Food and feeding activity of glass eel *Anguilla anguilla* (L.) stocked in earthen ponds

by

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ABSTRACT

Two small earthen ponds (surface 0.125 ha) were stocked with glass eel during spring 1989. The stomach content of these eels, sampled at regular intervals during the year, was analysed both qualitatively and quantitatively. The stomach content turned out to be very diverse and season dependent. Variations in the benthos communities in the ponds are reflected in the species composition of the food. Although these young eels are mainly benthivorous, Cladocera can frequently be observed in the stomachs. The daily consumption rate is calculated and on the basis of stomach analyses of eels sampled at 3h intervals a digestion model for a 24h cycle is presented.

INTRODUCTION

The many studies which have been undertaken to assess growth of the European eel under natural conditions have resulted in quite diverse observations and interpretations. Growth potential of eels under natural circumstances (as well as under intensive aquaculture conditions) turns out to be extremely diverse, as growth is influenced by a multitude of ecological factors which interact in many ways (Tesch, 1977).

Simplifying experimental models by e.g. following eel populations of one age group in restricted environments such as earthen ponds gives conclusive results and allows some extrapolations to the natural conditions. However, one has to bear in mind that such habitats, although more or less similar to natural conditions, are clearly different from natural waterbodies. Ponds normally do not permit escapement and migration is impossible. If the ponds are stocked only with glass eel, the absence of prey and predator fish will influence this monospecific fish community.

As in most experimental conditions densities are higher than in nature, these high densities will have their impacts on the fish population such as increased predation by birds, or, more importantly, infection pressure by pathogens (bacteria, fungi, parasites). Finally, due to these higher densities, food availability and intraspecific competition will play predominant roles in this ecosystem.

Previous experiments with glass eel stocked in earthen ponds showed that several factors may influence considerably the growth of the eels (and hence fish production in the ponds). Some of these factors were stocking density, pathology, origin of the glass eel and water quality (Belpaire et al., 1989). However, obviously the most important parameters affecting eel growth in earthen ponds are feeding activity and food availability. Studies on food and feeding activity of glass eel or small eels (<18cm) are scarce. De Nie (1987) studied feeding regimes of eels mainly belonging to size class 20-35cm in the shallow and eutrophic Tjeukemeer (The Netherlands) and compared it with food availability. Forsberg (1986) calculated food selection of elvers (±7cm) held in cages in a small acidified Swedish lake in relation to bottom fauna and zooplankton communities in the surroundings of the cages, while Henning and Zander (1981) studied the food and euryhyaline small-sized fish (including elvers) from a fresh water mud flat near Hamburg.

By analysing the stomach contents and food availability (benthos and plankton communities) in an experiment with two pond population of glass eels at different stocking rates it was possible to estimate the impact of food availability on feeding activity and growth of glass eel.

MATERIALS AND METHODS

Ponds

The two ponds stocked with glass eel are part of the fish culture centre "Volharding" at Rijkevorsel (Antwerp) and are the property of the Department of Nature Conservation and Development (Location on the NGI map 8/5-6: 224.8-175.0). The fish culture is in connection with the canal Dessel-Schoten. Both ponds are similar in shape (width 25m, length 50m, surface 0.125ha), depth (from 0.30m at the inlet side increasing with a gentle slope to 1.40m at the outlet), structure (the bottom consists of sand and mud) and water inflow

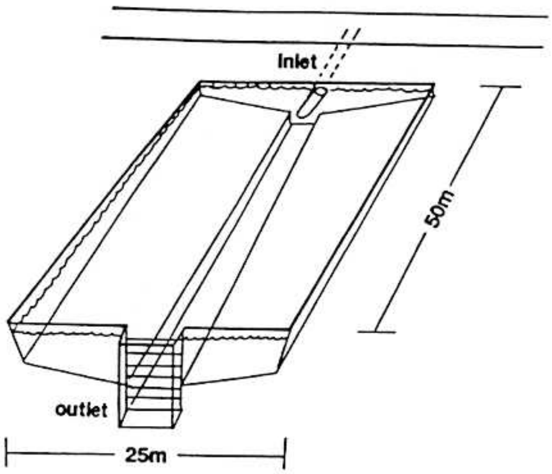

Figure 1: Schematic view of the ponds.

(Figure 1). Both ponds are temporary fish ponds which are kept dry during a part of the year (winter time). They are located in an area where the soil consists mainly of sand (lowland peat), consequently natural productivity of the ponds is rather low. The ponds were flooded with unfiltered water from the canal on 29 March, 1989.

Glass eel

The glass eel stocked in both ponds on 9 May originated from Scotland, and were transported by air to the Netherlands before continuing its route to Belgium by lorry. Before stocking a sample of glass eel was taken to analyse their weight and length. Stocking rates in both ponds were different: 877g glass eel (7.016kg/ha) in pond LD (Low Density) and 3304g glass eel (26.432kg/ha) in pond HD (High Density).

In order to study the feeding regime of the glass eel over the year, a sample of approximately 10 eels per pond was caught at regular time interval during the growing season (approximately every 3 weeks) by wading through the ponds with a dipnet. Both ponds were harvested on 25 October, the eels remained 169 days in the ponds. After weighing and measuring all sampled eels were immediately fixed and preserved in formaldehyde, in order to analyse the stomach content.

Pond HD was sampled intensively during 24 hours in September 5th and 6th to study diurnal feeding patterns. A sample of 10 eels was fished every three hours. By fishing subsequently in different parts of the pond disturbance of the feeding behaviour of the eels was avoided.

Stomach analysis

Preserved eels were dissected and stomach and gut were weighed. The fullness of the stomach was estimated as a percentage of its volume (on a 5% accuracy basis). This was also done for the intestine of the eels sampled during the 24h cycle. The intestine was divided in three parts. The different food items in the stomach were identified and their numbers were counted. For most of the food items dry weight was determined.

Benthos occurrence and water quality

The benthos population was studied by analysing bottom samples taken with a plexiglass benthos corer (diameter = 5.3cm). The core sample was restricted to an upper bottom layer of 5cm. In order to study benthic biomass and changes in species composition (succession) of the benthos population, 336 core samples (2 ponds, 12 samples per pond, 14 sampling dates) were taken over a period of 7 months over both ponds. The first samples were taken directly after flooding the ponds (thus before the stocking with eels). After sieving, bottom samples were stained with bengalic red, fixed by formalin and preserved in alcohol. All organisms were fixed, identified and counted. On each sampling date the water quality was analysed. Table 1 gives an overview of the extreme values measured in both ponds. All water parameters were normal with the exception of a high ammonium level (5.14 mg/l) recorded on 13 September, which was probably caused by intensive wading activity during the 24h sampling.

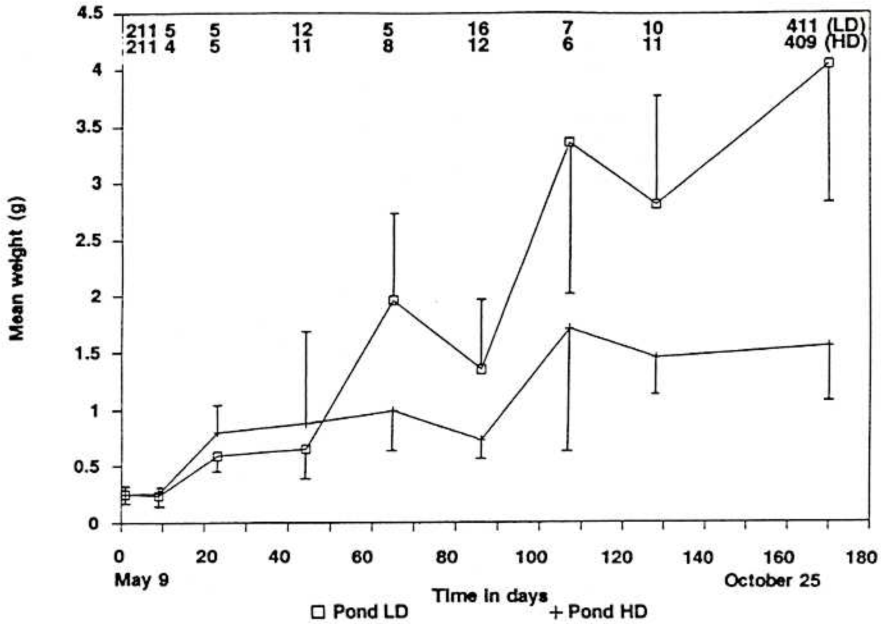

Figure 2: Growth curves of the LD (low density) and HD (high density) populations, vertical bars indicate s.d. On top: sample size.

RESULTS

EEL GROWTH

Although on most sampling dates sample size was limited (with the exception of samples taken at stocking and harvest time) some conclusions can be drawn concerning growth of elvers in fish ponds.

The growth curves of both eel populations are illustrated in Figure 2. The glass eel grew from 0.23 ± 0.04g (7.0cm) to 4.05 ± 1.20g (14.7cm) in pond LD and to 1.55 ± 0.45g (10.9cm) in pond HD during approximately 5½ months. Taking into account the low productivity of the ponds and the mean length increments of the glass eel populations during this rather short period (7.7cm for pond LD and 3.9cm for pond HD) it is obvious that eel growth potential is considerable in such ponds. Once more it is evident that the stocking density has a clear and significant effect on eel growth. From day 65 on the mean weight of the sampled eels of pond LD was significantly higher than the mean weight of the eels in the HD pond. This density dependent growth is even more striking when comparing the length frequency distributions of both populations at harvest time (Figure 3). Length-weight relationships at harvest time for the two populations are represented in Figure 4. The corresponding parameters are given in Table 2. When comparing the length-weight relationships between eels of both ponds belonging to the same length class (9.4-14.2cm) b-value was significantly higher ($P < 0.001$) for the LD population (LD: $b = 3.475$, $N = 152$, $R^2 = 0.92$; HD: $b = 3.043$, $N = 390$, $R^2 = 0.88$).

BENTHOS COMMUNITY IN THE PONDS

Species diversity

The analysis of the 336 core samples resulted in the identification of a large variety of species. In total at least 43 different species could be recognised, belonging to 21 orders and 32 families. A list of species (groups) occurring in the ponds is presented in Table 3.

Abundance and succession of the benthos species in function of time

Organisms occurring in these temporary ponds must be able to survive in a dormant stage in the pond bottom during the dry period, or are colonising the pond with the inflowing channel water. Some are able to move in or out of the water (e.g. some adult aquatic insects).

By counting all the different organisms in the samples it is possible to analyse abundance and distribution in time of the species. By comparing the frequency distributions of the benthic species, it is quite clear that succession is the main characteristic of this benthos pond community. Data are shown in a kite diagram in

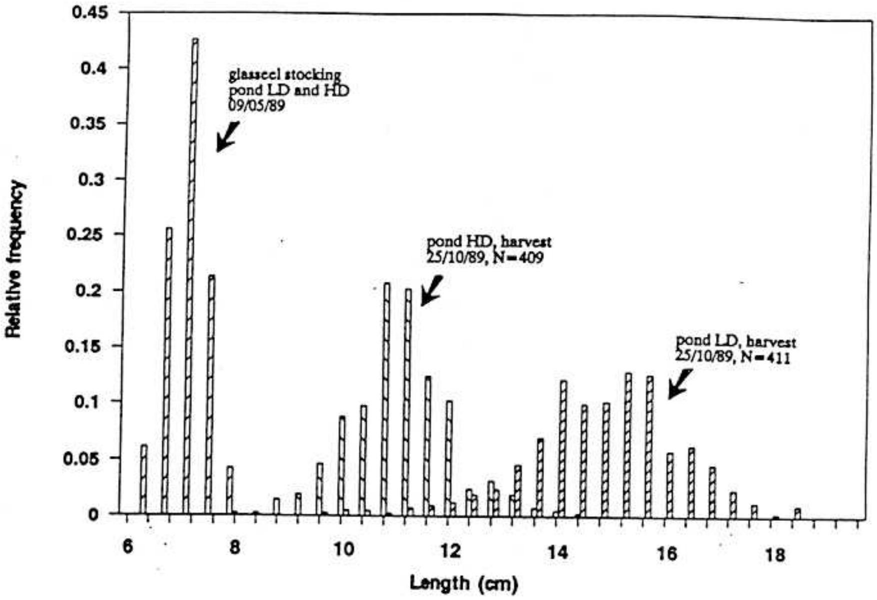

Figure 3: Length frequency of the glass eels at stocking time (9 May) and of the LD and HD population at harvest time (25 October).

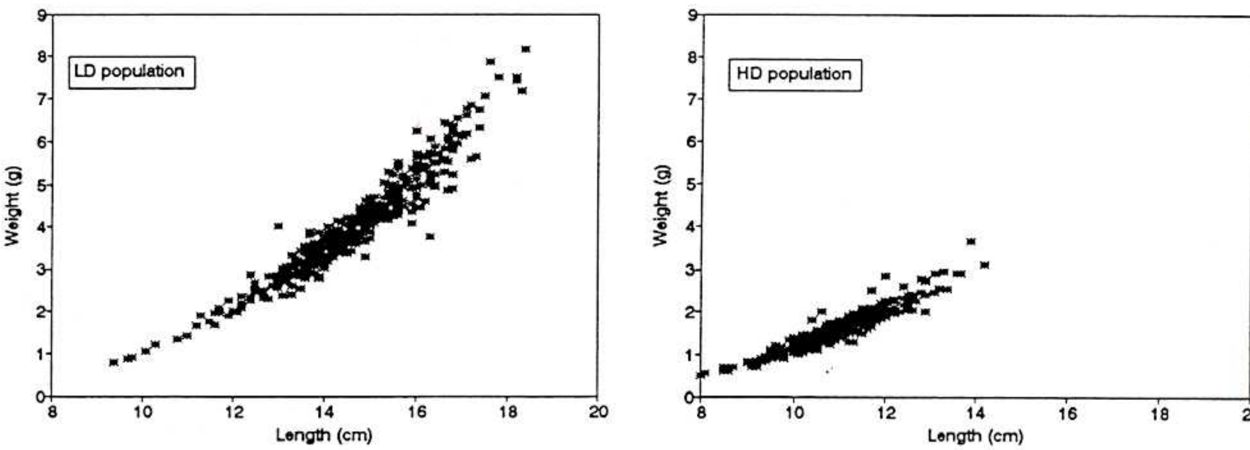

Figure 4: Length-weight relationship from a sample of eels of the LD and HD population at harvest time (25 October).

Figure 5. Worm-like species, Lumbriculidae/Dorydrilidae and nematodes were found in large numbers directly after filling the pond, followed up, later in the season, by Aelosomatidae and Tubificidae. Also among the chironomid species, succession is obvious. The Tanytarsini, which were the most abundant chironomids (reaching densities up to 20,000 individuals per square meter), colonise the ponds very rapidly and are followed up by a peak of Chironomini before going up again into another peak. After that, Tanypodinae increase and reach maximum numbers in mid summer. This is the time Ceratopogonidae increased to attain large densities in the late summer. Also zooplanktonic Crustacea, which also were represented in the benthos samples, showed succession patterns: copepods were frequent in the beginning of the season, while the daphnid species have their maximum in late summer and autumn. Nymphs of Ephemeroptera (*Centroptilum* and *Caenis*) were found especially in the late season. Although they didn't reach high numbers, their biomass was quite important, due to their larger size.

Effects of predation

As we were particularly interested to know if it was possible to observe the effects of eel predation on the benthos populations, a hypothesis test was carried out comparing the paired means of species density per sampling date. The results are represented in Table 4.

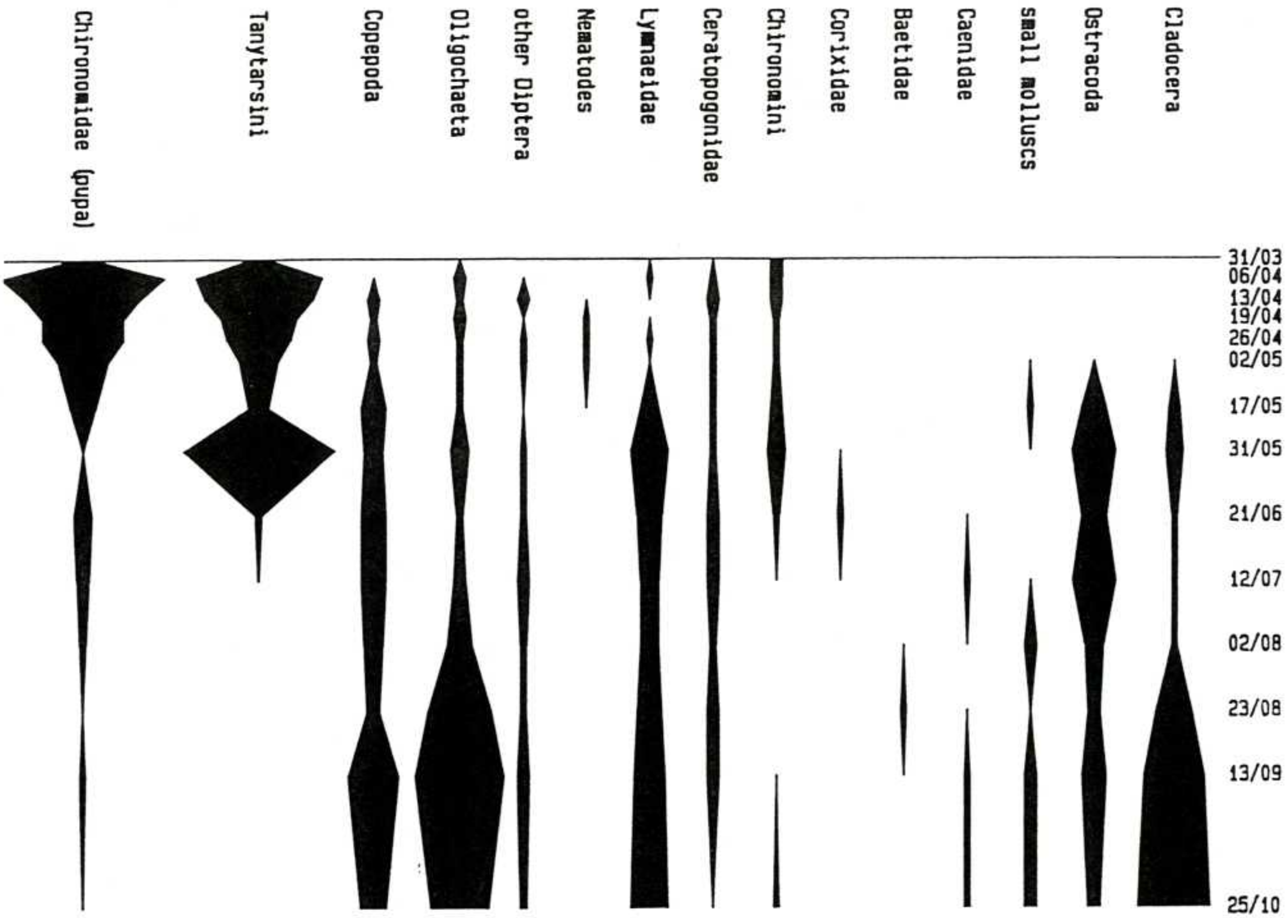

Figure 5: Kite diagram representing the densities of the most common benthic species over the year in pond LD.

Five species or species groups were found to be significantly different between the two ponds for the whole period after stocking. The densities of Cladocera, Ostracoda, Nematoda and two *Lymnaea* species were significantly higher in pond LD than in pond HD. Furthermore, during some periods of the year also other species groups such as Tanytarsini, Tanypodinae, Caenidae, Ceratopogonidae and most of the other molluscs were found to be more common in the LD pond.

FEEDING ACTIVITY OF THE ELVERS

Diversity of prey organisms

The stomach content of 155 eels sampled at regular time intervals between May and October 1989 (94 eels with non-empty stomachs) and during the 24h cycle on 5 and 6 September (61 eels with non-empty stomachs) was quite diverse: the identified benthic and zooplanktonic prey organisms in the stomachs are indicated underlined in Table 3. In addition, sometimes detritus which could not be identified, vegetable material and undetermined eggs were present.

Relative quantitative importance of the preys

A wide variety of organisms in the ponds is shown to be potential prey for the eels. However all species groups are not taken to the same extent and the relative quantitative importance (in dry weight) of the various prey organisms may differ considerably as shown in Figure 6, calculated on 61 stomachs collected on 5 and 6 September (length of these eels was 10.1 ± 0.8cm). During this period Cladocera and Ceratopogonidae were quantitatively the most important preys (together constituting in dry weight 68% of the food). Elvers in this length class (8.6-13.2cm) are shown thus not only to be benthivorous, but also planktivorous. Baetidae, Dytiscidae, Chironomidae, Caenidae, Oligochaetae, Trichoptera, Sphaeridae and Odonata are less common.

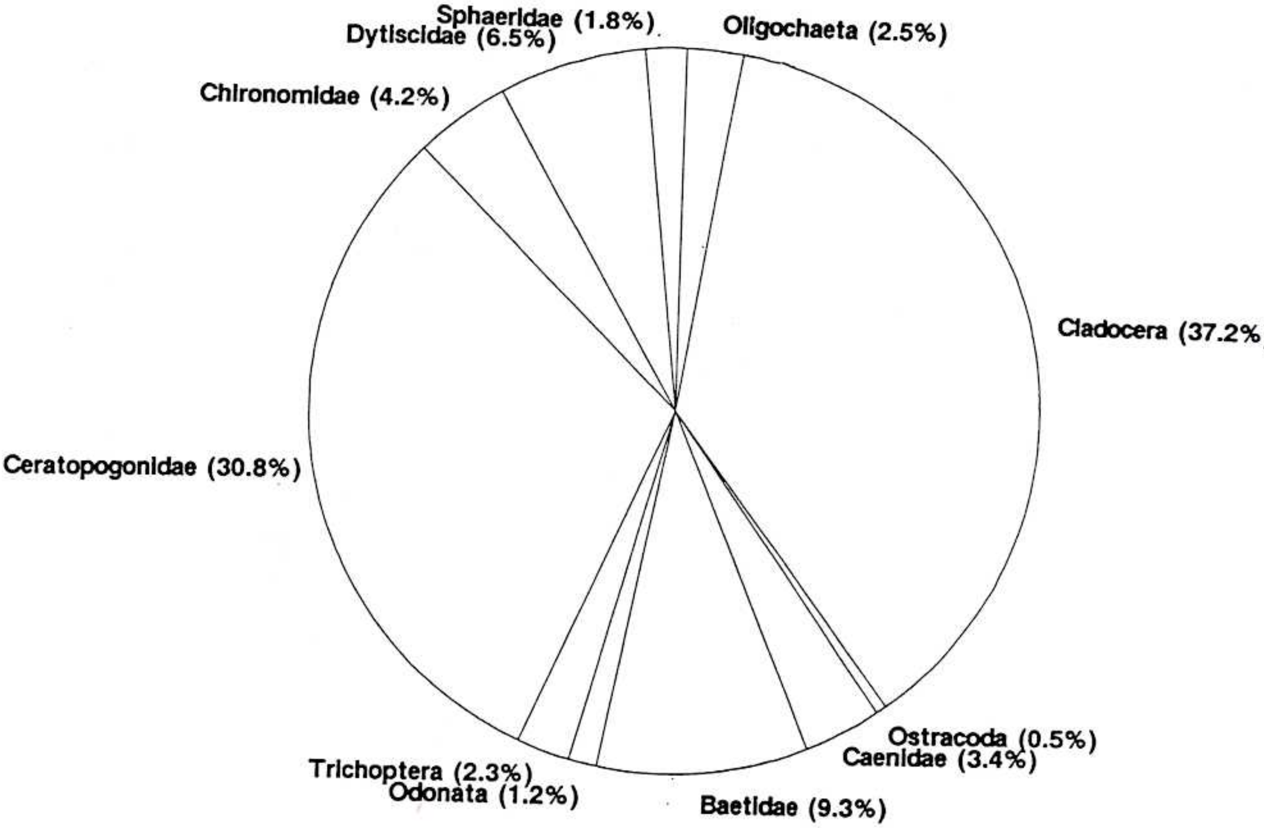

Figure 6: Relative quantitative importance (based on dry weights) of the various food items of eels sampled on 5 and 6 September in the HD pond.

Seasonal changes in feeding regime

Table 3 showed that the elvers predate on a wide variety of prey organisms. Obviously, the succession in the benthic community will influence thoroughly the feeding regime of the eels. By using the frequency of occurrence method (Hynes, 1950 and Windell, 1968) for the various organisms throughout the year it became evident that the food changed through the season. The results are represented in a kite diagram in Figure 7. In May, eels were mainly predating on Cladocera and Chironomids and to a lesser extent on Oligochaeta. The intake of Oligochaeta ceased during June but Ceratopogonidae became more important. Later, in July Caenidae (Ephemeroptera) appeared in the diet while Cladocera and Ceratopogonidae still had high occurrence frequencies. Chironomids became less important. From July on, Odonata were found in the stomachs and at the end of the season Sphaeridae were also present in the diet.

Food selection

The numbers of different food items in the stomachs which were at least 25% full (97 stomachs) were counted and their frequencies are presented in Figure 8. In 16% of these stomachs only one food item was present and in 54% of the cases 2 or 3 different food components were found. As the diversity of available food is quite important, and 70% of the fish had 3 or less different food items in their stomachs it may be concluded that even if the elvers may predate on a whole variety of prey organisms they usually predate in a more or less selective way.

It was obvious that some eels specialised in certain predation techniques. This was evident while analysing the stomachs sampled on 5 and 6 September. Figure 9 represents the frequencies of the proportion of the stomach content (expressed as weight percentages) filled with Cladocera. A proportion of eels (13%) fed mostly exclusively on Cladocera (90 to 100% of the dry weight of stomach contents). This illustrates the very selective feeding activity of these fishes, which requires an adapted predation strategy.

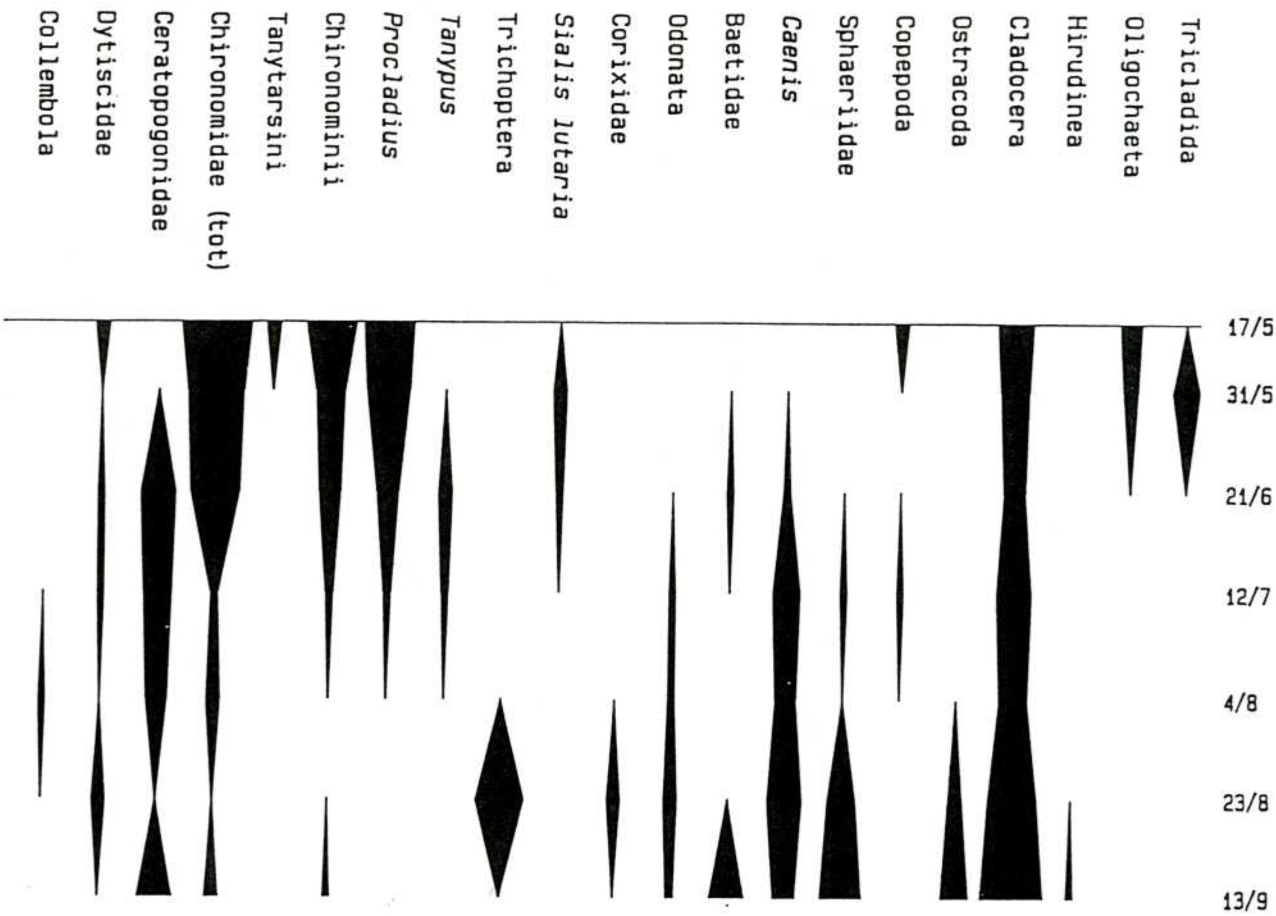

Figure 7: Changes in the frequency of occurrence (in % of food-containing stomachs) of the various food items throughout the year.

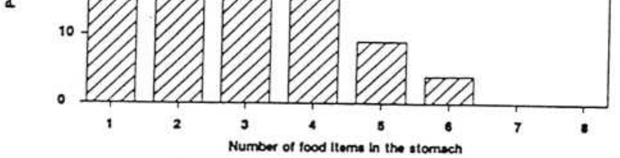

Figure 8: Frequency of occurence of the number of different food items in the stomach which were more than 25% filled.

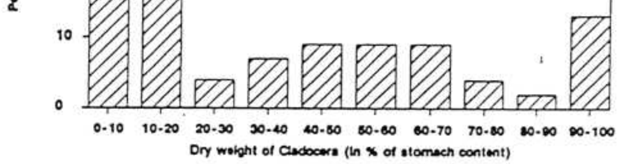

Figure 9: Feeding preference of some eels for Cladocera (stomach with degree of fullness >25%) on 5 and 6 September in the HD pond.

Daily feeding rhythmics

The daily feeding activity of the eels in the ponds was studied by analysing the stomachs of eels sampled on a 24h cycle in September. A total of 81 fish were sampled during 9 3h intervals. The mean relative wet weight of the stomach content (in percentage of the wet body weight of the fish) is expressed according to the time of the day in Figure 10. The stomach content (and consequently) the feeding activity was minimal in the afternoon and increased gradually at night. Eel feeding activity in the ponds was essentially nocturnal.

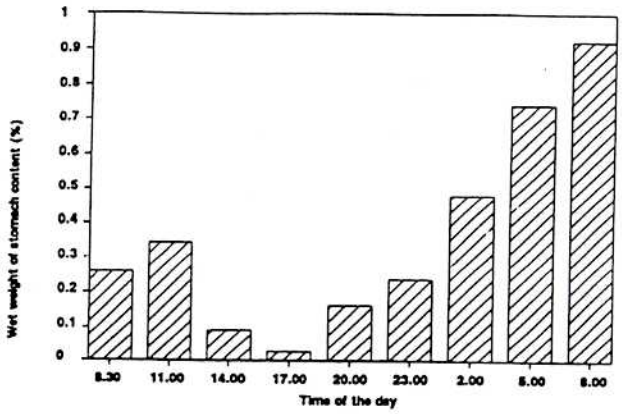

Figure 10: Wet weight of the stomach contents as percentage of the wet body weight of the fish according to time of day on 5 and 6 September in the HD pond.

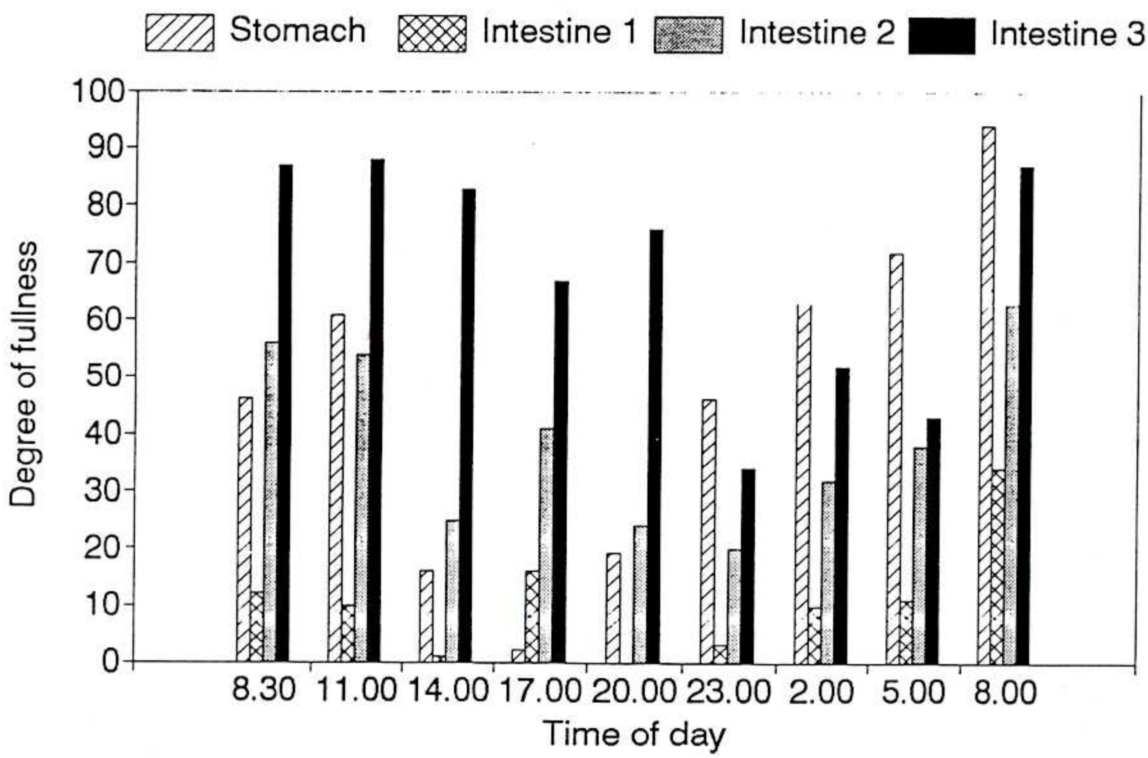

Figure 11: Mean degree of fullness of the stomach and the three parts of the intestine during the 24h cycle (pond HD, September 5 and 6).

Digestion

The intestine was divided into three equal parts of which the degree of fullness was estimated. Every 3 hours mean degree of fullness was calculated for the stomach and the different parts of the intestine. Results are shown in Figure 11.

In order to describe the course of the food within the digestive tract these data were subjected to an analysis of cosinor (Halberg et al., 1970). Table 5 gives the description of the function for the degree of fullness for the various parts of the digestive tract according to time of day.

As can be seen in Figure 12, the maximal degree of fullness of the various parts of the digestive tract shifts from 5-6 hours (stomach) to 8-9 hours (intestine part 1) to 9-10 hours (intestine part 2) and finally to 13-14 hours for the third part of the intestine. By comparing the time of maximal degree of fullness of stomach

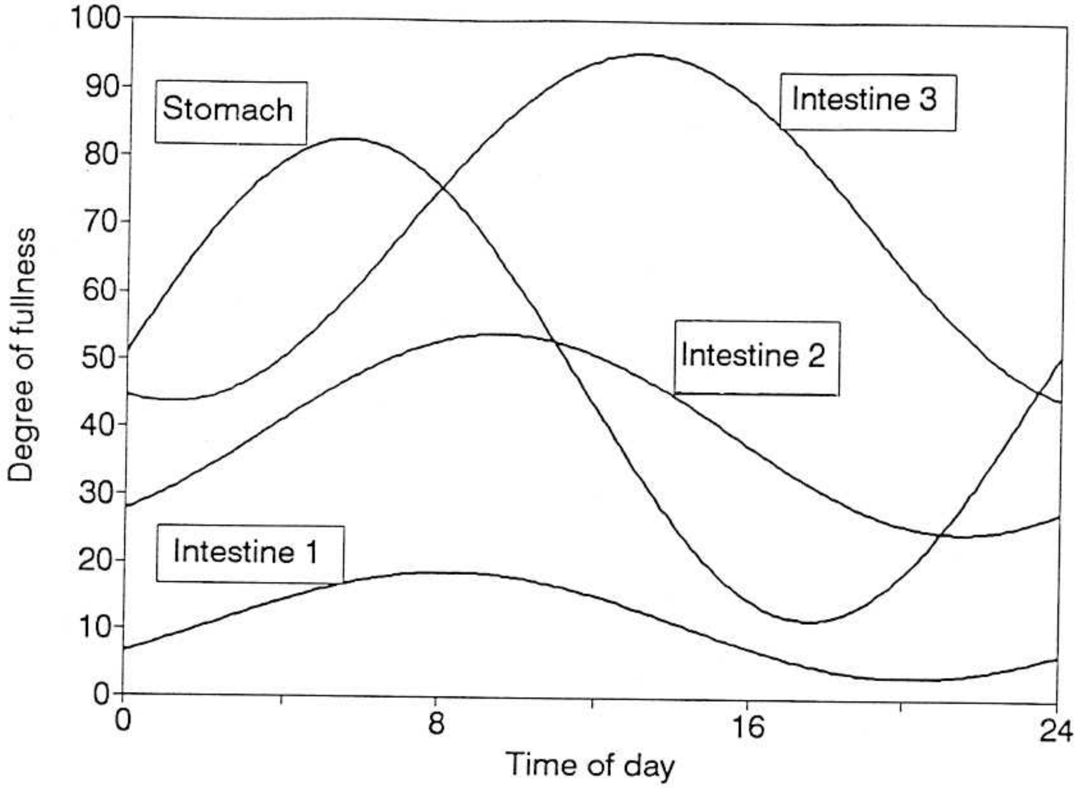

Figure 12: Most probably functions describing the fluctuations of the degree of fullness over a 24h period for the various parts of the digestive tract.

and the first part of the intestine an approximate digestion rate of 3-4 hours can be deduced (water temperature in this 24h cycle was fluctuating between 15.5°C at night and 19.5°C during the day).

The large amplitude (35.3%) of the stomach fullness function illustrates that the fullness of the stomach can vary considerably, part 1 and 2 of the digestive tract however, have only small amplitudes and small mean fullness degrees: the food is shifting gradually and in small quantities towards the end of the intestine, where it can accumulate (25.9% amplitude and 69.4% mean fullness degree for part 3 of the intestine).

Daily consumption rate

The daily consumption rate of the eels was estimated using the equation following Neveu, 1981

$$C = 24.S.R$$

S being the mean value of the stomach content over a day (in mg dry weight per g eel). R being the stomachal evacuation value

$$R = \frac{\log Y_2 - \log Y_1}{t_2 - t_1}$$

(Y_1 = dry weight at time t_1 and Y_2 = dry weight at time t_2)

For the 24h cycle of 5 and 6 September (pond HD) a daily consumption rate of 4.38mg dry weight per g eel was calculated (S = 1.69mg dry weight per g body weight).

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Table 1: Extreme values of water quality parameters in both ponds.

	Pond LD	Pond HD
T (°C)	5.1-26.4	5.8-25.7
pH	7.37-9.70	6.68-9.80
O_2 (mg/l)	8.5-16.9	4.1-19.0
Conductivity (μS/cm)	188-418	186-387
NH_4^+ (mg/l)	0.17-0.80	0.14-5.14
NO_2^- (mg/l)	0.08-0.27	0.08-0.21
NO_3^- (mg/l)	16.7-93.0	12.4-97.0
SO_4^{2-} (mg/l)	27.2-72.2	22.0-74.3
PO_4^{3-} (mg/l)	0.10-1.57	0.08-1.14

Table 2: Length-weight relationship (log W = log a + b log L) of the elver populations of the LD and HD pond at harvest time (25th October 1989).

Pond	Min Length (cm)	Max Length (cm)	N	Log a	b	R^2
LD	9.4	18.4	411	−3.066	3.138	0.95
HD	8.0	14.2	409	−3.116	3.174	0.91

Table 3: List of species or species groups recognised in the benthos samples. Species or species groups which are underlined were found to be present in eel stomachs.

PHYLUM	CLASS	ORDER	FAMILY	SPECIES
Arthropoda	Crustacea	Copepoda		
		Cladocera	Daphniidae	
		Ostracoda		
	Insecta	Diptera	Chironomidae	
			subfam. Chironominae	
			tribus Chironomini	*Chironomus*
				Polypedilum
			tribus Tanytarsini	
			subfam. Tanypodinae	*Procladius*
				Tanypus
			subfam. Podonominae	
			subfam. Orthocladiinae	
			Ceratopogonidae	
			Chironomidae (pupa)	
			Cecidomyiidae	
			Simuliidae	
			Culicidae	
			Chloropidae	
			Dixidae (pupa)	
		Ephemeroptera	Baetidae	*Centroptilum luteolum*
			Caenidae	*Caenis horaria*
				Caenis robusta
		Trichoptera	Philopotamidae	
			Sericotamidae	*Brachycentrus*
		Hemiptera	Corixidae	*Corixa punctata*
		Coleoptera	Dytiscidae	*Dytiscus*
				Bidessus
				Hyphydrus ovatus
		Homoptera	Aphididae	
		Odonata	Gomphidae	*Gomphus*
		Collembola	Poduridae	*Sminthurides*?
		Megaloptera	Sialidae	*Sialis lutaria*
		Hymenoptera	Cephidae	
	Arachnida	Acari	Hydrachnellae (Hydracarina)	*Piona*
		Araneae		
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	*Lymnaea peregra*
				Lymnaea ovata
				Lymnaea auricularia
				Lymnaea catascopium
				Myxas glutinosa
			Physidae	*Physa fontinalis*
		Mesogastropoda	Valvatidae	*Valvata macrostoma*
				Valvata cristata
		Stylommatophora	Succineidae	*Succinea putris*
	Bivalvia		Sphaeriidae	
Annelida	Oligochaeta		Aeolosomatidae	
			Tubificidae	
			Lumbriculidae +Dorydrilidae	
	Hirudinae	Rhynchobdellae	Glossiphonidae	*Glossiphonia*
Nematoda				

Table 4: Probability values from hypothesis tests (SAS-statistics) comparing the means of the benthos densities (12 samples per pond) per sampling date between the benthos species densities of pond LD and HD. Probability values <0.05 (*) indicate a significant difference between the species densities of the two ponds over the whole period (May-October 1989).

Copepoda	0.1869	*Lymnaea peregra*	0.0013*
Cladocera	0.0183*	*Lymnaea ovata*	0.0077*
Ostracoda	0.0311*	Ceratopogonidae	0.1898
Tanytarsini	0.1780	Aeolosomatidae	0.1284
Chironomini	0.1339	Tubificidae	0.4367
Tanypodinae	0.2016	Lumbriculidae + Dorydrilidae	0.0725
Podonominae	0.2244	Nematodes	0.0325*
Orthocladiinae	0.1753		

Table 5: Mathematical description of the degree of fullness of the parts of the digestive tract according to time (in hour) of the day (DF = degree of fullness, ST = stomach, I1 = intestine part 1, etc. . .).

$$DF_{ST} = 47.029 + 35.349 \cos [0.262(t - 5,565)]$$

$$DF_{I1} = 10.870 + 7.712 \cos [0.262(t - 8.224)]$$

$$DF_{I2} = 39.275 + 14.563 \cos [0.262(t - 9.489)]$$

$$DF_{I3} = 69.420 + 25.887 \cos [0.262(t - 13.118)]$$