



Abundance and reproduction of Nilsson's pipefish on tidal flats

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Nilsson's pipefish *Syngnathus rostellatus* were found on tidal flats in the Dollard (Ems estuary, Wadden Sea) in high numbers in May and June (20 to 150 1000 m⁻²) and August and September (150 to 300 1000 m⁻²). Low numbers were found in April, July, November and December. Nilsson's pipefish with eggs and larvae in their brood pouch were most numerous in May and August and September. Both the fraction of Nilsson's pipefish with a brood pouch and the fraction of brood pouches with eggs and larvae increased with fish length. Analysis of length-frequency distributions suggests that two cohorts live in the Dollard (spring cohort, April–August; summer cohort, July–December). Reproducing animals were found in both cohorts. It was assumed that the spring cohort was the previous year's summer cohort, which migrate to the tidal flats in spring, reproduced and then disappeared. The summer cohort was their offspring (0 group) which leave the tidal flats during November and December.

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INTRODUCTION

The Nilsson's pipefish *Syngnathus rostellatus* Nilsson is distributed from the Mediterranean and Portugal in the south (Almeida, 1986) to Norway in the north (Nijssen & de Groot, 1987). The species is abundant in coastal areas and estuaries, but is also found both demersally and pelagically in the offshore North Sea throughout the year (Creutzberg & van Noort, 1979; Fonds & Boerman, 1981; Witte *et al.*, 1991). The species lives on sandy bottoms and in seagrass-meadows and tolerates low salinities. It feeds on small crustaceans (Nijssen & de Groot, 1987). Nilsson's pipefish migrate to shallow coastal areas in spring, where densities increase to a maximum between August and October (Hovenkamp & Van der Veer, 1993). Nilsson's pipefish leave the Wadden Sea in December (Fonds, 1978). Although the reproductive ecology of some other pipefish species has been studied in detail (Berglund *et al.*, 1986a; Vincent *et al.*, 1995), the timing of reproduction of the Nilsson's pipefish is largely unknown.

All pipefish species show specialized parental care. Females transfer their eggs to the males, which fertilize them and brood them on their ventral surface. For *Syngnathus* species this is in a specialized pouch. The males supply the embryos with oxygen and nutrition, until they leave the pouch as independent free swimming young (Fiedler, 1954; Haresign & Shumway, 1981).

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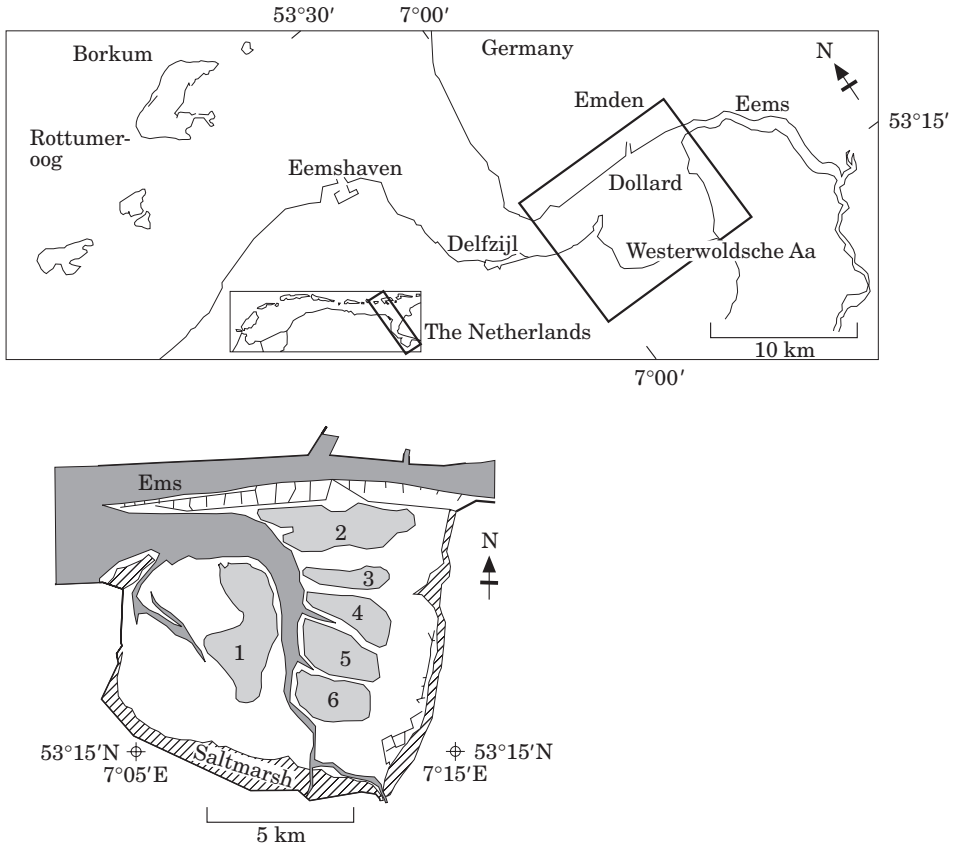


FIG. 1. Location of the Dollard in the Wadden Sea and the location of the sampled tidal flats (see Table I) in the Dollard.

The Ems–Dollard Estuary is an important nursery area for several flatfish species (Jager *et al.*, 1995) and is of importance for a number of other fish species. The objective of the present study was to investigate the function of the Dollard in the life cycle of the Nilsson's pipefish.

MATERIALS AND METHODS

STUDY AREA

The Ems–Dollard Estuary is situated in the eastern part of the Dutch Wadden Sea (Fig. 1). The Dollard is the inner most part of this estuary and has a brackish intertidal area of 100 km². The tidal flats make up 80 km² of this area, whereas 12 km² are tidal channels, gullies and creeks. The main freshwater inputs in the Dollard are the River Ems (*c.* 110 m³ s⁻¹) and the Westerwoldsche Aa (*c.* 15 m³ s⁻¹). Sediments are fine sand to silt. The tidal amplitude in the Dollard is 3 to 3.5 m (Jager *et al.*, 1995). Mean low water is 1.71 m below mean sea level, mean high water is 1.28 m above mean sea level (RIKZ, 2001).

DATA COLLECTION: SAMPLING

Sampling was carried out in 1993 and 1994. Six tidal flats in the Dollard, with a total area of 17 km², were selected for sampling. Table I gives some characteristics of the

TABLE I. Sampling and abiotic characteristics of the sampled tidal flats. Grid cells were 0.06 ha. m.s.l., mean sea level

Tidal flat	Area (ha)	Number of grid cells	Number of grid cells sampled per date		Tidal level, min.-max. (m, m.s.l)
			1993	1994	
1	496	66	10	10	0.0 ± 0.7
2	485	65	10	10	0.0 ± 0.7
3	141	18	4	0	0.0 ± 0.5
4	144	13	4	5	-0.40 ± 0.5
5	216	26	5	5	0.0 ± 0.6
6	195	23	5	5	0.0 ± 0.7

TABLE II. Summary of sampling dates, the total number of Nilsson's pipefish caught per date and number of fish measured per date

Date	1993		Date	1994	
	<i>n</i> Caught	<i>n</i> Measured		<i>n</i> Caught	<i>n</i> Measured
21 Apr	30	0	13 Apr	0	0
5 May	1179	181	27 Apr	8	0
26 May	2657	356	11 May	77	77
9 Jun	885	329	25 May	146	88
23 Jun	562	160	8 Jun	122	122
7 Jul	160	130	22 Jun	38	38
21 Jul	456	132	6 Jul	22	21
4 Aug	297	223	11 Jul	6	0
18 Aug	1414	256	27 Jul	1458	387
1 Sep	765	356	10 Aug	4627	427
15 Sep	2506	277	24 Aug	2137	231
6 Oct	1159	469	7 Sep	3304	508
3 Nov	0	0	5 Oct	1370	433
			2 Nov	350	145
			7 Dec	6	6
Total	12 070	2869		13 315	2332

tidal flats and Fig. 1 shows their location in the Dollard. The flats were divided into grid cells of 250 × 250 m. For every sampling date, on each tidal flat a number of these grid cells was randomly selected for sampling (random stratified sampling) (see Table I for the number of grid cells that was sampled per date). In 1993 the strata were sampled every 2 weeks from the end of April to September and then monthly to the beginning of November (Table II). In 1994 the strata were sampled every 2 weeks from April to early September and monthly after that until the beginning of December. The stratum LZ was not sampled in 1994 and the stratum LP had an extra grid cell in 1994 (Table I).

Stations were sampled from 2 h before high water (HW) slack to 1 h after HW. The sampling gear was a 20 cm high × 2 m wide beamtrawl, mesh size 0.5 × 0.5 cm, with one tickler chain. The total mass of the net was *c.* 15 kg. The net was towed by a rubber dinghy with a 40 hp outboard motor at *c.* 50 m min⁻¹ at a minimum water depth of

0.8 m. The length of a haul was *c.* 250 m. A metre wheel was used to check the distance fished (Jager *et al.*, 1995). Each sample thus covered *c.* 500 m² of tidal flat. Sometimes it was not possible to sample all strata because the water was too low for fishing or because of unfavourable weather conditions. Water temperature and salinity (in PSU) were measured with a WTW-conductivity meter at each sample. Samples were deep-frozen for preservation until sorting in the laboratory.

SAMPLE ANALYSIS

All Nilsson's pipefish from frozen samples were counted and stored in 70% ethanol. Numbers per sample were converted to numbers 1000 m⁻². All samples were selected for further analysis, except for five dates with very low Nilsson's pipefish numbers (Table II). From all selected dates, the total length (L_T) of all animals from the first (randomly selected) sample of each tidal flat was measured to the nearest mm. If a sample contained <40 pipefish, additional samples were analysed until at least 60 fish were measured (Table II). The Nilsson's pipefish were also examined for the presence of a brood pouch and the presence of eggs and larvae in this brood pouch. All stages between a flat ventral surface and a fully developed brood pouch were present in the field. It was necessary to set a criterion to separate developing brood pouches from fully developed pouches. Therefore, a fully developed brood pouch was defined as a ventral skin fold that could be opened. Reproducing animals were defined as animals that had a brood pouch. No distinction could be made between females and immature male individuals. Embryos were called 'larvae' if pigmented eyes were visible; otherwise they were noted as eggs. In other pipefish species, not all embryos in one brood pouch are deposited by one female (Jones & Avise, 1997), therefore, the embryos are not necessarily of the same developmental stage. If both eggs and larvae were present in one individual male, the animal was noted to carry larvae. Nilsson's pipefish were grouped into 3 mm length-classes and length-frequency distributions were calculated without correction for shrinkage.

To obtain a better estimate of growth in the early life of the Nilsson's pipefish, an extra data point for the growth curve was generated by measuring 46 larvae from the brood pouches of 12 adults caught on 26 May 1993 and 28 larvae from the brood pouches of one adult caught on 6 June 1994. Length increase of the cohorts was related to water temperature. Mean cohort length at date one was subtracted from the mean cohort length at date two and divided by the number of days between sampling. These 'growth rates' were related to the mean water temperatures as measured on date one and date two. The principal axis was estimated, and provided a single axis, which represents the relation between growth and temperature (Sokal & Rohlf, 1985). This method was used because the two variables were both measured with error and therefore a regression analysis was not feasible.

Attempts to age the Nilsson's pipefish, using otoliths, vertebrae and opercular bones, were not successful. No annual marks were visible in any of these bones, while at least one yearly mark was expected for the Nilsson's pipefish that were caught in spring and therefore this method was not considered reliable.

RESULTS

ABIOTIC FACTORS

Mean water temperatures increased from 8° C in April to a maximum of 20° C in June in 1993 and 25° C in July 1994 [Fig. 2(a)]. After that, temperatures decreased gradually to 7–8° C in November and December. In 1993 temperatures were higher than in 1994 before 22 June. From the beginning of July temperatures were higher in 1994, with a maximum difference of 7.5° C during the second half of July between both years.

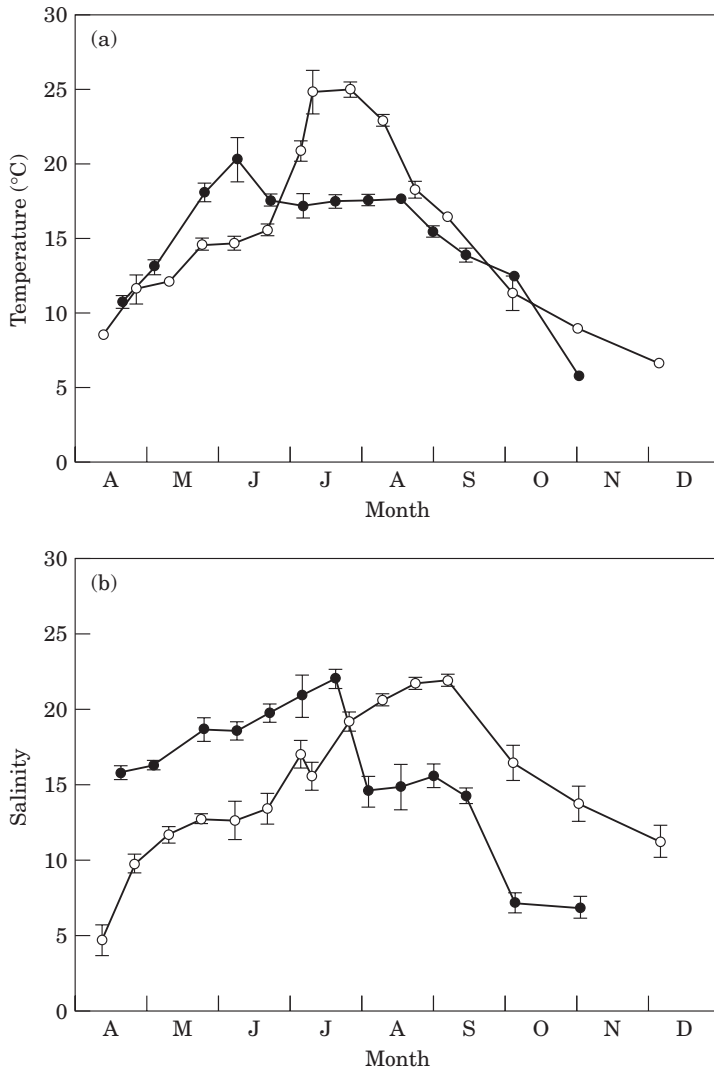


FIG. 2. Mean \pm S.D. (a) water temperature and (b) salinity per date in the Dollard in 1993 (●) and 1994 (○).

Between April and July, salinities were higher in 1993 (15–20) than in 1994 (5–16). Salinity dropped from 22 to 15 after 21 July 1993. In 1994 salinity reached its maximum of 22 on 7 September, and then gradually decreased to 11 on 7 December [Fig. 2(b)].

CATCHES

Nilsson’s pipefish were found on the tidal flats from late April to December (Fig. 3). In both years two peaks in pipefish catches were found, one in May and the other in August–September. In spring and late summer of 1993 the catches of Nilsson’s pipefish showed a maximum of 159 and 141 fish 1000 m^{-2} , respectively. In 1994 the spring peak was practically absent, but late summer

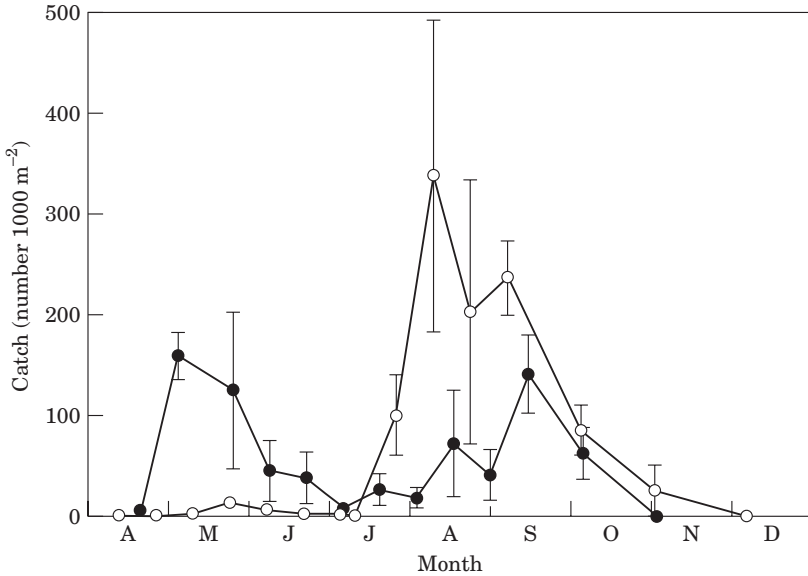


FIG. 3. Mean \pm s.d. catch of the Nilsson's pipefish on the tidal flats of the Dollard in 1993 (●) and 1994 (○).

catches ($338 \text{ fish } 1000 \text{ m}^{-2}$) were more than twofold those of 1993. Low catches were found in April, July and November–December ($0\text{--}5 \text{ fish } 1000 \text{ m}^{-2}$) in both years.

The length-frequency distributions of both 1993 and 1994 were separated into two cohorts by eye (Fig. 4). All animals caught from 5 May to 9 June 1993 belonged to one (spring) cohort. At later dates, a distinction between two cohorts had to be made. On 7 July 1993 the separation between the spring and summer cohort was made at 85 mm, on 21 July at 95 mm, on 4 August at 110 mm, and on 18 August at 120 mm. From 1 September on all Nilsson's pipefish belonged to the summer cohort. In 1994 there was no apparent temporal overlap between the spring cohort (11 May to 6 July) and summer cohort (27 July to 7 December).

The spring cohort was first caught at a mean length of *c.* 100 mm. Mean length increased to 130 and 110 mm, respectively, in 1993 and 1994. The summer cohort fish appeared in the catches at 65 mm L_T and reached a mean length of 100–110 mm in November–December 1993 (Fig. 4). Larval length varied between 3.5 and 11.5 mm, with a mode at 6.5 mm.

The rate of increase of mean length of the cohorts ranged from *c.* -0.07 to 1.27 mm day^{-1} . There was a positive correlation ($r=0.826$, $P=0.001$, $n=12$) between increase in mean L_T of the summer cohort and temperature (Fig. 5). Below 10°C there was no increase in mean length. Length increase of the spring-cohort was not significantly correlated with temperature.

REPRODUCTION

In both years Nilsson's pipefish with brood pouches, eggs or larvae were found on almost every sample date. In 1993 a maximum in the number of reproducing animals of $53 \text{ } 1000 \text{ m}^{-2}$ was found on 26 May (Fig. 6). On 15 September 1993

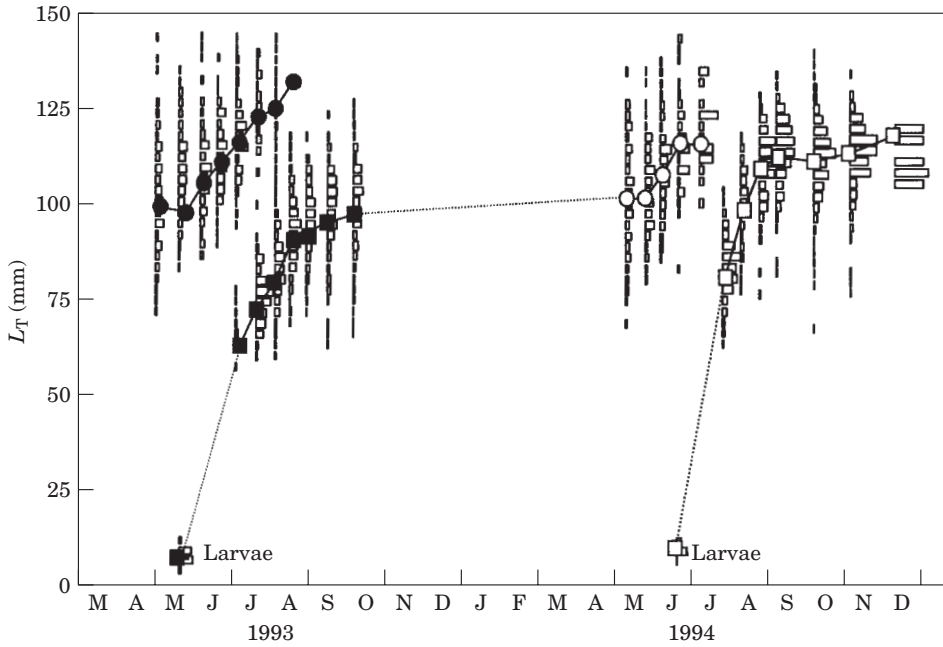


Fig. 4. Nilsson's pipefish in the Dollard. Mean length, L_T , (—) of spring (circles) and summer (squares) T cohort and relative length frequency distribution (▬, length classes of 3 mm, all bars per date add up to 100%) per sampling date in 1993 (●, ■) and 1994 (○, □). The dashed lines are hypothetical, assuming high growth and early reproduction of the summer cohort and low growth in winter.

the catch of reproducing animals showed a secondary peak of $8\ 1000\ m^{-2}$. The highest proportion of reproducing animals was found on 23 June. In contrast, in 1994 Nilsson's pipefish catches in spring on the tidal flats were low and consequently catches of reproducing fish were low as well (Fig. 7). In 1994, the highest catch of reproducing animals was found on 7 September ($28\ 1000\ m^{-2}$), but the highest proportions of reproducing pipefish were found in June.

The smallest animal having a brood pouch was 72 mm L_T . In 1993 c. 50% of the animals >110 mm had a brood pouch. Since only males have a brood pouch, this means that, assuming a sex ratio of 1, all Nilsson's pipefish >110 mm would be mature and ready to donate or receive eggs. In 1994 the percentage of animals having a brood pouch was lower, indicating that either the sex ratio was female biased or that the number of immature animals was high. There was a positive relation between the fraction of animals with a brood pouch and L_T (Fig. 8). Moreover, of the animals having a brood pouch, the pouches of large males more frequently contained embryos than the pouches of small males (Fig. 9). The number of eggs or larvae per pregnant individual could not be established, because the treatment of the samples caused damage to the fish and led to losses of eggs and embryos from the brood pouches.

DISCUSSION

Spring cohort Nilsson's pipefish entered the tidal flats of the Dollard in April. The fish with filled brood pouches were found on almost all sampling dates, but

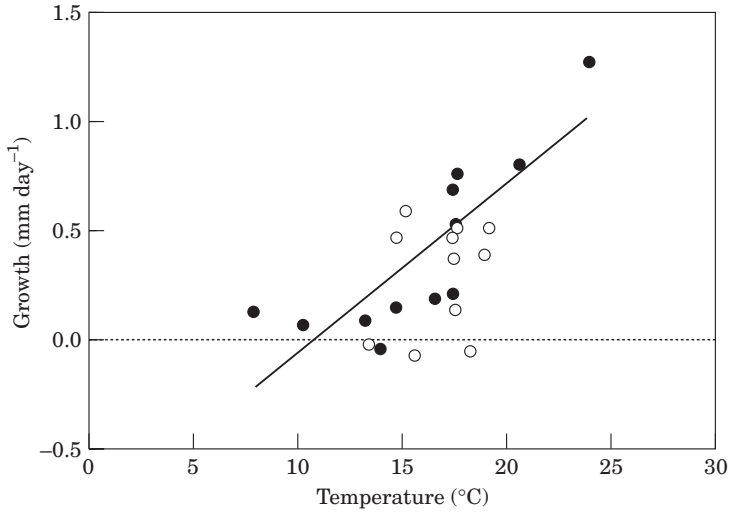


FIG. 5. The relation between mean temperature and length increase of Nilsson's pipefish cohorts between sampling dates (spring, ○, and summer, ●, cohorts). For the summer cohort, the line was derived from: $y = -0.81 + 0.08x$.

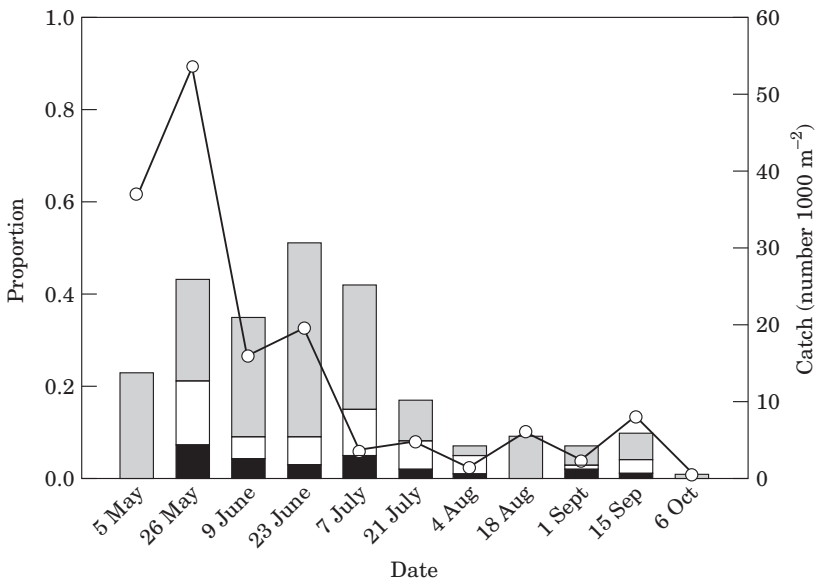


FIG. 6. Proportion of the Nilsson's pipefish with brood pouches only (▤), pouch with eggs (▥) and pouch with larvae (■) in the Dollard in 1993. —○—, Absolute catch density of reproducing fish per date.

a maximum of 30% filled brood pouches was observed in late May to early June. Catches of spring cohort fish decreased from early June to zero in August. From August to October the summer cohort caused a second maximum in catches. Among this group, a minor fraction had brood pouches with eggs and larvae, with highest catches of reproducing animals in September. From mid

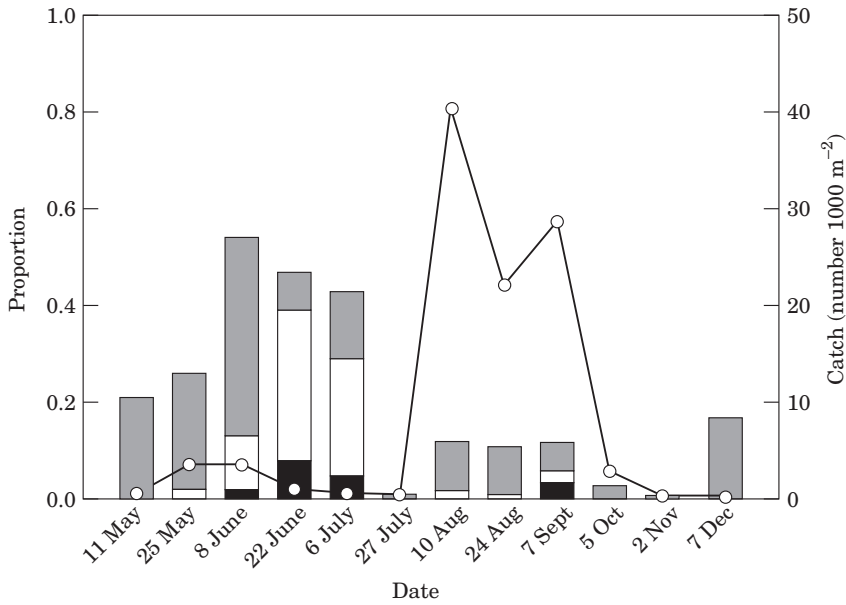


FIG. 7. Proportion of the Nilsson's pipefish with brood pouches only (□), pouch with eggs (□) and pouch with larvae (■) in the Dollard in 1994. —○—, Absolute catch density of reproducing fish per date.

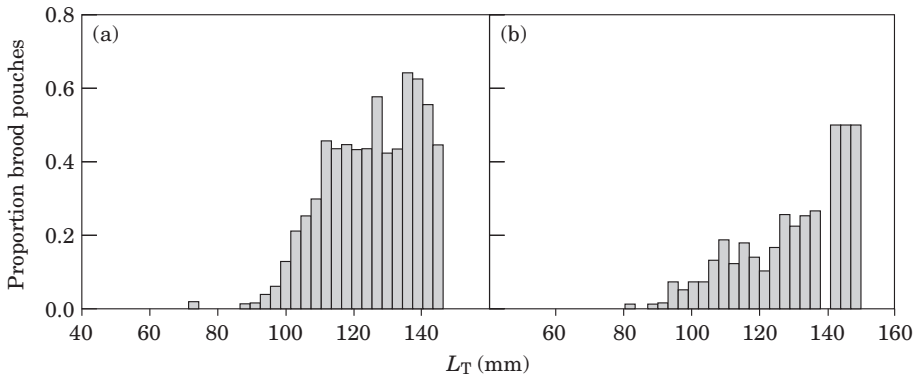


FIG. 8. Proportion of Nilsson's pipefish with a brood pouch in 1993 (a) and 1994 (b) 3 mm⁻¹ length category. The variation increases with length because of decreasing sample sizes.

September, Nilsson's pipefish catches decreased to zero in November–December, probably due to migration to the North Sea and mortality of the summer cohort (Fonds, 1978). Patterns in catches, however, varied considerably between 1993 and 1994.

This study shows that the Nilsson's pipefish can tolerate low salinities and large fluctuations in the salinities. Mean length of the pipefish only increased at temperatures >10°C. The presence of the fish in the Dollard seems to be determined by high water temperatures (>10°C) and probably relatively high salinities (>15) during spring. If conditions are not favourable, the Nilsson's

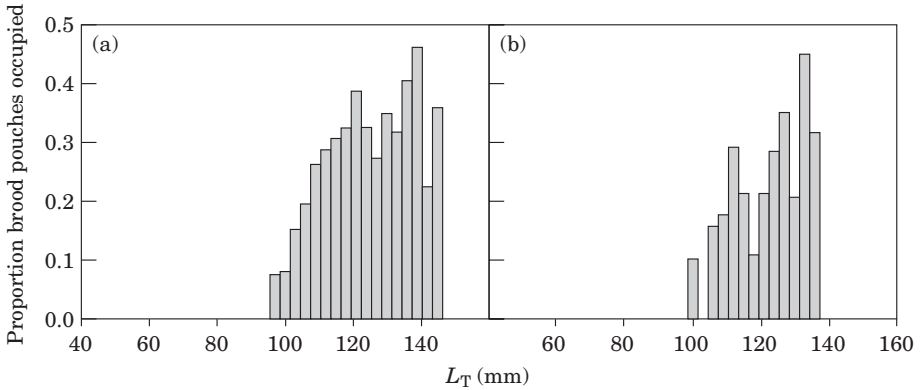


FIG. 9. Proportion of brood pouches of Nilsson's pipefish with eggs or larvae in 1993 (a) and 1994 (b), 3 mm^{-1} length category. The variation increases with length because of decreasing sample sizes.

pipefish probably remain in the outer parts of the estuary. Anecdotal information confirms occasionally high catches of the fish in the cooling water inlets of the Ems power plant and in the Eemshaven (port).

There are two options to explain the observed pattern of subsequent cohorts on the tidal flats. Due to temperatures $<10^\circ \text{C}$ [Fig. 2(a)], no growth in length was expected during winter (Fig. 5). The spring cohort may consist of animals that migrate from the channels in the Wadden Sea and outer Ems Estuary to the tidal flats in spring. This group probably consisted of the summer cohort of the previous year or years. The related *Syngnathus abaster* Risso reaches a maximum length of *c.* 13 cm and can obtain an age of 17 months (Franzoi *et al.*, 1993) and so the Nilsson's pipefish may also reach ages of >1 year. The spring cohort reproduced and left the tidal flats or died in July to August. The summer cohort consists of their offspring (0 year group), and leaves the tidal flats in November to December. This, in combination with the presence of reproducing animals in the samples, implies that reproduction started at the early age of 3 to 4 months. The offspring of the summer cohort were not caught in the same year, possibly because they were too small and passed through the net, or because the smallest stages were pelagic (Russell, 1976; Beyst *et al.*, 1999) and were not caught by a demersal sampling device. In fact, no *S. rostellatus* <60 mm were caught. Moreover, the relatively large mesh size allowed the small Nilsson's pipefish to escape and densities of all sizes of fish were probably severely underestimated due to net selectivity.

An alternative hypothesis to explain the observed patterns is that the offspring of the summer-cohort in 1993 are the same animals as the summer cohort in 1994. This hypothesis might also explain the reproduction of the summer cohort Nilsson's pipefish; the reproducing animals in this case would not be 0 year group fish, but 1 year-old fish that were born in September 1 year earlier. This alternative seems improbable because in this case two separately reproducing populations of the Nilsson's pipefish would inhabit the Dollard, a spring and a summer reproducing population. Herring *Clupea harengus* L. is one of the few species for which different spawning periods within an area have been reported (Munk & Christensen, 1990). Furthermore, this option implies very slow growth

of the offspring of the summer cohort, while the length-frequency distributions in Fig. 4 suggest very fast growth. Without reliable (calibrated) ageing of Nilsson's pipefish, it is not possible to exclude either of these options.

Densities of Nilsson's pipefish in other studies in estuarine areas and the Wadden Sea showed similar patterns, with low catches in winter and high catches in August and September, sometimes with a secondary maximum in May to June (Fonds, 1978; Hovenkamp & van der Veer, 1993). The mean lengths of two cohorts as found by Z. Jager (pers. comm.) from power plant cooling water sieves in the Ems Estuary in August (75 and 120 mm respectively) corresponded with the length of the summer and spring cohort as defined in this study in August (95 and 130 mm respectively). Patterns of abundance in the Westerschelde Estuary (south-west Netherlands) were similar to the patterns observed in the Ems-Dollard Estuary. Density of *Syngnathus* sp. (most likely *S. rostellatus*) also showed two peaks, a low maximum in April (c. 4 1000 m⁻²) and another maximum of 10 to 40 1000 m⁻² in August (Beyst *et al.*, 1999). In the period August to October the length frequency distribution in the Westerschelde Estuary also showed a bimodal pattern as the Dollard in 1993: the modal L_T was 55 mm and a large number of individuals measured between 65 and 105 mm. In the current study in the Dollard, a bimodal distribution was found from July to August 1993, modal length classes were found c. 70 and 115 mm. Moreover, two periods of recruitment were also found in the Westerschelde, the first one in February and the second period in July (Beyst *et al.*, 1999).

Nilsson's pipefish were caught on the tidal flats during high tide. The tidal flats completely emerge during low tide, and moreover Nilsson's pipefish were never observed on the tidal flats at low tide. The fish probably undertake tidal migrations, as has been shown for juvenile plaice *Pleuronectes platessa* L. (Wolff *et al.*, 1981) and flounder *Platichthys flesus* (L.) (Jager, 1999). Since Nilsson's pipefish are poor swimmers, it seems likely that the fish are transported to and from the tidal flats by the tidal currents. Nevertheless, it is probable that they feed on the tidal flats at high tide.

Since more animals were found with eggs than with larvae, egg incubation probably takes longer than incubation of larvae. A larger proportion of large than of small males had a brood pouch with embryos. This may indicate that female *S. rostellatus* prefer larger males for mating, as was demonstrated in the deep-snouted pipefish *Syngnathus typhle* L. (Berghlund *et al.*, 1986a). Vincent *et al.* (1995) found that all males of the Nilsson's pipefish in Sweden had full brood pouches and were unavailable for mating for 3 weeks during June. The fact that a maximum of 50% of the brood pouches was filled in this study, may indicate that for *S. rostellatus* in the Dollard, female reproduction was the limiting factor. Ahnesjö (1995) showed that in *S. typhle* male brooding capacity increased faster with temperature than female egg production. Since temperatures are higher in the Dollard than in Sweden, this might explain why brood pouch occupancy was lower in the Dollard than in Sweden. Vincent *et al.* (1995) estimate the duration of pregnancy of *S. rostellatus* at 1–2 months, the male fish reproduced twice in one season, in May and early July. In 1993 a larger fraction of males with embryos in their brood pouch were found among the Nilsson's pipefish >100 mm than in 1994. This did not result in a higher fraction of occupied brood pouches in 1994. This again suggests reproduction was not

limited by male brood pouch availability, as in *S. typhle* and the straight-nosed pipefish *Nerophis ophidion* (L.) (Berglund *et al.*, 1986b), but by female reproductive capacity.

The present study demonstrates that the Ems Estuary is an incubation area for the Nilsson's pipefish. The juvenile fish stay in the area during the summer months, therefore the area also provides a nursery for this species. Two length cohorts were present in substantial numbers on the tidal flats during high tide. It implies that the fish undertake tidal migrations.

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