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Status and future of herring and sprat stocks in the Baltic Sea

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Abstract

Spring-spawning herring spawn along the coasts of the entire Baltic Sea, whereas autumn spawners have spawning sites off the shores. The autumn-spawning herring stock has almost disappeared since the early 1970s, whereas there are several spring-spawning herring stocks in the Baltic. Feeding spring-spawning herring of different origin mix in the open areas in summer and autumn. The herring migrate back again during winter for spawning in the following spring.

The main distribution area of sprat is the Baltic Sea proper and Gulf of Finland. Sprat spawn mainly in May-August in the open part of the Baltic proper.

The major tool for stock assessment has since 1977 been the Virtual Population Analysis (VPA). In quantifying the amount of herring and sprat eaten by cod, improved estimates of natural mortality have been used since 1991 in single-species assessments.

The biggest annual catches of herring in the Baltic have been more than 400 000 tonnes and that of sprat over 200 000 tonnes. At the beginning of the 1990s the herring stocks were large especially in the central and northern parts of the Baltic Sea. The size of the sprat stock has increased at the same time.

The load of organochlorine compounds is higher and that of heavy metals at the same level in the Baltic Sea as in the adjacent waters. Despite of the residues in Baltic herring, fish are suitable for human consumption according to the standards used. Increasing levels of harmful substances and the possible diminution of the ozone layer can be a threat to the Baltic herring reproduction in the future.

The combination of a decreasing demand for, and an increasing abundance of Baltic pelagic fishes during recent years has made the need for restrictive management actions less pronounced. This situation will however probably change in the near future when the fleets try to compensate their vanishing income from high-priced cod by catching vast amounts of low-priced pelagic fish.

Keywords: herring, sprat, stock assessment, Baltic Sea, environmental conditions.

Introduction

The Baltic clupeoids herring and sprat have a central position in the Baltic marine/ brackish ecosystem. They constitute the bulk of fish biomass in the Baltic Sea and are important prey items by many predators including man, seal, cod and guillemot; they themselves consume large amounts of planktonic organisms, mysids and amphipods. They accumulate and store in their fat-bodies many foreign substances, some of which are harmful. These substances become transported not only vertically and horizontally by the vast migrations of the fish, but also from the trophic level of herbivorous plankton to the level of fish-eating mammals, birds and fishes.

Because of their important position the Baltic clupeoids have been studied widely. Fish ecologists study how herring and sprat are adapted to the different environmental conditions in the Baltic (in life-history parameters, growth, distribution, migrations), and to what extent populations are reproductively self contained or mixed. Fish stocks (assessment units) are defined according to both biological characteristics and practical aspects such as data availability. Fishery biologists have focused on how to estimate the present numbers and biomass of herring and sprat, and, in order to advise managers, how to predict, based on year-class strengths, future changes in abundance. Physiologists and ecotoxicologists have studied the effects of contaminants and nutrients.

Even though high fishing intensity has resulted in temporary decline of stock sizes in some parts of the Baltic, the recruitment, growth and age structure of herring and sprat stocks are mainly influenced by natural factors. The eutrophication of the coastal areas of the Baltic Sea is a man-made change of the environment with already detectable influence on pelagic fish stocks (see Eutrophication, page 50). Speculation about the consequences of an assumed global warming has also appeared for pelagic fishes in the Baltic (Greenhouse effect, page 51). A question which is of importance for the whole ecosystem is how man is going to apply his increasing capacity and efficiency to exploit the pelagic stocks in the Baltic. This also leads to consideration of whether short-term socio-economic considerations are the basis for management decisions or whether the concept of sustained use of living resources be the main objective of management in the future.

Herring and sprat stocks

Herring stocks

Carl von Linné named the Baltic Sea herring *Clupea harengus* var. *membras* thereby discriminating it from the Atlantic herring, *Clupea harengus*. The German herring researcher Friedrich Heincke (1898) published results of his investigations on spring- and autumn-spawning herring races, mainly based on the number of vertebrae and on seasonal development of gonads. Others, like Hessle (1925), Kändler (1942), Popiel (1964), Rannak (1967), Kompowski (1971), Otterlind (1985) and Ojaveer (1988) showed that Baltic Sea herring can be divided into several groups or populations. Apart from meristic and morphometric or otolith characters the spawning time has been a common means of discriminating two groups of herring in the Baltic Sea: spring spawners and autumn spawners. Despite this, some spawning of herring takes place in the Baltic also in the winter months and in summer, probably dependent on growth conditions changing from year to year.

The discrimination of herring into different populations according to its spawning time has been questioned by Aneer (1985) who argued that the annual growth, which depends on food supply, is the governing factor for the maturation and the time of spawning. This was supported by the situation in the Baltic Sea a few years ago, with an overall increase in growth of the herring and an almost disappearance of autumn-spawning herring since the early 1970s. Rechlin & Borrmann (1980) and Rechlin (1991) suggest, on the other hand, that the increased fishing activities and changes in the environment are the causes for the strong decrease of autumn spawners. Aneer's hypothesis is also questioned by the continued decrease of growth of herring since the mid-1980s (Neudecker 1990, Sjöstrand 1992), which has not resulted in the recovery of autumn-spawners in the Baltic Sea.

The geological evolution of the Baltic Sea indicates that herring can have lived in the area only since about 8000 years ago after the time of the freshwater Ancylus Lake. Both spring- and autumn-spawning herrings, may have been immigrating from today's North Sea into the Littorina Sea after the time of the Ancylus Lake when the salinity was still higher than it became later.

Spring-spawning herring spawn in coastal waters of relatively low salinity all over the northern Atlantic, whereas autumn-spawners do have spawning sites off the shores. The autumn-spawning herring may be suffering from the evolution into today's Baltic Sea since its immigration: the special environment of the shallow Baltic Sea with low salinity and low water temperature in winter appears to be more tolerable for species with reproduction and larval development well before the stress of the winter. Larvae of spring-spawners metamorphose during spring or in early summer whereas autumn-spawners stay as larvae throughout the winter until the next spring. Despite this, up to the beginning of 1970s in nearly all areas of the Baltic Sea, herring spawning in autumn were observed. Autumn-spawners dominated the commercial catches in the western Baltic and formed an important proportion of catches even in the central Baltic Sea during the 1960s (Rechlin 1971). The autumn-spawning herring year class in 1964 was the last numerous one observed in the area.

The almost extinction of this component of the Baltic Sea herring coincided with an increased fishing effort on herring and increasing areas with lack of oxygen in the bottom water layers in late summer/autumn during the early 1970s (Berner *et al.* 1973). Only a few years later the growth of spring-spawning herring, sometimes even a predator on autumn herring larvae (Rechlin 1991), increased (Wrzesinski 1983, Rechlin 1986). The growth decreased in the western Baltic, possibly in connection with low water temperature, again during the mid-1980s (Neudecker 1990). A similar tendency of decreasing growth of herring during the 1980s has been documented also for other areas of the Baltic Sea (Aro *et al.* 1992, Davidyuk *et al.* 1992, Parmanne 1992).

Among spring-spawning herring the discrimination of populations has partly been based on growth characteristics. The decreasing length in relation to age from the south-western Baltic Sea to the north-eastern parts of the area may be caused by changes in salinity and climatic factors. Another criterion is the link to a certain spawning area.

The south-western Baltic is inhabited by a fast-growing and migrating herring population with spawning sites around the Danish isles and along the German coast. The main spawning area is the waters around Rügen Island (Figure 1). The feeding areas of the adult stock are the transitional areas between the Baltic and the eastern North Sea. This herring population is called spring-spawning herring of the Western Baltic or Rügen herring. There is no clear border between this herring stock and spring-spawning herring in the Kattegat and all these spring-spawners are mixing at least during the feeding period. The age group 1 of the mixed stock is subject

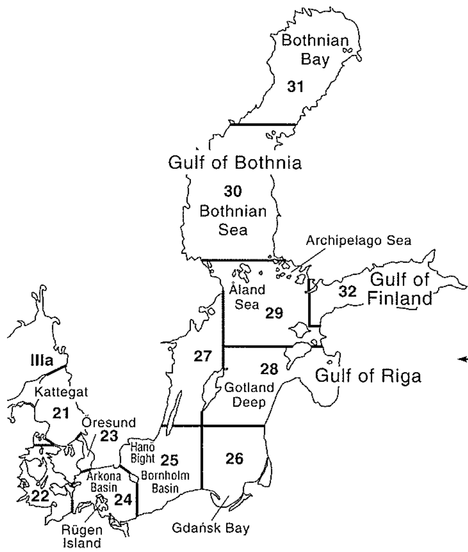

Figure 1. The Baltic Sea. Bold figures indicate ICES subdivisions.

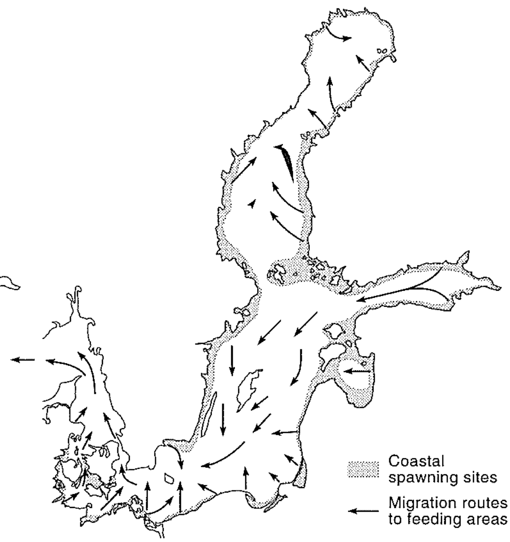

Figure 2. Feeding migrations of Baltic herring stocks (updated according to Anon. 1978).

for trawl fisheries during summer and autumn. The majority of spring-spawners investigated on spawning sites along the coast of the south-western Baltic shows infestation with the nematode *Anisakis* sp. every year. This infestation, described by Reimer (1970) as a natural tag, can only have taken place by feeding on euphausids in the area of Kattegat/Skagerrak/North Sea.

In addition to the Rügen spawning area there are several smaller spawning sites of herring along the coast of Poland (Figure 2). An important one for spring-spawning herring is situated in the Gdańsk Bay where the mouth of the river Wistula forms an estuarine area with good conditions for the spawning and hatching of larvae in spring.

The Hanö Bight at the southern coast of Sweden is also a spawning area of a herring population different by growth and otolith characters from that inhabiting the western Baltic Sea. Nevertheless, an exchange of spring-spawners between the Rügen spawning site and the Hanö Bight has been observed in German investigations in spring in the 1960s and also later by Otterlind (1985).

Along the Swedish coast northwards up to the entrance to the Gulf of Bothnia several spring-spawning herring populations have been investigated by Otterlind (1961) and Aneer *et al.* (1978), and Rannak (1967) described a number of different local spring-spawning herring populations from the eastern Baltic coasts from Lithuania to Latvia and Estonia. A detailed description of the diversity of the spring-herring along the eastern Baltic coast is also given by Ojaveer (1988).

The semi-enclosed Gulf of Riga and Gulf of Finland provide important spawning sites of spring-spawning herring populations. Two other spawning areas close by are the Archipelago Sea and the Åland Sea on the northern border of the Baltic proper. In the areas between about 56°N and 60°30'N there are major differences in growth rates of herring. The so-called sea herring is faster growing than the gulf herring and migrates over larger distances even as far as into the Bornholm Sea (Otterlind 1961, Parmanne 1990).

The Gulf of Bothnia is occupied by spring-spawning herring with minor differences in growth over all the area. The herring in the northernmost part of the Baltic Sea, the Bothnian Bay, differ morphologically from the fish in the other parts of the northern Baltic Sea (Parmanne 1990). The most distinct differences are in the dimensions of the head and the otolith. Spawning sites are situated along the western and eastern coasts and these herring stocks seem to be rather sedentary.

In the open areas of the Baltic proper feeding herring of different origin are mixing in summer and autumn. The migratory component of northern spring-spawners and spring-spawners from eastern and southern coasts together with few autumn-spawners meet for feeding in areas with sufficient zooplankton production in the central and southern Baltic proper. The intensity of the southwards migration is dependent on the food supply. Popiel & Strzyzewska (1971) assumed an influence of the strength of winters on the intensity of the feeding migration. After feeding, shoals of herring migrate again, partly to more northern areas, for wintering. The following spring the herring, now separated, spawn at different sites along the coasts of the Baltic Sea.

The adult spring-spawning herring from the western Baltic carries out a comparable migration in terms of distance up to the North Sea for feeding in summer and back again during autumn and winter for spawning next spring. With such feeding and spawning migrations over long distances, for feeding in one area and spawning in another, the herring stocks contribute to the flow of matter and energy inside the Baltic Sea and between the Baltic and North Seas.

The diversity of spring-spawning herring of the Baltic Sea in terms of meristic and morphometric characters, in growth and the use of certain spawning sites is rather well documented and so are the migrations of certain units or stocks. As mentioned above, feeding migrations result in a mixture of different components during summer and autumn. Only during the time of spawning on more or less separate sites along the coasts different herring tribes can relatively be discriminated. Smith & Jamieson (1986) emphasized the genetic similarity of the herring in the Atlantic and Baltic areas. The occurrence of herring of different origin observed sometimes on several spawning sites support the idea of gene flow. In the context of stock assessment and fishery management, however, the concept of several and partly distinct Baltic Sea herring stocks should not be discarded, otherwise necessary actions of regulating fisheries would not be undertaken because serious depletion of a local population could have been overlooked.

Sprat stocks

The clupeoid species *Sprattus sprattus* L. is wide-spread in north-eastern Atlantic waters, living in the Baltic Sea, in the North Sea and adjacent waters as far north as the Lofoten Area and west of the British Isles. Sprat is distributed along the Iberian coasts, in the northern Mediterranean (Gulf of Lion and the Adriatic Sea) and in the Black Sea.

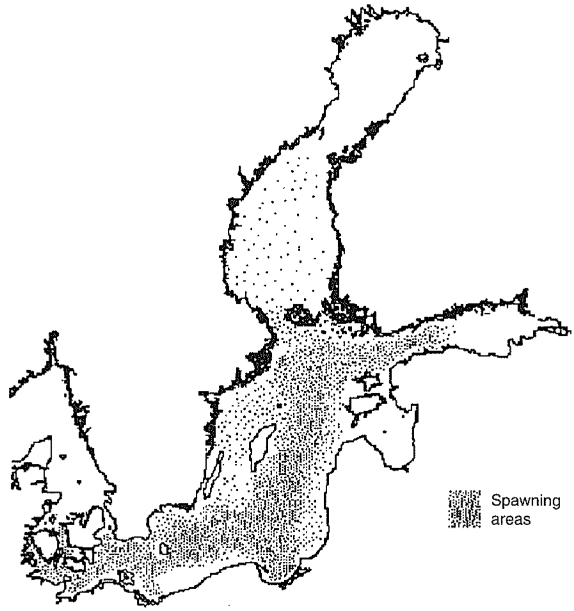

Figure 3. Main spawning areas of Baltic sprat (updated according to Anon. 1978).

With this distribution the sprat shows a high adaptability to rather different environments in terms of salinity and temperature (Figure 3). In water with a salinity below 6 psu (Kändler 1949) the pelagic sprat eggs are less buoyant and die. Sprat eggs, but no larvae, are found in the northern part of the Bothnian Sea (Sjöblom & Parmanne 1980).

Sprat is known to be a batch-spawner (Morawa 1955) with an individual period of spawning of about two months. The spawning time of this species in the Baltic Sea is therefore extended, beginning in some years in March (Grauman 1969) and ending in August (Morawa 1955).

There are morphometric differences and different growth characteristics of sprat in the Belt Sea area and in the Baltic proper. Rechlin (1974) showed significant differences for the length at age 1, l_1, of sprat from the Bight of Mecklenburg and areas of the Baltic proper like the Arkona Basin, the Bornholm Basin and the Gotland Sea although in the areas of the Baltic proper no such differences of l_1 have been found. According to these results the westernmost part of the Baltic Sea is inhabited by a sprat population probably more similar or even connected to the sprat in Kattegat and Skagerrak whereas the Baltic proper contains the proper Baltic sprat which also shows some differences, e.g. in growth, within the area.

The Bornholm Basin appears to be an area where sprat of western and eastern neighbouring waters are mixing in some years. Lindquist (1971) called the Gotland Sea sprat the 'pool of seniors' of Baltic sprat because he observed there a concentration of sprat with an age of 5 years and older, and Rechlin (1975) concluded a 'permanent recruitment' from a 'negative mortality' for ages 1-4 and the abundance of sprat up to age 7 in the stock of the Gotland Sea estimated for the period 1964-1970. The immigration into the central and deepest part of the Baltic proper is mainly connected with the formation of wintering shoals. The adult sprat winters in water with a temperature of, or above, 4°C below the halocline as long as the content of dissolved oxygen is sufficient (Rechlin,1967). After wintering the sprat shoals start spawning in deep water, migrate during the spawning season into the warmed-up surface water and continue there with spawning. For the area of the Gdańsk Bay, Elwertowski (1964) observed an emigration of sprat beginning with age 2 into the open sea areas. This emigration reaches its peak at age 4 and ends with age 5. Lishev & Uzars (1967) observed a northwards migration from the Latvian coast which increases with age.

Thus in essence, the sprat of the Gotland Sea area appears to be a mixture of sprat immigrating with increasing age from neighbouring areas into the open sea for wintering and spawning. On the other hand, there seems to be a feeding migration of sprat directed to shallower coastal waters in summer and autumn. Shvetsov & Gradalev (1989) showed that feeding migrations of sprat depend on hydrographic conditions and on age composition of the stock, from south to north and vice versa along the deep water of the Gotland Deep as well as from west to the coastal zone.

An international co-operation for the acoustic assessment of Baltic pelagic fish stocks started with annual surveys in 1978, later co-ordinated by ICES. Those acoustic surveys, carried out mainly offshore, showed differences in the distribution of main concentrations of herring and sprat so that for certain areas the estimated biomasses fluctuated considerably from year to year. However, the results summed, e.g. for sprat, were more stable for the whole area of the Baltic proper from year to year suggesting that migrations of the sprat occur over rather large distances. However, some authors (Aps *et al.* 1981, Aps & Ustinova 1986, Aps *et al.* 1987, Shvetsov *et al.* 1992a) claim that the sprat of the Baltic proper forms local populations separated from each other and with little mixing. This is based mainly on otolith characters, but still there is no clear proof of whether the sprat of the Baltic proper forms an uniform population or not.

Fishing

Herring fishery started during the Stone Age (Mortensen & Strubberg 1931) when people learned to prepare fine-meshed gill-nets. Gradually herring became the main species in the Baltic fishery.

In the first half of this millennium, during the Hansa Period, salted herring was an important export article in the southern Baltic Sea. In a good year the catch was more than 10 000 tonnes (Mortensen & Strubberg 1931) but the use of salted fish however diminished in the 17th and 18th century.

Engines in fishing vessels started to become common at the beginning of this century, first in Denmark and Sweden, then in Germany (Henking 1929). Motorization was rapid, in 1900 the number of motorized fishing vessels was 200, and 4570 by 1910 (Mortensen & Strubberg 1931).

At the beginning of this century herring was caught with gill-nets, seine-nets in summer and winter, and trap-nets. At that time fishermen started to use various seines and small trawls from motor vessels.

In 1912-1923, the mean annual herring catch of the Baltic Sea was 39130 tonnes (Kyle 1928), which was 50% of the total fish catch. At that time the herring catch was about 10% of the present catch. In 1912, the sprat catch was only 172 tonnes, but in 1923, at the same time with the growing trawl fishery, the sprat catch had reached 4128 tonnes (Kyle 1928).

Herring and sprat catches remained at a stable level from the early 1920s to about 1950; then there was a rapid growth in the catches due to the increased pelagic fishing (Thurow 1974). Thus the exploitation of the shoals in the open sea, and of young fish, increased. The fishing of the wintering sprat shoals in the Gotland area developed in 1960s (Rechlin 1975). In the 1970s the catches of clupeids further increased due to the well-developed technique of pelagic trawling, and the use of high-powered vessels (Elwertowski & Netzel 1985). The biggest annual catch of herring was more than 400 000 tonnes and that of sprat over 200 000 tonnes.

At present most of the herring catch is taken with pelagic trawls. Main trap-net fishing areas are around the island of Rügen, in the Gulf of Riga and off the coast of Finland but the share of trap-net catches is declining. In the 1980s total herring catches remained at a high level, but decreased in the 1990s far below the Total Allowable Catch (TAC) agreed by the International Baltic Sea Fishery Commission (IBSFC, Figure 4). The cause of the small catches has been marketing problems in many countries. For 1994, the biggest herring quotas were allocated to Sweden, EU, Poland and Finland.

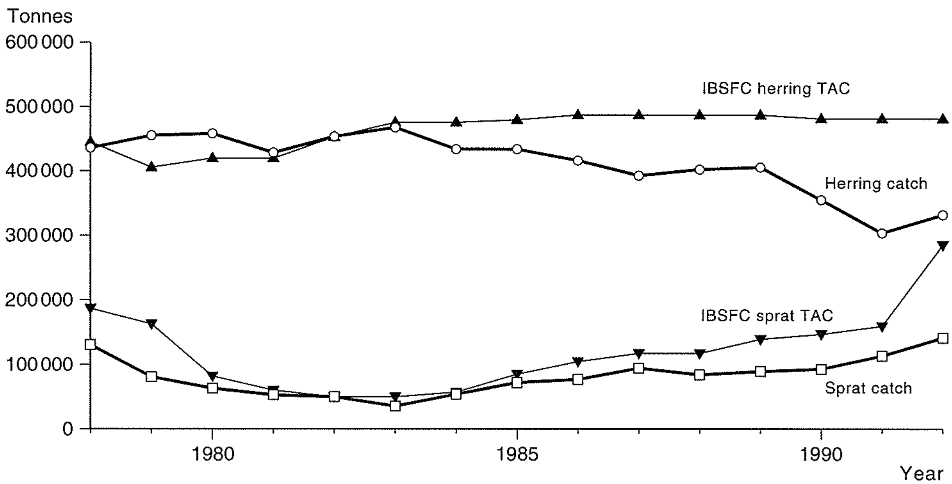

Figure 4. Catches and TACs of Baltic herring and sprat in 1978-1991.

In the sprat fishery the pelagic trawl is the main gear, the importance of other gears being insignificant. The sprat catches started to decrease in the late 1970s, but have then gradually increased since 1983, especially in the southern and central part of the Baltic Sea proper. In recent years the sprat catches have been smaller than the IBSFC quota (Figure 4). The biggest sprat quotas for 1994 were allocated to Poland, EU and Sweden.

Assessments of pelagic stocks

In 1974 the International Council for Exploration of the Sea (ICES) formed a new working group (Working Group on the Assessment of Pelagic Stocks in the Baltic) in order to consider the relevant parts of the requests from the newly established International Baltic Sea Fishery Commission (IBSFC). The requests were to 'analyse the state of exploitation of the stocks of herring, sprat, cod and flatfish in the Baltic Sea and advise as to regulations which might be used for approaching optimum yield of the stocks of the said species'. The Working Group, consisting of fishery biologists (members) from all countries bordering the Baltic, have met on an annual basis since 1974 and assessed stock sizes and exploitation levels for Baltic herring and sprat stocks. Its work presented in annual reports has become the basis for the advice on fishery management given by ICES through its Liaison Committee (1974-77) and since 1978 via the Advisory Committee for Fishery Management (ACFM).

Methods applied. During its first years of work the Working Group estimated the level of exploitation of the pelagic stocks by catch curve analyses and yield per recruit. The amount of available data was then small but has subsequently increased.

The major tool for stock assessment has since 1977 been the Cohort Analysis or Virtual Population Analysis (VPA) (e.g. Gulland 1985) by which the size of each year class (cohort) is estimated together with the annual mortality caused by fishing i.e. the level of exploitation. The input data demanded by the method are the numbers caught of each year class in successive years supplemented with value(s) of the mortality caused by other factors than fishing (natural mortality). The level of natural mortality is generally difficult to estimate, but is necessary when estimates of total stock size are of interest. A review of the attempts to estimate natural mortality for herring and sprat was given by Sparholt (1991). The estimates (expressed as instantaneous rates) for adult herring are in the range of 0.16-0.4 per year. These have, in most cases, been arrived at by catch curve analyses (Beverton 1963, Ojaveer 1974) and by using stock size estimates from acoustic surveys (Lassen & Sjöstrand 1980). A more sophisticated approach was taken by Sparholt (1988, 1989), who included both acoustic and young fish survey data and catch data in a stochastic integrated model. For sprat (age ≥ 1) the estimates range from about 0.4 to $1 \cdot y^{-1}$. Catch curves (Beverton 1963), regressions of effort against total mortality (Wlodarczyk 1978) and acoustic stock estimates (Shvetsov & Gradalev 1988) are among the methods used (but see also Lassen 1979, Shvetsov 1982, Hoziosky *et al.* 1989). The values applied in the assessments conducted during 1974-90 by the Working Group have been in the range $0.15\text{-}0.30 \cdot y^{-1}$ for the herring stocks and 0.2-0.5 for sprat. The values have been assumed constant over ages and in most cases over years. Improved estimates of the part of the natural mortality due to predation can be arrived at by quantifying the amount of herring and sprat eaten by cod. Since 1981 such work has been carried out by the ICES Working Group on Multispecies Assessments of Baltic Fish. The results from these analyses (Anon. 1993a) since 1991 have been incorporated in the appropriate single species assessments. The variation with time in the levels of natural mortality for herring and sprat is shown

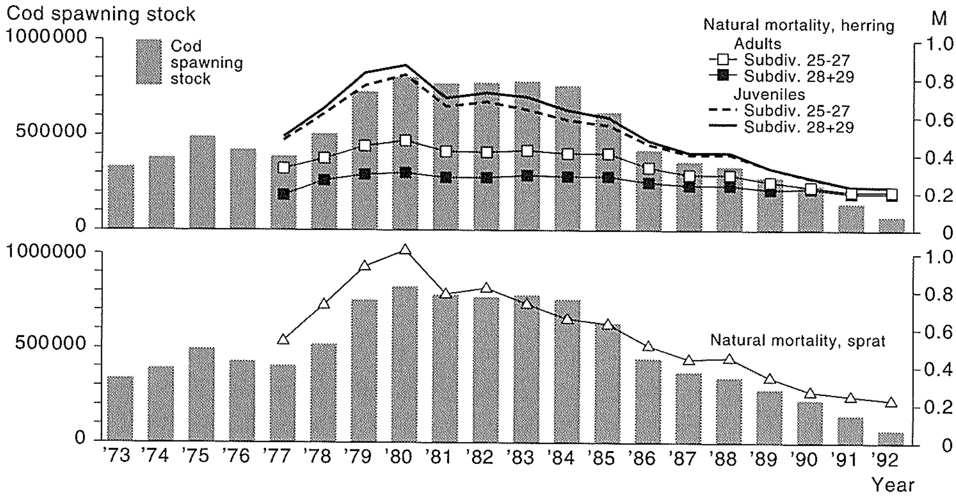

Figure 5. Levels of natural mortality for herring in subdivisions 25-29 and 32, and sprat in subdivisions 22-32 as estimated by Multispecies VPA. Spawning stock biomass for cod in subdivisions 25-32 is given.

in Figure 5 together with the changes in spawning stock size of the main predator cod. The mortalities are given as annual averages for adult and juvenile herring (age groups 2-9 and 0-1) and for sprat (ages 1-7).

Small fish are easier caught by cod than are large such that predation mortality is larger for young ages and slow-growing populations of prey. The average distributions (1977-92) of annual predation mortalities at age are (Anon. 1993a):

Age	0	1	2	3	4	5	6	7	8	9
Sprat	0.17	0.57	0.41	0.33	0.29	0.37	0.32	0.33		
Herring, subdivision 25-27	0.16	0.45	0.12	0.07	0.06	0.06	0.04	0.04	0.03	0.02
Herring, subdivision 28+29	0.23	0.43	0.16	0.19	0.15	0.15	0.13	0.14	0.12	0.10

Sprat remains during its whole life in the size range that makes it a suitable prey for cod, whereas herring grows out of this range at about age 2. This is more pronounced for the fast growing populations in the southern Baltic than for the slow growing herring in the northern and north-eastern parts.

The VPA needs auxiliary information to calculate the level of exploitation for the latest year with catch data. Suitable types of data for such calculations are abundance estimates from surveys or from the fishery in the form of Catches at age Per Unit of Effort (CPUE).

Acoustic Survey data. Estimates of pelagic stocks obtained by transforming the backscattering from fish of acoustic signals (echo sounders) to biomass of fish have been carried out in the Baltic since the end of the 1970s. Results from such investigations have been used for calibrating the VPAs for certain stocks of both herring and sprat since the beginning of the 1980s (Hagström *et al.* 1981-1987, Kästner *et al.* 1984, Shvetsov *et al.* 1986, 1987, 1992b, Shvetsov & Gradalev 1988).

Calibration and validation of VPA. The ways of calibrating the VPA with auxiliary information on stock abundance have developed rapidly during recent years (Anon. 1991, 1993b,c).

Baltic pelagic stocks have been assessed using several techniques: from assuming a continuation of an average exploitation level and various regression techniques on the stock estimates from acoustic surveys to applying more sophisticated tuning programmes such as the '*ad hoc* tuning method' by Laurec & Shepherd (1983) and the Extended Survivors Analysis (XSA) (Anon. 1991).

Stock units for assessment. Since 1990 the Working Group on the Assessment of Pelagic Stocks in the Baltic (WG Bal Pel) has assessed the herring in the Baltic and adjacent waters as four units:

- spring-spawning herring in the Skagerrak, Kattegat (division IIIa) and western Baltic (subdivisions 22-24);
- herring in the Baltic proper (subdivisions 25-29), inclusive the Gulf of Riga and the Gulf of Finland (subdivision 32);
- herring in the Bothnian Sea (subdivision 30);
- herring in the Bothnian Bay (subdivision 31).

Sprat have been assessed since 1989 as one stock in the whole area (subdivisions 22-32).

The number of assessment units was larger in earlier years and their borders have been changed repeatedly (Sjöstrand 1989). The stock units should, ideally, be chosen so that there is either no (or very little) overlap in their geographical distributions, or so that it is feasible to classify individual fishes in mixed catches and sort them according to stock. When mixing occurs, is it not only the catches but also fishes in samples from surveys that must be allocated to stock. However, the problem of stock discrimination is most pronounced in division IIIa and subdivisions 22-24 between Baltic spring-spawners and North Sea autumn-spawners, in Baltic proper between coastal and open sea spring-spawners, and in subdivision 28 between gulf herring and open-sea herring (see Herring stocks, page 30-33).

Results. The results from the assessments made in 1993 are presented in diagrams showing total stock size (as biomass of ages ≥ 1), number of recruiting fish (as 1-group) and exploitation level (as average fishing mortalities over a range of ages). The same diagrams also present the results of earlier assessments taken from the reports 1977-92 by the Working Group on Assessment of Pelagic Stocks in the Baltic. The values are in some instances obtained by summing the results from the smaller units assessed at the time. This is the case for herring in subdivisions 25-29 and 32 which was assessed as one unit in 1990-93 but as three or four smaller units in 1980-89 (Sjöstrand 1989). Herring in subdivision 31 in 1982-90 was assessed on the basis of catches only in the eastern part of the area, comprising about 95% of the catches. Sprat results for the period 1977-88 are the summed values for three units.

Variations in the time period 1974 to 1993

Herring stocks. The spring-spawners in the Skagerrak, Kattegat and western Baltic (subdivisions 22-24) have increased from a low level in 1976 of 200 000 tonnes to a peak in 1984 of 600 000 tonnes. Thereafter the stock has fluctuated between 400-550 000 tonnes (Figure 6A). Recruitment shows a slightly increasing trend and one outstanding year class in 1986 (Figure 6B). The exploitation appears to be on an (for a herring stock) unusually high level. The 1993 assessment indicates a decreasing trend in fishing mortality since the middle of the 1970s (Figure 6C).

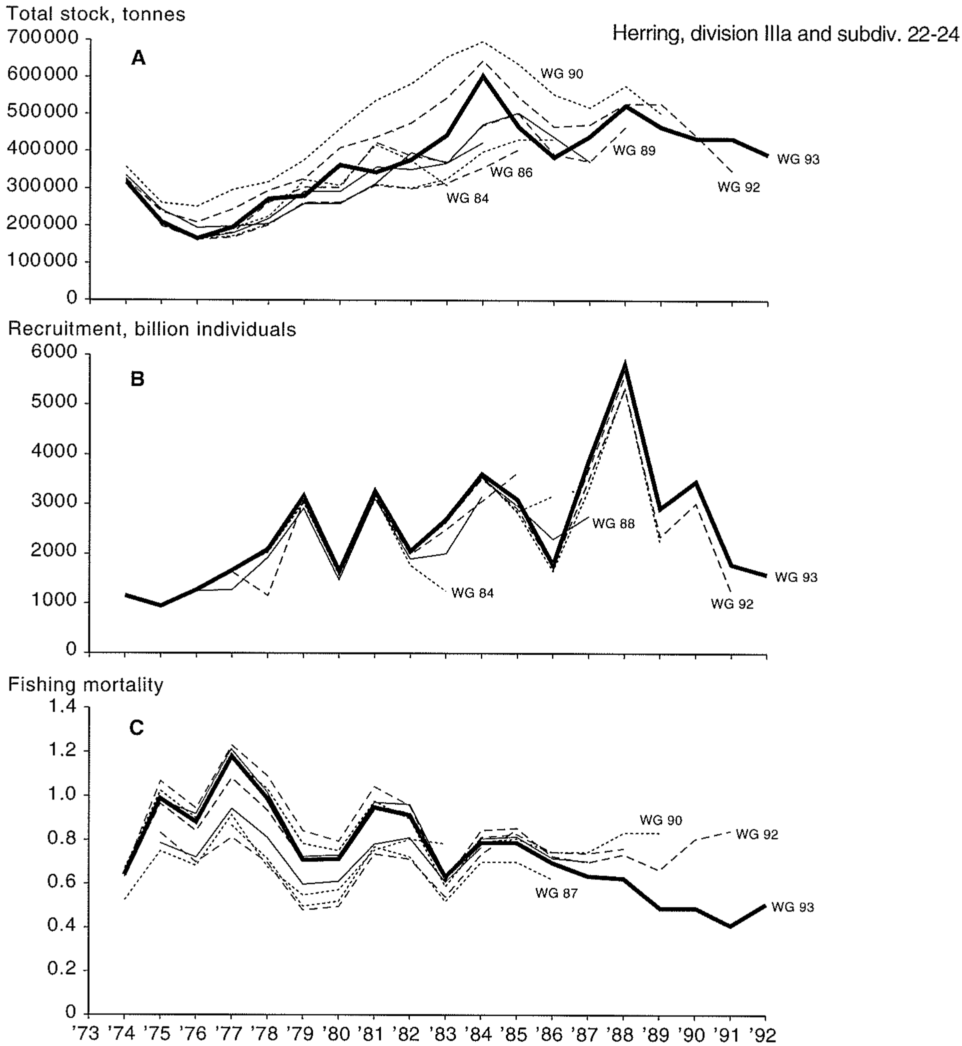

Figure 6. Herring in division IIIa and subdivision 22-24. Estimated by WG Bal Pel 1984-1993. A: Biomass of total stock (≥1-ringed fish). B: Recruitment of 1-ringed fish. C: Average fishing mortality over ages 2-7.

In the Baltic proper (subdivisions 25-29 and 32) the latest assessment indicates a decrease in stock size from 1978 to 1986 and then an increase to the same high level as in 1978 (3.5 million tonnes) (Figure 7A) with variable recruitment. The latest large year class hatched in 1989 (Figure 7B). The trajectory of the fishing mortality is dome shaped: an increase during 1978-1986 and thereafter a decline to the pre-1978 level (Figure 7C).

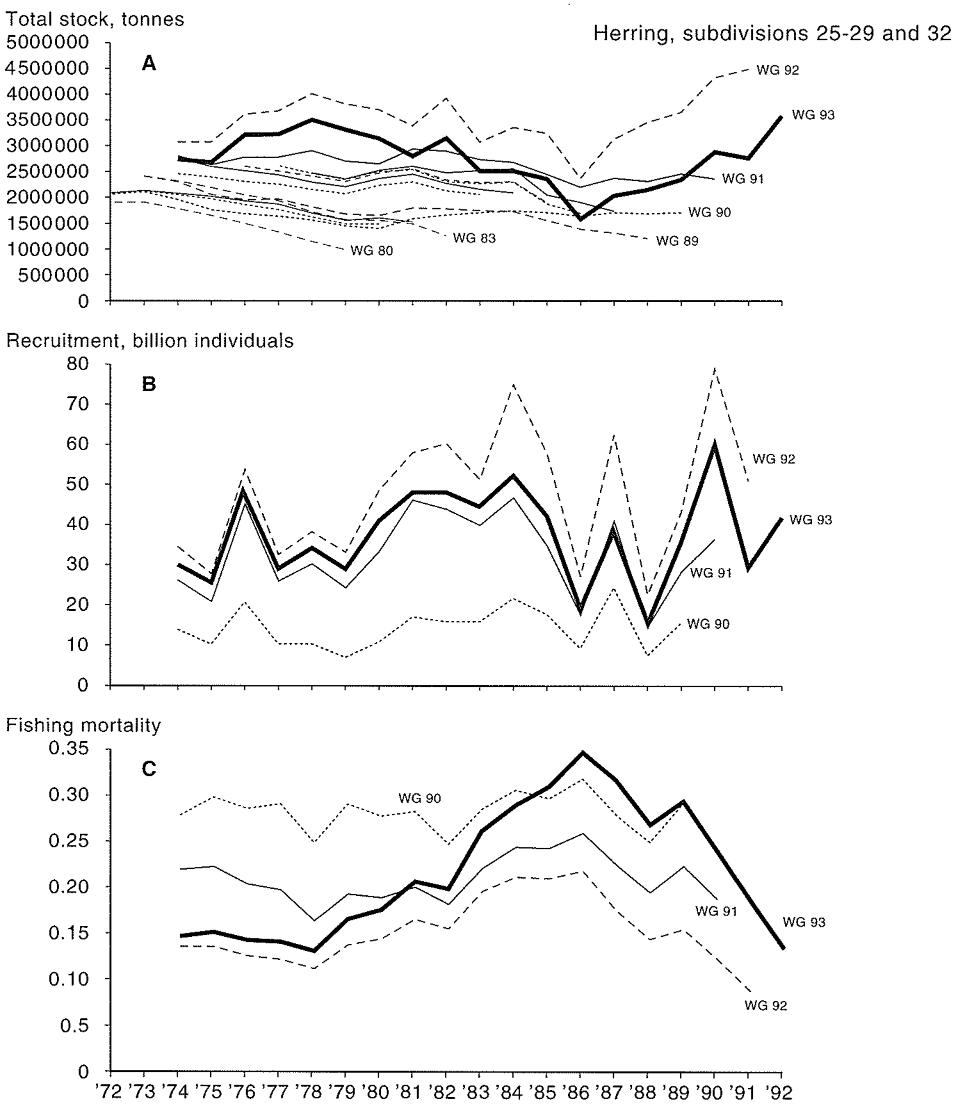

Figure 7. Herring in subdivisions 25-29 and 32 (Gulf of Riga included). Estimated by WG Bal Pel 1990-1993. A: Biomass of total stock (≥1-ringed fish). For the years 1980-89 the values given are the sums of assessments of stock units in subdivisions 25-27, 28+29S, 32 and Gulf of Riga. B: Recruitment of 1-ringed fish. C: Average fishing mortality over ages 3-8.

Herring in the Bothnian Sea (30) has increased steadily and more than doubled its stock size from 1980 to 1992 (Figure 8A). Both the 1988 and 1989 year classes have been large (Figure 8B) but fishing mortality has fluctuated around a value of 0.2, which is also the level of natural mortality used (Figure 8C). Also the herring

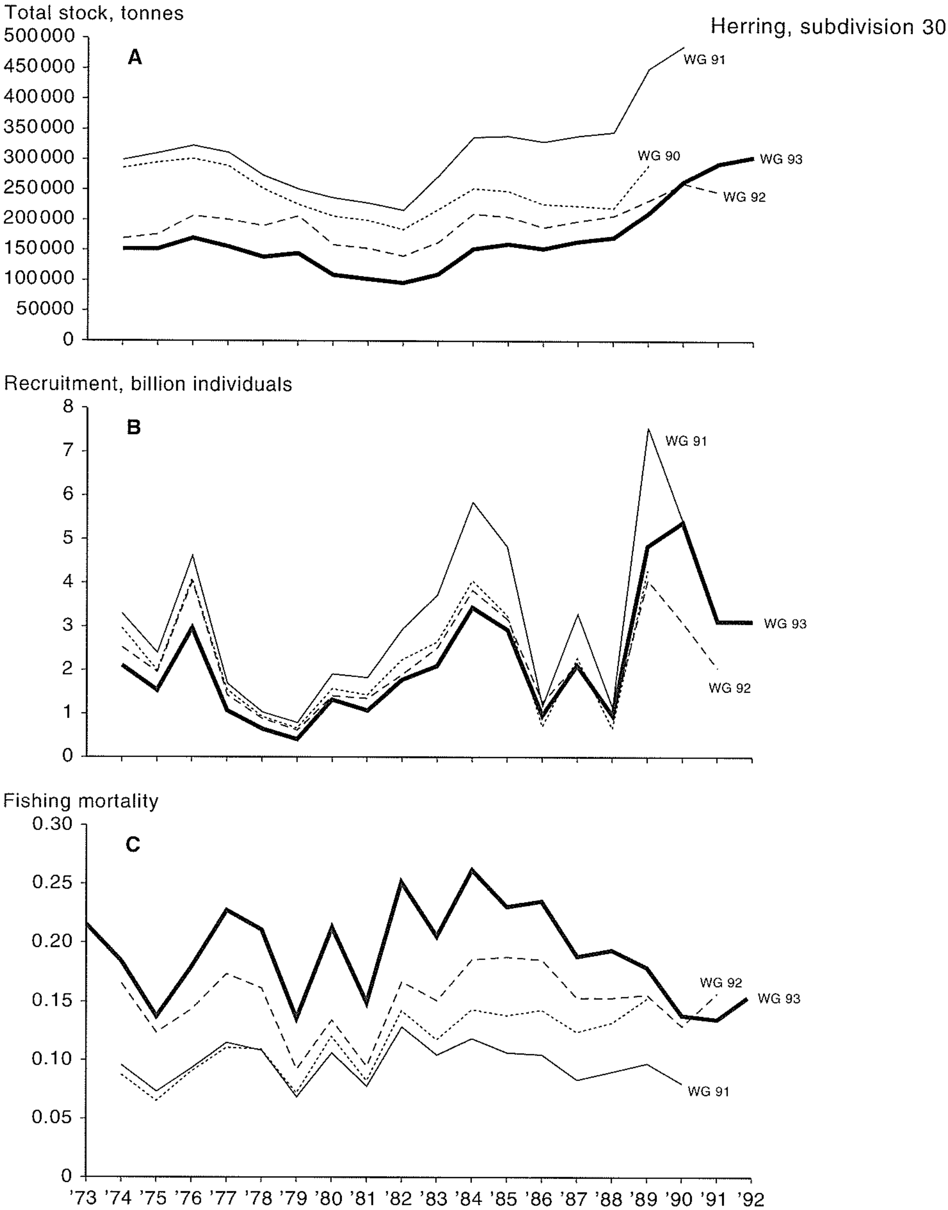

Figure 8. Herring in Bothnian Sea (subdivision 30). Estimated by WG Bal Pel 1990-1993. A: Biomass of total stock (≥1-ringed fish). B: Recruitment of 1-ringed fish. C: Average fishing mortality over ages 2-6.

stock in Bothnian Bay (31) appears to have increased since 1980 (Figure 9A). In this area there is a more marked difference between bad and good year classes. Also here was the 1988 (and 1989) year class very large (Figure 9B). Exploitation seems to be at a very low level even in comparison with the level of natural mortality (0.15) (Figure 9C).

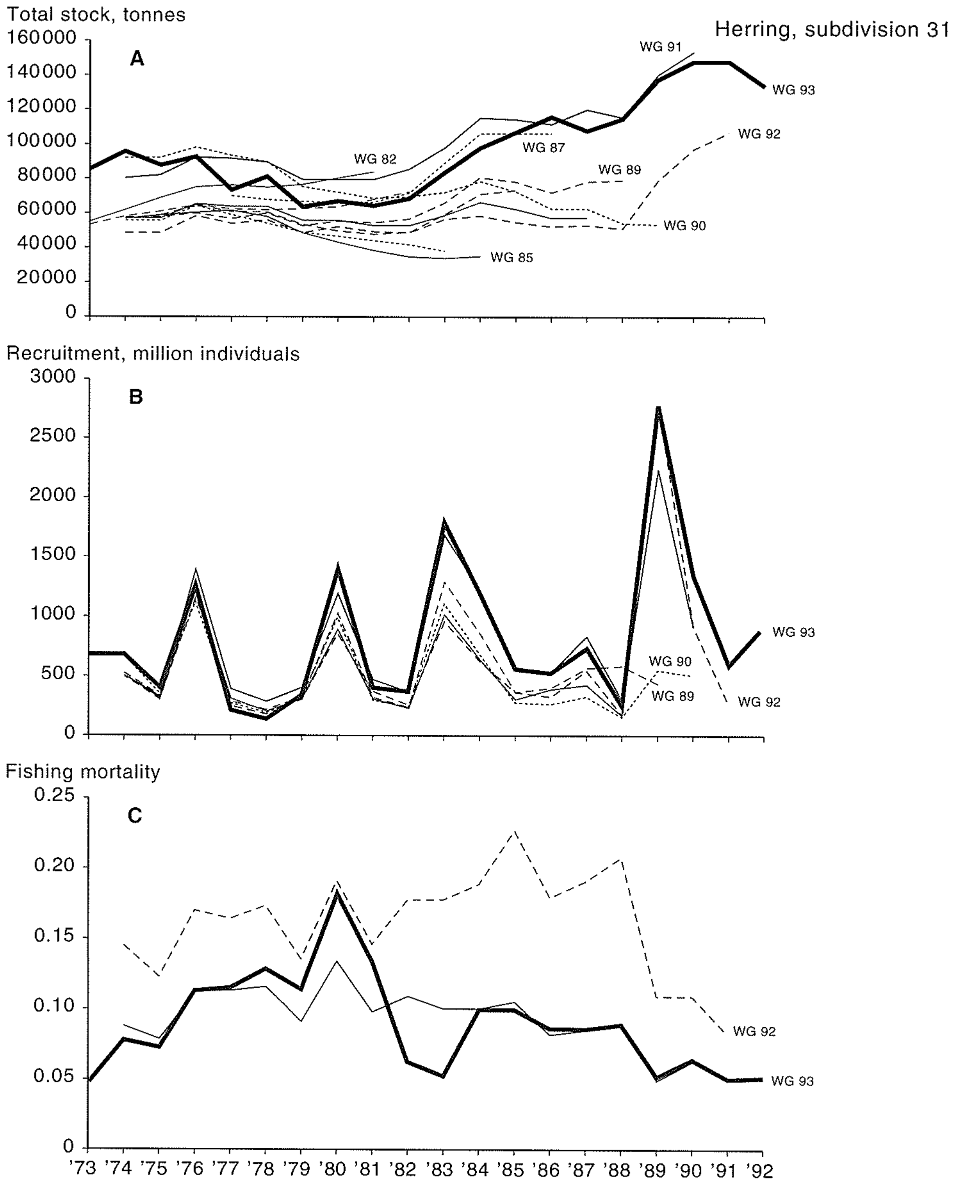

Figure 9. Herring in Bothnian Bay (subdivision 31). Estimated by WG Bal Pel 1991-1993. A: Biomass of total stock (≥1-ringed fish). B: Recruitment of 1-ringed fish. C: Average fishing mortality over ages 2-6.

Sprat stock. The development of the sprat stock shows a decline from high levels at the beginning of the 1970s to a low level in the beginning of 1980s. Thereafter a slow increase up to 1988 and then a rapid increase to around 3.5 million tonnes (Figure 10A). Superimposed on this pattern are the peaks in biomass caused by the very large year classes 1975 and 1982. The recruitment has also been high for the year classes after 1987 (Figure 10B) and fishing mortality has decreased steadily and is now at a low level (Figure 10C).

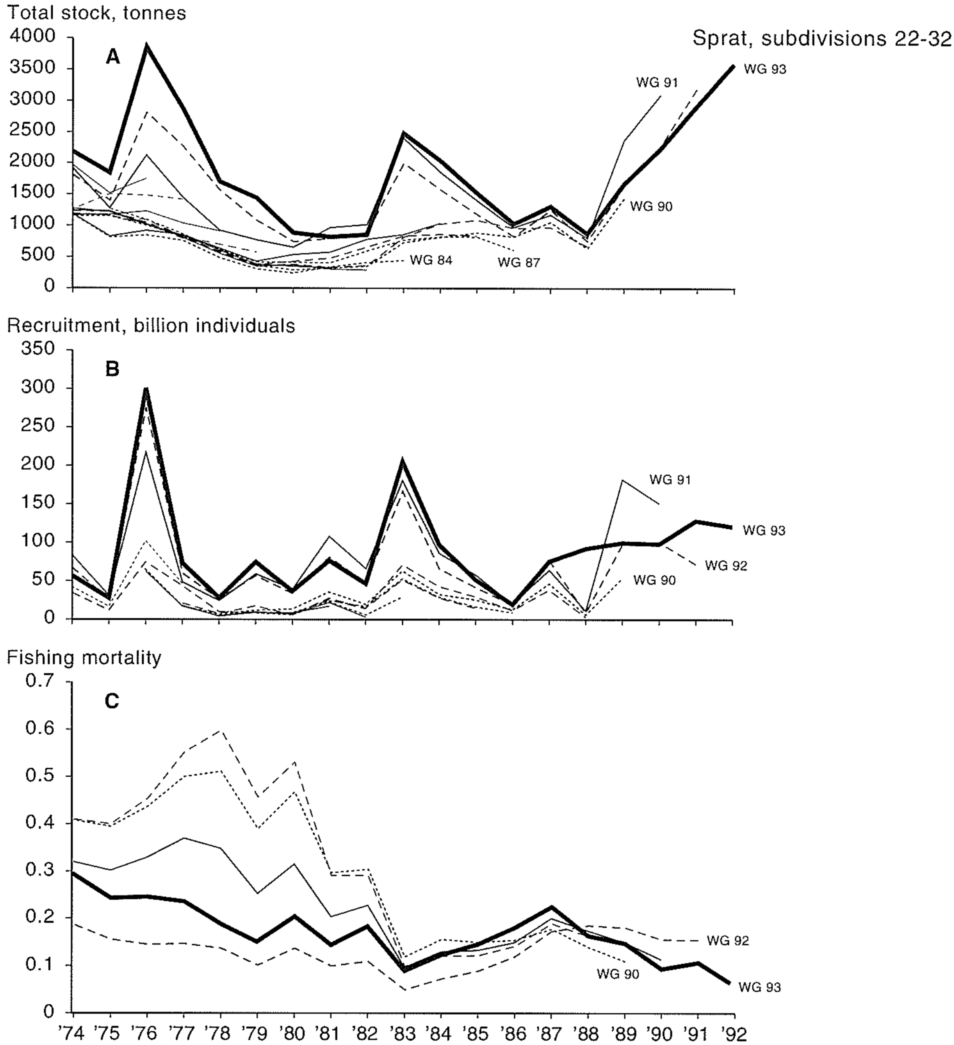

Figure 10. Sprat in subdivisions 22-32. Estimated by WG Bal Pel 1989-1993. A: Biomass of total stock (≥1-ringed fish). For the years 1977-90 the values are the sum of values from assessments of stock units in subdivisions 22-25, 26+28 and 27-29, 32. B: Recruitment of 1-ringed fish. For the years 1977-90 the values are pooled as in A. C: Average fishing mortality over ages 2-6.

Variation in estimates for the same year. The variation in estimates of stock size and level of exploitation can be considerable (Figures 6-10). An improved data base, and developments in assessment methods have resulted in continuous revisions of the estimates during the time of the Assessment Working Group.

Influence from natural mortality. The biggest contribution to the variation of stock estimates and level of exploitation derives from the different levels of natural mortality that have been applied.

Figure 11 presents the outcome of the assessment of herring in the Baltic proper made in 1990 with constant natural mortality ($M = 0.2$) together with the 1993 assessment of the same stock when variable levels of mortality as estimated by the Multispecies VPA were applied. The figures give biomasses of catches, of fishes dead

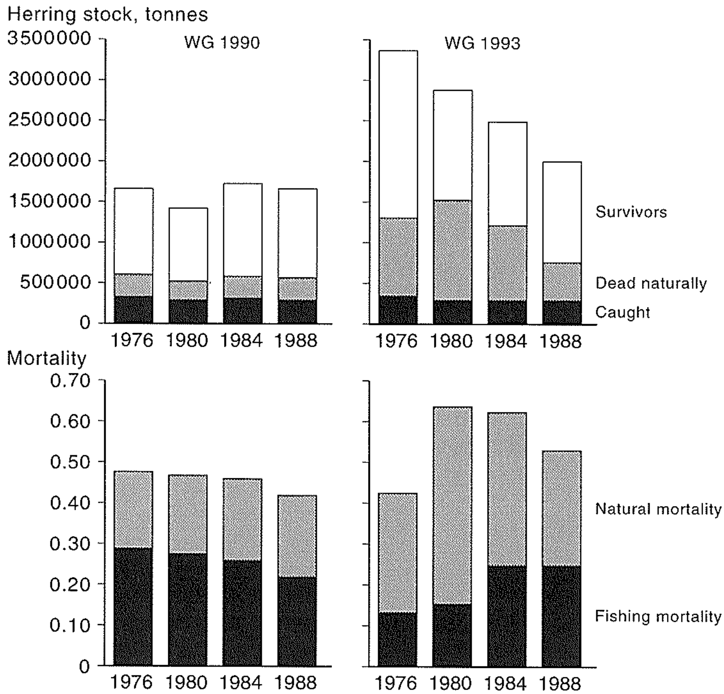

Figure 11. Herring in subdivisions 25-29 and 32 (Gulf of Riga included). Estimates of stock partitions using different values of natural mortality.

from other causes and of survivors. Data for the years 1976, 1980, 1984 and 1988 have been selected. Given are also the accompanying levels of fishing and natural mortalities calculated as averages over ages 1-9. The mortality caused by predation is much larger than the fishing mortality and consequently the amounts eaten by predators are much larger than the catches.

The variation demonstrated on these graphs is, however, not only an effect of different values of predation mortality, but also caused by the different tuning methods in use 1990 and 1993 (see section below).

It seems likely that the application of M values that have been calculated for areas (stock units) 25-27 and 28-29 by the Multispecies WG on the larger stock unit in subdivisions 25-29 and 32 (Gulf of Riga included) has caused an overestimation of (natural) mortality and hence stock size. About 50% of catches in numbers in this larger stock unit comes from the areas subdivision 32 (the Gulf of Finland) and the Gulf of Riga. The procedure used implicitly assumes that herring from these Gulfs are predated upon by cod at the same rate as herring in the Central Baltic (subdivisions 25-29). This is probably not the case as cod after, for example 1985, has decreased significantly in abundance in these gulfs. This change in cod abundance is reflected in both catch data and in trawl survey results. The same effects can be expected on the stock and mortality estimates for the sprat stock. The natural mortality values calculated on the basis of cod predation refers strictly to areas 25, 26 and 28 but have been assumed to be representative for the total distribution area of Baltic sprat. This could have resulted in overestimates of M and stock size for the period prior to the increase of the cod and likewise to the latest years with a decreasing cod stock.

Influence from tuning procedures. Two different tuning techniques were applied to the same stock in Anon. (1993d), in an attempt to evaluate the methods of retrospective analysis (Anon. 1991). The two methods compared, the Laurec-Shepherd (LSh) '*ad hoc* method' and the Extended Survivors Analysis (XSA) are both included among the ICES standard procedures for assessments. The results for herring in subdivision 25-29 and 32 have been chosen as an example (Figure 12) and show the effects on average fishing mortality, the fishing mortalities for the oldest age group (F_{old}), the total stock (age-groups ≥ 1) and the number of young fish (age 1) from tuning. The results are expressed as relative to the Laurec-Shepherd technique ((XSA / LSh) – 1) × 100.

Figure 12 shows that the average fishing mortality in 1974 is estimated about 10% higher with the XSA; this difference is then steadily increasing to ca. 30% for

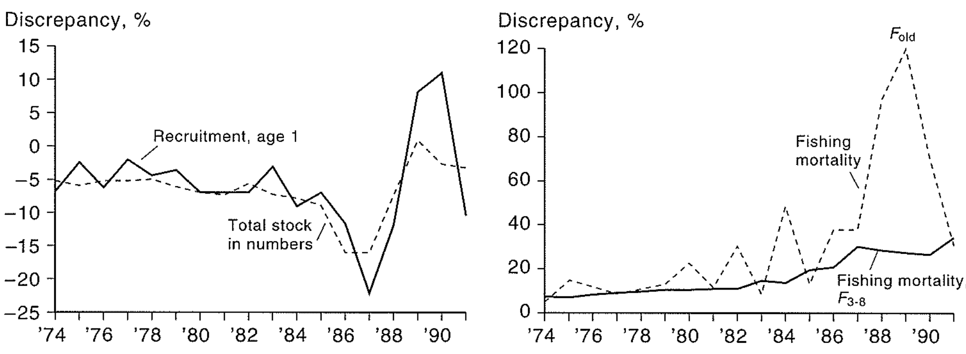

Figure 12. Herring in subdivisions 25-29 and 32 (Gulf of Riga included). Comparison of results from applying Extended Survivors Analysis and Laurec-Shepherd tuning techniques. Recruitment at age 1, total stock in numbers, average fishing mortality (F_{3-8}) and fishing mortality for the oldest age group (F_{old}).

the 1991 values. The relative difference in total stock numbers is generally smaller at 5-15% in which case it is the Laurec-Shepherd technique that produces the highest values. The differences for F_{old} and the recruitment estimates is also of note.

The general impression from the suite of assessments made during the recent 15 years is, that even if the estimates of the absolute levels of stock sizes and recruitment have varied considerably, the picture of the stock dynamics, and of the pattern of good and bad year classes has been relatively stable between years. It is inherent in the VPA that the convergence of fishing mortality estimates back in time is better (irrespective of input values for the last year) when fishing mortality is a large proportion of the total mortality. This is not the case, especially for the herring stocks in the Bothnian Sea and Bay.

The revised estimates of stock size from introducing higher natural mortality levels, have very little influence on the (short-term) catch predictions and the calculated TACs. That is because the estimated levels of fishing mortality decrease when natural mortality and stock size increases and these changes counterbalance each other.

Environment

Natural variation

Since its development from the freshwater Ancylus Lake into the marine Littorina Sea about 8000 years ago, and later into today's brackish Baltic Sea the salinity has been one of the crucial environmental factors for the whole ecosystem including the fish fauna. An influx of marine water through the transition area of the Skagerrak and the Kattegat into the Baltic Sea and river discharge of fresh water result in the well known stratification of the water column.

However, fresh water discharge to the Baltic takes place continuously, whereas influx of marine water, hampered by thresholds at the entrances from the Kattegat into the Baltic, is episodic. The strong stratification of the water hamper the mixing of water below the halocline at a depth of about 60 m in the central Baltic Sea. Therefore, during periods without influx of salt water saturated with oxygen, hydrogen sulphide may be produced as a result of the mainly biological reduction of oxygen in the bottom water of the Baltic Sea basins. Nutrients in the bottom water become transported back into the euphotic layer only in case of upwelling following the replacement of stagnant water by the inflowing salt water. So, dissolved oxygen, salinity and the amount of nutrients available for the primary production, decrease during periods of stagnation before man-made eutrophication occurred. Thus, a relative lack of nutrients at times has been the normal situation in the Baltic Sea in the past.

The temperature is another environmental factor with influence on the fauna and flora in the Baltic Sea and on species distribution. Especially in spring and summer, processes like reproduction and growth are influenced by the temperature regime. Periods with low average temperature in winter and also during summer appear to have some influence on growth, probably via decreased feeding activity and/or shortening of feeding season. Herring and sprat seem to be adapted to the rather strong stratification of temperature in the Baltic Sea in summer.

Heavy metals

Concentrations in water and fish. Metals are discharged to the Baltic Sea from industries and through rivers, sewage systems and the air. The concentration of heavy metals in herring in the Baltic Sea is at the same level as in the North Atlantic except for mercury, for which values in the Baltic Sea are lower than those from the North Atlantic (Perttilä *et al.* 1982a). Cadmium, lead, copper, and zinc in herring and sprat in the southern Baltic are comparable to those concentrations reported for the other regions of the Baltic Sea during ICES (1977) cooperative studies (Falandysz & Lorenc-Biala 1984).

There may be great vertical differences in the concentration of harmful substances in the water. When developing embryos of Baltic herring were exposed to hexane extracts of sea-surface microlayer, extracts from some locations produced significant embryo mortality as well as severe deformities in live hatched larvae. A control sample of bulk water collected from 20 cm under the surface and extracted in the same way produced no significant mortality or deformities (Kocan *et al.* 1987). The sea-surface microlayer contained varying amounts of Zn, Cd, Cu, Ni, Fe, Pb and Co, in concentrations 100 times above those found in subsurface bulk water (Westernhagen *et al.* 1987). Fertilization and the beginning of embryonic development of the Baltic herring are affected by copper, cadmium and zinc already at low concentrations (Ojaveer *et al.* 1980). In spring, herring eggs may be situated near the surface, where the temperature is highest (Rajasilta 1992). Herring larvae may be located at 0-0.2 m depth (Schnack 1974, Sjöblom & Parmanne 1978). The high concentrations of heavy metals close to the surface may threat the reproduction of herring, and can cause malformations observed in the Baltic Sea (Grauman & Sukhorukova 1982, Grauman & Lisheva 1990).

Fish as food. In all herring and sprat samples analysed in different regions of the southern Baltic Sea, the total mercury level in the muscles was below the threshold limit of 0.5-1.0 ppm for human consumption (Falandysz *et al.* 1985). In the northern Baltic Sea the mercury content of herring was 0.02-0.07 $mg \cdot kg^{-1}$, i.e. in most cases less than 10% of the limit value that causes usage restrictions (Kiesvaara *et al.* 1992). On the other hand, the amount of cadmium in the eastern part of the Gulf of Finland was 60% of the limit value (which is 0.1 $mg \cdot kg^{-1}$), and 10-20% in other areas in the northern Baltic Sea (Kiesvaara *et al.* 1992). Despite the loadings of residues, Baltic fish are still edible.

Effects on fish. Acid effluents containing sulphuric acid, iron and many other metals may cause additional mortality and lower catches of Baltic herring in the area affected by the TiO_2 industrial waste waters (Parmanne *et al.* 1986). About 6 km from the outlet of a titanium dioxide factory the mortality of the spawn was over 90% (Oulasvirta 1990). Deformed embryos were at times abundant. In a more remote area, acute lethal effects could not be demonstrated. However, in certain weather conditions the effluent wells up and eggs may be destroyed as far as 67 km from the outlet (Oulasvirta 1990).

Petroleum hydrocarbons

Petroleum hydrocarbons enter the Baltic Sea as a result of marine transportation, municipal and industrial waste deposition, through runoff, atmospheric input, to a small extent offshore production and from natural sources. The even distribution of petroleum hydrocarbons in the Baltic Sea indicate the high contribution of the atmospheric input (Dahlmann 1990).

In the Baltic Sea the breakdown of oil is slow due to the low average temperature. Oil causes additional mortality to the fish stocks, especially of eggs and larvae. In the laboratory 25% of herring eggs from the *Tsesis* oil spill (October 1977) area hatched in comparison to 54% of those from the unaffected area (Aneer & Nellbring 1982). In addition to low hatching, other effects of oil on herring are developmental abnormalities (curvature in the notochord end) and abnormal swimming movements (Vuorinen & Axell 1980, Urho & Hudd 1989).

Organochlorine compounds

Contents in fish. Samples originating from the Baltic Sea are, on average, more heavily contaminated by chloro-organic pesticides and polychlorinated biphenyls than those from the North Sea (Luckas & Lorenzen 1981). The concentration of total DDT of fish in the Baltic Sea is ten times higher than in the North Sea (Huschenbeth 1986). There is a gradual decrease in the level of DDT from the Baltic Sea through the Öresund, Kattegat and the North Sea (Jensen 1982).

In the northern Baltic Sea DDT and PCB concentrations are lower than in the Baltic proper (Miettinen *et al.* 1985). The Gulf of Finland has been more polluted by organochlorine compounds than the Gulf of Bothnia (Perttilä 1985).

In the 1970s and 1980s the DDT concentration in fish decreased continually in the southern Baltic Sea, whereas PCB levels increased (Jensen 1982, Huschenbeth 1985). In the northern Baltic Sea the DDT and PCB concentrations have decreased between 1970 and 1986 (Miettinen *et al.* 1985, Haahti & Perttilä 1988).

In a fat fish, such as herring, contents of dioxin (Kruse 1990) and PCB (Miettinen *et al.* 1985) can be higher than in many other fish. In the Baltic Sea herring contains high levels of polychlorinated dibenzodioxins and dibenzofurans (Svensson *et al.* 1991) and the organochlorine concentrations in Baltic herring increase significantly with age (Perttilä *et al.* 1982b).

There are few data concerning the harmful substances in the Baltic sprat (Roots & Aps 1993) but being a fat fish, the concentrations may be high. As sprat is one of the most economically important fishes in the Baltic Sea and a food item of salmon and cod, more data are needed.

Fish as food. Despite of the load of organochlorines in Baltic herring, fish are suitable for human nutrition according to the standards used. The tolerances laid down in the 'Directive on maximum amounts in animal foodstuffs' for HCB, HCH isomers, lindane and DDT were not exceeded (Luckas & Lorenzen 1981). In the southern Baltic Sea in 1981 the residues of organochlorine pesticides and polychlorinated biphenyls in muscular tissue of herring and sprat were low and below the acceptable tolerance limits in edible parts of fish (Falandysz 1985). Fish from the Baltic Sea contained PCB- and CHC-concentrations of 0.1-0.01 of regulatory limits (Kruse & Krüger 1990). In all fish and crustacean samples taken in the Baltic Sea, the concentration of six different PCBs were under the limit for human consumption (Krüger & Kruse 1988).

Fish from the Baltic Sea are a source of polychlorinated dibenzofurans and dibenzodioxins for persons who eat fish regularly. The clinical consequences of such exposure are uncertain (Svensson *et al.* 1991). However, according to the Nordic TWI (Tolerable Weekly Intake) value (Anon. 1990), a person weighing 70 kg can consume 350 g of Baltic herring each day for the rest of his life without any health risks caused by dioxine and furan compounds (Kiesvaara *et al.* 1992).

Effects on fish. Increasing levels of harmful concentrations in the Baltic Sea may threat the reproduction of local herring. In the southern Baltic Sea the hatching success of herring was significantly affected by the contents of chlorinated hydrocarbons observed in the parent fish (Hansen *et al.* 1985). The concentration levels of DDE in the tissues were more significantly related to the viable hatch of the larvae than PCB levels. Fish, which had been given oral doses of DDT, developed hyperactivity and abnormal diurnal activity (Bengtsson & Larsson 1981). It is difficult to separate the effects of various organochlorines and thereby determine threshold levels for each compound which causes particular effects. These compounds may act, antagonistically or synergistically depending on the particular substance, the fish species and the residue levels present in the tissues (Rosenthal *et al.* 1986).

Herring is an important food item for salmon. The mortality of the eggs and yolk sac fry of salmon was high in the beginning of 1990s, as it was also in 1974 (the so-called 'M 74'). It is not known whether the observed mortality is connected with the amount of harmful substances in the food of salmon.

Eutrophication

Herring larvae and young fish use zooplankton as food (Ojaveer 1981). With the increase in herring age and length, the importance of plankton in the diet decreases and the proportion of larger crustaceans (Mysidae, Amphipoda) increases (Ojaveer 1981). There have been changes in the amount of Baltic herring food due to the eutrophication. The zoobenthic biomass has greatly increased above the halocline due to the general eutrophication of the Baltic Sea (Cederwall & Elmgren 1980, Baltic Marine Environment Protection Commission, 1990). In the Baltic Sea the increasing trend of fish biomass is considered to be caused by eutrophication, partly through the increased growth of herring and sprat (Otterlind 1986, Nehring *et al.* 1989).

As a consequence of eutrophication and reduced transparency some benthic red and brown algae may disappear in shallow coastal areas and the vegetation may shift to floating filamentous plants (Kangas & Niemi 1985, Vogt & Schramm 1991). If the benthic vegetation disappears locally, spawning and nursery areas for fish larvae and young fish become smaller, which will result in reduced fish reproduction (Hansson 1985, Schulz & Nehring 1991). Low oxygen concentrations (<1 mg $O_2 \cdot l^{-1}$) can also develop in the algal belts, and an increase in the amounts of filamentous algae as a response to the eutrophication might constitute a new hazard to the reproductive success of the Baltic herring (Aneer 1985).

There has been changes in herring fishing due to the anthropogenic environmental impact. Trap-net catches have decreased in the inner bays, but increased in the outer zones in the sea area off Turku, SW Finland, obviously due to the lack of suitable spawning grounds in the eutrophicated inner bays (Kääriä *et al.* 1988). The same trend is also observed in the sea area off Helsinki (Halme & Hurme 1952, Sjöblom *et al.* 1979). Off the south-eastern coast of the Baltic Sea the amount of spring-spawning herring larvae has decreased as compared to the 1950s and this may be attributed to the reduction of spawning areas due to the anthropogenic impact (Grauman & Lisheva 1990). The decrease of herring year-class strength in the Gulf of Riga in 1980s in comparison the 1960-1970s was possibly caused by the increase of anthropogenic pollution of the Gulf (Trauberga & Line 1990). In the Gulf of Finland in the 1970s, a deterioration in reproduction conditions probably took place as a result of an increase in anthropogenic influences (Ojaveer *et al.* 1985). According to Raid (1991) the degradation of the conditions for the early development of herring has not yet seriously affected the reproduction of the stocks, but the continuous worsening of environmental conditions may begin to reflect on stock condition in the future.

The effects of increased eutrophication on herring and sprat stocks could thus be both positive and negative. It is difficult to evaluate the possible effects of eutrophication due to the other factors affecting the stocks. The changes observed in the Baltic Sea are the result of a combination of different causes. There is little information concerning the influence of environmental conditions on the pelagic fish stocks in the Baltic Sea, and more research is suggested (Baltic Marine Environment Protection Commission, 1990).

Greenhouse effect

Temperature. The predicted rate of increase of global mean temperature during the next century is about 0.1-0.3°C per decade, depending on the emissions. There will be spatial differences in the development of the temperature. The warming is predicted to be 50-100% greater than the global mean in high northern latitudes in winter (IPCC, 1990). If, however, the increasing temperature of the Earth weakens the Gulf Stream from the Sargasso Sea to the Norwegian coast, the warming of the northern Europe and thus the Baltic Sea can deviate from the common trend.

Stratification. Higher temperatures may result in lesser amounts of organic material reaching the bottom thus tending to favour the proliferation of a pelagic fish community (Frank *et al.* 1988). Conversely, there may be an increased vertical stratification of the water column due to higher freshwater discharge, higher temperatures and lower winds. The increased vertical stratification reduces the exchange of gases between atmosphere and deep water, which can result in oxygen deficiency at greater depths. This can cause failure of cod recruitment (Wieland & Zuzarte 1991). Diminishing predation of cod on Baltic herring and sprat can result in bigger stock sizes of pelagic fish. However, the harmful effect of strong vertical stratification on cod recruitment may be compensated by the increased inflows of saline water to the Baltic Sea.

Fish distribution and growth. Major chances in the distribution areas of Baltic herring and sprat are unlikely. Herring spawns in the whole Baltic Sea up to the northernmost Bothnian Bay. A slight increase in salinity due to the possible enhanced inflow from the North Sea to the Baltic would possibly enhance the reproduction of sprat in the northern Baltic Sea proper and in the Gulf of Finland, but would not make the salinity in the Gulf of Bothnia sufficient for successful sprat reproduction. An extended feeding period is possible and could lead to additional growth, as suggested for Atlantic herring (Frank *et al.* 1988).

Reproduction and radiation. A warm climate would obviously favour the reproduction of Baltic herring, as strong year classes often develop in the years with an early warm spring (Rannak 1971, Evtyukhova *et al.* 1989, Kaleis & Ojaveer 1989, Parmanne 1991).

As a result of stratospheric ozone depletion, UV radiation is likely to increase over the next few decades. Pelagic eggs of marine fishes may be quite sensitive to natural UV irradiation (Hunter *et al.* 1979). The key habitat parameter for assessment of UV effects is vertical distribution and to be greatly affected by increased UV radiation, the UV-sensitive stages of a species must occur primarily at depths of 5 m or less depending on the attenuation of UV in the habitat (Hunter *et al.* 1982). In the Baltic Sea water is more turbid than in the ocean, but a big proportion of herring larvae may occur in May and June close to the surface depths of 0-0.2 m (Schnack 1974, Sjöblom & Parmanne 1978). Thus the diminution of the ozone layer can be a threat to the Baltic herring larvae.

In response to a ozone reduction, zooplankton could be significantly impacted by UV-B radiation. The predicted increase in daily UV-B irradiance within the upper 1-2 m can cause a significant reduction in survival of most zooplankton species examined (Hardy & Gucinski 1989).

Uncertain future. There are still uncertainties regarding the magnitude and even direction of the final effects of climate change on Baltic herring and sprat remain large. A warming will likely be favourable for the fish growth and thus to the stock size, but increased radiation can be a threat for reproduction.

Fishery management in the Baltic Sea

In response to decreasing fish stocks in different areas of the northern hemisphere, the countries bordering the Baltic Sea agreed upon a convention, which obliges the governments to be active in the preservation of living resources in the Baltic Sea. The foundation for international management is the *Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts* from 13 September 1973 Gdańsk, Poland, which was ratified during 1974 by all Baltic States. The Convention states that, 'The Contracting States shall:

- co-operate closely with a view to preserving and increasing the living resources of the Baltic Sea and the Belts and obtaining the optimum yield,and, in particular to expanding and co-ordinating studies towards these ends .....'.

The *International Baltic Sea Fishery Commission* was established in 1974 in order to execute the intentions of the Convention. The Commission has chosen to regulate the fish stocks in the Baltic chiefly by annual catch limitations (Total Allowable Catches, TACs). Advice on the appropriate levels of stock sizes, of catches and exploitation 'within biologically acceptable limits', has been received from the ICES.

The goals expressed in the Convention as 'rational exploitation', 'increasing the living resources' or 'obtaining the optimum yield' have not been translated into more precisely expressed Management Objectives by the Commission. Such objectives for each stock, expressed in terms of minimum levels of stock sizes and/or preferred levels of exploitation should have been the background against which the annual TACs were to be decided.

Since national fishery zones were created in the end of the 1970s, the Commission has divided the agreed (species) TACs for the whole Baltic into smaller TACs for each one of the national fishery zones, whereas the ICES gives its advice per fish stock (assessment unit) whose area distributions in most cases do not coincide with fishery zones. The procedure makes it difficult for the Commission to cope with divergent developments in the stocks. A side-effect is that comparisons between recommended and agreed TACs has become difficult.

The combination of a decreasing demand for, and increasing abundance of Baltic pelagic fishes during recent years has made the need for restrictive management actions less pronounced. The IBSFC has under these circumstances agreed upon such high catch levels, that catches for the last 10 years have not reached the quotas (Figure 4). This situation will however probably change in the near future.

The large and efficient fleets that were attracted by the cod boom in the Baltic Sea in 1980-85 are switching their effort to pelagic species because of the rapidly decreasing cod supply. As the market for herring and sprat for human consumption is limited, large catches will be for fish meal and oil. The price relations between cod, herring/sprat and industrial fish are roughly 15 : 3 : 1. To get economical compensation for the loss of, say, 50 000 tonnes cod, catches of clupeoids must be in the order of 250 000-700 000 tonnes. Will the managers in this situation be able to adhere to the objective of sustained exploitation or will short-term socio-economic considerations jeopardize the pelagic stocks in the Baltic Sea?

Future research

The precision of stock assessment is dependent not only on the data quality (catches, age distributions, mean weights) but also on the level of mortality: the higher the mortality the better stock estimates. The present situation with low natural and low fishing mortality paradoxically increases the demands on auxiliary abundance information, such as results from hydroacoustic and young fish surveys. These surveys need better international coordination in time and space and a strict standardization of methodology. The survey results deserve more stringent analyses than carried out to date.

The models used for assessments, single species and multispecies, should be developed in several dimensions: by including more species of predators (e.g. seals and birds), by incorporating younger life stages (larvae, 0-group fish) and by increasing the spatial disaggregation with which the models can cope. The observed variation in distributions (and migrations) of both prey and predators should thereby be modelled in a more realistic way.

The predictions of future stock sizes and yield could be made more useful to managers by dividing the fishing mortalities between fishing fleets.

The vast problem-complex dealing with fish growth, feeding rates (stomach contents) and the dynamic of food organisms (zooplankton) deserves joint efforts from the countries bordering the Baltic Sea.

Intensified research on pelagic species in the Baltic is required but it is restricted by shortage of funds.

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