

## Diet and food selection by *Ramnogaster arcuata* (Osteichthyes, Clupeidae)

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The goals of this study were to describe the diet and estimate the trophic level and food selection of Jenyns's sprat *Ramnogaster arcuata*, one of the common fishes in the Bahía Blanca estuary in Argentina. The copepods *Acartia tonsa* [53.7% index of relative importance ( $I_{RI}$ )] and *Eurytemora americana* (13.4%  $I_{RI}$ ), the mysid *Arthromysis magellanica* (13.9%  $I_{RI}$ ) and the small shrimp *Peisos petrunkevitchi* (8.2%  $I_{RI}$ ) were the most important food items for this species, and its diet exhibited monthly variability with respect to the principal prey categories. The zooplankton species in the study area consisted of 32 taxa. *Acartia tonsa* was the most abundant species [54% individuals ( $N$ )  $m^{-3}$ ], followed by *Balanus glandula* (13.8%  $N$   $m^{-3}$ ) and *E. americana* (10.1%  $N$   $m^{-3}$ ). The rest of the zooplankton groups represented <3%  $N$   $m^{-3}$ . The most preferred items throughout the year were *A. magellanica* and *Idotea* sp. The trophic level value estimated was 3.1. © 2011 The Authors

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Key words: Argentina; Bahía Blanca; Clupeiformes; prey selectivity; south-western Atlantic Ocean; trophic level.

### INTRODUCTION

The study of fish stomach contents is a common way of investigating the food web in marine biological communities. Food is recognized as the main factor regulating the growth, abundance and migration patterns of fishes (Nyunja *et al.*, 2002). Information about the food and feeding habits of fishes inhabiting estuaries and coastal lagoons indicates the trophic spectrum of each species that resides within these areas and allows the determination of predator–prey relationships. This information helps in understanding the community dynamics of coastal areas and may also be utilized as input data for holistic models, which may be useful as management tools. Few studies, however, have been undertaken on the spatial and temporal variation in the food habits of the planktivorous fishes of the South Atlantic Ocean.

Jenyns's sprat *Ramnogaster arcuata* (Jenyns 1842) is a small pelagic, zooplanktivorous fish species (Cousseau, 1985) that lives in coastal areas in the south-western Atlantic Ocean from southern Brazil (estuary of the Patos Lagoon) to Tierra del Fuego in southern Argentina (Roux, 1973; Cousseau, 1982; Vieira & Castello, 1997;

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Cione *et al.*, 1998). It has often been reported to be an estuarine-resident species that completes its whole life cycle within estuaries (Garcia & Vieira, 2001) in the Patos Lagoon, Brazil. In Argentina, however, Cousseau *et al.* (2001) have referred to *R. arcuata* as an estuarine-dependent species in the Mar Chiquita Lagoon (Buenos Aires coast) because it spawns in marine waters adjacent to the estuary during late spring and early summer, and only its larvae and juveniles are either transported or migrate into the estuary, where they find shelter and food. In the Bahía Blanca estuary ( $38^{\circ} 45' - 39^{\circ} 25' S$ ;  $61^{\circ} 15' - 62^{\circ} 30' W$ ), *R. arcuata* exhibits a wide spatio-temporal distribution in which it completes its life cycle (Lopez Cazorla, 1987, 2004; Lopez Cazorla & Sidorkewicz, 2009). It also represents a key food item for the striped weakfish *Cynoscion guatucupa* Cuvier 1830 and the flounder *Paralichthys orbignyanus* (Valenciennes 1839) (Lopez Cazorla, 1987, 1996, 2004; Lopez Cazorla & Forte, 2005), which are two of the most economically important fishes in the area. The coastal habits and short life span of *R. arcuata* make it an excellent organism to be considered as a bio-indicator of aquatic environmental health (Lopez Cazorla & Sidorkewicz, 2009). Little attention has, however, been paid to the trophic ecology that typifies *R. arcuata* not only in the Bahía Blanca estuary but also throughout its geographical distribution.

The Bahía Blanca estuary ecosystem has undergone severe perturbations since the 1980s as a result of industrial activity, intensive marine traffic, dredging and pollution (Hoffmeyer, 2004). Much of the waste derived from these activities reached the estuary with little or no treatment, thereby contaminating both its sediments and biota (Ferrer, 2001). These disturbances could cause variations in community structure that might affect the trophic ecology of the species that reside in this estuary (Whitfield & Elliott, 2002).

Furthermore, in spite of the ecological importance of *R. arcuata*, only one study has been undertaken on its diet, which was carried out four decades ago in another region of the Buenos Aires coast by Olivier *et al.* (1968). Studies on food selection of other fishes inhabiting the Bahía Blanca estuary have been focused on economically important commercial species, such as the *C. guatucupa* (Sardiña & Lopez Cazorla, 2005a), and the whitemouth croaker *Micropogonias furnieri* Desmarest 1823 (Sardiña & Lopez Cazorla, 2005b). The present study represents the first analysis of the trophic ecology of *R. arcuata*, which allows the determination of its position in the trophic web of this estuary.

Although *R. arcuata* is known to be a zooplanktivorous feeder in waters of the south-west Atlantic Ocean (Olivier *et al.*, 1968; Cousseau, 1985), its annual diet variability and its prey selectivity have been not described to date. Therefore, the present study aimed to analyse the fluctuations in the diet of *R. arcuata* during an annual cycle and to determine the general diet for the total population of this species in order to understand its ecological role and to estimate its trophic level. In addition, the research sought to compare stomach contents with prey availability in plankton samples to assess the feeding selectivity of this species.

## MATERIALS AND METHODS

*Ramnogaster arcuata* was collected monthly in diurnal net tows during ebb tide in the Bahía Blanca estuary ( $38^{\circ} 45' - 39^{\circ} 25' S$ ;  $61^{\circ} 15' - 62^{\circ} 30' W$ ) between September 2005 and August 2006. A detailed description of the study area is available in Lopez Cazorla & Sidorkewicz

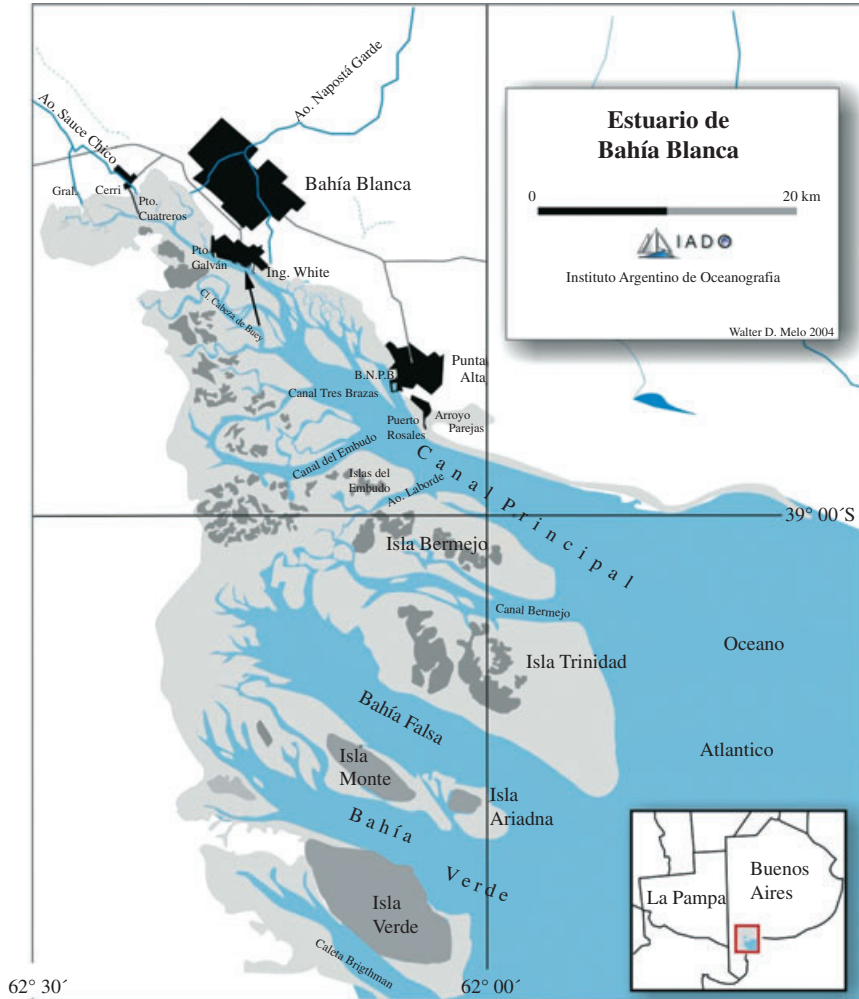


FIG. 1. Bahía Blanca estuary, Argentina. The arrow indicates the sampling station.

(2009). Captures were conducted in an area close to Ing. White port (Fig. 1) by artisanal fishermen or commercial fishing vessels using shrimp nets (60 mm mesh in the wings and 10 mm mesh in the codends, 2 m vertical opening and 10 m horizontal aperture). Zooplankton samples were taken simultaneously with the fish collection. Sampling was conducted during the morning daylight hours and high tide conditions from the bottom to the surface using a conical 200  $\mu\text{m}$  mesh plankton net (0.3 m mouth diameter, 1.0 m long). Samples were fixed in a 4% formalin solution.

All fish were measured (total length,  $L_T$ , mm) and subsequently grouped into 10 mm size classes. A sub-sample composed of 10 randomly selected specimens of each size class was used for the study. The total mass ( $M_T$ , g) of each fish was measured, and its stomach contents were removed (total stomach content mass,  $M_{SC}$ ) and preserved in a 10% formalin solution.

## TROPHIC ECOLOGY

The vacuity index ( $I_V$ ) was calculated as the number of empty stomachs divided by the total number of stomachs examined multiplied by 100 (Moliner & Flos, 1992). Feeding

intensity was analysed by means of the stomach fullness index ( $I_{SF}$ ) (Okach & Dadzie, 1988), calculated as:  $I_{SF} = 100 M_{SC} M_T^{-1}$ .

Stomach contents were analysed under a binocular microscope and identified to the lowest possible taxonomic level. The wet masses of each prey item were recorded after superficial drying with absorbent paper. The individuals of each prey item consumed were subsequently counted. Stomachs with undetermined contents as a consequence of advanced stages of digestion ( $n = 127$ ) were excluded from the diet composition analysis. The dominance index ( $I_D$ ), which measures the extent to which one or a few species dominate the diet, was estimated by the following equation:  $I_D = \sum_{j=1}^N (P_j)^2$ , where  $P_j$  is the proportion of each prey item contributing to the whole diet, and  $N$  is the number of the prey categories. The estimation range varied from  $I_D = 1$ , indicating absolute dominance, thus corresponding to the situation where there is only one category, to  $I_D = N^{-1}$ , indicating that all the categories were equally represented. This index was estimated for the number and mass of each prey item.

An index of relative importance ( $I_{RI}$ ) was used to express the dietary importance of specific prey items within the population diet and was calculated from the equation:  $I_{RI} = \%F_o (\%N_c + \%M_c)$ , where  $\%F_o$  (frequency of occurrence) is the percentage of stomachs within the sample population containing a specific prey item;  $\%N_c$  (numerical composition) is the number of items of a specific prey category expressed as a percentage of the total number of prey items of all stomachs examined and  $\%M_c$  (mass composition) is the mass of a specific prey item expressed as a percentage of the total mass of ingested prey (Pinkas *et al.*, 1971). The  $I_{RI}$  values were standardized to 100% by calculating the percentage of the total  $I_{RI}$  contributed by each prey type ( $\%I_{RI}$ ) and ranged from 0 (absent from diet) to 100 (the only prey item consumed) (Barry *et al.*, 1996; Cortés, 1997). The monthly contribution of the different categories of food items to the diet of *R. arcuata* was determined by the monthly  $\%F_o$ ,  $\%N_c$  and  $\%M_c$ .

The trophic level for *R. arcuata* was calculated using the following equation based on Cortés (1999):  $T_{Lk} = 1 + (\sum_{j=1}^n P_j T_{Lj})$ , where  $T_{Lk}$  = the trophic level of species  $k$ ,  $P_j$  = proportion of the prey category  $j$  in the diet of species  $k$ ,  $n$  = the total number of prey categories and  $T_{Lj}$  = the trophic level of prey category  $j$ . The  $T_{Lj}$  values for each prey item were obtained from Cortés (1999), Pauly *et al.* (2000) and Ebert & Bizarro (2007) (Table I).

## FOOD AVAILABILITY

Zooplankton was identified to the lowest possible taxonomic level and counted under a stereoscopic microscope. Counts were standardized to the number of individuals ( $N$ )  $m^{-3}$ . The annual abundance ( $N$   $m^{-3}$ ) of each zooplankton species was calculated taking into account the mean monthly abundance, and the per cent frequency of occurrence ( $\%F_{oz}$ ) was calculated as the percentage of the samples containing each species.

TABLE I. Trophic levels of *Ramnogaster arcuata* prey

Species group	Trophic level
Molluscs (excluding cephalopods)	2.1 <sup>a</sup>
Decapod crustaceans (shrimps, crabs, prawns and lobsters)	2.52 <sup>a</sup>
Other invertebrates (all invertebrates except molluscs, crustaceans and zooplankton)	2.5 <sup>a</sup>
Zooplankton	2.0 <sup>b</sup>
Amphipods and isopods	3.18 <sup>c</sup>
Euphausiids and mysids	2.25 <sup>c</sup>
Other crustaceans and unidentified crustaceans	2.4 <sup>c</sup>

<sup>a</sup>Cortés (1999).

<sup>b</sup>Pauly *et al.* (2000).

<sup>c</sup>Ebert & Bizarro (2007).

## DIET SELECTION

Ivlev's electivity index ( $E$ ; Ivlev, 1961) was used to measure feeding selectivity, comparing the use of food with respect to its availability. This index has been successfully used to determine prey selectivity in a wide range of marine and freshwater fishes (Alwany *et al.*, 2003) and it is also one of the indices used in the ECOPATH multispecies approach (Christensen & Pauly, 1992). Ivlev's index is defined as:  $E_i = (r_i - p_i) (r_i + p_i)^{-1}$ , where  $r_i$  is the proportion of the food type  $i$  consumed, and  $p_i$  is the proportion of this food type available in the environment, both of which were estimated based on the abundance (% $N$ ). The  $E$  values range from  $-1.0$  to  $+1.0$ , with values between  $0$  and  $+1.0$  indicating preference, values between  $0$  and  $-1.0$  indicating avoidance, and values equal to  $0$  indicating no selection because the food item concerned is taken in the same proportion as it is available. Electivity index variation was estimated in terms of numerical abundance for all food items.

The results of feeding selectivity of *Peisos petrinkevithci* were not included in the present study because this species could not be sampled quantitatively by the plankton net.

## STATISTICAL ANALYSIS

A non-parametric one-way ANOVA Kruskal–Wallis test (Zar, 1999) was used to examine the size distribution of *R. arcuata* and the  $I_{SF}$  on a monthly basis. Comparisons between median values were made with a Mann–Whitney  $U$ -test (Zar, 1999). The monthly diet changes were evaluated using the prey item % $F_o$  values with an agglomerative hierarchical group analysis based on a Euclidean distance matrix. Grouping was performed following the Ward method (Anderberg, 1973).

## RESULTS

### TROPHIC ECOLOGY

The total numbers of sampled and sub-sampled *R. arcuata* individuals were 2588 and 728, respectively. The individuals collected ranged from 33 to 131 mm  $L_T$  (mean  $\pm$  s.d.  $L_T$  sampled:  $70.1 \pm 19.8$  mm) (Fig. 2). The mean  $L_T$  increased from 59.2 mm in October to 98.5 mm in July (Table II). The size range was greatest during September to February (spring to summer), and it was lowest during March to August (autumn to winter). Significant differences in the monthly  $L_T$  means were recorded (Kruskal–Wallis  $H_{11,600} = 188.2$ ,  $P < 0.01$ ). Only one of the fish examined had an empty stomach, and the vacuity index was  $<1\%$ . The feeding intensity, which was evaluated based on the  $I_{SF}$ , was moderate throughout the year. The mean  $\pm$  s.d. value was  $0.7 \pm 1.1$  ( $n = 727$ ). Feeding activity, as measured by  $I_{SF}$ , showed

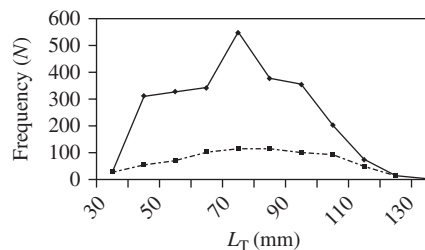


FIG. 2. Total length ( $L_T$ ) frequency distribution of *Ramnogaster arcuata* in Bahía Blanca estuary [ $N$ , sample = 2588 (◆) and  $n$ , sub-sample = 728 (■)].

TABLE II. Mean  $\pm$  S.D. and range (minimum to maximum) of total length ( $L_T$ ) of *Ramnogaster arcuata* captured in Bahía Blanca estuary between September 2005 and August 2006. The sample ( $N$ ) and sub-sample ( $n$ ) size, and stomachs whose contents were determined ( $S_{dc}$ ) are also indicated

Month	$L_T$ (mm)		$N$	$n$	$S_{dc}$
	mean $\pm$ S.D.	Range			
September	70.5 $\pm$ 23.6	34–119	376	80	78
October	59.2 $\pm$ 19.1	33–99	182	54	52
November	62.9 $\pm$ 15.5	35–96	204	56	54
December	76.9 $\pm$ 22.4	46–116	375	78	57
January	77.9 $\pm$ 18.3	42–114	245	71	64
February	76.1 $\pm$ 17.2	43–109	210	64	47
March	73.4 $\pm$ 12.5	52–105	113	41	39
April	94.5 $\pm$ 12.6	75–120	144	48	36
May	87.2 $\pm$ 15.9	66–122	123	54	31
June	93.0 $\pm$ 16.6	63–123	149	56	50
July	98.5 $\pm$ 14.4	67–120	261	63	37
August	95.8 $\pm$ 18.0	61–131	206	63	56
Total			2588	728	600

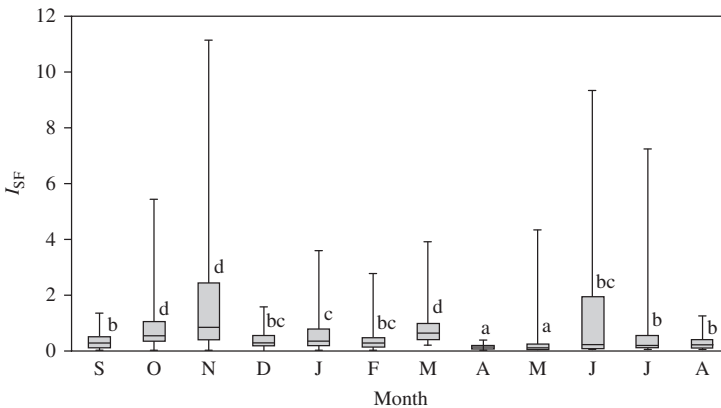


FIG. 3. Monthly variation in median stomach fullness index ( $I_{SF}$ ) in *Ramnogaster arcuata* in Bahía Blanca estuary ( $n = 727$ ). Box plot (range, quartile deviation and median). Different lower case letters indicate significant differences ( $P < 0.05$ ) between medians.

significant variations through the year (Kruskal–Wallis  $H_{11,727} = 158.5$ ,  $P < 0.01$ ), with highest level of  $I_{SF}$  in November and June (spring and the beginning of winter, respectively), while it was lowest in April and May (autumn) (Fig. 3).

Trophic dominance, estimated both in number and in mass, showed a similar tendency from September to April (spring to autumn). In contrast, a different behaviour for these variables was recorded from June to August (winter) when the diet comprised a similar number of prey items, but was dominated by only a few in terms of biomass (Fig. 4).

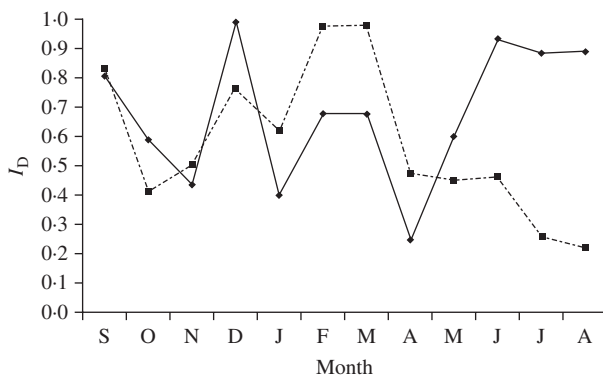


FIG. 4. Monthly trophic dominance ( $I_D$ ) in number (■) and mass (◆) of *Ramnogaster arcuata* during the period September 2005 (S) to August 2006 (A).

The general diet of *R. arcuata* ( $n = 600$ ) included a wide variety of items represented by 18 taxa. The order of prey importance was *Acartia tonsa*, *Arthromysis magellanica*, *Eurytemora americana* and *P. petrunkevitchi*, with *A. tonsa* constituting 53.7% of the  $I_{RI}$  (Table III). *Acartia tonsa* was the most important prey category based on % $F_o$  and % $N_c$ , but it was only third most important based on % $M_c$ . *Arthromysis magellanica* was the second most important prey category based on % $F_o$  and % $M_c$ . The third most important prey category based on % $F_o$  and % $N_c$  was *E. americana*, and the fourth most important was *P. petrunkevitchi* based mainly on % $M_c$  (Table III).

The diet of *R. arcuata* exhibited considerable monthly variation with respect to the principal specific prey items. The monthly feeding composition for the six most important items based on % $N_c$  and % $M_c$  is shown in Table IV. The highest abundance in the number of *E. americana* was recorded at the beginning of spring (September and October), and zoea of *Neohelice granulata* were found during the middle of spring (October and November). *Acartia tonsa* was most abundant in summer and beginning of autumn (January to April), *Idotea* sp. and *Labidocera* sp. in autumn (May and April to June, respectively) and *A. magellanica* at the beginning of summer (December) and winter (July and August). In terms of mass, *E. americana* was the most important food item at the beginning of spring (September), while *A. tonsa* was the most important species in summer (January to March). *Labidocera* sp. were important in autumn (April), *A. magellanica* was the most important food item in spring (October to December) and at the end of winter (August) and *P. petrunkevitchi* was important in autumn and winter (May to July), while *Sagitta friderici* was important mainly in spring (November, 52.9%).

In terms of % $F_o$ , the monthly variations in the diet composition are shown in Table IV. Four groups could be identified, which approximately coincide with the seasons (Fig. 5). One was represented by the summer months (January, February and March), during which the main prey item was *A. tonsa*. Another group was represented by the autumn months (April, May and June), during which the main prey item was *Labidocera* sp. In the winter (July and August), the principal prey item was *A. magellanica*, and in the spring (September, October and November), *E. americana* and the zoea of *N. granulata* were the main food items.

TABLE III. Diet composition of *Ramnogaster arcuata* (number of stomachs in which at least one prey occurred,  $n = 600$ ) and zooplankton abundance in Bahía Blanca estuary. The most important items are indicated in bold

Food item	Composition					
	Diet				Zooplankton	
	% $F_o$	% $N_c$	% $M_c$	% $I_{RI}$	% ( $N\ m^{-3}$ )	% $F_{oz}$
Crustaceana						
Copepoda						
<i>Acartia tonsa</i>	<b>32.9</b>	<b>55.6</b>	7.4	<b>53.7</b>	<b>54.1</b>	<b>100</b>
<i>Eurytemora americana</i>	<b>21.6</b>	<b>21.1</b>	2.8	<b>13.4</b>	<b>10.1</b>	42
<i>Euterpina acutifrons</i>	1.7	0.1	0.0	0.0	2.1	100
<i>Paracalanus parvus</i>	6.2	2.9	0.4	0.5	1.9	75
<i>Calanoides carinatus</i>	9.6	1.3	0.4	0.4	2.9	42
<i>Labidocera fluviatilis</i>	1.5	0.1	0.0	0.0		
<i>Labidocera</i> sp.	9.9	2.7	1.1	0.9		
Cirripedia						
<i>Balanus glandula</i> (larvae)	12.8	1.6	0.1	0.6	<b>13.8</b>	<b>83</b>
Malacostraca						
<i>Arthromysis magellanica</i>	<b>29.9</b>	0.9	<b>17.2</b>	<b>13.9</b>	0.3	42
<i>Noemysis americana</i>	1.83	0.0	0.4	0.0	0.4	58
Isopoda						
<i>Idotea</i> sp.	<b>22.9</b>	1.3	1.4	1.6	0.5	75
Decapoda						
<i>Neohelice granulata</i> (zoea)	<b>21.1</b>	8.1	0.5	4.7	1.9	75
<i>Cyrtograpsus altimanus</i> (zoea)	<b>13.5</b>	2.8	0.2	1.0	0.9	67
<i>Peisus petrunkevitchi</i>	5.2	0.2	<b>61.3</b>	<b>8.2</b>	—	—
Mollusca						
Gastropoda (larvae veliger)	1.8	0.0	0.0	0.0	1.1	75
Chaetognatha						
<i>Sagitta friderici</i>	4.2	0.9	6.7	0.8	0.1	33
Pisces						
Alevins					0.0	8
Eggs					0.3	25

% $F_o$ , per cent frequency of occurrence; % $I_{RI}$ , index of relative importance; % $M_c$ , per cent mass composition; % $N_c$ , per cent numerical composition; % $N\ m^{-3}$ , per cent number of individuals  $m^{-3}$ ; % $F_{oz}$ , per cent frequency.

The estimated trophic level for the total population of *R. arcuata* was 3.1. This result allowed this species to be characterized as a secondary consumer ( $T_L < 4$ ).

#### FOOD AVAILABILITY

Zooplankton belonging to 32 taxa were identified during the sampled period. *Acartia tonsa* was the most abundant species, followed by *Balanus glandula* and *E. americana*. The remaining components of the zooplankton represented <3% (Table III). *Acartia tonsa* was also the most frequently encountered species. The same % $F_{oz}$  was observed for *Euterpina acutifrons*, although its abundance was lower than 3%. Other species exhibiting % $F_{oz} > 50\%$  were *B. glandula* larvae, *Paracalanus*



TABLE IV. Per cent abundance (% $N_c$ ), mass (% $M_c$ ) and occurrence (% $F_o$ ) of the most important food items found in the diet of *Rammogaster arcuata* throughout the year. The highest values of each parameter are indicated in bold

Month	% $N_c$						% $M_c$						% $F_o$									
	At	Ea	Lsp	Am	Ido	ZN	Pp	At	Ea	Lsp	Am	Ido	ZN	Pp	At	Ea	Lsp	Am	Ido	ZN	Pp	
September	0.4	<b>91</b>	0.0	0.0	0.4	0.1	0.0	0.4	<b>89.5</b>	0.0	0.0	3.2	0.1	0.0	11.3	<b>100</b>	0.0	0.0	23.8	10.0	0.0	0.0
October	0.5	<b>55</b>	0.0	1.3	2.1	<b>32</b>	0.0	0.1	12.7	0.0	<b>75.4</b>	4.7	3.6	0.0	9.4	<b>77.4</b>	0.0	20.8	<b>37.7</b>	<b>49.1</b>	0.0	0.0
November	0.1	0.6	0.0	2.4	0.8	<b>69</b>	0.0	0.01	0.1	0.0	<b>39.2</b>	0.6	3.3	0.0	5.6	9.3	0.0	<b>38.9</b>	25.9	<b>68.5</b>	0.0	0.0
December	0.0	0.0	0.0	<b>87.0</b>	6.5	5.2	0.0	0.0	0.0	0.0	<b>99.3</b>	0.6	0.1	0.0	0.0	0.0	0.0	<b>94.6</b>	8.9	3.6	0.0	0.0
January	<b>77.4</b>	0.0	0.0	0.1	0.2	2.3	0.0	<b>59.5</b>	0.0	0.0	9.6	1.2	0.9	0.0	<b>84.4</b>	0.0	0.0	17.2	14.1	<b>65.6</b>	0.0	0.0
February	<b>98.8</b>	0.0	0.0	0.4	0.0	0.6	0.0	<b>80.0</b>	0.0	0.0	19.6	0.0	0.3	0.0	<b>91.3</b>	0.0	0.0	10.9	0.0	10.9	0.0	0.0
March	<b>98.9</b>	0.0	0.0	0.1	0.3	0.3	0.0	<b>80.8</b>	0.0	0.0	15.1	1.7	0.1	0.0	<b>97.4</b>	0.0	0.0	17.9	<b>30.8</b>	17.9	0.0	0.0
April	<b>57.8</b>	0.0	<b>37.1</b>	0.4	2.5	0.0	0.0	20.5	0.0	<b>38.8</b>	19.4	6.8	0.0	0.0	<b>61.8</b>	0.0	<b>44.1</b>	5.9	14.7	0.0	0.0	0.0
May	0.9	0.0	<b>38.1</b>	0.9	<b>55.0</b>	0.0	0.7	0.0	0.0	4.2	4.2	15.6	0.0	<b>75.4</b>	6.9	0.0	<b>55.2</b>	13.8	<b>55.2</b>	0.0	6.9	0.0
June	26.9	0.0	<b>62.0</b>	1.1	1.9	0.0	3.9	0.2	0.0	1.5	1.4	0.1	0.0	<b>96.5</b>	<b>34.0</b>	0.0	<b>42.0</b>	16.0	20.0	0.0	<b>32.0</b>	0.0
July	7.9	0.0	9.2	<b>38.2</b>	13.2	0.0	27.6	0.0	0.0	0.03	5.7	0.1	0.0	<b>93.9</b>	10.5	0.0	5.3	<b>55.3</b>	7.9	0.0	<b>34.2</b>	0.0
August	1.9	2.6	26.2	<b>30.2</b>	21.6	0.0	0.0	0.0	0.2	1.6	<b>94.2</b>	3.4	0.0	0.0	5.3	7.0	10.5	<b>64.9</b>	<b>43.9</b>	0.0	0.0	0.0

Am, *Arthromysis magellanica*; At, *Acartia tonsa*; Ea, *Eurytemora americana*; Ido, *Idotea* sp.; Lsp, *Labidocera* sp.; Pp, *Peisoides petrunkevitchi*; ZN, *Neohelice granulata* zoea.

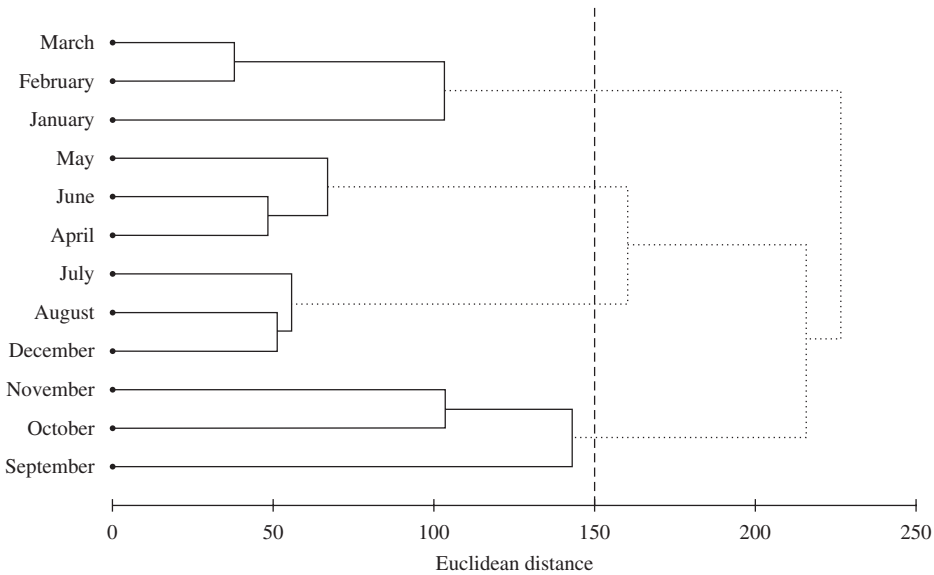


FIG. 5. Dendrogram of the cluster analysis based on the per cent frequency of occurrence ( $%F_o$ ) of the prey items in the stomach contents of *Ramnogaster arcuata* in Bahía Blanca estuary.

*parvus*, zoea of *N. granulata*, *Idotea* sp., veliger larvae, zoea of *Cyrtograpsus altimanus* and *Neomysis americana* (Table III).

The monthly variations in the available zooplankton that were the most abundant in the diet and the total zooplankton density ( $N\ m^{-3}$ ) are shown in Table V. In September, *E. americana* was the most abundant species, followed by *A. tonsa*, while during October, *A. tonsa* was the most abundant species, followed by *E. americana*.

TABLE V. Monthly variations of the zooplankton available abundance [number of individuals ( $N$ )  $m^{-3}$ ] found in Bahía Blanca estuary

Month	At	Eam	Amag	Ido	ZN	ZCy	$N\ m^{-3}$
September	24.6	47.0	0.5	0.4	5.2	1.5	316.04
October	64.1	19.9	0.5	0.9	4.2	0.9	730.05
November	48.5	0.2	0.5	0.5	6.3	0.5	355.35
December	90.9		0.1	0.2	3.3		712.26
January	90.5		0.1	0.1	0.5	1.4	1878.93
February	88.2		0.0	2.7	0.1	0.2	2084.91
March	78.2		2.1	0.4	1.7	0.9	433.18
April	93.2		0.1	0.3			1211.68
May	35.6		4.7	0.9	0.9		2115.65
June	58.6	24.1	0.2	0.8			407.63
July	3.6	14.6	0.6	0.6		1.2	86.91
August	6.3	10.8	0.5	0.5	0.9		186.11

Amag, *Arthromysis magellanica*; At, *Acartia tonsa*; Eam, *Eurytemora americana*; Ido, *Idotea* sp.; ZCy, *Cyrtograpsus altimanus* zoea; ZN, *Neohelice granulata* zoea.

From December to May (summer to autumn), *A. tonsa* exhibited high abundances, ranging from 90.9 to 35.6%, while *E. americana* was absent, and the remaining species did not reach 5% abundance. In June, *A. tonsa* was more abundant in number than *E. americana*, whereas in July and August, the latter species exhibited the highest values. The other species did not reach 2% (Table V).

## DIET SELECTION

Values of  $E$  for *R. arcuata* are shown in Fig. 6. The prey items mostly preferred throughout the year were *A. magellanica* and *Idotea* sp. *Eurytemora americana* was preferred in spring (September to November) and avoided in winter (June to August). *Neohelice granulata* and *C. altimanus* were selected from spring to the beginning of summer (October to January) and avoided for the rest of the year. *Acartia tonsa*, although it was dominant both in the diet of *R. arcuata* and in the zooplankton available, was weakly preferred during summer (February and March) and winter (July) and tended to be avoided for the rest of the year, showing negative  $E$  values.

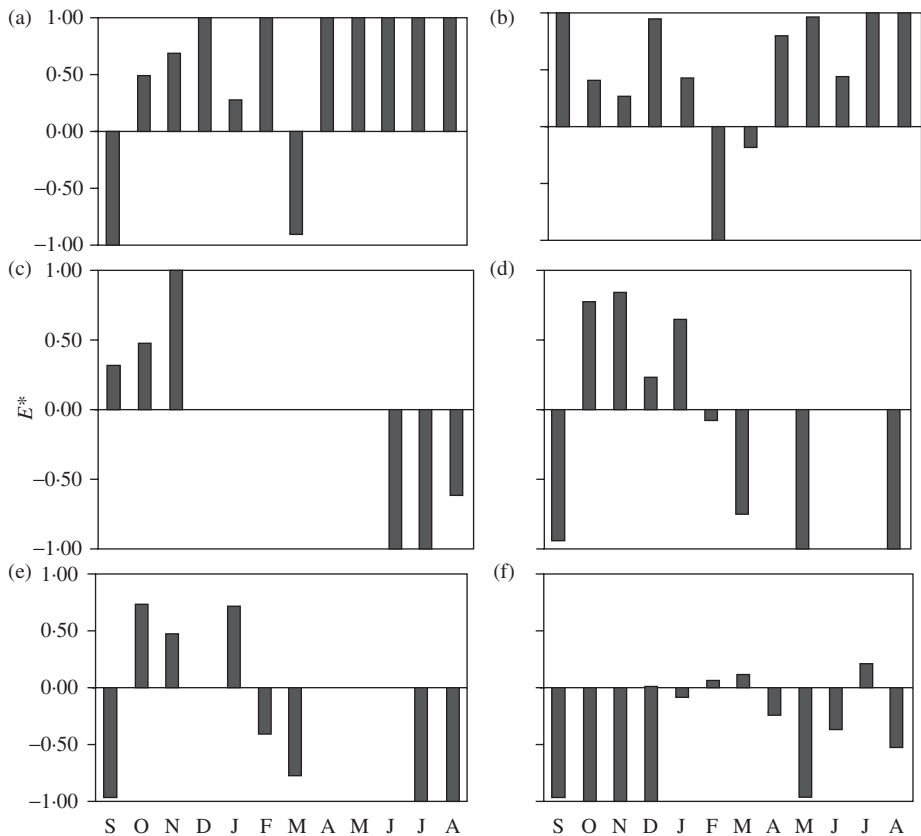


FIG. 6. Ilev electivity index ( $E$ ) values of the most important food items in *Ramnogaster arcuata*'s diet in Bahía Blanca estuary. (a) *Arthromysis magellanica*, (b) *Idotea* sp., (c) *Eurytemora americana*, (d) *Neohelice granulata* zoea, (e) *Cyrtograpsus altimanus* zoea and (f) *Acartia tonsa*.

## DISCUSSION

In the Bahía Blanca estuary, *R. arcuata* behaves as an estuarine species (Lopez Cazorla, 1987, 2004). Juveniles appear in September, and the adults remain in the estuary throughout the year. The minimum  $T_L$  registered from September to December was attributed to the minimum size retained by the net and coincided with the reproductive period, which begins in the study area in spring, as was reported by Lopez Cazorla & Sidorkewicz (2009). The two highest  $I_{SF}$  values recorded throughout the year were associated with the spawning period, with the first occurring in November, after the 2005 spawning period, and the second occurring in June, before the 2006 period. These findings are in agreement with those of Hunter & Goldberg (1980), who suggested that the spawning frequencies for clupeoids are limited by their energy reserves and food availability. This could explain why the spawning period for *R. arcuata* occurs during spring, when zooplankton densities begin to increase, as was mentioned by Hoffmeyer (2004).

In comparison with other regions, the diet of *R. arcuata* in the Bahía Blanca estuary partially coincides with findings from the coastal waters of Mar del Plata, Argentina (Olivier *et al.*, 1968), *i.e.* the diet consists mainly of Calanoidea (90.6%). Although the diet of *R. arcuata* is mainly composed of copepods in the Bahía Blanca estuary, other prey items that have not been previously recorded, such as the mysid *A. magellanica* and the small shrimp *P. petrunkevitchi*, were also important (% $I_{RI}$ , Table III).

The monthly variation of the prey items *A. tonsa*, *E. americana*, *A. magellanica* and *P. petrunkevitchi* in the diet of *R. arcuata* coincides with the seasonal variation in the abundance of these species in the zooplankton of the Bahía Blanca estuary, as was reported by Hoffmeyer (1983, 1994), Mallo & Cervellini (1988) and Cervellini (2004). Additionally, these zooplankton species play a key role in the trophic cycle in the plankton and represent important food items for several fishes in this estuary (Lopez Cazorla, 1987, 1996, 2004; Lopez Cazorla & Forte, 2005; Sardiña & Lopez Cazorla, 2005a, b, c).

Food and feeding habits determine the position of animals within food webs and define their ecological role (Pauly *et al.*, 1998). The  $T_L$  estimated in the present study for *R. arcuata* (3.1) is within the range estimated for other Clupeiformes inhabiting other regions of the world, such as *Brevoortia tyrannus* (Latrobe 1802) ( $T_L = 2.25$ ) (Froese & Pauly, 2011); anchovies and sardines inhabiting non-tropical shelves ( $T_L = 3.00 \pm 0.15$ , mean  $\pm$  s.e.) (Pauly & Christensen, 1995) and *Engraulis ringens* Jenyns 1842 ( $T_L = 2.2$ ) (Pauly *et al.*, 2000). In Argentine waters, *R. arcuata* presented a  $T_L$  less than that reported for *Sprattus fuegensis* (Jenyns 1842) ( $T_L = 3.4$ ) (Froese & Pauly, 2011); higher than that reported for *E. anchoita* Hubbs & Marini 1935 [ $T_L = 2.48$  according to Froese & Pauly (2006) and  $T_L = 2.77$  according to Milessi (2008)], and *Brevoortia aurea* (Spix & Agassiz 1829) ( $T_L = 2.75$ ) (Froese & Pauly, 2011); slightly higher than the data reported by Olivier *et al.* (1968) ( $T_L = 3.05$ ) for this species in coastal waters of Mar del Plata. The small difference between the  $T_L$  of *R. arcuata* found in Mar del Plata coastal waters and the Bahía Blanca estuary ( $T_L = 3.1$ ) could be the result of a wider food spectrum in the estuary. This result could also be a consequence of the characteristics of the Bahía Blanca estuary, which is shallow, with mean depth of *c.* 10 m and has a semi-diurnal tidal regime with amplitude of *c.* 4 m, and of the coastal behaviour of this fish. These factors could

allow *R. arcuata* to consume neritic and benthic species during the tidal cycle, such as mysids and isopods ( $T_L = 2.5$  and  $3.18$ , respectively) and *P. petrunkevitchi* ( $T_L = 2.52$ ; Sea Around Us, 2006), which are species with a  $T_L$  higher than zooplankton ( $T_L = 2.0$ ; Pauly *et al.*, 2000).

The diet composition of some fishes depends on the abundance of prey items in the environment (Nip *et al.*, 2003). The diet of *R. arcuata*, to some extent, appeared to follow this pattern. *Acartia tonsa* was the principal prey item of *R. arcuata* in terms of numerical abundance. The values of  $E$  for *A. tonsa*, however, tended to be negative because the proportion of this copepod was usually lower in the diet than in the environment. *Eurytemora americana* was actively selected by this fish in the spring, although the percentage of the abundance of this prey item decreased in the environment in this period. In contrast, in the winter, the abundance of this copepod increased in the environment, but not in the diet, and the values of  $E$  were negative at this time. *Arthromysis magellanica* and *Idotea* sp. were strongly selected almost throughout the year. *Idotea* sp. as a consequence of its benthic-vagrant behaviour (Olivier *et al.*, 1968), which may cause its abundance in the plankton samples to be misrepresented and the  $E$  value overestimated. The zoea of *N. granulata* and *C. altimanus* were selected during the spring and summer, when these species were most abundant in the environment, and avoided for the rest of the year, when they were less abundant.

Taken together, these findings show that prey selection by *R. arcuata* seems to be related to the size of prey items rather than to their abundance in the environment because the prey items that were strongly selected were the largest components of the zooplankton in this estuary. Although *P. petrunkevitchi* is a demersal-benthic prey species, which was not found in the zooplankton samples, it was the dominant prey item in terms of  $\%M_c$  in the general diet of *R. arcuata*. The same dominance in  $\%M_c$  of *P. petrunkevitchi* was also observed in the diets of juveniles of *C. guatucupa* and *M. furnieri* inhabiting this estuary (Sardiña & Lopez Cazorla, 2005a, b).

The results from this study confirm that *R. arcuata* is an important predator of zooplankton, and this is very useful information for assessing its potential interactions with the shallow water communities of the Bahía Blanca estuary. The trophic level estimated (3.1) may indicate that this species can be characterized as secondary consumer ( $T_L < 4$ ).

Given the limited information previously available about the diet and the trophic ecology of *R. arcuata*, this study represents an advance in the knowledge about this fish and provides an interesting conceptual framework for future comparisons and for understanding the effects of factors that could cause changes in ecosystem structure, such as overfishing, pollution and dredging.

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