Abundance estimation of Northeast Atlantic Mackerel based on tag recapture data - a useful tool for stock assessment?

Maria Tenningen [imr] *, Aril Slotte [imr], Dankert Skagen [imr]

[imr] *Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway. E-mails: maria.tenningen@imr.no, aril.slotte@imr.no, dankert@dwsk.net*

** Corresponding author tel.: +47 55236827, fax: +47 55238531*

Abstract

In the present study we utilize tag recapture data to estimate year class abundance and spawning stock biomass of mackerel (*Scomber scombrus* L.) in the Northeast Atlantic for the period 1986-2008. On average 20 000 jigged mackerel have been tagged annually with internal steel tags in the spawning area west of Ireland and the British Isles, and the tags have been recaptured in commercial catches screened through metal detectors. The spawning stock biomass estimates derived from two different tag-based models were highly variable but were on average 2 and 2.3 times higher than the ICES official estimate. The official estimate is considered uncertain and most likely an underestimate of the actual biomass, due to unregistered mortality in the fisheries and lack of fishery-independent, age-disaggregated data. Hence, tag-based estimates could potentially improve the current assessment if included in the ICES stock assessment on a regular basis. These estimates also involve some uncertainty that needs consideration, especially related to variable tagging mortality, detector efficiency and migrations of the stock.

Keywords: tagging, abundance, biomass, mortality, uncertainty

1. Introduction

The Northeast Atlantic (NEA) mackerel supports a very valuable fishery, with landings that have ranged between 470 000 and 820 000 tonnes (t) since the mid 1990s (ICES, 2009a). Based on their respective spawning grounds the stock is divided into three spawning components; the western, southern and North Sea components, and these are managed as one stock; the Northeast Atlantic Mackerel (ICES, 2009a). At present, the official International Council for the Exploration of the Seas (ICES) assessment is based on an integrated catch-at-age model (ICA, Patterson and Melvin, 1996) and a triennial egg survey estimate of spawning stock biomass (ICES, 2009a; Lockwood et al., 1981). The stock assessment is heavily dependent on catch-at-age data and since 2005, ICES has recognized that the level of unaccounted mortality in the fishery may be significant (ICES, 2006). There are strong indications that large amounts of landings are unregistered (ICES, 2009a) and discarding and slipping of unwanted mackerel at the fishing grounds may be significant (Borges et al., 2008; ICES 2009a). While some discard sampling has been carried out since 2000 and is included in the assessment, there is not enough data to capture the full scale of discarding (ICES, 2009a).

Due to the lack of fishery-independent data and unreliable catch data there is a need for alternative fishery-independent estimates of stock biomass. The egg surveys are an important part of the assessment, but are only carried out every third year and do not provide age-structured data. There is also ongoing work with the use of acoustic methods for abundance estimation of the mackerel stock, but at the moment the estimates are not reliable enough to be used in the assessment as indicators of abundance (Gorska et al., 2007; ICES, 2009b; Nesse et al., 2009; Slotte et al., 2007).

Tagging studies are commonly used to estimate fish population abundance and mortality rates (for a review see Pine et al., 2003; Schwarz and Seber, 1999) and may be a useful tool for stock assessment (Cadigan and Brattey, 2001; Kleiber et al., 1987; Schwarz and Taylor, 1998). The Institute of Marine Research in Norway (IMR) has used internal metal tags to tag NEA mackerel since 1969 (Hamre, 1970) and these data have been used for mortality estimates (ICES, 2009a). The Norwegian tagging data and data from experiments conducted by other countries have also been very valuable for tracing the mackerel migrations and distribution (Rankine and Walsh, 1982; Uriarte and Lucio, 2001). Until the late 1970s Norwegian tagging data were also used to estimate stock size (Hamre, 1978). Tags were then recovered by magnets installed at reduction plants, but as the use of mackerel changed from fish meal to mainly human consumption very few tags were recovered and the tag data could no longer be used for stock assessment. Since 1986 metal detectors have been installed at Norwegian fish factories making it possible to estimate stock abundance from tag data again.

The main objective of this paper is to use tag recapture data to provide age-structured abundance and biomass estimates for the NEA Mackerel stock for the period 1986-2008, and to compare these tag-based estimates with official ICES estimates of SSB based on the ICA model and the triennial egg survey SSB estimates.

2. Methods

2.1. Tagging experiments

Tag releases from 1984 to 2006 were included in the analysis. Between 5600 and 34000 mackerel were tagged in each year, except in 1987 and 2005 when no tagging experiments were carried out (Table 1). The same personnel have been involved in the tagging operations since 1984, thereby reducing the variation in mortality caused by the tagging operation. The 3-4 week long tagging experiments have been carried out between May and the middle of June in the spawning area west of Ireland and west of the Hebrides (Figure 1).

Mackerel were caught by jigging (manual until 2005 and automatic since 2006) and the tags used were individually numbered pieces of steel, rounded at the ends, 20 mm long, 4 mm wide and 1 mm thick. The fish were unhooked and released into vats with running sea water. Damaged individuals were discarded while the ones in good condition were allowed to swim for a maximum of 30 minutes in the tank before tagging. The total length was measured and the tag number was recorded before the tag was inserted into the abdominal cavity or muscle tissues through a small cut. After tagging, the fish were immediately released back to the sea. Individuals that were injured during the fishing and tagging process were used for age-length keys (ALK), by measuring individual lengths and removing otoliths for age reading. The age was read from the otoliths according to the standard age reading methodology used for mackerel at the Institute of Marine Research, IMR. The method involves examination of whole otoliths with a light microscope and determination of age by counting annuli. ALKs consisting of 500 to 1000 fish were available for each tagging year.

2.2. Tag recaptures

Every year since 1986 between 4000 and 45000 tonnes of mackerel have been screened through metal detectors at Norwegian fish factories (Table 2). All catches landed at one of these factories were screened through the detector. If a tagged fish was detected, a batch of 10-40 fish, including the one tagged, was automatically removed from the conveyor belt into a vat. A handheld detector was then used to screen the fish in the vat, and the recovered tagged individuals were sent frozen to IMR where the individual tag numbers with associated data were recorded. The individual fish were weighed, the total length was measured and the age was read from otoliths as described in section 2.1. On some occasions the otoliths were lost or unreadable and length at release and the relevant ALK were used to age the fish. At each factory there was one person employed by IMR who made sure the detector was working properly and estimated the efficiency of the detector. The efficiency was measured in most of the screened landings by marking between 5 and10 fish and counting how many of these were detected by the instrument. Percentage efficiencies were then given for each landing (Table 2). The body lengths and the total weight were measured manually in a sample of about 100 fish from each screened catch, and sometimes samples were shipped to IMR for aging.

2.3. Numbers screened per year class

The numbers of fish screened per age class and year were calculated by first converting the amount of fish screened in tonnes to number of fish using the average individual weight in the sample from the catch. The length distribution of the sampled fish was applied to the whole landing and then converted to an age distribution using ALKs from the same year, quarter and area. The numbers of fish screened per age class and year were then corrected for the efficiency of the detector.

2.4. Abundance-at-age

Age structured abundances were estimated for the years 1986-2008 for mackerel between 2-12 years. Two different models were used for the calculations, both based on the Lincoln-Petersen model (Ricker, 1975).

2.4.1. Software

A computer program called MERKAN, developed specifically for this project, was used to both extract and organize relevant data from raw data files and to perform analyses.
The program selects data related to tag release at specified time and area, and recaptures in landings screened for tags at specified time and area. Each tag has a unique number that allows linking the information at recapture to information at release. Data on screened catches are also selected according to time and location. All information on tagged fish, recaptured tags and screened landings are allocated to year classes as described in sections 2.1, 2.2 and 2.3.
The result of this data extraction is assembled in 3 tables in the program:
$R_{ycl,i}$: Number of tags released from year class *ycl* in year *i* in the selected area
$r_{ycl,i,j}$: Number of tags recaptured from year class *ycl*, released in year *i* in the selected area and recaptured in year *j* at the selected time and location
$N_{scrycl,j}$: Numbers screened in the selected time in year *j*, belonging to year class *ycl*.
These tables were used in the subsequent calculations.

2.4.2. Model 1 - MERKAN

The abundance at release time (Year *i*) by year class was calculated as:

$$N_{ycl,i} = R_{ycl,i} * s_i * \left(\sum_{j=i+1}^{2008} N_{scr\,ycl,j} \Big/ \sum_{j=i+1}^{2008} r_{ycl,i,j} \right)$$

where s_i is the assumed fraction of tagged individuals that survive the tagging operation and the other notations are as described in section 2.4.1. The calculations were done within the MERKAN program and tags recaptured the same year they were released were excluded to allow for one year of mixing of the tags among the population. The lowest age at release included in the calculations was two years. Mackerel abundance was estimated with this method between 1986 and 2006, with the exception of 1987 and 2005, as no tagging experiments were completed in these years. 2006 was the last year in which abundance was estimated because two years of recoveries is the minimum required to estimate abundance. Except for the loss of tags due to fish not surviving the tagging operation, the mortality in the tagged population was assumed to be the same as in the untagged population. We will refer to this model as MERKAN in the following sections.

2.4.3. Model 2 – HAMRE (Hamre, 1978)

This model estimates abundance in the tag recapture years rather than in the release years as in MERKAN. The calculations were carried out in excel and the following model was used to estimate abundance in the year classes:

$$N_{ycl,j} = N_{scr\ ycl,j} * \left(\sum_{i=1986}^{j-1} R_{ycl,i} * s_i * e^{-Z_{ycl,i,j}} \Big/ \sum_{i=1986}^{j-1} r_{ycl,i,j} \right)$$

where $Z_{ycl,i,j}$ is the cumulative total mortality in the year class, *ycl*, between tag release and recapture and the other notations are the same as were explained for the MERKAN. An initial tagging survival rate, s_i, was assumed and thereafter the natural and fishing mortality rates estimated by the ICES assessment for the NEA mackerel stock (ICES, 2009b) were applied to the tagged individuals by year class. The abundance was estimated for the years 1986-2008 for 3-12 year old mackerel. We will refer to this model as HAMRE in the following sections.

2.5. Biomass estimates

The biomass was estimated by converting the numbers-at-age to total weight in each year by using the mean weight-at-age in the stock as estimated by ICES (2009 b). The total weights of 3-12 year old fish were then summed for each year.

2.6. Tagging survival

The initial tagging survival rate was set at a constant 60% in all years and for all ages. This assumption was based on tagging survival experiments carried out by Hamre (1970) and Lockwood *et al.* (1983). In the experiment carried out by Hamre (1970) 100 internally tagged mackerel were kept in a keep net for three weeks, together with a control group of 100 mackerel. The survival rate of the tagged mackerel was 82% and the control group survival was 91%. In the Lockwood et al. (1983) experiment 93 tagged and 92 untagged mackerel were kept in a keep net for 15 days. The survival of the tagged group was 81.7% and control group survival was 95.7%. The same tagging methodology was used in the survival experiments as has been used in this study, but additional mortality is caused by releasing the fish in the sea, occasional bad weather conditions, sea bird predation on the newly tagged mackerel and long term mortality. There is no available data on the mortality resulting from releasing the fish in the field and to assess the implications of over- and underestimation of the survival rate the biomass estimates were also calculated for tagging survival rates of 70% and 50%.

2.7. Uncertainty

Some of the uncertainties in the MERKAN results were estimated by bootstrap. Two sources of uncertainty were covered: the age distribution of the released mackerel and the landings which were screened for tags. The terms $R_{ycl,i}$ were recalculated for each bootstrap replicate by reallocating the total number of released tags to year classes with a new age distribution. This age distribution was drawn according to a multinomial distribution with the original fractions at age as expectation values, and with a sampling size that was set at 100, which is the normal number of individuals that are length sampled by IMR. This was done separately for each experiment (release year). The landings were redrawn randomly with replacement, for each bootstrap replicate, from the material of single landings until the number of redrawn landings matched the actual number of landings for all the years included in the material. The amount screened and the tags found in the drawn landings were used. The abundance and biomass estimates from MERKAN are presented as medians with 25th and 75th percentiles based on 1000 bootstrap replicates.

2.8. Length and age distributions of discarded, tagged and screened mackerel

Length and age distributions were compared to examine whether the ALKs, used to age the tagged mackerel, were representative of the tagged population and whether the tagged population was representative of the commercial catches. Age distributions of the tagged and screened mackerel were used rather than lengths to avoid the influence of growth in the time between tagging and screening. Due to very large sample sizes and the use of ALKs for the screened and tagged mackerel the statistical analyses were complicated. The sample sizes were therefore standardized to 100 and the significances of group differences were statistically tested with factorial ANOVA. By reducing the sample sizes the statistical precision was reduced, but the statistical analyses became biologically more meaningful. The results from a power analysis (power = 0.8, standardized effect = 0.5, using the observed means and standard deviations) showed that between group differences of about 1.5 cm in length and slightly less than one year in age would result in statistical significance when using sample sizes of 100.

3. Results

3.1. Abundance-at-age

The tag recapture models indicated higher abundances compared with the official estimates based on the ICA model in most of the analyzed year classes (ICES, 2009b, Figure 2). Exceptionally high abundances were estimated for the 2001–2004 year classes. The tag estimates fluctuated from year to year, especially for the old and young year classes. There were also high levels of uncertainty in the estimates. More stable estimates were produced for the intermediate year classes, 1988-1994. The estimates of 2-year old mackerel by MERKAN and correspondingly 3-year olds by HAMRE were low in many of the assessed year classes when considering the general trends in the time courses.

3.2. Biomass estimates

The biomass estimates based on MERKAN ranged from 3.1 to 7.2 million tonnes in the years 1986-2006, while the estimates from the HAMRE model ranged from 1.2 to 9.5 million tonnes (Figure 3).The estimates for 2007 and 2008 from the HAMRE model were 13.5 and 26.5 million tonnes respectively (due to the exceptionally high values these years estimates have been excluded from Figure 3). The ICA model estimates were well below the lower confidence limit of the tag model estimates (Figure 3, ICES, 2009a). SSB estimates from the triennial egg survey were also about 15% below the tag estimates (Figure 3, ICES, 2008). The tag recapture estimates indicate a reduction in biomass in the 1990s, which is not indicated by the ICA estimates. The ICA model on the other hand indicates a decrease in the SSB from the late 1990s to 2002 and then an increase from 2002 to 2006, also indicated by the egg surveys. This increase can also be seen in the tag estimates that indicated a substantial increase in the stock biomass from 2002/2003.

The choice of tagging survival rate between 50-70% influenced the biomass estimates by between 0.4 million tonnes in the lowest estimate to 3.2 million tonnes in the highest estimate (Figure 4).

3.3. *Length and age distributions of discarded, tagged and screened mackerel*

The mean lengths of the ALKs and the tagged mackerel differed by less than 1.5 cm in all years, except for 1990 when the difference was 2 cm (Figure 5). The mean lengths were lower in the ALKs in 15 out of 22 years and the difference between the groups was statistically significant ($p<0.001$). The mean ages of the tagged and screened mackerel differed by less than one year in all years and there was no consistent bias in the data (Figure 5). The differences in the age distributions of the two groups were not statistically significant.

4. Discussion

Both tag recapture models produce abundance estimates that are larger and more variable than the official estimates (ICES, 2009a). These results are in accordance with previous studies (ICES, 2008, Simmonds et al., 2010). Simmonds et al. (2010) used Bayesian state-space models to investigate the agreement between data from egg surveys, tagging data and catch-at-age and the results indicate a SSB that is substantially higher than the official ICES estimate. The triennial egg survey SSB estimates have on average been 30% higher than the official SSB estimates (ICES, 2008). The survey estimates are furthermore believed to underestimate the stock size by up to 40% due to incomplete coverage of the egg distribution and unaccounted egg mortality before first capture (ICES, 2005; Portilla et al., 2007).

One of the main assumptions in this study is complete mixing of the tagged individuals with the whole NEA mackerel stock. This assumption may be difficult to satisfy when considering the highly migratory and widely distributed NEA mackerel stock. Migration and distribution studies do, however, indicate that the whole stock is present in the northern North Sea and Norwegian Sea in autumn and winter (Uriarte and Lucio, 2001) when most of the landings have been screened. The fisheries are also selective and tend to target larger individuals (Kvalsvik et al., 2002), but the age distributions of the tagged and screened mackerel did not indicate any bias in the samples. The size selectivity of the fisheries should, anyhow, not influence the tag based estimates because year classes are treated separately, both with respect to the numbers released, the numbers recaptured and the numbers screened, and the year class abundance is determined by the concentration of tags in the screened catches. Likewise, the cumulated mortality is summed over ages within the year class.

A substantial increase in biomass is indicated by the tag models from 2002 to 2006 and 2008 respectively. The official estimates (ICES, 2009a) and the egg surveys (ICES, 2008) also indicate an increase in the stock in these years, but the reduction in tag recapture rate since 2005 is too distinct to be explained by solely an increase in the stock size. Mackerel distribution areas during spawning and summer feeding have expanded and moved further north and northwest in the more recent years (ICES, 2009b). These changes may indicate an increase in the stock, but may also have introduced a bias in the tag based estimates if the changes result in variation in the mixing rate of the tags with the whole population. It is, however, also likely that methodological issues have introduced a source of error. First, the change from manual to automatic jigging in 2006 may have involved a decrease in the survival rate of the tagged mackerel. Secondly, there is reason to believe that the detection of tags and testing of detector efficiency has become less reliable at some of the factories during the last years resulting in loss of tags and overestimation of the detector efficiency. Small sample sizes may also have resulted in highly uncertain estimates in the last years of the study period. Nevertheless it is important to improve the temporal and spatial coverage of the fisheries and increase both the number of tagged individuals and the screened landings. According to Robson and Regier (1964) the tagged sample size times the size of the sample examined for tags should be at least three or four times the expected population size to avoid bias in the estimates. Samples of that size may be difficult to reach when the stock is as large as the NEA mackerel, but at the moment between 20 000 and 40 000 tonnes are screened each year while the total catch is around 600 000 t and there is therefore potential to substantially increase the amount screened. Given international co-operation detectors could be installed internationally and by installing two detectors at the large mackerel ports in the UK, for example, the amount screened could be doubled.

The MERKAN model estimates were not affected by uncertainty in catch data as no assumption on mortality was required other than initial tag loss, but the estimates varied substantially among years. The uncertainty related to the level of tagging survival rate and how it varies between years and sizes is probably the greatest uncertainty source in these estimates, and an assumption of a constant rate is highly unrealistic. The mean lengths of the age-length keys were significantly lower than the mean lengths of the tagged mackerel and the difference seems to be due to a larger proportion of small mackerel (below 25 cm) in the ALKs. These mackerel are mainly 0- and 1-year olds and not included in the data and should thereby not introduce any bias in the age distribution of the tagged mackerel, but this may indicate that small mackerel are more vulnerable to the tagging operation and therefore have lower tagging survival rate. An attempt was made to study the variation in wind strength and sea bird predation pressure on the newly tagged mackerel and how these influenced recapture rates, but no effect was found, although the data were of too poor quality to be assessed properly. Some of the uncertainty related to variation in tagging survival rate is reduced in the HAMRE model as several tag release experiments are summed.

Some of the uncertainty was estimated by bootstrapping some of the raw data. The age distribution of the tagged fish at release is based on samples of the fish caught for tagging. The uncertainty due to the relatively small sample size was included in the bootstrap, assuming a multinomial distribution. Furthermore, the potential uncertainty caused by few landings screened and low numbers of tags found in each landing, was included by randomly drawing (with replacement) the landings to be used in the analysis. Clearly, these sources, although important, do not cover the whole range of sources of uncertainty. To cover all relevant sources adequately would be a major task, in particular because their distributional properties often are poorly known.

In order to improve the dataset in the future and to reduce the uncertainty involved in the estimates a more automatic tagging and recapture method should be introduced. Passive integrated transponder tags (PIT) are presently considered to be more successful than the traditional tagging method. The technology does not require constant surveillance and manual data collection, which seem to cause problems in the current method. Automatic detection of tags and data collection would also make it easier to install more detectors, also internationally.

Given the lack of fishery independent, age-structured data, tag recapture estimates could be of great value, and perhaps be included in the stock assessment of the Northeast Atlantic mackerel on a regular basis. The tag recapture dataset provides age-structured abundance estimates that are not directly influenced by the unreliable catch data, and the stock estimates can be carried out on a yearly basis at a relatively low cost. One disadvantage with the MERKAN estimates in an assessment is that they do not cover the most recent years. The HAMRE model, on the other hand, requires fishing and natural mortality rates as input and these are derived from the assessment model. However, if the tag-based estimates were used in the assessment, the fishing mortality rates would probably change themselves. One possible way forward is to feed the mortality information embedded in the tag recapture data into the HAMRE model, and use either the resulting index as a relative measure of abundance, or derive expected recaptures from the assessment model and fit that to the data. Such approaches would require further modelling work and a careful evaluation of the effect of the noise in the data. Further studies of the survival rate of the tagged mackerel and an improved understanding of the migration and distribution patterns and changes in these patterns are essential.

Acknowledgements

We would like to thank the whole mackerel tagging team at the IMR, especially Sigmund Myklevoll who has been the leading man from the start of the tagging program. Thanks to Knut Hestenes and Helga Gill for excellent help with data processing and Aud Vold and Johannes Hamre for constructive comments on the manuscript.

References

Borges, L., van Keeken, O.A., van Helmond, A.T.M., Couperus, M., Dickey-Collas, M., 2008. What do pelagic freezer-trawlers discard? ICES J. Mar. Sci. 65, 605-611.

Cadigan, N.G., Brattey, J., 2001. Estimation of the exploitation rates and migration rates of cod (*Gadus Morhua*) in NAFO division 3KL and subdivision 3Ps during 1997-2000 from tagging experiments. ICES CM 2001/O:04.

Gorska, N., Korneliussen, R.J., Ona, E., 2007. Acoustic backscatter by schools of adult Atlantic mackerel. ICES J. Mar. Sci. 64, 1145-1151.

Hamre, J., 1978. The effect of recent changes in the North Sea mackerel fishery on stock and yield. Rapp. P.-v. Réun. Cons. int. Explor. Mer 172, 197-210.

Hamre, J., 1970. Internal tagging experiments of mackerel in the Skagerrak and the northeastern North Sea. ICES CM 1970/H:25.

ICES. 2005. Report of the working group on mackerel and horse mackerel egg surveys. ICES Document CM 2005/G:09, 130 pp.

ICES. 2006. Report on the working group on the assessment of mackerel, horse mackerel, sardine and anchovy. ICES Document CM 2006/ACFM:08, 631 pp.

ICES. 2008. Report of the working group on mackerel and horse mackerel egg surveys. ICES Document CM 2008/LRC:09, 107 pp.

ICES. 2009a. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2009. ICES Advice. Book 9. Widely Distributed and Migratory Stocks, 113 pp.

ICES. 2009b. Report of the widely distributed migratory stocks ICES Document CM 2009/ACOM:12, 563 pp. (http://www.ices.dk/reports/ACOM/2009/WGWIDE/WGWIDE09.pdf)

Kleiber, P., Argue, A.W., Kearney, R.E., 1987. Assessment of Pacific skipjack tuna (*Katsuwonus pelamis*) resources by estimating standing stock and components of population turnover from tagging data. Can. J. Fish. Aquat.Sci. 44, 1122-1134.

Kvalsvik, K., Misund, O.A., Engås, A., Gamst, K., Holst, R., Galbraith, D., Vederhus, H., 2002. Size selection of large catches: using sorting grid in pelagic mackerel trawl. Fish. Res. 59, 129-148.

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

Lockwood, S.J., Pawson, M.G., Eaton, D.R., 1983. The effects of crowding on mackerel (*Scomber scombrus*): physical conditions on mortality. Fish. Res. 2, 129-147.

Nesse, T.L., Hobæk, H., Korneliussen, R.J., 2009. Measurements of acoustic-scattering spectra from the whole and parts of Atlantic mackerel. ICES J. Mar. Sci. 66(6), 1169-1175.

Patterson, K.R., Melvin, G.D., 1996. Integrated catch at age analysis, version 1.2. Scottish Fisheries Research Report No. 58. The Scottish Office of Agriculture, Environmnet and Fisheries Department. 60 pp.

Pine, W.E., Pollock, K.H., Hightower, J.E., Kwak, T.J., Rice, J.A., 2003. A review of tagging methods for estimating fish population size and components of mortality. Fish. Res. 28(10), 10-23.

Portilla, E., McKenzie, E., Beare, D., Reid, D., 2007. Estimating natural interstage egg mortality of Atlantic mackerel (Scomber scombrus) and horse mackerel (Trachurus

trachurus) in the Northeast Atlantic using a stochastic model. Can. J. Fish. Aquat.Sci. 64(12), 1656-1668.

Rankine, P.A., Walsh, M., 1982. Tracing the migrations of minch mackerel. Scot. Fish. Bull. DAFS Mar. Lab., Aberdeen 47, 8-13.

Ricker, W.E., 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Canada Bull. 191. 382pp.

Robson, D.S., Regier, H.A., 1964. Sample size in Petersen mark-recapture experiments. Trans. Am. Fish. Soc. 93(3), 215-226.

Schwarz, C.J., Seber, G.A.F., 1999. Estimating Animal Abundance: Review III. Statist. Sci. 14 (4), 427-456.

Schwarz, C.J., Taylor, C.G., 1998. Use of the stratified-Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Can. J. Fish. Aquat.Sci. 55, 281-296.

Simmonds, E.J., Portilla, E., Skagen, D., Beare, D., Reid, D.G., 2010. Investigating agreement between different data sources using Bayesian state-space models: an application to estimating NE Atlantic mackerel catch and stock abundance**.** ICES J. Mar. Sci. 67, 000–000.

Slotte, A., Skagen, D., Iversen, S.A., 2007. Size of mackerel in research vessel trawls and commercial purse-seine catches: implications for acoustic estimation of biomass. ICES J. Mar. Sci. 64, 989-994.

Uriarte, A., Lucio, P., 2001. Migration of adult mackerel along the Atlantic European shelf edge from a tagging experiment in the south of the Bay of Biscay in 1994. Fish. Res. 50, 129-139.

Tables

Table 1. Tags released in the years 1984-2007 and yearly recaptures one year after release (R_{y+1}) to 10 years after release (R_{y+10}).

Release year	N. released	Recaptures									
		R_{y+1}	R_{y+2}	R_{y+3}	R_{y+4}	R_{y+5}	R_{y+6}	R_{y+7}	R_{y+8}	R_{y+9}	R_{y+10}
1984	708	2	1	1	3	1	0	1	0	0	0
1985	408	7	3	4	3	3	0	1	1	0	0
1986	16983	5	5	1	5	2	2	0	1	0	0
1988	20068	10	9	6	3	3	8	4	0	0	1
1989	20789	14	8	2	5	2	2	2	1	3	0
1990	19744	10	6	14	11	2	2	3	3	2	1
1991	21382	11	24	17	2	3	3	2	1	2	1
1992	15800	17	17	5	4	6	3	1	1	0	1
1993	22279	32	22	8	11	14	3	1	3	2	0
1994	26934	26	30	17	25	12	9	7	2	1	0
1995	24448	30	36	46	24	20	8	12	2	1	0
1996	18858	33	52	26	21	13	11	7	1	1	0
1997	34375	108	68	50	32	28	11	2	2	1	0
1998	21900	60	40	41	20	15	6	0	1	0	0
1999	12379	30	26	16	9	3	2	0	0	0	
2000	5552	17	16	13	6	0	0	0	0		
2001	20623	72	50	27	10	2	5	0			
2002	17272	55	34	11	4	3	0				
2003	11806	32	8	4	5	2					
2004	13649	23	13	10	8						
2006	27312	29	11								
2007	27678	4									

Table 2. Mackerel screened for tags in the years 1986–2008 and the efficiency of the detector.

Year	Screened (t)	Eff. (%)
1986	3966.7	97.8
1987	7376.9	89
1988	7391.7	96.9
1989	5866.1	99.6
1990	10855.4	97.8
1991	9483.4	99
1992	10831.2	90.3
1993	21086	95.2
1994	25536.2	92
1995	16332.7	91.1
1996	18481.6	92.2
1997	20898.8	90.9
1998	26280.9	95.4
1999	22846.7	96.6
2000	26647.2	95.6
2001	26984.4	98.8
2002	29089.6	96
2003	45592	92.2
2004	44918.7	96.6
2005	30819.6	95.2
2006	24039.6	97.7
2007	22669.6	97.2
2008	18946.6	97.7

Figures

Figure 1. Tag releases (squares) in the spawning area west of Ireland and recaptures (circles) from fisheries in the northern North Sea, 1986-2008.

Figure 2. Mackerel year class abundance (numbers at age 10^9) estimated by the MERKAN (filled circles) and the HAMRE (filled squares) models compared with the official ICA estimates (open squares, ICES, 2009b). The MERKAN estimates are presented as bootstrap medians with 25th and 75th percentiles.

Figure 3. Stock biomass estimates of 3-12 year old mackerel, 1986-2006, based on the MERKAN and the HAMRE models. The estimates are compared with the official SSB estimates (ICES, 2009a) and the triennial egg survey SSB estimates (ICES, 2008). The MERKAN estimates are presented as bootstrap medians with 25th and 75th percentiles.

Figure 4. The influence of various tagging survival rates (50, 60 and 70%) on the biomass estimates based on the MERKAN (a) and the HAMRE (b) models, 1986-2006.

Figure 5. Comparisons of the mean lengths with 95% confidence intervals of the ALKs used to age the tagged mackerel and the tagged mackerel (Figure a) and the mean ages with 95% confidence intervals of the tagged and screened mackerel (Figure b).

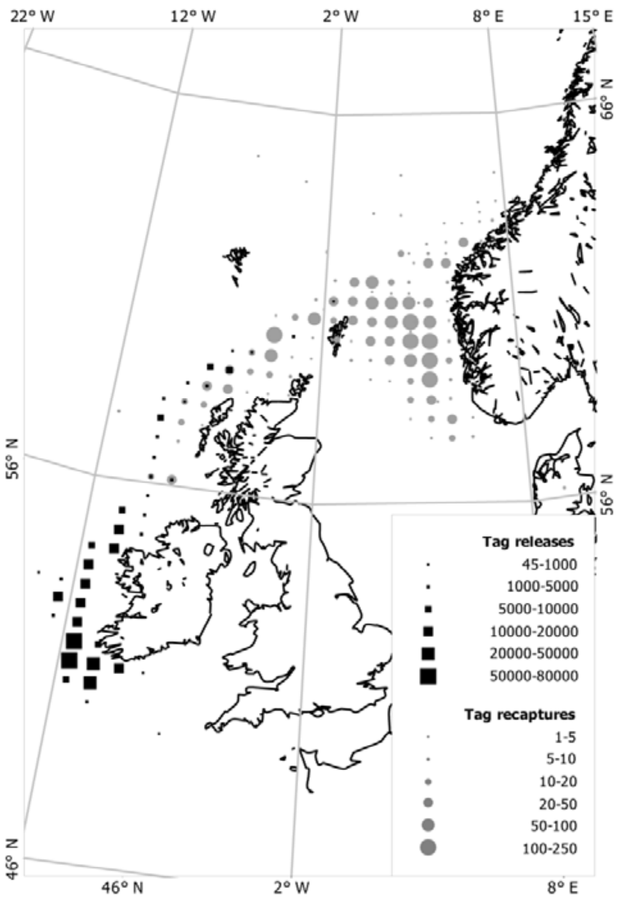
22° W
12° W
2° W
8° E
15° E
66° N
56° N
56° N
46° N
46° N
2° W
8° E
Tag releases
45-1000
1000-5000
5000-10000
10000-20000
20000-50000
50000-80000
Tag recaptures
1-5
5-10
10-20
20-50
50-100
100-250

Figure 1.

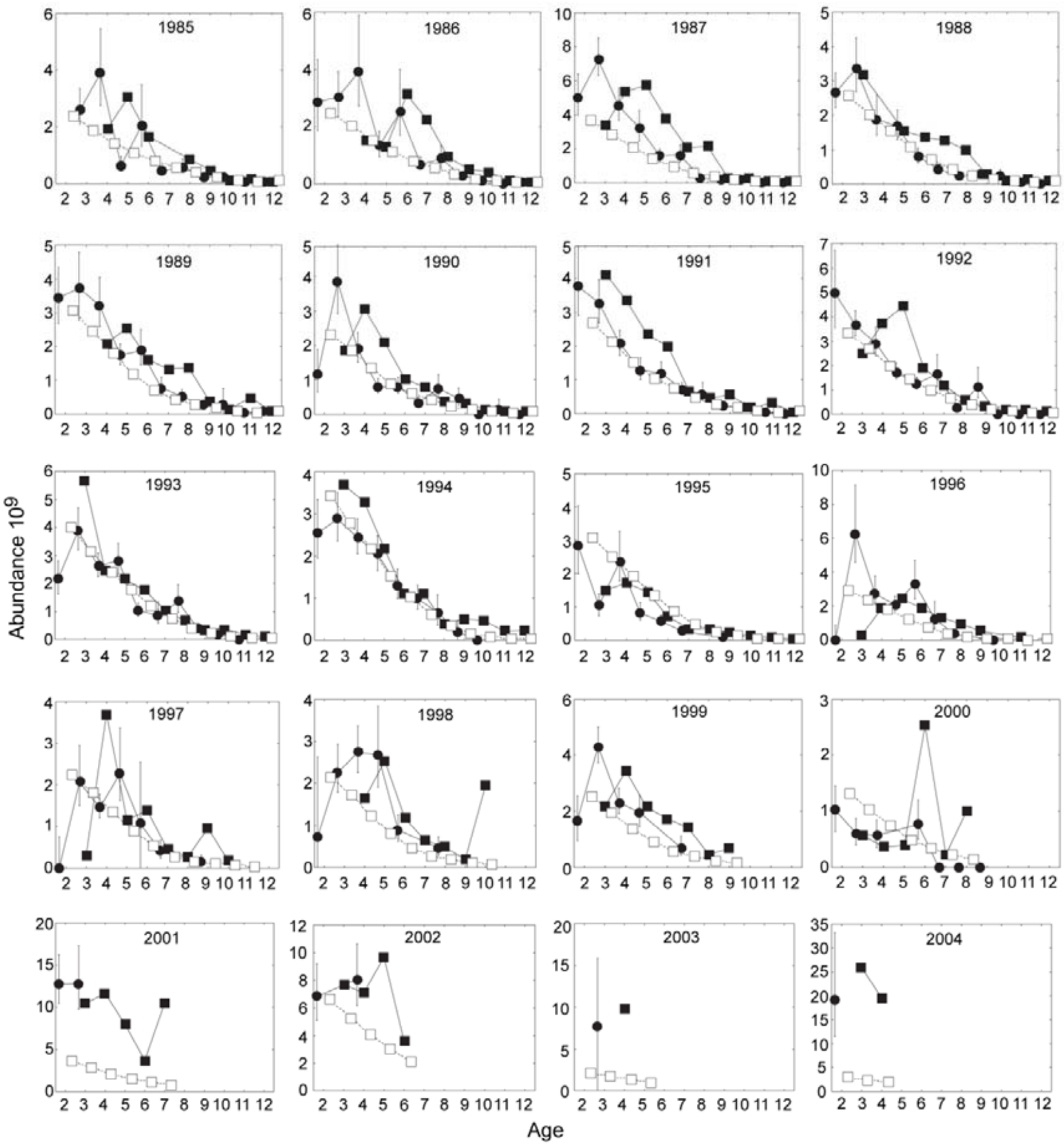
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Abundance 10^9
Age

Figure 2.

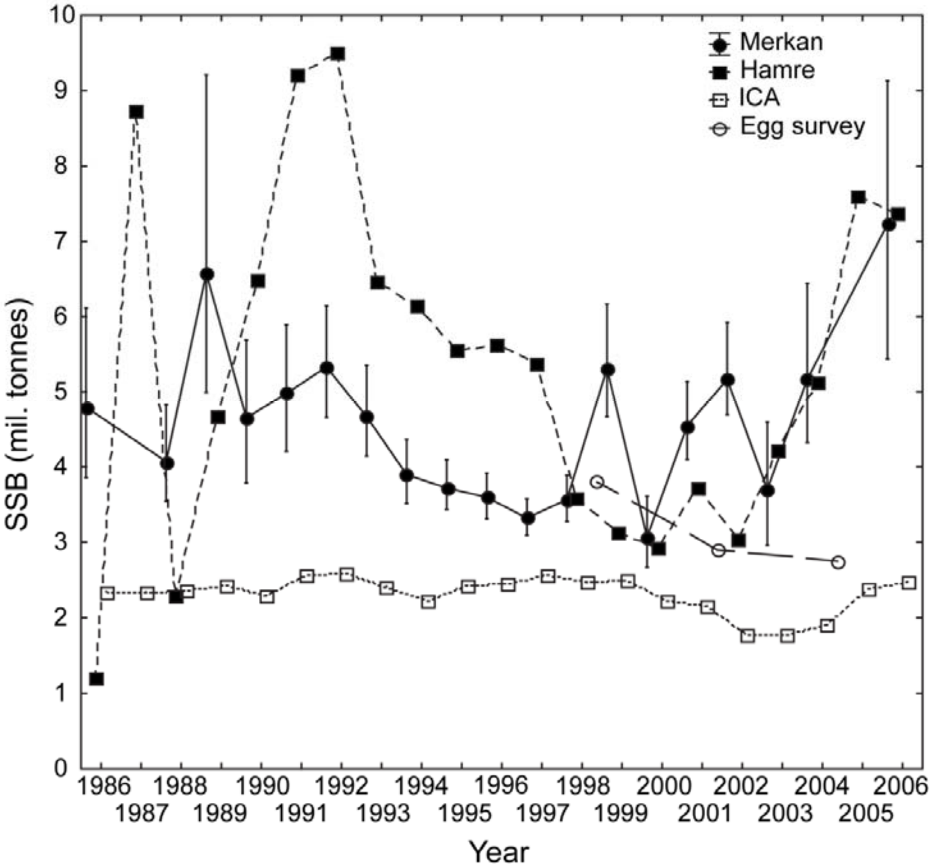

Figure 3.

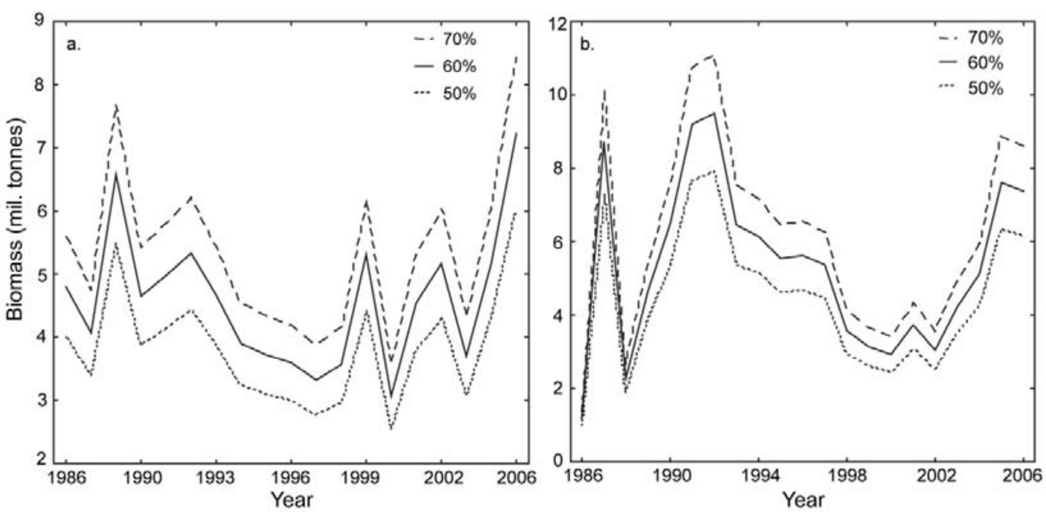

Figure 4.

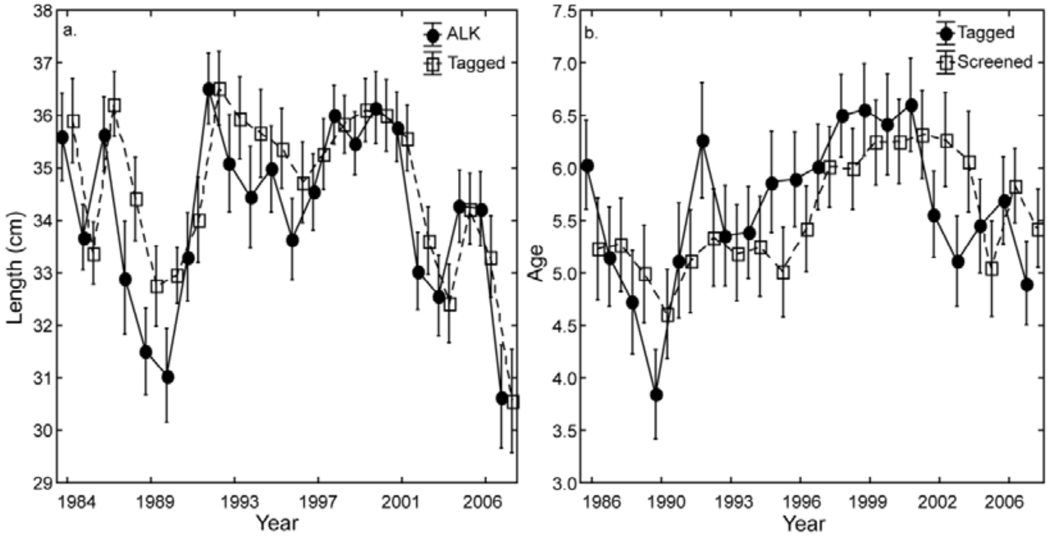

Figure 5.