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Vertical migration and spatial distribution of pelagic 0-group gadoids (cod, haddock, whiting and Norway pout) prior to and during settlement in the North Sea*

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*This paper investigates diel vertical migration and spatial distribution in 0-group gadoids in the central and northern North Sea in late spring and early summer, covering the pelagic phase of development and the transition to a demersal habit. The species investigated include cod (*Gadus morhua L.*), haddock (*Melanogrammus aeglefinus *L.), whiting (*Merlangius merlangus L.*) and Norway pout (*Trisopterus esmarkii NILSSON*).*

In the northern North Sea in June there was considerable overlap in the spatial distribution of the pelagic 0-group gadoids. The catch rates of the various species were often positively correlated. The presence of high concentrations of fish in the same area is likely to increase intra- and interspecific competition.

During the pre-settlement stage in the northern North Sea in June, pelagic 0-groups of around 3 cm in length exhibited diel vertical migration patterns, the extent and the timing of which varied. In 1991, catches of fish near the surface peaked in the evening, whilst in 1992 the peak was in the middle of the day, as was the peak catch rate of haddock west of Denmark. However, west of Denmark, near-surface catches of pelagic 0-group cod and whiting peaked at night. It is likely that the concentration of fish near the surface is a feeding response, with the 0-groups shadowing the vertical migration patterns of the copepods on which they feed.

During settlement to take up a demersal life style in July 1994 in the central North Sea, 0-group cod of 4-6 cm in length were demersal by day and pelagic at night. Cod of over 8 cm in length were wholly demersal, having completed the transition to a demersal life style.

The provision of possible management measures, such as the implementation of temporary closed areas, to protect pre-recruit 0-group gadoids on settlement sites is discussed.

Key words : North Sea, gadoids, pelagic, 0-group, vertical migration, spatial distribution

INTRODUCTION

The principal gadoids of the central and northern North Sea in terms of economic importance and abundance are cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*) and Norway pout (*Trisopterus esmarkii*). In June the 0-groups are

Paper presented at the Workshop "Problems related to fishing and biodiversity", Split, 1999 pelagic and tend to be of a similar size range, with overlapping distributions. They feed on a range of zooplankton as well as on each other (ROBB and HISLOP, 1980; ROBB, 1981; BROMLEY *et al.*, 1997). In summer cod switch to a demersal habit. The biological and ecological processes influencing this stage in the life history of gadoids are not well understood. The aims of the present study were to investigate the vertical migration patterns and spatial distribution of 0-gadoids during the pelagic phase and over the transition to a demersal habit, covering the period June-July. This was achieved through a series of three research vessel trawl surveys in the North Sea during 1991-1994. Depth stratified 24h trawling was undertaken at selected sites.

MATERIAL AND METHODS

The survey areas and the sites and dates of 24 h depth-stratified fishing are shown in Fig. 1 and Table 1. The abundance of pelagic 0-group gadoids in the area east of the Shetland Isles was surveyed in June 1991 and in June1992, and the area west of Denmark was surveyed in June 1992. Sampling was undertaken using an International Young Gadoid Pelagic Trawl (IYGPT), (HOLDEN, 1981) with a 6 mm stretched mesh cod end. Depth-stratified 24 h fishing was undertaken at two sites where high concentrations of a mixture of 0-group gadoids were found. The 24 h site approximately 60 miles south-east of Lerwick in the Shetland Isles (Fig. 1) was sampled in June 1991 and again in 1992 when two 24h fishing cycles were

Table 1. Details of 24h fishing cycles with the IYGPT and 4m beam trawl

Date	Ship	Gear	ICES Rect-angle and position	Headline depth (m) below surface	No of tows	No of 24 h cycles	Water depth m	Surface and bottom temper-ature °C	Surface and bottom salinity ppt
17-20 June 1991	Clupea	IYGPT	48F0 60°00'N 00°00'E	10, 35, 135	18	1	147	10.35 8.25	-
8-9 June 1992	Corystes	IYGPT	42F5 56°40'N 05°30'E	10, 25	12	1	55	18.8 14.7	34.97 34.96
11-13 June 1992	Corystes	IYGPT	48F0 60°00'N 00°00'E	10, 35, 110	36	2	147	12.8 7.5	35.30 35.30
23-25 July 1994	Corystes	IYGPT *	41F3 56°15'N 03°30'E	10, 30, 60	36	2	70	18.8 6.0	33.51 34.98
25-26 July 1994	Corystes	Beam trawl	41F3 56°15'N 03°30'E	0.38m **	18	1	70	18.8 6.0	33.51 34.98

* *Tow duration was 40 minutes during this sample series to improve catch rates.*
** *Beam height above bottom.*

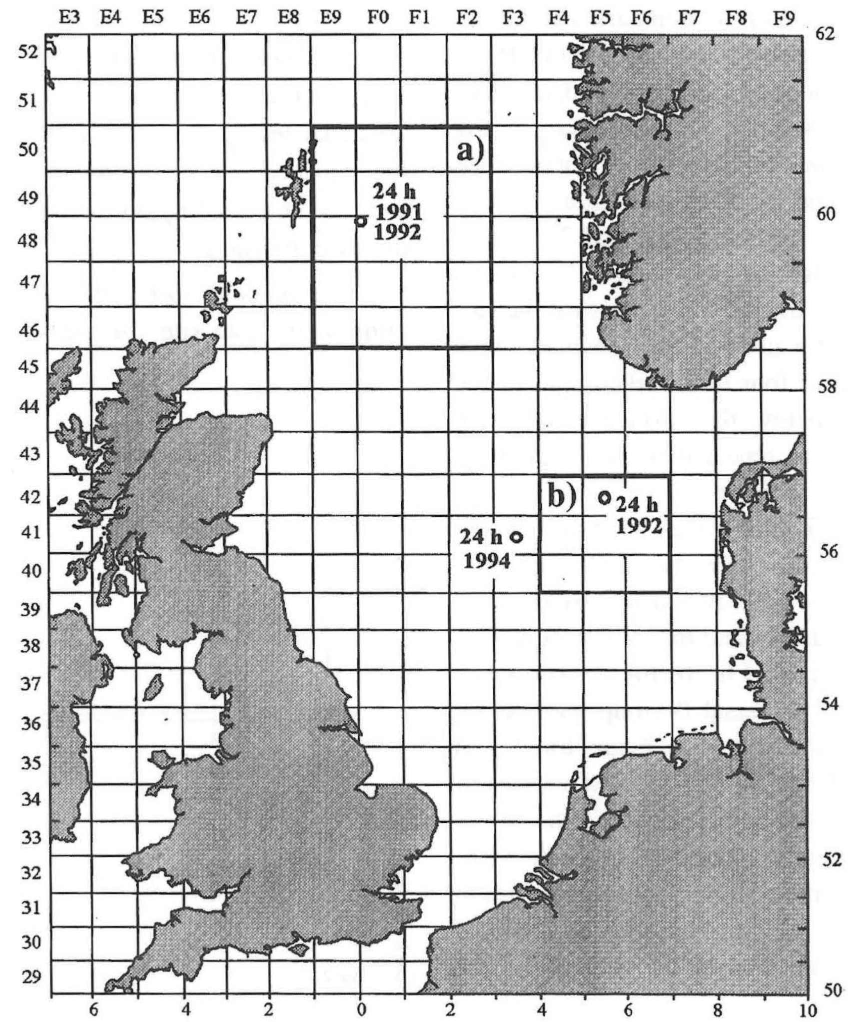

Fig. 1. Chart of the North Sea showing the survey rectangles (a) east of Shetland and (b) west of Denmark and the positions of 24h trawling sites

undertaken. The 24 h site west of Denmark was sampled in June 1992. In July 1994, exploratory fishing identified the location of a cod settlement site in the central North Sea and intensive depth-stratified fishing over two 24 h periods was undertaken at this site. Details of all the 24 h fish sampling are given in Table 1. In order to sample the demersal 0-groups at the cod settlement site, additional 24 h sampling was undertaken in July using a 4-m beam trawl with a 5-6 mm stretched mesh liner in the cod end. Water depth, temperature and salinity were measured at all sites and in 1992 surface light intensity was also measured. On the cod settlement site in the central North Sea in July, a day grab was used to sample the bottom sediment and biota.

During fishing for pelagic 0-groups using the IYGPT, the depth of the headline below the surface and the configuration of the net during towing were monitored electronically. The spread of the wing ends was approximately 10 m and the towing speed was 3 knots through the water, although this varied slightly, since control over the depth of fishing was achieved by adjusting both warp length and towing speed. During the surveys of pelagic 0-goups east of the Shetlands and west of Denmark, each ICES rectangle was sampled once with the IYGPT in order to get an index of 0-group abundance. The trawl was deployed for 1 h at a time, during which it was fished for 30 minutes at a headline depth of 10 m and for 30 minutes at a depth 35 m. The protocol for depth stratified 24 h sampling of the pelagic 0-groups was to conduct a series of three 30 minute tows, one near the surface, one in mid-water and the third just above the bottom, every four hours (the depth of the trawl headline below the surface is given in Table 1). This was repeated six times giving a total of 18 tows over each 24 h period. Duplicate 24 h fishing cycles were undertaken at two sites (Table 1). In the shallower water west of Denmark only two depth bands were sampled (near-surface and mid-water), giving a total of 12 tows per 24 h. In July 1994, during sampling of the demersal 0-group gadoids on the settlement site, the 4-m beam trawl was towed at 4 knots for 30 minutes and a series of 18 such tows was undertaken over 24 h.

The catches of 0-group cod, haddock, whiting and Norway pout (or random sub-samples in the case of large catches) were sorted, counted and each fish measured to the nearest 0.5 cm below.

RESULTS

Diel vertical migration patterns of pelagic 0-group gadoids

The average catch rates and size range of the pelagic 0-group gadoids caught during depth-stratified 24 h fishing are summarised in Tables 2 and 3.

At the 24h site south-east of Lerwick in June 1991, catches of 0-group cod, haddock and whiting all tended to follow similar trends (Fig. 2). Hardly any fish were caught near the bottom. In mid-water, catches of whiting were high in the morning and became progressively smaller during the rest of the day. Cod and haddock catches followed a similar trend, but the mid-morning peak was not so pronounced. Near the surface, the trend was reversed with low catches in the morning, building up to a peak at high levels in the evening for all species. The results are consistent with an upward migration of fish into surface waters during the afternoon and evening, followed by a downward migration in the early morning.

In contrast to 1991, on the first day of sampling at the 24h site south-east of Lerwick in

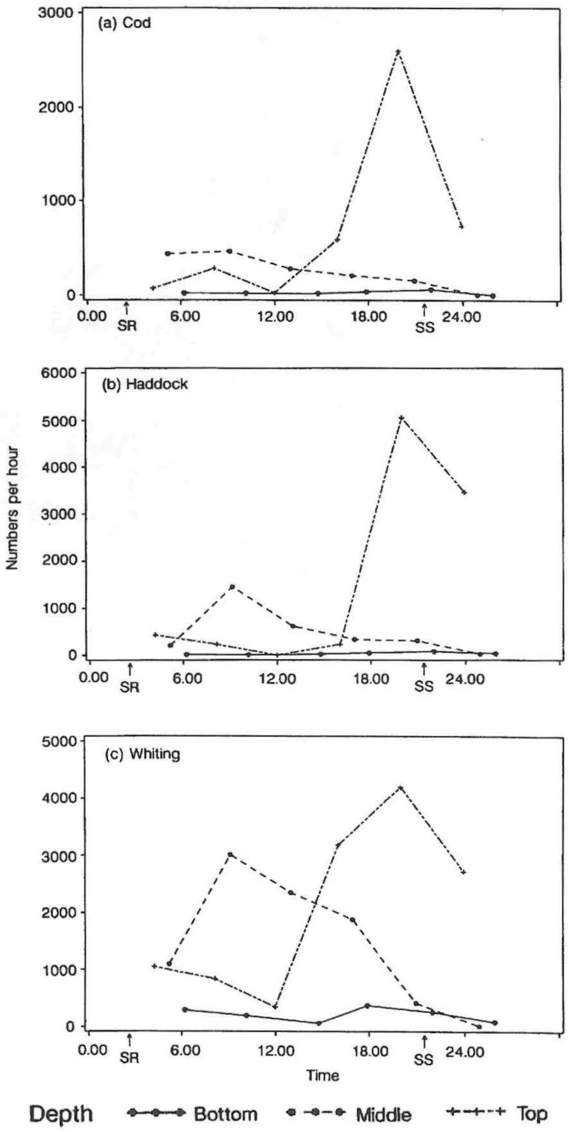

Fig 2. The catch rates of pelagic 0-group cod, haddock and whiting during depth stratified 24 h fishing south-east of Lerwick in June 1991 using the IYGPT (SR=*sunrise*, SS=*sunset*)

Table 2. Summary of the numbers of pelagic 0-group gadoids caught per hour during fishing surveys and 24 h depth stratified sampling in June 1991 and 1992

	1991			1992		
Location and species	Number of tows	Mean number caught h^{-1}	SD	Number of tows	Mean number caught h^{-1}	SD
a) Survey east of Shetland						
Cod	20	182	288	20	21	36
Haddock	20	153	311	20	377	528
Whiting	20	119	191	20	788	953
Saithe	20	25	44	20	2	4
Norway pout	20	1526	5551	20	79	252
b) 24h site south-east of Lerwick						
Cod	18	334	606	36	34	36
Haddock	18	699	1368	36	1265	1402
Whiting	18	1241	1308	36	1136	1649
Saithe	18	20	57	36	0	1
Norway pout	18	260	340	36	3	9
a) Survey west of Denmark						
Cod	18	1381	4469	8	754	1389
Haddock	18	11	17	8	3	6
Whiting	18	26	48	8	475	659
Saithe	18	655	2775	8	4	9
Norway pout	18	3	10	8	45	127
a) 24 h site west of northern Denmark						
Cod				12	271	734
Haddock				12	1	2
Whiting				12	442	395
Saithe				12	2	5
Norway pout				12	0	1

Table 3. The mean lenght of fish sampled at the 24 h sampling sites

Species	South-east of Lerwick 1991 length cm (SD)	South-east of Lerwick 1992 length cm (SD)	West of Denmark 1992 length cm (SD)
Cod	3.59 (0.78)	3.85 (0.52)	4.12 (0.64)
Haddock	3.77 (1.02)	4.26 (1.04)	7.43 (1.37)
Whiting	2.38 (0.76)	3.03 (0.56)	2.87 (0.70)

June 1992 the catches of cod, haddock and whiting near the surface were positively related to surface light intensity and peaked in the middle of the day (Fig. 3). On the second day of sampling, when the surface light intensity was reduced due to cloud cover, the pattern was more erratic and catch rates were lower.

In the shallower waters west of Denmark in June 1992, the few haddock that were caught were most abundant near the surface in the mid-morning and thereafter, catches followed a pattern that appeared to be related to surface light intensity (Fig. 4). By contrast, catches of cod and whiting near the surface were greatest at night and dipped to a low level in the early morning (Fig. 4). Catches of cod were erratic during the rest of the day, but catches of whiting increased again to follow a pattern that appeared to be related to light intensity.

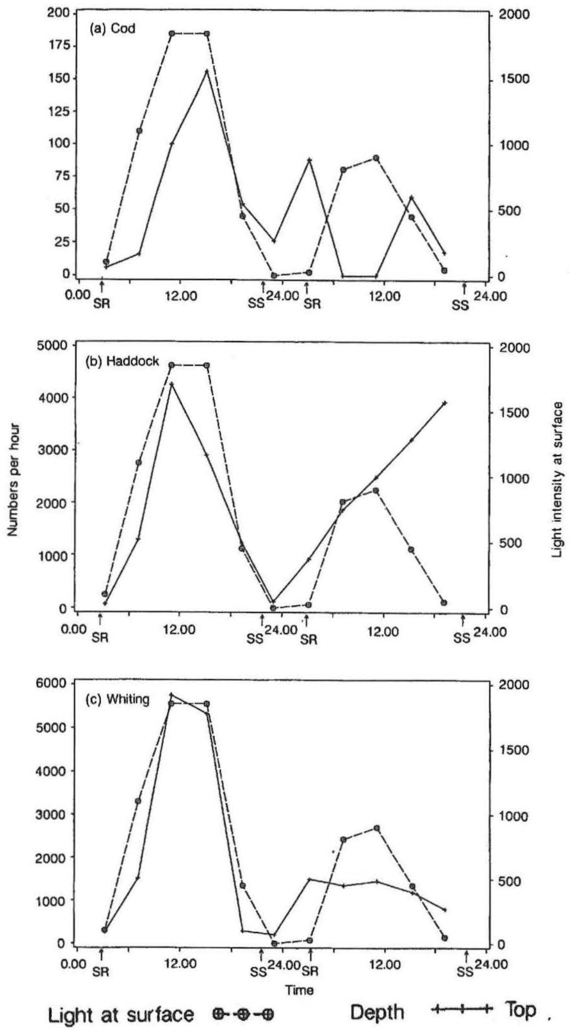

Fig 3. The catch rates of pelagic 0-group cod, haddock and whiting caught near the surface during 24 h fishing south-east of Lerwick in June 1992 using the IYGPT. Surface light intensity is in microeisteins m^{-2} s^{-1} at the time the net was deployed. (SR=*sunrise*, SS=*sunset*)

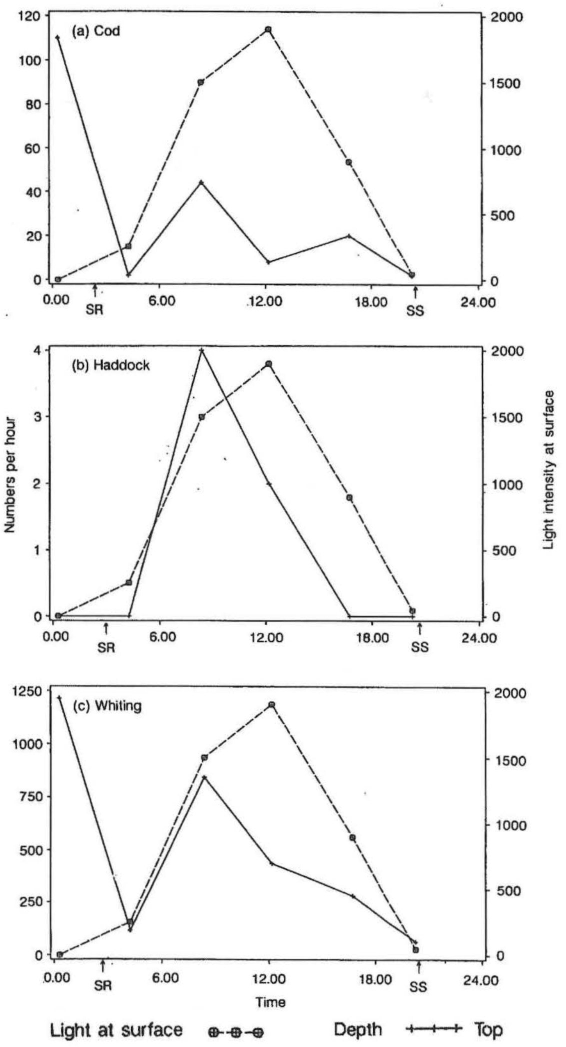

Fig 4. The catch rates of pelagic 0-group cod, haddock and whiting caught near the surface during 24 h fishing west of Denmark in June 1992 using the IYGPT. Surface light intensity is in microeisteins m^{-2} s^{-1} at the time the net was deployed. (SR=*sunrise*, SS=*sunset)*

Transition to a demersal habit on the cod settlement site in the central North Sea in July

By July in the central North Sea, the 0-groups were generally larger and there was a marked difference in the diel vertical migration patterns compared with a month earlier. All the 0-group cod were on or close to the bottom during daylight hours and could be caught in the beam trawl (Fig. 5), but not in the pelagic trawl. At night, the situation was reversed, with 4-6 cod cm having migrated upwards throughout the water column, and they were no longer taken by the beam trawl. Some 6-8 cm cod also migrated upwards at night, whilst others remained on the bottom. Cod of over 8 cm in length were fully demersal and were not caught in mid-water.

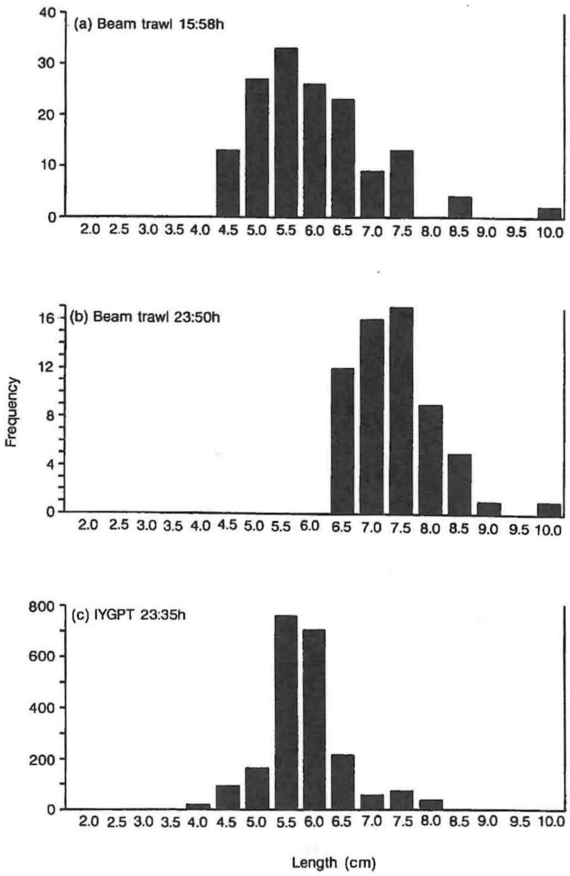

Fig 5. Length frequency distribution (numbers caught per hour) of cod in (a) the beam trawl in the day, (b) the beam trawl at night, (c) the IYGPT at night in the central North Sea in July 1994

Spatial correlation in the abundance of pelagic 0-group gadoid species

The catch rates of pelagic 0-group gadoids sampled in the June surveys are summarised in Table 2. In 1991 there was a good year class of 0-group cod in all areas. In 1992 there were substantial catches of cod west of Denmark, but relatively few were caught east of the Shetlands. About twice as many haddock were caught in northern waters during 1992 compared with 1991. Whiting were ubiquitous and generally abundant, more so in 1992 than in 1991.

Strong positive correlation was often found between the catch rates of the various species of pelagic 0-group gadoids caught in the survey areas during June, indicating an association between the distribution of the different species, particularly east of the Shetlands. There were significant positive correlations ($P \leqslant 0.05$) between the catches of cod, haddock and whiting in both 1991 and in 1992 (Table 4) - the only exception being the relationship between cod and whiting in 1991, which was not significantly correlated. The relationship between the catches of haddock and whiting east of Shetland in 1992 is shown in Fig. 6 as an example. Data from the ICES pelagic 0-group survey (ANON., 1984; HOLDEN, 1981) for the same area east of Shetland over the period 1974-1983 were also analysed. Results showed that positive correlation between the catches of the various species of gadoids was a persistent feature (Table 5). The weakest relationship was between Norway pout and whiting. No significant negative correlations were found.

Table 4. Correlation between the catch rates of the various species of 0-group gadoids in ln numbers per hour caught during the surveys east of Shetland (+ indicates that the correlation is positive and $P \leqslant 0.05$)

Comparison	Survey east of Shetland 1991	1992
Cod v. Haddock	+	+
Cod v. Whiting	Not significant	+
Haddock v. Whiting	+	+

Table 5. Number of years over the period 1974-1983 when there was a positive correlation ($P \leqslant 0.05$) between ln numbers per hour of the various species of pelagic 0-group gadoids caught in the survey area east of Shetland during the ICES 0-group surveys

Species	Cod	Haddock	Norway pout
Haddock	8		
Norway pout	7	7	
Whiting	6	7	3

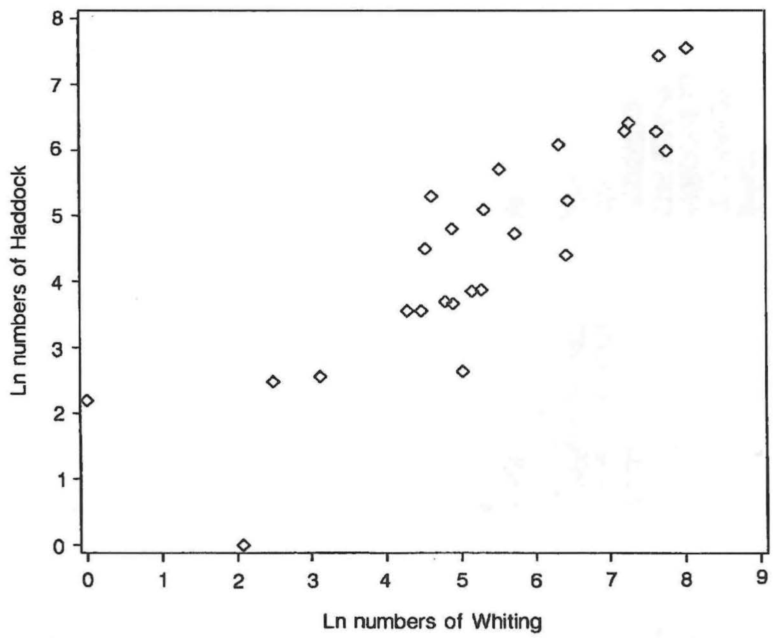

Fig 6. The relationship between the catch rates (ln numbers h^{-1}) of pelagic 0-group haddock and whiting during the survey of the region east of Shetland in June 1992 using the IYGPT

DISCUSSION AND CONCLUSIONS

Previous studies have also shown that pelagic 0-group gadoids tend to be most abundant in the upper water layers of the North Sea during June, but strong diel vertical migration patterns have not previously been detected (ROBB, 1981). This was possibly due to a lower sampling frequency in earlier studies. The evidence presented here suggests that diel vertical migration is a widespread but somewhat variable phenomenon in pelagic 0-group gadoids. Patterns varied between years, between sites, between species and even from day to day at the same site.

Catches of whiting south-east of Lerwick in 1991 (Fig. 2c) suggest that whiting were concentrated at a depth of about 35-45 m in the morning and rose to a depth of about 10-20 m below the surface in the evening. Cod and haddock probably also migrated upwards, but only moderate numbers were caught in mid-water during the morning. At this time, either the fish were more evenly dispersed through the water column than were the whiting, or they were concentrated at a depth that was not well sampled by the tow in mid-water.

Although there were instances when it appeared that light intensity directly influenced the migration of fish into the surface layers, the relationship appeared to be variable and sometimes reversible. Other factors, such a temperature, wave action, lunar and tidal cycles and predation pressure might influence the pattern of vertical migration. There is evidence that feeding is an important factor influencing vertical migration. At the 24 h site south-east of Lerwick in 1991, stomach content analysis showed that peak feeding in pelagic 0-groups often occurred during the period 1600-2000 h (BROMLEY *et al.*, 1997). This was the case for 2-3 cm cod, 2-6 cm haddock and 1-3 cm whiting. These size groups fed heavily on zooplankton, particularly copepods. The time of peak feeding corresponded with the time when peak numbers of fish were caught near the surface. This suggests that the fish might be making feeding migrations, possibly in response to diel fluctuations in prey density with depth.

Diel vertical migration in the pelagic 0-group gadoids might therefore be a means of tracking vertical shifts in prey distribution, enabling the fish to maximise feeding rate. Patterns of diel vertical migration in copepods vary between species, between areas and between seasons (LEE and WILLIAMSON, 1975; DARO, 1985). The action of a factor such as light intensity on the migratory behaviour of the 0-groups is therefore likely to be complex, since light can influence the behaviour of the prey organisms. If the behaviour of the fish is influenced by the vertical migration patterns of the prey, it is perhaps not surprising that the diel vertical migration pattern of 0-groups is variable, since the prey might be positively, negatively or neutrally phototactic depending on species.

The pattern of vertical migration in the central North Sea indicates that 0-group cod become increasingly demersal in habit in July. The failure to catch any 0-group cod in mid-water during the daytime on the settlement ground was almost certainly because the fish were on or close to the bottom. Daytime avoidance of the gear is an unlikely explanation since fish of 4-5 cm were caught in mid-water during the day in the northern North Sea in June 1991. Possibly, by July, cod on the settlement grounds took cover on the bottom to avoid visual-feeding predators during the day. The day-grab indicate the seabed on the cod settlement ground was hard and rough with the presence of *Flustra foliacea* L., which would provide cover for young cod. This is the sort of bottom type that was found to reduce predation on young cod in tank experiments (LINDHOLM *et al.*, 1999).

Preliminary analysis of the stomach contents of cod in the central North sea in 1994 showed that the 4-8 cm fish were feeding mainly on planktonic copepods and hyperids, which have been found to concentrate above the thermocline (DARO, 1985). The prey of 0-group cod caught on the bottom late in the day was at an advanced stage of digestion. The diel vertical migration of these fish into the water column at night is therefore likely to be a feeding migration. LOUGH *et al* (1989) found a similar migration pattern in cod on Georges Bank, but these fish fed just above the bottom at night. They did not appear to migrate up throughout the water column as in the present study; possibly due to differences in the behaviour of the prey organisms on Georges Bank. The migration patterns of the 0-groups found in the central North Sea in July were somewhat similar to those found in the northern North Sea in August (BAILEY, 1975), though by August, most of the cod were fully demersal.

The 1991 and 1992 surveys east of Shetland and data from the ICES 0-group surveys all showed that correlation between the abundance of the various species was a persistent feature. It is possible that the biotic and environmental requirements of a range of gadoid species are fairly similar during the pelagic 0-group phase. Regions that provide suitable conditions for one species might provide suitable conditions for a range of species to develop. Such regions might be more productive or predation pressure could be low, allowing improved survival rates. The association between species was weakest between whiting and Norway pout. The Norway pout feed almost entirely on copepods (ROBB and HISLOP, 1980; ROBB, 1981; BROMLEY *et al.*, 1997). Older pelagic 0-group whiting can be highly piscivorous and it is possible that differences in feeding requirements might tend to dissociate the spatial distribution of whiting and Norway pout.

During the surveys in the present study and in the earlier international 0-group surveys from 1974-1983, 0-group abundance was, in effect, estimated by integrating the catch from a limited number of depth bands, usually 3 bands, during each tow. Particularly in deep water, therefore, the water column is not evenly sampled. Caution must be taken when interpreting such data since one of the depth bands always sampled was near the surface. The present findings show that pelagic 0-groups of all the principal gadoid species are likely to concentrate in the near-surface layer at the same time (thought the actual time of day is likely to vary). When this happens, particularly high catch rates are likely to be encountered, which could substantially bias the estimated mean abundance of fish upwards for all species in these particular hauls. This could cause an artefact whereby the abundance of a range of species will appear to be positively correlated between individual hauls during a spatial survey, when in reality they might not be correlated, or at least, not as strongly correlated as the results might suggest. Trawl sampling using a double oblique hall (V-dive) between the surface and bottom would be a more appropriate sampling strategy during abundance surveys, but this can in practice only be achieved effectively with automatic winches.

Little is known about gadoid settlement areas, but the transition to a demersal habit could have a marked influence on survival and recruitment. If there are discrete nursery grounds, then interannual variation in the dispersion of pelagic 0-groups prior to settlement could lead to highly variable survival rates. Conversely, if the location of nursery grounds varies, depending on where the fish happen to be when they settle out, this could also cause erratic survival depending on the conditions where the fish settle out. Further investigation of this phase in gadoid development is required to determine its importance in contributing to fluctuations in recruitment. It is possible that the bulk of cod recruitment in the North Sea might come from a limited number of nursery grounds and that high concentrations of pelagic 0-groups could occur in areas where they might not be able to reach suitable settlement sites. Should the settlement sites be found to be discrete areas that persist from year to year in the same place, this opens up options for specific management actions to conserve the integrity of the settlement sites. Such options include limiting trawling with gears that might damage the bottom, limiting industrial fishing and taking measures to protect the grounds from other forms of disturbance or pollution, including the dumping of waste from drilling operations. Though the present study pertains to the North Sea, in principle, the approaches developed here may be applicable to other areas where gadoids are abundant.

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Vertikalna migracija i prostorna raspodjela pelagijskih O-grupa gadoida (bakalara, kolje, merlana i norveške ugotice) prije i tijekom naseljavanja u Sjevernom moru

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SAŽETAK

U radu se iznose rezultati istraživanja dnevne vertikalne migracije i prostorne raspodjele 0-grupe gadoida u srednjem i sjevernom dijelu Sjevernog mora krajem proljeća i početkom ljeta, uzevši u razmatranje pelagijsku fazu razvoja i prijelaz na demerzalni način života. Istraživane su sljedeće vrste riba: bakalar (*Gadus morhua* L.), kolja (*Melanogrammus aeglefinus* L.), merlan (*Merlangius merlangus* L.) i norveška ugotica (*Trisopterus esmarkii* Nilsson).

U sjevernom dijelu Sjevernog mora uočeno je u lipnju značajno preklapanje u prostornoj raspodjeli pelagijskih faza 0-grupe gadoida, a odnosi lovina različitih vrsta bili su često pozitivno korelirani. Prisutnost velikih koncentracija riba na istom području je vjerojatno povećavalo intra- i interspekcijsku kompeticiju.

Tijekom stadija pred-naseljavanja u sjevernom dijelu Sjevernog mora pelagijske 0-grupe od oko 3 cm dužine pokazivale su različite primjere širine i vremenskog rasporeda migriranja. U 1991. lovine kolje zapadno od Danske dale su pik blizu površine u večernjim satima, dok je pik u 1992. dobiven sredinom dana. Međutim, lovine pelagijske 0-grupe merlana i bakalara dale su zapadno od Danske pik blizu površine noću. Za vjerovati je da je koncentracija riba blizu površine bila uvjetovana prehranom, jer su 0-grupe riba slijedile vertikalnu migraciju kopepoda s kojima se hrane.

Tijekom naseljavanja i prelaska na demerzalni način života u srednjem dijelu Sjevernog mora u lipnju, bakalar 0-grupe od 4-6 cm dužine bio je tijekom dana demerzalan, a tijekom noći pelagijski, dok je iznad 8 cm dužine bio posve demerzalan.

Diskutiraju se također moguće mjere gospodarenja, kao što je provedba vremenske zaštite područja, u cilju zaštite 0-grupe gadoida prije obnavljanja u područjima naseljavanja.