Within Stock Structure and TACs: an investigation into the spawning origin of North Sea herring using otolith microstructure and the dynamics of Downs herring.

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Abstract

North Sea herring is assessed and managed as one stock. However due to the phenotypic plasticity of herring, there are components of the stock that express differences in growth, maturation and recruitment. In addition there is a separate sub-TAC to protect the spawning of the Downs component within the North Sea herring TAC. The component parts of North Sea herring mix at different life stages, e.g. as juveniles or during the summer feeding phase of the adults. Many investigators have tried to split these components with mixed success using meristic characteristics, size or growth. We have applied a well-established method of determining spawning type (autumn, winter or spring) by otolith microstructure to herring landed into the Netherlands in 2003 to 2005. The results suggest that winter-spawned fish from the southern North Sea dominated the catch in 2004, whereas autumn-spawned fish from northern components dominated in 2005. Our results suggest that the previously struggling Downs component is now highly productive again. Other available data suggest that there may be a trend in the ratio between northern and southern spawned North Sea herring, and this probably means that management by a fixed ratio TAC conflicts with the precautionary approach.

Keywords: herring, North Sea, Downs, microstructure, otolith, spawning type

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Introduction

North Sea herring (*Clupea harengus* L.) is assessed and managed as one unit (ICES, 1965; Burd, 1985; Cushing, 1992; Nichols, 2001). However due to the phenotypic plasticity of herring (Jennings & Beverton, 1991; Winter & Wheeler, 1996; McQuinn 1997) there are components of the stock (Heincke, 1898; Cushing & Bridger, 1966), which express differences in growth, maturation and recruitment patterns (Bjerkan, 1917; Cushing, 1958; 1967; Burd, 1978; Almatar & Bailey, 1989a; Hulme 1995). Currently the stock is managed assuming a fixed ratio between the components (EU 2005). This is despite a lack of scientific evidence to support this equilibrium between the subcomponents. Historically in the 1930 to 1950s, the fishery on the southern component dominated the catches (Cushing & Bridger, 1966; Burd, 1978) and only after the collapse of the stock did catches from the northern components dominate the fishery (Nichols, 2001).

Many scientists have commented that the different components have different sensitivities to over fishing, with the Downs herring (the herring that spawn in December and January in the southern North Sea and eastern English Channel) being more easily over-fished than the other components (Cushing, 1968; Anderesen *et al.*, 1974; Burd, 1985). This suggests that the current management of the whole North Sea stock should consider the dynamics of the components and the regional nature of the fisheries on North Sea herring, as well as the dynamics of the whole stock.

Understanding the dynamics or biology of each component is difficult because whilst spawning occurs in specific areas (which often support specific fisheries), the subcomponents mix during the summer feeding season (Harden Jones, 1968) and hence the total catch from each sub-component cannot be easily estimated (Cushing & Bridger, 1966) or the source of sampled fish cannot be easily identified (Baxter & Hall, 1960; Almatar & Bailey, 1989b). A distinction must also be made between the spawner type in terms of the origin of the fish, and the behaviour exhibited by that fish once mature (McQuinn 1989; Brophy & Danilowicz, 2003). In this work, spawner type refers to the spawning component that the fish came from, i.e. its origin, as it assumes that there is a very high probability of natal spawning-origin fidelity. There is much evidence to the contrary (see McQinn 1997, Corten 2001) but Downs herring spawning in the English Channel in 2003 and 2004 were 100% from Downs spawned fish (see below).

Since the 1960s scientists have attempted to determine the spawning original of North Sea herring from both commercial catches and surveys, using a variety of methods, including tagging, meristic characteristics, differences in length at age and the supply of larvae (Cushing, 1958; Wood, 1959; 1983; ICES 1965; Corten & Kamp 1979; Burd & Hulme, 1984). The difference in spawning time and location between the components means that the larvae hatch in waters of different temperatures and experience different temperature fields as they develop (Sinclair & Tremblay, 1984; Heath *et al.*, 1997). The resulting differences in meristic characteristics (Zijlstra, 1958) are now thought to be too variable (due to between year variability in temperature) to use in a robust manner to determine spawned origin (Hulme, 1995), and to some extent this also may hold true for the use of relative size as an indicator of origin.

However the differences in temperature between years do not hide the generalised seasonal pattern in temperature development (e.g. in the North Sea, warm autumns leading to cooler early winters and cold late winter/early spring). These patterns in temperature change the growth of the larvae (refs) and these growth differences are shown in the microstructure or larval growth ring pattern of the otolith of herring. Thus the components can be identified to their approximate spawning time by the otolith microstructure of the larval part of the otolith (ICES 2004, Moksness and Fossum 1991, Mosegaard and Madsen 1996) and this method has been successfully used in the Skagerrak, Norwegian, Irish and Celtic Seas (Stenevik et al., 1996; Brophy & Danilowicz, 2002; ICES 2004).

This method of looking at the microstructure of the otolith core of older fish was used, in parallel with results from other surveys, to consider the variability in the ratio of autumn to winter spawned fish in the North Sea.

Methods

Samples of herring caught by Dutch vessels were collected from December 2003 to June 2005 (Figure 1). As this was a preliminary investigation, the sampling strategy was one of maximising the coverage samples, rather than the number of fish within a sample. Hence 710 fish were analysed, from 61 samples (see figure 1). The sagittal otoliths were retrieved from the herring and cleaned. Whilst whole otoliths were preferred, broken otoliths were also used as long as the nucleus is intact. The otoliths were retrieved from archives and remounted with the sulcus side up in thermoplastic resin (Buhler 40-8100) at 150°C allowing for repeated relocation of the otolith for grinding and polishing on both sides. The otoliths were polished using grinding and polishing films with decreasing grain sizes from 30 µm to 0.3 µm to optimise the visual resolution to a focal plane through the otolith nucleus and a transect from this to the edge. During the polishing the otolith was checked under a high powered microscope to prevent over-polishing.

All otoliths were classified as autumn, winter or spring spawning types using a Leica™ DMLB compound light microscope with 16- and 32 times magnification. The criteria for classification to spawning type in this study were the following (and are further documented in Mosegaard *et al* 2001):

Autumn spawner

Characterised by primary increments of less than 2.5 µm wide in the otolith region of 200 µm from the centre. In this region, all increments appear to have fairly constant widths (Figure 2). Primary increments will often be visible from the nucleus to the end of the larval zone if the optical focus is produced right at the polished surface of the otolith. A minimum necessary requirement for definition of an autumn spawner is a zone of more than 30 legible increments near the end of the larval zone (about 200 µm from the nucleus).

Winter spawner:

Otolith increments are gradually increasing from about 1 µm near the end-of-yolk-sac-structure (which is about 9 to 12 µm from the nucleus), to more than 3 µm at a distance of 150 µm from the nucleus (Figure 3). The rate of increase in increment widths increases at about 200 µm from the centre. The microstructure changes gradually from faint increments in an inner zone with high transparency to very pronounced increments with a high visual contrast and less transparency at about 100 µm from the centre.

Spring spawner:

This is the most variable otolith type, depending on stock and exact timing of hatch. The otolith core is often quite opaque. Late hatched individuals have increments that are relatively wide (about 4 µm) already 20-40µm from the nucleus (Figure 4).

The December 2004 and June 2005 fish were also aged by annual rings following normal in house procedures that are accepted and quality controlled by ICES.

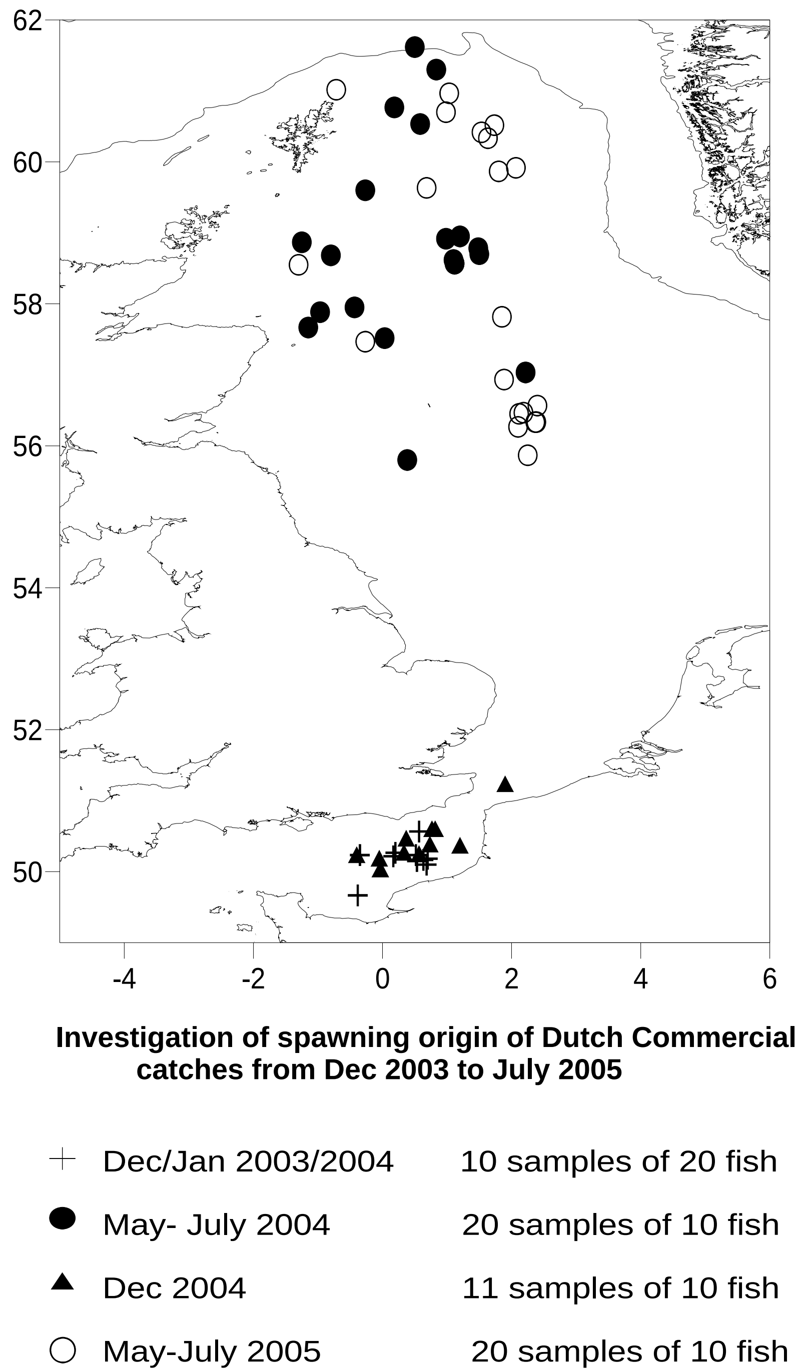


Figure 1. Sampling of spawner type from the Dutch catches between December 2003 and July 2005.

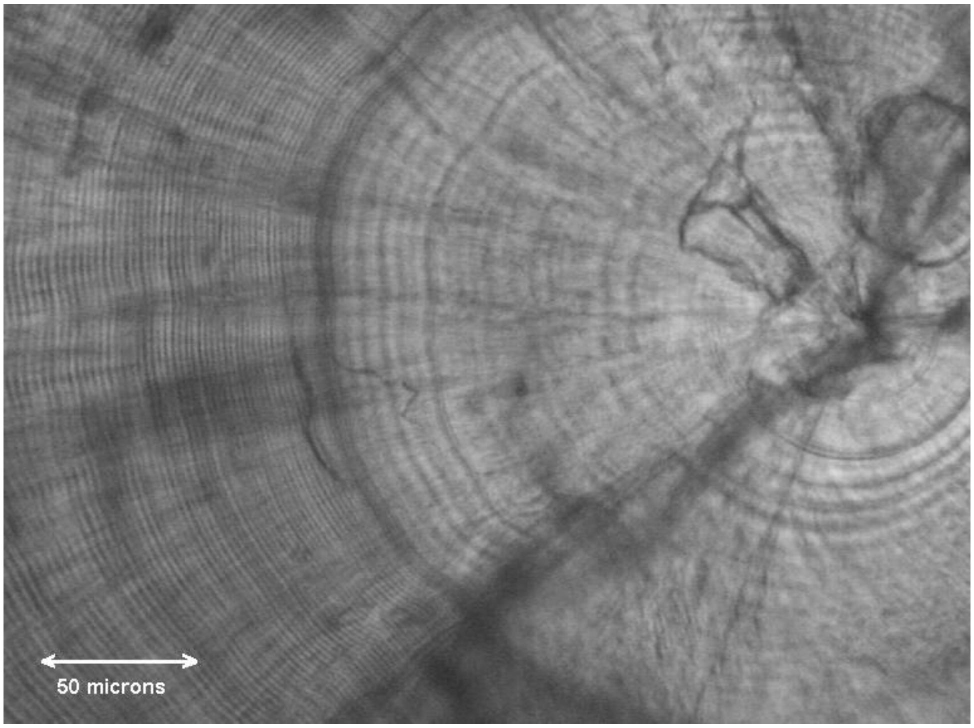


Figure 2: Autumn spawner

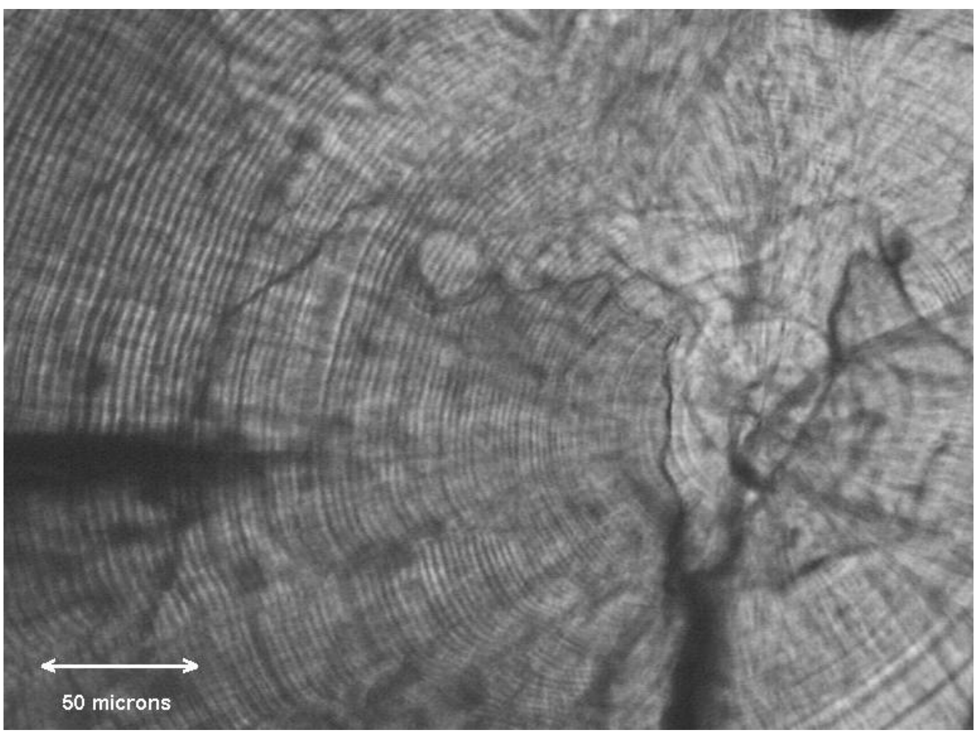


Figure 3: Winter spawner

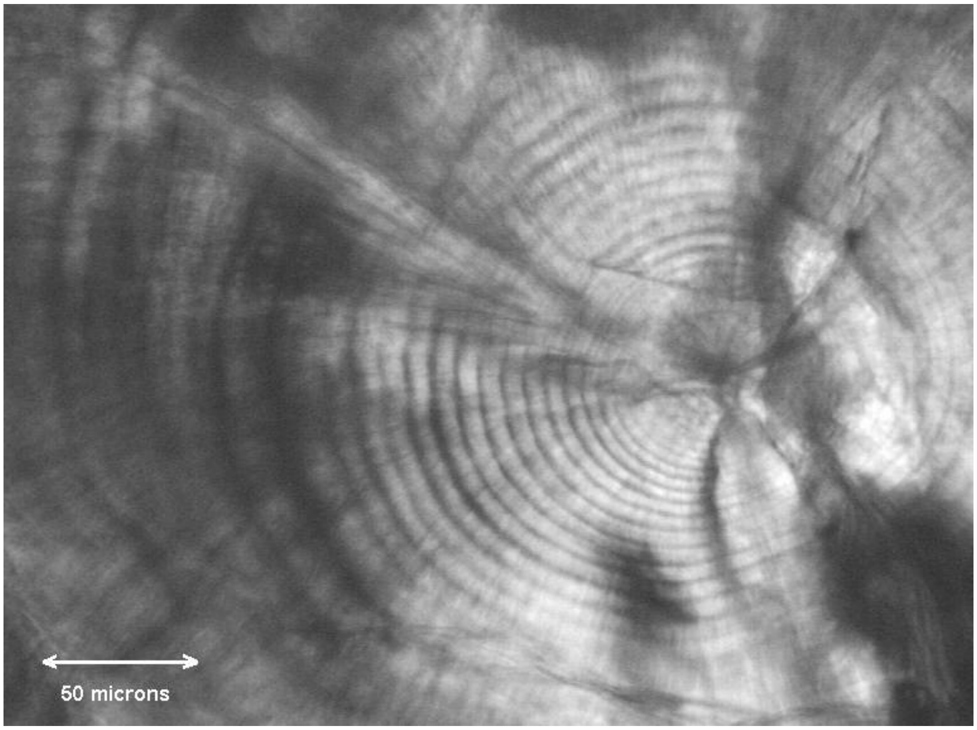


Figure 4: Spring spawner

Results

20% of herring sampled could not be allocated to a spawner type due to difficulty in the preparation of the otoliths (Figure 5). These unallocated fish were spread across the whole sampling area and appeared evenly distributed throughout the samples, and across length classes.

Catches of herring in the southern North Sea and English Channel.

All fish that could be allocated to a spawning type, that were caught in the southern North Sea or English Channel during the run up to spawning were found to be winter spawners. 100% of 253 fish from 21 samples were winter spawners (Figure 5). The sex ratio of these fish was 51:49 males to females. No immature fish were caught and 97% of females and 100% of males were ripe or spent.

Catches of herring from the feeding aggregations.

Fish sampled from the Dutch summer catches displayed a high degree of mixing of spawning types (figure 5). Autumn spawned and winter spawned fish appeared to have similar distributions in 2004 but winter spawned fish were more southerly in 2005 (Figure 6). The centre of gravity of fish in 2004 was the same for autumn and winter spawners (<20 nautical miles) whereas in 2005 the centre of gravity of the winter spawners was >130 nautical miles south of autumn spawners. The spring spawned fish (only caught in 2004) were in the northerly and eastern samples.

When the proportion of fish from each spawning type in the summer catches is compared, it is apparent that winter spawned fish dominated the catch in 2004 (Figure 6) whilst the autumn spawners dominated in 2005.

In 2004, the sampling represented 31% of the catches by the Dutch fleet in q2 and q3 (by rectangle raised catch) and when the samples are applied to the catch on the basis of catch per rectangle 40% of the catch was from autumn spawned fish and 60% from winter spawned fish. The catch data for 2005 where not available at time of writing of this manuscript but the sampling data suggest that the situation in 2005 would be reversed with the majority of the fish being autumn spawned.

In both summers of 2004 and 2005 there was a significant difference between the length frequencies of the winter spawned and autumn spawned fish (Figure 7). In both cases the 2000 year class dominated the catch and in 2004 and 2005 the winter spawned fish from 2000 were smaller.

There was no significant difference in sex ratios between winter and autumn spawned herring. There was no difference between spawner type in the maturity of the males (approximately 50% and 92% mature in 2004 and 2005 respectively). There was a difference between spawner type in the females in 2004 (82% and 60% for autumn and winter spawned fish respectively) but there was no difference between spawner types by 2005 (approximately 90% of all females in the catch were mature).

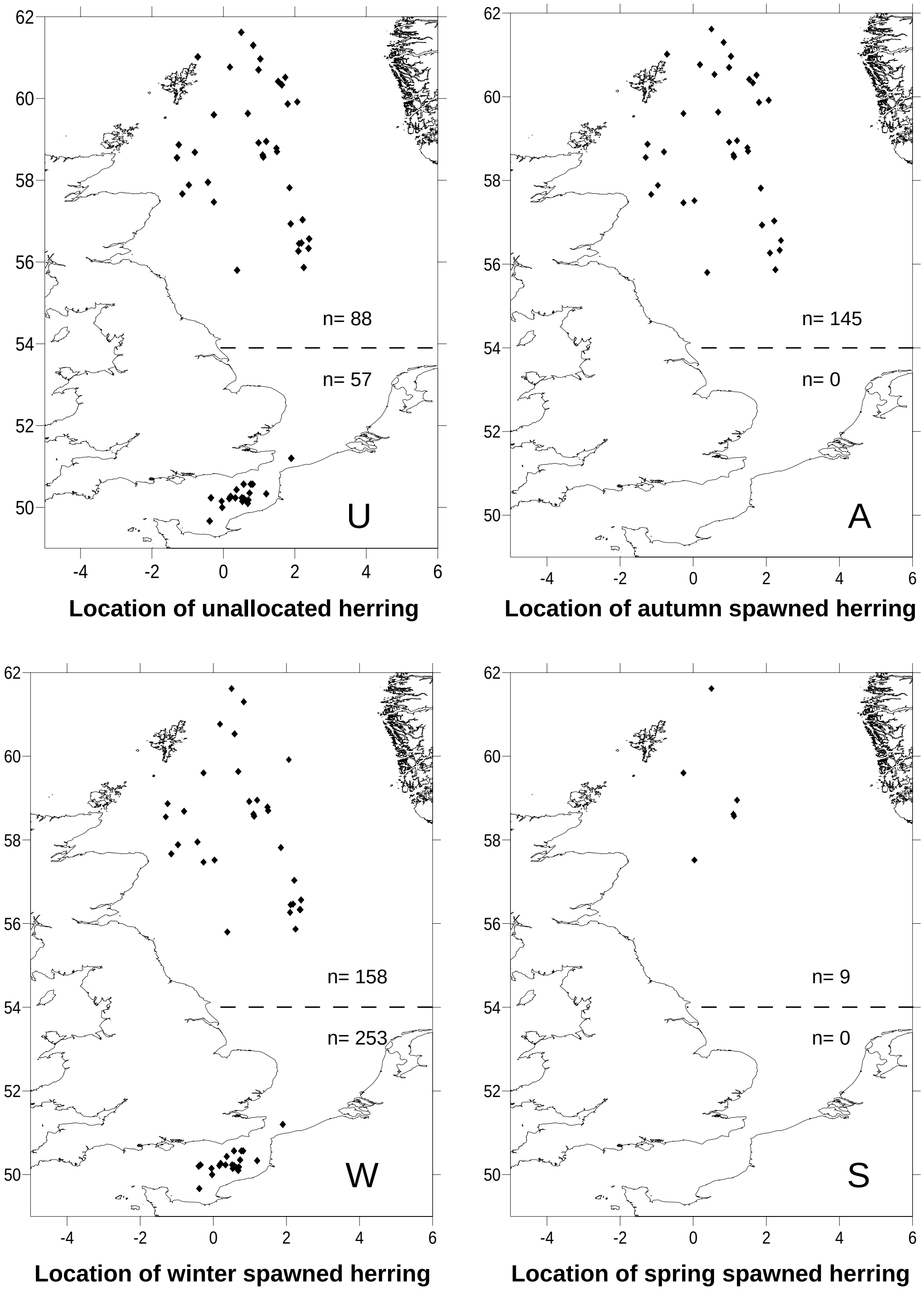
Other data available- Proportion of recruits

Time series of herring abundance are available from other sources. Preliminary analysis of the spawner type of juvenile fish in Danish catches and surveys (using the same method of determination as used here, and not counting the spring spawned fish) suggest that between 4 to 25 % of the juveniles per year class from North Sea autumn to winter spawners come from winter spawned herring. These data may include winter spawned fish from other stocks as well. There is not trend in the proportion of winter spawners over the year classes 1996 to 2004 with high interannual variability.

The IBTS estimates of small juveniles (<13cm, 1 w ring fish, as suggested by Wood, 1983) also show a variability between years of approximately to %. This index of recruits by year class (Figure 8) shows an increase in variability with time since 1985, suggesting that the potential to produce more recruits has increased (Figure 8). However there is no concordance between the proportions by year class of the Danish juvenile index and the IBTS estimates, but as the estimates in the Danish juveniles are preliminary, further investigation is required.

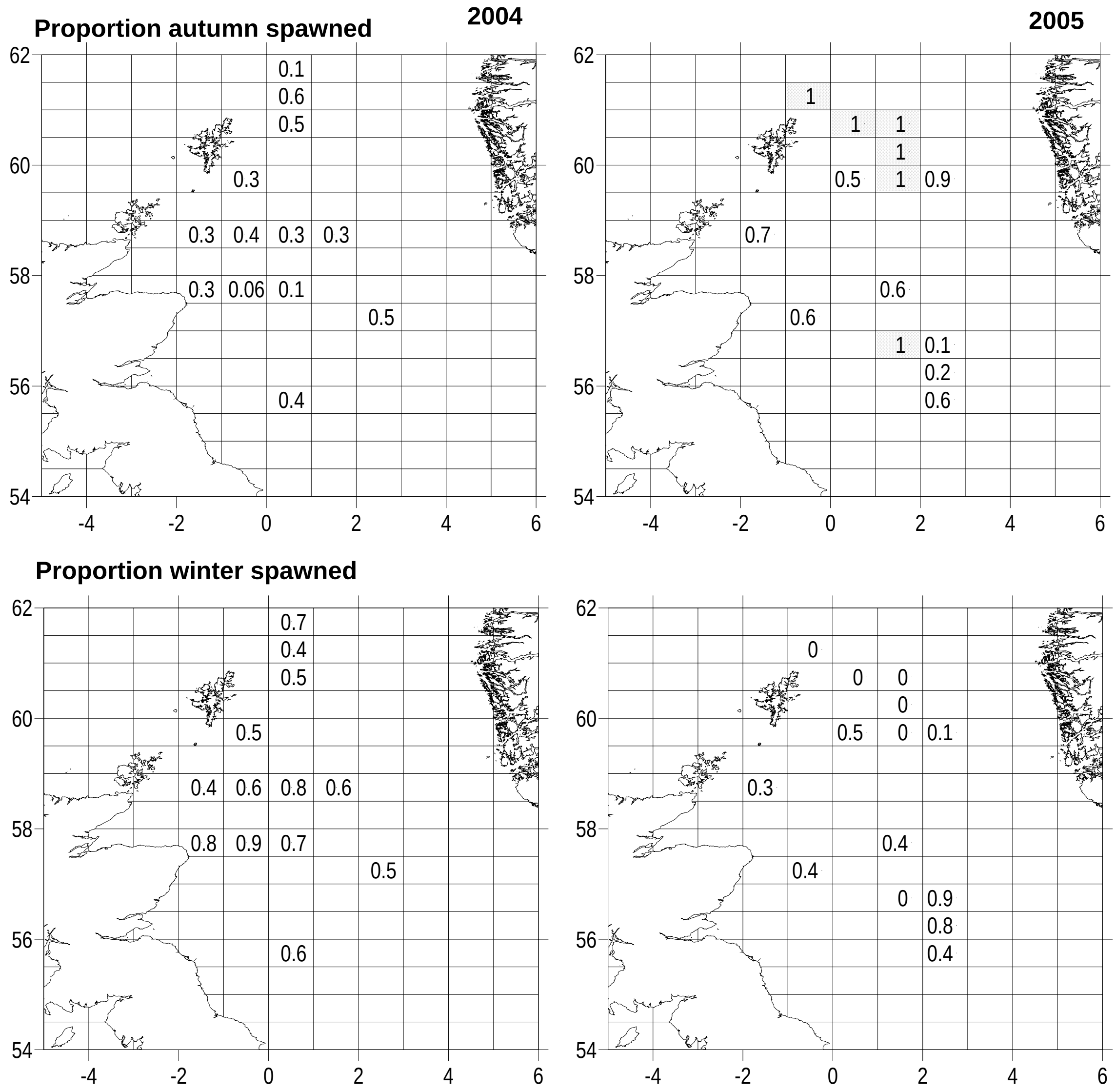
Other data available- Proportion of SSB

Larval surveys on the autumn and winter spawning sites are also carried out every year. By applying a temperature based growth model the approximate age of the larvae can be estimated, and then the daily mortality rates. These two estimates enable the larval production by spawning site to be calculated. Unfortunately, the number of surveys carried out per year on the northern components was reduced in the mid 1990s. This means that only the year classes 1980 to 1993 can be investigated. The relative production by spawning component did vary between years between 1980 and 1993. The production from all components increased from throughout the 1980s, but then the production in the northern areas declined (Figure 9a). This decline in northern production increased the relative importance of Downs larval production in the south (Figure 9b). Once differences in fecundity of the components (Zijlstra, 1973) where accounted for, the proportion of adult SSB (spawning stock biomass) that was Downs herring showed an upwards trend from 12 % in 1985 to 59% in 1993.



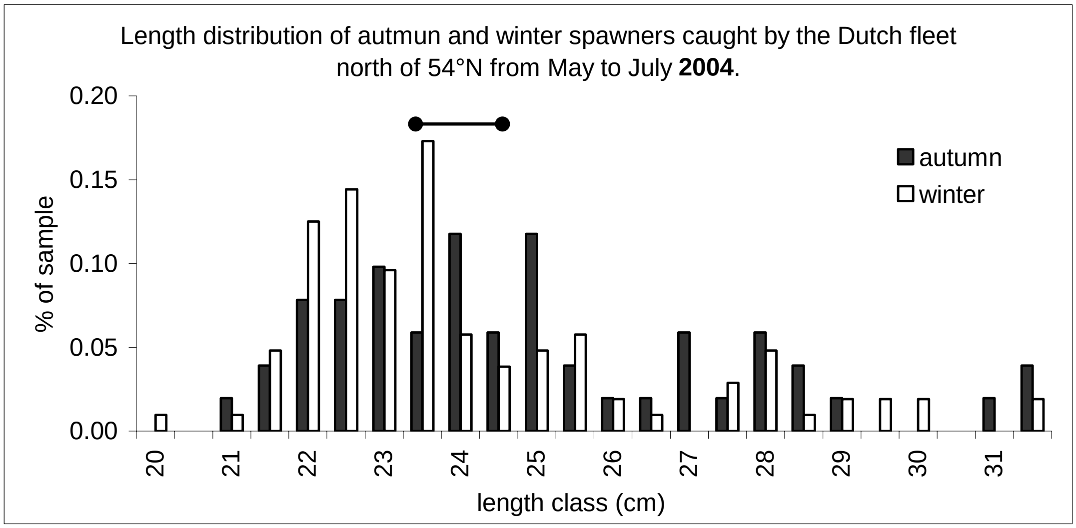
n denotes the number of fish allocated to spawner type,
from either north of 54°N (summer catches) or south.

Figure 5. Location of herring from each spawner type within the sampled Dutch catch of North Sea herring from December 2003 to July 2005.



Note: the standard deviation between 6 samples within 1 ICES rectangle is 0.15.

Figure 6. Proportion of herring by spawner origin within the sampled Dutch catch of North Sea herring in the summer fisheries of 2004 and 2005.



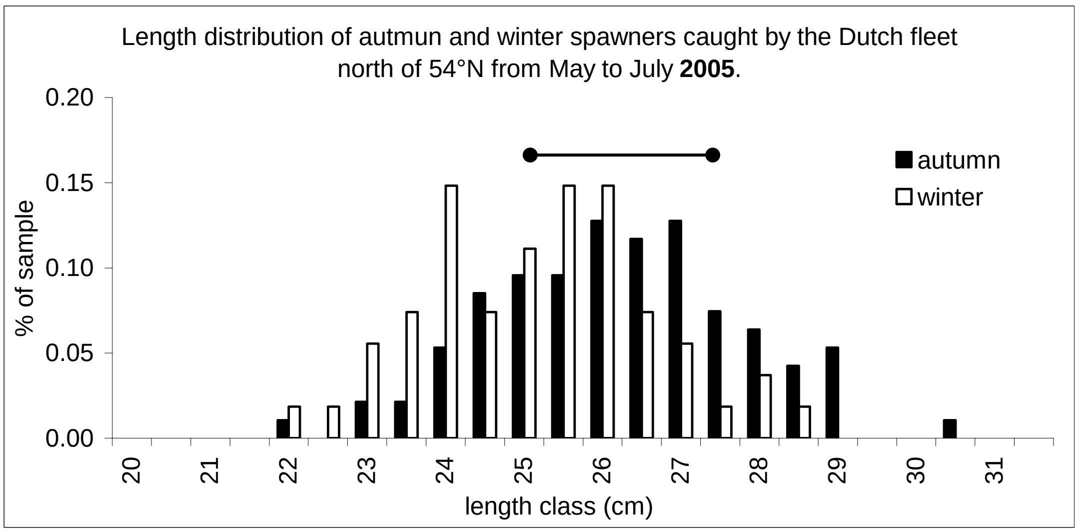


Figure 7. Length Frequency of herring sampled for spawner type from the Dutch catch in summers of 2004 and 2005. Bar denotes significant difference between length frequencies (Kolmogorov-Smirnov Two sample Test, P<0.05).

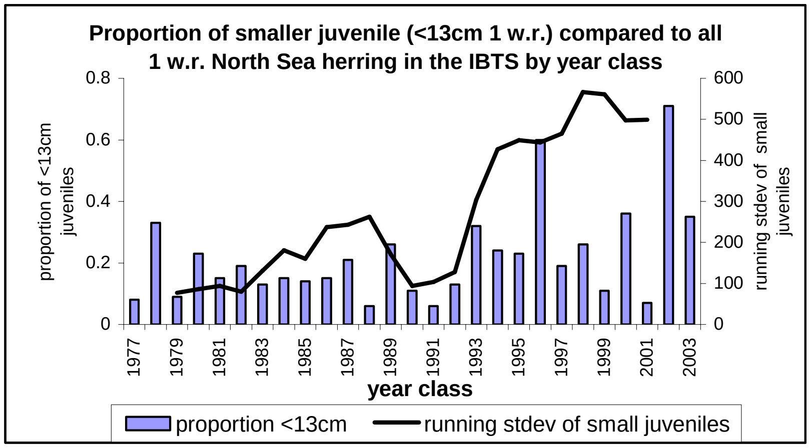
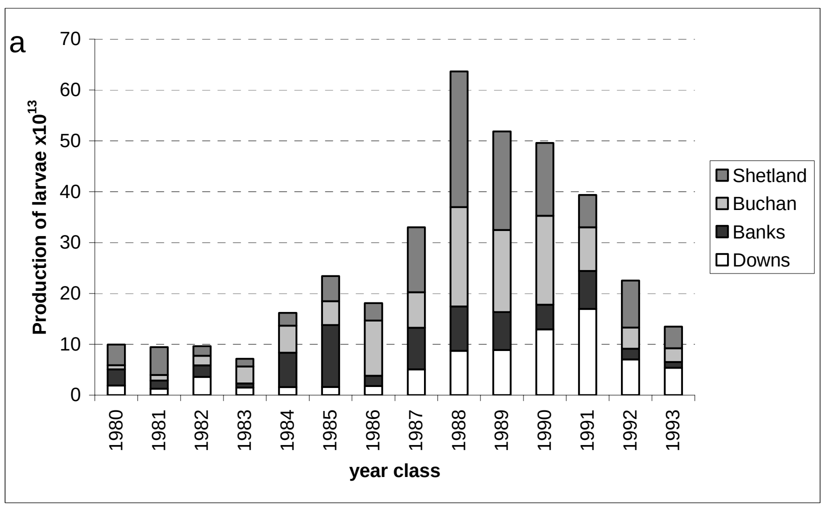


Figure 8. Proportion of juveniles caught in Q1 IBTS that are smaller than 13cm in length, which may denote winter spawned fish, and the running standard deviation (5 years) of the total number of small juveniles per year class.



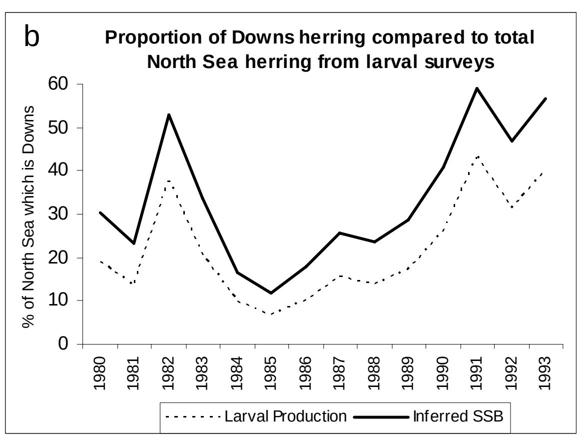


Figure 9. a) larval production by spawning component of North Sea herring for year classes 1980 to 1993. **b)** Proportion of North herring that is Downs, inferred from larval production estimates and mean fecundity per spawning component (Hickling, 1940; Zijlstra, 1973).

Discussion

In terms of natal homing, the Dutch catch in winter 2003 and 2004 show that the adults spawning on the gravel banks of the southern North Sea and English Channel are 100% winter spawned herring. It could be either that the strong 2000 year class (which may be southern produced) may overwhelm any vagrant fish originally from the north autumn spawning sites (sampling levels are too low), or North Sea herring express complete fidelity to their natal spawning site (which is unlikely, McQuinn, 1997; Corten 2001) . Further work is required to test this hypothesis but it appears that the winter fishery in 2003 and 2004 was based on harvesting the production from the spawning activity on which it had fished in previous years.

It is clear that there is large between year variability in the origin of herring in the Dutch catches of North Sea herring in the summer. In 2004 the catches were dominated by winter spawned fish, whereas in 2005, the catches were dominated by autumn spawned fish. The situation in 2005 conforms to recent dogma on the relative strengths of the components whilst the strong 2000 year class (dominated by winter spawned fish) appears to have changed the relative importance of the winter spawned fish in the catches in 2004. There also appears to be a spatial pattern in 2005 compared to a lack of pattern in 2004 (Figure 6). This would also change the ratio in the spawning origin of the catches from each nation or targeted fishery.

The variability between years of the source of catches should not greatly matter to management if it is random. However a trend in the ratio between components would cause a problem for management. Other available information does suggest that there is a trend in SSB (Figure 9) and also in recruitment (Figure 8). Hence management should not assume that a fixed ratio of the TAC scheme should work. As each component shows differing productivity and also different recruitment patterns (also see Winters & Wheeler, 1987; Myers, 2001), it is probably not precautionary to assume that the ratios between the components (with components supporting different fisheries) are static with time. It is also probable that harvestable production does not come alone from the Shetland, Buchan and Banks spawning sites and that much of the growth in biomass in North Sea herring in recent years may well come from fish spawned in the southern North Sea. Simulations are required to test whether trends in component productivity, which have been identified, will prevent a precautionary management of the fisheries.

The current data also suggest that the difference in size between the winter and autumn spawned females in the summer of 2004, was on the maturity threshold of the fish. This suggests that the winter females (from the 2000 year class) at approximately 23.5 cm did not mature whereas the autumn spawned fish from the same year class, at approximately 24 cm in length did mature (Figure 7). Almost all of these fish were mature by 2005. This would have implications for determining the SSB from catch at age stock assessment methods.

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