Aquat Ecol (2006) 40:349–360
DOI 10.1007/s10452-006-9039-1

ORIGINAL PAPER

Effects of NaCl salinity on the population dynamics of freshwater zooplankton (rotifers and cladocerans)

S. S. S. Sarma · S. Nandini · Jesús Morales-Ventura · Israel Delgado-Martínez · Leticia González-Valverde

Received: 10 February 2005 / Accepted: 24 February 2006 / Published online: 4 August 2006

Abstract Salinization of freshwater bodies due to anthropogenic activity is currently a very serious problem in Mexico. One of the consequences may be changes in the rotifer and cladoceran populations, both of which are generally abundant in freshwater bodies. Under laboratory conditions we evaluated the effect of different salt (sodium chloride) concentrations (0–4.5 g l^{-1}) on the population dynamics of ten freshwater zooplankton species (rotifers: *Anuraeopsis fissa*, *Brachionus calyciflorus*, *B. havanaensis*, *B. patulus* and *B. rubens*; cladocerans: *Alona rectangula*, *Ceriodaphnia dubia*, *Daphnia pulex*, *Moina macrocopa* and *Simocephalus vetulus*). All of the zooplankton species tested were adversely affected by 1.5–3.0 g l^{-1} NaCl. In the range of salt concentrations tested, the population growth curves of *B. patulus* and *B. rubens* showed almost no lag phase and reached peak abundances within a week or two; *A. fissa* had a lag phase of about a week, while both *B. calyciflorus* and *B. havanaensis* started to increase in abundance immediately following the initiation of the experiments. Increased NaCl levels reduced the population abundances of *A. fissa*, *B. calyciflorus* and *B. havanaensis* at or beyond 1.5 g l^{-1}. NaCl at 1 g l^{-1} had little effect on the population growth of cladocerans. *M. macrocopa*, which was more resistant to NaCl than the other cladoceran species, showed positive population growth even at 4.5 g l^{-1}. The rates of population increase (r, day^{-1}) were generally higher for rotifers than for cladocerans. Depending on the NaCl concentration, the r of rotifers ranged from +0.57 to –0.58 day^{-1}, while the r for cladocerans was lower (+0.34 to –0.22 day^{-1}).

Keywords Cladocerans · Freshwater bodies · Population dynamics · Rotifers · Salinity

S. S. S. Sarma (✉) · I. Delgado-Martínez · L. González-Valverde
Laboratorio de Zoología Acuática, Edificio UMF, Universidad Nacional Autónoma de México – Campus Iztacala, Tlalnepantla, Edo. de México AP 314, CP 54090, Mexico
e-mail: sarma@servidor.unam.mx

S. Nandini
UIICSE, División de Investigación y Posgrado, Universidad Nacional Autónoma de México – Campus Iztacala, Tlalnepantla, AP 314, CP 54090 Edo. de México, Mexico

J. Morales-Ventura
National Institute of Fisheries (DGIDT), Santa Cruz Atoyac, Mexico City, Mexico

Introduction

Natural changes, such as the seasonal evaporation of water from freshwater bodies, can contribute to an increase in the salinity of many aquatic

ecosystems (Das et al. 1995; Williams et al. 1998). Salinization of freshwater bodies due to anthropogenic activity is currently a serious problem in Mexico (Mendoza and Acevedo 2001; Alcocer and Sarma 2002). Zooplankton groups, particularly rotifers, cladocerans and copepods, represent the dominant component in freshwater bodies and are the natural food link between the primary producers (algae) and zooplanktivorous fish. As such they are important in the maintenance of an ecological balance in freshwater ecosystems (Nogrady et al. 1993). Unlike copepods, which are dominant in marine systems, rotifers and cladocerans are largely restricted to freshwater habitats. In addition, both of these groups are generally very sensitive to salinity (Dodson and Frey 2001; Wallace and Snell 2001). Thus, an increase in salt levels in freshwater ecosystems affects the dynamics and abundance of rotifers and cladocerans (Akopian et al. 2002).

The ionic composition of Mexican inland waters varies considerably. For example, the water of natural saline lakes such as Alchichica and Atexcac comprise 39% sodium, 7% magnesium and 3% potassium with 36% chloride and 6% bicarbonate. In terms of salinity, the water of inland saline lakes of Mexico contain 12–14 g salts per liter (Figueroa 2002). On the other hand, freshwater lakes, such as Cuitzeo, which 40 years ago had low salt levels (<0.3 g l^{-1}), now show increased salinity (up to 5 g l^{-1}) mainly due to anthropogenic processes. In Cuitzeo, the predominant ions are sodium (61%), potassium (17%), magnesium (13%) and calcium (8%) (Torres and Días 2002).

The use of freshwater zooplankton for evaluating the impact of increased salinity levels has some relevance to the management of freshwater bodies and aquacultural ponds. First, it permits the limits of salt tolerance to be established so that remedial measures can be taken to protect freshwater waterbodies from salinization (Peredo-Alvarez et al. 2003). Second, if a certain freshwater zooplankton species can tolerate high salinity, its mass cultures can be attempted for use as live food for both fish and shrimp cultures. It has been documented that several fish belonging to the family Aetherinidae prefer mildly saline conditions (up to 10 g l^{-1}), particularly during their early life history stages (Martínez-Palacios et al. 2004). Third, it has been reported that with gradual acclimatization, some euryhaline zooplankton may eventually tolerate very high salinity levels (>50 g l^{-1}) (Mustahal et al. 1991). If attempts to culture freshwater zooplankton at various salinity levels succeed, it may reduce the dependence on the costly, imported and often mixed *Artemia* cysts for aquaculture (Campos-Ramos et al. 2003).

Unlike the life table demographic method, population dynamics offers the possibility of studying more than one generation of individuals within a short period (Sarma and Nandini 2002). This also enables the sum of the mortality and natality of a population to be quantified through changes in abundance (Krebs 1985).

In the investigation reported here, we evaluated the effect of different salt (sodium chloride) concentrations on the population dynamics of ten freshwater zooplankton species (rotifers: *Anuraeopsis fissa* (Gosse), *Brachionus calyciflorus* Pallas, *B. havanaensis* Rousselet, *B. patulus* (Müller) and *B. rubens* (Ehrenberg) (all in Brachionidae); cladocerans: *Alona rectangula* Sars (Chydoridae), *Ceriodaphnia dubia* Richard, *Daphnia pulex* Leydig, *Simocephalus vetulus* Schoedler (all three in Daphniidae) and *Moina macrocopa* Goulden (Moinidae).

Materials and methods

The single-celled green alga *Chlorella vulgaris* (stock CL-V-3; CICESE, Ensenada, Baja California, Mexico) was batch cultured on defined medium (Bold's basal medium; Borowitzka and Borowitzka 1988) in 2-l transparent bottles and used as food for the zooplankton. Log-phase algae were harvested by centrifugation at 4,000 rpm; the algal concentrate was then rinsed in distilled water and resuspended in moderately hard water [U.S. Environmental Protection Agency (EPA) medium: 96 mg $NaHCO_3$, 60 mg $CaSO_4$, 60 mg $MgSO_4$ and 4 mg KCl in 1 l distilled water (Weber 1993)]. A hemocytometer was used for estimating the density of the algae.

The zooplankton species to be tested were originally collected from different freshwater

bodies (with a salinity < 0.5 g l^{-1}) in Central Mexico and have been cultured in our laboratory for the past 5 years. Stock cultures of the zooplankton species were maintained in EPA medium containing *Chlorella* at a density of 0.25×10^6–1.5×10^6 cells ml^{-1}.

Saline concentrations for the experiments were prepared daily using analytical grade NaCl. Unless otherwise specified, the term 'salt' used in this study refers to NaCl and the resulting salinity is due to the concentration of this salt. The range of NaCl concentrations to be tested depended on the zooplankton species, and as such we chose an overall range of 0 g l^{-1} (no NaCl added) to 4.5 g l^{-1}. Thus, for *Anuraeopsis fissa*, *Brachionus calyciflorus* and *B. havanaensis*, we used NaCl concentrations of 0.375, 0.75, 1.5 and 3.0 g l^{-1} water. For *B. patulus*, *B. rubens*, *Ceriodaphniadubia* and *Moina macrocopa*, we deleted the lowest (0.375 g l^{-1}) NaCl concentration and replaced it with one at the higher end of the range (4.5 g l^{-1}). For *Alona rectangula*, *Daphnia pulex* and *Simocephalus vetulus*, the NaCl concentrations were 0.5, 1.0, 2.0 and 4.0 g l^{-1}. Depending on the zooplankton species, we selected one of the three food densities (0.25×10^6, 0.5×10^6 or 1.5×10^6 cells ml^{-1}), which was enough food to enable one population cycle of the specific zooplankton to be completed. *A. fissa*, *B. calyciflorus* and *B. havanaensis* received a daily algal density of 0.25×10^6 cells ml^{-1}; *A. rectangula*, *D. pulex* and *S. vetulus* received double this level, while the remainder of the zooplankton species to be tested received an algal density of 1.5×10^6 cells ml^{-1}. Similarly, the inoculation densities in the test jars were dependent on the body size of zooplankton species. Thus, with the exception of *D. pulex* and *S. vetulus* [for which the initial density was 0.1 individual (ind.) per milliliter], it was 0.4 ind. ml^{-1}.

All experiments were conducted simultaneously. The general test conditions were similar for all species, and these were used for maintaining both stock and mass zooplankton cultures without crashes. These were: a temperature of 20±1°C, a pH of 7.0–7.5, a continuous but diffused fluorescent illumination, three replicates for each treatment, daily replenishment of algal food with fresh test medium, test volumes of 50 ml for cladocerans and 25 ml for rotifers. For cladocerans, we estimated the density by total counts, while for rotifers, aliquots of 1–5 ml for each replicate were used when the density was higher than 10 ind. ml^{-1}. The growth experiments lasted 3 weeks for all species except *M. macrocopa* for which it was 2 weeks. For each zooplankton species we used 20 [=five salt concentrations (including the control) × four replicates] transparent test jars. Thus, in all we used 200 jars for the ten zooplankton species. Into each of the test jars, we introduced individuals of a mixed age group (about 70% juveniles) of a specified zooplankton species using a Pasteur pipette under stereomicroscope at a magnification of 20×.

Based on the data of population abundance, we obtained the peak density and the growth rates (r) using one of the two following equations, depending the nature of the growth curve for each replicate (Krebs 1985):

$$r = (\ln N_t - \ln N_0)/t$$

where N_t and N_0 are the final and initial population densities and t is the time

$$\frac{dN}{dt} = rN\frac{(K-N)}{K}$$

where, K is the carrying capacity.

For each species, data of the peak population abundance and the r were treated statistically using analysis of variance (ANOVA) for evaluating the differences among the treatments (Sokal and Rohlf 2000).

Results

Population growth curves of *B. patulus* and *B. rubens* (Fig. 1) showed almost no lag phase and reached peak abundances within a week or two. Increases in the NaCl concentration decreased the population densities, but adverse effects were visible only at salt concentrations higher than 3 g l^{-1}. At a salinity of 4.5 g l^{-1}, *B. patulus* population barely survived beyond 2 days, while *B. rubens* showed some growth for the first 5 days but eventually collapsed in less than 2 weeks. The population growth curves of *A. fissa*,

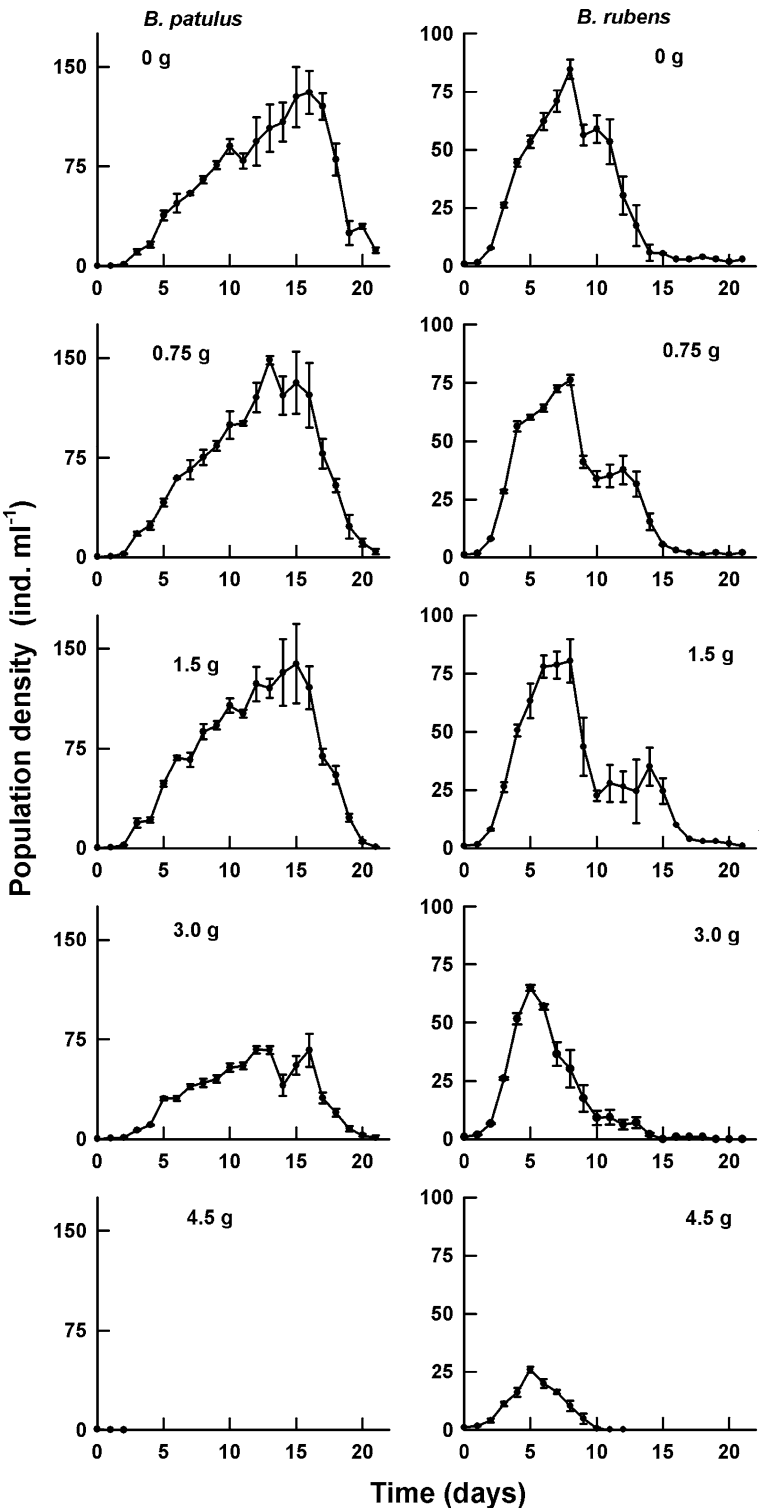


Fig. 1 Population growth curves of *Brachionus patulus* and *B. rubens* under different salt (NaCl) concentrations. Points are the mean ± standard error based on three replicates. Note the differences on the *Y-axis* scales

B. calyciflorus and *B. havanaensis* differed greatly from those of *B. patulus* and *B. rubens* (Fig. 2). *A. fissa* had a lag phase of about a week, while both *B. calyciflorus* and *B. havanaensis* started to increase in abundance immediately after the initiation of the experiments. Depending on the NaCl concentration, *B. calyciflorus* reached peak abundances in less than a week, *B. havanaensis* in about 10 days and A. *fissa* in 2 weeks. Increased NaCl concentrations had a negative effect on the population abundances of *A. fissa*, *B. calyciflorus* and *B. havanaensis* at and beyond 1.5 g l^{-1}. Regardless of the NaCl concentration, *A. fissa* was always numerically more abundant than the other rotifer species.

C. dubia and *M. macrocopa* showed a decreased population abundance with an increase in NaCl concentration. However, *M. macrocopa* maintained a population density of about 4 ind. ml^{-1} even at the highest salt concentration tested (4.5 g l^{-1}), while *C. dubia* did not grow at this salt concentration and all replicates died after the second week. In general, increased levels of NaCl had a more adverse effect on *C. dubia* than *on M. macrocopa* (Fig. 3). Salt concentrations at or below 1 g l^{-1} had little effect on the population growth of *A. rectangula*, *D. pulex* and *S. vetulus* (Fig. 4); however, at 2 and 4 g l^{-1}, all these cladoceran species were negatively affected. Regardless of the salt concentration, *A. rectangula* was always numerically more abundant than the other cladoceran species.

Peak population densities of all the zooplankton species tested were significantly influenced by the salt concentration ($p>0.05$, *F*-test, one-way ANOVA). The rates of population increase were in general higher for rotifers than for cladocerans (Table 1). Depending on the salt concentration and the algal density chosen, the *r* of rotifers ranged from +0.574 to –0.58 day^{-1}, while the *r* for cladocerans was lower (+0.34 to –0.22 day^{-1}).

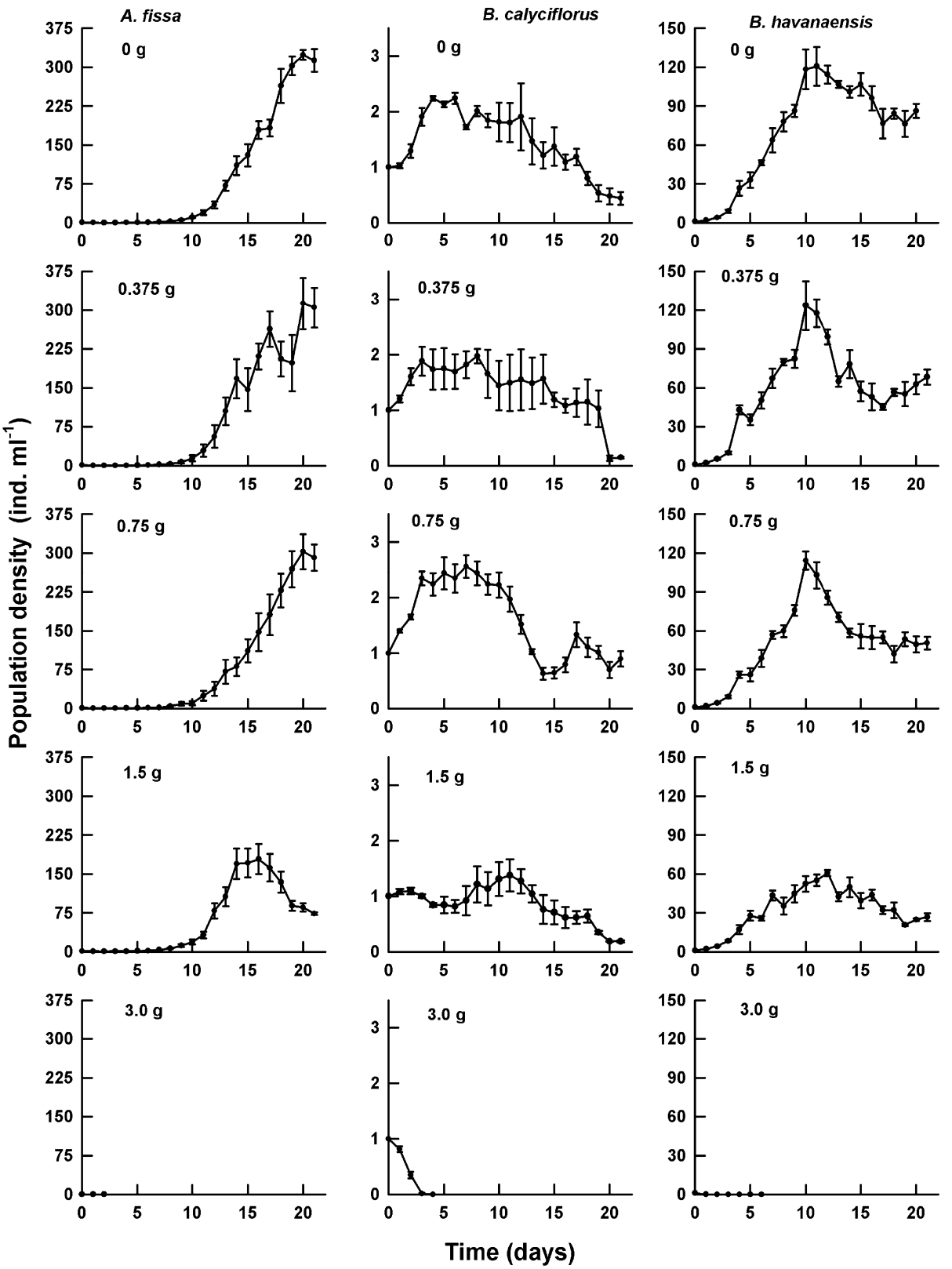
Discussion

Among the abiotic factors influencing the survival and abundance of zooplankton inhabiting temporary water bodies, salinity is one of the most important (Williams 1987; Dodson and Frey 2001; Wallace and Snell 2001). The dominant ions of the freshwater bodies from which the present zooplankton species were originally collected (from the State of Mexico and Mexico City) were carbonates, bicarbonates and sulfates rather than the chlorides which are dominant in sea and brackish waters (Figueroa 2002). There is some debate on the validity of using pure NaCl as the source of salinity when investigating organisms collected from bodies of water with different ionic compositions (Kefford et al. 2004). However, Sarma et al. (2005a) reported that invertebrate organisms such as rotifers that inhabit temporary water bodies in which high salt concentrations are the result of different ionic composition were able to tolerate the same levels of salinity based on NaCl concentration. For example, Sarma et al. (2002) observed that both *Hexarthra jenkinae* and *Brachionus rotundiformis* collected from a natural lake with high sulphate and carbonate levels (with a salinity of about 10 g l^{-1}) grew well when reared on a medium containing NaCl at 12 g l^{-1}. Kefford et al. (2004) have compared the salinity tolerances of freshwater invertebrates, including cladocerans, using different salts [for example, pure NaCl, Ocean Nature (Aquasonic, Australia) and pure Na_2SO_4]. Although they found differences in the median lethal concentrations depending on the source of the salts, there was a linear relation between tolerance levels to Ocean Nature salts and NaCl. The results of the present study are not directly comparable to those of Kefford et al. (2004) because the test species are not of marine origin and because tolerance capacities may differ when the test species are allowed to grow at sublethal salt levels. In most studies, including that of Kefford et al. (2004), the influence of salt concentrations at the population level was not carried out.

In nature, freshwater zooplankton may sporadically be exposed to NaCl when rivers carrying them enter the ocean (Akopian et al. 2002). Field observations indicate that very few species of

▶

Fig. 2 Population growth curves of *Anuraeopsis fissa*, *B. calyciflorus* and *B. havanaensis* under different salt (NaCl) concentrations. Points are the mean ± standard error based on three replicates. Note the differences on the *Y-axis* scales


A. fissa
B. calyciflorus
B. havanaensis
0 g
0.375 g
0.75 g
1.5 g
3.0 g
Population density (ind. ml-1)
Time (days)

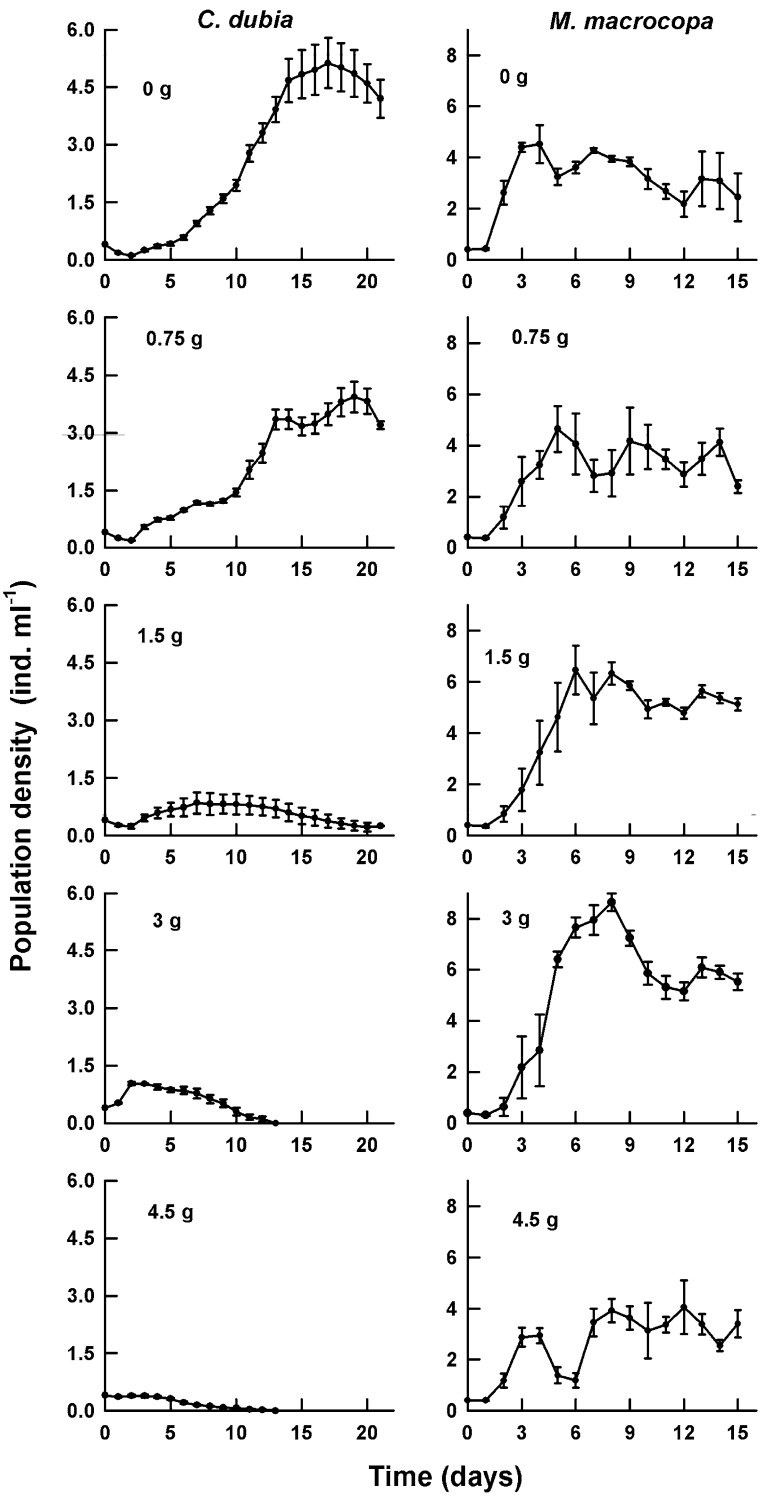
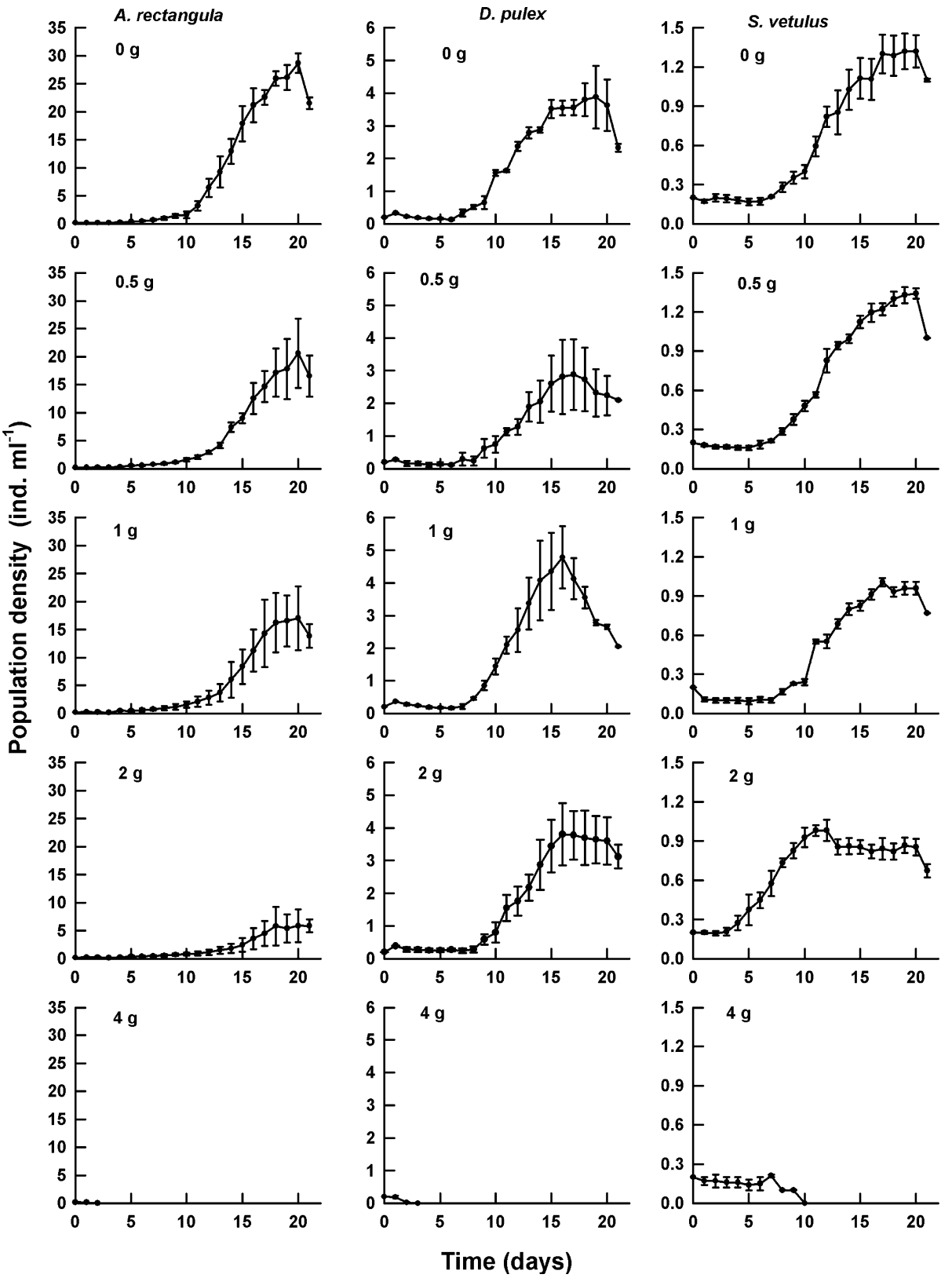


Fig. 3 Population growth curves of *Ceriodaphnia dubia* and *Moina macrocopa* under different salt (NaCl) concentrations. Points are the mean ± standard error based on three replicates. Note the differences on the *X- and Y-axis* scales

freshwater rotifers tolerate high salt concentrations (at or above 5 g l^{-1}) (Green 1993). However, there are very little quantitative data available on the population growth of many common species of rotifers and cladocerans in relation to salt stress. Peredo-Alvarez et al.


A. rectangula
D. pulex
S. vetulus
0 g
0.5 g
1 g
2 g
4 g
Population density (ind. ml-1)
Time (days)

◀
Fig. 4 Population growth curves of *Alona rectangula*, *Daphnia pulex* and *Simocephalus vetulus* under different salt (NaCl) concentrations. Points are the mean ± standard error based on three replicates. Note the differences on the *Y-axis* scales

(2003) documented the population growth of *B. calyciflorus* and *B. patulus* (strains different from those used here) under different concentrations of NaCl and observed that both of these

Table 1 Data on rate of population increase per day (*r*) obtained for different zooplankton species grown in different NaCl concentrations

Zooplankton species	Salt concentration (g l^{-1})	*r* (Mean ± standard error)[a]
Rotifers		
Anuraeopsis fissa	0.0	0.378±0.006
	0.375	0.375±0.010
	0.75	0.371±0.005
	1.5	0.286±0.029
	3.0	Not determined[b]
Brachionus calyciflorus	0.0	0.194±0.028
	0.375	0.155±0.026
	0.75	0.156±0.026
	1.5	0.173±0.059
	3.0	–0.578±0.11
B. havanaensis	0.0	0.407±0.055
	0.375	0.451±0.025
	0.75	0.447±0.019
	1.5	0.352±0.021
	3.0	Not determined
B. patulus	0	0.435±0.005
	0.75	0.416±0.014
	1.5	0.412±0.004
	3.0	0.382±0.006
	4.5	Not determined
B. rubens	0.0	0.566±0.003
	0.75	0.561±0.005
	1.5	0.563±0.006
	3.0	0.462±0.006
	4.5	0.336±0.006
Cladocerans		
Alona rectangula	0	0.305±0.001
	0.5	0.260±0.012
	1.0	0.255±0.003
	2.0	0.191±0.005
	4.0	Not determined
Daphnia pulex	0	0.196±0.010
	0.5	0.182±0.012
	1.0	0.189±0.004
	2.0	0.179±0.001
	4.0	Not determined
Simocephalus vetulus	0	0.129±0.030
	0.5	0.133±0.010
	1.0	0.123±0.002
	2.0	0.101±0.001
	4.0	–0.05±0.006
Ceriodaphnia dubia	0	0.228±0.001
	0.75	0.164±0.005
	1.5	0.023±0.011
	3.0	–0.081±0.007
	4.5	–0.218±0.010
Moina macrocopa	0	0.331±0.012
	0.75	0.221±0.006
	1.5	0.297±0.005
	3	0.338±0.005
	4.5	0.181±0.002

[a]Values represent mean ± standard error based on three replicates

[b]Not determined:no growth occurred

rotifer species did not grow when the salt concentration in the medium exceeded 2–3 g l^{-1}. We also observed that *A. fissa*, *B. calyciflorus* and *B. havanaensis* did not grow when the NaCl concentration was at or above 3 g l^{-1}. Freshwater cladocerans have also been reported to be sensitive to salt levels in the environment (Williams 1998). In agreement with this, we also found that, with the exception of *M. macrocopa*, all of the cladoceran species tested were unable to survive or reproduce beyond 2 weeks when the salt level was 4.5 g l^{-1}. Resting eggs of rotifers or the ephippia of cladocerans are likely to be able to tolerate higher levels of salinity (Nielsen et al. 2003). Bailey et al. (2004) conducted hatching experiments with rotifer cysts (*B. calyciflorus*) and cladoceran diapausing eggs (*Daphnia* and *Bosmina* species) at different salinities (0, 8, 16 and 32 g l^{-1}). *Bosmina liederi* did not hatch at any of the salinity levels tested (>0 g l^{-1}), while in the other zooplankton species, hatching failed at salt concentrations at or higher than 16 g l^{-1}. Mere hatching or the survival of a zooplankton species at a given salinity, however, does not guarantee its contribution to the population; it is survival beyond the age of maturity and offspring production that contribute to the positive population growth (Stearns 1992). The net result of a survival of a species and its egg output is reflected in its population growth rate. Therefore, the responses of zooplankton species to acute salinity stress require further long-term evaluations (e.g. demographic or population growth studies). In the present study, we observed that *M. macrocopa* (and *B. rubens* to some extent) grew at a salinity of 4.5 g l^{-1}, while all of the other zooplankton species tested failed to reproduce and maintain a population at this salt concentration. The upper limit of salinity tolerance of freshwater organisms is around 5–8 g l^{-1}, while many invertebrates show little mortality at up to 2.2 g l^{-1} (Berezina 2003). We also found that *B. patulus*, *B. rubens* and *M. macrocopa* not only survived but also reproduced at 3 g l^{-1}, while *A. rectangula*, *D. pulex* and *S. vetulus* reproduced at 2 g 1^{-1}. The other species were able to reproduce at lower salinity (1.5 g l^{-1}).

The patterns of population growth for both the rotifer and cladoceran species studied were similar to those observed in previous studies (Nandini and Sarma 2003; Peredo-Alvarez et al. 2003). For example, *A. fissa* and *B. patulus* generally reached peak population growth at or around 2 weeks, while less time was needed for *B. calyciflorus* or *B. rubens*. For cladocerans, *Moina* generally reaches peak abundances earlier than genera such as *Ceriodaphnia*, *Daphnia* and *Simocephalus*. There appears to be an inverse relation between the body size of zooplankton and their numerical abundances when cultured under similar test conditions. Smaller taxa are generally numerically more abundant than larger species (Sarma et al. 2005b). *Anuraeopsis* among the rotifers and *Alona* among cladocerans are much smaller than the other species considered here and, consequently, their peak abundances were higher. However, rotifers, due to their small size, are always more abundant than cladocerans when cultured under optimal experimental conditions. Depending on the food concentration, the peak densities of *A. fissa* vary from 100 to 2500 ind. ml^{-1} (Dumont et al. 1995), while those of *A. rectangula* are known to vary from 5 to 80 ind. ml^{-1} (Nandini and Sarma 2003). In terms of tolerance to salinity, however, we did not find any clear relation with zooplankton body size. Although a few species of rotifers and cladocerans have adapted to sea water, their body sizes are not different from the range found in freshwater species (Dodson and Frey 2001; Wallace and Snell 2001).

The rate of population increase is yet another important variable which is sensitive to environmental changes (Forbes and Calow 1999); it is also believed to be characteristic of a species. For example, species of *Moina* and *Brachionus* generally have higher growth rates than genera such as *Simocephalus* and *Anuraeopsis* (Dumont et al. 1995; Sarma et al. 2001; Nandini and Sarma 2003). However, under stressful conditions, including salinity, the growth rates of freshwater zooplankton can be negative (Sarma et al. 2002). Certain life history characteristics, including the population growth rates of cladocerans, have been recently reviewed (Sarma et al. 2005b). Based on population growth data, the highest *r* values of *Alona*, *Ceriodaphnia*, *Daphnia*, *Moina* and *Simocephalus* were determined to be 0.28,

0.32, 0.39, 0.61 and 0.31 d^{-1}, respectively. In the control populations of the present study, the growth rates of these genera were 0.30, 0.23, 0.20, 0.33 and 0.13, respectively. Thus, the growth rates of the cladocerans studied here were within the documented range reported in the literature (Sarma et al. 2005b). For herbivorous rotifers of the genera *Anuraeopsis* and *Brachionus*, the range of growth rates has been reported to be 0.1–2.2 day^{-1} (Sarma et al. 2001); *r* values for the rotifer species observed in this study fell within this range.

Several aetherinids (e.g. *Chirostoma* spp.) grow better at slightly elevated salinities of around 7–10 g l^{-1} (Martínez-Palacios et al. 2004). Consequently, our results have some application in the aquaculture of these fishes, many of which have high commercial value but experience high mortality during larval stages due to the lack of appropriate live food (Figueroa-Lucero et al. 2004). Rotifers such as *B. rubens* and cladocerans such as *M. macrocopa* – when sufficiently acclimatized to high salinities – could be used as starter food for such fish species (Morales-Ventura et al. 2004).

In summary, based on the ten zooplankton species tested in our investigation, we conclude that – with the exception of euryhaline species such as *Brachionus plicatilis*, which was not considered in this study (see Walker 1981) – freshwater rotifers and cladocerans are not able to survive and reproduce at salinities higher than 5 g l^{-1}. Low tolerance levels of freshwater rotifers and cladocerans from natural waterbodies have also been reported (Blinn et al. 2004).

Acknowledgements This investigation was supported by a project from CONACyT-41786-Q (Mexico). Two anonymous reviewers have improved our presentation.

References

Akopian M, Garnier J, Pourriot R (2002) Cinétique du zooplancton dans un continnum aquatique: de Marne et son réservoir à l'estuaire de la Seine. C R Biol 325:807–818

Alcocer J, Sarma SSS (eds) (2002) Limnology of Mexico: Basic and applied aspects. Hydrobiologia 467:228

Bailey S, Duggan IC, van Overdijk CDA, Johengen T, Reid DF, MacIssac HJ (2004) Salinity tolerance of diapausing eggs of freshwater zooplankton. Freshw Biol 49:286–295

Berezina NA (2003) Tolerance of freshwater invertebrates to changes in water salinity. Russ J Ecol 34:261–266

Blinn DW, Halse SA, Pinder AM, Shiel RR, McRae JM (2004) Diatom and micro-invertebrate communities and environmental determinations in the western Australian wheatbelt: a response to salinization. Hydrobiologia 528: 229–248

Borowitzka MA, Borowitzka LJ (1988) Micro-algal biotechnology. Cambridge University Press, Cambridge

Campos-Ramos R, Maeda-Martinez AM, Obregon-Barboza H, Murugan G, Guerrero-Tortolero DA, Monsalvo-Spencer P (2003) Mixture of parthenogenetic and zygogenetic brine shrimp *Artemia* (Branchiopoda: Anostraca) in commercial cyst lots from Great Salt Lake, UT, USA. J Exp Mar Biol Ecol 296:243–251

Das RC, Mohapatra P, Mohanty RC (1995) Salt induced changes in the growth of *Chlorococcum humicolo* and *Scenedesmus bijugatus* under nutrient limited cultures. Bull Environ Contam Toxicol 54:695–702

Dodson SI, Frey DG (2001) Cladocera and other branchiopoda. In: Thorp JH, Covich AP (eds) Ecology and classification of North American Freshwater invertebrates. Academic Press, London, pp 850–914

Dumont HJ, Sarma SSS, Ali AJ (1995) Laboratory studies on the population dynamics of *Anuraeopsis fissa* (Rotifera) in relation to food density. Freshwater Biol 33:39–46

Figueroa JLA (2002) Los axalapascos de la cuenca oriental, Puebla. In: Espino GL, Calderón JLG (eds) Lagos y presas de México. AGT Publisher, Mexico City, pp 81–107

Figueroa-Lucero G, Meza-Gonzalez O, Hernandez-Rubio MC, Barriga-Sosa IDA, Rodriguez-Canto A, Arredondo-Figueroa JL (2004) Growth, survival and mandible development in the larvae of the shortfin silverside *Chirostoma humboldtianum* (Valenciennes) (Atheniniformes: Atherinopsidae) under laboratory conditions. Aquaculture 242:689–696

Forbes VE, Calow P (1999) Is the per capita rate of increase a good measure of population-level effects in ecotoxicology? Environ Toxicol Chem 18:1544–1556

Green J (1993) Zooplankton associations in East African lakes spanning a wide salinity range. Hydrobiologia 267:249–256

Kefford BJ, Palmer CG, Pakhomova L, Nugegoda D (2004) Comparing test systems to measure the salinity tolerance of freshwater invertebrates. Water SA 30:499–506

Krebs CJ (1985) Ecology: the experimental analysis of distribution and abundance, 3rd edn. Harper and Row, New York

Martínez-Palacios CA, Morte JC, Tello-Ballinas JA, Toledo-Cuevas M, Ross LG (2004) The effects of saline environments on survival and growth of eggs and larvae of *Chirostoma estor estor* Jordan 1880 (Pisces: Atherinidae). Aquaculture 238:509–522

Mendoza AO, Acevedo GJ (2001) El lago de Pátzcuaro. In: Espino GL, Calderón JLG (eds) Lagos y presas de México. AGT Publisher, Mexico City, pp 127–148

Morales-Ventura J, Nandini S, Sarma SSS (2004) Functional responses during the early larval stages of the charal fish *Chirostoma riojai* (Pisces: Atherinidae) fed zooplankton (rotifers and cladocerans). J Appl Ichthyol 20:417–421

Mustahal T, Yamasaki S, Hirata H (1991) Salinity adaptability of five different strains of the rotifer *Brachionus plicatilis*. Jpn Soc Sci Fish 57: 1997–2000

Nandini S, Sarma SSS (2003) Population growth of some genera of cladocerans (Cladocera) in relation to algal food (*Chlorella vulgaris*) levels. Hydrobiologia 491:211–219

Nielsen DL, Brock MA, Crosslé K, Harris K, Healey M, Jarosinski I (2003) The effects of salinity on aquatic plant germination and zooplankton hatching from two wetland sediments. Freshwater Biol 48:2214–2223

Nogrady T, Wallace RL, Snell TW (1993) Rotifera. SBP Academic Publishers, The Hague

Peredo-Alvarez VM, Sarma SSS, Nandini S (2003) Combined effect of concentrations of algal food (*Chlorella vulgaris*) and salt (sodium chloride) on the population growth of *Brachionus calyciflorus* and *Brachionus patulus* (Rotifera). Rev Biol Trop 51:399–408

Sarma SSS, Nandini S (2002) Comparative life table demography and population growth of *Brachionus macracanthus* Daday, 1905 and *Platyias quadricornis* Ehrenberg, 1832 (Rotifera, Brachionidae) in relation to algal (*Chlorella vulgaris*) food density. Acta Hydrochim Hydrobiol 30:128–140

Sarma SSS, Larios-Jurado PS, Nandini S (2001) Effect of three food types on the population growth of *Brachionus calyciflorus* and *Brachionus patulus* (Rotifera: Brachionidae). Rev Biol Trop 49:75–82

Sarma SSS, Elguea-Sánchez B, Nandini S (2002) Effect of salinity on competition between the rotifers *Brachionus rotundiformis* Tschugunoff and *Hexarthra jenkinae* (De Beauchamp) (Rotifera). Hydrobiologia 474:183–188

Sarma SSS, Beladjal L, Nandini S, Cerón-Martínez G, Tavera-Briseño K (2005a) Effect of salinity stress on the life history variables of *Branchipus schaefferi* Fisher, 1834 (Crustacea: Anostraca). Saline Syst 1:4, 1–11

Sarma SSS, Nandini S, Gulati RD (2005b) Life history strategies of cladocerans: comparisons of tropical and temperate taxa. Hydrobiologia 542:315–333

Sokal RR, Rohlf FJ (2000) Biometry. WH Freeman, San Francisco

Stearns S (1992) The evolution of life histories. Oxford University Press, New York

Torres AC, Días JA (2002) El lago de Cuitzeo. In: Espino GL, Calderón JLG (eds) Lagos y presas de México. AGT Publisher, Mexico City, pp 157–169

Walker KF (1981) A synopsis of ecological information on the saline lake rotifer *Brachionus plicatilis*, Müller, 1786. Hydrobiologia 81:150–167

Wallace RL, Snell TW (2001) Phylum Rotifera. In: Thorp JH, Covich AP (eds) Ecology and classification of North American freshwater invertebrates. Academic Press, 2nd edn. New York, pp 195–254

Weber CI (ed) (1993) Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms. US EPA/600/4–90/027F, Ohio

Williams DD (1987) The ecology of temporary waters. Croom Helm/Timber Press, London, Sidney/Portland, Ore.

Williams WD (1998) Salinity as a determinant of the structure of biological communities in salt lakes. Hydrobiologia 381:191–201

Williams WD, De Deccker P, Shiel RJ (1998) The limnology of Lake Torrens, an episodic salt lake of Central Australia, with particular reference to unique events in 1989. Hydrobiologia 384:101–110