https://doi.org/10.17895/ices.pub.8877

ICES Marine Science Symposia, 215: 382–390. 2002

Changes in the perception of the migration pattern of Northeast Atlantic mackerel during the last 100 years

Svein A. Iversen

Iversen, S. A. 2002. Changes in the perception of the migration pattern of Northeast Atlantic mackerel during the last 100 years. – ICES Marine Science Symposia, 215: 382–390.

The perception of mackerel migration has changed over time from the old hypothesis that mackerel undertook relatively short migrations from spawning grounds off the coast to deeper waters nearby where they hibernated during the winter, to the present recognition of mackerel as a highly migratory species. The stock size and migration pattern of the different spawning components/stocks of mackerel in the Northeast Atlantic have changed over time and, as a consequence, the fishery and its management as well. Changes in the migration pattern of Western mackerel were observed, particularly when the North Sea mackerel collapsed in the late 1960s. They migrated more extensively into the Norwegian Sea and North Sea, probably in effect replacing the depleted North Sea mackerel. A tagging experiment in 1994 demonstrated that Southern mackerel mixed with and followed the same migration route as the Western mackerel.

Keywords: management, migration, Northeast Atlantic mackerel.

Svein A. Iversen: Institute of Marine Research, PO Box 1870 Nordnes, 5817 Bergen, Norway; tel: +47 55 23 84 07; fax: +47 55 23 85 55; e-mail: sveini@imr.no.

Introduction

Atlantic mackerel (*Scomber scombrus* L.) is distributed in European and African waters from Morocco to northern Norway, in the Skagerrak, the Kattegat, the Baltic Sea, the Mediterranean, and in the Black Sea. In the western Atlantic, it is found from Labrador to Cape Lookout, North Carolina (USA).

The investigations of mackerel on both sides of the Atlantic started within ICES following a suggestion by Dr Hugh Smith, representative of the United States to ICES, at a meeting in Copenhagen in 1910 (Nilsson, 1914). The issue raised was the cause of the decline in catch in the US fishery from 500 000 barrels in 1885–1886 to only 3000 barrels in 1910. Smith proposed two hypotheses for this decrease in availability: 1) migration to western Europe, or 2) changes in physical conditions affecting the development of the eggs and young stages and resulting in poor recruitment. This meeting triggered a first attempt at tagging mackerel in 1911 as well as two papers by Ehrenbaum (1914) and Nilsson (1914) which summarized old and new information about different aspects of the migration patterns and biology of mackerel, based on studies of the spatial and temporal distribution of the fishery, biological parameters of mackerel, and plankton samples.

Sixty years later, in 1970, the ICES Liaison Committee focused on another drastic decline in mackerel stock size, this time in the North Sea (ICES, 1970). The Committee evaluated North Sea mackerel in subsequent years until the ICES Mackerel Working Group was established and met for the first time in 1974 (ICES, 1974). In 1992 (ICES, 1992), this group was replaced by the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy (WGMHSA). Since 1974, the Working Group has met annually, among other things, to describe the temporal and spatial distribution of both the fishery and the stocks. Since 1995, the WGHMSA (ICES, 1995) has combined mackerel from different areas into a single Northeast Atlantic mackerel stock. This stock consists of three spawning populations or components named according to their spawning areas: Southern, Western, and North Sea. The Southern component spawns in Spanish and Portuguese waters and the Western component spawns in the Bay of Biscay and northwards around Ireland and west of Scotland. Because the egg distribution of the Southern and Western components overlaps in the Bay of Biscay, it is impossible to define the northern border of the Southern component and the southern border of the Western component. The third component spawns in the North Sea and is considered to be a distinct stock (Iversen, 1999; ICES, 2000a).

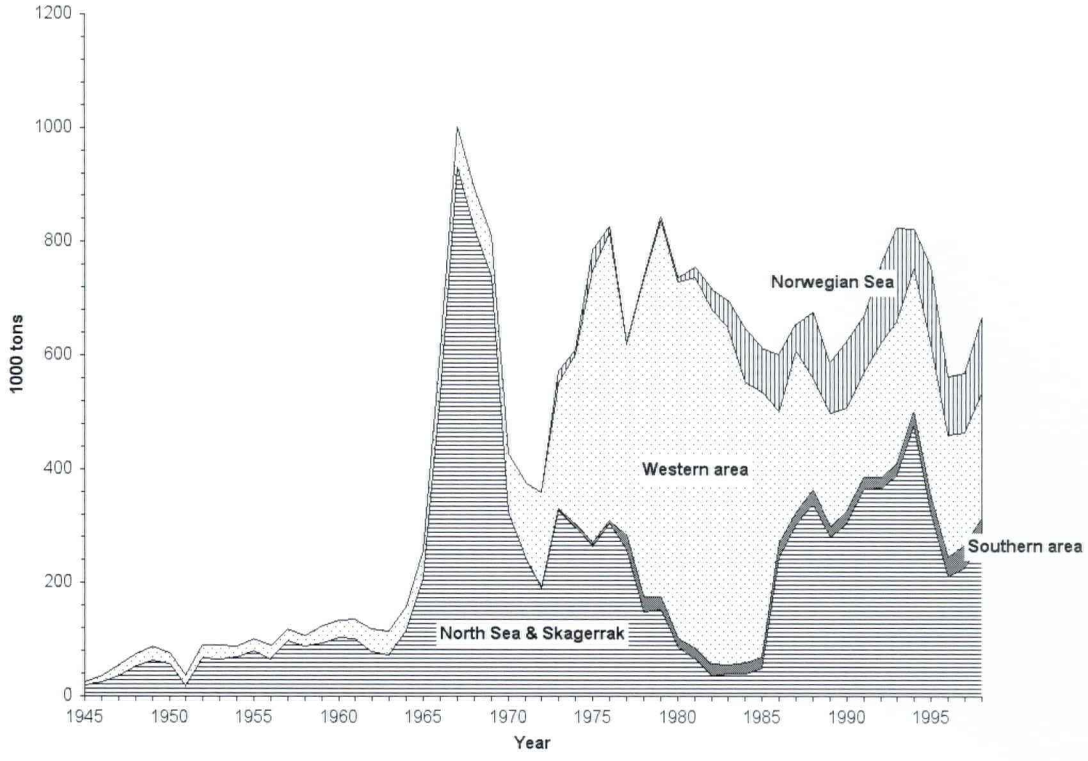

Figure 1. The development of mackerel catches by area, 1945–1998.

Materials

The study of mackerel migrations over the years has been based on the distribution of the fishery, plankton surveys (i.e., mackerel eggs), tagging data, and, to some extent, trawl and acoustic surveys.

The fishery

Figure 1 shows the development of the mackerel fishery since 1945. The fishery was hardly regulated or managed until 1970, after which time different measures such as quotas, closed areas, etc. have been introduced. Until the late 1960s, the North Sea stock was large, with a spawning stock biomass of about 3.5 million t in 1965. The fishery expanded greatly in this area resulting in a rapid stock decline and a collapse in the early 1970s, with no subsequent evidence of recovery (Iversen and Eltink, 1999; ICES 2000b). During this period, North Sea catches were relatively low, but increased in the 1980s when the Western and Southern mackerel changed their migration pattern by migrating substantially into the North Sea and Norwegian Sea to feed. This was reflected by increased catches in the North Sea and by the start of a new mackerel fishery in the Norwegian Sea in the 1970s (Figure 1), where catches increased from 200 t in 1970 to 100 000 t in 1986 and have since stabilized at this level.

The latest report from the WGHMSA (ICES, 2000a) presents catch statistics since 1977 from the southern area where catches increased from a low level of about 15 000 t to 44 000 t in 1998 (Figure 1).

Tagging experiments

Nilsson (1914) and Ehrenbaum (1914) cited without reference that Dr Weigold tagged 350 specimens of mackerel at the Helgoland Biological Station in the summer of 1911 using aluminium rings. The rings, the same type used for tagging birds, were placed around the caudal peduncle. Two of the tagged fish were recovered, one shortly after liberation close to the tagging area and the other about 70 days later at Dunkirk.

The next tagging experiment was carried out by Arne Revheim during the summer of 1950 when 560 mackerel were tagged outside Bergen and in the Hardanger Fjord using an external Lea tag (Figure 2) attached to the back of the fish by a steel loop (Revheim, 1951). He tried different ways of attaching modified tags to the fish during 1950–1953. From 1954 to 1963, Norway

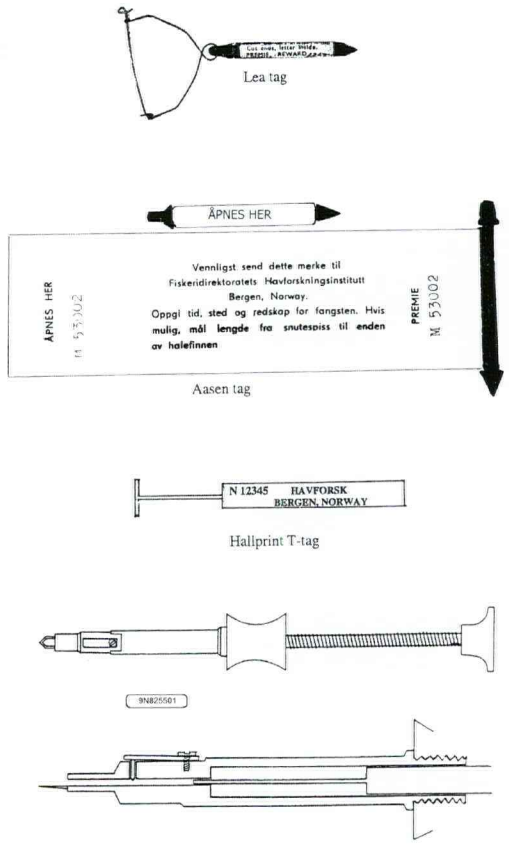

Figure 2. Different tags and tagging equipment used for mackerel.

tagged mackerel annually with modified Lea tags (Aasen tag) attached with a nylon gut loop (Figure 2). The Aasen tag consists of a yellow plastic sheet (alcatene) with number and text rolled onto a blue plastic spool. More than 35 000 fish were tagged during this period, and the tagging area was extended to include the southern part of Norway and the western part of the Norwegian Skagerrak coast.

Norway started using internal tags on mackerel in 1966 (Revheim, 1966; Hamre, 1970). A little steel tag (Figure 2) was inserted with a special tagging pump (Myklevoll, 1994). This method had been developed for herring in the 1950s (Fridriksson and Aasen, 1952). The mackerel tagging programme in the North Sea was carried out every year until 1987, during which 231 000 tagged fish were released.

Norway started another tagging programme in 1970 in the area west and southwest of Ireland and, in some years, also in the Hebrides, Shetland, and Orkney areas. This programme has been carried out in May each year, except 1987, until the present time. During these years, 482 000 tagged fish were released. Most of the fish were tagged with internal steel tags, but also some with Hallprint T-tags (Figure 2). The experiment with steel tags was started mainly for stock assessment purposes at a time when most of the catches were used for meal and oil production; the tags were retained on magnets installed in the factories. Since most of the catches in later years were used for human consumption, special tag screeners were developed and installed at two of the main Norwegian factories processing mackerel for human consumption (Hoff *et al.*, 1988).

Other mackerel tagging experiments were conducted elsewhere as follows:

Denmark: 800 Lea hydrostatic tags in 1959, and 899 internal steel tags in 1969 (Agger, 1970a, 1970b).

England: Bolster (1974) summarized English tagging experiments carried out in the western UK during 1962–1967. Tagging mortality experiments were conducted in 1975 (Eaton, 1978, 1980).

The Netherlands: 418 T-tags in 1963 (Postuma, 1965).

Scotland: 8133 internal steel tags/external tags during the period 1974–1980 (Rankine and Walsh, 1982).

Spain: 10 000 internal steel tags in 1994 (Uriarte, 1995).

European Union: About 150 000 internal and external T-tags were released in 1997 and 1998 by Portugal, Spain, Ireland, and Norway. The taggings were carried out in the southern area (Divisions IXa and VIIIc east and west), southwest and west of Ireland, Scotland, Orkneys, Hebrides, and Shetland. Adult fish were tagged in all areas, while juvenile fish were tagged in Division IXa and in Donegal Bay (Anon., 1999a).

Returns from the different tagging experiments have been used in assessing stock size, mortality, and migration patterns and in allocating catches in the North Sea and Norwegian Sea to the western and North Sea mackerel stocks.

Information from these tagging experiments was used by the authors mentioned above as well as by ICES working groups. However, there is undoubtedly considerably more information remaining to be extracted from the tagging data.

Hamre (1970) and Eaton (1980) investigated the mortality caused by tagging and respectively determined rates of 18% and 22%. Both authors concluded that the handling of the fish was probably the main reason for the mortality.

The historic perception of mackerel migration

According to Ehrenbaum (1914), "Anderson who was the mayor of Hamburg, well known for his theories as to the sources of herring, wrote in 1746 that the mackerel, like herring, hibernated in the Arctic regions thereby making long migrations thence each year. A French admiral declared that his men had seen thousands of mackerel in the bays of the Greenland coast in the spring, the fish having buried their heads in the mud, and hibernating in that position, as a result of which they became blind, and were thus very easily caught."

However, the more common view was that mackerel hibernated at the bottom during the winter rather close to the areas where they were observed and fished during the summer.

According to Sars (1869,1878), the home of mackerel was the Atlantic Ocean along the entire west coast of Europe from the Orkneys and west of Scotland to the Mediterranean. He suggested that they were widely dispersed and formed schools only when approaching the coasts for spawning. This migration probably took place at different depths, but not at the bottom. Sars thought that mackerel which visited the Scandinavian coasts might remain in the North Sea, while the great majority returned to the open Atlantic before returning to the North Sea the next season, generally through the English Channel, but with some probably taking a northern route around the coast of Scotland. He thought that the Channel was the "principal seat" of the mackerel.

Like most other scientists, Allen (1898) also assumed that the spawning area was close to the coast, both in the western area and in the North Sea. When fishing mackerel with handlines (feathering) during the spawning time, only males were reportedly caught, implying that females stopped feeding during spawning time. It is difficult to ascertain the source of these observations because later data showed that mackerel of both sexes feed and are caught by handline throughout the spawning season. Allen referred to the first approach to the coast as the spawning migration and the second approach later in the summer-autumn to the same areas as the feeding migration. At that time, there was no information about the location of the wintering area. Sars (1869,1878) and Browne Goode (referred to by Allen, 1898) had both demonstrated that the old theory of mackerel hibernating at the bottom during the winter was unrealistic. Allen suggested two alternative wintering theories: 1) close to the surface in the open ocean far from the coast, or 2) in deeper layers of the sea close to their summer localities (the coast); but he preferred the second alternative.

Garstang (1898) studied meristic parameters of mackerel from European and American waters and concluded that no transatlantic migration of mackerel could occur. This was subsequently confirmed by the fact that no fish tagged on one side of the Atlantic was ever recovered on the other side. He found close agreement between American and Canadian mackerel, and also concluded that Irish and Channel mackerel belonged to different races and only migrated from shallow to deeper waters at the same coast. He also concluded that North Sea mackerel, which he restrictively defined as fish occurring only off the east coast of England from Yarmouth and southwards, migrated from the Channel in the spring and returned to that area in the autumn, thus ensuring a complete mixture of Channel and North Sea mackerel during the winter. Garstang divided the Irish race into western and southern parts and concluded that the southern Irish race was rather similar to the Channel race since they shared the same wintering area.

Ehrenbaum (1914) agreed with Sars that the reason for the coastward migrations was spawning. He concluded that mackerel spawned close to shore except in the North Sea where they also spawned in open waters, particularly the southern part which he regarded totally as a spawning ground. Later investigations demonstrated that some spawning takes place along the coast and in the fjords, but the main spawning area is located in the open North Sea (Iversen, 1973).

Ehrenbaum also summarized data from the European mackerel fisheries and concluded that mackerel were widely distributed in the North Sea, west and south of Ireland, in the Mediterranean, and in the Black Sea. In parts of the Black Sea, he found that the fishery for mackerel was the most important one.

The modern perception of mackerel migration

North Sea mackerel

Based on the catches of the Dutch trawl fleet and results from the Dutch and Norwegian tagging experiments (Revheim, 1951, 1954, 1955), Postuma (1965) concluded that North Sea mackerel wintered in and close to the Norwegian Deep, moved in different directions in the spring, and returned to the wintering area in the autumn. Hamre (1978) summarized the migration pattern of North Sea mackerel as observed before the stock collapsed in the late 1960s. After spawning, parts of the stock migrated northwards around Shetland during July/August. In September/October, they migrated from the Kattegat and Skagerrak (Agger, 1970a) and the northern part of the North Sea to the Reef in the eastern North Sea. High mackerel abundance in the latter area provided the basis for a Dutch trawl fishery (Postuma, 1972). Later in the autumn, mackerel moved to deeper waters in the northern part of the Norwegian Trench, Shetland area, and Viking Bank for wintering. In April/May, they returned to the surface layer for feeding, and migrated towards the spawning area in the central part of the North Sea and Skagerrak. Little is known of the present migration of this stock. Mapping of the spawning area

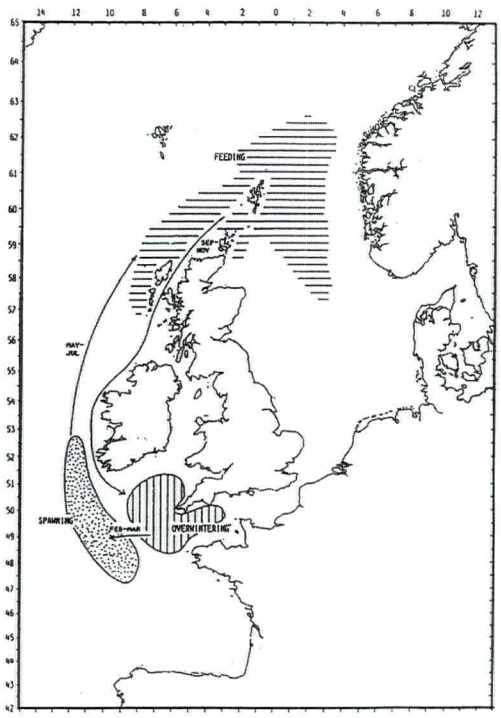

Figure 3. Schematic outline of the migration of the adult Western mackerel stock in the late 1970s (ICES, 1990).

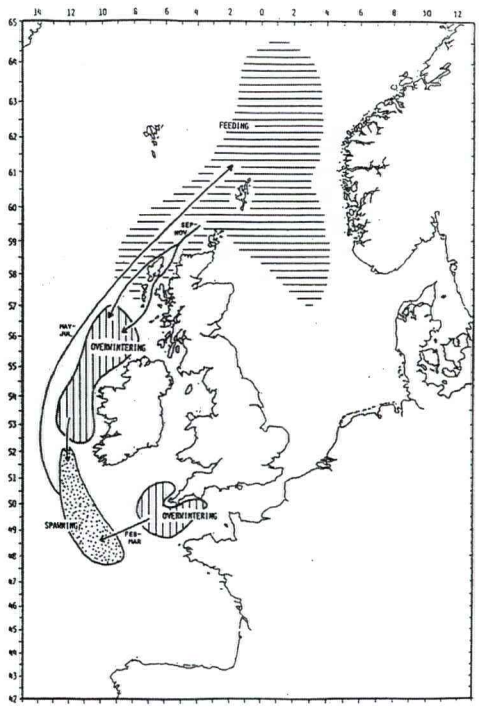

Figure 4. Schematic outline of the migration of the adult Western mackerel stock in the early 1980s (ICES, 1990).

since the late 1960s suggests that the main area has moved southwesterly in recent years (ICES, 2000b). It is assumed that North Sea mackerel still have a migration pattern similar to that described by Hamre (1978).

Western mackerel

Based on tagging experiments, Hamre (1971) described an extensive migration of mackerel from the western area after spawning into the northwest part of the North Sea (Shetland area) in July–August. Bolster (1974) found a similar migration, based on the English tagging experiments in 1962–1967, to the Shetland area, but also demonstrated a migration eastwards along the south coast of England and north coast of France where they mixed with North Sea mackerel. This view was adopted by the first ICES Mackerel Working Group (ICES, 1974). Norwegian tagging data (Hamre, 1971) indicated that about 30% of the mackerel in the Shetland area were North Sea fish and about 70% were Western fish. This feeding migration to the Shetland area subsequently moved more extensively into the North Sea and Norwegian Sea (Bakken and Westgård, 1986; Iversen and Skagen, 1989). Based on a shift in the main fishing area in the early 1980s, Walsh and Martin (1986) postulated that this was due to changes in distribution of the fish and suggested that they might stem from major variations in the strength of the North Atlantic drift at the shelf edge. When the drift was strong, Western mackerel had a more northerly distribution during the feeding migration, and when the current was weak, the fish migrated more directly into the North Sea. Reid *et al.* (1997) hypothesized that the migration from the spawning area follows the cooler water surrounding the warm saline core of the Shelf Edge Current. Western mackerel usually stayed in the North Sea until the end of the year, but in later years, this duration was observed to be prolonged until February/March (Reid and Eltink, 1999).

Steven (1948) demonstrated that the old hypothesis that mackerel in the western area spawned along the coast was false. He showed that spawning took place in open waters, particularly around the 200-m line. This was confirmed by the international triennial egg surveys carried out since 1977. Mackerel spawn in the western area during March–July and then migrate northwards to feed. Joint working groups of European Union (EU) and Norwegian scientists (ICES, 1988, 1990) reviewed and discussed available information on mackerel migrations from different sources. These two reports described the shift in distribution and migration pattern of Western mackerel in the late 1970s (Figure 3), the early 1980s (Figure 4), and in the latter half of the 1980s (Figure 5). Considerable changes have been observed over the years

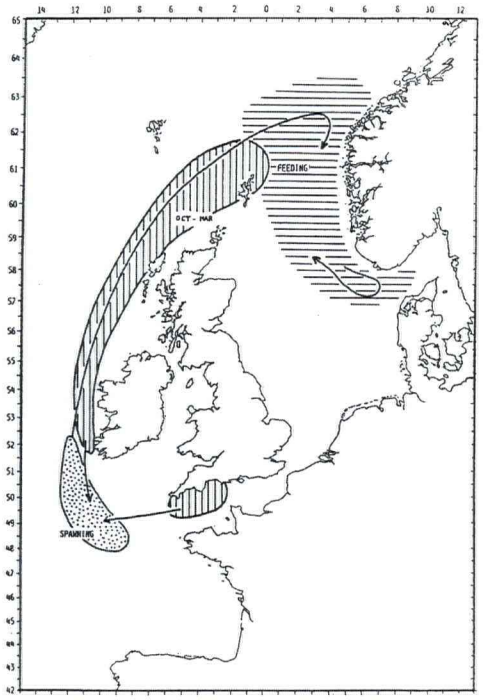

Figure 5. Schematic outline of the migration of the adult Western mackerel stock in the latter half of the 1980s (ICES, 1990).

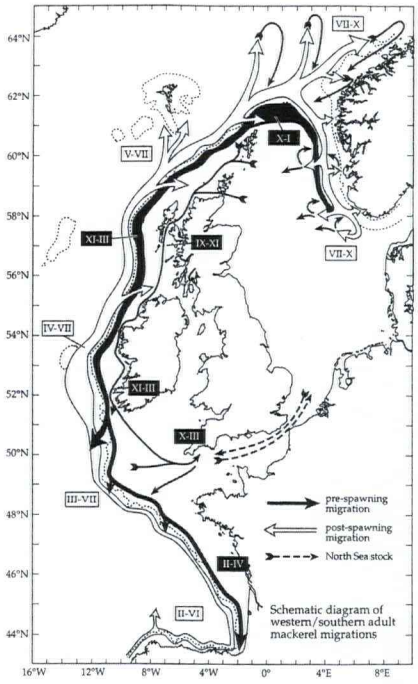

Figure 6. Schematic diagram of Western/Southern adult mackerel migrations from the SEFOS project (Anon., 1997). Roman numerals = months.

in the feeding migration and the wintering area. The wintering area has extended northwards from southwest of England to Irish and later Scottish waters. Similarly, the feeding area around Scotland and Shetland has been extended into the North Sea and Norwegian Sea.

Southern mackerel

Little was known about the distribution and migration patterns of mackerel in the southern area until a tagging experiment was carried out in 1994. This revealed that fish, after spawning in the southern area, migrated northwards, mixed with Western mackerel, and entered the Norwegian Sea and North Sea (Uriarte, 1995).

Other studies

In recent years, when the North-East Atlantic Fisheries Commission (NEAFC) attempted to construct a management regime for mackerel in international waters, distribution and possible migration patterns in the Norwegian Sea were explored (Belikov *et al.*, 1998). Russian scientists used specially equipped aircraft to study the distribution of mackerel schools in international waters of the Norwegian Sea (Anon., 1999b).

Two large EU projects completed in 1997 (Anon., 1997) and in 1999 (Anon., 1999a) dealt rather extensively with mackerel:

1) SEFOS or the Shelf Edge Fisheries and Oceanography Study (Anon., 1997) was an EU-supported project carried out in 1994–1996. This project studied migration based on tagging experiments, acoustic surveys, and the spatial and temporal distribution of the fishery. This is the most extensive analysis published about mackerel migration in recent years. Figure 6 gives a schematic diagram of Western/Southern adult mackerel migrations. This migration path covers quite well the present perception of the migration of Southern and Western mackerel. However, the arrows indicating the migration of the North Sea mackerel in Figure 6 do not reflect the migration pattern of this stock, and the migration and distribution in the northern part of the Norwegian Sea is rather limited. Relatively large catches have been taken both in the international and in the Faroese economic zones of the Norwegian Sea in recent years. A suggested migration pattern in these areas is shown in Figure 7 (Belikov *et al.*, 1998).

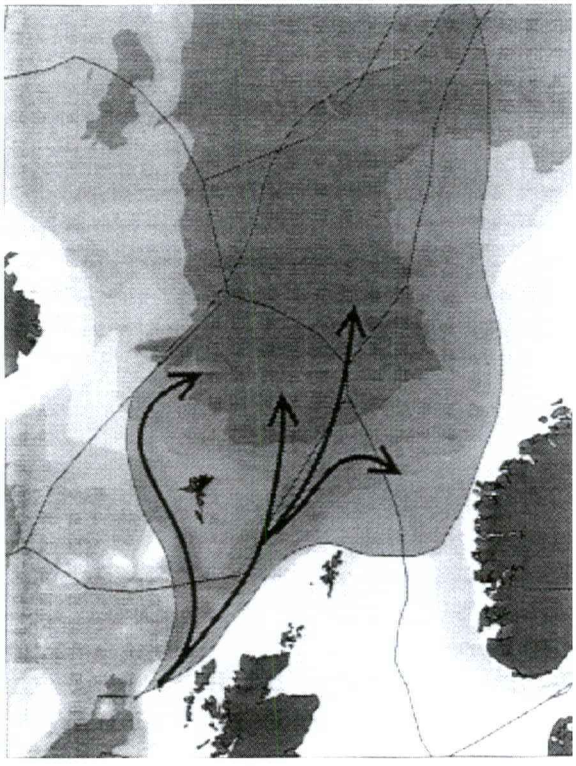

Figure 7. A likely migration pattern and summer distribution for mackerel in the Norwegian Sea (Belikov *et al.*,1998).

2) The EU tagging project 96-035 (Anon., 1999) demonstrated that adult fish from western and southern areas migrated northwards west of the British Isles and Ireland at the end of the summer and in early autumn (1997 and 1998) into the Norwegian Sea and northern part of the North Sea. Mackerel may also enter the North Sea through the Channel, but it was not possible based on this study to conclude whether or not this is an important migration route. The return migration to the spawning grounds in winter followed the same route, but in the opposite direction.

Migration patterns and management of the fishery

Owing to the collapse of the North Sea stock, the fishery was considerably restricted in this area. However, given the recent change in migration pattern of Western fish into the Norwegian Sea and North Sea after the spawning season, larger quotas were accepted in these areas. To protect the North Sea stock and immature mackerel which were observed in considerable quantities in the central and southern North Sea, ICES, for many years, recommended closing Divisions IVb,c for the entire year. The northern part of the North Sea (ICES Division IVa) and the Norwegian Sea have been open for fishing during the second half of the year after the Western (and Southern) mackerel have entered the area. Since these mackerel have left the area later in recent years (Reid and Eltink, 1999), ICES recommended prolonging the fishing period by one month in 2000. However, data from the fishery in the first quarter of 2000 (Reid, 2000) demonstrated that the Western and Southern mackerel probably left the North Sea in December 1999. It will be interesting to follow the fishery in coming years to see if the migration patterns are changing again.

The Southern, Western, and North Sea mackerel mix in the North Sea and Norwegian Sea during the second half of the year. Since it is impossible to allocate the catches in these areas to the different components/stocks, ICES has assessed these three components/stocks as a unit, Northeast Atlantic mackerel (ICES, 1995), since 1995.

The recent development of the fishery in the Norwegian Sea has demonstrated that mackerel migrate into Faroese waters, and consequently the Faroe Islands are now recognized as the third so-called "mackerel coastal state" together with the EU and Norway. Except for international waters, where no management regime has yet been agreed, the EU and Norway have traditionally set the mackerel quotas. When the Faroe Islands became a "coastal state" in 1999, the quota for 2000 was established trilaterally.

Acknowledgement

Many authors have worked on topics relevant to the understanding of mackerel migration patterns. The author has been unable to cite all of these papers and apologizes for that omission. However, Lockwood's 1988 book *The Mackerel. Its Biology, Assessment and the Management of a Fishery* has to be mentioned. I want to thank my colleagues Johannes Hamre, for reading and commenting on the manuscript, and Sigmund Myklevoll, who has tagged mackerel every year since 1962 and for the nice overviews he has made of all the Norwegian tagging experiments.

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