ASPECTS OF TROPHIC ECOLOGY OF RED SWAMP CRAYFISH (*Procambarus clarkii* Girard)
IN ALENTEJO, SOUTH OF PORTUGAL

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ABSTRACT

Food habits of crayfish from different habitats were studied. A large part of the diet is vegetal material, particularly detritus. Significant quantities of animal remains occur in crayfish stomachs: insects, crayfish and fish. For smaller individuals about 50% of the diet is animal material while larger animals are typical phytophagous. Variations in food habits can be related to the availability of different food types, emphasizing the opportunistic aspect of crayfish trophic behaviour. Results suggest the possibility of strong effects in the communities, in conditions of short detritic food supply and high crayfish biomass.

INTRODUCTION

During the last decades several exotic species were introduced into inland waters of the Iberian Peninsula. One of those introductions was *Procambarus clarkii* (Girard), referred to as Louisiana crayfish, red crayfish, or red swamp crayfish, native to north eastern Mexico and the south-central U.S.A.. It has been successfully introduced in all continents, except Antarctic and Australia (Hobbs III et al., 1989). In Portugal its presence was noticed in the late seventies (Ramos & Pereira, 1981) coming from Spain where this species was intentionally introduced in 1973 (Huner, 1981) for aquaculture purposes. Red swamp crayfish developed since then a fast colonization.

P. clarkii is very well adapted to the environmental conditions of many aquatic habitats in south-central Portugal, particularly the semipermanent aquatic systems, which are the typical red swamp crayfish habitat (Huner, 1981). Crayfish very frequently presents high standing stocks and dominates the aquatic community as the major consumer.

Red swamp crayfish trophic behaviour has been related to hypothetical negative impacts, namely on indigenous fish populations and rice fields.

This study presents preliminary data on trophic relations of Louisiana red crayfish populations in several lotic and lentic habitats at the south of Portugal, in an attempt to relate its trophic activity to community changes. It is a part of a larger program on the assessment of *P. clarkii* ecological role within these natural ecosystems.

MATERIALS AND METHODS

Sampling with traps and hand nets took place during the autumn of 1990.

Crayfish were sampled at 0.1 - 0.8 m depth in 4 different habitats near Evora, Alentejo, south of Portugal. Sampling sites location was: Degebe stream (S. Miguel de Machede village - Moinho Encarnado), Valverde stream (Valverde village), Vale de Vasco stream (downstream Vigia Reservoir) and Vigia Reservoir (littoral zone near the dam). All the streams are semi-permanent. Main characteristics of sampling sites are indicated in Table 1. Vegetal cover was evaluated with the scale of Braun Blanquet. For substrate characteristics, dominant fractions were visually evaluated. For statistical treatments an

Table 1. Main characteristics of sampling sites.

Sampling site	Vegetation cover	Sediment type	Presence of trees
#1 - Degebe stream	3	Sandy mud	+
#2 - Valverde stream	4	Mud	+
#3 - Vale de Vasco stream	3	Mud	0
#4 - Vigia reservoir	0	Stony sand	0

Figure 1. Average stomach contents of length classes from the 4 sampling sites - modified Main Food Index (%), trophic niche width (B) and vegetal food: animal food ratio.

arbitrary scale was adopted with higher values for the coarser sediments. Once captured, specimens were weighted to the nearest 0.1 g to obtain fresh weight (W). Total length (from tip of rostrum to tip of telson) was measured to the nearest 0.1 mm with calipers and sex was determined. Digestive tracts were removed and preserved in a 10% buffered formalin solution.

Diets were studied by stomach contents analysis which can be misleading as the gastric mill can make many ingested food unrecognizable, particularly those organisms without much hard skeletal structure. To minimize these effects, digestive tracts were removed immediately after capture.

For diet characterization, Main Food Index of Zander (1982) was used, modified (MFI'; Bernardo, 1990) to solve the problem of numeric evaluation of non discrete food items

$$MFI' = (F \times V)^{1/2}$$

with F = frequency of occurrence and V = volumetric proportion.

MFI' for each food type were corrected so that in a diet the sum equals 100%.

Heterogeneity of the diet was evaluated with the Niche Width (B; Levins, 1968) using MFI' as the proportional values for each food type

$$B = \left(\sum_{i=1}^n p_i^2 \right)^{-1}$$

with B = niche width, p_i = proportion of food type i , and n = number of food types.

In order to summarize the information, Principal Components Analysis (PCA; Legendre & Legendre, 1983) was utilized on the log transformed volumetric proportions of food categories of each stomach content.

Average values of volumetric proportions for size classes and sexes were compared with analysis of variance (one-way ANOVA).

RESULTS

Number of animals captured in each sampling site was: Degebe stream: 120; Valverde stream: 79; Vale de Vasco stream: 37; Vigia reservoir: 53. No attempts were made to evaluate standing stocks but consecutive 24 hours capture at Degebe stream in semi-confined conditions provided a minimum figure of 1.3 individuals m^{-2} .

For the average diets evaluation, three size classes were considered - class 1: 6 - 9cm; class 2: 9 - 11cm; class 3: 11 - 15cm. No further classes were defined because of the small number of crayfish with significant stomach contents with less than 7cm of length and larger than 13cm. For this reason and to consider all possible stomach contents in the calculation of average diets, size classes have unequal ranges. Even so, and because of the high number of empty stomachs or with insignificant content, it was not possible to evaluate average diets of each size class for all the sampling sites.

The total length (L, cm) - weight (W, g) regression equations were as follows:

- Males $W = 4 \times 10^{-3} \times L^{3.866}$ ($r=0.964$; $p<0.001$)

- Females $W = 8 \times 10^{-3} \times L^{3.604}$ ($r=0.965$; $p<0.001$)

Figure 1 presents average values of MFI' for the length classes in the 4 sampling sites. These results show the abundance of plant material in crayfish food. The average crayfish consumed about one half of its diet in vegetal detritic matter. Part of these detritus comes from fallen leaves of riparian trees but most of it is the result of aquatic macrophytes decay. Green plant material reached MFI' average values as high as 15.4%, but was usually much lower and for some cases this food type was not found.

Significant quantities of animal remains occurred in stomach contents (Fig.1). Macro-invertebrates (exclusively insects) were the main animal material with a wide variation from 0 to about 55% average values. Another animal food source was fish. Small mosquitofish, *Gambusia affinis*, from site #1 (Degebe stream) were the only identified specimens. Fish material from the other samples could not be identified. Although some of the groups present no fish in their diets, in sites #3 (Vale de Vasco Stream) and #4 (Vigia Reservoir) fish is about 20% for the classes of smaller crayfish. Exoskeleton fragments, skin, and muscle tissues of crayfish were also present in stomachs.

Sediment may have some importance in stomach contents, reaching values as high as 16.8% for class 1 at Valverde stream. However part of the sediment may be accidental, being ingested with some prey or detritic material. Residual food category (Others) includes synthetic and unidentified materials.

Results clearly show the increased consumption of plant detritus with

growth. Class 3 diets present more than 70% of detritus and small amounts of animal preys while for class 1 predation provides the larger percentage of food (Fig.1). With the increase of vegetal detritus all three animal food types decrease as confirmed by a strong negative correlation ($p < 0.001$) of detritus with each animal category. As a result, diet heterogeneity measured by niche width decreases to B as low as 1.83 and 1.67 for classes 3 (Fig.1). Strong correlations were found between length and vegetal detritus ($r = 0.439$, $p < 0.001$) and between length and macro-invertebrates ($r = -0.505$, $p < 0.001$).

Table 2. One-way ANOVA comparison of plant material (detritic + green) in the average diets of length classes (n.s. = not significant).

Sampling site	Comparisons	F	Level of significance
#1 Degebe stream	Class 1 - Class 2	0.013	n.s.
	Class 1 - Class 3	4.370	$p < 0.05$
	Class 2 - Class 3	6.225	$p < 0.05$
#2 Valverde stream	Class 1 - Class 2	0.495	n.s.
#3 Vale de Vasco str.	Class 2 - Class 3	4.821	$p < 0.05$
#4 Vigia reservoir	Class 1 - Class 2	0.229	n.s.

ANOVA was carried out to compare dietary vegetal component of each length class for each sampling site (Table 2). Presence of plant material in classes 3 is significantly higher than in the other classes but no significant dif-

Figure 2. Principal components analysis of stomach contents. Symbols representing stomach contents indicate the sampling sites.

ferences exist between classes 1 and classes 2.

In order to evaluate sex related differences on diet, correlations of sex with food types were undertaken. The only significant correlation ($p < 0.001$) emphasize the importance of male predation on fish. Comparison of fish in male contents ($X = 28.5\%$) and in female contents ($X = 3.6\%$) from sampling sites #3 and #4, chosen for the higher values of fish intake, confirms the existence of a significant difference of fish consumption by males and females ($F = 7.04$, $p < 0.02$, ANOVA).

Principal components analysis (PCA) was used to describe the variability of stomach contents. In order to evaluate if differences in diet composition could be related to environmental characteristics, each symbol representing a stomach content was identified according to the habitat it came from (Fig.2). The first and second axes of the PCA explained, respectively, 28.5% and 19.7% of the total variance. Food type vectors are represented, expressing the opposition, along axis 1, of vegetal detritus to animal food types. Green vegetal material (Veget.) is the main contributor to axis 2. Predominance of vegetal regime is observed for groups from muddy environments with important aquatic vegetation. Individuals coming from stony habitats with no macrophytic cover are plotted in association with the animal food vectors - macro-invertebrates, fish and crayfish.

Correlations of environmental parameters and diet components (Fig.3) emphasize (1) the relation of detritic vegetal regime with the abundance vegetation cover and (2) the increase of macro-invertebrate consumption in habitats without vegetation and with coarse sediment.

Figure 3. Significant correlations of environmental and diet parameters (dotted lines indicate negative correlations).

DISCUSSION AND CONCLUSIONS

Crayfish were described as herbivores, predators and detritivores (Lorman & Magnuson, 1978). Various species of crayfish have been fairly well established as detritivores (Morshiri & Goldman, 1969; Mason, 1975; Cantarino et al., 1980) but herbivory can be particularly important, causing reductions in macrophyte biomass (Abrahamsson, 1966; Rickett, 1974; Flint & Goldman, 1975; Lodge & Lorman, 1987; Feminella & Resh, 1989).

Results from stomach analysis (Fig.1) reveal *P.clarkii* much more as a shredder than as a grazer. Vegetal detritus is the main food source and green plant material assumes no relevance - for some of the sampling sites there was no green vegetation in the diet. According to these data, red crayfish cannot be considered a pest with considerable potential impact on macrophytes but, as Huner (1981) states, food limited populations will eat virtually any vegetation available. In these conditions, a shift in dietary intake is expected and red crayfish grazing reduces dramatically the vegetation cover (Feminella & Resh, 1989). However, consumption is not the exclusive cause of the decline of vegetation abundance. A large percentage of the loss of vegetation results from cutting the stems near the bottom (Lorman & Magnuson, 1978).

The detritic plant material itself is of little nutritional value but bacterial colonization of this substrate alters its composition (Odum & de la Cruz, 1967). This protein rich microflora constitutes the primary food source for detritophagous rather than the refractory, nitrogen-poor plant detritus (Newell, 1965; Fenchel, 1970). During the decomposition of vegetal material, micro-organisms assimilate nitrogen and C:N ratio declines, increasing accordingly the nutritional value (Harrison & Mann, 1975; Pomeroy, 1980).

Plasticity of trophic behaviour makes possible the dietary shifts from

detritic to green plant material and also the changes of vegetal and animal proportions. Vegetal food in the diet is more abundant in samples from sites #1 and #2, where vegetal food supply is higher, than from habitats as site #4 (Figs. 1 and 2). Correlations of environmental and diet parameters (Fig. 3) indicate a direct relation between availability and consumption, typical of opportunistic species.

Animal food sources such as mollusks, especially snails, annelid worms, leeches and frogs were mentioned as crayfish preys (Rickett, 1974; Huner, 1981), but none was detected in the stomachs. Utilization of animal resources seems to be actually narrower than could be expected.

Animal material is much more important in the diets of rapidly growing juveniles than of adults. A definite shift in food habits was found to accompany increase in length as previously mentioned for several crayfish species (e.g. Abrahamsson, 1966; Mason, 1975). Identical phenomena have been observed in other predominantly phytophagous and/or detritophagous taxa, such as fish - e.g. mugilids (Hickling, 1970; Odum, 1970; Albertini-Berhault, 1974; Bernardo, 1990) or grass carp (Sing et al., 1976).

Young specimens feed extensively on macro-invertebrates (insects), the main animal food source, which decreases in the larger crayfish, as they tend to be herbivorous.

Cannibalism can provide a significant dietary animal supplement. Cannibalism among crayfishes is a well known fact (Mason, 1975; Lorman & Magnuson, 1978). However the presence of crayfish tissues in the stomachs does not necessarily mean active cannibalistic behaviour as crayfish remains may actually have been eaten as detritus (Lorman & Magnuson, 1978). Also, for some species at least, most adults, and all juveniles, consume their exuviae following ecdysis (Mason, 1975). The presence of crayfish muscle in the observed contents denies this last hypothesis as being the exclusive source.

Fish is a food of some importance, comprising up to approx. 20% (MFI) of stomach contents for some groups. The significantly higher fish consumption by male crayfish is possibly related to the larger male claws.

Crayfish species have been considered an important source of energy and matter transfer from the primary and secondary consumer levels to the terminal aquatic predators, mainly the fishes (Fedoruk, 1966; Schramm, Jr. & Maceina, 1986). However, the possible role of crayfish as a fish predator in particular situations has not been considered. Under confined experimental conditions (30 l aquaria), *P. clarkii* predation on small cyprinids (*Rutilus alburnoides*) was observed even in the presence of vegetal detritic food (Bernardo, unpubl. data). These observations and the results of this study, particularly of sites #3 and #4, suggest crayfish may perform a role of some importance as a predator of fish populations, namely indigenous cyprinids.

The trophic shift observed in habitats of scarce plant food and the laboratory experiments referred above, suggest an effective predation might exist. In summer, most running waters turn into a succession of shallow pools where confined conditions could increase fish vulnerability, namely of young-of-the-year cyprinids. In these situations, predation by dense crayfish populations, as is frequently the case in Alentejo fresh waters, could significantly alter fish standing stocks. Low precipitation and long hot summers could increase crayfish pressure.

The relation of the availability of different food resources with their differential consumption supports the frequently mentioned opportunistic character of *P. clarkii*. Euriphagy is perhaps a major factor in red crayfish ecological success, making possible the spreading of this species in a wide variety of habitats.

These preliminary results suggest that crayfish, above a certain density and in conditions of short detritic food supply, can significantly affect prey and macrophyte populations. Further work is in progress in an attempt to assess the direct effects of active predation and grazing.

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