



# Salinisation of arid temporary pools alters crustacean hatching success but not phenology dynamics

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**Abstract** The widespread acceleration of freshwater salinisation due to human activities, such as pollution, resource extraction and urbanisation coupled with climate change, poses a significant threat to aquatic ecosystems. Limited work has been directed towards salinisation effects in temporary wetland systems. These systems are characterised by unique crustacean communities reliant on dormant egg production. We assessed salinisation effects on temporary

wetland crustacean communities from semi-arid pans in the Khakhea–Bray Transboundary Aquifer region of South Africa using a laboratory-based approach. Sediment from pans containing crustacean resting eggs was exposed to water with varying salinities (0–10 ppt), and emergent hatchlings were assessed over a 30-day hydroperiod. At salinities of 2.5 ppt and above, there were significant decreases in emergent taxa richness and abundance. Spinicaudata and Ostracoda were the most sensitive taxa to high salinities. Cladocera, Copepoda, Notostraca and Anostraca hatchlings had shallower decreases with salinity, but hatchability still fell rapidly. There was a limited effect on community hatching phenology dynamics from salinity, with all taxa showing reduced hatchability over time overall, with the exception of Cladocera which exhibited a clear unimodal response, peaking around 20 days post-inundation. This suggests that the main impact of salinisation in these systems will be reductions in hatching success and hence reduced recruitment, leading to changes in predation pressures, food web structure and functioning of these ecosystems, with implications for associated ecosystem services.

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## Introduction

Globally, the salinisation of freshwater ecosystems and projected shifting climates have been identified as major threats to aquatic ecosystems, particularly in arid and semi-arid regions (Engelbrecht et al., 2015; Cunillera–Montcusí et al., 2022). Various anthropogenic activities such as agriculture, resource extraction and urbanisation can act as drivers of freshwater salinisation (Cunillera–Montcusí et al., 2022). Climate change can further intensify this process, where increased temperatures and alterations in the hydrological cycle can lead to greater salt concentrations within freshwater systems (Williams, 2001). Salinisation can lead to low survival rates and shifts in species composition in freshwater ecosystems (Pinder et al., 2005). For many aquatic taxa, increases in salinisation and changes in ion concentrations of the external medium force the organisms to regulate their internal ion concentrations accordingly (osmoregulation) (Cunillera–Montcusí et al., 2022). This increase in osmoregulation has energetic costs that can lead to reduced performance of the organism in the long term, resulting in increased stress and/or mortalities (Kaushal et al., 2021). This may lead to changes in species diversity, modifying community composition, structure and function.

Temporary depression wetlands, also known as pans, are intermittently inundated systems that have varying hydroperiods (Goudie & Wells, 1995). Their key defining feature is that they dry unpredictably or annually, with hydroperiod being the main driver of population dynamics in these systems (Calhoun et al., 2017). Often found in arid and semi-arid areas, they support highly specialized assemblages of often rare species that are adapted to living in these waters (Brendonck et al., 2022a). In many regions, these systems represent much of the available standing surface water (Williams, 2000), and are therefore heavily utilised by local communities for household and agricultural activities. Temporary wetland systems are vulnerable and at a high risk of the effects of salinisation due to their endorheic nature (Nicolet et al., 2004). These pans also have no outflow to external waterbodies, and this allows no outward drainage or flushing, facilitating an accumulation of salts (Mabidi et al., 2018). Given a lack of baseline studies in certain parts of the world, there is limited knowledge on the extent of salinisation which these systems have

been exposed to, and how key specialist taxa are likely to respond to this environmental pressure.

The large branchiopods form the ‘flagship’ group of aquatic taxa for temporary wetland systems (Brendonck et al., 2007). These branchiopod crustaceans are specialised for life in these systems, with strategies to cope with variable hydrological regimes and disturbances as temporary pans cycle between wet and dry phases (Bird et al., 2019). This group relies on banks of resting eggs to bridge the dry phases. These eggs lie dormant in the substrate in a diapause stage, also called the resting stage, and can remain viable for years if rehydration does not occur (Brendonck, 1996). The dormant egg bank is comprised of eggs from various species and is also a means of maintaining genetic, phenotypic, species and community diversity (Brock et al., 2003). The external egg morphology is very diverse and species-specific, while constituting a key taxonomic tool to allow the description of communities even when there is no water present (Brendonck et al., 2007). The egg morphology is also functionally important in mediating the dispersal of the large brachiopods and contributes to the distribution patterns observed in the group (Bilton et al., 2001; Meyer–Milne et al., 2020). In addition to large branchiopods, microcrustaceans such as copepods, cladocerans and ostracods form part of the crustacean community and similarly produce resting eggs that facilitate population persistence across hydroperiods (Bird et al., 2019).

Crustacean egg dormancy facilitates reproductive “bet–hedging” or risk spreading strategies, where the proportion of eggs that hatch with each inundation should correspond with the likelihood of completing the life cycle with the successful formation of resting eggs (Simovich & Hathaway, 1997; Pinceel et al., 2017). The large branchiopod eggs show both quiescence and diapause dormancy, with the quiescence dormancy initiated by external factors but terminated as soon as conditions become favourable (Brendonck, 1996; Cáceres, 1997). Some diapause stage eggs in the egg bank will, however, not hatch irrespective of environmental cues, as this is internally controlled (Brendonck, 1996). This ensures a fraction of eggs remain dormant in each growing season, thereby buffering against the probability of total reproductive failure in any one inundation event (Pinceel et al., 2017). Nevertheless, for those eggs that are responsive to initiation by external factors, light, temperature, and

salinity have all been identified as important cues for effective hatching (Brendonck, 1996; Vanschoenwinkel et al., 2009; Pinceel et al., 2013; Tladi et al., 2020).

There are knowledge gaps on crustacean hatching phenology with salinisation effects, with only a few studies (Nielsen et al., 2007; Santangelo et al., 2014; Mabidi et al., 2018) that have assessed the hatching success of crustaceans with changes in salinity. Understanding hatching phenology for crustacean species in these systems is important since the first colonizers' maturation and quick accumulation of an egg bank inside a population may, due to founder effects, reduce the likelihood of other genotypes establishing (Brendonck et al., 2017). This is particularly pertinent given predicted shifting climate dynamics, altered hydroperiods and increased disturbances in temporary pan systems (Waterkeyn et al., 2009).

Large branchiopods, inhabiting temporary wetlands, play a pivotal role in the food web structure due to their remarkable diversity and composition of diverse feeding functional groups (Brendonck et al., 2022a). This group, which occurs specifically in temporary systems, plays an important role in these environments and is key to maintaining ecosystem stability, functioning and services. In addition to these specialist taxa, the pans contain other micro-crustacean groups which are often ubiquitous habitat generalists found in both permanent and temporary water bodies (Brendonck et al., 2002b; Williams, 2006). Aquatic organisms in the pans which include the crustaceans may, however, have varied hatching dynamics, facilitating temporal community variability and phenology.

This study aims to contrast dormant egg hatching dynamics between specialist large branchiopod and microcrustacean components in relation to salinisation, with sediment collected from pan systems in the semi-arid Northwest Province in South Africa, using a laboratory-based approach. We hypothesized that (1) the hatching success of the resting eggs of the large branchiopods would be reduced by increased salinities more than the other micro-crustacean taxa, and that (2) salinisation would influence the hatching phenology of the crustaceans through delayed hatching. The hatching phenology aspects considered for this study were the asynchrony of initial hatching and the time of hatching peaks in relation to salinity and time among the different taxa.

## Methods

### Sediment collection

In June 2021, samples were collected from 10 temporary pans in the semi-arid Khakhea–Bray Transboundary Aquifer region, South Africa [(- 25.978254)–(- 26.143701) S, and 23.47345–23.78585 E]. The temporary pans vary in size, with surface area ranging from 80 to 1900 m<sup>2</sup>. The region has a typical semi-arid savannah climate, with low rainfall (300–450 mm) during the wet season (November–March) and high evapotranspiration rates of 2050–2250 mm per annum (Seward & van Dyk, 2018). High temperatures are experienced during the dry season, when the mean temperature ranges from 22 to 34 °C (April–October) (Mpakairi et al., 2022). The pans from which the sediment was collected generally had low conductivity during the wet season before they dried out (mean ± standard deviation: 135.47 ± 39.1 µScm<sup>-1</sup>), as well as low total dissolved solids (129.33 ± 33.9 mgL<sup>-1</sup>), salinity (0.07 ± 0.02 ppt) and slightly high pH (10.51 ± 0.51). Using a shovel, approximately 15 kg of dry sediment was collected in 20 l plastic buckets from different points at the centre of each of the 10 dry pans. In each pan, the top 5 cm of soil was used, as it has been shown to contain much of the egg bank in the system (Vanschoenwinkel et al., 2013). Pan selection was based on observing large numbers of crustaceans, including large branchiopods, during a site visit in the previous wet season (T. Dalu, *pers. comm.*). The collected sediment samples were taken back to the laboratory, where they were kept at room temperature under dry conditions for eight months until February 2022, when the hatching experiments commenced.

### Hatching experiment

Hatching experiments were conducted in controlled environment (CE) rooms (25 °C; 12:12 light/dark regime) at the Department of Zoology and Entomology, Rhodes University. These conditions were similar to those measured at the collection site in the field at the time of sampling. The hatching experiments were conducted over a 30-day period from 21 February to 23 March 2022.

In the laboratory, 3 kg subsamples from each pan were transferred into a 110 l plastic storage box with

a lid and homogenised by repeatedly shaking. All the sediment subsamples were mixed to make one composite sediment sample for the pan system which was used in the experiments. Samples from the different pans were mixed in this way to minimize variability and maximize the diversity of crustacean eggs available for use across treatments. The mixed sediment was then serially sieved through a 5 mm mesh and 500 µm mesh sieve to remove stones, roots and other debris. A 200 g sample of the sieved sediment was placed into each of the 30 separate 2.3 l (19cm×19cm×9cm) polypropylene containers. In each of the containers with sediment, 2 l of the treatment salt solution (i.e., distilled water (control), 0.5 ppt, 1 ppt, 2.5 ppt, 5 ppt and 10 ppt) was added. The treatment solutions were made by adding the appropriate amount of natural unrefined Oryx desert salt (crystal white salt harvested from the Kalahari Desert, South Africa, free from additives and preservatives) per litre of distilled water, and the salinity measurement was verified by an AquaRead multiparameter meter (Model AP-700 and AP-800, AquaRead Ltd, UK). The initial water level within each container was marked. The water level was then topped up to this original mark every two days, with distilled water, to keep the containers from drying and to account for the loss by evaporation, as that will cause changes in ion concentrations. Five replicates were each used for the control and treatments (5 replicates×6 treatments), and all containers were arranged in a randomised manner within the CE room to remove potential spatial confounds.

All containers were sampled every 3 days after inundation (Henri et al., 2014). Prior to each sample being collected, pH, temperature (°C), dissolved oxygen (mg L<sup>-1</sup>), conductivity (mS cm<sup>-1</sup>), turbidity (NTU) and total dissolved solids (mg L<sup>-1</sup>) were measured in each container, using the same AquaRead multiparameter. To count hatchlings, all water in each container was carefully decanted and filtered over an 84 µm mesh sieve. The filtrate was then poured back into the container. Hatchlings on the sieve were washed into labelled containers and fixed with 5% formalin for 10 days. The hatchlings were then stained with 0.25% w/v Rose Bengal Solution and preserved in 70% ethanol, and later identified to order level using an Olympus stereo microscope using identification guides by Day et al., (1999; 2001) and Olesen (2007). Abundances were determined for the following crustacean groups: Anostraca

(fairy shrimps), Notostraca (tadpole shrimps) and Spinicaudata (clam shrimps), Cladocera (water fleas), Copepoda (copepods), and Ostracoda (seed shrimps).

Linear models were used to test for differences in the environmental variables measured at different salinities [pH, temperature (°C), dissolved oxygen (mgL<sup>-1</sup>), conductivity (mScm<sup>-1</sup>), turbidity (NTU) and total dissolved solids (mgL<sup>-1</sup>)], (averaged over time). A mixed generalized linear model (GLMM) was fit with a negative binomial family (accounting for residual overdispersion and/or zero inflation) to examine the total numbers of individuals hatched among taxonomic groups over the total experimental period. A quadratic term was included for the experimental period term (i.e. sampling day), as this improved the model fit, as evidenced by lower AIC (Akaike Information Criterion) ( $\Delta > 2$ ). Models were fit as a function of the taxonomic group and salinity, and their interaction, as well as over time. The individual experimental unit was included as a random effect to account for repeated measures of multiple taxa per replicate and over time. Analysis of deviance was used to infer the main effects with Chi-square tests, and Tukey comparisons were used for post-hoc tests as needed. All analyses were carried out in the R software package (R Core Team, 2022).

## Results

The mean pH values across all the treatments ranged from 7.57 to 7.97, with pH, significantly decreasing with rising salinity. The mean dissolved oxygen in the containers was similar across all the treatments, ranging from 3.74 to 3.94 mg L<sup>-1</sup>. Conductivity levels and total dissolved solids increased significantly with rising salinity, (Table 1). Turbidity levels were lowest in the 2.5 ppt and 0 ppt treatment solutions and were higher in all the other treatments, albeit non-significantly. Temperature was also statistically similar ( $P > 0.05$ ) among salinity groups (Table 1).

Hatching of crustaceans from six different taxa occurred over the 30-day period of the experiment. By day 3, all the taxa present in the study had hatched in the lower salinity treatments. Taxon richness was highest in the treatment solutions of 1 ppt and below, with 6 taxa emerging (Anostraca, Notostraca, Spinicaudata, Cladocera, Copepoda and Ostracoda). The large branchiopod taxa that

**Table 1** Environmental variables (mean  $\pm$  standard deviation) measured in the containers at the five different salinity treatments

Variable	0 ppt	0.5 ppt	1 ppt	2.5 ppt	5 ppt	10 ppt	<i>t</i>	<i>p</i>
Temperature (°C)	23.80 $\pm$ 0.4	23.23 $\pm$ 0.5	23.26 $\pm$ 0.6	23.21 $\pm$ 0.5	23.26 $\pm$ 0.6	23.24 $\pm$ 0.5	0.192	0.849
pH	7.97 $\pm$ 0.2	7.85 $\pm$ 0.2	7.75 $\pm$ 0.3	7.75 $\pm$ 0.2	7.64 $\pm$ 0.3	7.57 $\pm$ 0.2	5.685	<0.001
Dissolved oxygen (mg L <sup>-1</sup> )	3.92 $\pm$ 0.7	3.97 $\pm$ 0.7	3.89 $\pm$ 0.7	3.98 $\pm$ 0.7	3.97 $\pm$ 0.7	3.74 $\pm$ 0.5	1.935	0.063
Conductivity (mS cm <sup>-1</sup> )	0.81 $\pm$ 0.3	3.14 $\pm$ 0.8	5.54 $\pm$ 1.2	12.22 $\pm$ 2.9	22.31 $\pm$ 4.4	43.81 $\pm$ 4.4	66.682	<0.001
Turbidity (NTU)	606.98 $\pm$ 364.0	802.79 $\pm$ 428.6	715.17 $\pm$ 534.9	507.66 $\pm$ 285.7	772.18 $\pm$ 527.3	824.48 $\pm$ 444.2	1.204	0.239
Total dissolved solids (mg L <sup>-1</sup> )	0.52 $\pm$ 0.2	2.04 $\pm$ 0.5	3.60 $\pm$ 0.8	8.15 $\pm$ 1.3	14.50 $\pm$ 2.8	28.56 $\pm$ 2.9	64.581	<0.001

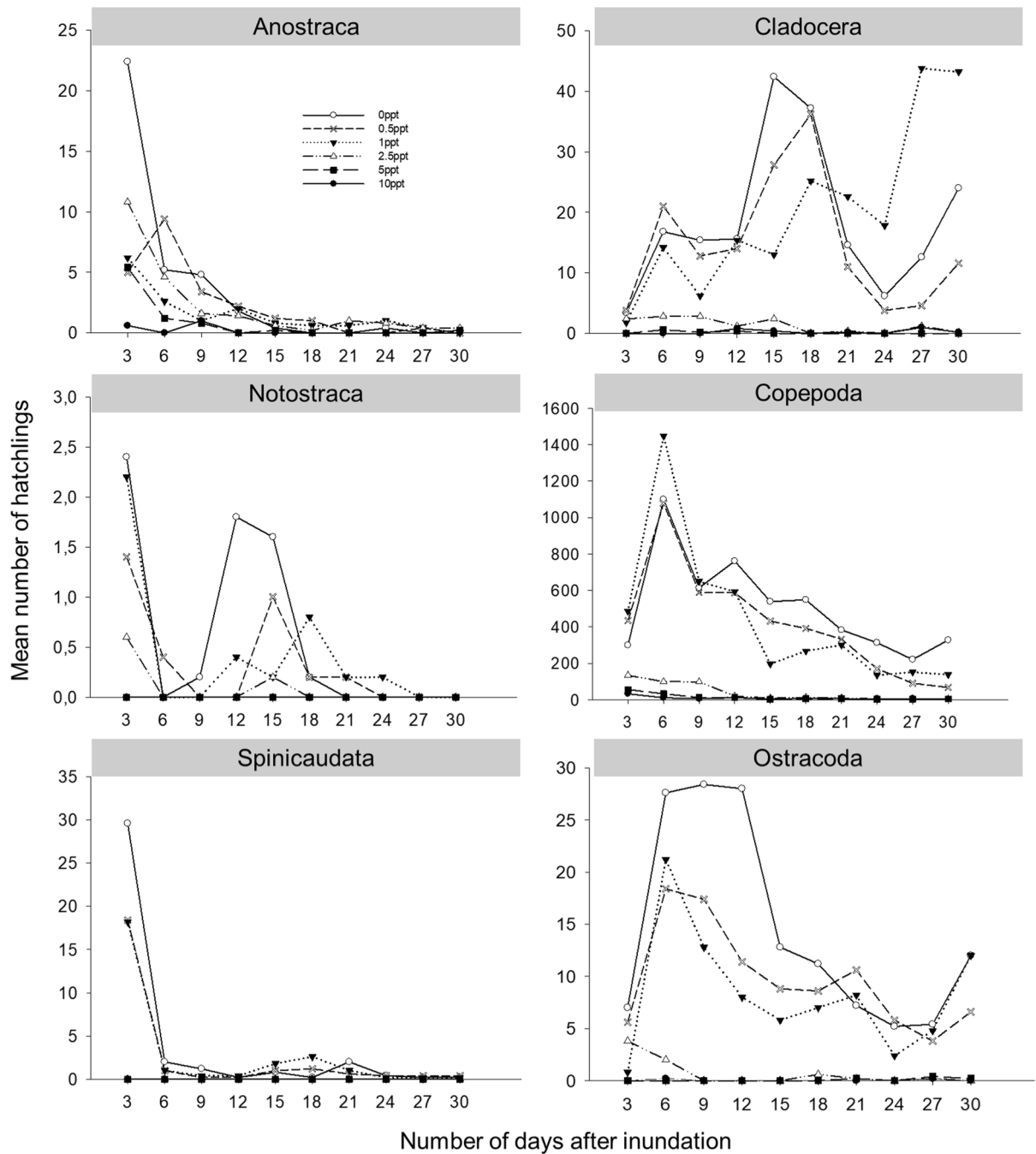
*p* values are from linear models of each variable across salinities, with significant terms in bold

emerged from the sediment were of the genera *Branchipodopsis*, *Ozestheria*, *Streptocephalus* and *Triops*. The microcrustacean taxa emergent were *Daphnia*, *Ceriodaphnia*, *Eucyclops*, *Ectocyclops* and ostracods of the family Cyprididae. Copepoda were by far the most abundant taxa across salinities, with 71 384 individuals recorded overall, followed by Cladocera with 2 776 individuals and lastly Ostracoda (1 664 individuals). These three taxa had significantly higher numbers than the Anostraca (521 individuals), Notostraca (71 individuals) and Spinicaudata (433 individuals) (Fig. 2).

For the large branchiopods, the hatchlings exhibited a single early peak, with the highest densities on day 3 across all treatments, except for Anostraca at 0.5 ppt, which were highest on day 6. Notostraca in 0 ppt exhibited a second peak in hatching activity on day 12 and day 15, while no hatchlings were observed for Notostraca at salinities of 5 and 10 ppt throughout the 30-day period. The Spinicaudata did not hatch over the 30-day period for salinities of 2.5 ppt and above. For the Anostraca no hatching was observed from day 18–30 at 5 ppt and 10ppt treatment solutions. Small changes in salinity concentration from 0.5 to 1 ppt caused a large drop in hatching for the Anostraca (Fig. 1).

The highest hatchling abundance for the microcrustacean taxa, however, generally occurred later and were more varied. Copepoda hatchlings peaked on day 6 for the lower salinity treatments (0 ppt, 0.5 ppt, 1 ppt) and on day 3 for the higher salinities (2.5 ppt, 5 ppt, 10 ppt), although at very low numbers. The Ostracoda hatchling peak at 0 ppt spanned days 6–12. At 0.5 ppt and 1 ppt, Ostracoda hatchlings peaked on day 6, while at 2.5 ppt and 5 ppt peaked at day 3 (at very low numbers). Cladocera hatchlings peaked on day 15 at 0 ppt, day 18 at 0.5 ppt and day 30 at 1 ppt. Very few Cladocera emerged at salinities above 1 ppt (Fig. 1).

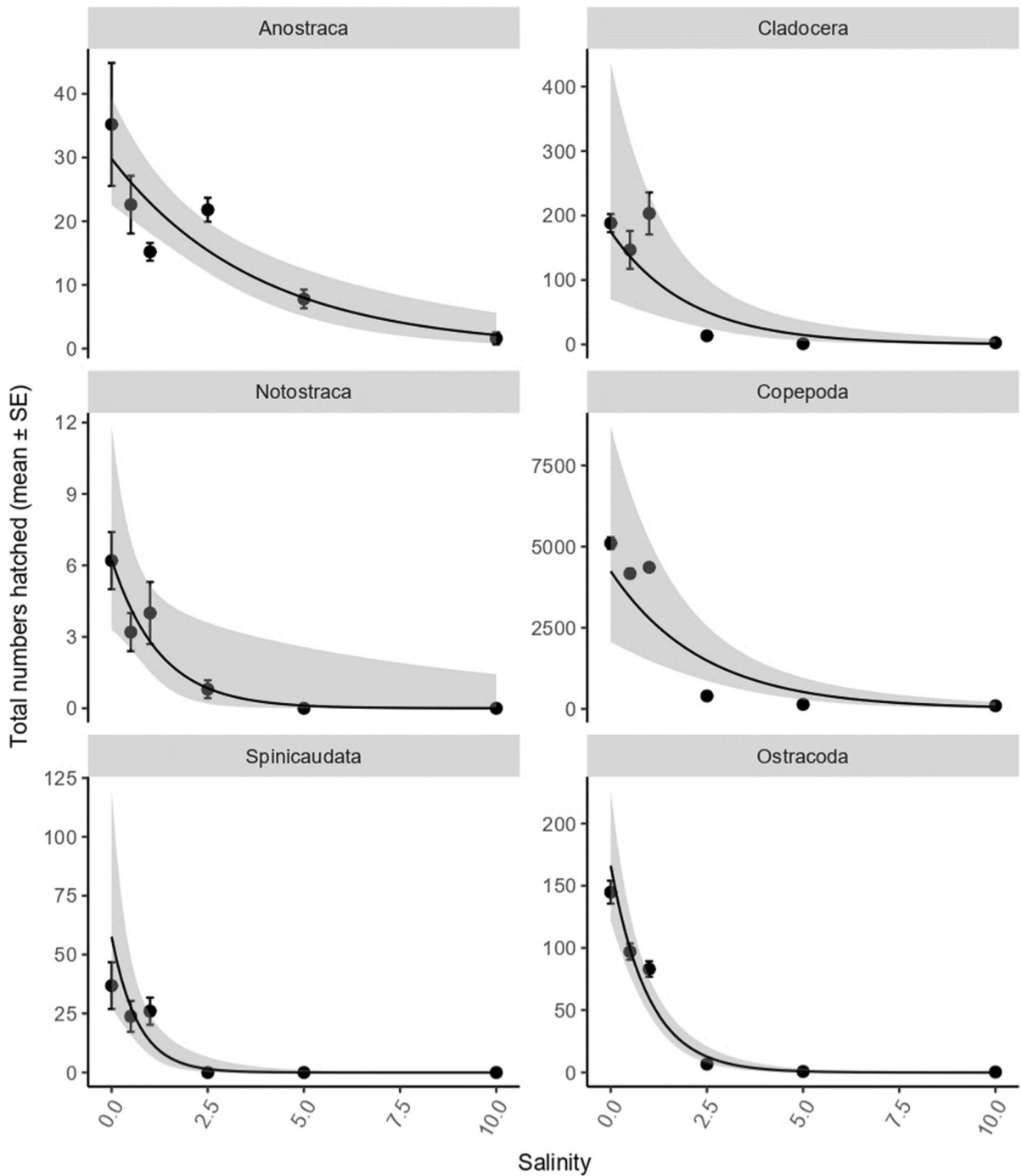
The number of hatchlings differed significantly among taxonomic groups in two-way interactions with salinity regime (GLMM:  $\chi^2=70.576$ ,  $df=5$ ,  $P<0.001$ ) and time (GLMM:  $\chi^2=212.776$ ,  $df=10$ ,  $P<0.001$ ) (Figs. 2 and 3). The responses of the various taxa differed with salinity reductions as well as over time. However, overall responses to salinity over time among taxa were similar owing to a non-significant interaction (GLMM: salinity  $\times$  time:  $\chi^2=2.272$ ,  $df=2$ ,  $P=0.321$ ; taxon  $\times$  salinity  $\times$  time:  $\chi^2=16.245$ ,  $df=10$ ,  $P=0.093$ ). Therefore, temporal responses among taxa were not mediated by salinity regime. All taxa displayed a negative relationship with



**Fig. 1** Mean number of hatchlings of large branchiopods (left panel) and other crustacean taxa (right panel) that emerged from sediment from the Khakhea Bay Transboundary Region at five different salinity treatments

increasing salinity in terms of abundance. For the large branchiopods hatchability responses were similar, but Anostraca hatchability responses to salinity were significantly different to the micro-crustaceans

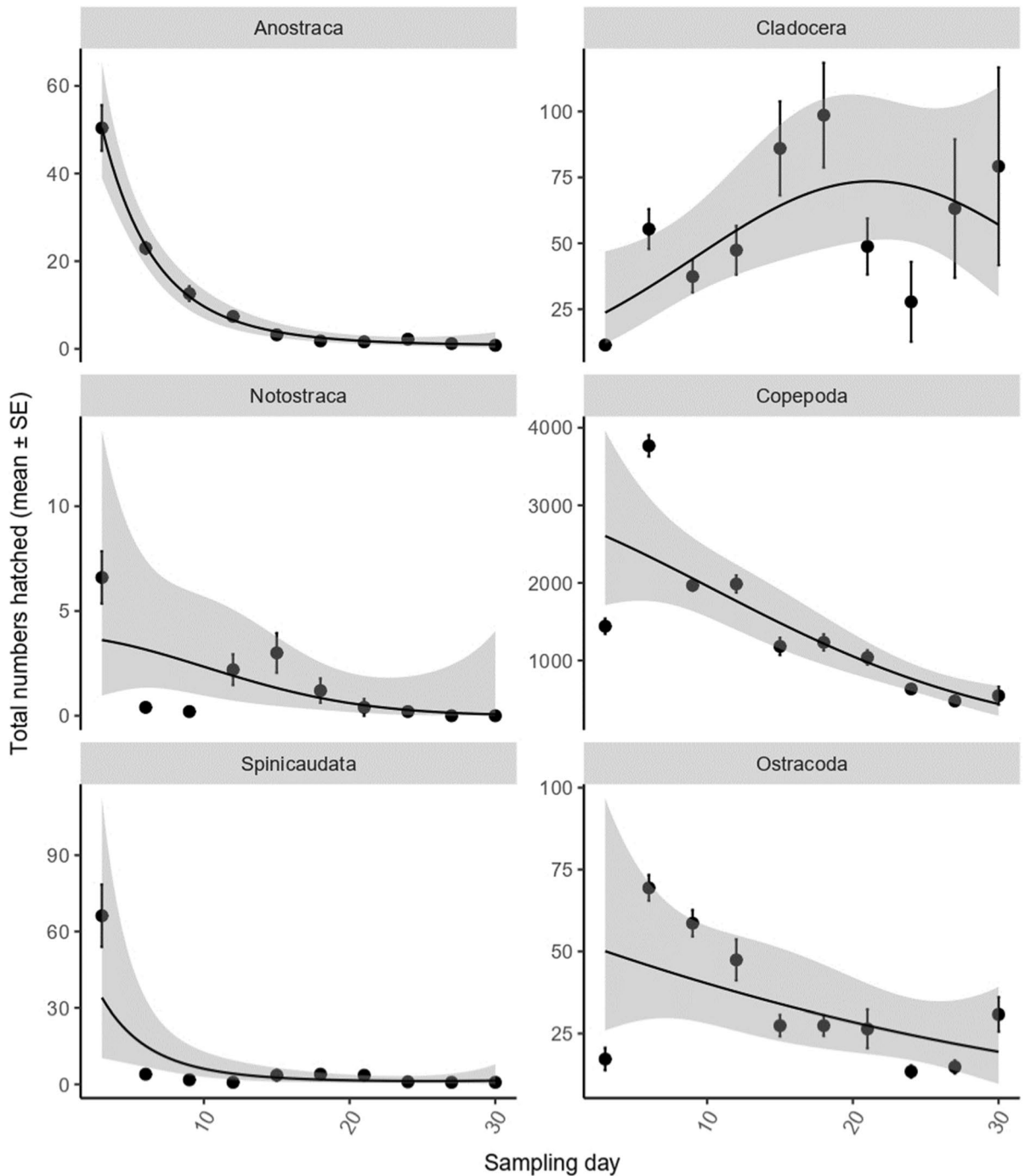
which showed steeper declines (Cladocera, Copepoda and Ostracoda) (Tukey: all  $P < 0.05$ ). Copepoda and Cladocera hatching trends significantly differed to Ostracoda, which had the steepest decline with



**Fig. 2** Mean numbers of individuals hatched per taxon over the entire experimental period across salinities. Means are shown alongside standard errors. Lines correspond to the

negative binomial generalized linear model fit with confidence intervals shaded in grey. Note y-axes differ among panels





**Fig. 3** Mean numbers of individuals hatched per taxon over all salinities over time. Means are shown alongside standard errors. Lines correspond to the negative binomial generalized

linear model fit with confidence intervals shaded in grey. Note y-axes differ among panels



rising salinity (Tukey: both  $P < 0.05$ ) (Fig. 2). Over time, Anostraca showed the strongest reductions in hatchability, with stronger negative trends than the Cladocera, Copepoda and Ostracoda, which tended to continue hatching later (all  $P < 0.001$ ). Cladocera was the only taxon with non-linear hatchability trends over time, which initially rose before falling, and this was also significantly different to Copepoda (Tukey:  $P < 0.001$ ), which in turn differed to Ostracoda (Tukey:  $P < 0.05$ ) (Fig. 3). Other trend comparisons were not statistically clear (Tukey: all  $P > 0.05$ ).

## Discussion

The present study highlights that salinisation of temporary wetland ecosystems alters the hatching success of crustacean communities in terms of overall community structure but has very little effect on the phenological hatching dynamics. Our results showed that the Spinicaudata and Ostracoda were particularly sensitive to high salinities with reduced hatching success as salinity increased. The other taxa were found to be less sensitive to high salinities, but hatching rates still reduced rapidly with rising salinity levels. Over time, hatching rates generally declined for all taxa, but for the Cladocera in particular there was a later hatching peak irrespective of the salinity, which manifested unimodally in time. Overall, all the taxa were negatively affected by salinisation, therefore rejecting the first hypothesis. Larger crustaceans generally hatched earlier in the hydroperiod compared to smaller groups across salinities, therefore rejecting our second hypothesis. While these results offer little insight into the specifics of how crustacean communities may shift with increasing salinisation, it still successfully highlights how broad taxonomic contributions may vary.

High salinities have been shown to inhibit growth and lead to high mortalities in freshwater crustacean taxa in other studies (Thiéry & Puente, 2002; Hulsmans et al., 2006; Vanschoenwinkel et al., 2009; Castro-Mejía et al., 2011; Mabidi et al., 2018). Here, all taxa were adversely affected by high salinities, with hatching success decreasing to variable extents. Changes in salinisation can have direct effects, such as physiological changes, which can lead to species extirpation (Nielsen et al., 2003a). Increases in salinity can also influence the hatching of large

branchiopod crustaceans from eggs, through either reducing the viability of the egg bank or blocking the cues that trigger hatching. Mortality soon after hatching may also occur due to high salinities (Nielsen et al., 2003b; Bailey et al., 2004). At the individual level, increases in salinisation can affect osmoregulation, leading to high metabolic costs, which can affect the general fitness of the organisms (James et al., 2003). Therefore, high salinities disturb growth, abundance, and overall viability (Nielsen et al., 2003b).

Our results show that for all the large branchiopods taxa, the highest hatching occurred in the first six days. The peak hatching observed in the early inundation period has been shown in other studies (Brendonck, 1996; Waterkeyn et al., 2009). Within these temporary pan systems with varying hydroperiods, the associated desiccation can act as a selective force that can lead to differentiation in the life history stages in the populations that have experienced disturbances (Vanschoenwinkel et al., 2010). In this study, the start of inundation corresponded with the hatching of a higher fraction of the large branchiopod eggs, which allows for a higher probability of completing the life cycle (Vanschoenwinkel et al., 2010; Brendonck et al., 2022a). Even within a single batch of dormant eggs, hatching frequently varies greatly, and this variation is regarded to be an adaptation to maintain population stability in an unstable environment (Brendonck, 1996). Shifting climatic patterns can lead to erratic and shorter hydroperiods (Waterkeyn et al., 2009), and early hatching of the dormant eggs can lead to a smaller fraction of the ‘reserve’ fraction left in the dormant egg bank. This may lead to the local extinction of some of the populations (Bhusnale et al., 2016). We, however, did not observe any shifting patterns of hatching with increases in salinity and therefore salinisation did not have effects on the hatching phenology of the crustacean dormant eggs overall.

From this study, the micro-crustaceans Cladocera and Copepoda and also the Notostraca and Anostraca (large branchiopods) had a shallower decrease with salinity. The Copepoda and Cladocera likely show higher tolerance to higher salinity levels due to them being generalist species found across a range of temporary and permanent systems of varying physico-chemical composition. Cladocerans have been shown to be tolerant of a broad range of salinities (De Deckker,

1982; Hall & Burns, 2002; Nielsen et al., 2003a; Gonçalves et al., 2007; Santangelo et al., 2014). These micro–crustacean taxa are not only found in freshwater habitats but also found in high saline waters such as coastal and brackish habitats. Some calanoid copepods have also been found to have wide salinity tolerance (Horváth et al., 2014). Similarly Nielsen et al. (2003a) found that copepods are adapted to tolerate a wide range of salinities, while Hall & Burn (2002) showed that larger copepod females exhibited higher hatching success at high salinity levels. These generalist and salt–tolerant species may benefit from the reduction of competition and predation pressures in the temporary pan systems that otherwise impedes larger taxa from hatching. Anostraca did hatch at high salinities here. The anostracan *Artemia salina* has been recorded in a salt pan in South Africa in a previous study (De Roeck et al., 2007). This tolerance may reflect that they developed salt tolerance in order to survive the hydro chemical fluctuations associated with them inhabiting ephemeral water bodies where salt concentrations change in relation with the rates of evaporation (Sarma et al., 2005).

Increased anthropogenic activities in semi–arid regions, particularly agricultural intensification to support growing human population levels (Dalu et al., 2017), are likely to compromise temporary pan systems through associated salinisation dynamics. The evolutionary consequences of salinisation may increase with longer exposure time and may have detrimental implications for the more sensitive taxa (i.e. due to reduced genetic diversity). Salinity is a strong evolutionary pressure that can alter functional aspects related to trait diversity, food web structures and trophic dynamics (Latta et al., 2012). Across trophic chains, the intolerant taxa may disappear, with the tolerant species having a competitive advantage towards destabilizing the food web structure (James et al., 2003). This can have cascading effects on the ecosystem functioning (e.g. bottom–up and top–down control) (Cunillera–Montcusí et al., 2022), thereby affecting human societies relying on them for various ecosystem services.

## Conclusion

Overall, our results showed that the hatching success of resting eggs of all the taxa both the large

branchiopods and the micro–crustacean taxa were inhibited by high salinities. The increase in salt concentrations and concentrations above 2.5 ppt have implications for the more sensitive biota, such as the Spinicaudata and Ostracoda, when it exceeded the tolerance level of these biota. There were, however, limited effects of salinity on the hatching phenology of the crustaceans in the temporary wetlands since no obvious temporal shifts in the hatching patterns were observed with increases in salinity. The current study provides some understanding of the impacts of freshwater salinisation on the hatching success of crustaceans in temporary pan systems. The findings of this study also highlight which broad taxonomic groups are affected, potentially stimulating autecological assessments at finer taxonomic resolutions for key groups. Future studies might include species level assessments of salinity tolerances within each taxon (e.g. Copepoda/Cladocera) and further refining of the taxonomy of their juvenile phases. The endorheic nature of temporary pans coupled with climate change and the agricultural landscapes in which they dominate, likely favour salinisation increases at landscape levels. Effective monitoring systems and research in these temporary pan systems can therefore provide information that will contribute to significantly advancing and developing of better conservation management strategies.

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**Data availability** The datasets generated during the current study are available from the corresponding author (CPM), upon reasonable request.

## Declarations

**Conflict of interest** The authors declare that there are no competing interests.

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