

Observations on long-term changes in prevalence of fish species with southern biogeographic affinities in the northern North Sea

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ABSTRACT

Recent observations made in the scientific and popular literature have suggested that the characteristics of both marine and terrestrial plant and animal communities are changing rapidly due to increasing global air and sea temperatures. It is well known, for example, that the Lusitanian planktonic copepod, *Calanus helgolandicus*, almost completely replaced its more boreal congener, *Calanus finmarchicus* in the northern North Sea between the late 1960s and late 1990s. The exact causative mechanisms underpinning this dramatic shift are still poorly understood, but global temperature change is likely to be involved. In this paper we examine the hypothesis that the piscian species composition of the northern North Sea is changing in response to climate. To do this we use a rich dataset on fish abundance collected by trawl during research surveys carried out by Fisheries Research Services, Aberdeen. The surveys cover water depths of less than 200m around all of Scotland's coasts, and span a period of 79 years (1925-2003). The data exist in the form of length-frequencies for 348 different species, while additional information (e.g. age, sex, weight and stage of sexual maturity) is available for the commercially important component (e.g. cod, whiting & haddock). Our detailed analyses of the data suggest that the northern North Sea is currently experiencing waves of immigration by exotic, southern species (eg. red mullet, anchovy & pilchard) which are unprecedented in the context of the 79 year history of our extensive databases. Changes in the size structure of the invading species also indicates that some of the recent arrivals are actually 'recruiting' on northern North Sea grounds. Finally, the striking long-term spatial changes in fish species abundance and composition observed are discussed in the context of sea surface temperatures which have risen over the last decade.

KEYWORDS

anchovy, sardine, horse mackerel, mackerel, lesser weaver, tub gurnard, red-mullet, bluemouth, bib, poor cod, John dory, long-term change, northern North Sea, climate change.

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INTRODUCTION

Long-term and seasonal changes in the abundance and distribution of fish have been noted since fishing activity by humans began. Over the last millennium, fluctuations of pelagic, demersal and shellfish stocks all around the globe have been regularly observed. There are numerous records, for example, of herring, mackerel, sardine and anchovy fisheries suddenly emerging in certain areas only to disappear again (Alheit & Hagen, 1997; Cunningham, 1889-90; Parrish & Saville, 1965; Parrish & Saville, 1967; Southward, Boalch & Maddock, 1988). Similarly, demersal fish stocks have experienced population expansions followed by rapid collapses. In the mid-1960s the “gadoid explosion” led to unusually high landings of cod, haddock and whiting (Cushing, 1984; Hislop, 1996) around British coasts, while in the mid-1990s the once prolific cod fisheries of the Grand Banks completely ceased to exist in many areas (deYoung & Rose, 1993).

In the last decade global air and sea temperatures have begun to rise due to greenhouse warming (Levitus et al., 2000). At the same time scientists have begun to note profound changes in the composition of both marine and terrestrial ecosystems at all trophic levels (Crick et al., 1997; Dunn & Winkler, 1999; McCleery & Perrins, 1998; Myneni et al., 1997). The abundance of the boreal copepod, *Calanus finmarchicus*, has fallen in the North Sea where it has been replaced by its Lusitanian relative, *C. helgolandicus*. *C. finmarchicus* overwinters in deep offshore waters and a reduction in the volume and depth of the upper surface of Norwegian Sea Deep Water, resulting in unfavourable conditions for over-wintering, has been promulgated as an explanation for its decline (Heath et al., 1999). Changes in the diversity of the North Atlantic copepod community have been linked to a warmer dynamic equilibrium (Beaugrand et al., 2000) and simultaneous modifications of water masses, currents and atmospheric forcing. Recent (1998) influxes into the North Sea of warm-water doliolids are connected to unusual incursions of oceanic water caused by changes in the North Atlantic Oscillation (Edwards et al., 1999).

Higher than average sea temperatures are correlated with low recruitment of cod at the latitudinal limits of its range (O'Brien et al., 2000; Planque & Frédou, 1999), while (Reid, de Fatima Borges & Svendsen, 2001) related abrupt changes in the abundance and composition of the plankton and fish community *circa* 1988 to recent increases in the North Sea horse mackerel fishery. Pronounced increases in tropical fish in the Bay of Biscay area have been noted (Quero, Du Buit & Vayne, 1998) by scientists in France, while (Swaby & Potts, 1999) made the first British record of the sailfin dory, *Zenopsis conchifer*, noting that the species is advancing northwards along the continental shelf west of the British Isles at a rate of 60km per decade. Other studies show similar patterns. Information on first records of southerly fish species caught in Cornish waters have been collated and published (Stebbing et al., 2002) and nearly 20 completely new species recorded (by 2001). The fish species noted include big-eyed tunny (*Thunnus obesus*), sailfin dory, short-nosed seahorse (*Hippocampus hippocampus*) and barracuda (*Sphyraena sphyraena*). In the Irish Sea, the occurrence of the warm-water species, anchovy (*Engraulis encrasicolus*), has increased between 1990 and 1998 according to trawl data from research surveys (Armstrong et al., 1999). Change has also been noted by British commercial fishermen. The spider-crab fishery (*Maia squinado*), for example, is advancing steadily further northwards (Anon., 2003).

In 1996 a paper was published describing the long-term variation in the abundance of southern species in the southern North Sea (Corten & van de Kamp, 1996) in relation to hydrography. Two periods of increase in the prevalence of southern species were described (mid-1970s & 1990) using data from the International Bottom Trawl Surveys (IBTS). Both periods co-incided with positive temperature anomalies, which in turn correlated with southerly winds over The Netherlands, indicating increased flow of Atlantic water through the Dover Strait. The authors concluded that the increases were not part of a systematic long-term trend, but the result of increased transport of southern fish species into the North Sea and favourable winter temperatures. The aim of this paper is to use the Corten and van de Kamp approach as a basic template. This time, however, only Scottish trawl survey data will be used because they are available much further back in time. The scientific goal will be to ascertain whether the increases noted by Corten and van de Kamp in the early 1990s in the southern North Sea are: (a) reflected in Scottish seas and (b) continuing into the 2000s.

MATERIAL AND METHOD

For this study we used a trawl survey database maintained by Fisheries Research Services (FRS), Aberdeen. FRS are responsible for managing Scottish commercial fisheries and have been collecting data on fish distribution and abundance in the seas around Scotland since the late nineteenth century. The data were originally stored in the form of paper notebooks built up on a cruise by cruise basis and were thus difficult to interrogate. Recently, however, all available trawl survey data have been organised into a single computer database, which can be searched relatively quickly. This database is an extremely rich resource and contains information on the long-term spatial and seasonal distributions of over 300 different fish species, extending back in time until 3rd March 1925. For all species caught the data are stored as length-frequencies caught by haul, although information on age, sex and state of sexual maturity is available for the commercially important component.

The trawl data were first analysed visually using a range of maps. Following this preliminary examination the data were then divided into six International Council for the Exploration of the Sea (ICES) standard Demersal Sampling Areas (Shetland; Moray Firth; Buchan; Forties; Central; & West Orkney) within which numbers of individuals caught per hour during each of four quarters (NB. January- March = Quarter 1) were calculated. It should be noted that since the early 1980s FRS has been sending its research vessel trawl data collected in the North Sea to ICES to be incorporated into the IBTS database. Some of the data described here, therefore, will be a subset of the IBTS data.

The following 12 fish species were classified as “southern” by Corten and van de Kamp (1996): *Echilichthys vipera* (lesser weaver); *Trisopterus minutus* (poor cod); *T. luscus* (bib); *Engraulis encrasicolus* (anchovy); *Trigla lucerna* (tub gurnard); *Mullus surmeletus* (red mullet); *Zeus faber* (John dory); *Dicentrarchus labrax* (bass); *Spondyliosoma cantharus* (black sea bream); *Sardina pilchardus* (sardine); *Trachurus trachurus* (horse-mackerel) and *Scomber scombrus* (mackerel). In their scheme, a fish species gained southern status either if its abundance was greater in the southern North Sea during the summer months, or its distribution was restricted to the southern

North Sea. They used the *Atlas of North Sea Fishes* to determine the distributional ranges of the fish (Knijn et al., 1993). The same group of species was examined here, but neither bass nor black sea bream have yet been recorded by Fisheries Research Services (FRS) in Scottish waters. In addition, we looked at data for the relatively deep water species, *Helicolenus dactylopterus* (bluemouth) and *Aspitrigla cuculus* (red gurnard), because of their affinities for shelf edge, and therefore warmer water.

RESULTS

Pelagic species

The location of the six standard ICES demersal sampling areas are displayed in Fig. 1. The long-term trends in the selection of southern fish species are complex and difficult to describe, although there have been increases since *circa* 1990 for nearly all species examined. In general terms the numbers of mackerel caught per hour have increased since 1925 in the four most northerly areas (Shetland, West Orkney, Moray Firth & Buchan). Further south, however, this trend is less noticeable with highest numbers occurring between 1935 and 1960 in Forties and between the late 1950s and mid-1960s in Central (Fig. 2).

Research vessel catches of horse-mackerel were very low until the early 1980s in Shetland, West Orkney, Forties and Central, while in Moray Firth and Buchan high catches were also recorded in the late 1950s in addition to a long-term increase that commenced during the early 1980s (see Fig. 3).

Anchovies and sardines are well known southern species, very rare around Scotland, and only very small numbers were noted prior to the mid-1990s (Fig. 3). Disregarding the low numbers noted in the late 1950s and late 1970s, the anchovy first appeared in Forties in the first quarter of 1996. In 1998 (quarter 1) they were also being recorded in Central, Buchan and West Orkney, and by 2003 they were being captured in all six areas. The overall long-term trend is strongly upwards since 1996 (Fig 3).

After 1990, sardines were first noted in West Orkney in 1996 from where they appear to have spread gradually into the other areas. They were caught by FRS for the first time in the Moray Firth in 2003 (quarter 1). The overall long-term trend is very similar to that of anchovy with another abrupt increase starting in the mid-1990s (Fig. 3).

Demersal species

In 1993 (quarters 1 and 2) bluemouth made a dramatic appearance in the north-western North Sea (Fig. 4) in all areas except Central where numbers peaked in 2000 (Heessen, Hislop & Boon, 1996). Following this invasion, numbers have begun to decline again; a process which is continuing into 2003. The average lengths of invading bluemouth are displayed in Fig. 5, which shows how the fish have grown on the grounds since they appeared in the early 1990s.

Bib was rare in the north-western North Sea and no long-term trends were clear in the data (Fig. 4). John dory was completely absent from Forties and Central between 1925 and 2003 according to our data, and relatively rare in the other four sea areas.

Generally speaking, long-term trends in CPUE were spatially consistent, with two pronounced peaks noted. The first occurred between 1955 and 1965 and the second after 1990 (Fig. 4). Poor cod were most abundant in Shetland and Moray Firth and the overall long-term trend in numbers was similarly shaped to that described above for John dory (Fig. 4). Between 1990 and 2003, a U-shaped trend can be discerned (present in all areas) due to peaks in the early 1990s and 2000s and a trough centred on 1995.

Numbers of red gurnard were highest in Shetland and lowest in Forties and Central. The long-term trend for red gurnard is again fairly spatially consistent and the bimodal pattern, with two peaks (*circa* 1945–1955; 1990–2003), is well summarised by the pooled data in Fig. 6. The mean lengths of the gurnard are also plotted (Fig. 5) and the growth of two clear cohorts are very clear from the data.

Very small catches of red mullet were noted between 1945 and 1972. In the mid-1990s they started to appear in increasing numbers in all sea areas (Fig. 6) except Forties. Lesser weavers have only been noted in Buchan (mostly prior to 1955) and Central. By far the highest CPUEs for the lesser weaver fish were recorded in Central where numbers have exploded since 1994 (Fig. 6).

Tub gurnards were only rarely recorded in the north-western North Sea. They were most prevalent in Shetland and West Orkney where nearly all were recorded before 1950. None have ever been recorded by us in Forties, and recent observations in Buchan and Central give rise to the peak in the pooled data since 1995 that can be discerned in Figure 6.

Sea surface temperature

Sea surface temperatures since 1925 are plotted in Figs 5a, b. In Fig. 7 average sea surface temperatures (hollow circles) in the north-western North Sea between 1925 and 2003 are plotted by month. The horizontal dotted line represents the average temperature between 1925 and 2003, while the solid black line is a smoothing filter intended to reflect long-term trend. The long-trends are complex but, since *circa* 1980, there has been a strong increase into the present. Since 1990, sea surface temperatures have been fairly consistently above the 79 year average. The detailed spatial characteristics of this temperature increase are displayed in Fig. 8 as decadal average sea surface temperatures for quarter 1. The influence of the North Atlantic Current, flowing into the Norwegian sea is immediately apparent, as is the 'tongue' of relatively warm water entering the northern North Sea via the Fair Isle Current (Fig. 8). The presence of anchovies is recorded on the map as crosses.

DISCUSSION AND CONCLUSIONS

The findings of the present study suggest that changes are occurring in the ecosystem of the northern North Sea. Most of the southern species we have studied show sudden, almost exponential increases in abundance since the mid-1990 and this pattern was particularly noticeable in the case of anchovy, sardine, red mullet, lesser weaver and bluemouth. The poor cod, John dory, horse mackerel, tub gurnard, red gurnard have also risen recently but there were similarly sized peaks in the mid to late 1950s too. The bib was rare, but regularly observed throughout the 79y period of the

study and does not exhibit a systematic long-term trend. It is perhaps a poor indicator of warm waters. Disregarding the bib, two groups of species can be identified based on the characteristics of their long-term trends in CPUE. Anchovy, sardine, red mullet, lesser weaver and bluemouth were all almost non-existent in the northern North Sea until the 1990s, whereas mackerel, horse mackerel, John dory, poor cod, red and tub gurnard were also relatively abundant during the mid to late 1950s; in addition to the recent increases. The invasion of the northern North Sea by bluemouth has been described before by Dutch scientists (Heessen et al., 1996) who suggested that the large pulse of oceanic water that entered the North Sea in 1990 (Heath et al., 1991) might have transported bluemouth eggs and larvae into the area. This study now extends the time-series to 2003 and our data for average bluemouth length (Fig. 5) show that a second recruitment of bluemouth occurred in the northern North Sea in 1998.

It is also clear that sea temperatures have increased and is likely that these rises are a causative factor. During this study, however, we calculated quarterly average sea surface temperatures for the relevant areas and regressed them against the catch per unit effort data for each species. In only one, the red gurnard, was a statistically significant regression noted with R^2 values of 48.6% for the first quarter data. It may be that the data are too noisy and still relatively sparse for significant correlations to emerge; or it may be that the temperature/fish relationships are non-linear or that temperature may interact with other factors (e.g. windspeed). It is possible that the 'climate envelope' approach is far too simplistic. This assumes that if average temperatures increase in northerly latitudes, for example, we will see a corresponding northward movement of entire species assemblages (Davis et al., 1998). The special effect of changing temperature, however, may affect each component of the ecosystem differentially and the eventual outcome of rising temperature may be impossible to predict. We see a recent rise in the abundance of some species (e.g. anchovies & sardines) which appears to be related to rising sea surface temperatures. In others, however, (e.g. John dory & red gurnard) we also observe the recent (1990-present) increases but find it difficult to explain why abundances were also high during the late 1950s (Figs 4 & 6). In conclusion, profound changes are taking place in the ecosystem of the North Sea, perhaps in response to climate change, but we cannot relate them directly to temperature very easily and the changes we observe may also be influenced by associated changes other components of the fauna.

FIGURES

ICES Demersal Sampling Areas Shetland (01), Moray Firth (03),
Buchan (04), Forties(05), Central (06),
West Orkney (09)

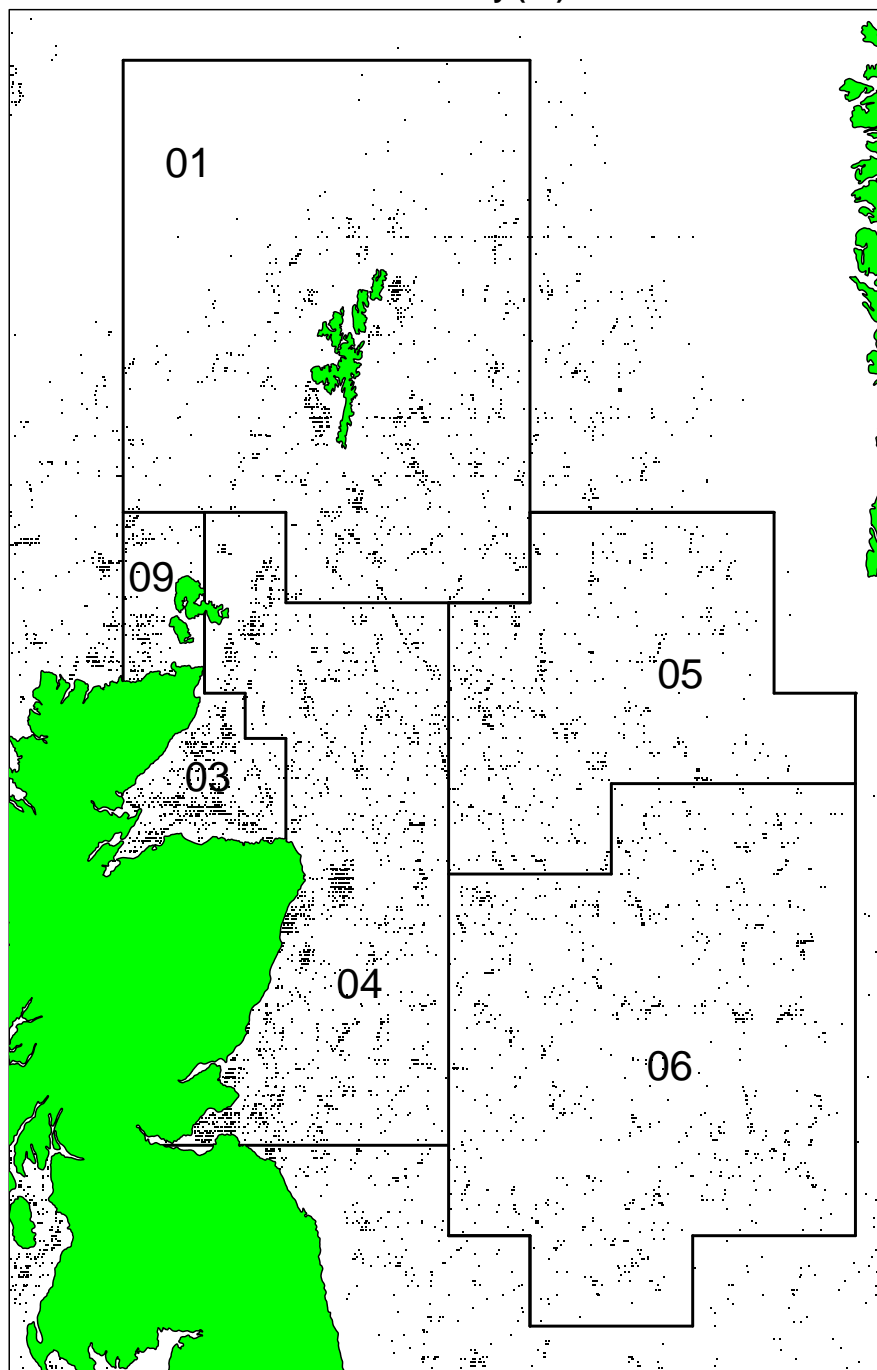


Figure 1. Locations of ICES Demersal Sampling Areas with locations of trawl stations.

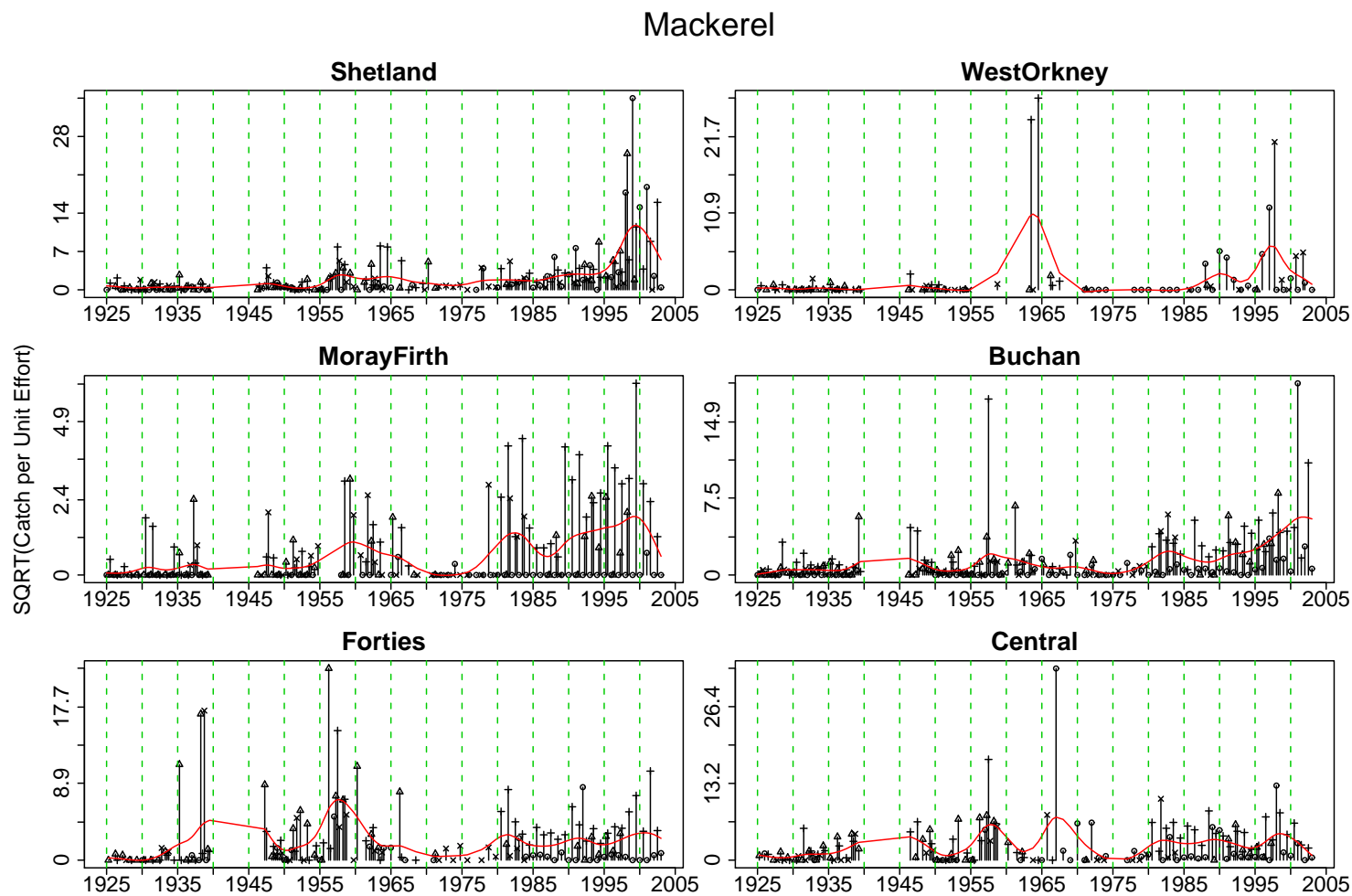


Figure 2. Time series of catch per unit effort for mackerel in the six ICES Demersal Sampling Areas.

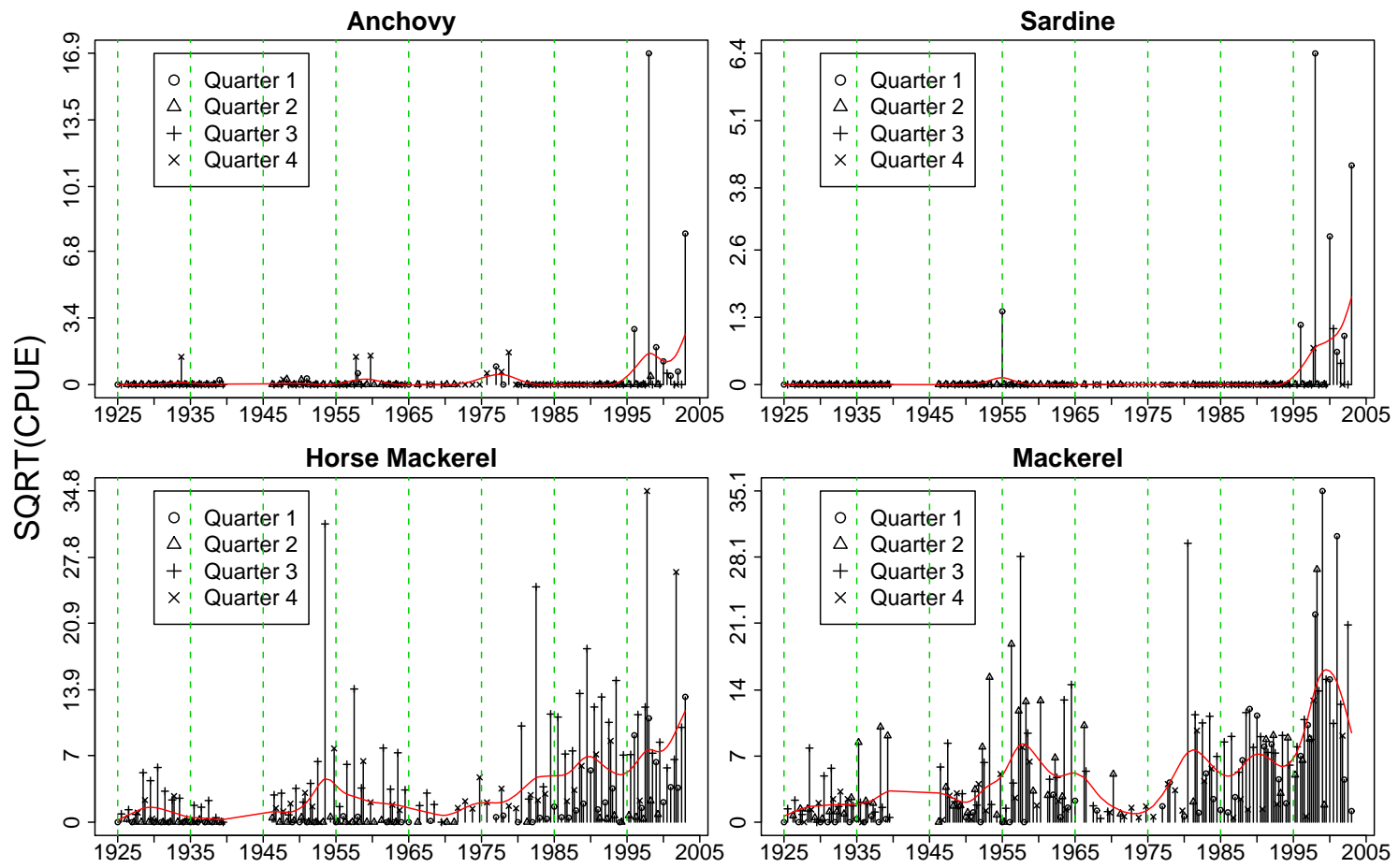


Figure 3. Catch per unit effort for anchovy, sardine, horse mackerel and mackerel in the six ICES Demersal Sampling areas pooled.

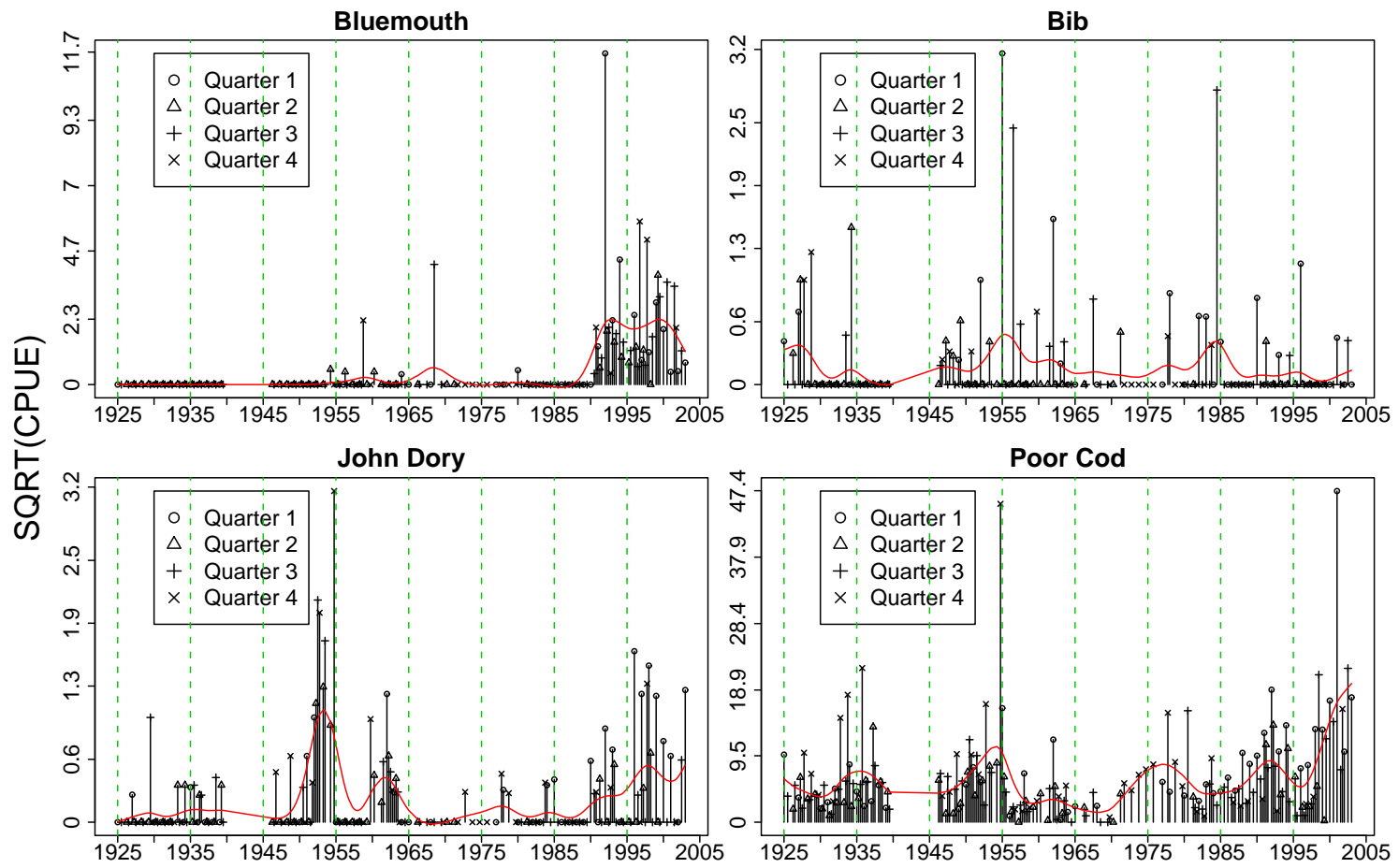


Figure 4. Catch per unit effort of bluemouth, bib, johndory and poor cod in the six ICES Demersal Sampling areas pooled between 1925 and 2003.

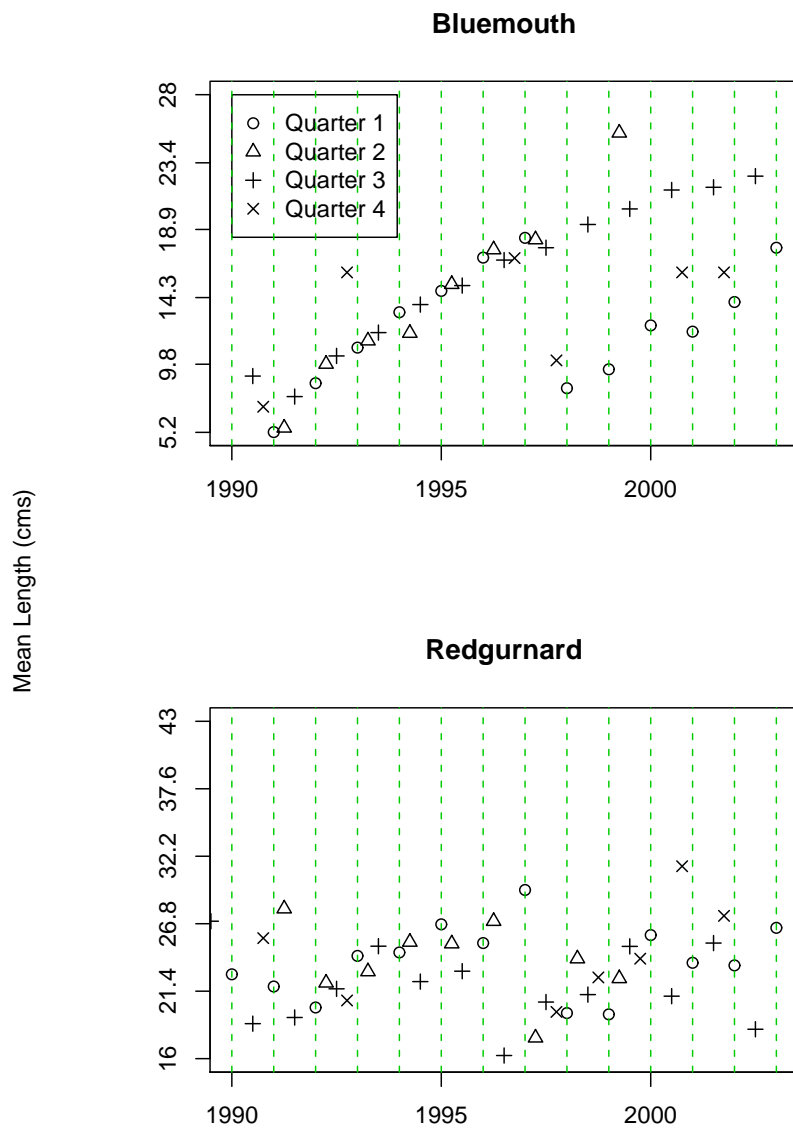


Figure 5. Mean lengths of bluemouth and redgurnard in the six ICES areas pooled between 1990 and 2003.

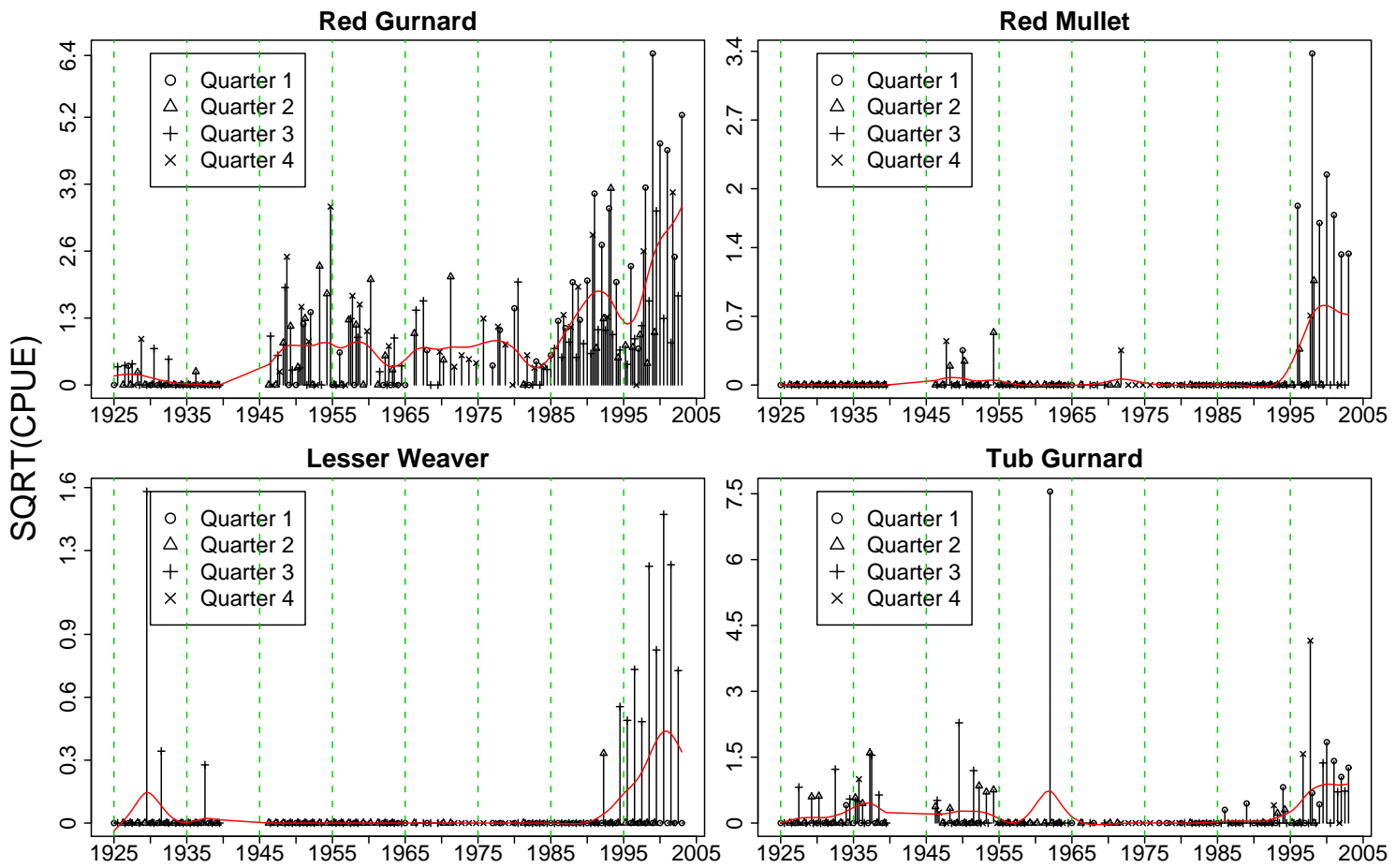


Figure 6. Catch per unit effort for red gurnard, red mullet, lesser weaver and tub gurnard in the six ICES Demersal Sampling areas pooled between 1925 and 2003.

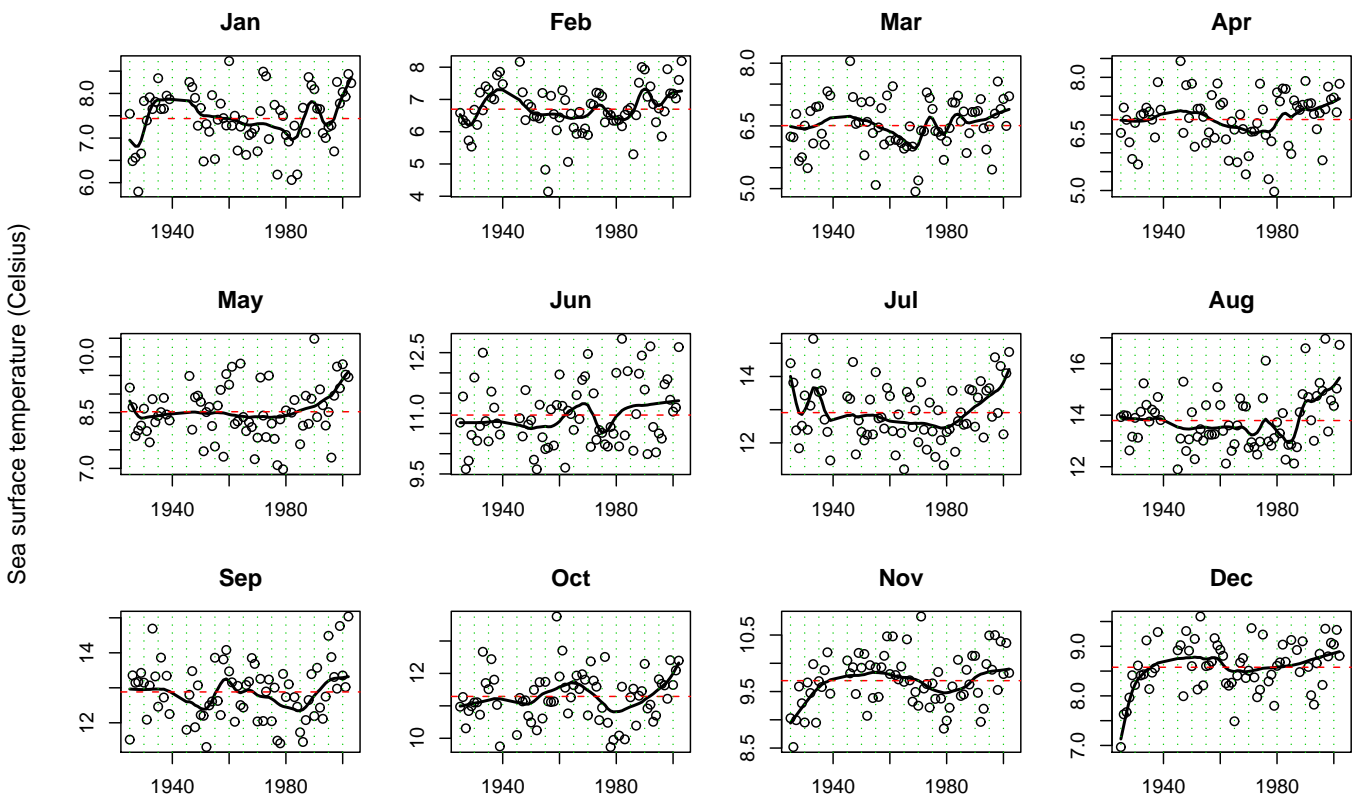


Figure 7. Sea surface temperature in the north-western North Sea by month between 1925 and 2003.

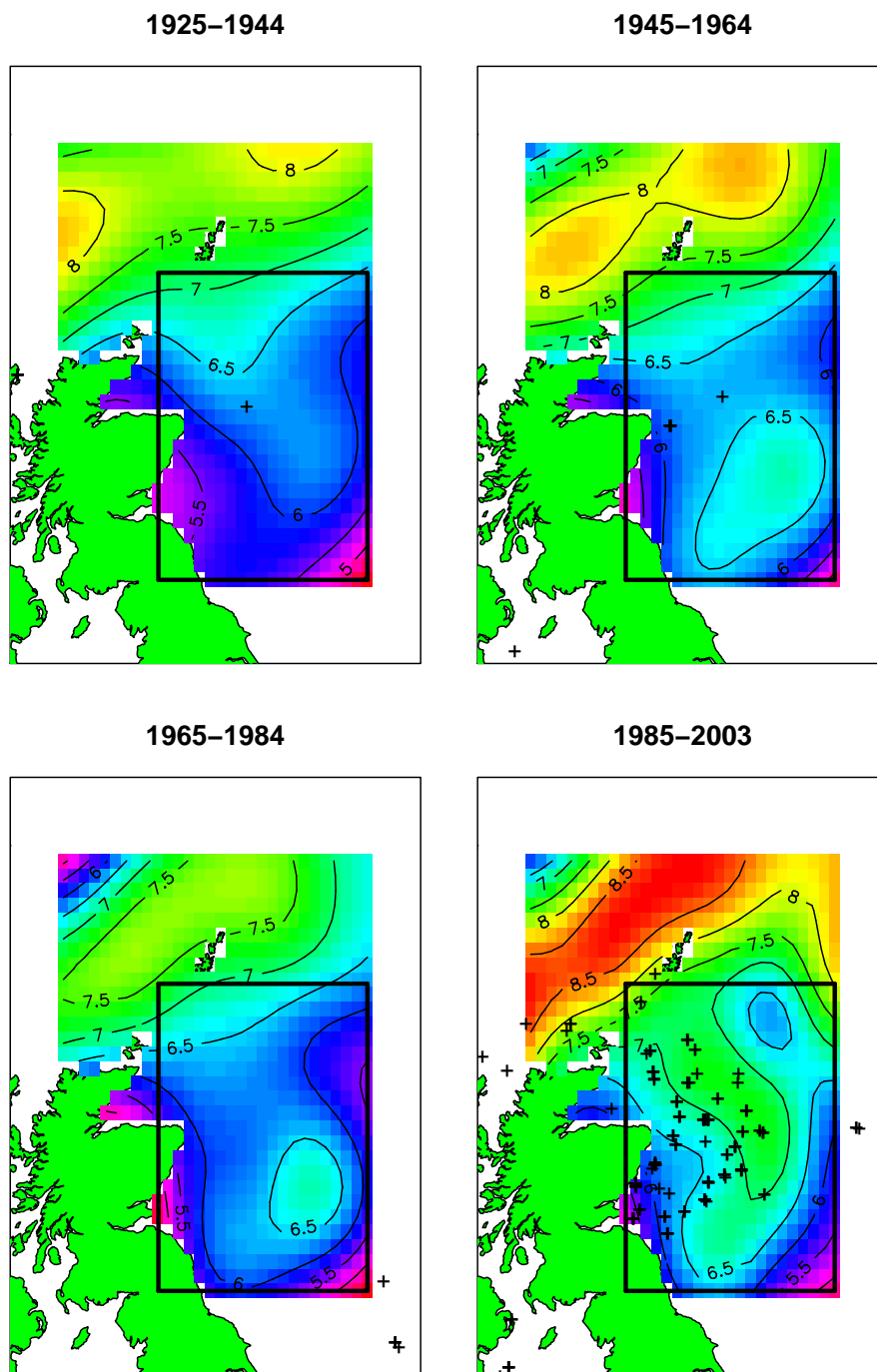


Figure 8. Average sea surface temperature in 20y periods in the north-western North Sea between 1925 and 2003.

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