# Stock Annex: Mackerel (*Scomber scombrus*) in subareas 1–7 and 14 and divisions 8.a–e, 9.a (the Northeast Atlantic and adjacent waters)

Stock specific documentation of standard assessment procedures used by ICES.

**Stock:** Mackerel

**Working Group:** Working Group on Widely Distributed Stocks (WGWIDE)

Created:

Authors:

**Last updated**: September 2019

**Last updated by:** WGWIDE 2019. T. Brunel, T. Jansen, L. Nottestad, A. Campbell and S. Sánchez

## A. General

### A.1. Stock definition

Atlantic mackerel (Scomber scombrus) occurs on both sides of the North Atlantic and has traditionally been grouped into five spawning components, some of which have been thought to be isolated natal homing populations. Previous studies have provided no evidence of cross-Atlantic migration and no, or weak, support for isolated spawning components within either side of the North Atlantic (Jansen and Gislason, 2013).

ICES currently uses the term "Northeast Atlantic (NEA) mackerel" to define the mackerel present in the area extending from the Iberian peninsula in the south to the northern Norwegian Sea in the north, and Iceland in the west to the western Baltic Sea in east.

In the Northeast Atlantic, mackerel spawn from the Portuguese waters in the south to Iceland in the north and from Hatton Bank in the west to Kattegat in the east. Spawning starts in January/February in Iberian Peninsula waters and ends in July to the north-west of Scotland and in the North Sea (ICES, 2013a). While spawning varies locally from day to day (Bakken, 1977; Iversen, 1981), it seems to form one large spatio-temporal continuum on the larger scale. However, relatively low levels of spawning in the English and Fair Isle channels separates the main spawning areas in the North Sea from the western areas along the continental shelf edge (Johnson, 1977). Recent studies on distribution, eggs distribution and abundance and mark–recapture experiments (Reid, 1997; Uriarte and Lucio, 1996; Uriarte et al., 2001) have questioned the limits of previously established stocks and proposed to consider NEA mackerel as one single stock divided into three spawning components. These components are not completely independent but reproductive exchanges occur, and no differences were observed between these components outside the spawning season (Jansen and Gislason, 2013). Despite this lack of complete spatial or temporal separation, NEA mackerel is divided into three distinct entities, namely the Southern, Western and North Sea spawning components (ICES 1977; 2013.a). Catches cannot be allocated specifically to spawning area components on biological grounds, but by convention; catches from the Southern and Western components are separated according to the areas in which these are taken:

| Mackerel in the Northeast Atlantic | | | |
|---|---|---|---|
| Mainly distributed and fished in ICES Subareas and Divisions 2.a, 3.a, 4, 5, 6, 7, 8, and 9.a | | | |
| Spawning component | Western | Southern | North Sea |
| Main spawning areas | 6, 7, 5, 3.a,b,d,e, | 8.c, 9.a | 4, 3.a |

The Western component is defined as mackerel spawning in the western area (ICES Divisions and Subareas 6, 7, and 8.a,b,d,e). This component currently accounts for ~75% of the entire Northeast Atlantic stock. Similarly, the Southern component (~22%) is defined as mackerel spawning in the southern area (ICES Divisions 8.c and 9.a). Although the North Sea component has been at an extremely low level since the early 1970s, ICES considers that the North Sea component still exists as a discrete unit (~3%). This component spawns in the North Sea and Skagerrak (ICES Subarea 4 and Division 3.aN).

Jansen and Gislason (2013) recently reviewed the concept of spawning components on the basis of spawning and age distribution data. Spawning intensities, proxied by larval abundances, were found to be negatively correlated between the North Sea and Celtic Sea, which indicates that the two spawning components may be connected by substantial straying. This finding was based on unique larvae samples collected before the collapse of North Sea component, thus showing that the exchange is not a recent phenomenon due to the collapse. Furthermore, analyses of old as well as more recent age distributions showed that strong year classes spread into other areas where they spawn as adults (i.e. "twinning"). The authors found that this was in accordance with the lack of solid evidence of stock separation from previous analyses of tagging data, genetics, ectoparasite infections, otolith shapes, and blood phenotypes. Because no method has been able to identify the origin of spawning mackerel unequivocally from any of the traditional spawning components, and in the light of their results, they concluded that straying outweighs spatial segregation. Jansen and Gislason (2013) therefore proposed a new model where the population structure of mackerel was described as a dynamic cline, rather than as connected contingents. Temporal changes in hydrography and mackerel behaviour may affect the steepness of the cline at various locations (Jansen, 2014; Jansen and Gislason, 2013; Jansen *et al*., 2013).

### A.2. Fishery

As a widely distributed and migratory species, NEA Mackerel is exploited over a wide geographic range throughout the year. Significant fisheries extend from the Gulf of Cadiz, along the western and northern Iberian costs, through the Bay of Biscay, S, W and N of the United Kingdom and Ireland, into the northern North Sea and the Norwegian Sea and, in more recent years as far north as 72°N and west into Icelandic and east Greenland waters.

The fishery is international and, as such it is exploited by several nations using a variety of techniques determined by both the national fleet structure and the behaviour of the mackerel. At the onset of the spawning migration, large mackerel shoals move out of the northern North Sea initially to the west before moving south down the west coast of Scotland and Ireland. The timing of this migration is variable but generally occurs around the end of quarter 4 and the start of quarter 1. During this time, they are targeted primarily by Scottish and Irish pelagic trawlers with RSW tanks and also by freezer (factory) vessels (primarily Dutch and German). Prior to the onset of this migration the mackerel are overwintering, relatively static and are targeted by a large Norwegian purse-seine fleet. During summer, the mackerel are more widely dispersed as they feed in Northern waters. At this time Russian pelagic freezer trawlers and, in more recent times, Icelandic, Faroese and Greenlandic pelagic vessels are active. The southern fishery takes place at the start of the spawning season upon completion of the spawning migration. The Spanish fleet is comprised of both bottom and pelagic trawlers and also a large artisanal fleet. There are other smaller scale fisheries such as a Norwegian gillnet fleet and an English handline fleet that operates in the otherwise restricted area known as the Cornwall box.

There exist a number of national and international agreements to control the exploitation of the NEA Mackerel stock. Targeted fishing is prohibited in the North Sea with the purpose of protecting the North Sea stock component which has failed to recover from extremely heavy exploitation during the 1970s. The Cornwall box is an area off the SW coast of England that is a known juvenile area. It supported a very large fishery prior to its introduction in the early 1980s after which the only permitted fishing in this area is by handliners. A number of countries have discard prohibition. Unfortunately, there has been no overarching agreement in the most recent period which would permit control of the overall exploitation and catches have exceeded advice. Since 2015 within the EU a landing obligation comes into force, under this new law all the species managed through TACs and quotas must be landed. Due to its gradual implementation, at the moment it only affects to all the EU pelagic and industrial vessels but by 2019 it is expected to affect all European commercial fisheries.

## A.3. Ecosystem and behavioural aspects

### A.3.1. Feeding

Post larval mackerel feed on a variety of zooplankton and small fish. They prefer larger prey species over smaller prey (Pepin *et al*., 1987; Langoy *et al*., 2006). Feeding patterns vary seasonally, spatially and with size. Mackerel stops feeding almost completely during winter. Main zooplankton prey species in the North Sea are: Copepods (mainly *Calanus finmarchicus*), euphausiids (mainly *Meganyctiphanes norvegica*), while primary fish prey species are: sandeel, herring, sprat, and Norway pout (Walsh and Rankine, 1979; Mehl and Westgård, 1983; ICES, 1989; ICES, 1997). In the Norwegian Sea euphausiids, copepods (mainly *Calanus finmarchicus* and *Oithona*), *Limacina retroversa, Maurolicus muelleri,* amphipods, Appendicularia and capelin are the main diet during the summer feeding migration (Langoy *et al.,* 2006; Prokopchuk, 2006; Langoy *et al*., 2010).

In the North Sea, mackerel and horse mackerel are responsible for virtually all of the predation on 0-group herring as well as a large part of the consumption of 0-group Norway pout and of all ages of sandeel (ICES, 2008). Mackerel has also fed opportunistically on available NSS herring larvae along the continental shelf coast of Norway (Skaret *et al*., 2014). This may have a significant impact on the herring larval survival rate, and largely depends upon the degree of overlap in time and space, which can vary from year to year.

Spatial and temporal overlap between NEA mackerel and Norwegian spring-spawning herring particularly in the outskirts or periphery of mackerel distribution (northern Faroese, Icelandic and Jan Mayen waters) may cause increased interspecific competition between mackerel and herring for preferred food such as *Calanus finmarchicus* (Debes *et al.*, 2012; Langøy *et al.*, 2012; Óskarsson *et al.*, 2012). Mackerel may partly outcompete herring during summer because mackerel are generally larger, faster, more enduring when migrating and more effective plankton eaters, including a wider food niche (wider diet breadth) than herring (Nøttestad *et al.*, 2012). Mackerel may thus both compete better for preferred zooplankton species and size fractions as well as better utilize smaller plankton species available in the northern part of the Northeast Atlantic Ocean compared with herring.

The mackerel seems to be very opportunistic, and from one year to the next they may exploit any available oceanic areas for feeding purposes (Langøy *et al.*, 2012). A westwards and northwards expansion has been observed in the Nordic Seas in recent years (since 2007), as far as Icelandic and south Greenlandic waters in the west and as far north as Spitzbergen (Nøttestad, 2014). Historically, expansions into Icelandic waters are known to coincide with periods of warm waters (Astthorsson *et al.*, 2012).

The dynamics and environmental drivers of the mackerel summer distribution are not yet uncovered. Surveys in recent years indicate substantial interannual variation and provides hypothesis on relations to temperature and food (Holst and Iversen, 1992; Holst and Iversen, 1999; Gill *et al.*, 2004; ICES, 2006; ICES, 2007; ICES, 2009). When the mackerel stock is large (as in the recent years) and plankton abundance is low, mackerel has to spread out further to the north and to the west to forage on suitable plankton aggregations. The record high surface temperatures observed in the Nordic Seas during summer in recent years (Hughes *et al.*, 2011; Nøttestad *et al.*, 2012) made this expansion possible and has resulted in an increase in the potential feeding habitat for mackerel (as defined by water temperatures above 6°C).

### A.3.2. Spawning

Even though spawning occurs widely on the shelf and shelf edge from the Bay of Biscay to the southern Norwegian Sea, most of the egg production is concentrated in two core spawning areas (Figure A.3.2.1). One elongated area along the shelf break from Spanish and Portuguese waters in January to March, and one around southwest Ireland to the west of Scotland where spawning peaked in April (Beare and Reid, 2002; Iversen, 2002) but the spawning peak has shifted to March in the most recent years. In the central North Sea spawning takes place in May–July.

Spawning activity along the shelf edge has varied to the north and to the south at various times over the decades since the 1980s although the centre of gravity of spawning has remained relatively stable off the southwest of Ireland over this period (Hughes, 2013; Beare and Reid, 2002) In the North Sea there is a westward shift in the main spawning area from the central part of the North Sea in the early 1980s to the western part in recent years (2005 and 2008) (Anon, 2009).

In the recent period (since the 2007 survey) an expansion of the spawning distribution for the western spawning component has been observed (ICES, 2013b). Spawning occurs now further to the west (up to 20° of latitude west) and to the north (up to the southern Norwegian Sea) (ICES, 2013b; Nøttestad *et al*., 2012; 2013). However, most of the egg production of the western component remains in the traditional spawning grounds, located on the shelf edge in the southwest of Ireland to the west of Scotland. The egg production in the new areas remains marginal. The causes of this geographical expansion of spawning remain unclear, but are suspected to be triggered by the increase in the stock size (i.e. density-dependent space occupation) coupled with changes in the potential spawning habitat linked to environmental conditions (ICES, 2013b). As a consequence of this expansion of spawning to the North, juveniles 0-group mackerel are now found in the Nordic seas (Iceland, Barents sea, ICES 201 3.a).

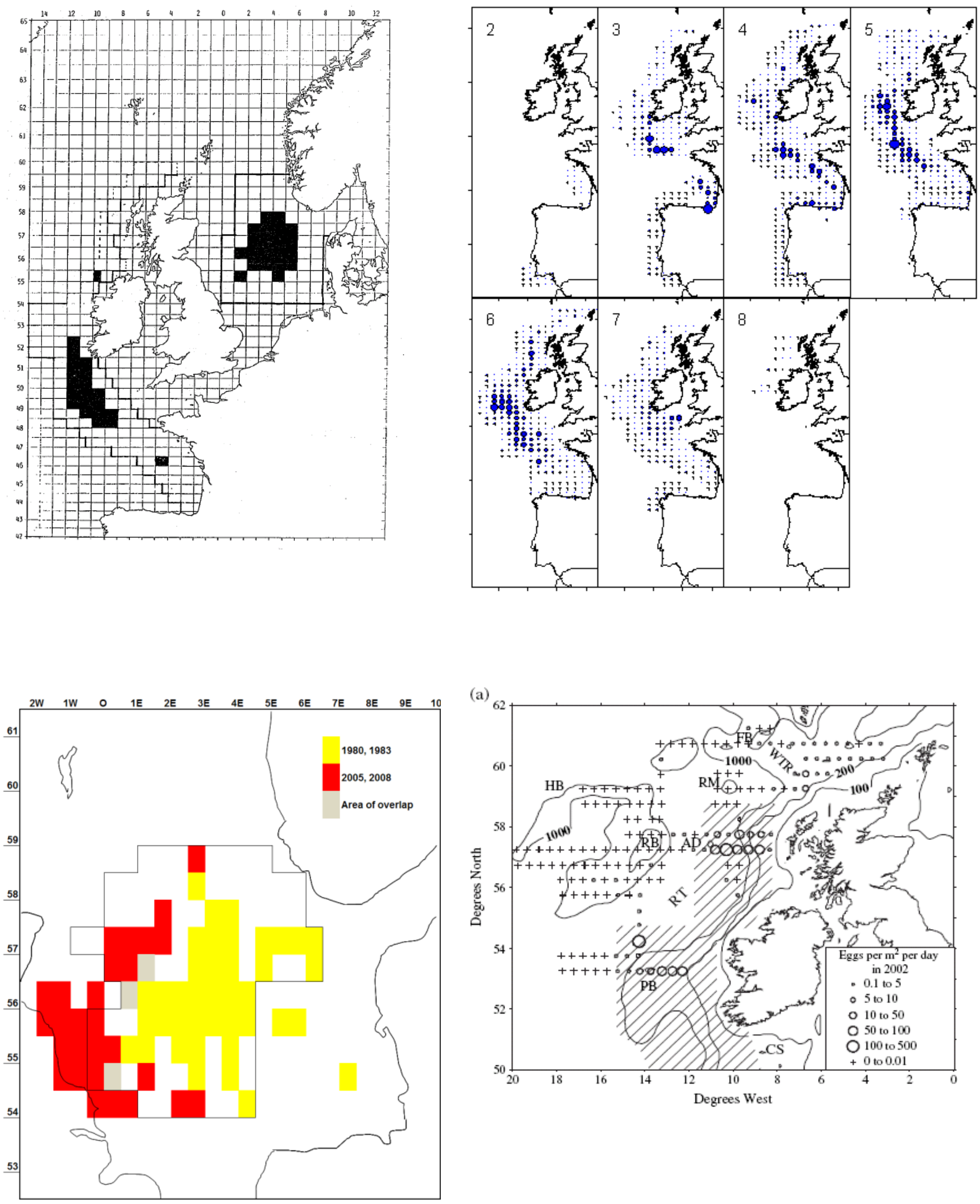


**Figure A.3.2.1. NEA mackerel spawning areas. Upper left: Shaded areas indicate 100 eggs/m2 in at least two of the years in the period 1977–1988 (from ICES, 1990). Upper right: Average distribution of mackerel eggs by ICES statistical rectangle in 1992–2007, each map represents a survey between February and August (from Anon, 2009). Lower left: North sea spawning area defined by a daily egg production of at least 50 mackerel eggs per m2 of sea surface in any of the years 1980, 1983, 2005 and 2008 (from Anon, 2009). Lower right: Experimental survey in May 2002 (from Dransfeld et al., 2005).**

## A.3.3. Migration

Mackerel performs extensive migrations between spawning grounds, feeding grounds and overwintering areas. The migration pattern has changed substantially through time (see Figure A.3.3.1).

Tagging studies (Uriarte and Lucio, 1996; Belikov *et al*., 1998; Uriarte *et al*., 2001) have demonstrated that mackerel travel from both the western and southern spawning ground north up into the North Sea and Nordic Seas. The migration can be considered as having two elements;

1 ) A post-spawning migration from the spawning areas along the western European shelf edge (Uriarte *et al.*, 2001);
2 ) A pre-spawning migration from feeding grounds in the North and Norwegian Seas (Walsh *et al.*, 1995; Reid *et al.*, 1997). This pre-spawning migration includes shorter or longer halts that sometimes are referred to as overwintering.

Studies of the timing and the routes for the post-spawning feeding migration are limited. Patterns of food and temperature related distributions in the Norwegian Sea in summer are emerging from summer surveys in the Norwegian Sea in 1992 and 2002–2009. However, the big picture of when and where is the thermal preference dominating/subordinate in relation to other activities like feeding, spawning and predator avoidance remains to be drawn.

Swimming speed during migration is related to fish length (Pepin *et al.*, 1988). Tagging has shown that juveniles of the southern/western component do not migrate as far as the adults (Uriarte *et al.*, 2001). The larger fish reaches furthest to the north and west during the feeding migration in summer (Holst and Iversen, 1992; Nøttestad *et al.*, 1999; Anon 2009; ICES, 2009). This effectively results in a spatial gradient in the mean length of the fish measured during the IESSNS (Nøttestad *et al.*, 2012; 2013), with larger mean length in the north and west, and smaller mean length to the southeast. Similarly, the large mackerel also arrive to the feeding areas (observed in eastern Danish waters) before and leave later than small mackerel (Jansen and Gislason, 2011).

When the NEA mackerel return in late summer and autumn from the feeding areas on the European shelf and in the Nordic Seas, they aggregate through autumn and early winter along the continental shelf edge, where they are targeted by commercial trawlers and purse-seiners. Later in winter the commercial fleets and the fisheries-independent bottom-trawl survey find the mackerel further towards the southwest. The path of the migration, as suggested by the location of commercial and survey catches coincides with the location of the relatively warm high saline eastern Atlantic water flowing northeastwards on and along the continental shelf edge, flanked by cooler water masses. The mackerel population is found further upstream in warmer waters as the current cools through winter and this process is associated via climatic variability, with large impacts on the mackerel migration and fisheries (Jansen *et al.*, 2012; Walsh and Martin, 1986; Reid *et al.*, 2003; Walsh *et al.*, 1995; Reid *et al.*, 1997; Reid *et al.*, 2001). However, other factors than temperature preferences are affecting the mackerel behaviour and can in different scenarios have different weights. D'Amours and Castonguay (1992) showed that mackerel from the northern component of the West Atlantic mackerel migrated into Cabot Straight with approximately 4ºC in order to get to their spawning grounds. They argued that the fish's thermal preferences could be subordinate to their reproductive requirements, a point supported by the fact that this stock always enter the Cabot Straight around the same date (Anon., 1896; Castonguay and Beaulieu, 1993).

The Spanish spring fishery in the Bay of Biscay has been occurring earlier each year, and since this fishery is targeting spawning mackerel, this indicates that the spawning migration in the southern component occurs earlier each year (Punzon and Villamor, 2009). In winter 2011–2012 the timing of the spawning migration was even more pronounced in the Cantabrian Sea from early January to February compared to March and April just some years ago.

However, the triennial egg survey in 2013 showed that the peak of spawning in the Cantabrian Sea was later than in both 2007 and 2010. Mackerel egg surveys gave indication of earlier spawning for 2010 and 2013 in the western spawning component with a peak in egg production early in March compared to the earlier years when peak production was in centered on May. However, the timing of the spawning in the Southern component, although variable, mainly occurs in April.

Timing of overwintering, spawning migration and spawning of the NEA mackerel has previously been linked to temperature, with, e.g. earlier overwintering and spawning related to increased temperatures (Reid *et al*., 1997; Jansen *et al*., 2012; Punzón and Villamor, 2009; Jansen and Gislason, 2011). In spring and summer 2012 the measurements of plankton concentrations were among the lowest in the entire time-series since 1996 in the northern and western parts of the Northeast Atlantic.

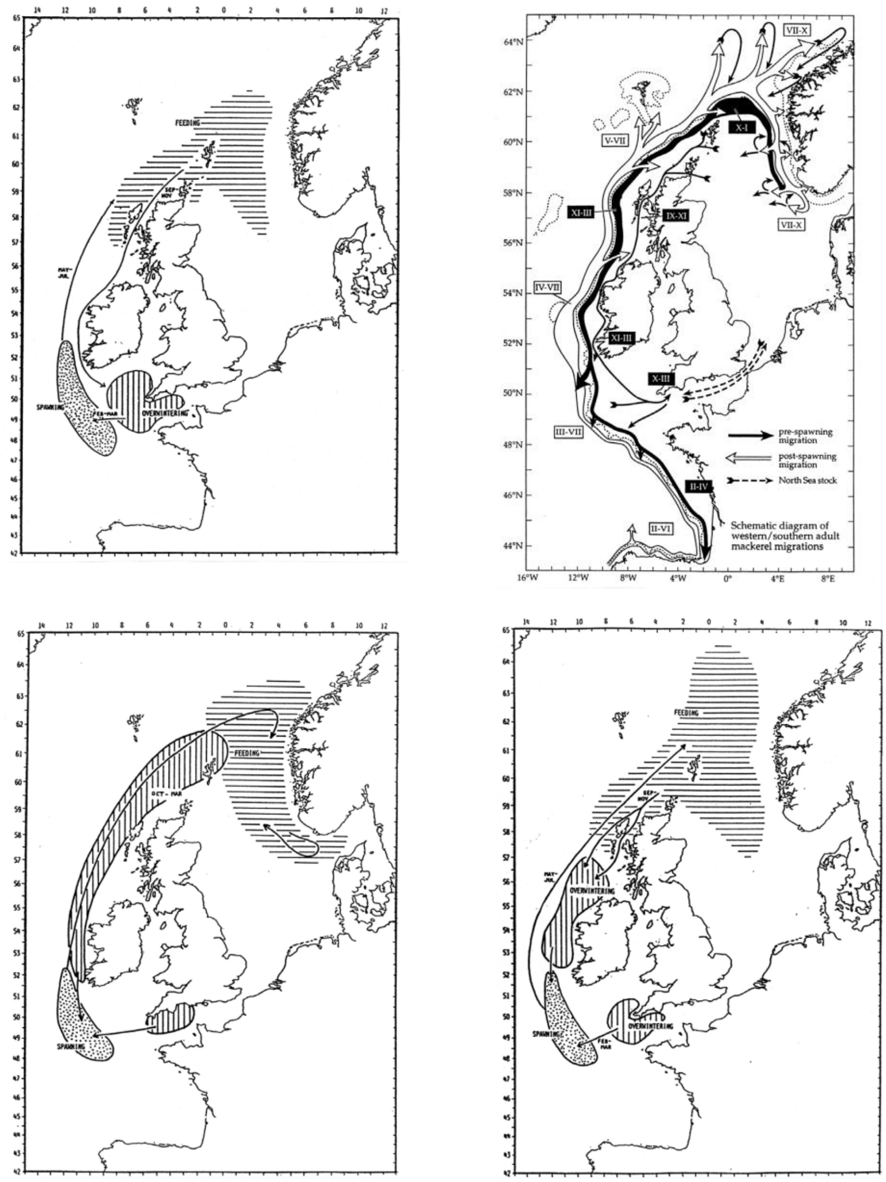


**Figure A.3.3.1. Schematic outline of the migration of the western and southern (in top right map) adult mackerel through time. From left: late 1970s (ICES, 1990), early 1980s (ICES, 1990), latter half of 1980s (ICES, 1990), mid-1990 (Anon, 1997).**

## B. Data

### B.1. Commercial catch

#### Data Compilation and Archiving

Prior to the annual assessment WG, national data submitters are responsible for submitting details of commercial catch and the associated sampling (carried out under the DCF in EU countries) to the stock coordinator. This information is supplied aggregated to ICES subarea and quarter. The data are usually detailed in an Excel spreadsheet (known as the 'exchange format'). Information on misreported catches, unallocated catches and discards can also be included on the spreadsheet. An up to date fleet description and a breakdown of catch by ICES statistical rectangle are also requested. For nations with minor (and generally unsampled) catches, the stock coordinator will retrieve the data from the Statlant database, hosted by ICES.

Upon completion of error checking, the stock coordinator will compile the data in order that it can be used in the assessment. A key step in this process is the allocation of samples to unsampled catches. The stock coordinator will choose appropriate samples (and their relative weightings) on the basis of fleet type, quarter and geographic area. Once the samples have been assigned the stock coordinator will produce a vector of catch numbers, weights and lengths in addition to the total catch. This was traditionally done using a bespoke software application known as *sallocl* (Patterson, 1998). Presently, a web-based data portal known as InterCatch is used which is hosted by ICES and has the advantage of acting as a central repository for the data. Frequent comparisons are made using both approaches as a quality check.

#### Discards

The working group has estimated the level of discards since 1978. However, this is based on estimates provided by only a few countries and is routinely identified as being an underestimate. The level of underestimation is variable and unknown.

The primary reason for the discarding or slipping (where the entire catch is released prior to being brought on board) of mackerel is on the basis of size. The discarding of high proportions of the total catch resulted in the establishment of the Cornwall box catch restrictions around the SW coat of England. Small mackerel is also often caught in the horse mackerel directed fishery, primarily in the English Channel, and is subsequently discarded either because of quota restrictions or unfavourable market conditions. Widespread discarding of fish weighing under 600 g also occurred in the early 1990s in response to the high prices paid for large fish which has been proposed as a possible reason for the low abundance of some year classes.

#### Data quality

If they are in possession of supplementary information, national data submitters can identify misreported catches. Often, catches will be transferred from one ICES area to another to account for information on misreporting. While not considered to be an issue in recent years, there is evidence of large-scale misreporting between ICES Subareas 4a and 6.a and 4.a and 2.a in the past.

A significant proportion of the complete catch time-series is considered to be of relatively poor quality in that it is believed that there is a significant underreporting of catch. A study into unaccounted mortality (Simmonds, 2007) suggested significant unaccounted mortality equivalent to 1.6 to 3.4 times the reported catch. This unaccounted mortality could be the result of unreported discards and slipping, fish that escape but subsequently die or unreported catch. Improved monitoring and stricter reporting requirements have resulted in improved confidence in recent years.

## B.2. Biological

### B.2.1. Weighting of spawning components

The SSB estimates from the egg surveys in the North Sea and the western/southern area are used to compute the proportion of the NEA mackerel represented by each of the three spawning components. For a complete time-series of proportion of each component, see the report of the 2014 Benchmark Workshop on Pelagic Fish (ICES, 2014b) and the WGWIDE reports since then.

### B.2.2. Weight-at-age in stock

The mean weights-at-age in the stock are based on available samples from the area and season of spawning of each of the spawning components.

For the southern component, stock weights are based on the samples from the Portuguese and Spanish catch taken in 8.c and 9.a in the 2nd quarter of the year, complemented by egg survey samples when available. For the Western spawning component, samples come from commercial catches, and when available, the egg survey for the areas and months corresponding to spawning (Table 2.2.1). In addition, fish sampled during the May tagging experiments by Norway in the northwest of Ireland are also included. For the North Sea spawning component, mean weights-at-age were calculated from samples of commercial catches collected from Area 4a in June combined with data collected during the North Sea egg survey in May–June when available.

There are occasional year with missing data in the mean weights per spawning component (especially age 1). Since trends are present in the mean weights at age, it was considered appropriate to fill these gaps using the local average (among the 5 neighbouring years), which are more likely to be representative of the weight of the specific year with missing data than, for instance, a mean over the whole time series.

The mean weights-at-age for the total stock are then calculated as weighted mean of the weights in each component, where the weighting is the egg survey based estimate of SSB in the three components. For a complete time-series on mean weights-at-age in the three components see the report of the 2017 Benchmark Workshop on Pelagic Fish (ICES, 2017) and the WGWIDE reports since then.

**Table 2.2.1. Areas and month corresponding to the core spawning used for the selection of samples to compute mean stock weights-at-age in the western component. Establish based on egg survey results (see ICES, 2017).**

| MONTHS | ICES SUBDIVISION |
|---|---|
| March | 7.b,j,h, 8.a,b |
| April | 6.a, 7.b,c,j,h, 8.a |
| May | 6.a, 7.b,c,j,k, 8.a,d |

### B.2.3. Proportions of individuals mature at age

The proportions of individuals mature at age are based on the following information:

North Sea component: The present proportions mature were calculated in 1984 on the basis of analysis of Norwegian biological samples from June–August 1960–1981. This revealed that 74% of the two year-old mackerel, which appeared in the catches, were sexually mature. By comparing fishing mortalities for II-group mackerel with the fishing mortalities for the 3-group the year after, when they are fully recruited to the spawning stock, it seems that about 50% of the II-group mackerel are available to the fishery. Assuming that only the spawning component of the stock is available in the fishery, maturity ogive for the North Sea stock was estimated (ICES, 1984).

Western component: Since the 2014 mackerel benchmark (ICES, 2014b) time varying proportions of individuals mature at age are calculated based on samples from the Dutch, Irish, German and UK commercial catches collected from February to July. Proportions of mature fish at age were calculated grouping the data in blocks of five years, and moving this five-year window from 1980 to the terminal year in the assessment. Due to the scarcity of samples for age 1 fish, the time varying estimate for this age is replaced by the mean across all years.

Catch data for the western component originate from different areas. Analysis done during the 2017 benchmark (ICES WKWIDE 2017) have shown that the proportion of juveniles is higher in some areas (Celtic Sea, English Channel) than others (Bay of Biscay, west of Ireland, West of Scotland). Since the proportion of the data coming from these different areas vary over time, this can introduce changes in the proportion of individual mature at age, not linked to actual changes in maturation schedules, but to variation in the proportion of the samples coming from areas of higher juvenile concentration. It was therefore decided, as a way of standardizing for potential variations in the spatial origin of the samples, to compute separate maturity ogives for each of 5 geographical zones (see table below), and to take the average of these ogives, weighted by the respective size (in $km^2$) of these geographic areas.

| GEOGRAPHICAL AREAS | ICES SUBDIVISIONS | WEIGHT |
| --- | --- | --- |
| Bay of Biscay | 8.ab | 7.3% |
| Eastern Celtic Sea | 7.a,e-h | 20.7% |
| West Ireland | 7.b,c,j,k | 26.7% |
| West Scotland | 6.ab | 42% |
| English Channel | 7.d | 2.9% |

Southern component: Based on a histological analysis of mackerel samples collected during the 1998 Egg Survey (ICES, 2000; Perez *et al.*, 2000).

The proportions of mature mackerel-at-age for the total stock are calculated as the mean of the proportions in the three spawning components weighted by the respective size of each component (as estimated by the egg surveys).

#### B.2.4. Natural mortality and proportion of F and M before spawning

Natural mortality (M) has been fixed at 0.15 for decades. This value was calculated based on estimates of total mortality derived from tagging data combined with catch data (Hamre, 1980). The first mackerel working group report where this value was given in was 1983 (ICES, 1984).

Given the variability of the time of spawning, time varying proportions of F and M before spawning are used. The time of spawning is calculated for both the western and southern spawning component in each egg survey year as the Julian day where 50% of the total egg production has occurred. The time of spawning for the whole stock is then taken as the average of the time in these two components (weighted by their respective size). Assuming that natural mortality is constant through the year, the proportion of M occurring before spawning is equal to the proportion of the year before spawning time.

The proportion (per age group) of the catches taken before spawning time are calculated for each survey year as the sum of the quarter 1 catches plus the necessary proportion of the quarter 2 catches (if spawning time occurs in the second quarter) or as the necessary proportion of the catches in the first quarter (if spawning time occurs in the first quarter). Proportions of fishing mortality before spawning ($F_{prop}$) per age group are then estimated using an optimizer to find the $F_{prop}$ value which minimizes the (square of the) difference between the observed proportion of catches before spawning, and the proportion of catches before spawning calculated based on the $M_{prop}$ value and F at age values from the last available assessment. In order to reduce the effect of the noise in the data, average $F_{prop}$ values are calculated by groups of age-classes: ages 1–2, ages 3–4 and ages 5 and older. $F_{prop}$ for age 0 is by convention set to 0.

Time-series of $M_{prop}$ and of $F_{prop}$ at age based on linear interpolation between survey years are used as input to the assessment model. The $M_{prop}$ and $F_{prop}$ values of the latest survey are used for the most recent years, but these values are updated using linear interpolation when a new survey is carried out.

## B.3. Surveys

### B.3.1. Mackerel Egg surveys (MEGS)

Two mackerel egg surveys have been performed since 1968. Both are triennial survey and are presently only adding new information to the time-series every third year. The Atlantic survey that started in 1977 covers the western–southern spawning grounds in the Northeast Atlantic while the other survey covers the spawning in the North Sea and Skagerrak (Figure A.3.2.1).

Each survey is split into several sampling periods covering the whole spawning area in order to get an egg production curve covering the whole spawning season. Plankton samplers currently used are Gulf 7 high speed plankton samplers or Bongo plankton nets with a mesh size of 280 µm. The Gulf samplers are open torpedo-shaped frames with a flowmeter mounted in the nosecone to measure the volume of water sampled. The Bongo's are ringnets with 280 µm mesh size. All samplers are towed in double oblique hauls at a speed of approximately 5 knots. Next to the plankton samples pelagic trawl samples of adult fish are collected in order to determine the sex ratio and collect ovary samples to estimate fecundity and atresia of female fish.

All eggs are sorted out from plankton samples and identified to species. The mackerel eggs in the samples are staged according to development (Lockwood *et al.*, 1981). The stage 1 eggs are used to estimate the daily egg production per sampling period. The total annual egg production is then calculated by integrating all periods in the egg production curve. Spatio-temporal coefficient of variation (CV) of the egg production is estimated. The mackerel SSB is estimated by dividing the total annual egg production by the realized fecundity of the females and multiplying by the sex ratio. The coordination of the surveys and SSB estimation are the responsibility of the working group for mackerel and horse mackerel egg surveys (WGMEGS). Preliminary results are reported by WGMEGS to WGWIDE in the year of the survey, the results of the survey are finalized and reported in the year after the survey.

#### B.3.2. International Bottom Trawl Surveys (IBTS)

Observations from bottom-trawl surveys conducted between October and March from 1998 to the assessment year was compiled. Surveys conducted on the European shelf in the first and fourth quarters are collectively known as the International Bottom Trawl Survey (IBTS). All surveys sample the fish community on the continental shelf and upper shelf slope. IBTS Q4 covers the shelf from Spain to Scotland, excluding the North Sea, while IBTS Q1 covers the shelf waters from north of Ireland, around Scotland, and into the North Sea.

Trawl operations during the IBTS have largely been standardized through the relevant ICES working group (ICES, 2013c). Trawling speed was generally 3.5–4.0 knots, and trawl gear is also standardized and collectively known as the Grande Ouverture Verticale (GOV) trawl. Some countries use modified trawl gear to suit the particular conditions in the respective survey areas. In some cases, the standard GOV was modified, which was not expected to change catchability significantly. However, subsequent trawls deviated more significantly from the standard GOV type, namely the Spanish BAKA trawl, the French GOV trawl, and the Irish mini-GOV trawl. The BAKA trawl had a vertical opening of only 2.1–2.2 m and was towed at only 3 knots. This was considered substantially less suitable for catching juvenile mackerel and, therefore, was excluded from the analysis. The French GOV trawl was rigged without a kite and typically had a reduced vertical opening, which may have reduced the catchability of pelagic species like mackerel. Catchability was assumed to equal the catchability of the standard GOV trawl because testing has shown that the recruitment index was not very sensitive to this assumption (Jansen et al., 2015). Finally, the Irish mini-GOV trawl, used during 1998–2002, was a GOV trawl in reduced dimensions. The reduced wingspread and trawl speed were accounted for in the model (Jansen et al., 2015).

A geostatistical log-Gaussian Cox process model (LGC) incorporating spatio-temporal correlations was used to describe the catch rates of mackerel recruits over space and time. The modelled recruitment index (square root transformed catch rate) surface in autumn year Y-1 and winter year Y was mapped every year.

The time series of spatially integrated recruitment index values are used in the assessment as a relative abundance index of mackerel at age 0 (recruits).

Data handling, modelling and post processing of the model output has been described in detail in Jansen *et al*. (2015).

#### B.3.3. International Ecosystem Summer Survey in Nordic Seas (IESSNS)

IESSNS is a swept-area surface trawl survey targeting the Northeast Atlantic mackerel stock as they feed in Nordic seas during summer (Nøttestad *et al.*, 2016). The survey provides an age-segregated index of mackerel and is the only annual fishery independent tuning series used in the mackerel assessment (ICES, 2014b). The survey was first executed in 2007 and annually since 2010. Survey coverage has gradually expanded to follow the geographical expansion of the mackerel stock. In 2016, four nations (Norway, Iceland, Faroe Islands and Greenland) and five vessels participated in the survey covering approximately 3 million km$^2$, which is double the coverage in 2007.

Trawl design, its operation, and sampling protocol are standardized between vessels and nations (ICES, 2013c). This includes a specifically designed and standardized pelagic trawl (Multpelt 832) towed in the surface at the speed of 5 nmi for 30 minutes using a curved tow track (ICES, 2013b; Valdemarsen *et al.*, 2014; Nøttestad *et al.*, 2016). Trawl opening is approximately 30 m vertical height * 60 m horizontal spread. Trawl rigging maintains headline at surface during trawling. For details on trawl design, rigging and operational details see Valdemarsen *et al.* (2014), ICES (2013c) and Nøttestad *et al.* (2016). Trawl catch sampling involves total catch weight, species composition determined from a subsample of total catch, and age is recorded for 10 – 25 individuals.

The survey is considered a “static point sampling survey” with a survey design focusing on representative sampling of mackerel and to prevent double counting of individuals. The design includes predetermined location of trawl stations and survey transects. Transects are from east to west, except in Icelandic exclusive economic zone (EEZ) where transects are across-shelf north and south of Iceland. The survey begins in the southern part of the Nordic seas, in the beginning of July, and heads northward as the 30-40 days survey period progresses. Three different methods have been used to determine transect/station location from 2007 to 2016:

- 2007 – 2011: distance between transects ranged from approximately 40-60 nmi and distance between stations on a transect ranged from 30-60 nmi. The first transect located in the middle of first rectangle (defined as the rectangle where the survey starts) and the first station manually located approximately 10 nmi from beginning of first transect. Other transects and stations located approximately at the predetermined distance from the first transect/station. Effort varies between different parts of the Nordic seas.
- 2012 – 2014: distance between transects ranged from approximately 40-60 nmi, but distance between stations varies (30 – 60 nmi) with latitude as the aim was to have one station in each rectangle (rectangle size: 1°latitude by 2°longitude). First station location, on transect, was manually selected with an aim to minimize sailing time. Other transects and stations located approximately at the predetermined distance from the first transect/station. Effort varies between different parts of the Nordic seas.
- 2015 onward: stratified random sampling within eight permanent and two dynamic strata implemented. Permanent strata are constant between years and cover the core mackerel distribution area in the Norwegian Sea and in the Icelandic EEZ. The dynamic zones are located at the westward and the northward distribution range periphery. Distance between stations varies between strata and ranges from 40 nmi to 80 nmi. Within each strata, there is equal distance between all stations and transect. A combination of spatial variance in mackerel abundance, in years 2010-2014, and available survey time determines effort. Effort increase as abundance and spatial variability in abundance increases.

The IESSNS index was first included in the mackerel assessment at the mackerel benchmark in February 2014 (ICES, 2014b). At the time, the index was calculated as an annual age-segregated density index including age 6 – 11, and year 2007 and from 2010 onwards. The density index was the total estimated biomass divided by the geographical survey area where mackerel was present. The index was calculated by gridding the survey area into rectangles (rectangle size: 1°latitude by 2°longitude in years 2007-2014, and 2°latitude by 4°longitude in 2015-2016) using a R-code. The area south of latitude 62 °N in the North Sea (east of longitude -2 °W) was excluded from further analysis (ICES, 2014b). Justification of index calculation method was apparent lower catchability of fish at age <6, variable and expanding coverage of the IESSNS survey coverage between years, uncertainty in catch efficiency with respect to vertical distribution of the stock in the North Sea, and the fact that the survey is only covering the oceanic part of the stock leaving out mackerel further south. Thus the age-disaggregated indices constructed for analytical assessment purpose was spatially restricted to Nordic Seas, leaving out North Sea south of 62°N, delimited to age 6+ and scaled by the total area covered each year (number of fish per square km; equivalent to catch-per-unit-effort).

Prior to the benchmark in January 2017, it was decided to revise how the IESSNS index was calculated as three more years of IESSNS data had been collected. The revised index is an annual age-segregated abundance index including age 3 – 11, and year 2010 and from 2012 onwards (Olafsdottir *et al.*, 2017). The index is calculated using stratified approach in the StoX software (Salthaug *et al.*, 2017). Survey coverage was acceptable for the included years; hence, the density index was replaced by an abundance index. Ages 3 to 5 were included as internal consistency has improved compared to the 2014 benchmark (ICES, 2014b), and a large proportion of the stock is in this age range. Years 2007 and 2011 were excluded due to limited spatial coverage of the survey compared to the other years (ICES, 2017a). Southern boundary of the survey area were set at latitude 60 °N as in the years 2010, and from 2012-2016, where there is sufficient coverage for the area north of 60 °N given the stratification method used to calculate the index. For details, see Olafsdottir *et al.* (2017).

### B.4. Commercial cpue

### B.5. Other relevant data: Tagging data

Steel tags

Institute of Marine Research in Bergen has conducted tagging experiments with internal steel tags on mackerel since 1969, both in the North Sea and west of Ireland and the British Isles during the spawning season May–June. In the assessment prior to 2017 the tagging time-series was restricted to releases of the western component during the years 1977–2004 and from screening of commercial catches at factories with metal detectors from 1986–2006. During this period, the same methodology was used during both the tagging process and screening, and it was hence suggested to be a very consistent time-series. Tagging with the steel tags continued until 2009 with screening until 2010. However, a change in the fishing process from manual jigging to automatic tagging machines, which could have induced differences in post tagging mortality, as well as some uncertainty regarding screening efficiency at the factories, led to the conclusion that this part of the time-series should be excluded from the assessment.

RFID tags

The radio-frequency identification (RFID) tagging project on NEA mackerel was initiated in 2011, and replaced the manual method with steel tags, at the Institute of Marine Research, Bergen (IMR) in Norway. RFID is a technology that uses radio waves to transfer data from an electronic tag, called an RFID tag, through a reader for the purpose of identifying and tracking the object. The RFID tagging project has moved away from manual and expensive system to an automatic and cost-effective scanning system. The actual format of the tagging data used in the assessment is as numbers tagged of a year class in a specific year, the numbers recovered of this year class from that release year in all successive years, as well as the numbers screened by year class in all years.

In the WKPELA benchmark 2017 the RFID time series in terms of numbers per year class released, screened and recaptured per release year and recapture year was accepted for use in the assessment from 2017 onwards. During the period 2011—2016 as many as 313 558 mackerel has been tagged with the new tags and 2430 of these tags have recaptured. This includes an experiment off the Norwegian Coast on young mackerel in September 2011 as well as three experiments carried out in August in Iceland 2015-2017, none of which is included as input data in the assessment. In the assessment only data from the releases at the spawning grounds in May-June of Ireland and the Hebrides are included.

The RFID-tagged mackerel are currently recaptured at 17 European factories processing mackerel for human consumption. The project started with RFID antenna reader systems connected to conveyor belt systems at 8 Norwegian factories in 2012. Now there are 5 operational systems in at 4 factories in UK (Denholm has 2 RFID systems), 3 in Iceland, 1 at the Faroes and 1 in Denmark

There is a web-based software solution that is used to track the different systems, import data on catch information, and biological sampling data of released fish and screened catches. Based on this information the system can estimate numbers released and screened by year class in a known biomass landed, which is used to estimate abundance by year class and totally. Research institutes, fisheries authorities or the industry need to provide additional data about catches screened through the RFID systems, such as total catch weight, position of catch (ICES rectangle), mean weight in catch, etc. Regular biological sampling of the catches landed at these factories is also needed. Altogether, these data are essential for the estimation of numbers screened per year class, which is needed as input to the tag data-table currently used in the SAM-assessment for steel tags.

Since the 2019 inter-benchmark process (ICES 2019), only a subset of the RFID data collected is used in the assessment. Investigation conducted at this benchmark indicated that the recapture rates of the given tagging experiment tended to decrease over time (potentially indicating long term mortality due to tagging, tag loss, tag malfunction), which contributed in introducing spurious trend in the assessment, if the whole data set is used. To avoid this bias, only the first 2 years of recapture are used for each tagging experiment. In addition, other criteria's were applied to the data that could be used (removing data from fish tagged as 4 years old or younger, excluding the first two years of tagging experiment, 2011 and 2012).

# C. Historical stock development

## The assessment model

### SAM

A benchmark assessment for NEA Mackerel was carried out in 2014 during the Benchmark Workshop for Pelagic Stocks (WKPELA: ICES, 2014b). Following this benchmark investigation, the tool chosen for the assessment is SAM, the state–space assessment model (Nielsen and Berg, 2014). Since 2014, this method has been implemented using both the R package *stockassessment* and the online webpage interface on [www.stokassessment.org](www.stokassessment.org).

In SAM, the "states" (fishing mortalities and abundances-at-age) are constrained by the survival equation and follow a random walk process. The variances of the random-walk processes on abundances and fishing mortalities are parameters estimated by the model.

SAM is a fully statistical model in which all data sources (including catches) are treated as observations, assuming a lognormal observation model. The corresponding variances, so-called observation variances, are also parameters estimated by the model. Observations variances can be used to describe how well each data source is fitted in the model and effectively correspond to the internal weight given by the model to the difference data sources.

The other parameters estimated are the catchabilities of the surveys.

Uncertainties (standard errors) are estimated for all parameters and for all states (Fs and Ns).

#### Modifications to SAM for the NEA mackerel assessment

In the SAM mackerel assessment, tagging–recapture data from the Norwegian tagging program are used as input data. In order to incorporate the tagging–recapture information, tag recoveries (per year and for each year class) were predicted from the model, based on the number of fish screened in the processing factories, the amount of tagged fish of the same year class released in the previous years, and the corresponding abundances of this year class in each release year estimated by the model, conditional to a post-release survival rate (time invariant and for all ages) which is a parameter estimated by the model. Given the nature of these data (count data with overdispersion) a negative binomial observation model is used.

Two distinct tagging recapture time series are used in the assessment. The steel tag series, providing information on the historical part of the assessment (recaptures until 2006) and the RFID tags time series, informing the model for the recent years (recaptures since 2014). Due to the differences in the two time series with respected to tagging protocols, estimation of number recaptures and number scanned, the two series are used as two different dataset. This means, concretely, that the model estimates a post-release survival parameter for each series. Since the first time both were used together (WKPELA 2017), a large difference is observed in the estimated survival rates of the two tagging series, with around 40% and 10% survival for the steel tags and RFID tags respectively. Part of the difference may indeed be explained by actual differences in survival, potentially due to the change in catching methods (hand jigging for the steel tags v.s. automatic jigging for the RFID tags). However, the parameter called post release survival actually encompasses all processes happening after tagging, by which the concentration of tags in the population decreased comparted to the time of release. Processes such as tag loss, which are more likely to occur with RFID tags (ICES 2019) would contribute to a lower estimated survival rate. In addition, in the mathematical formulation of the expected recaptures, the survival rate appears together with other term (numbers scanned, numbers tags detected in the factories). Any bias in these measurements would be confounded with the estimate of survival rate (ICES 2019).

#### Assessment model configuration

Catches for NEA mackerel for the period prior to 2000 are considered highly unreliable, due to a massive underreporting in the historical period. However, valuable information is available from other data sources (tags, egg survey) for the years before 2000. Instead of discarding all data prior to 2000, it was decided during the 2014 benchmark mackerel assessment to start the assessment in 1980, and reduce as much as possible the influence of the catches until 2000. This was done by arbitrarily down weight the catches for the years prior to 2000, by imposing a high observation variance of these catches (equal to 1.35).

Furthermore, the model incorporates the steel and RFID tagging–recapture data, and three survey indices: the IBTS recruitment index, the mackerel egg survey SSB index and abundances indices from the IESSNS. In order to account for year effects (correlation of year to year variations across age-classes) in the IESSNS survey, the model has a AR1 observation error correlation structure for this survey.

More details on the input and on the survey indices incorporated in the assessment are given in the tables below (Y being the current year in which the assessment is carried out).

INPUT DATA TYPES AND CHARACTERISTICS:

| Name | Year range | Age range | Variable from year to year |
|---|---|---|---|
| Catch in tonnes | 1980–(Y-1) | | Yes |
| Catch-at-age in numbers | 1980*–(Y-1) | 0–12+ | Yes |
| Weight-at-age in the commercial catch | 1980–(Y-1) | 0–12+ | Yes |
| Weight-at-age of the spawning stock at spawning time. | 1980–(Y) | 0–12+ | Yes |
| Proportion of natural mortality before spawning | 1980–(Y) | 0–12+ | Yes |
| Proportion of fishing mortality before spawning | 1980–(Y) | 0–12+ | Yes (constant before 1989) |
| Proportion mature-at-age | 1980–(Y) | 0–12+ | Yes |
| Natural mortality | 1980–(Y) | 0–12+ | No, fixed at 0.15 |

*** catches-at-age before 2000 are heavily down weighted which makes that in practice, they have little influence on the assessment.**

| TUNING DATA: | | | |
|---|---|---|---|
| Type | Name | Year range | Age range |
| Survey (SSB) | ICES Triennial Mackerel and Horse Mackerel Egg Survey | 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016,2019. | Not applicable (gives SSB) |
| Survey (abundance index) | IBTS Recruitment index (square root transformed) | 1998–(Y-1) | Age 0 |
| Survey (abundance index) | International Ecosystem Summer Survey in the Nordic Seas (IESSNS) | 2010, 2012–Y | Ages 3-11 |
| Tagging/recapture | Norwegian tagging program | Steel tags: 1980 (release year)–2006 (recapture year) | Ages 2 and older (age at release) |
| | | RFID tags: 2013 (release year)–(Y-1) (recapture year) | Ages 5 and older (age at release) |

Model configuration as defined during the 2019 inter-benchmark is given in the table below. In addition, the model has an age range from 0 to 12 and a plus group is set at 12 years. The reference fishing mortality, $F_{BAR}$, is calculated over the ages 4 to 8.

| SAM PARAMETER CONFIGURATION: | | |
|---|---|---|
| Setting | Value | Description |
| Coupling of fishing mortality states | 0/1/2/3/4/5/6/7/7/7/7/7/7 | Different F states for ages 0 to 6, one same F state for ages 7 and older |
| Coupling of catchability parameters | -1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>0/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/2/3/4/5/6/7/8/9/9/-1 | No catchability parameter for the catches<br>One catchability parameter estimated for the egg<br>One catchability parameter estimated for the recruitment index<br>One catchability parameter for each age group estimated for the IESSNS (age 3 to 11) |
| Power law model | -1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1 | No power law model used for any of the surveys |
| Coupling of fishing mortality random walk variances | 0/1/2/2/2/2/2/2/2/2/2/2/2<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1 | Separate F random walk variances for age 0, age 1 and a same variance for older ages |

| | | |
|---|---|---|
| Coupling of log abundance random walk variances | 0/1/1/1/1/1/1/1/1/1/1/1 | Same variance used for the log abundance random walk of all ages except for the recruits (age 0) |
| Coupling of the observation variances | 0/1/2/2/2/2/2/2/2/2/2/2<br>3/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>4/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/5/6/6/6/6/6/6/6/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1 | Separate observation variances for age 0 and 1 than for the older ages in the catches<br>One observation variance for the egg survey<br>One observation variance for the recruitment index<br>One observation variance for the IESSNS age 3 and one for the ages 4-11. |
| Type of error correlation structure | "ID", "ID", "ID", "AR" | Auto-regressive correlation structure for the IESSNS index, independent observations assumed for the other data sources |
| Specification of the error structure | NA/NA/NA/NA/NA/NA/NA/NA/NA/NA/NA/NA<br>NA/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>NA/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1<br>-1/-1/-1/0/0/0/0/0/0/0/0/-1<br>-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1/-1 | A single correlation coefficient between all pairs of neighbouring ages ($\rho_{3-4} = \rho_{4-5}, \ldots = \rho_{10-11}$) in the autocorrelation structure for the IESSNS |
| Correlated random walks for the fishing mortalities | 0 | F random walk of different ages are independent |
| Stock–recruitment model | 0 | No stock-recruitment model (random walk) |

Due to the high uncertainty in the recruitment estimates for the terminal year, Y-1, for the NEA Mackerel, the value estimated by SAM is arbitrarily replaced by the output of RCT 3 (see short-term prediction section).

## D. Short-term projection

In a given assessment year Y, advice is given on catches for the following year Y+1 based on deterministic projections three years ahead (Y to Y+2). These projections are based on an assumption of the current year's (also called intermediate year) catch (see section below on "Assumptions for the intermediate year catch") from which fishing mortality in the current year Y is inferred, and a range of management options for the advice year, Y+1 (fishing mortality in Y+2 being the same as Y+1), are provided.

### Initial abundances at age

The survivors at the 1st of January of year Y estimated by SAM are used as starting abundances at age in the first year of the short-term forecast. The recruitment estimate at age 0 from the assessment in the terminal assessment year (Y-1) is considered too uncertain to be used, because this year class has not yet fully recruited into the fishery. The last (Y-1) SAM recruitment estimate is therefore replaced by predictions from the RCT3 software (Shepherd, 1997). The RCT3 software performs a linear regression between the IBTS recruitment index and the SAM estimates over the period 1998 toY-2, and, based on this regression, predicts the Y-1 recruitment from the Y-1 IBTS index value. The final Y-1 recruitment is the average between the prediction from this regression and a time tapered geometric mean of the SAM recruitments up to Y-2, weighted by the inverse of their respective prediction standard errors. The historic performance of the IBTS index thus determines the influence of the Y-1 index value on the Y-1 recruitment produced by RCT3. A weak correlation of the survey index with the SAM estimates brings the RCT3 estimate close to the SAM geometric mean, while a strong correlation brings it close to recruitment predicted from the IBTS index for the year Y-1. The "time tapered geometric mean" is a weighted geometric mean, where the most recent years are given the highest weights.

The abundance of the survivors-at-age 1 (in Y) used as starting values for the short-term forecast is then estimated by bringing forward recruitment-at-age 0 (in Y-1) applying the total mortality-at-age 0 in year Y-1 estimated by SAM.

### Conditioning of the short-term forecast

#### Recruitment

The recruits at age 0 in year Y, Y+1 and Y+2 are set to the geometric mean.

#### Exploitation pattern

The exploitation pattern (relative selection pattern) used in the predictions from Y to Y+2 is defined as the average of the exploitation pattern of the last three years in the assessment (Y-3 to Y-1), obtained by dividing the fishing mortalities-at-age of those three years by the value of $F_{BAR}$4–8 in the corresponding years.

#### Maturity-at-age, weight-at-age in the catch and weight-at-age in the stock

The three-year average of Y-3 to Y-1 is used for the proportion mature-at-age as well as stock and catch weights-at-age.

#### Proportion of natural and fishing mortality occurring before spawning

The three-year average of Y-3 to Y-1 is used for the proportions $F_{prop}$ and $M_{prop}$.

#### Assumptions for the intermediate year (Y)

The catch in the intermediate year (Y) is taken as a TAC constraint. The catch is estimated from declared quotas modified by e.g. paybacks (e.g. EU COMMISSION REGULATION (EC) No 147/2007), discards (assumed to be equal to the last reported discards in year Y-1), interannual transfers and expected overcatch. Scientists from the relevant countries present at the WGWIDE each year provide the information on inter-annual transfers and expected overcatch.

#### Management Option Tables for the TAC year

The different management options for the catch in Y+1 are presented, covering the ICES MSY approach and ICES precautionary approach, and the agreed management strategy. The zero catch and constant catch options are also given for illustration

#### Software implementation

The deterministic projections are calculated in R using FLR, based on the function *stf()* from the library FLAsh. The output of the R script was compared with the output of the old ICES software MFDP and the results were found to be identical.

## E. Medium-term projections

No short term projections are carried out at WGWIDE for this stock.

## F. Long-term projections

No long term projections are carried out at WGWIDE for this stock.

## G. Biological reference points

### Precautionary reference points.

***$B_{lim}$*** - There is no evidence of significant reduction in recruitment at low SSB within the time-series (ICES, 2019) hence the previous basis for $B_{lim}$ is retained. $B_{lim}$ is taken as $B_{loss}$, the lowest estimate of spawning–stock biomass from the revised assessment. This was estimated to have occurred in 2003; $B_{loss}$ = 1,99 Mt.

***$F_{lim}$*** - $F_{lim}$ is derived from $B_{lim}$ and is determined from the long term equilibrium simulations (*EqSim)* as the F that on average would bring the stock to $B_{lim}$; $F_{lim}$ = 0.46.

***$B_{pa}$*** - The ICES basis for advice requires that a precautionary safety margin incorporating the uncertainty in actual stock estimates leads to a precautionary reference point $B_{pa}$, which is a biomass reference point designed to avoid reaching $B_{lim}$. Consequently, $B_{PA}$ was calculated as $B_{lim}$ * exp(1.645 σ) where σ = 0.14 was taken as the estimate of spawning biomass uncertainty in the most recent year (2018) as estimated by the updated assessment; $B_{PA}$ = 2.5Mt.

***$F_{pa}$*** – The ICES basis for advice requires that a precautionary safety margin incorporating the uncertainty in actual stock estimates leads to a precautionary reference point $F_{pa}$, which is a fishing mortality reference point designed to avoid reaching $F_{lim}$. Consequently, $F_{pa}$ was calculated as $F_{lim}$ * exp(1.645 σ) where σ = 0.14, the estimated standard deviation of ln(F) in the final assessment year (2018) provided by the SAM assessment; $F_{pa}$ = 0.37.

### MSY reference points

A sequence of *EqSim* simulations (part of the ICES MSY R package) were conducted in line with ICES Technical Guidelines to derive an estimate for $F_{MSY}$ of 0.23.

Recruitment was parameterised by a mixed model approach (26% Ricker, 25% Segmented Regression and 48% Beverton & Holt), fit to data points from the period 1998-2016 using the bootstrap procedure in the ICES MSY R package. Autocorrelation in recruitment was included within the simulation. Since there is a trend in weight at age over the most recent period, the *EqSim* default 10-year window for the bootstrapping of the biological and fishery selectivity vectors was reduced to the most recent 5 years.

*EqSim* incorporates an estimate of assessment and advice error as a two parameter error function applied to the target F. Following the procedure described in the ICES WKMSYREF3 report (ICES, 2015), the most recent estimates of fishing mortality were compared to those in the annual short term forecasts with the realised catches giving estimates of 0.28 and 0,26 for the *EqSim* $F_{cv}$ and $F_{phi}$ parameters.

$MSYB_{trigger}$ is a biomass reference point that triggers a management response to avoid stock depletion when fishing at $F_{MSY}$. It is defined as the $5_{th}$ percentile on the distribution of SSB when fishing at $F_{MSY}$. However, fishing mortality on NEA Mackerel has been significantly greater than the $F_{MSY}$ estimate for a number of years, and particularly in the most recent period. Thus, the $B_{pa}$ value of 2.50Mt was selected as the appropriate value for $MSYB_{trigger}$.

A summary of the reference points is given below:

| Type | | Value | Technical basis |
|---|---|---|---|
| Management Plan | SSBtrigger | N/A | |
| | F target | N/A | |
| MSY Approach | MSY Btrigger | 2.50 Mt | Bpa |
| | MSY target | 0.23 | Stochastic simulation |
| Precautionary Approach | Blim | 1.99 million t | Bloss from 2019 interbenchmark assessment (2003) |
| | Bpa | 2.50 million t | exp(1.654*$\sigma_{SSB}$)*Bim,$\sigma_{SSB}$=0.14 |
| | Flim | 0.46 | The fishing mortality that, on average, leads to $B_{lim}$ |
| | Fpa | 0.37 | exp(1.654*$\sigma_f$)*Fim,$\sigma_F$=0.20 |

## H. Other Issues

### H.1. Management plans and evaluations

The management plan adopted in 2008 has been tested on the basis of the previous assessment model. A new long term management plan evaluation was carried out in 2014 (ICES, 2014c) on the basis of the 2014 benchmark method.

The benchmark assessment performed in 2017 (WKWIDE: ICES, 2017a) lead to a substantial revision of the perception of the stock. On the request of the coastal states, ICES has updated the tables that were presented in its response to the EU, Norway, and the Faroe Islands request to ICES to evaluate a multi-annual management strategy for mackerel in the Northeast Atlantic (ICES, 2014c).

The options that are precautionary and maximize the median long-term yield are identified. F targets around 0.22–0.24 combined with Bo values of around 3.4–4.2 million t result in the highest median long-term yields, when no TAC constraint applies. When the TAC constraint applies, a larger number of ($F_{target}$, $B_{trigger}$) combinations result in the highest median long-term yields. Generally, these combinations have F targets around 0.22–0.26 and $B_{trigger}$ values around 2.8 to 4.2 million t, with higher F targets being associated with higher $B_{trigger}$ values. Increasing the $F_{target}$, or the $B_{trigger}$ values results in increased interannual variability in yield.

For any given ($F_{target}$, $B_{trigger}$) combination, the effect of incorporating a TAC constraint is minor. The difference in median long-term yield with or without constraint never exceeds 5%. For most ($F_{target}$, $B_{trigger}$) combinations, the probability of SSB falling below $B_{lim}$ and the interannual yield variability are somewhat lower with TAC constraint than without it.

Results from preliminary modelling of density-dependent weights suggest that higher target Fs would likely be possible while remaining precautionary. However, better scientific understanding of the link between stock size and growth and the development of an appropriate modelling approach would be needed before these types of changes in growth can be incorporated in the evaluation of the harvest control rule.

## H.2. Data limited approach for NEA mackerel

### Context

In 2013 ICES was required to provide advice for the mackerel stock on the basis of no agreed quantitative assessment and corresponding management target and reference points, an exploitation rate which was potentially above the previous reference levels and no international agreement on catches.

For other stocks for which no quantitative assessment was available ICES had previously employed the WKLIFE Data Limited Stocks (DLS) approach (ICES, 2012) to provide precautionary management advice. ICES considered the DLS Method 3.2 approach, which uses survey trend based scaling of catches, applicable to the NEA mackerel. WKLIFE3 (ICES, 2013e) had evaluated the method using a simulated gadoid stock and concluded that for overexploited stocks without a defined management target, a precautionary buffer which reduced catch levels by 20% would be required to prevent increasing risk to the stock when the control rule was applied over the longer term; however, caveat scenarios in which the precautionary buffer might not be required were also discussed.

ICES ACOM eventually gave advice on NEA mackerel based on a recent catch, citing the preliminary nature of the most recent egg survey, the lack of good uncertainty estimates and the lack of agreement on whether a precautionary buffer (20% reduction in catches in the first year of application) should be applied. WKLIFE3 later examined the ICES NEA mackerel advice in 2013 and made the following comment:

**"Mackerel in the Northeast Atlantic**: In the 2013 advice season, ACOM treated this stock in an *ad hoc* way rather than as a data-limited stock proposed by their own ADG. The rationale for this is neither adequately nor clearly explained in any ICES document. On balance, WKLIFE do not understand the rejection of the DLS guidance and support the ADG's recommendation to treat this stock with a Category 3 method incorporating the *precautionary buffer*."

As a result of the uncertainty in the application of the ICES DLS Method 3.2 to mackerel, WKPELA (ICES, 2014b) agreed that a more detailed, stock-specific evaluation of the ICES DLS Method 3.2 application to the NEA mackerel should be conducted in order to provide guidance for management advice in the event that a quantitative assessment was not available.

#### NEA mackerel simulations

WKPELA (ICES, 2014b) used a MSE simulation framework in FLR, R version 2.10.1 (2009-12-14), Core package of FLR, fisheries modelling in R. Version: 2.3-644. Flash Version: 0.7.0. Evaluations were carried out based on a simulated mackerel stock with stock dynamics (growth, recruitment, etc.), single fleet exploitation and a single fishery-independent survey index.

#### Fishery-independent time-series

WKPELA considered that the triennial egg survey index of SSB with a CV of the order of 24% gave the only, more or less complete, index of SSB (the egg survey does not include egg mortality and so it is not considered an absolute SSB estimate).

#### Harvest control rule

As the survey is carried out triennially setting the catch for three years as multi-annual advice (y+1 to y+3) is appropriate and the DLS Method 3.2 becomes:

$C_{(y+1,y+2,y+3)} = C_{(y)} *Fac$ Equ. H.2.1

where Fac is derived from DLS Method 3.2 such that with S(y) the survey index in year y

$Fac = ( ( S_{(y)} + S_{(y-1)} ) /2 ) / ( ( S_{(y-2)} + S_{(y-3)} + S_{(y-4)} ) /3 )$ Equ. H.2.2

Mackerel egg survey indices are available every three years so that $S_{(y-1)}$, $S_{(y-2)}$ and $S_{(y-4)}$ are derived by linear interpolation from the surveys in $S_{(y)}$, $S_{(y-3)}$ and $S_{(y-6)}$ such that after simplification:

$Fac = 3/2 * ( 5*S_{(y)} + S_{(y-3)} ) / ( S_{(y)} + 7*S_{(y-3)} + S_{(y-6)} )$ Equ. H.2.3

Interannual variability, which could result from noise in the survey index series, is damped by the use of an uncertainty cap, such that:

$Fac > 1.2 => Fac = 1.2$ Equ H.2.4a

$Fac < 0.8 => Fac = 0.8$ Equ H.2.4b

In addition to the uncertainty cap, the application of ICES precautionary buffer margin of -20% for the first application of the rule was evaluated.

$C_{(y+1,y+2,y+3)} = C_{(y)} * 0.8 * Fac$ at the first application and Equ H.2.5a

$C_{(y+1,y+2,y+3)} = C_{(y)} * Fac$ for subsequent iterations Equ H.2.6b

#### DLS simulation results

Twelve scenarios were evaluated, four rule implementation options (with and without the PA buffer and the uncertainty cap) under three different stock starting conditions:

historic fishing mortalities, F=0.22 (~$F_{MSY}$) and F=0.45 (~2*$F_{MSY}$). In all cases the stock was conditioned from 1981 to 2009 and DLS management simulated to start in 2009 with first year of catch under this regime in 2010.

The performance of the DLS method was considered in the context of ICES precautionary criteria by comparing the lower 5th percentile of SSB in each forecast year with a $B_{lim}$ proxy ($B_{loss}$, Figure H.2.1). The inclusion of the precautionary buffer had a major influence on the likelihood that SSB had a greater than 5% probability of falling below $B_{lim}$. In all cases in which the precautionary buffer was not applied a substantially higher percentage than 5% of the stocks fall below $B_{lim}$ and a significant proportion collapse; the inclusion of the PA buffer appears to prevent collapse in the medium term, independent of the starting conditions in the scenarios examined. This suggests that the application of the ICES DLS Method 3.2 as simulated, using triennial egg surveys to calibrate catch set for a period of three years is precautionary when the buffer is applied; it is not without the application of the buffer.

#### DLS method conclusions

WKPELA (ICES, 2014b) concluded that the simulations provided very clear guidance that exploitation using the ICES DLS Method 3.2 using the triennial egg survey based on equation H.2.3 would provide precautionary management advice for the provision of triennial multiannual TAC (three years) for the NEA mackerel stock in the absence of an agreed assessment.

The application of the ICES DLS Method 3.2 to the NEA mackerel requires the inclusion of the precautionary buffer at 20% in the first year of implementation (Equation H.2.4ab) and risk of SSB<$B_{lim}$ is also reduced by the application of the uncertainty cap at 20% in each change of three year TAC (Equ H.2.5ab).

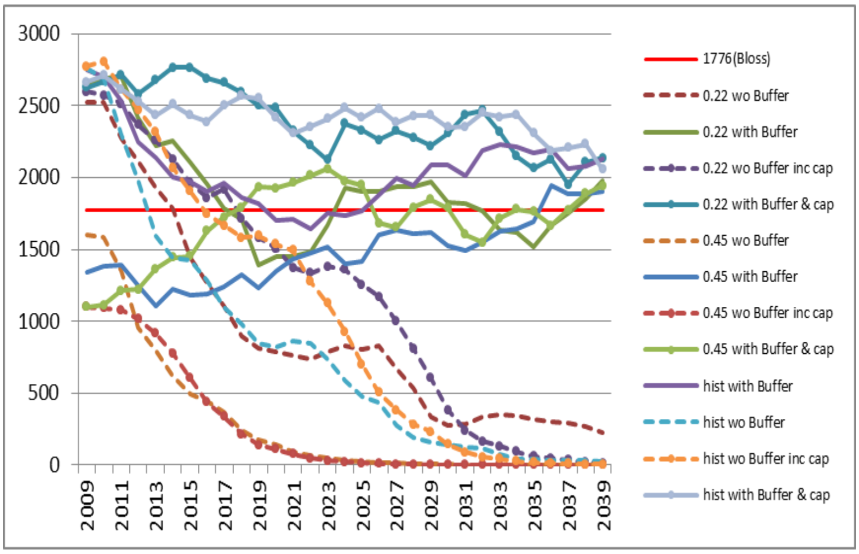


**Figure H.2.1. Summary of NEA mackerel DLS Method 3.2 simulations in terms of ICES precautionary criteria. Three starting options 1) stable F=0.22, 2) stable F=0.45 and 3) historic state in 2009. Two options for calculating future catch are tested 1) PA Buffer included (solid lines) or not (dotted lines) 2) +/-20%cap on TAC change included (symbol on the line) or not (no symbol). These results demonstrate that it is essential to include the precautionary buffer if the lower 5% on SSB is to be kept above the assumed $B_{lim}$.**

## I. References

Anon. 1896. Twenty-Eighth Annual Report Department of Marine and Fisheries Dawson Press Ottawa Canada.

Anon. 1997. SEFOS, Shelf Edge Fisheries and Oceanography Study. Final Report: May 1997.

Anon. 2009. Report from the international meeting on mackerel distribution and migration in the Northeast Atlantic. Bergen, April 2009.

Astthorsson, O. S., Valdimarsson, H., Gudmundsdottir, A., and Óskarsson, G. J. 2012. Climate-related variations in the occurrence and distribution of mackerel (*Scomber scombrus*) in Icelandic waters. ICES Journal of Marine Science, 69.

Bakken, E. 1977. The spawning period for mackerel in the North Sea. ICES C M 1977/H:26.

Beare, D.J., and Reid, D.G. 2002. Investigating spatio-temporal change in spawning activity by Atlantic mackerel between 1977 and 1998 using generalized additive models. ICES J. Mar. Sci. **59**: 711–724.

Belikov, S.V., Jakupsstovu, S.H., Shamrai, E.A., and Thomsen, B. 1998. Migration of mackerel during summer in the Norwegian Sea. ICES-CM-1998/AA:8.

Castonguay, M., and Beaulieu, J.L. 1993. Development of a hydroacoustic abundance index for mackerel in Cabot Strait. Department of Fisheries and Oceans Atlantic Fisheries Research Documents 93/12.

D'Amours, D., and Castonguay, M. 1992. Spring migration of Atlantic mackerel, *Scomber scombrus*, in relation to water temperature through Cabot Strait (Gulf of St Lawrence). Environ. Biol. Fish. **34**: 393–399.

Debes, H., Homrum, E., Jacobsen, J.A., Hátún, H., Danielsen, J. 2012. The feeding ecology of pelagic fish in the southwestern Norwegian Sea –Inter species food competition between herring (*Clupea harengus*) and mackerel (*Scomber scombrus*). ICES CM 2012/M:07. 19 pp.

Dransfeld, L., Dwane, O., Molloy, J., Gallagher, S., Reid, D.G. 2005. Estimation of mackerel (Scomber scombrus L., 1758) and horse mackerel (*Trachurus trachurus* L., 1758) daily egg production outside the standard ICES survey area. ICES J Mar Sci, 1705-1710.

Gill, H., Skaret, G., and Tenningen, E. 2004. Toktrapport for M/S "libas, M/S "endredyrøy" og flyet "arktika" i norskehavet, 15–30 juli 2004. Cruise Report, Institute of Marine Research, Bergen, Norway.

Hamre, J. 1980. Biology, exploitation and management of the NorthEast Atlantic mackerel. Rapp P-V Reun (CIEM), 177, 212-242.

Holst, J.C., and Iversen, S.A. 1992. Distribution of Norwegian spring-spawning herring and mackerel in the Norwegian Sea in late summer, 1991. ICES CM1992/H:13.

Holst, J.C., and Iversen, S.A. 1999. Distribution of mackerel in the Norwegian Sea during summer, 1991–1998. ICES CM 1999/ACFM:6/WD.

Hughes, S.L., Holliday, N.P., and Beszczynska-Möller, A. (Eds). 2011. ICES Report on Ocean Climate 2010. ICES Cooperative Research Report. No. 309. 69 pp.

Hughes K 2013 A multivariate spatial analysis of Northeast Atlantic fish stocks over time PhD Thesis submitted to NUI Galway http://ir.library.nuigalway.ie/xmlui/handle/10379/3961?show=full.

ICES. 1977. Report of the mackerel working group. ICES CM 1977/H:2.

ICES. 1984. Report of the mackerel working group. ICES CM 1984/Assess:1. ICES. 1989. Data base report of the stomach sampling project 1981.

ICES. 1989. Data base report of the stomach sampling project 1981.

ICES. 1990. Second report of the EEC - Norwegian joint scientific group on migration and area distribution of mackerel (western stock). ICES CM 1990 / H:5.

ICES. 1997. Database report of the stomach sampling project 1991. ICES cooperative research report. 1997.

ICES. 2000. Report of the working group on the assessment of mackerel, horse mackerel, sardine and anchovy (WGMHSA). ICES CM 2000/ACFM:05.

ICES. 2006. Report of the planning group on Northeast Atlantic pelagic ecosystem surveys (PGNAPES). ICES CM 2006/RMC:08.

ICES. 2007. Report of the planning group on Northeast Atlantic pelagic ecosystem surveys (PGNAPES). ICES CM 2007/RMC:07.

ICES. 2008. Report of the working group on multispecies assessment methods (WGSAM). ICES CM 2008/RMC:06.

ICES. 2009. Report of the planning group on Northeast Atlantic pelagic ecosystem surveys (PGNAPES). ICES CM 2009/RMC:06. ICES 2011. WKLIFE.

ICES. 2012. ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice. ICES CM 2012/ACOM 68. 42 pp.

ICES. 2013.a. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 27 August–2 September 2013, ICES Headquarters, Copenhagen, Denmark. ICES CM 2013/ACOM:15. 950 pp.

ICES. 2013b. Report of the Ad hoc Group on the Distribution and Migration of Northeast Atlantic Mackerel (AGDMM) 30–31 August 2011 and 29–31 May 2012 ICES Headquarters, ICES CM 2013/ACOM:58. 215 pp.

ICES. 2013c. Report of the Workshop on Northeast Atlantic Mackerel monitoring and methodologies including science and industry involvement (WMNAMMM), 25–28 February 2013, ICES Headquarters, Copenhagen and Hirtshals, Denmark. ICES CM 2013/SSGESST:18. 33 pp.

ICES. 2013d. Report of the Workshop to consider reference points for all stocks (WKMSYREF), 23–25 January 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:37. 18 pp.

ICES. 2013e. Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other key parameters for data-limited stocks (WKLIFE 3). 28 October–1 November 2013. ICES CM 2013/ACOM:35. Xx pp.

ICES. 2014a. Report of the Workshop to consider reference points for all stocks (WKMSYREF2). ICES CM 2014/ACOM:47. 8–10 January 2014. 99 pp.

ICES. 2014b. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA 2014). 17–21 February 2014. Copenhagen, Denmark. ICES CM 2014/ACOM:43. 344 pp.

ICES. 2014c. Report of the EU Workshop on the NEA Mackerel Long-term Management Plan (WKMACLTMP). ICES CM 2014/ACOM:63. 118 pp.

ICES, 2015. Report of the joint ICES-MYFISH Workshop to consider the basis for $F_{MSY}$ ranges for all stocks (WKMSYREF3), 17th – 21st November 2014, Charlottenlund, Denmark. ICES CM 2014/ACOM:64. 156 pp.

ICES. 2017a. Report of the Benchmark Workshop on Widely Distributed Stocks (WKWIDE 2017). 30 January–3 February 2017. Copenhagen, Denmark. ICES CM 2017/ACOM:36.

ICES. 2017b. Report of the Workshop on

ICES. 2019. Interbenchmark Workshop on the assessment of northeast Atlantic mackerel (IBPNEAMac). ICES Scientific Reports. 1:5. 71 pp. http://doi.org/10.17895/ices.pub.4985

Iversen, S.A. 1981. Spawning and trends in spawning stock size of the North Sea mackerel during the period 1973–1980. ICES CM 1981/H:16.

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.

Jansen, T. 2014. Pseudocollapse and Rebuilding of North Sea Mackerel (Scomber scombrus). ICES Journal of Marine Science, 71(2), 299-307. doi: doi.10.1093/icesjms/fst148.

Jansen, T. and Gislason, H. 2011. Temperature affects the timing of spawning and migration of North Sea mackerel. Continental Shelf Research, 31: 64–72.

Jansen, T., Gislason, H. 2013. Population Structure of Atlantic Mackerel (*Scomber scombrus*). PLoS ONE 8(5): e64744. doi:10.1371/journal.pone.0064744.

Jansen T, Campbell A, Kelly C, Hatun H, Payne MR. 2012. Migration and Fisheries of North East Atlantic Mackerel (*Scomber scombrus*) in Autumn and Winter. PLoS ONE 7(12): e51541. doi:10.1371/journal.pone.0051541.

Jansen, T., Campbell, A.., Brunel, T., Worsøe Clausen, L. 2013. Spatial Segregation within the Spawning Migration of North Eastern Atlantic Mackerel (*Scomber scombrus*) as Indicated by Juvenile Growth Patterns. PLoS ONE 8(2): e58114. doi:10.1371/journal.pone.0058114.

Jansen, T., Kristensen, K., van der Kooij, J., Post, S., Campbell, A., Utne, K. R., Carrera, P., Jacobsen, J. A., Gudmundsdottir, A., Roel, B. A., & Hatfield, E. M. C. 2015. Nursery areas and recruitment variation of North East Atlantic mackerel (*Scomber scombrus*). ICES J.Mar.Sci., 72(6), 1779-1789.

Johnson, P.O. 1977. A review of spawning in the North Atlantic mackerel *Scomber scombrus* L. Fish Res Tech Rep, MAFF Direct Fish Res 77: 1–22.

Langoy, H., Nøttestad, L., Skaret, G., Cecilie, T., Broms, A., and Fern, A. 2006. Feeding ecology of Atlantic mackerel (*Scomber scombrus*) in the Norwegian Sea: Diet, prey selection and possible food competition with herring (*Clupea harengus*) in different water masses. ICES CM 2006/ F:12.

Langoy, H., Nøttestad, L., Skaret, G., Broms, A., and Fern, A. 2010. Prey selection and overlap in distribution and diets of mackerel, herring and blue whiting during late summer in the Norwegian Sea. Unknown.

Langøy, H., Nøttestad, L., Skaret, G., Broms, C., & Fernö, A. 2012. Overlap in distribution and diets of Atlantic mackerel (*Scomber scombrus*), Norwegian spring- spawning herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) in the Norwegian Sea during late summer. Marine biology research, 8(5–6), 442–460.

Lockwood, S.J., Nichols, J.H., and Dawson, W.A. 1981. The estimation of a mackerel (*Scomber scombrus* L.) spawning stock size by plankton survey. J. Plankton Res. **3**: 217–233.

Mehl, S., and Westgård, T. 1983. The diet and consumption of mackerel in the North Sea (a preliminary report). ICES CM 1983/H:34.

Nielsen, A. and Berg, C.W. 2014, Estimation of time-varying selectivity in stock assessments using state–space models, Fisheries Research, Available online 20 February 2014, ISSN 0165-7836, http://dx.doi.org/10.1016/j.fishres.2014.01.014.

Nøttestad, L. 2014. Makrell. In: Havforskningsrapporten 2014 (Eds. Gjøseter *et al*.). p. 156.

Nøttestad, L. K.R. Utne, V. Anthonypillai, Ø. Tangen, J.W. Valdemarsen, G.J. Óskarsson, S. Sveinbjörnsson, S. Jónsson, Ó.A. Ingólfsson. H. Debes, E. Mortensen, L. Smith, J.A. Jacobsen, K. Zachariassen. 2012. Cruise report from the coordinated ecosystem survey (IESSNS) with RV "G. O. Sars", M/V "Brennholm"; M/V "Christian í Grótinum" and RV "Arni Fridriksson" in the Norwegian Sea and surrounding waters, 1 July–10 August 2012. 50 p. Working Document to ICES Working Group on International Pelagic Surveys (WGIPS), ICES Headquarters, Copenhagen, Denmark, 3–7 December 2012 and to ICES Working Group on Widely distributed Stocks (WGWIDE) Lowestoft, UK, 21–27 August 2012.

Nøttestad, L. Oskarsson G.J., Debes, H. *et al*. 2013. Cruise report from the coordinated ecosystem survey (IESSNS) with M/V "Libas", M/V "Eros"; M/V "Finnur Fríði" and RV "Arni Fridriksson" in the Norwegian Sea and surrounding waters, 2 July–9 August 2013. ICES Working Group on Widely distributed Stocks (WGWIDE), ICES Headquarters, Copenhagen, Denmark, 27 August–2 September 2013.

Nøttestad, L., Utne, K. R., Óskarsson, G. J., Jónsson, S. Þ., Jacobsen, J. A., Tangen, Ø., Anthonypillai, V., et al. 2016. Quantifying changes in abundance, biomass and spatial distribution of Northeast Atlantic (NEA) mackerel (Scomber scombrus) in the Nordic seas from 2007 to 2014. ICES Journal of Marine Science, 73: 359-373.

Nøttestad, L., J. Giske, J.C. Holst, and G. Huse. 1999. A length-based hypothesis to explain feeding migrations in pelagic fish. Canadian Journal of Fisheries and Aquatic Sciences 56 (Supplement I): 26–34.

Olafsdottir, A. H., Utne, K. R., Nøttestad, L., Jacobsen, J. A., Jansen, T., Óskarsson, G. J., Jónsson, S. Þ., Smith, L., Salthaug, A., í Hömrum, E., and Slotte, A. 2017. Preparation of data from the International Ecosystem Summer Survey in Nordic Seas (IESSNS) for use as an an-nual tuning series in the assessment of the Northeast Atlantic mackerel (Scomber scombrus L.) stock. Working Document (WD) for WKWIDE 2017. 36 pp.

Óskarsson, G.J., Sveinbjörnsson, S. Guðmundsdóttir, A. and Sigurðsson, Th. 2012. Ecological impacts of recent extension of feeding migration of NE-Atlantic mackerel into the ecosystem around Iceland. ICES CM 2012/M:03. 25 pp.

Patterson, K.R. 1998. A programme for calculating total international catch-at-age and weight-at-age. WD to Herring Assessment Working Group 1998.

Pepin, P., Koslow, J.A., and Pearre, S. 1988. Laboratory study of foraging by Atlantic mackerel, *Scomber scombrus*, on natural zooplankton assemblages. Can. J. Fish. Aquat. Sci. **45**: 879–887.

Pepin, P., Pearre, S., and Koslow, J.A. 1987. Predation on larval fish by Atlantic mackerel, *Scomber scombrus*, with a comparison of predation by zooplankton. Can. J. Fish. Aquat. Sci. **44**: 2012–2017.

Perez, J.R., Villamor, B., and Abaunza, P. 2000. Maturity ogive of the Northeast Atlantic mackerel (*Scomber scombrus* L.) from the southern area using histological and macroscopic methods. ICES CM 2000/ACFM:5/WD.

Punzon, A. and Villamor, B. 2009. Does the timing of the spawning migration change for the southern component of the Northeast Atlantic Mackerel (*Scomber scombrus*, L. 1758)? An approximation using fishery analyses. Continental Shelf Research, 29. 8: 1195–1204.

Prokopchuk, I. and Sentyabov E. 2006. Diets of herring, mackerel and blue whiting in the Norwegian Sea in relation to *Calanus finmarchicus* distribution and temperature conditions. ICES Journal of Marine Science 63:117–127.

Reid, D.G., Turrell, W.R., Walsh, M., and Corten, A. 1997. Cross-shelf processes north of Scotland in relation to the southerly migration of western mackerel. ICES J Mar Sci., 54: 168–178.

Reid, D.G., Eltink, A., and Kelly, C.J. 2003. Inferences on the changes in pattern in the prespawning migration of the western mackerel (*Scomber scombrus*) from commercial vessel data. ICES CM 2003/Q:19.

Reid, D.G., Walsh, M., and Turrel, W.R. 2001. Hydrography and mackerel distribution on the shelf edge west of the Norwegian Deeps. Fish. Res. **50**(1): 141–150.

Salthaug, A., Aanes, S., Johnsen, E., Utne, K. R., Nøttestad, L., and Slotte, A. 2017. Estimating Northeast Atlantic mackerel abundance from IESSNS with StoX. Working Document (WD) for WGIPS 2017 and WKWIDE 2017. 103 pp.

Shepherd, J.G. 1997. Prediction of year-class strength by calibration regression analysis of multiple recruit index series. ICES Journal of Marine Science, 54: 741–752.

Simmonds, E.J. 2007. Are reported catches sufficient to account for biomass in the NE Atlantic mackerel stock. ICES CM 2007/ACFM:31/WD:11.

Skaret, G., H. Langøy, E.K. Stenevik, K.R. Utne and A. Slotte. 2014. Investigation of mackerel predation on herring larvae on the Norwegian coastal shelf. Rapport fra Havforskningen Nr. 6 2014. 17 p. (In English).

Uriarte, A., and Lucio, P. 1996. Results of a tagging survey of mackerel in the Bay of Biscay in 1994. ICES CM 1996/S:10.

Uriarte, A., Alvarez, P., Iversen, S., Molloy, J., Villamor, B., Martins, M.M., and Myklevoll, S. 2001. Spatial pattern of migration and recruitment of Northeast Atlantic mackerel. ICES CM 2001/O:17.

Valdemarsen, J.W., J.A. Jacobsen, H.A. Einarsson, L. Nøttestad, G.J. Oskarsson, S. Rosen, S. Sveinbjörnsson, L. Smith, K.R. Utne and K. Zachariassen. 2014. Swept area estimation of the Northeast Atlantic mackerel stock using a standardized surface trawling technique. Working Document (WD) to WKPELA 17–21 February 2014,17 p.

Walsh, M., and Martin, J.H.A. 1986. Recent changes in the distribution and migration of the western mackerel stock in relation to hydrographic changes. ICES CM 1986/H:17.

Walsh, M., and Rankine, P. 1979. Observations on the diet of mackerel in the North Sea and to the west of Britain. ICES CM 1979/H:45.

Walsh, M., Reid, D.G., and Turrell, W.R. 1995. Understanding mackerel migration off Scotland - tracking with echosounders and commercial data, and including environmental correlates and behaviour. ICES J. Mar. Sci. **52**(6): 925–939.