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RESEARCH ARTICLE

Population ecology of *Sinelobus stanfordi* (Crustacea: Tanaidacea) in a temperate southern microtidal estuary

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Sinelobus stanfordi is a tanaidacean of worldwide distribution of considerable significance within coastal ecosystems. The aim of this research was to provide essential information on the poorly-known population biology of this species. Benthic samples were taken seasonally from winter 2005 through summer 2007 along 155 km of shoreline within the Río de la Plata Estuary, Argentina. The density of this tanaidacean was higher in vegetated than in bare sediments. The smaller individuals flourished in spring and summer, whereas the larger mature members prevailed in the cooler seasons. Females were always twice as abundant as males. Copulatory females, with 18 ± 8 eggs each, were collected during all the seasons. Five cohorts were distinguished by the von Bertalanffy growth function. This research represents a baseline investigation for future studies on the population dynamics of *S. stanfordi* both in this estuary and in other places where this species is found.

Keywords: Tanaidacea; population traits; Río de la Plata Estuary; intertidal zone; Argentina

Introduction

Tanaidaceans are a group of small benthic crustaceans distributed worldwide with great relevance in coastal trophic chains, since they constitute a major food source for higher levels, including species of commercial interest (Aguirre León & Díaz Ruiz 2000; Suárez Morales et al. 2004; Jaume & Boxshall 2008). Furthermore, because of tanaidaceans' sensitivity to pollutants and to physicochemical variations in water, this Order has been considered a potential indicator of pollution in water quality monitoring studies (Guerra García & García Gomez 2004; Ambrosio et al. 2014).

The genus *Sinelobus* Sieg, 1980 (Tanaididae) was originally considered to be monotypic, comprising a sole cosmopolitan species, *S. stanfordi* (Richardson, 1901). This species had been reported as an alien taxon in Europe (van Haaren & Soors 2009), but the individuals found in that region were, in fact, recently shown to belong to a new species, *S. vanhaareni* Bamber, 2014 (Bamber 2014). Moreover, three more species have been included in this genus in recent years: *S. pinkenba* Bamber, 2008, from Queensland, Australia; *S. barretti* Edgar, 2008, from Tasmania; and *S. Bathykolpos* Bamber, 2014 from Hong Kong (Bamber 2008; Edgar 2008; Bamber 2014). Although the status of the species found in Argentina has not been confirmed, we chose to maintain the classification as *S. stanfordi* in order to make comparisons with previous Argentine studies.

Sinelobus stanfordi is a euryhaline species that can be found in a wide range of habitats and physicochemical characteristics of water (Hendrickx & Ibarra 2008; van Haaren & Soors 2009; Ambrosio et al. 2014). The individuals build tubes in diverse

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substrates, mainly on sandy bottoms and within algae or macrophytes (Gardiner 1975). The relevance of this crustacean to coastal food chains and to the interrelationships with other macroinvertebrate species has been well documented (Ferreira et al. 2005; Cohen & Bollens 2008; Heiman et al. 2008; Kassuga & Masunari 2008), along with the species' potential use as a biomonitoring tool (Gómez et al. 2012; Ambrosio et al. 2014). Most of the pertinent literature deals with the morphology and distribution of *S. stanfordi*, whereas publications about the species' population ecology are much less abundant (dos Santos 2000).

The Río de la Plata Estuary receives freshwater from the del Plata Basin, the second largest watershed in South America (with an area of 3.2 million km^2), encompassing territories within Argentina, Bolivia, Brazil, Paraguay and Uruguay. Along the Argentine shoreline the vegetation is dominated by the California bulrush, *Schoenoplectus californicus* (C.A. Mey.) Soják, which provides refuge to several vertebrate and invertebrate species (Gómez & Rodrigues Capítulo 2000). Among the invertebrates, *S. stanfordi* and *Kalliapseudes schubarti* Mañé-Garzon, 1949 are the two tanaidacean species present in the benthic communities of this estuary (Taberner 1983; César et al. 2000; Gimenez et al. 2006). *Kalliapseudes schubarti* is less abundant and is mainly found in the outer portion where salinity is higher because of proximity to the Atlantic Ocean (AC Ferreira, pers. obs.). In contrast, *S. stanfordi*, in addition to being more abundant, is distributed along the entire salinity gradient of the estuary. Because of this wide distribution, the main aim of this research was to investigate and determine the preference between vegetated and bare sediments, the temporal distribution and the population structure of this species along the Argentine shore of the Río de la Plata Estuary. This information will provide a baseline for future investigations on the ecology of this tanaid and will also be useful as a point of comparison for similar studies in other tanaidacean species present in additional systems around the world.

Materials and methods

This research was carried out over 10 sampling sites distributed along a length of 155 km of Argentine coastline on the freshwater portion of the Río de la Plata Estuary (conductivity < 5000 µS cm^{-1}), between coordinates 34°27′10″S, 58°30′21″W and 35°16′45″S, 57°13′19″W (Fig. 1). Five seasonal samplings were made in winter 2005 (Wi05), spring 2005 (Sp05), autumn 2006 (Au06), winter 2006 (Wi06) and summer 2007 (Su07). Benthic samples were taken in the intertidal zone with an Ekman grab (100 cm^2) in two different habitats: sediments within stands of the California bulrush (*S. californicus*); and sediments free of vegetation.

At all sites, invertebrate samples were taken in triplicate from each habitat and fixed in situ with 5% (v/v) formaldehyde. The benthic material was sorted with sieves (250 µm) and processed according to Rodrigues Capítulo et al. (1997). The *S. stanfordi* individuals were sorted, counted and classified according to developmental stage after Toniollo & Masunari (2007), namely: manca stages II and III (i.e. M II and M III differentiated by the absence or only incipient presence of pleopods, respectively; Fig. 2A–B); juveniles (with well developed pleopods and secondary dimorphism absent, which stages we classified ad hoc according to their size as: Juv I, from 1.05 to 2 mm; and Juv II, from 2.05 to 3 mm; Fig. 2C); males (individuals with strong forceps and antennas; Fig. 2D); copulatory females (i.e. Cop fem carrying eggs in one or two marsupia; Fig. 2E) and preparatory females (i.e. Prep fem evidenced by the presence of oostegites; Fig. 2F).

Individuals were measured from the tip of the carapace to the distal medial margin of the pleotelson with a micrometric ocular. Age structure, size distributions and sex ratio were determined according to the abundance of each developmental stage, while fecundity was defined as the number of eggs per copulatory female. Population growth was estimated on the basis of monthly size-frequency histograms through modal-progression analysis and the von Bertalanffy growth function (von Bertalanffy 1960). The differences among cohorts were evaluated by comparing the slopes of the growth function curves (Zar 1999). The habitat preferences of *S. stanfordi* were assessed through a Mann-Whitney U test according to the abundance

Figure 1 Study area showing the sampling sites (S1–S10) located along 155 km of the Argentine coast of the Río de la Plata Estuary (Argentina, South America) with the most populated areas indicated in grey. Sampling period: winter 2005 through summer 2007.

of the species in the sediments free of vegetation and those related to the California bulrush. The spatial and temporal differences in abundance of this tanaid in the study area were assessed by a two-way ANOVA (with factors 'Site' and 'Season'). All statistical analyses were based on Zar (1999), with the significance level set at $P < 0.05$.

The relationship between the abundance of this crustacean and the environmental conditions (water quality) has been presented in a previous publication (cf. Ambrosio et al. 2014).

Results

Sinelobus stanfordi was found in only eight of the 50 samples taken in the sediments free of vegetation over the length of the entire estuary (giving a total of 345 individuals), whereas in sediments associated with the California bulrush, the species was present in 39 out of the 50 samples analysed (1382 individuals), with the difference in abundance being highly statistically significant ($P < 0.01$). On the basis of this finding, the results presented in this section pertain to the data collected among the bulrush stands.

Although the crustaceans were distributed throughout the entire study area, the abundance at each site exhibited a wide temporal variability over the year, which eliminated any statistical differences between sampling sites ($P = 0.80$). Despite the absence of statistical differences over time ($P = 0.59$), the densities recorded nevertheless were generally higher during the warmer seasons (spring, summer and autumn; 2206 ± 2942 ind m^{-2}, 853 ± 1291 ind m^{-2} and 1000 ± 933 ind m^{-2}, respectively) and were the lowest in winter (586 ± 1309 and 640 ± 696 ind m^{-2} in Wi05 and Wi06, respectively) (Fig. 3).

More than 1300 individuals were measured and classified according to their developmental stages.

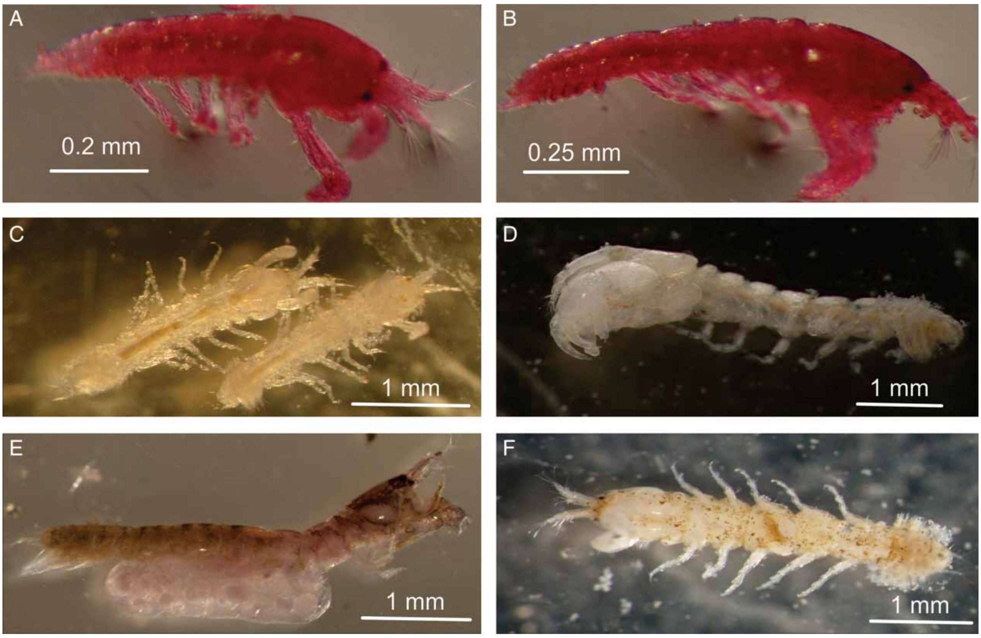

Figure 2 Developmental stages of *Sinelobus stanfordi*. **A,** Manca II; **B,** manca III, **C,** juvenile; **D,** male; **E,** copulatory female; **F,** preparatory female.

Table 1 lists their minimum, maximum and mean sizes (mm). All developmental stages were represented throughout the year (Fig. 4), with sizes ranging from 0.45 to 4.60 mm. During the colder periods (Wi05 and Wi06), the frequency distribution was shifted towards the largest body sizes, corresponding to the advanced juvenile stages along with the mature adults (Fig. 4). In contrast,

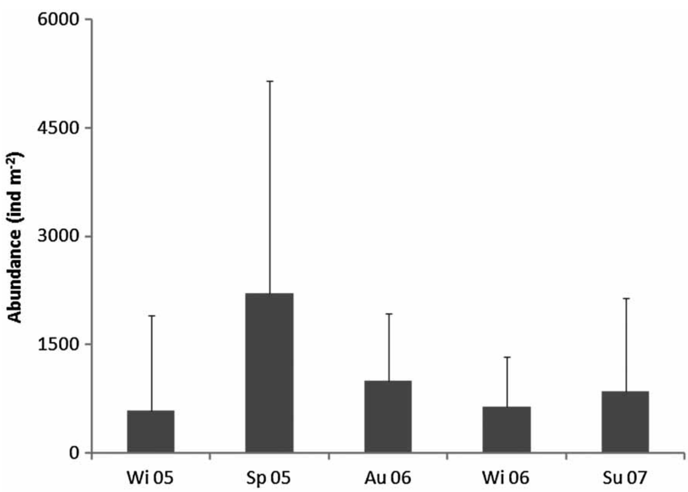

Figure 3 Mean density of *Sinelobus stanfordi* in the different seasons studied. Wi05, winter 2005; Sp05, spring 2005; Au06, autumn 2006; Wi06, winter 2006; Su07, summer 2007.

during the warmest periods (Sp05 and Su07), the frequency distribution shifted towards the smallest sizes—those corresponding to the earliest developmental levels (mainly the manca and Juv I stages; Fig. 4). In Au06, the age structure was dominated by juvenile individuals (mainly Juv II; Fig. 4).

Females were always more abundant than males, at an average ratio of 0.7:0.3. Copulatory females were recorded in all seasons, at a maximum of 283 ind m^{-2} during Sp05 and a minimum of 33 ind m^{-2} during Wi06 (over the 10 sites sampled). The mean fecundity was 18 ± 8 eggs per female, with a maximum of 37 and a minimum of five eggs present in one or two marsupia.

Five cohorts throughout the year were identified (Fig. 5) whose growth constants (k) varied between 1.31 and 2.52 (cohorts three and five, respectively), while the infinite lengths fell between 5.09 and 6.27 mm (cohorts five and four, respectively; Table 2). The multiple-comparison test between the slopes demonstrated significant differences between the cohorts ($P < 0.05$), with cohorts four and five being the most similar to each other. The greatest number of hatches occurred in the spring (cohort five).

Table 1 Minimum (Min), maximum (Max) and mean size (mean ± SD) in mm for each developmental stage.

	M II	M III	Juv I	Juv II	Prep fem	Cop fem	Males
Min	0.45	0.75	1.1	2.01	2.1	2.1	2.3
Max	1.2	1.8	2	3	4.4	4.3	4.6
Mean	0.88 (± 0.09)	1.14 (± 0.14)	1.74 (± 0.16)	2.47 (± 0.26)	3.21 (± 0.45)	3.19 (± 0.40)	3.26 (± 0.36)
n	222	144	319	286	225	64	122

n, number of individuals measured; M, manca; Juv, juveniles; Prep fem, preparatory females; Cop fem, copulatory females.

Discussion

The presence of vegetation in aquatic environments is of great relevance since these plants provide not only food but also refuge to small invertebrates such as *S. stanfordi* (Ferreiro et al. 2011; Cortelezzi et al. 2013). Accordingly, along the whole estuary, this tanaid was more abundant among the bulrush stands than in the bare sediments. These results coincide with those of dos Santos (2000) who also recorded high densities of *S. stanfordi* among bulrush stands as well as among other macrophyte species such as *Ceratophyllum demersum* L., *Bacopa monnieri* (L.) Wettst. and *Websteria confervoides* (Pior.) S.S. Hooper. A high number of *S. stanfordi* individuals, however, can also be found in hard substrata in association with sessile invertebrates including sponges, balanids, corals and bivalves (Gardiner 1975; van Haaren & Soors 2009). Therefore, the high densities recorded in some of the samples taken in sediments free of

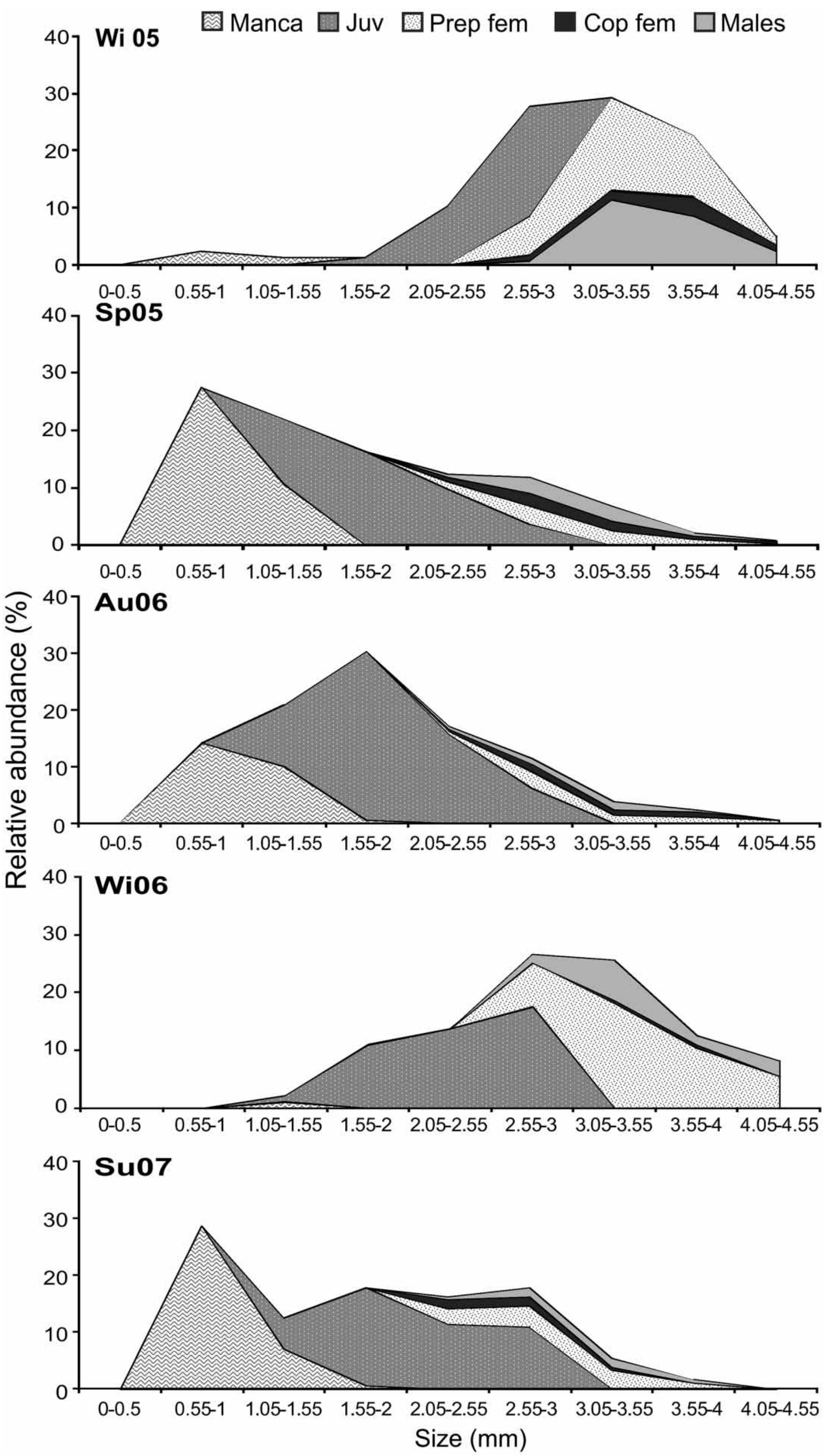

Figure 4 Size distribution of *Sinelobus stanfordi* at different sampling opportunities. Wi05, winter 2005; Sp05, spring 2005; Au06, autumn 2006; Wi06, winter 2006; Su07, summer 2007.

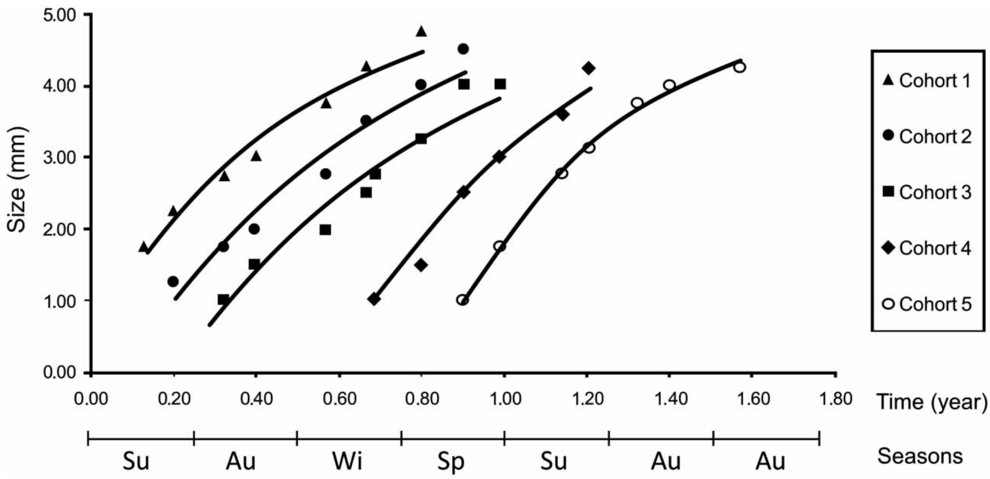

Figure 5 Cohorts identified within the population of *Sinelobus stanfordi* in the Río de la Plata Estuary.

vegetation could be explained by the presence of stones covered by the invasive freshwater mussel *Limnoperna fortunei* (Dunker, 1857), since in the Río de la Plata Estuary *S. stanfordi* has been found forming part of the fauna usually associated with that mollusc (Spaccesi & Rodrigues Capítulo 2012).

The abundance of *S. stanfordi* was higher during the warmer seasons (spring, summer and autumn) than in winter, in accordance with the results of dos Santos (2000) for populations of this species in a temperate zone of Brazil. Although that pattern was observed in the present work, the lack of statistical differences within the seasonal distribution in our study resulted from the high dispersion of data. Such dispersion can be explained by two conditions—the spatial distribution of the species and the dynamics of the study area (it being a microtidal estuary). Many tanaidaceans exhibit a clustered distribution (Modlin & Harris 1989; Leite et al. 2003), and if this is not taken into account a priori when sampling is done, the omission can lead to 'false zero' values of density that increase the dispersion of the data (Martín et al. 2005). In addition, the Río de la Plata Estuary is a complex and constantly changing system in which water levels and environmental conditions can vary on all temporal scales (e.g. daily, monthly and seasonally), so as to produce a great variability in the population dynamics of the benthic fauna (Rodrigues Capítulo et al. 2003). Consequently, the sampling design of future studies should consider both the spatial and temporal distribution patterns of *S. stanfordi* at a mesoscale level.

The greater abundance of the copulatory females recorded in the spring and summer coincides with a

Table 2 Growth constants (k), infinite lengths ($L\infty$) and t_0 of *Sinelobus stanfordi* cohorts identified in the Río de la Plata Estuary.

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
$L\infty$	5.39	5.88	5.95	6.27	5.09
k	2.09	1.48	1.31	1.60	2.52
t_0	–0.04	0.07	0.19	0.58	0.82

higher recruitment of the young stages. The lesser abundances of young individuals during cold seasons, however, might be caused by an increased mortality of those developmental phases under low temperatures (Toniollo & Masunari 2007). In the present study, the young stages overlapped in size with the mature ones, as reported for a natural population of *K. schubarti* in a tropical coastal lagoon in Brazil (Pennafirme & Soares Gomes 2009). The mean size of each developmental stage of *S. stanfordi* was furthermore larger than that obtained by Toniollo & Masunari (2007) in laboratory cultures of the same species. This difference might be caused by the difficulties found in the proper classification of the corresponding developmental stage when working with material collected in the field. Moreover, the individuals measured in the report cited could also represent another very similar *Sinelobus* species having slightly different developmental stages, but this possibility could be resolved only by a verification of the definitive status of that species.

As with most of the tanaidacean species, the females of *S. stanfordi* were present in a greater proportion than the males (Masunari 1983; Kneib 1992; De la Ossa Carretero et al. 2010). Although certain species often exhibit what is referred to as sexual reversion or protogynous hermaphroditism (Modlin & Harris 1989; Gutu & Sieg 1999), such a possibility has been discarded for this species since sexual dimorphism is present from the juvenile stage onwards, and no such form of hermaphroditism has been detected in cultures in the laboratory (Toniollo & Masunari 2007).

Sinelobus stanfordi is a multiparous species (Toniollo & Masunari 2007), which characteristic explains the presence of copulatory females during the whole sampling period. A reproductive peak was, however, observed during the warmest seasons. These results coincide with those reported for *Hargeria rapax* (Harger, 1879), another tanaidacean found in temperate zones (Modlin & Harris 1989). Two populations of *K. schubarti* inhabiting different latitudes of Brazil likewise exhibit differences in reproductive peaks and growth rates (Leite et al. 2003; Pennafirme & Soares Gomes 2009). It would therefore be interesting to know whether populations of *S. stanfordi* from tropical or subtropical latitudes exhibit the same seasonal dynamic observed in the present study.

Although we noted significant differences in the slopes of the growth curves for the five cohorts, these plots—corresponding to individuals whose births occurred at the beginning of the spring (e.g. cohorts four and five)—were quite similar to each other. In addition, with births taking place during the winter season (e.g. cohorts two and three) we noted a deceleration in the birth rates as reflected in lower *k* values. This phenomenon is common to other crustacean species within this temperate region, such as the shrimp *Palaemonetes argentinus* Nobili, 1901 (Rodrigues Capítulo & Freyre 1989). Furthermore, Toniollo & Masunari (2007) stated that the development from the M II stage to the copulatory stages (for both males and females) occurred within 35 days in summer, whereas in winter the corresponding transition took almost 65 days.

In conclusion, this work constitutes the first in-the-field population study on *S. stanfordi* in a temperate estuary. The results reported here provide information about the population dynamics of this species which should be most useful for future investigations. Therefore, further studies on this tanaid would need to take the following into account: the species is more likely to be found in vegetated areas than in bare sediments; the sampling design should consider the spatial distribution pattern in order to avoid 'false zero' values; a higher recruitment of copulatory females and young individuals occurs during warmer seasons, at least in temperate regions; and five cohorts can be found in temperate areas. These data constitute a baseline for the comparison of populations of *S. stanfordi* in other regions where this species is found.

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Disclosure statement

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