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

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ABSTRACT

Two small earthen ponds (surface 0.125 ha) were stocked with glasseel during spring 1989. The stomach content of those 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 into the species composition of the food. Although those 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 multiple studies which were undertaken trying to assess growth of the European eel under natural conditions resulted in quite diverse observations and interpretations. Growth potential of eels under natural circumstances (as well as under intensive aquaculture conditions) turned out to be extremely diverse.
These growth variations are the result of environmental influences, caused by a multitude of ecological factors. Field surveys on eel populations in natural waterbodies attempting to evaluate these factors and their impact on growth, condition, etc... of the eel population are hard to perform as these factors are so multiple and are interacting in so many ways.
Furthermore some of these factors may be unknown or are difficult to study and can not be brought into account while analysing the data.
Due to their complexe multivariate character, these surveys need a thorough statistical analysis of the data in order to give conclusive interpretations. It may therefore be more appropriate to study eel populations in more "controllable" environments with less

interacting factors.

Simplifying experimental models by e.g. following eel populations of one age group in restricted environments such as earthen ponds possibly give conclusive results and certainly allow some extrapolations to the natural conditions. However one has to bear in mind that such habitats, although more or less similar to natural conditions, represent a series of clear differences with natural waterbodies. Ponds normally do not permit escapement and migration is impossible. If the ponds are stocked only with glasseel, 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 e.g. increased predation by birds, or more important 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.
Former experiments with glasseel 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 glasseel 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.

MATERIAL AND METHODS

Ponds

The two ponds stocked with glasseel are part of the fish culture centre "Volharding" at Rijkevorsel (Antwerpen) and are 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). 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 is mainly consisting of sand (lowland peat), consequently natural productivity of the ponds is rather low. The ponds were flooded on the 29th of March, 1989.

Glasseel

The glasseel stocked in both ponds on the 9th of May was originating from Scotland, and was transported by air to the Netherlands before continuing its route to Belgium by lorry. Before stocking a sample of glasseel was taken to analyse their weight and length. Stocking rate in both ponds was different : 877g glasseel (7.016kg/ha) in pond LD (Low Density) and 3304g glasseel (26.432kg/ha) in pond HD (High Density).
In order to study the feeding regime of the glasseel over the year, a sample of eels were 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 October 25th, the eels remained 169 days in the ponds. After weighing and measuring all sampled eels were immediately fixated and preserved, 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 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 core (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 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, fixated by formalin and preserved in alcohol. All organisms were identified and counted. At each sampling date the water quality was analysed. Table 1 gives an overview of the extreme values measured in both ponds.

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

RESULTS

Eel growth

Although at 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 is illustrated in Figure 2.

The glaseel 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 5 ½ months. Taking into account the low productivity of the ponds and the mean length increments of the glasseel 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 were 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 relationship at harvest time for the two populations are represented in Figure 4. The corresponding parameters are given in Table 2.

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	0.94
HD	8.0	14.2	409	-3.116	3.174	0.91

Benthos community in the ponds

Species diversity

The analysis of the 336 core samples (2 ponds, 12 samples per pond, 14 sampling dates) resulted in the identification of a whole variety of species. In total at least 43 different species could be recognized, belonging to 21 orders and 32 families. A list of species (groups) occuring 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 tot survive in a dormant stage in the pond bottom during the dry period, or are colonizing 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 mean characteristic of this benthos pond community.

For 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), are colonizing the ponds very rapidly and are followed up by a peak of Chironomini before going up again into another peak. After that, Tanypodinae are increasing and reach maximum numbers in mid summer. This is the time Ceratopogonidae increase to attain large densities in the late summer. Also the zooplanctonic Crustacea, which also were represented in the benthos samples, showed succession patterns : copepods were frequent in the beginning of the season, while the

Table 3 : List of species or species groups recognized in the benthos samples. Underlined species (groups) were also 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*
Nematodes				

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.

Attempting to visualise these succession patterns, the data were represented in a kite diagram (Figure 5).

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.

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

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

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 significant 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. These results clearly demonstrate the predation role of the fish on the benthos populations.

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) and during the 24h cycle in September 5^{th} and 6^{th} (61 eels with non-empty stomach) was quite diverse : the identified benthic and zooplanctonic prey organisms are presented in Table 3. In addition, sometimes detritus which could not be identified, vegetable material and undetermined eggs were present in the eel stomach. Some organisms may not be found in the stomach due to their high digestability (e.g. nematodes).

Relative quantitative importance of the preys

A whole variety of organisms in the ponds are shown to be potential preys for the eels. However all species groups are not taken in the same measure and the relative quantitative importance (in dry weight) of the various prey organisms may differ considerably as shown in Figure 6, calculated on 61 non-empty eel stomachs collected on the 5^{th} and 6^{th} September (length of these eels was 10.1 ± 0.8cm).

For this period Cladocera and Ceratopogonidae turn out to be quantitatively the most important preys (together constituting in dry weight 68% of the food).

Elvers in this length class (8.6-13.2cm) show thus not only to be benthivorous, but also planctivorous.

Baetidae, Dytiscidae, Chironomidae, Caenidae, Oligochaetae, Trichoptera, Sphaeridae and Odonata are less common.

Seasonal changes in feeding regime

Table 3 showed that the elvers are predating on a whole 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 on 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. However not so selective as (larger) eels in a natural environment (Lake Constance) as demonstrated by BERG (1988) where in 64% of the stomachs (fullness >25%) only one food item was found.

In some cases it was obvious that some eels specialised themselves to certain predation techniques. This was evident while analysing the stomach content of the eels (with fullness of stomach >25%) sampled on 5th and 6th September.
Figure 9 represents the frequencies of the proportion of the stomach content (expressed as weight percentages) filled with Cladocera. It is remarkable that a proportion of eels (13%) fed mostly exclusively on Cladocera (90 to 100% of the dry weight of their stomachs were Cladocera). This illustrates the very selective feeding activity of these fishes, which requires an adapted predation strategy.

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 studied 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 in function of the time of the day (Figure 10). The stomach content (and consequently) the feeding activity is minimal in the afternoon and is increasing gradually at night. Eels feeding activity in the ponds is essentially nocturnal.

Digestion

The intestine was divided into three equal parts of which the degree of fullness was estimated. For each time of the day (per 3h) mean degree of fullness was calculated for the stomach and the different parts of the intestine, and was expressed in function of time (Figure 11).

In order to describe the course of the food within the digestive tract these data were subjected to an analysis of cosinor. Table 5 gives the description of the function for the degree of fullness for the various parts of the digestive tract in function of the time of the day.

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

$$DF_{ST} = 47.029 + 35.349 \cos [0.262(t - 5.565)]$$
$$DF_{I1} = 10.870 + 7.712 \cos [0.262(t - 8.224)]$$
$$DF_{I2} = 39.275 + 14.563 \cos [0.262(t - 9.489)]$$
$$DF_{I3} = 69.420 + 25.887 \cos [0.262(t - 13.118)]$$

As can be seen on 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 and the first part of the intestine an approximate digestion rate of 3-4 hours can be supposed (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 stomacal 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 September 5^{th} en 6^{th} (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).

LITERATURE

BELPAIRE, C., VAN VLASSELAER, L., PODOOR, N. and OLLEVIER, F. (1989). Glasaalopkweek in vijvers. Studierapport, Leuven, Zoölogisch Instituut, 104p.

BERG, R. (1988). Der Aal im Bodensee, Freilanduntersuchungen zur Biologie und Bewirtschaftung des Aals (*Anguilla anguilla L.*) im Bodensee. ökologie & Landwirtschaft, 246p.

HYNES, H.B.N. (1950). The food of fresh-watersticklebacks (*Gasterosteus aculeatus* and *Pygosteus pungitius*), with a review of methods used in studies of the food of fishes. J.Anim.Ecol., 19(1), 36-58.

NEVEU, A. (1981). Variations saisonnières et journalières de l'alimentation de l'Anguille (*Anguilla anguilla* L.) dans des conditions naturelles. Ecol.applic., 2(2), 99-116.

WINDELL, J.T. (1968). Food analysis and rate of digestion. In : Ricker W.E. (ed.) Methods for assessment of fish production in fresh-water. Oxford, Scientific publications, 197-205.

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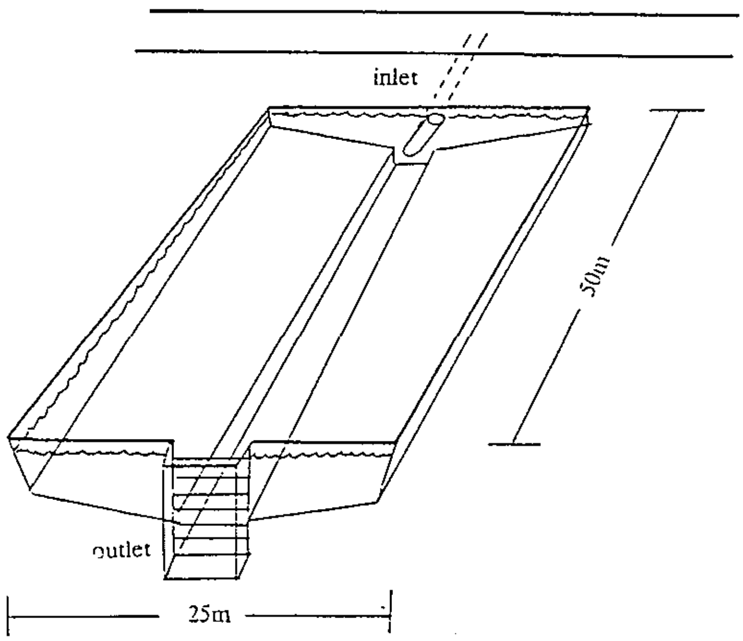

Figure 1 : Schematic view of the ponds.

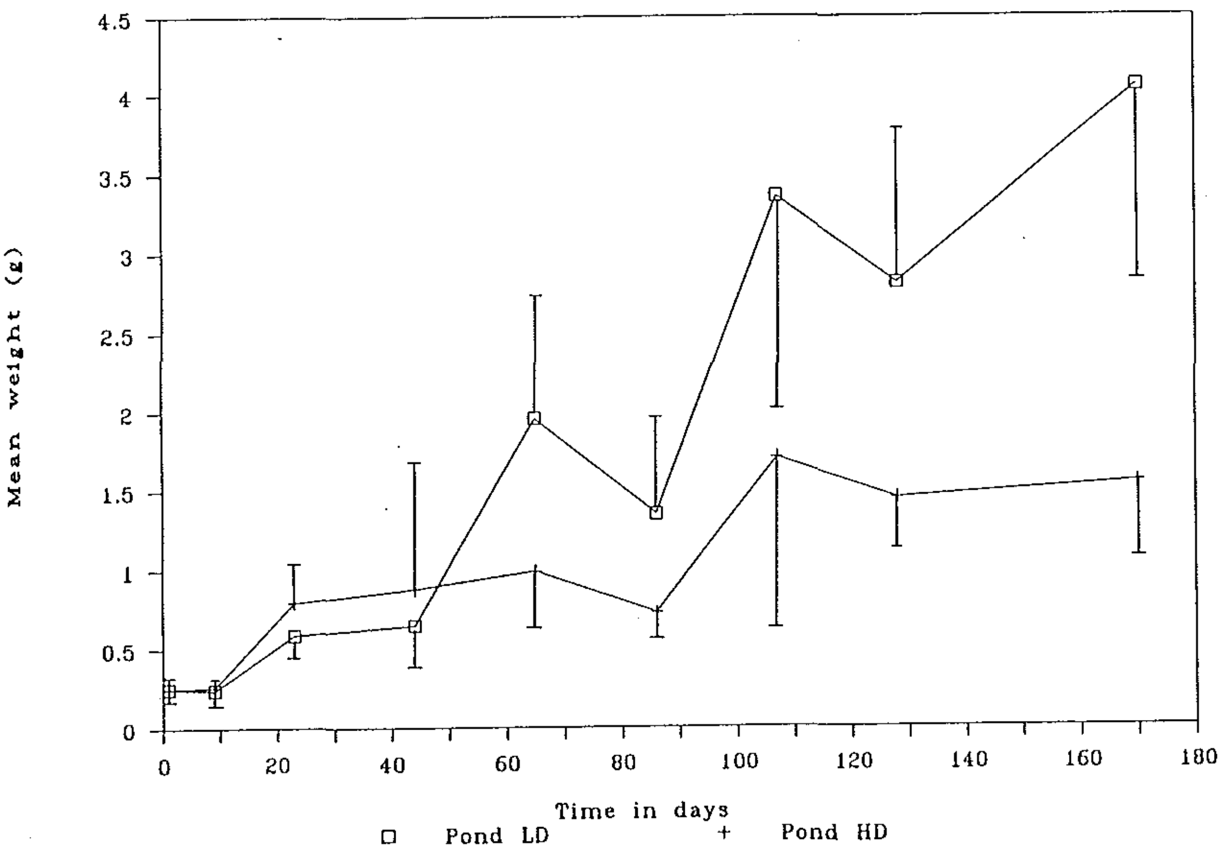

Figure 2 : Growth curves of the LD (low density) and HD (high density) population in function of the time of the year (from May 9th to October 25th).

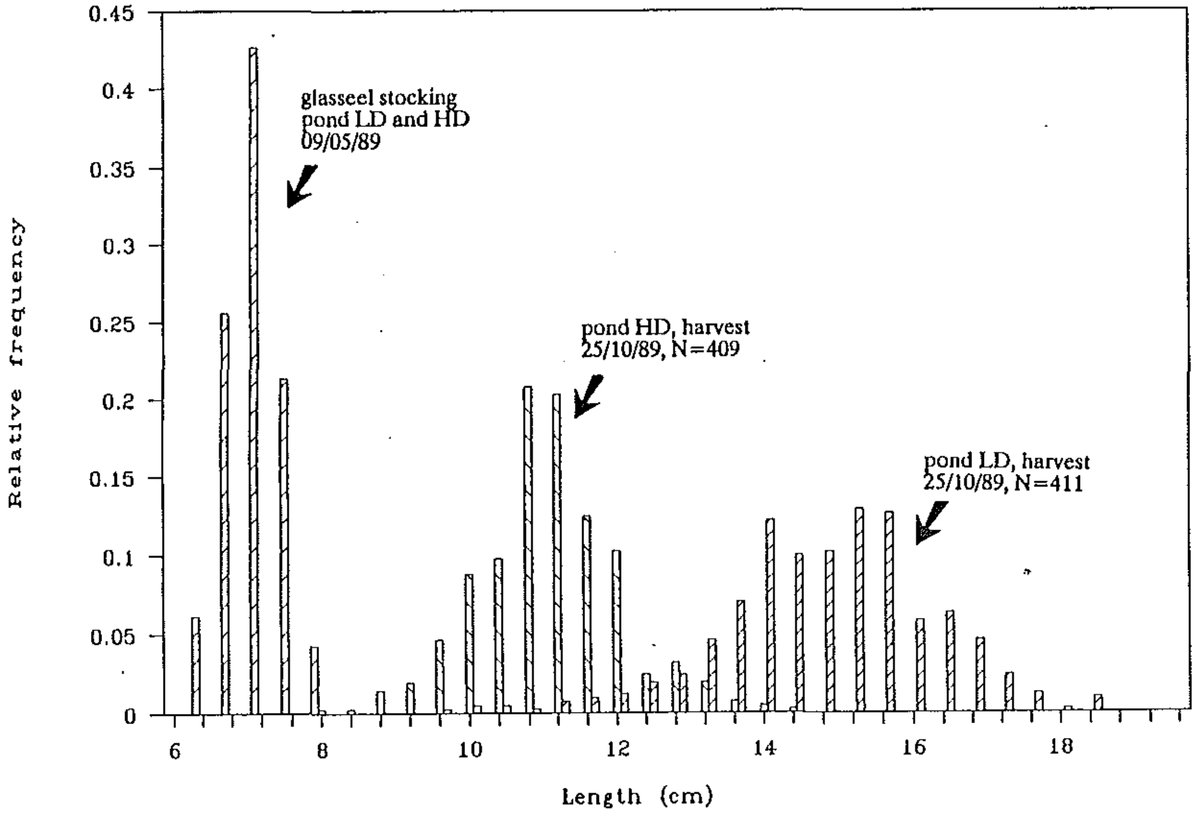

Figure 3 : Length frequency distribution of the glasseel at stocking time (May 9th) and of the LD and HD population at harvest time (October 25th).

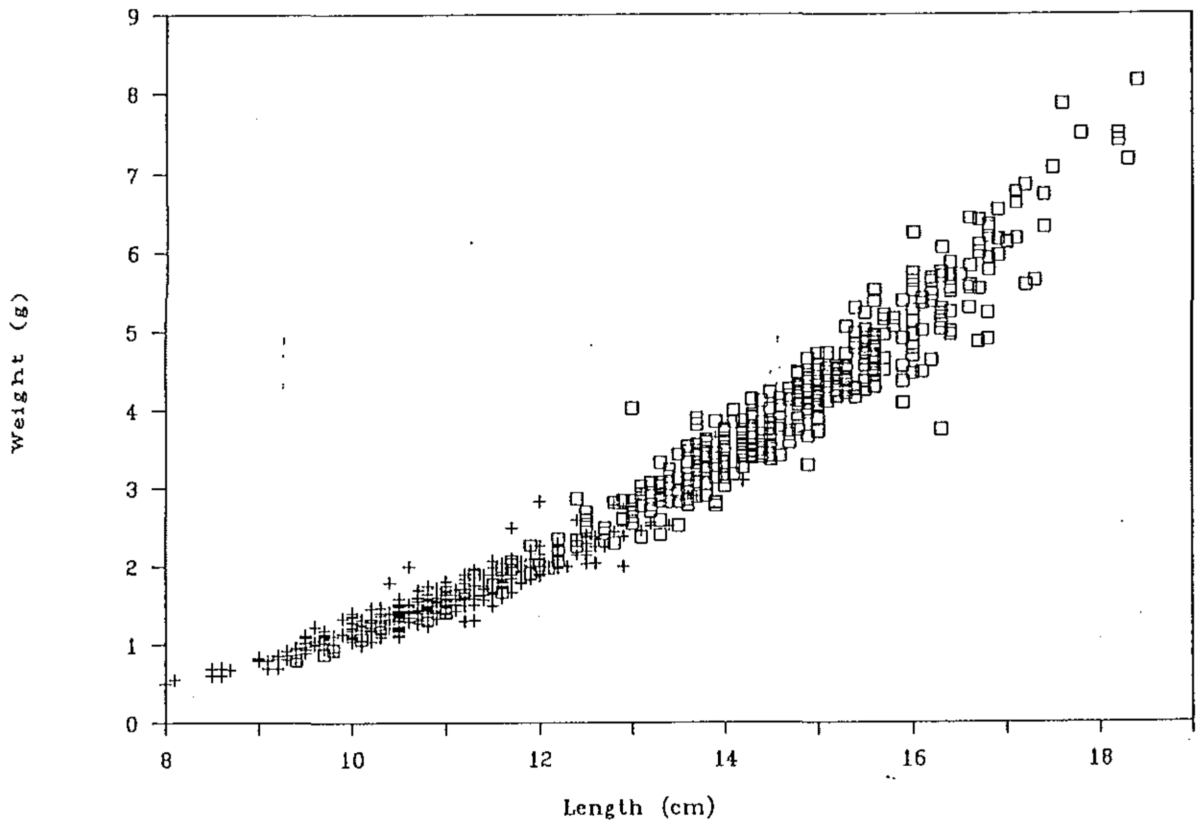

Figure 4 : Length-weight relationship of a sample of eels of the LD and HD population at harvest time (October 25th).

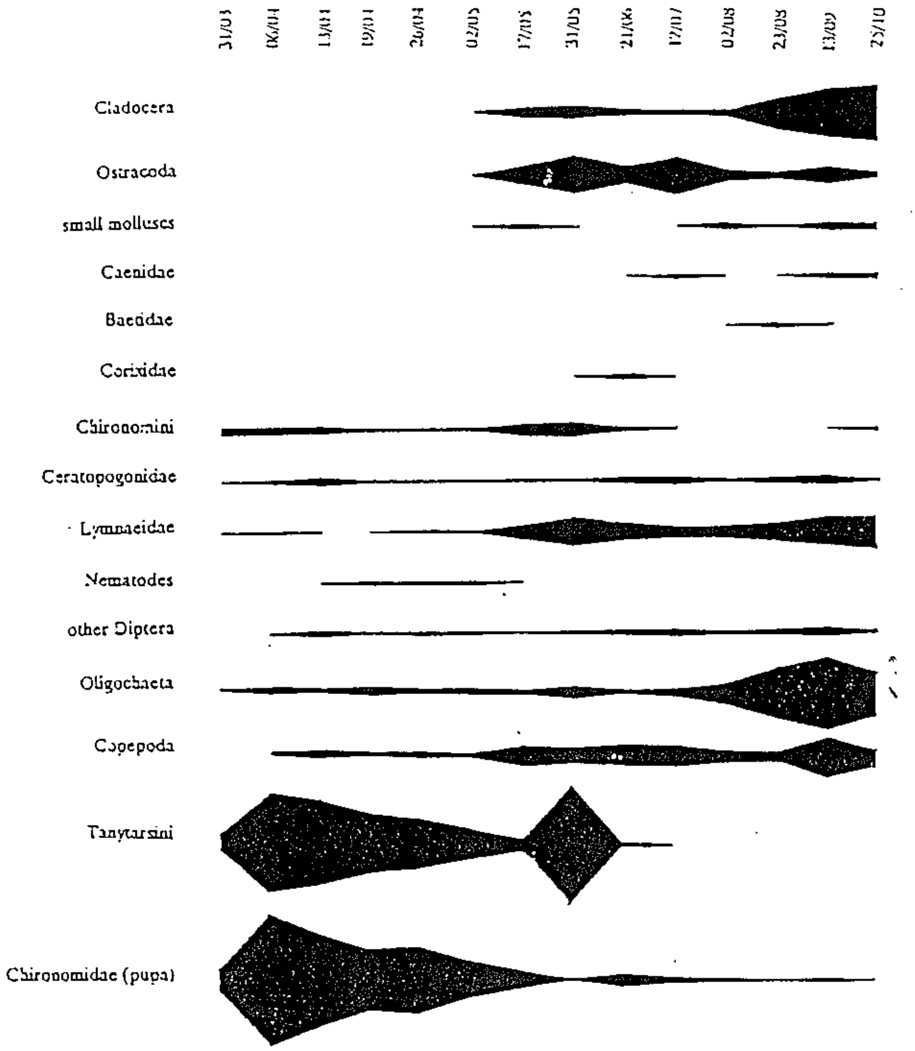

Figure 5 : Kite diagram representing the densities of the most common benthic species over the year in pond LD.

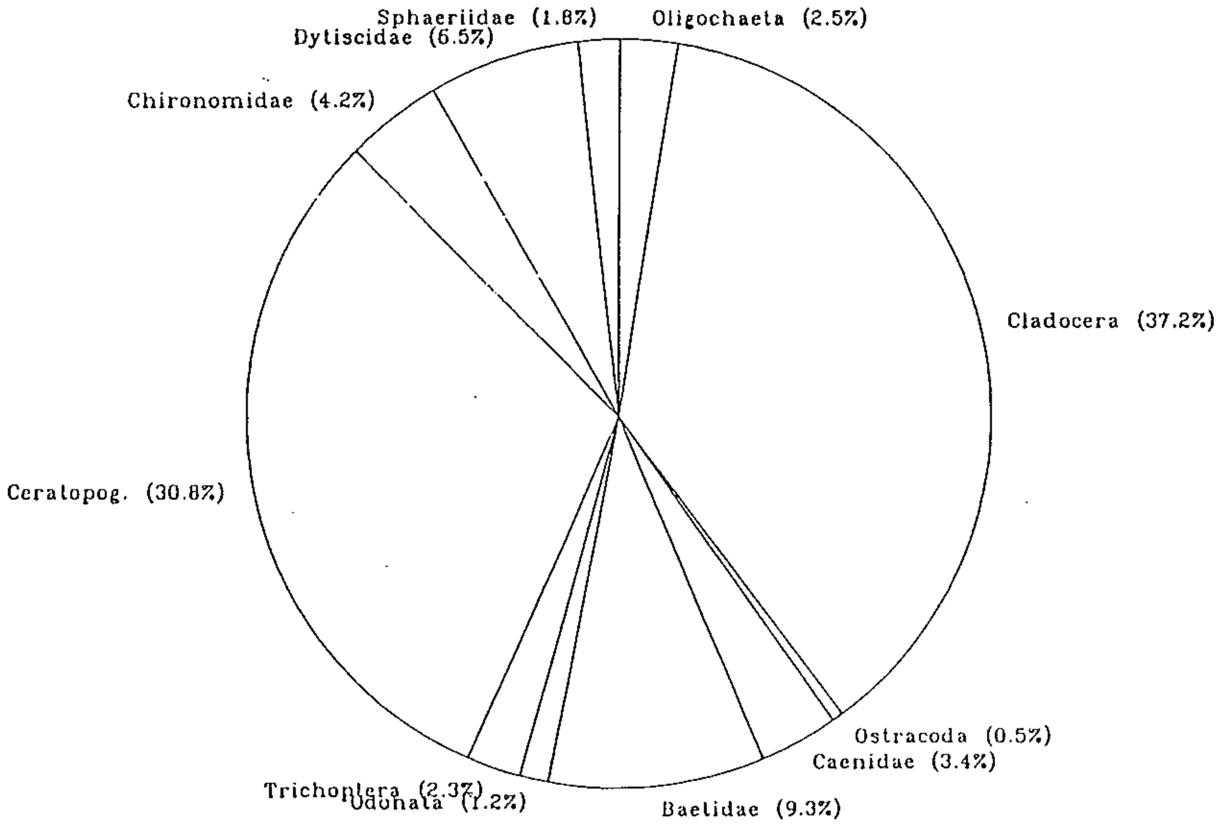

Figure 6 : Relative quantitative importance (based on dry weights) of the various food items of eels sampled on the 5th and 6th September in the HD pond.

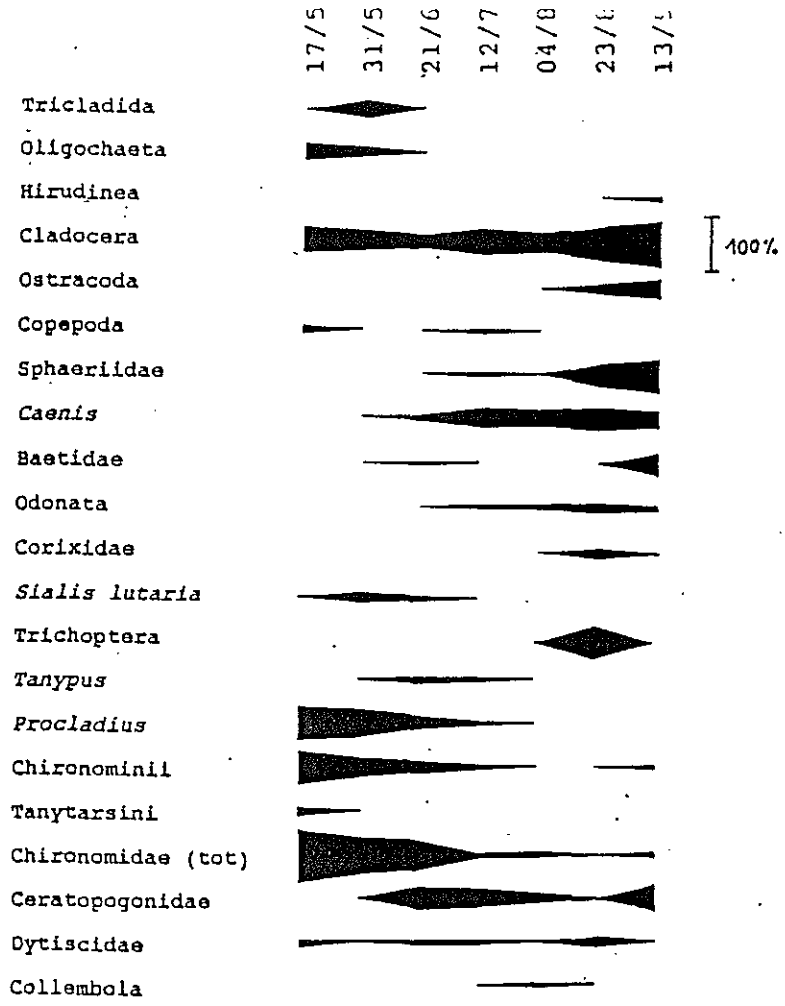

Figure 7 : Changes in the frequency of occurrence (in % of non-empty stomachs) of the various food items throughout the year.

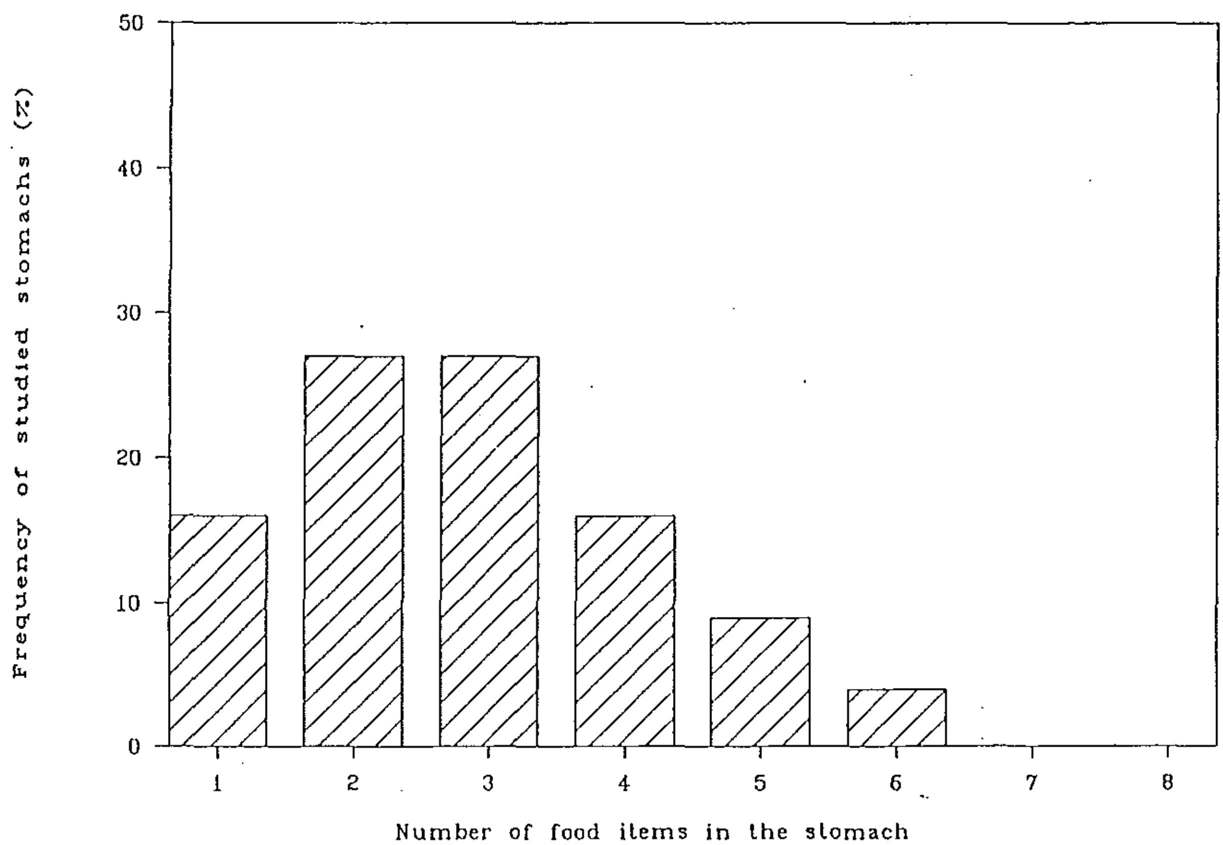

Figure 8 : Frequency of occurrence of the number of different food items in the stomach (stomach with degree of fullness >25%).

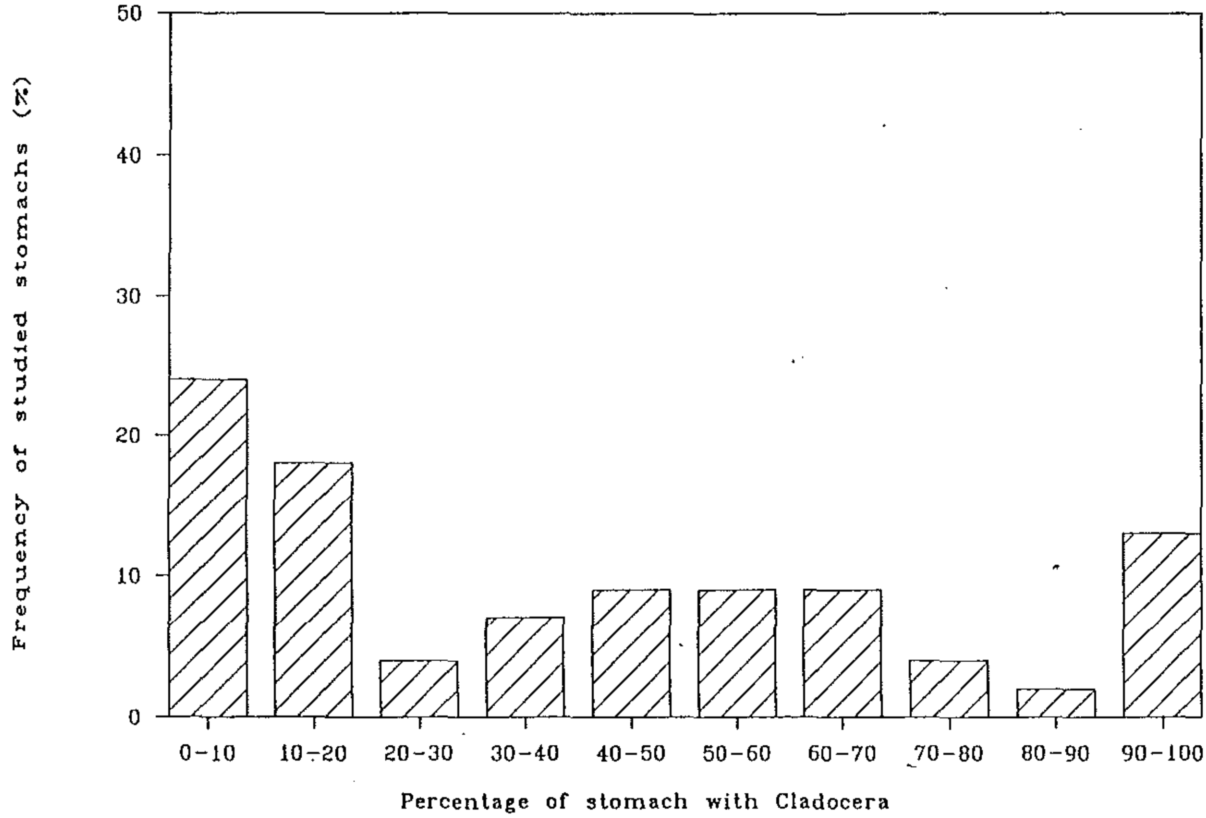

Figure 9 : Feeding preference of some eels for Cladocera (stomach with degree of fullness >25%).

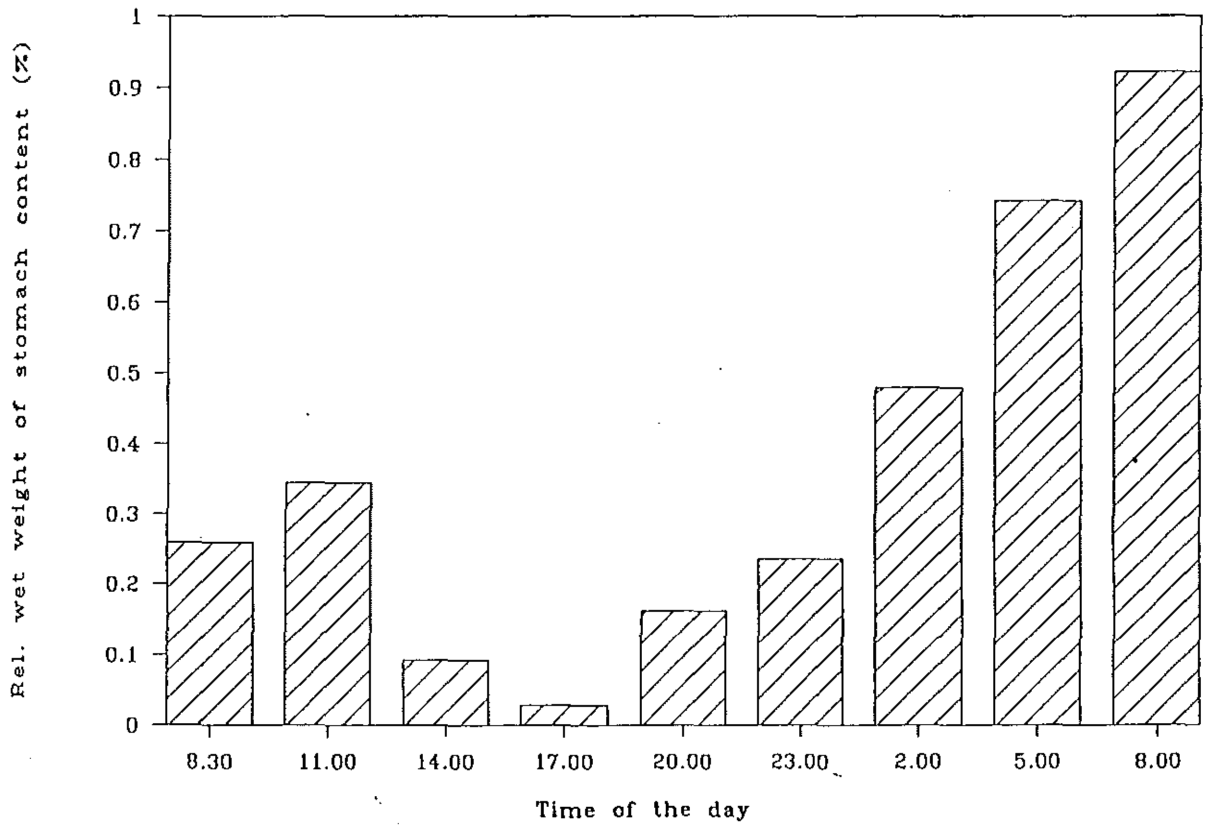

Figure 10 : Mean relative wet weight of the stomach content (in percentage of the wet body weight of the fish) in function of the time of the day.

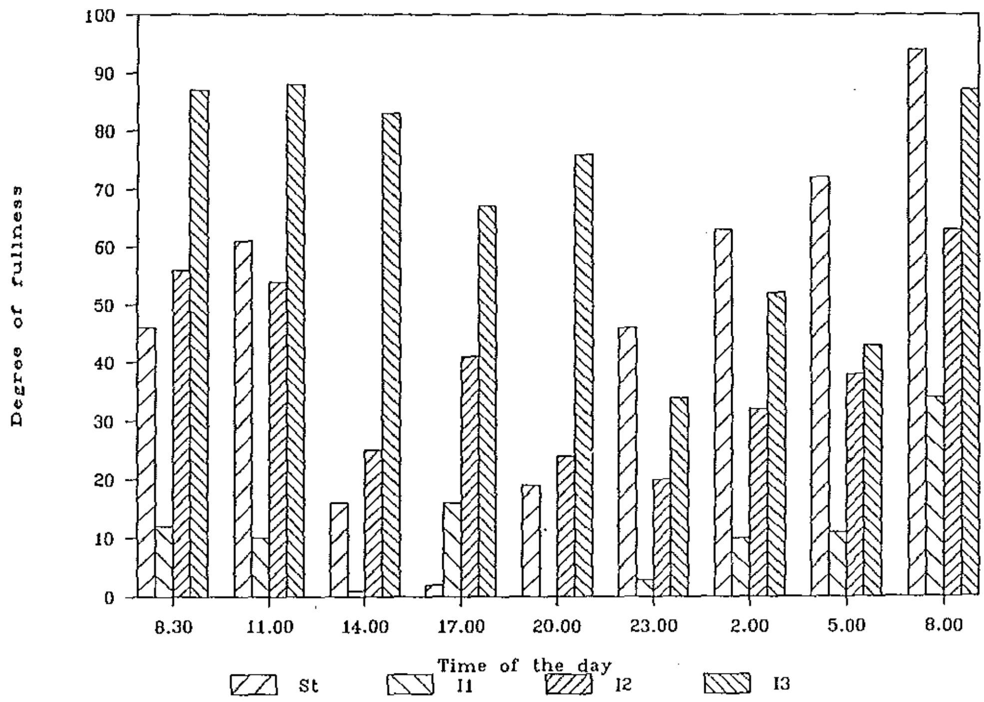

Figure 11 : Mean degree of fullness of the stomach and the three parts of the intestine during the 24h cycle (pond HD, September 5th en 6th).

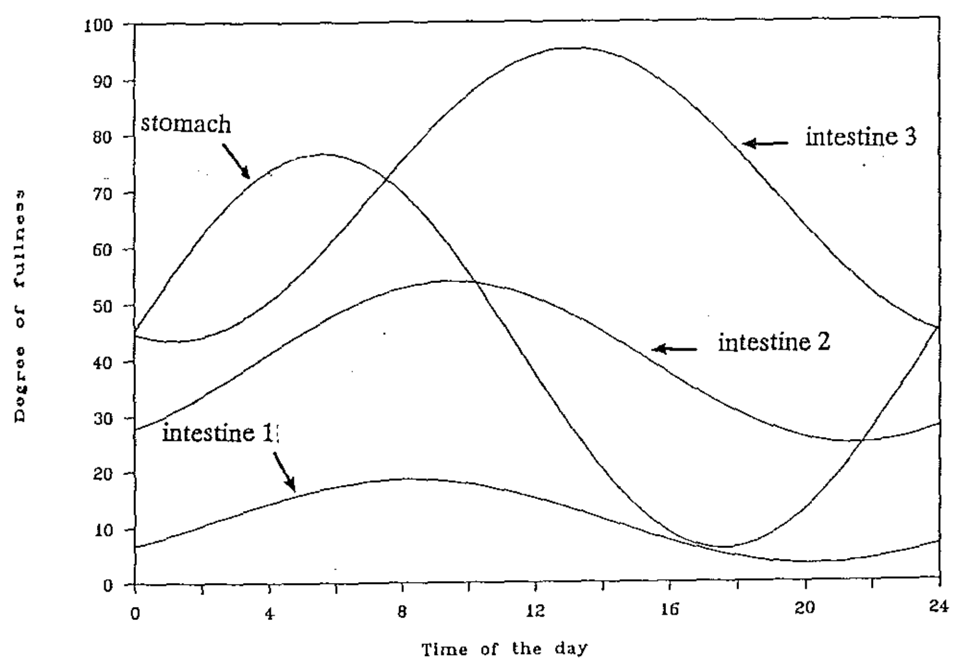

Figure 12 : Most probable functions describing the fluctuations of the degree of fullness over a 24h period for the various parts of the digestive tract.