Chapter 5
Seasonal Structure of the Fish and Crustacean Community of the Zeeschelde Estuary

Between July 1994 and June 1995, 55 fish species, two shrimp species and four crab species were recorded in 135 samples taken at the cooling-water filter screens of the nuclear power plant Doel. The fish community was composed of 36 marine species, 16 freshwater species and three diadromous species. Only few species dominated the fish community contributing to >96% of the numbers caught on cooling-water filter screens. These were three Gobiidae *Pomatoschistus minutus*, *P. lozanoi* and *P. microps*, two Clupeidae *Clupea harengus* and *Sprattus sprattus* with addition of *Syngnathus rostellatus*, *Pleuronectes flesus* and *Dicentrarchus labrax*. It was notable that all these dominating fish species had a marine nature and occurred as juveniles. Both freshwater and diadromous species represented only a small fraction of the fish community. The abundance of two shrimp species, the common shrimp *Crangon crangon* and the prawn *Palaemontes varians* equalled total fish abundance. The brackishwater reach was seasonally used by the community resulting in an exceptionally clear pattern of species occupancy. It was argued that young fish and crustaceans use the highly turbid Zeeschelde estuary as a refuge from predators.

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Introduction

Communities of fish and crustaceans inhabiting estuaries represent a combination of freshwater and marine species both living at the edge of their distribution, estuarine residents and migrating species passing the estuary on their way to the spawning grounds (Claridge *et al.*, 1986; Wheeler, 1988; Day *et al.*, 1989; Potter *et al.*, 1990; Potter *et al.*, 1997). The spatial organization of estuarine species communities is highly correlated with salinity and substratum type (Henderson, 1989; Hamerlynck *et al.*, 1993). The temporal structure is often the result of seasonal migrations of young fish and crustaceans, moving between coast and adjacent estuaries (McLusky, 1989; Robertson and Duke, 1990*b*). Most species spawn in deeper offshore waters which may be favourable for egg survival and dispersion (Blaber, 1997). After hatching, larvae are drifted to the coastal and estuarine nurseries, where they become mobile and then migrate to shallow and turbid areas using the tides as a means of transport

(McLusky, 1989; Daan *et al.*, 1990). For temperate estuaries, this pattern of movements is resulting in consecutive migration waves of juveniles of marine fish, crabs and shrimps. (Wharfe *et al.*, 1984; Claridge *et al.*, 1986; Pomfret *et al.*, 1991, Potter *et al.*, 1997). In tropical estuaries, seasonality in species communities is less apparent (Day *et al.*, 1989; Laroche *et al.*, 1997) and sometimes masked by large variances in catch data (Robertson and Duke, 1990*a*). It has, however, been widely recognized that both temperate and tropical estuaries and inshore areas act as nurseries as they provide almost unlimited food resources (Day *et al.*, 1989) and offer shelter from predators (Cyrus and Blaber, 1992; Ruiz *et al.*, 1993)

Seasonal changes in the structure of the fish and crustacean communities in the highly turbid Zeeschelde estuary, Belgium (Fig. 1.1) are the focus of this chapter. Therefore, sampling was conducted for one year in a power station cooling-water inlet providing a wealth of regular data. This alternative fishing technique was most convenient in an area where trawling and netting are difficult because of extreme tides, heavy shipping and harbour activities and unexpected weather conditions. The nature of fish migrations is further discussed by questioning whether or not the upper reaches of the Zeeschelde are a nursery area offering enhanced protection.

Material and methods

Sampling regime

Samples of fish, shrimps and crabs were collected every two weeks from the cooling-water intake screens of the Nuclear Power Plant Doel, located in the brackish part of the Zeeschelde (Fig. 1.1). Sampling started in July 1994 and finished in June 1995. The cooling-water intake is situated 2 m above the bottom and withdraws 25.1 $m^3 s^{-1}$ water corresponding to 0.35 % of the local Zeeschelde flow. Since the mesh size of the intake screens is 4 mm, neither larvae nor smaller crustaceans such as Mysidacea could be sampled. Approximately $8 \times 10^6 m^3$ cooling-water was monitored in 135 samples.

Fish and crustaceans were separated from debris, identified to species level, counted, measured and preserved in 7 % formol. The genus *Pomatoschistus* was identified according to Hamerlynck (1990). Subsamples were taken for large catches of fish or crustaceans by dividing the total catch in equal parts. For each species, biomass (ash-free dry weight) was calculated using length-biomass regressions (Hostens and Hamerlynck, 1993; Maes, unpublished).

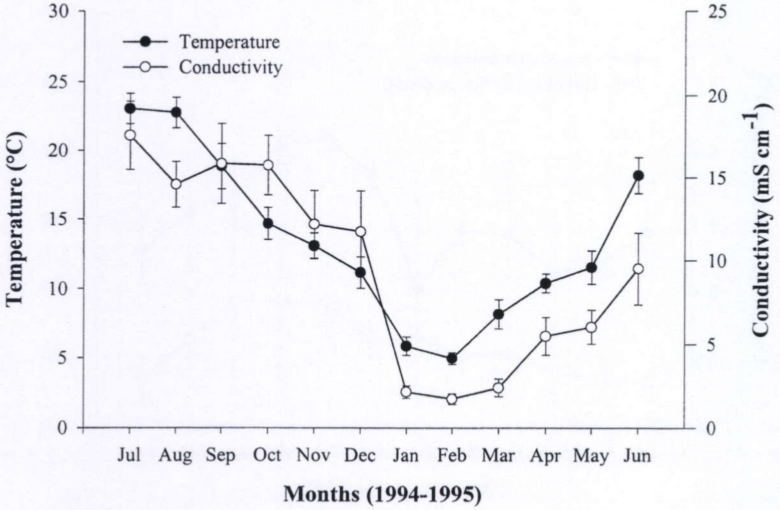

Fig. 5.1. Seasonal changes in water temperature and conductivity at the sampling site.

During sampling the following environmental variables were measured using a water quality multiprobe logger (Hydrolab, Datasonde 3): temperature (°C), conductivity ($mS\cdot cm^{-1}$), salinity (‰), dissolved oxygen concentration ($mg\cdot l^{-1}$) and turbidity (NTU). Secchi disc depth was measured in cm.

Data analysis

Abundance data ($numbers\cdot 10^{-3}$ m^{-3} cooling-water sampled) and biomass data (g $ADW\cdot 10^{-3}$ m^{-3} cooling-water sampled) were root-root transformed prior to statistical analysis (Field *et al.*, 1982). To study the temporal community structure, correlation biplots, based on principal component analysis (PCA), were used to project n-dimensional data in two-dimensions (Ter Braak, 1994). Variables (species) were represented as species vectors; samples as points. The species vectors are pointing towards samples when reaching their maximum abundance or biomass. Eigenvalues indicate the amount of variability expressed by each principal component.

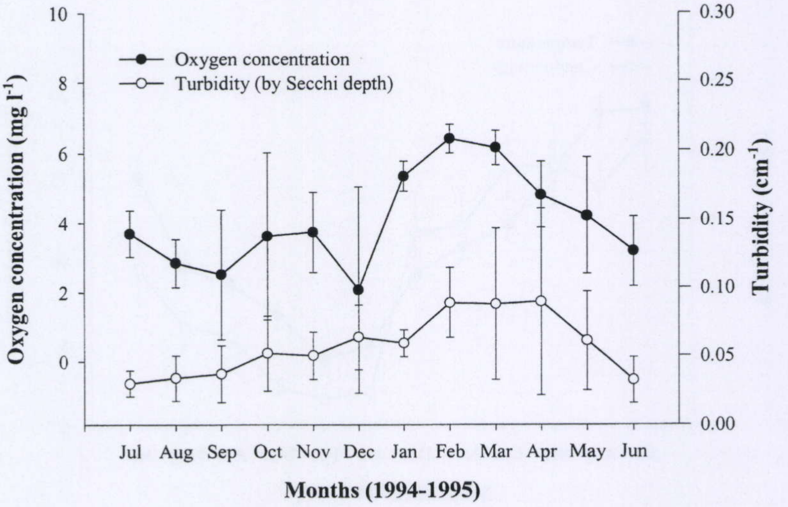

Fig.2. Seasonal changes in oxygen concentration and turbidity at the sampling site.

Results

Environmental data

Minimum and maximum temperatures recorded in the Zeeschelde ranged from 4.9 °C in February to 24.8 °C in August (Fig.5.1). Mean salinity and oxygen concentration were 7.99‰ and 4.59 mg·l^{-1}, respectively (Figs. 5.1, 5.2). Maximum salinities were measured in summer and minimum salinities in winter. The oxygen concentration showed an opposite pattern, with maxima in winter and minima in summer when the oxygen concentration dropped just below 2 mg·l^{-1}. Secchi disc depths were on average 19.6 cm and never exceeded 48 cm (Fig. 5.2). Mean turbidity was 165 NTU.

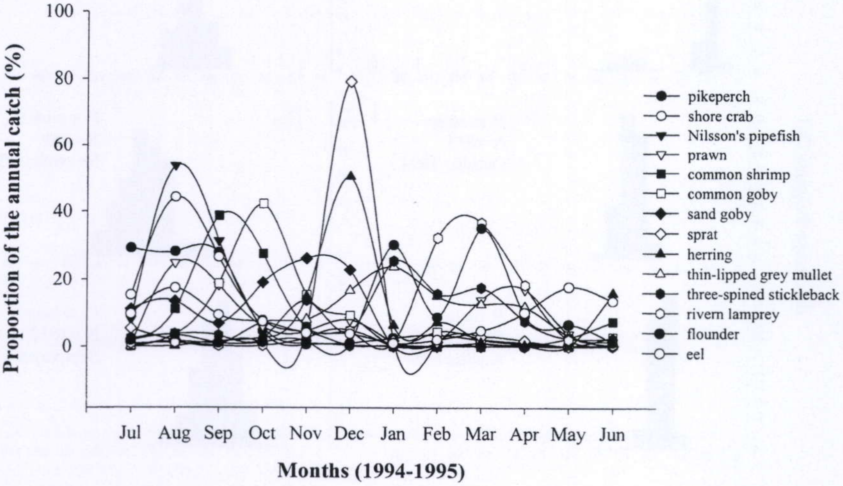

Fig. 5.3. Seasonal use of the estuary by 15 dominant fish species. For each species, the proportion of the annual catch was estimated by dividing the monthly catch by the total annual catch.

Species number and composition

In total, 55 fish species and six crustacean species were caught. Of the fish species, 36 were marine migrants and 16 species typically occur in fresh water (Table 5.1). Both groups included species that spend part of their life in estuaries as well as species occasionally entering estuaries. None of the species were strictly estuarine dependent i.e. they can either spawn and mature in fully marine or freshwater environments. European eel *Anguilla anguilla* was the only catadromous species, while river lamprey *Lampetra fluviatilis* and twaite shad *Alosa fallax* are anadromous (Table 5.1). Crustaceans caught at Doel included two shrimp species and four crab species (Table 5.2). It was noted that, except for shore crab *Carcinus maenas*, all crab species were exotics. A living specimen of the blue crab *Callinectes sapidus* was recorded for the first time in Belgium.

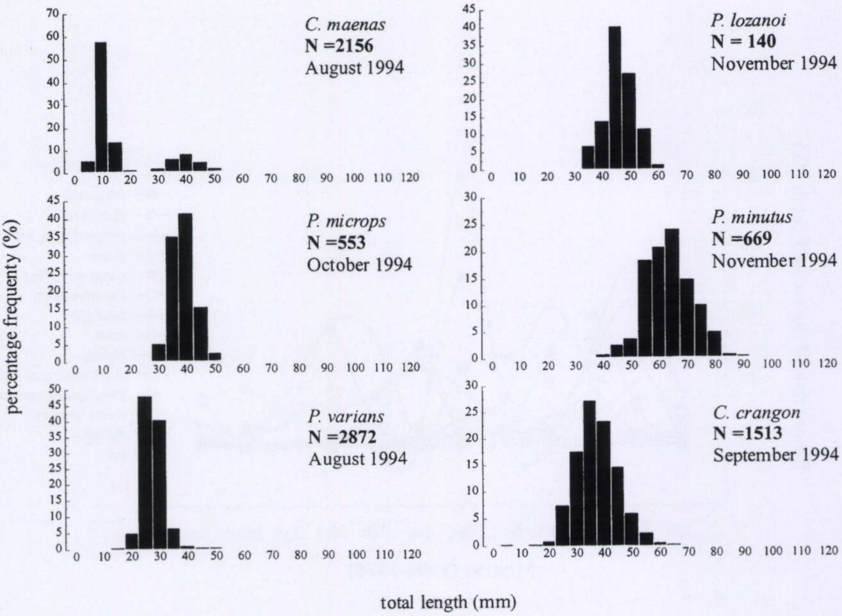

Fig. 5.4. Length-frequency distributions of three crustacean species and three Gobiidae measured in the month when each of them reached peak abundance.

Abundance and biomass data

In terms of numbers, eight species made up >95 % of the total catches. The most abundant species were the prawn *Palaemonetes varians* (37.4 %) and the common shrimp *Crangon crangon* (29.8%). The most numerous fish species were Gobiidae [common goby *Pomatoschistus microps* (12.6 %), sand goby *P. minutus* (7.8 %) and Lozano's goby *P. lozanoi* (1.0 %)], Clupeidae [herring *Clupea harengus* (6.4 %) and sprat *Sprattus sprattus* (1.7 %)] and Nilsson's pipefish *Syngnathus rostellatus* (2.5 %). In terms of biomass, the same species, with addition of bass *Dicentrarchus labrax* and flounder *Pleuronectes flesus*, dominated the community: Herring (29.2 %), prawns (18.0 %), sand goby (17.7 %), common shrimp (10.6 %), sprat (7.5 %) common goby (5.0 %), bass (4.5 %), flounder (1.9 %) and Nilsson's pipefish (1.0 %).

Table 5.1. *Species list, mean abundance (numbers* $\times 10^{-3}$ m^{-3} *cooling-water sampled) and standard deviation of fish sampled in the cooling-water of the nuclear power plant Doel over the period July 1994 to June 1995.*

Scientific name	**common name**	**mean**	**±SD**
Anadromous species			
Lampetra fluviatilis (L.)	River lamprey	0.06	0.14
Alosa fallax (Lacepède, 1803)	Twaite shad	< 0.01	< 0.01
Catadromous species			
Anguilla anguilla (L.)	Eel	0.16	0.15
Freshwater species			
Abramis brama (L.)	Bream	< 0.01	< 0.01
Carassius auratus (L.)	Goldfish	< 0.01	< 0.01
Carassius carassius (L.)	Crucian carp	< 0.01	< 0.01
Cyprinus carpio L.	Carp	< 0.01	< 0.01
Leuciscus leuciscus (L.)	Dace	< 0.01	< 0.01
Leucaspius delineatus (Heckel, 1843)	Moderlieschen	< 0.01	< 0.01
Rhoedeus sericeus (Pallas, 1776)	Bitterling	0.02	0.07
Rutilus rutilus (L.)	Roach	0.02	0.05
Tinca tinca (L.)	Tench	< 0.01	< 0.01
Gasterosteus aculeatus L.	Three-spined stickleback	0.19	0.30
Pungitius pungitius (L.)	Ten-spined stickleback	0.01	0.02
Cottus gobio L.	Bullhead	< 0.01	< 0.01
Lepomis gibbosus (L.)	Pumpkinseed	< 0.01	< 0.01
Gymnocephalus cernuus (L.)	Ruffe	< 0.01	< 0.01
Perca fluviatilis L.	Perch	0.06	0.09
Stizostedion lucioperca (L.)	Pikeperch	0.16	0.37
Marine species			
Clupea harengus L.	Herring	37.48	92.09
Sprattus sprattus (L.)	Sprat	10.00	36.30
Engraulis encrasicolus (L.)	Anchovy	0.05	0.36
Osmerus eperlanus (L.)	Smelt	0.06	0.10
Ciliata mustela (L.)	Five-bearded rockling	< 0.01	< 0.01
Gadus morhua L.	Cod	< 0.01	< 0.01
Merlangius merlangus (L.)	Whiting	< 0.01	< 0.01
Trisopterus luscus (L.)	Bib	< 0.01	< 0.01
Raniceps raninus (L.)	Tadpole-fish	< 0.01	< 0.01
Atherina presbyter Cuvier, 1829	Sand-smelt	< 0.01	< 0.01
Spinachia spinachia (L.)	Fifteen-spined stickleback	< 0.01	< 0.01
Syngnathus acus L.	Greater pipefish	< 0.01	< 0.01
Syngnathus rostellatus Nilsson, 1855	Nilsson's pipefish	14.47	44.25
Eutrigla gurnardus (L.)	Grey gurnard	< 0.01	< 0.01
Trigla lucerna L.	Tub gurnard	< 0.01	< 0.01
Myoxocephalus scorpius (L.)	Bull-rout	< 0.01	< 0.01
Agonus cataphractus (L.)	Hook-nose	< 0.01	< 0.01
Cyclopterus lumpus L.	Lumpsucker	< 0.01	< 0.01
Liparis liparis (L.)	Sea snail	< 0.01	< 0.01
Dicentrarchus labrax (L.)	Bass	2.00	3.36
Trachurus trachurus (L.)	Horse mackerel	0.04	0.43
Liza ramada (Risso, 1826)	Thin-lipped grey mullet	0.03	0.06
Pholis gunnellus (L.)	Butterfish	< 0.01	< 0.01
Zoarces viviparus (L.)	Eelpout	< 0.01	< 0.01
Ammodytes tobianus L.	Sandeel	0.01	0.06

Table 5.1. *Continued.*

Scientific name	**common name**	**mean**	**±SD**
Marine species continued			
Hyperoplus lanceolatus (Le Sauvage, 1824)	Greater sandeel	< 0.01	< 0.01
Callionymus lyra L.	Dragonet	< 0.01	< 0.01
Pomatoschistus lozanoi (de Buen, 1923)	Lozano's goby	6.20	19.01
Pomatoschistus microps (Krøyer, 1838)	Common goby	46.29	85.82
Pomatoschistus minutus (Pallas, 1770)	Sand goby	74.33	164.89
Scomber scombrus L.	Mackerel	< 0.01	< 0.01
Scophthalmus rhombus (L.)	Brill	< 0.01	< 0.01
Limanda limanda (L.)	Dab	0.01	0.05
Pleuronectes flesus L.	Flounder	0.45	1.46
Pleuronectes platessa L.	Plaice	< 0.01	< 0.01
Solea solea (L.)	Sole	0.03	0.07

Seasonal community structure

The seasonal changes in the community of fish and crustaceans were analysed using correlation biplots based on PCA. Principal Component Analysis with abundance data yielded the same information as PCA based on biomass data. Therefore, only the correlation biplot with biomass data is shown in Fig. 5.6. The total amount of variability explained by the first two eigenvalues corresponding to the first two principal components was 45.5 %. Only species representing >0.1 % of the total catches were included in the analysis. Including more species only affected the total variability expressed by the eigenvalues but did not change community structure.

The analysis placed all samples on a circle (Fig. 5.6*a*). Samples taken in the same month were closely located to each other in the biplot and arranged in a clear seasonal succession. (Fig. 5.6*b*). Five groups of species were more or less separated by the analysis:

Group A [dwarf crab *Rhithropanopeus harrisii*] comprised only one species, an exotic crab species which has recently settled in the Zeeschelde.

Group B [shore crab *Carcinus maenas*, *Syngnathus rostellatus*, *Crangon crangon*] occurring mainly in late summer and early fall (August, September) when temperature and salinity were both high.

Group C [*Pomatoschistus minutus*, *P. lozanoi, P. microps*] scoring highest biomass in Fall (October, November).

Group D [*Dicentrarchus labrax, Clupea harengus, Sprattus sprattus*] of which most individuals were caught in December. High numbers of larvae of both Clupeidae reached the Zeeschelde starting from May, but were not quantified.

Group E [thin-lipped grey mullet *Liza ramada,* river lamprey *Lampetra fluviatilis*, three-spined stickleback *Gasterosteus aculeatus*, *Pleuronectes flesus*] with species mainly sampled in winter and early spring (January, February, March, April), when high oxygen concentrations were recorded. In this period, numbers of freshwater species caught at Doel were relatively high. Not only *Gasterosteus aculeatus*, but *also* bitterling *Rhoedeus sericeus*, ruffe *Gymnocephalus cernuus* and bream *Abramis brama* took advantage of decreased salinities during winter and early spring.

The period between March and June was characterized by low abundance and biomass. Three species namely European eel, pikeperch *Stizostedion lucioperca* and prawn were badly represented by the analysis and could therefore not be placed in a species set. The proper reconstruction of the penaid shrimp *P. varians* was obstructed by two abundance maxima (April and August). Eel and pikeperch were present throughout the year with no marked abundance maximum.

The dominant species almost exclusively consisted of juveniles (Figs. 5.4, 5.5) and reached maximum abundance in the following chronological order starting from July: (1) Young of shore crab *C. maenas*, (2) young of prawn *P. varians*, (3) Nilsson's pipefish *S. rostellatus*, (4) Young of common shrimp *C. crangon*, (5) Young of common goby *P. microps*, (6) Young of Lozano's goby *P. lozanoi*, (7) Young of sand goby *P. minutus*, (8) Juvenile herring *C. harengus*, (9) Juvenile sprat *S. sprattus* (10) Recently metamorphosed river lamprey *L. fluviatilis*, (11) O+flounder *P. flesus*, (12) Spring stock of prawn *P. varians* (Fig. 5.3).

Table 5.2. *Species list, mean abundance (numbers* × *10^{-3} m^{-3} cooling-water sampled) and standard deviation of crustaceans sampled in the cooling-water of the Nuclear Power Plant Doel over the period July 1994 to June 1995.*

Scientific name	**common name**	**mean**	**±SD**
Crangon crangon (L.)	Common shrimp	175.32	383.73
Palaemonetes varians (Leach, 1814)	Prawn	219.88	333.05
Eriocheir sinensis H. Milne Edwards, 1854	Chinese mitten crab	< 0.01	< 0.01
Callinectes sapidus Rathbun, 1896	Blue crab	< 0.01	< 0.01
Rhithropanopeus harrisii (Gould, 1841)	Dwarf crab	0.24	0.60
Carcinus maenus (L.)	Shore crab	0.71	2.04

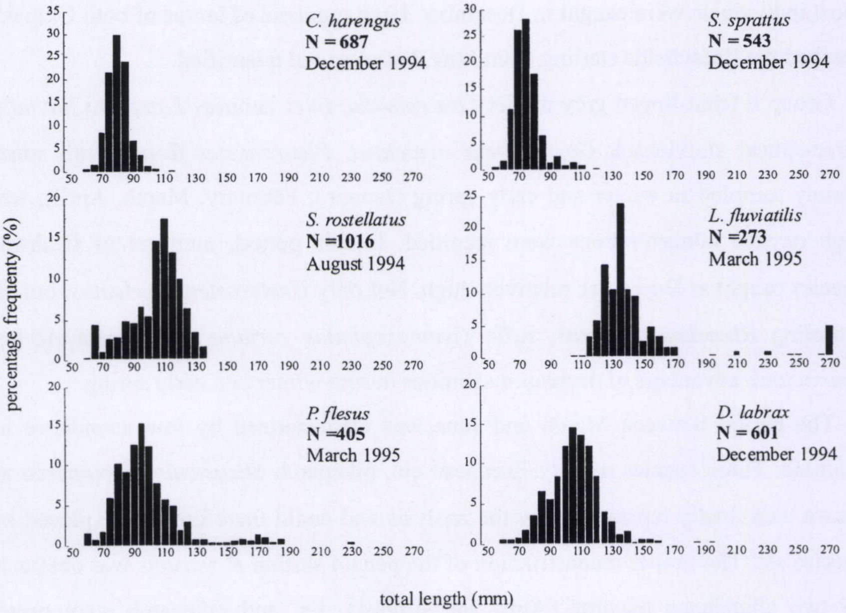

Fig. 5.5. Length-frequency distributions of six fish species measured in the month when each of them reached peak abundance.

Discussion

Species number

Henderson (1989) observed a linear relationship between species number and latitude based on cooling-water intake data of seven English coastal power plants. In addition, the species number generally declined in estuaries with declining salinities. With respect to latitude and mean salinity of the present sampling area the maximum expected number of fish species is close to 60. Sampling at Doel yielded 55 species indicating that almost all species occurring in the Zeeschelde are caught.

The capture of river lamprey, smelt, and twaite shad is noteworthy, since they are indicators of good water quality. During the late 1980s, the Zeeschelde estuary was heavily affected by domestic and industrial wastewater (Van Eck *et al.*, 1991), but water quality is gradually improving (Van Damme *et al.*, 1995). We thus expect increasing numbers of these species for the near future.

Seasonal structure of the fish and crustacean community

Principal Component Analysis on the sampling data showed an exceptionally clear annual pattern resulting in well-defined temporal changes in the species composition. Young of Decapoda and pipefish arrive in summer, followed by juvenile Gobiidae in late fall and O-group Clupeidae in early winter. There has been published an extensive literature on temporal fish distribution of northern temperate estuaries (Iglesias, 1981; Evans and Talmark, 1984; Claridge *et al.*, 1986; Costa, 1988; Day *et al.*, 1989; Henderson, 1989, Elliott *et al.* 1990; Potter *et al.*, 1997). The observed changes in temporal fish distribution are likely to be caused by seasonal migrations of marine fish into the brackishwater area and have been related to reproduction cycle, to variations in temperature and salinity, to food availability and to reduced predation pressure (McLusky, 1989; Blaber, 1997).

Many fish species complete their life cycle in tropical and subtropical estuaries (Blaber *et al.*, 1989, Robertson and Duke, 1990*a*), but there is less evidence they do so in temporal regions (Claridge *et al.*, 1986, Potter *et al.*, 1990). Although Elliott and Dewailly (1995) listed 27 species out of 186 occurring in 16 European estuaries as estuarine dependent, almost all species can mature and spawn at sea. Evidently European temperate estuaries are not critical to the survival of their visitors, except for diadromous species such as European eel, Salmonidae and anadromous Clupeidae.

Abiotic water conditions (salinity and temperature) are often evoked as controls for seasonal patterns of species occurrence (Thiel *et al.*, 1995). Although a few environmental variables were measured during this study, correlations with seasonal fish distribution were not made because they are trivial. Euryhalinity is a precondition for estuarine visitors and inhabitants (Blaber, 1997) while temperature is probably relevant when it reaches extreme values.

Increased estuarine productivity and food resources are linked with immigration of marine juveniles and the role of estuaries as nursery areas is documented in great detail (Haedrich, 1983; Boddeke *et al.*, 1986; Elliott *et al.*, 1990; Blaber *et al.*, 1995). However mechanisms to find these nursery areas are poorly understood (Day *et al.*, 1989). Indeed, juveniles of many species are probably not attracted to estuarine nursery as such but to shallow and turbid areas in general (Blaber and Blaber, 1980). Mobile fish and crustaceans appear to use these waters as a refuge from marine predators. It is experimentally proven that animals reduce or eliminate their anti-predator behaviour under turbid conditions (Abrahams and Kattenfeld, 1997). Since this behaviour is costly as it prevents fish from mating and foraging, a reduction in anti-predator behaviour should have a compensatory increase in feeding rates (Abrahams and Kattenfeld, 1997). It has thus been postulated that turbidity gradients existing between the sea and the adjacent estuaries, act as one of the orientation cues for juveniles migrating into estuaries (Blaber, 1997).

The number of studies on the effects of turbidity on brackishwater and marine species is rather limited. The most detailed studies to date on estuarine fish distribution and turbidity have been conducted in South African and Australian estuaries (Blaber and Blaber, 1980; Cyrus and Blaber, 1992; Blaber, 1997). Evidence was presented that juveniles occurring in estuaries occupy different turbidity ranges from those of adults and it was concluded that the influence of high turbidity on fish may be linked to reduced predation pressure. Visual predators were found to be more affected by turbid water than were macrobenthic species (Hecht and van der Lingen, 1992).

The observed migration sequence of juvenile crustaceans and fish in our data, match more or less with changes in the diet of Gadidae, their major predators in the adjoining coastal area (Hamerlynck and Hostens, 1993). After feeding on copepods in May and June, the fraction of gobies and shrimps in the diet of most Gadidae increases (Hamerlynck and Hostens, 1993; Salvanes and Jarle, 1993). With increasing length of the Gadidae, the fraction of gobies in the diet decreases and the fraction of larger fish including Clupeidae and juvenile Gadidae increases. (Hyslop *et al.* 1991; Henderson *et al.*, 1992). In the highly turbid Zeeschelde estuary, numbers of whiting *Merlangius merlangus*, cod *Gadus morhua* and bib *Trisopterus luscus* are unusually small relative to their prey both in cooling-water samples and in additional fyke catches (Maes *et al.*, 1997). This suggests that the Zeeschelde may be avoided by large numbers of piscivores and may act as a refuge for prey species.

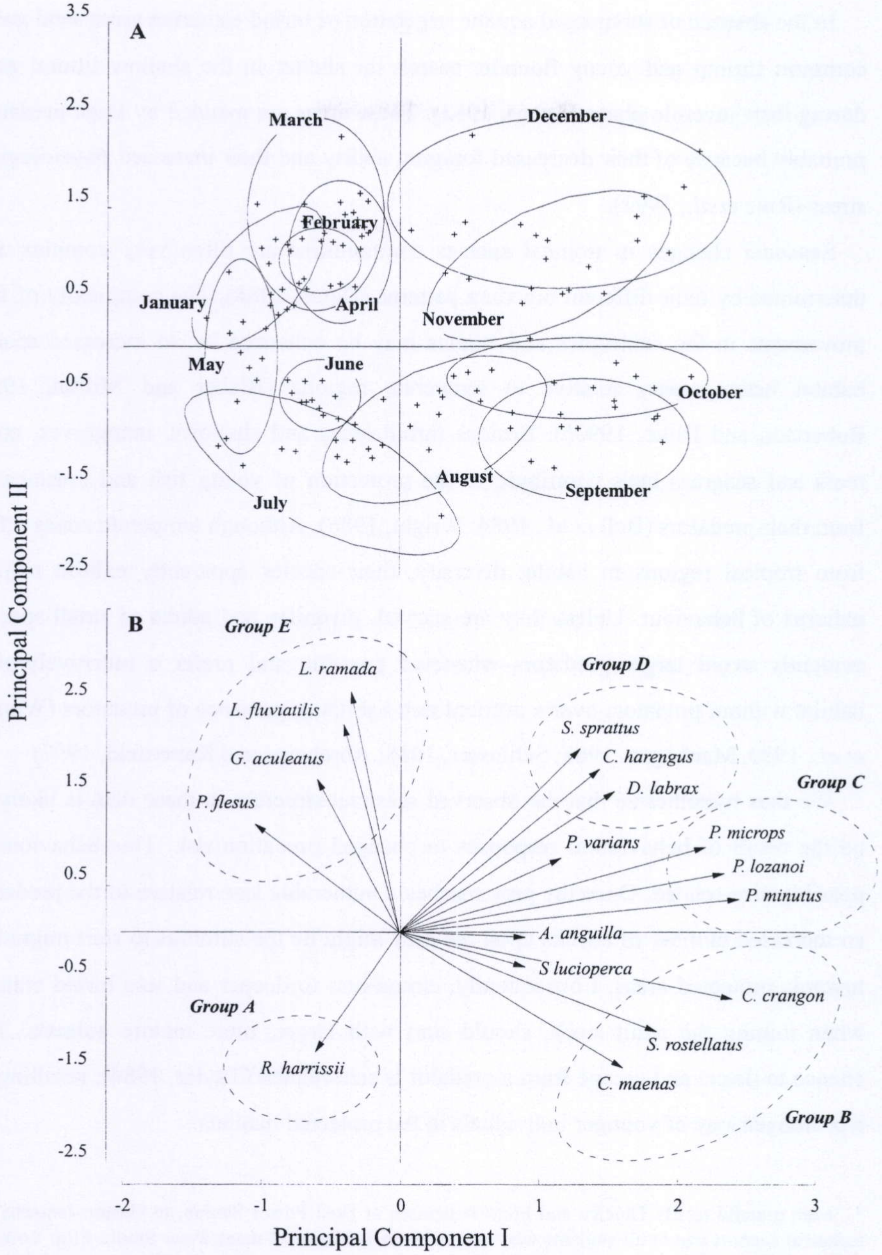

Fig. 5.6. Correlation biplot based on Principal Component Analysis. Position of the sample scores (A) and the species vectors (B) with respect to first two principal components. For a better interpretation of the biplot the sample scores are grouped by month and the species scores are multiplied by three.

In the absence of submerged aquatic vegetation or turbid estuarine areas sand goby, common shrimp and young flounder search for shelter in the shallow littoral zone during their juvenile phase (Evans, 1983). These areas are avoided by large predators probably because of their decreased foraging ability and their increased physiological stress (Ruiz *et al.*, 1993).

Seasonal changes in tropical species communities are often very complex and determined by their different breeding patterns (Davis, 1988). The complexity of fish movements in the subtropics and tropics may be enhanced by an increased spatial habitat heterogeneity relative to temperate regions (Blaber and Milton, 1990, Robertson and Duke, 1990*b*). Besides turbid areas and shallows, mangroves, coral reefs and seagrass beds contribute to the protection of young fish and crustaceans from their predators (Bell *et al.*, 1984, Wright, 1986). Although temperate zones differ from tropical regions in habitat diversity, their species apparently exhibit similar patterns of behaviour. Unless they are starved, juveniles and adults of small species evidently avoid larger predators whenever possible and prefer a nutritively-poor habitat without predators over a nutrient rich habitat in presence of predators (Werner *et al.*, 1983, Manhagen, 1988; Schlosser, 1988; Abrahams and Kattenfeld, 1997)

We thus hypothesize that the observed seasonal structure in these data is likely to be the result of behavioural responses to changed predation risk. This behaviour is possibly size-related. Once the prey reaches a vulnerable size relative to the predator, an increased number of attacks upon the prey might be the stimulus to start migration towards protected areas. Consequently, emigration to deeper and less turbid waters, when joining the adult stock, should start with larger, more mature animals. The chance to detect and escape from a predator is size-related (Taylor, 1984), resulting in a prolonged stay of younger individuals in the protected habitats.

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