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North Sea trawl surveys: Diel and depth effects on the catch rates

by

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ABSTRACT

Data from the Scottish participation in the International Young Fish Survey for the period 1976 to 1993 were analysed to examine the effect of light level and depth on catch rates. The species selected for this study were common dab, herring, haddock and whiting. Differences between day and night were observed for the juvenile common dab and herring and for the adult common dab and haddock. Differences between shallow and deep water were observed for the juveniles of all the species and for the adults of common dab, haddock and whiting. The mean lengths and the composition of the common dab and whiting catches were affected by both light and depth, indicating behaviour differences between the juveniles and adults of these species. While light seems to have no effect on the mean length and the catch composition of herring, differences were observed between shallow and deep waters. In the case of haddock, neither the light level nor the depth had any noticeable effect on the mean length and catch composition of the catches. We conclude that the diel behaviour and he geographic distribution are important factors in determining the quantity and composition of trawl catches, but their effects are species dependent. When trawl surveys are not exact replicates in terms of fishing times and areas, the estimation of catch indices should allow for the possible bias introduced by these factors. There is a need for models of the capture process that take account of such effects.

Key words: Trawl survey, North Sea, demersal fish

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Introduction

Catch data from trawl surveys are used to derive abundance indices and biomass estimates for commercially important fish stocks. Such data are routinely collected in surveys conducted in the North Sea (see for example Anon., 1992) and in the Northwest Atlantic (see for example Doubleday and Rivard, 1981). In the North Sea, many research vessels from the surrounding countries participate in a coordinated exercise known as the International Young Fish Survey (IYFS). Standard indices of fish abundance are calculated for the juveniles of herring, cod, whiting, haddock, Norway pout, sprat and mackerel.

Many factors influence the capture efficiency of sampling gear and consequently the derived abundance indices (Stewart and Galbraith, 1987; Stewart et al., 1991). However, no account is taken of variation in the catch rates due to these factors, with the exception of herring where the abundance index is calculated excluding the night hauls. One of the assumptions of trawling surveys is that all fish in the survey area are equally vulnerable to the sampling gear (Gunderson, 1993). The implication is that a constant proportion of the target fish must always be near the bottom, bellow the height of the trawl headrope, but this is not true for species whose distribution changes with time due to vertical diel migrations. In addition, the spatial distribution of the fish in relation to the gear and the behaviour of the fish in the vicinity of the gear are sources of bias in estimates (Parrish, 1963).

Previous studies have demonstrated that the day time catches for some species (herring, cod, haddock, beaked redfish and American plaice) are higher than the night time catches (Woodhead, 1964; Beamish, 1966; Pitt et al., 1981; Atkinson, 1989; Engas and Soldal, 1992; Marshall and Frank, 1994). On the other hand, the day time catches of sole and yellowtail flounder were reported lower than those at night time (Woodhead, 1964; Walsh, 1988). These differences have been attributed to changes in fish behaviour which determine the interactions between fish and gear. Additionally, differences in the size composition of the catch have also been observed between day time and night time catches (Beamish, 1966; Walsh, 1988; Engas and Soldal, 1992), which suggest differences in behaviour and catchability between young and adult fish. For many demersal fish, a positive correlation between size of fish and depth has been reported (Macpherson and Duarte, 1991; Sinclair, 1992; Swain, 1993). Furthermore, the density of fish may vary within the surveyed area since gradients can occur related to oceanographic parameters like water depth, salinity, temperature, etc. (Daan et al., 1990; Gunderson, 1993).

In this work we consider the data from the Scottish IYFS in the period 1976-1993 covering four species: Herring, haddock, whiting and common dab. These species were selected firstly because they are commercially important and abundant in the North Sea, and secondly because they represent groups of species with fundamentally different behaviour (herring: pelagic; haddock and whiting: demersal; common dab: benthic). The aim is to show how the catch rates and the mean lengths are affected by time of fishing and whether the water depth is an important determinant of the distribution and the density of these species.

Materials and methods

Catch data from the Scottish research ships participating in the IYFS were examined, covering the 18 annual surveys from 1976 to 1993. The surveys were always conducted during the first quarter of each year. Three research vessels were involved. From 1976 to 1984 the side trawler "Explorer" was used and from 1985 to 1993 was replaced by the stern trawler "Scotia". Some hauls in 1978 and 1979 were performed by the smaller vessel “Clupea”. There were 912 valid hauls during the whole period. For 867 of the hauls (95%) the duration of towing was one hour. The "Grande Overture Vertical" (GOV) bottom trawl was used in all surveys. A cod-end with mesh size of 20 mm was used. The Scottish vessels surveyed mainly in the northwest North Sea, extending into the central North Sea in some years (Fig. 1). Stations fished between sunrise and sunset were classified as day-time hauls (599) and those between sunset and sunrise as night-time ones (225). The hauls which started before sunrise or sunset (41 and 47 hauls respectively) and finished after sunrise or sunset, were classified as day or night ones depending on when the main part of the haul occurred. The number of the day and of the night hauls was 637 (70%) and 275 hauls (30%) respectively. Two depth zones were chosen to give roughly equal division of hauls, namely shallow waters (0-75 m) and deep waters (>75 m). Overall, 495 (54%) and 417 hauls (46%) of the hauls were designated as shallow and deep respectively. All catches were standardised to one hour towing duration.

The catch rate, as the average number of fish caught per hour, was calculated separately for the juvenile and the adult components. The distinction between juveniles and adults was based on the length ranges used in the IYFS for estimating the preliminary abundance indices. Hence, for herring, haddock and whiting, juveniles were deemed to be fish of total length <20 cm. For common dab there is no equivalent measure, so we decided to classify as juveniles those fish with length <15 cm. According to Leeuwen and Vethaak (1988), the back-calculated length at age 2 for common dab is 15.6 cm. Thus we have designated the majority of common dabs aged <2 as juveniles. Mean lengths were also calculated. All estimators (mean lengths of total catch, catch rate for juveniles and adults separately) were compared according to time of fishing (day and night) and depth strata.

Mann-Whitney's non parametric U-test was performed to examine statistically the differences in the catch rates. A one way analysis of variance was used to examine differences in mean length (Sokal and Rohlf, 1981).

Results

Catch rates

The catch rates of common dab were generally higher during the night tows (Figs 2a,b). The night catches were, on average, 4.98 and 3.29 times the day catches for the juveniles and the adults respectively. The Mann-Whitney test showed significant differences (5% level) between day and night for the juveniles (p = 0.002) but not for the adults (p = 0.055, Table 1). All the catch rates were higher in shallow compared to deep water (Figs 2c,d). On average the shallow catch rates were 13.05 and 10.4 times the deep catch rates for the juveniles and the adults respectively. These differences are highly significant for both the juveniles and the adults (U-test p values <0.001, Table 1).

The catch rates of day hauls for both juvenile and adult herring were higher than at night in all years (except 1978 and 1990 for adults, Figs 3a,b). The day catch rates of herring were on average 8.06 and 4.84 times the night catch rates for the juveniles and the adults respectively. The Mann-Whitney test showed a significant difference for the juveniles but not for the adults (p= 0.000 and p = 0.223 respectively, Table 1). In relation to depth the catch rates of the juveniles were higher in shallow water in all years (except in 1977 and 1990) whereas those of the adults were higher in deep water (except 1976, 1979, 1980 and 1983) (Figs 3c,d). On average the shallow water catch rate of juveniles was 7.91 times the deep catch rate. The opposite applies to the catch rate of adults which in deep water was 7.32 times the catch rate in shallow water. The difference was found to be significant for the juveniles but not for the adults (p = 0.002 and p = 0.178 respectively, Table 1).

The day and night catch rates of haddock showed a similar pattern to those of herring (Figs 4a,b). The daytime catch rates were higher than at night both for juveniles and for adults with exceptions in 1976, 1982 and 1985 for juveniles and in 1976, 1992 and 1993 for the adults. The catch rates of juveniles showed large fluctuations. On average the daily catch rates were 3.19 and 2.10 times the night catch rates for the juveniles and adults respectively. The difference was not significant for the juveniles and significant for the adults (p = 0.090 and p = 0.010 respectively, Table 1). Haddock were always more abundant in deep water (Figs 4c,d) except for the adults in 1979. On average the shallow catch rates were 8.4 and 4.2 times the deep catch rates for the juveniles and adults respectively. Highly significant differences were found both for the juveniles and adults (p = 0.003 and p = 0.000 respectively, Table 1).

The daytime catch rates of juvenile whiting were higher than at night in 14 out of the 18 years, whereas negligible differences were observed for the adults (Figs 5a,b). The catch rates of the adults showed an increasing trend after 1985. On average the day catches of juveniles were 2.75 times the night catches whereas the catches of the adults were nearly the same. The test showed no significant differences (p = 0.110 and p = 0.837 respectively) between day and night catch rates (Table 1). The catch rates for juvenile whiting were higher in shallow water except for 1981 and 1985, whereas those of the adult whiting were higher in deep water except for 1977 and 1986 (Figs 5c,d). The shallow catch rates of juveniles were 4.11 times the deep catch rates whereas the deep catch rates of adults were 6.67 times the shallow catch rates. Highly significant differences were found both for juveniles and adults (p=0.002 and p=0.001 respectively, Table 1).

Mean length

For 13 out of 18 years, the mean length of the common dab catch was larger by day than by night (Fig. 6 and also in deep compared to shallow water. The ANOVA test showed significant differences in both cases (p = 0.023 and 0.014 respectively, Table 2).

In 15 out of 18 years the estimated mean length of herring caught at night was larger than that of the day hauls (Fig. 6) but not significantly (p = 0.328, Table 2). An increasing trend was observed from 1982 to 1991 both for the day and for the night herring mean lengths. In all years (except for 1977) the mean lengths of herring caught in deep water were significantly larger than those from the shallow water stations (p = 0.043).

The mean lengths of haddock catches by day and by night showed a similar fluctuation (Fig. 67) but did not show a clear pattern. No significant differences were found (p = 0.212, Table 2). No difference was found between the mean length of haddock in shallow and deep water (p=0.749).

In 12 out of 18 years the mean lengths of the whiting from the night hauls were larger than those of the day hauls and the difference was significant (p = 0.025, Fig. 6, Table 2). The mean lengths of whiting from the shallow and the deep water showed a similar pattern to the mean lengths of the herring. In all years (except 1984) this was larger at the deep than at the shallow water stations and the difference was highly significant (p<0.001).

Discussion

Our results show that the time of the day and the depth are important determinants of the catch rates and of the size composition of trawl catches. However these effects are not the same for all the species. Thus, the catch rates of juvenile common dab and herring and the adult haddock were affected by the time of fishing. With the exception of adult herring the catch rates of the juveniles and the adults of all the species were affected by the depth. The study of mean lengths showed the time of day to be an important determinant for the common dab and whiting, while the depth had a notable effect on the mean length of the common dab, herring and whiting.

In the context of trawl surveying to determine catch indices relating to population density, the important requirement is to produce unbiased time series. This may be achieved by ensuring that annual surveys are conducted in identical circumstances with regard to, for example, the time of day and area distribution of fishing, and using the same fishing method, vessel an so forth. Unfortunately, this ideal approach is impractical over a long period while there are ongoing changes in fishing methodology and there may also be substantial alteration of the stock distribution and/or behaviour affecting the catcability.

Common dab occur mostly in shallow waters where there is illumination and according to Ortega-Salas (1988) they feed during the day mainly on benthic organisms (Pihl, 1994). The higher catch rate during the night hauls could be attributed to the avoidance of the gear during the day hauls. Similar differences between day and night catches were reported by Parrish et al. (1964) for common dab and by Walsh (1988) for yellowtail flounder. Walsh (1991) reported that a large proportion (95%) of juvenile yellowtail flounder and American plaice managed to escape under the groundgear and Parrish et al. (1964) suggested that juvenile common dab can escape from the forward part of the trawl. The different mean lengths of the common dab catches between shallow and deeper waters indicates that the bathymetrical distribution of the species is size dependent. The bigger individuals prefer deeper waters. The mean lengths during the day hauls are larger than during the night hauls. This indicates that the small fish are more able to avoid the gear during the day by escaping through the meshes or under the groundgear.

Differences between the day and night catch rates of herring are well known and only the daylight hauls are taken into account to estimate the standard abundance indices of these species in the North Sea. Herring is a pelagic species but it migrates vertically from the deeper water by day to the upper water by night (Parrish et al., 1964). Thus, during the day more fish are available to the bottom trawl and in our results this has been more evident for the juveniles than the adults. The bathymetrical distribution of herring according to our results was size depended. The juvenile herring preferred shallower water whereas the adult deeper waters. This was evidence from the catch rates (the juveniles were more abundant in shallow and the adults were more abundant in deep waters) and of the mean lengths (bigger fish in deep waters). The mean lengths of the night catches of herring were larger than those of the day catches, suggesting that a greater bigger proportion of the small fish undertakes vertical migration. This finding is supported by Woodhead (1964) who observed similar size differences in herring catches according to the time of day. Differences in feeding behaviour between juveniles and adults could be a possible explanation.

There are a lot of contrasting references about the day and night catch rates of haddock. Higher night catch rates have been reported by Jones (1956) in Faroe islands (4-5 times) and by Parrish et al. (1964) in Moray Firth. However, higher day catch rates have been reported by Parrish et al. (1964) in Buchan deeps and in Orkney and Shetland Islands, by Woodhead (1964) in Northern coast of Norway (2.8 times) and in Skolpen Bank (3.5 times), by Shepherd and Forrester (1987) in Northwest Atlantic and by Engas and Soldal (1992) in Barents Sea. According to Beamish (1966) haddock were on the bottom during the day and off the bottom during the night in Nova Scotia and in the Gulf of St. Lawrence. Haddock generally swim in the direction of the tow between the wings and bridles (Main and Sangster, 1981). When the fish become tired they turn back and they swim upwards. Some fish rise far enough to escape over the headline and some small fish escape through the netting panel in the top of the gear. It is possible that during the day a higher proportion of the fish could avoid the gear because of the better visual conditions, either through the meshes or over the headline. According to Parrish et al. (1964) lower selectivity has been observed for haddock in darkness than in daylight. Although more fish escape during the day, according to our observation the day time catch rates were higher. This leads to the conclusion that the proportion of the haddock that is close to the bottom and vulnerable to the trawl, is higher during the day. This was more evident in our results for the adult fish. Part of the diet of the haddock consisted of Crustacea. Larger fish (3 and more years) feed on fish such as Norway pout, herring and sprat (Daan, 1989). Some of the prey such as Euphaciacea, herring and sprat, rise on the water column during the night. The fish follow their prey in the water column during the night and the density on the bottom is reduced.

There were no indications of size depended bathymetrical distribution of the species since the catch rates both of juvenile and of adult haddock were higher at deeper water. Furthermore, there were no significant differences in the mean length of the species in shallow and in deep waters.

Less attention has been given in the diurnal behaviour of whiting. Parrish et al. (1964) reported that the catches of whiting were higher during darkness and Woodhead (1964) recorded that the catches just after sunrise were higher than the day time catches. Gordon (1977) reported that the number of fish per hour fishing in midwater trawl is greater during darkness in the West Coast of Scotland. From our results there are some indications that the catch rates of the juvenile whiting are slightly higher during the day whereas no differences have been observed for the adult whiting. A vessel effect is possible for the catch rates of the adult whiting. The catch rates of the adults were generally higher after 1985 when the research vessel "Scotia" was used for sampling. On the other hand, there was no difference in the catch rates of the juveniles from 1986-1989. Generally, the juveniles showed higher catch rates during the day when the incoming year class was strong. When the population density is high the competition for food increases. More fish may then undertake vertical migration during the night searching for prey that move to the surface such as Euphausiidae and Crangonidae, which contribute significantly to the whiting diet (Hislop et al., 1991). The adults feed mainly on fish living close to the bottom. The bathymetrical separation of juvenile and adult whiting was quite clear. The juveniles were more abundant in the shallow areas and the adults in the deeper waters. The minimum mean length of whiting in the deep water was 19.7 cm whereas the maximum mean length in the shallow water was 21.6 cm.

The effects on the catch indices of the factors considered in this study are quite different between species and between components of the same species. Very likely they are particular to the region concerned, the North Sea in this case. We conclude that catch indices based on simple averages of the catch rates without regard to extraneous causes of variability are liable to be biased. The longer the time series, the more likely it is that such problems will occur. Clearly there is a need for more sophisticated models of the capture process to remove unwanted variability from the catch indices revealed by trawl surveys.

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Tables

Table 1. Mann-Whitney's U-test, p values obtained from comparison of catch rates for each species and condition labeled as D-N (day to night) or S-D (shallow to deep water). P<0.05 for 5% significance.

Age group	Condition	Dab	Herring	Haddock	Whiting
Juveniles	D-N	0.002	0.000	0.090	0.110
	S-D	0.000	0.002	0.003	0.002
Adults	D-N	0.055	0.223	0.010	0.837
	S-D	0.000	0.178	0.000	0.001

Table 2. Analysis of variance, p values obtained from comparison of mean lengths and juvenile/adult ratios for each species and conditions labeled as D-N (day to night) or S-D (shallow to deep water). P<0.05 for 5% significance.

		Dab	Herring	Haddock	Whiting
Mean lengths	D-N	0.023	0.328	0.212	0.025
	S-D	0.014	0.043	0.749	0.000
Log(j/a)	D-N	0.010	0.222	0.486	0.073
	S-D	0.036	0.000	0.315	0.000

Figures

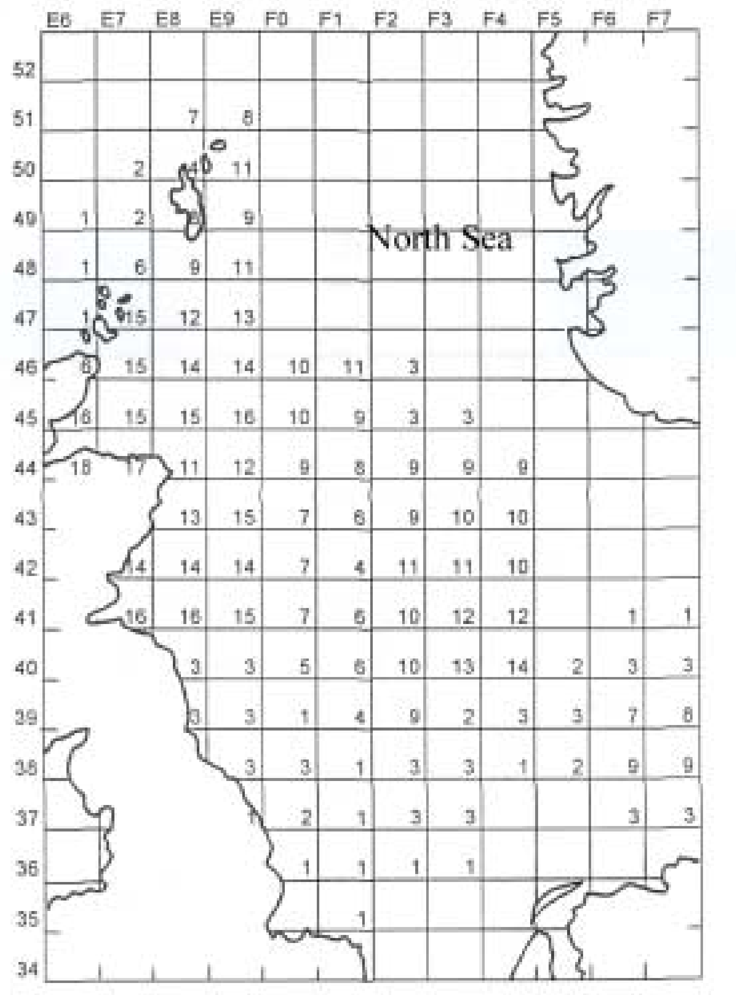

Fig. 1. Sampling intensity in the North Sea showing the number of years when each square was sampled by the Scottish vessels.

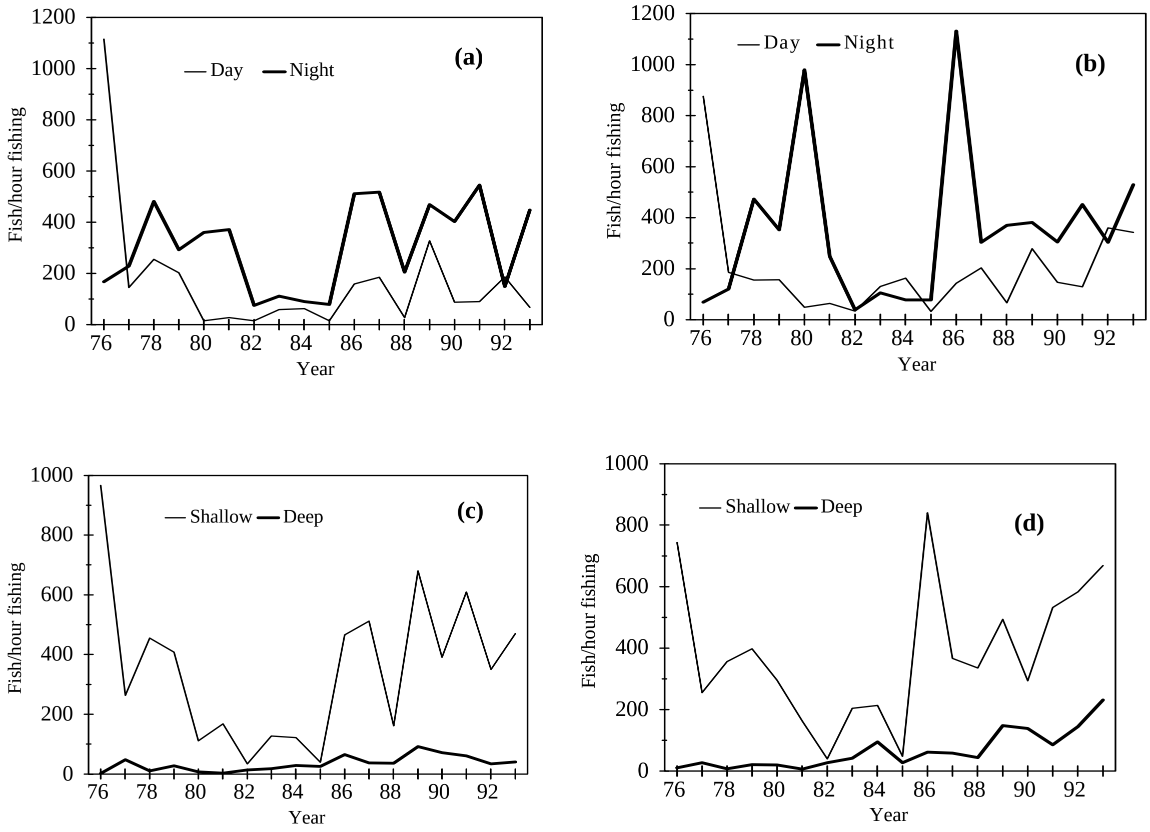

Fig. 2. Catch rates of common dab for the period 1976-1993. a, c) Juveniles, b, d) Adults.

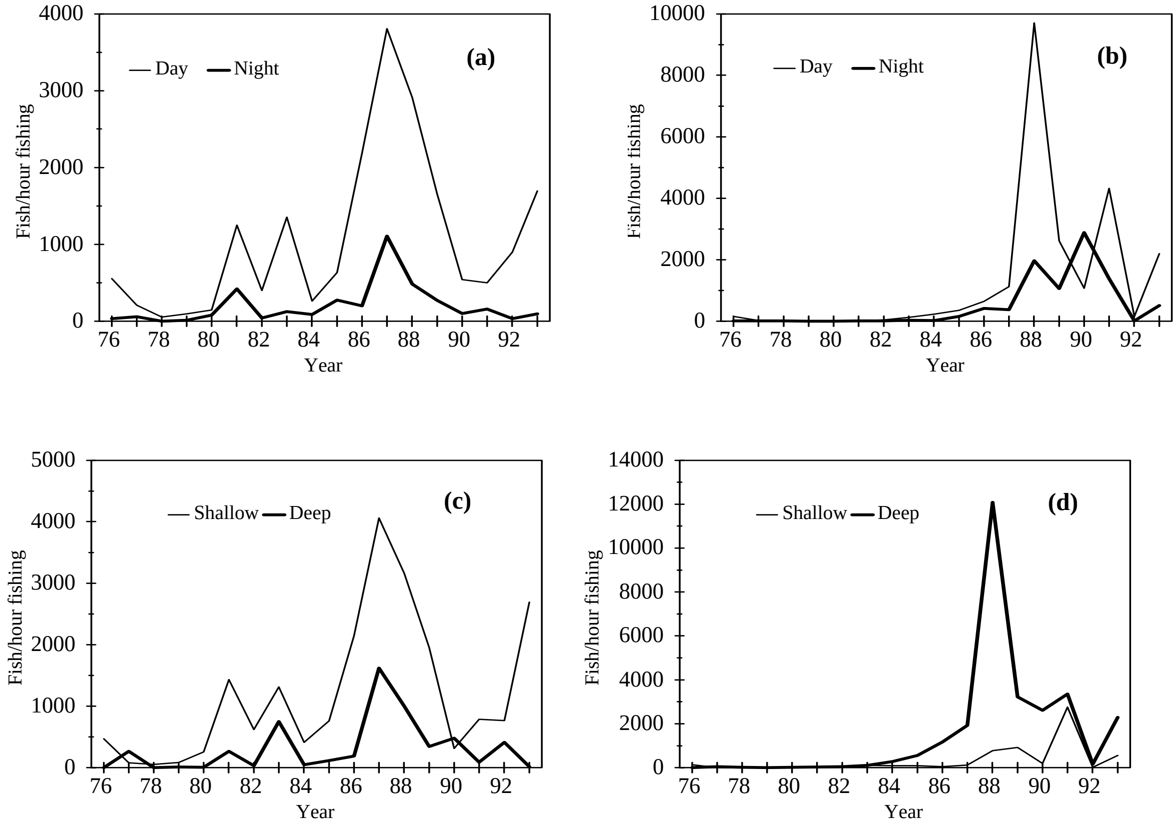

Fig. 3. Catch rates of herring for the period 1976-1993. a, c) Juveniles, b, d) Adults..

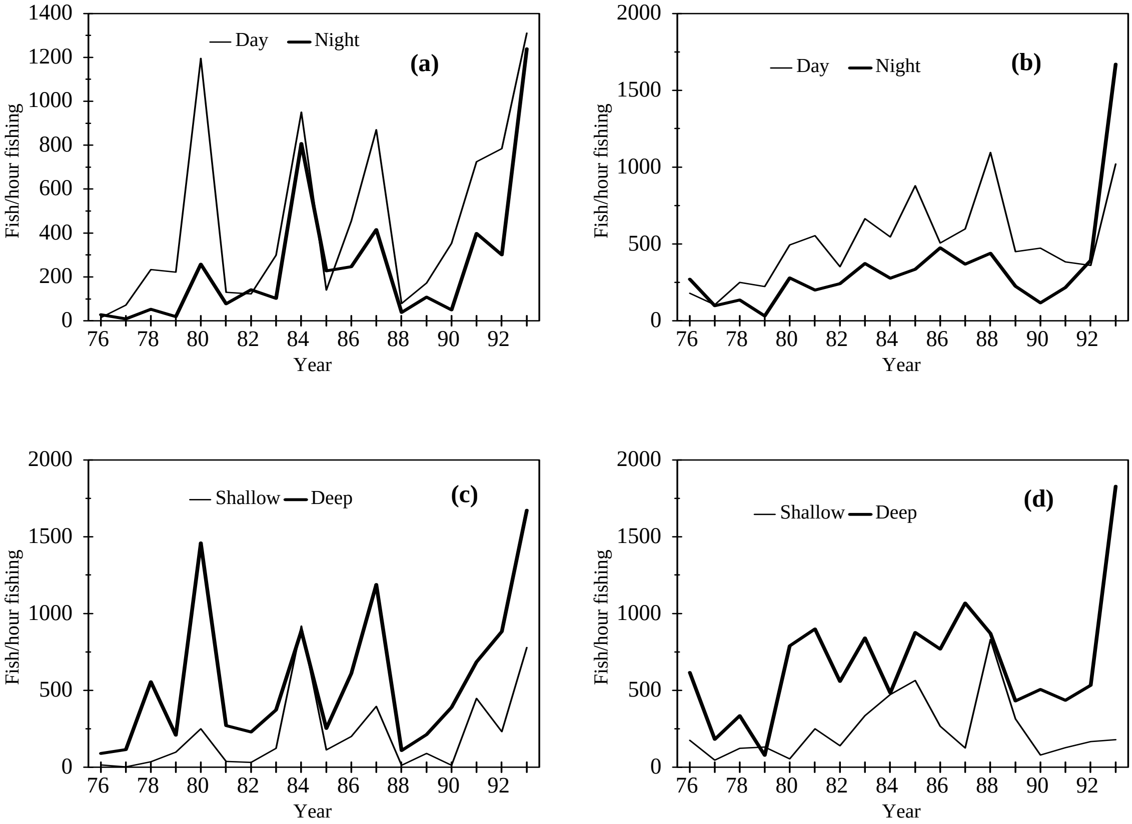

Fig. 4. Catch rates of haddock for the period 1976-1993. a, c) Juveniles, b, d) Adults.

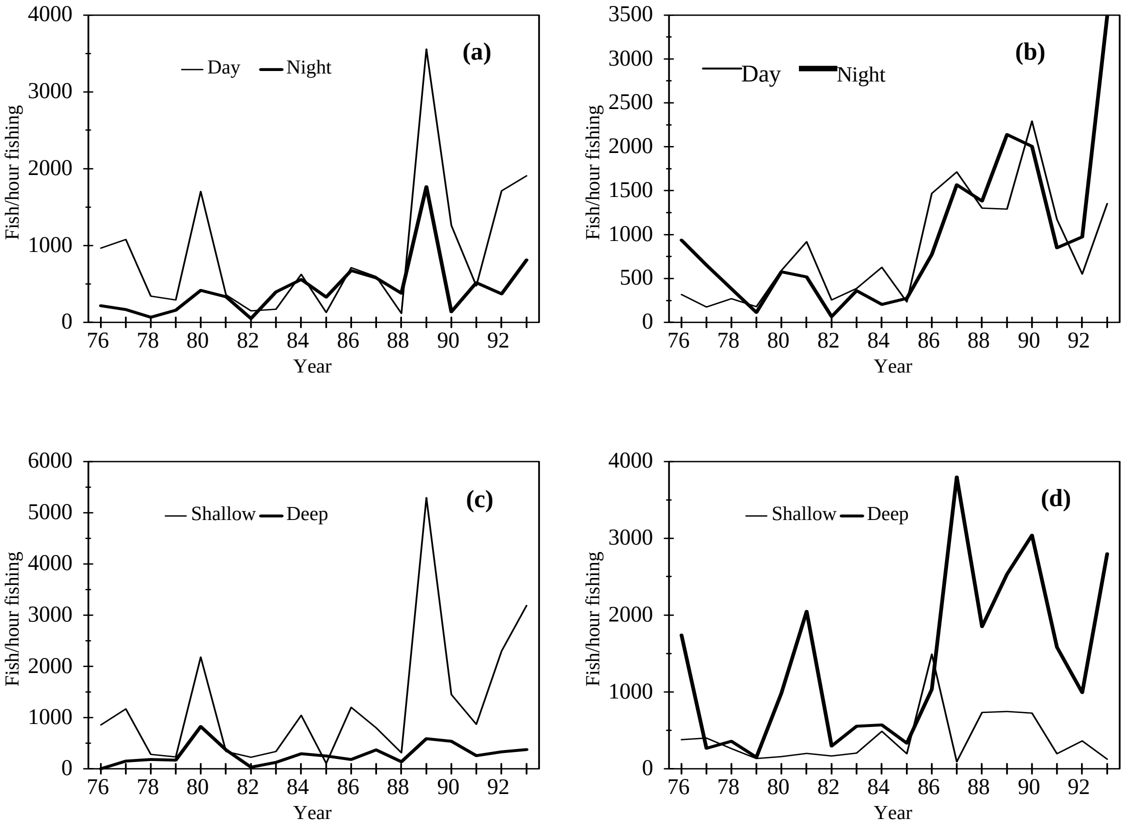

Fig. 5. Catch rates of whiting for the period 1976-1993. a, c) Juveniles, b, d) Adults.

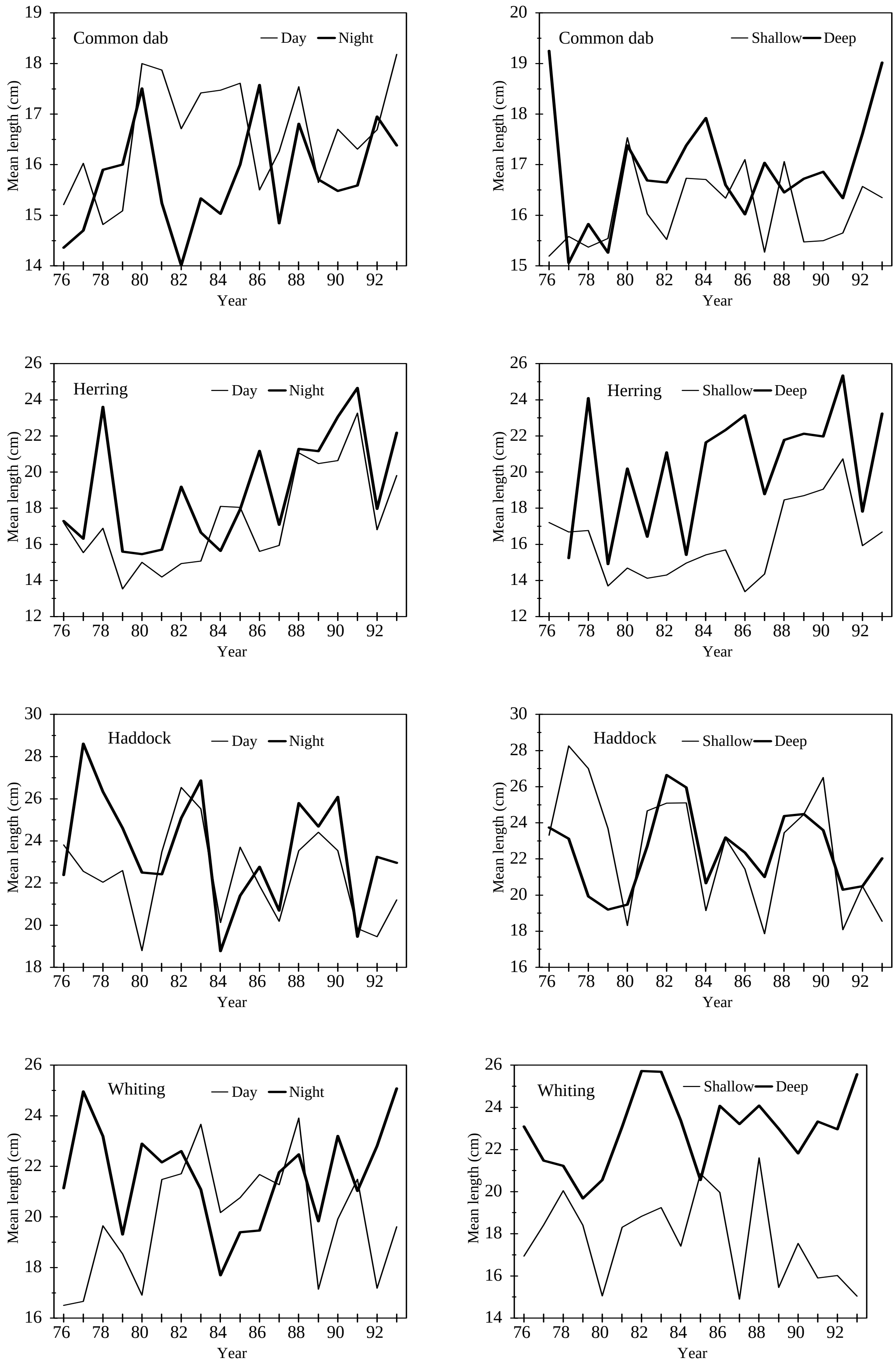

Fig. 6. Mean lengths for the period 1976 to 1993.