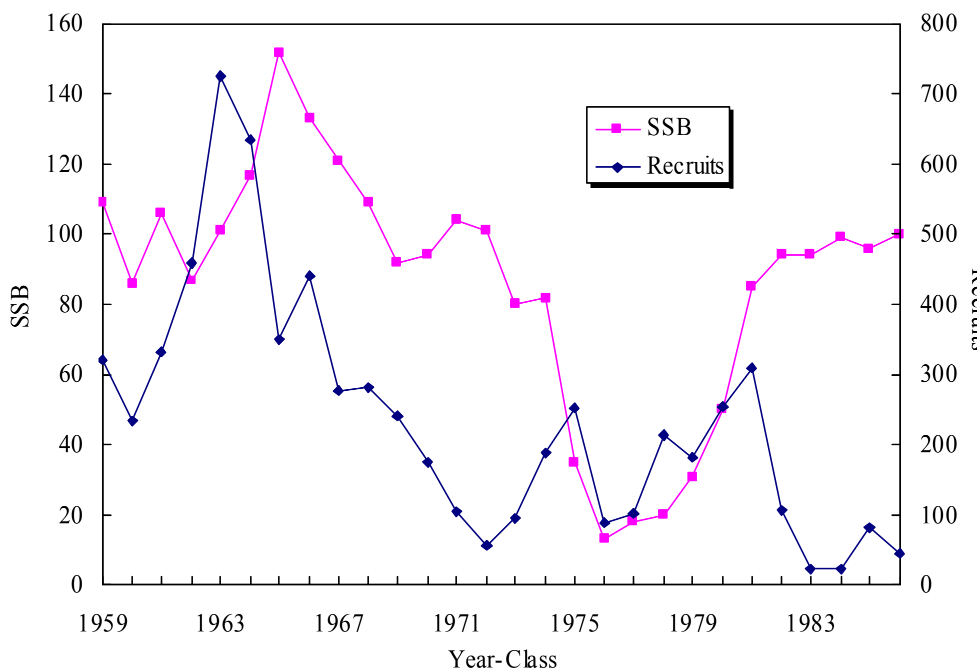

Fig. 2. Dynamics of recruitment and biomass of the spawning stock 3NO cod in 1959-1986.

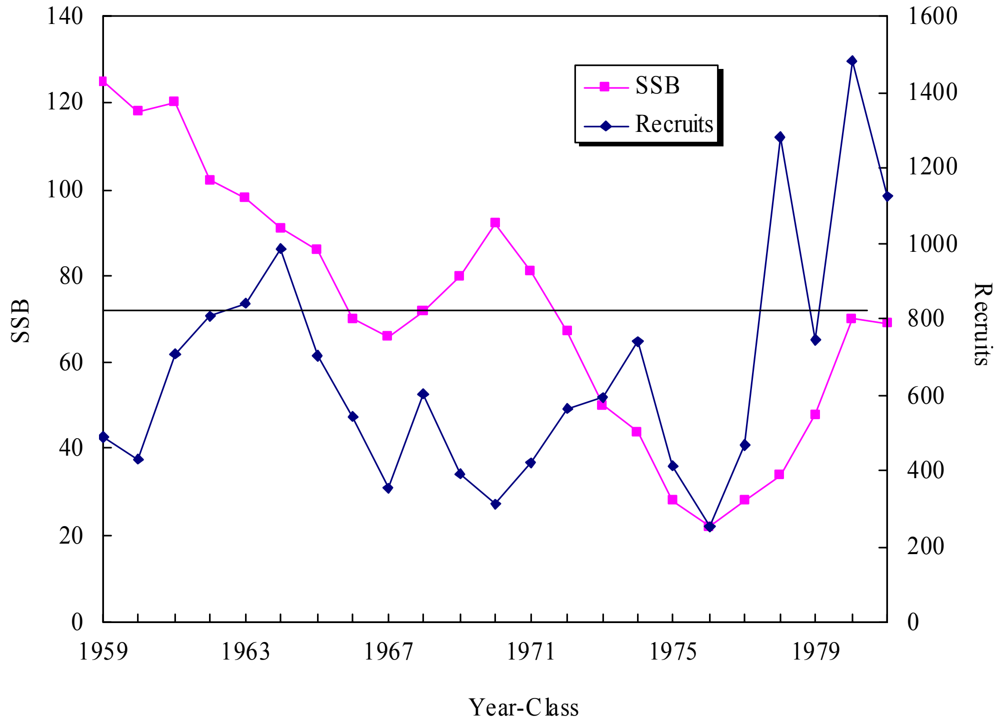

Fig. 3. Dynamics of recruitment and biomass of the spawning stock 3Ps cod in 1959-1981.

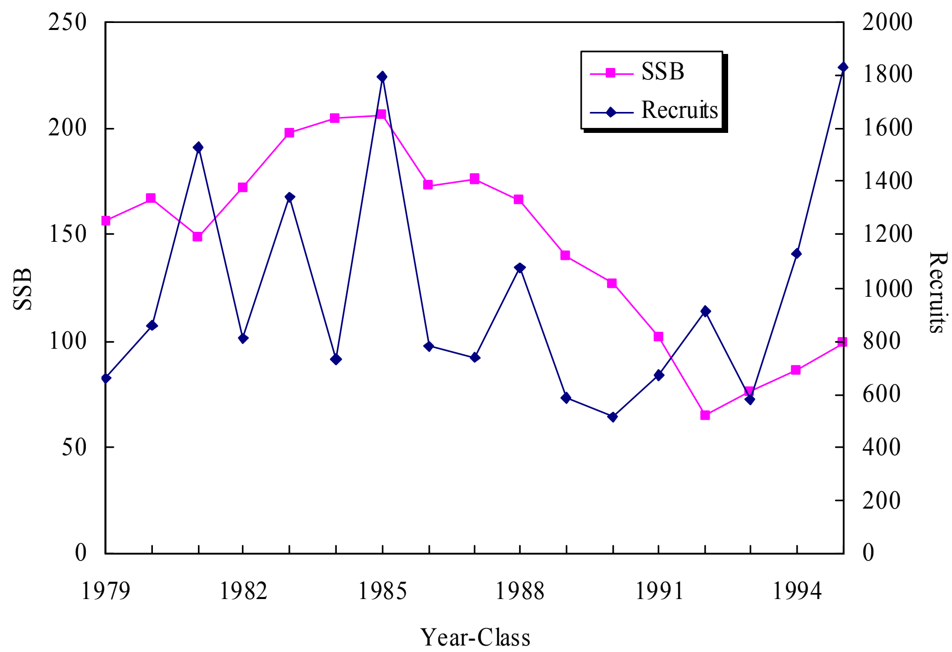

Fig. 4. Dynamics of recruitment and biomass of the spawning stock 4VWX silver hake in 1979-1985.

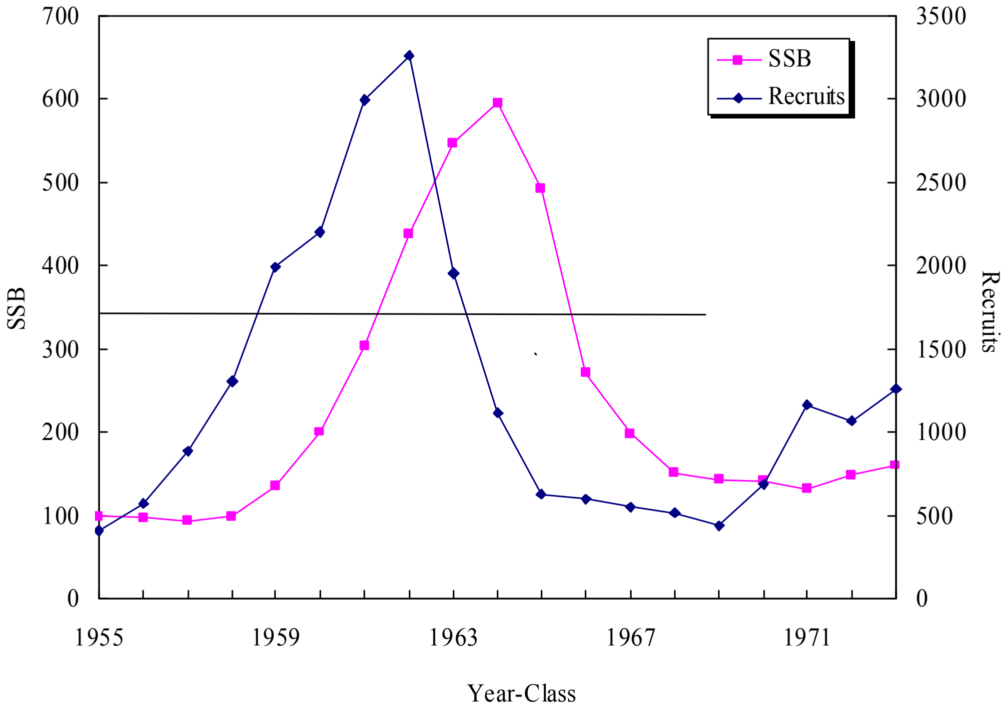

Fig. 5. Dynamics of recruitment and biomass of the spawning stock 5Ze silver hake in 1955-1972.

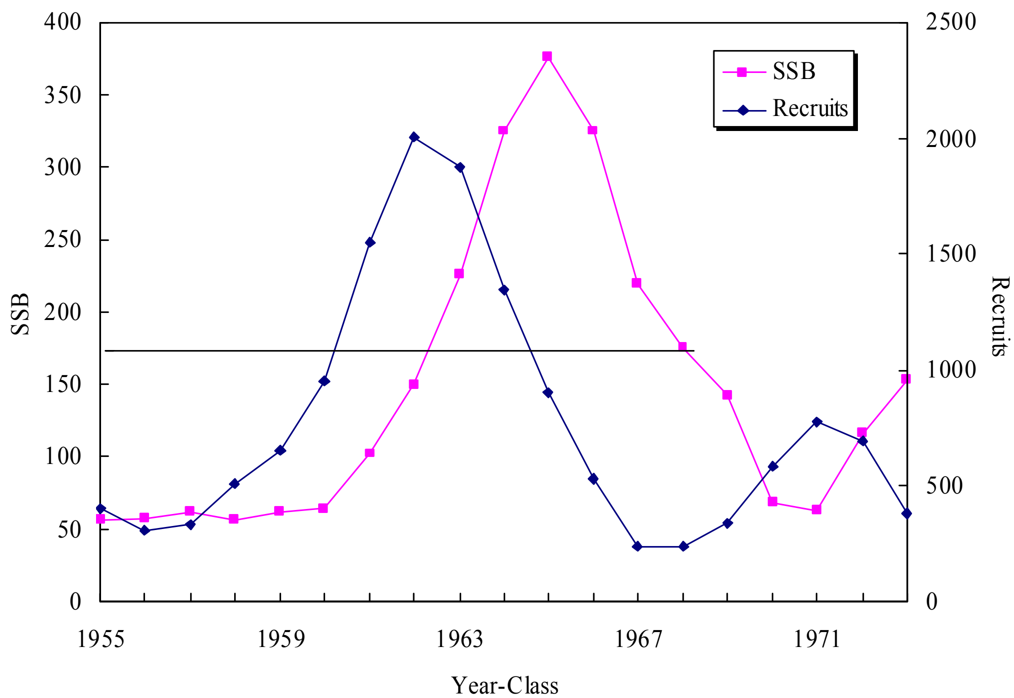

Fig. 6. Dynamics of recruitment and biomass of the spawning stock 5Zw+6 silver hake in 1955-1972.

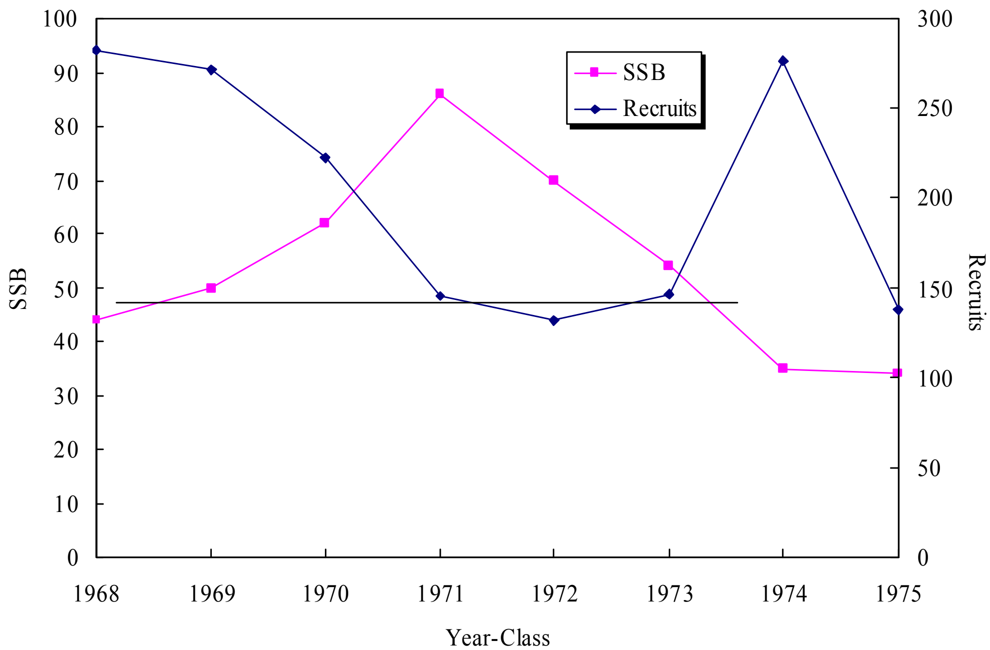

Fig. 7. Dynamics of recruitment and biomass of the spawning stock 5Ze red hake in 1955-1972.

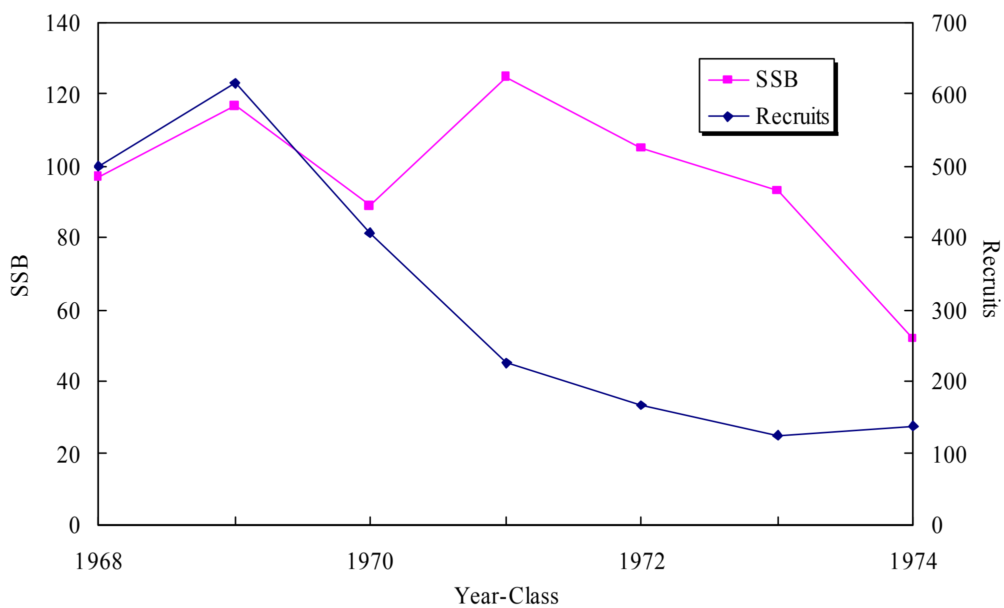

Fig. 8. Dynamics of recruitment and biomass of the spawning stock 5Zw+6 red hake in 1968-1974.

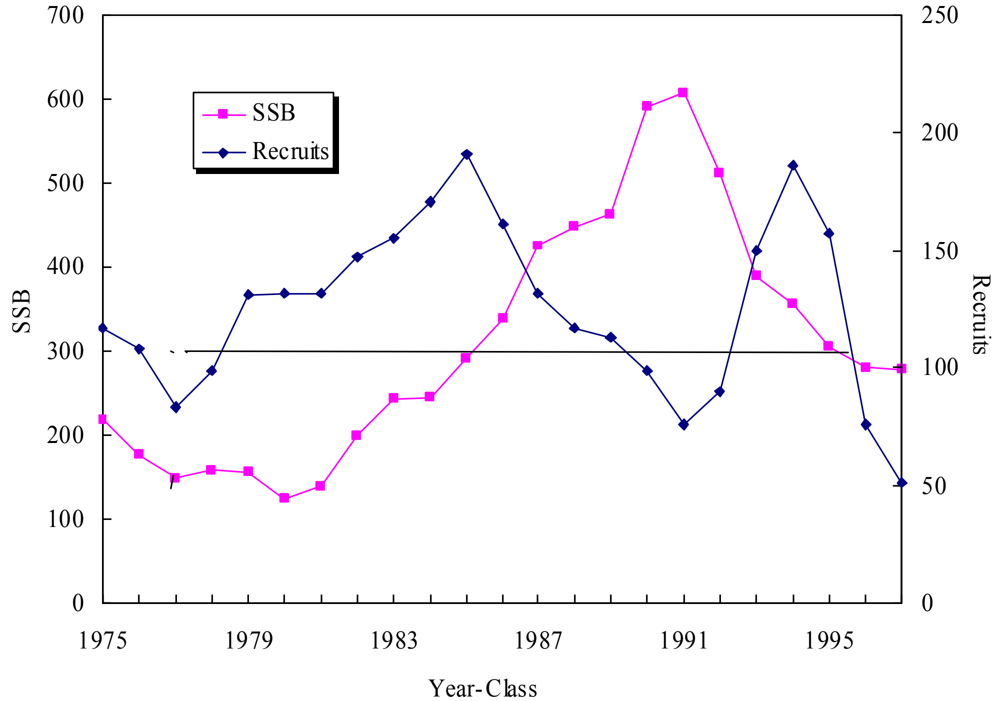

Fig. 9. Dynamics of recruitment and biomass of the spawning stock 2+3 Greenland halibut in 1975-1997.

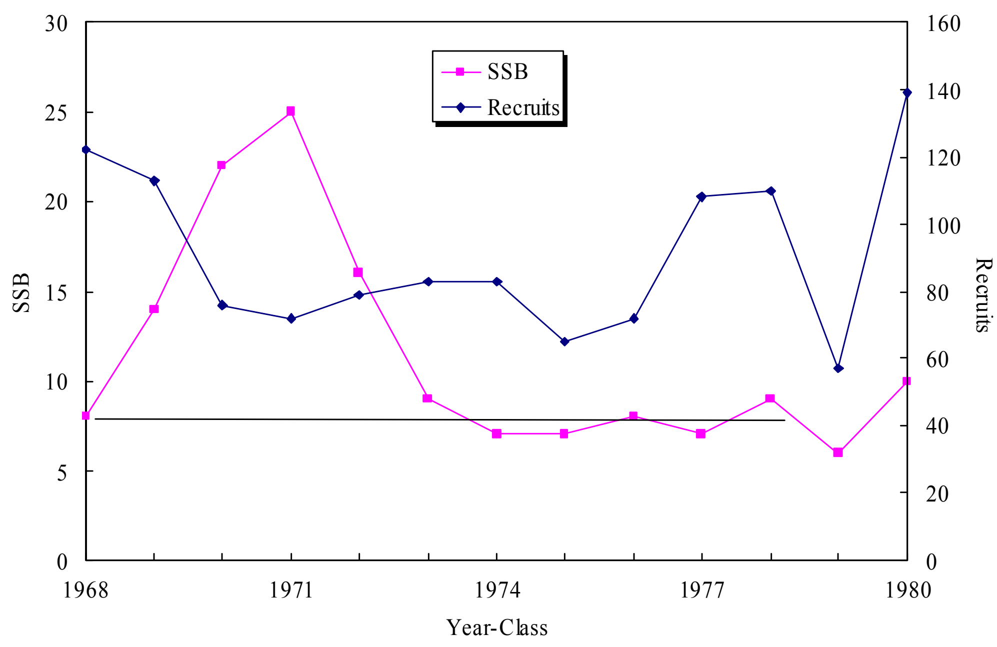

Fig. 10. Dynamics of recruitment and biomass of the spawning stock 3LNO yellowtail flounder in 1968-1980.

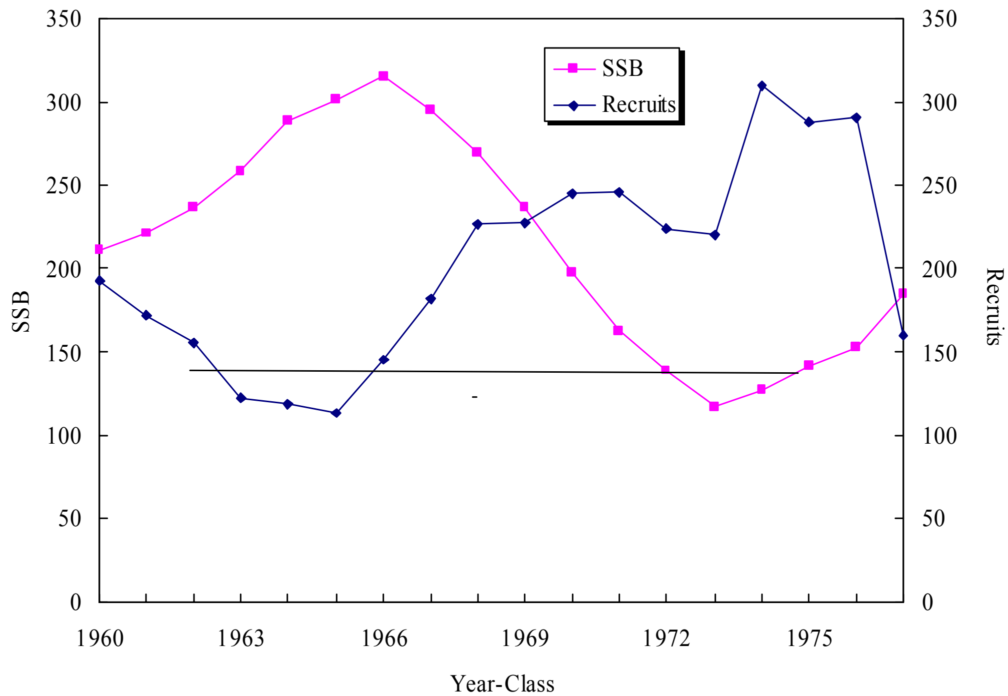

Fig. 11. Dynamics of recruitment and biomass of the spawning stock 3LNO American plaice in 1960-1977.

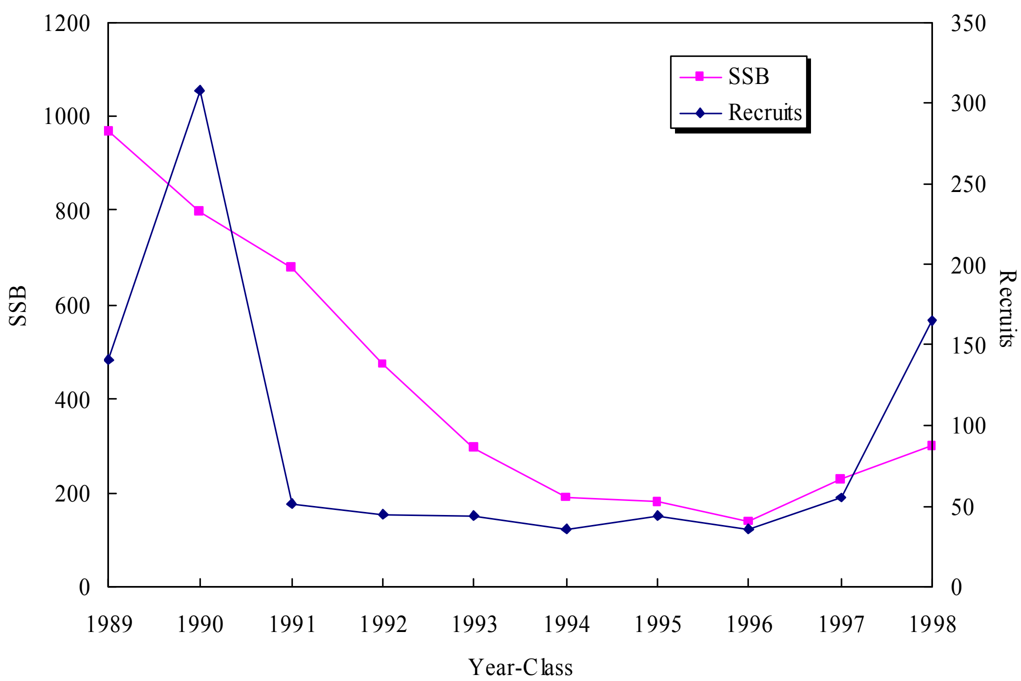

Fig. 12. Dynamics of recruitment and biomass of the spawning stock 3M beaked redfish in 1989-1998.

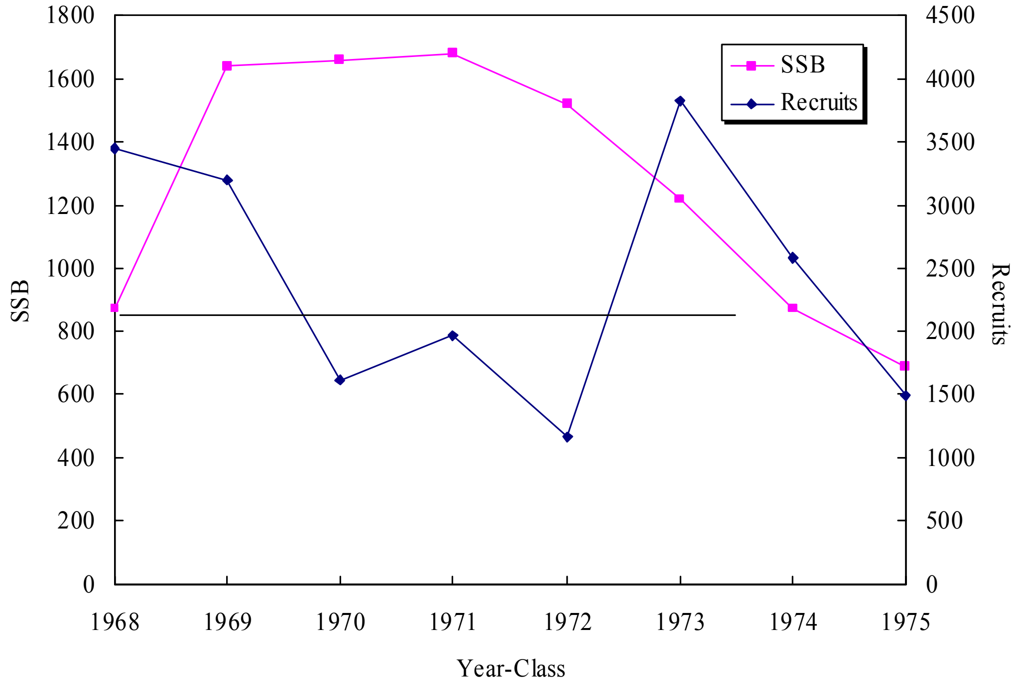

Fig. 13. Dynamics of recruitment and biomass of the spawning stock 3-6 Atlantic mackerel in 1968-1975.