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ORIGINAL ARTICLE

Availability of the euryhaline rotifer *Proales similis* as prey after rapid salinity transfer

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Abstract

In this work, we examined the effects of rapid changes in salinity on the availability (mobility and swimming) of the prey rotifer *Proales similis*. Rotifers were transferred as follows: 5 to 15, 25 and 35 (T1); 15 to 5, 25 and 35 (T2); 25 to 5, 15 and 35 (T3) and 35 to 5, 15 and 25 ppt (T4) during 1–240 min. Results showed that in T2 and T3, the percentage of mobile rotifers in the water column recovered up to 100% after 15 min. At T1 and T4, mobility regained slower at 35 and 5 ppt respectively. All individuals transferred at 15 and 25 ppt maintained their mobility above 93% after 15 min. In general, swimming speed ranged from 0.37 to 0.65 mm s^{-1} and was higher at 15 ppt and lower at 35 ppt. In all salinities, swimming increased with time and recovered better in T2 and T3. These data suggest that *P. similis* can acclimate to a wide range of salinity gradients in the short term (1–240 min). According to the literature and our results, *P. similis* has a greater tolerance to sudden salinity changes than brachionid rotifers used traditionally in fish larviculture.

KEYWORDS
larviculture, live feed, mobility, prey availability, salinity transfer, swimming speed

1 | INTRODUCTION

Live feeds such as rotifers are an essential component of larviculture techniques for many marine and freshwater finfish species (Hagiwara et al., 2007; Ogata, 2017; Snell et al., 2019; Yanes-Roca et al., 2018). Since its introduction (the 1970s), the *Brachionus plicatilis* species complex (at least 15 species according to Mills et al., 2017) have been widely used in marine aquaculture (Hagiwara & Marcial, 2019; Lubzens et al., 2001; Snell et al., 2019). For this reason, there is more literature about its ecological, biological and nutritional aspects than other rotifers taxa (Kailasam et al., 2015; Ogata, 2017; Snell et al., 2019). These studies have helped improve culture techniques and feeding protocols for fish larvae. In addition to *Brachionus*, other marine genera such as *Encentrum*, *Synchaeta*, *Colurella* and recently, *Proales* have been investigated in their biology and ecology (Bosque et al., 2001; Rebolledo, Nandini, Sarma, et al., 2018; Schmid-Araya, 1992; Suchar & Chigbu, 2006; Wullur et al., 2009); this is a first step in evaluating its potential in larval fish aquaculture.

Appropriate prey selection (e.g., body size, body shape and nutritional quality) increases heavily larval survival of many cultured fish species (Cunha & Planas, 1999; Hagiwara et al., 2007, 2014; Ogata, 2017). Rotifers of the genus *Brachionus* have served to culture fish species classified as uncultivable (Kotani, 2017). Today, several species are cultured because adequate prey has been found. More than one characteristics make rotifers suitable as live food in the aquaculture industry, including (i) a small body size (~65–300 μm; *Proales* and *Brachionus* genera) which is within the margin of the predator's mouth size, (ii) have a wide geographic distribution that facilitates it is obtaining in the field, (iii) can tolerate a broad range of salinity and temperature at which fish larvae are rearing, (iv) appropriate energy content and reasonable nutritional value

and (v) they reaching high densities in mass cultures (Conceição et al., 2010; Contreras-Tapia et al., 2020; Hagiwara et al., 2007; Lubzens et al., 2001; Snell et al., 2019).

The use of *P. similis* in aquaculture has been raising great interest in the last years and has been considered an ideal live prey for marine and freshwater fish larviculture (Hagiwara et al., 2014; Rebolledo et al., 2021; Wullur et al., 2009). It resembles that the use of *P. similis* in aquaculture is as promising as that of *B. plicatilis*, given that they share common advantages. However, there is still much to explore regarding its husbandry and proper utilization limitations related to differential salinity conditions for its culture and later use as a live feed.

Proales similis is a euryhaline rotifer found in inland saline waters and marine environments (Román-Reyes et al., 2017; Walsh et al., 2008; Wullur et al., 2009). This species has been isolated for experimental purposes (aquaculture and ecotoxicology) in Japan and Mexico (Rebolledo et al., 2021; Rebolledo, Nandini, Escobar-Sánchez, & Sarma, 2018; Wullur et al., 2009). The main characteristic of *P. similis* as live prey is its morphology. Its body is comparatively smaller (in length, 63–83 μm) than the *B. plicatilis* species complex (102–299 μm), which has favoured the feeding of fish larvae with a small mouth size (Mills et al., 2017; Snell et al., 2019; Wullur et al., 2009). Unlike *B. plicatilis*, *P. similis* lacks a lorica rich in scleroproteins; therefore, it has a flexible body that could facilitate its consumption and ingestion by the larvae (Wullur et al., 2011). It is known that *P. similis* achieves high growth rates at 2–25 ppt and temperatures above 25°C (Román-Reyes et al., 2017; Wullur et al., 2009). Extrapolating the results of laboratory-based studies, it can reach high densities in massive cultures such as *B. plicatilis* (Lubzens et al., 2001). In the same way as *B. plicatilis*, resting egg production of *P. similis* has been successfully achieved in the laboratory (Snell et al., 2019), thus allowing its distribution and availability in different parts of the world as live feed for fish larvae.

Proales similis can grow and reproduce in low and high salinity (2–35 ppt), making it an ideal candidate for a broad spectrum of fish species with high aquaculture potential (Rebolledo et al., 2021; Román-Reyes et al., 2017; Wullur et al., 2009). Such fish families list includes Atherinidae, Lutjanidae, Serranidae, Chanidae, Sparidae, Sciaenidae, Percidae, Latidae, Mugilidae, Siganidae, Scatophagidae, among others whose feeding protocols involve rotifers (Imentai et al., 2019; Kailasam et al., 2015; Labatut & Olivares, 2004; Martínez-Palacios et al., 2004; Wullur et al., 2011). Generally, fish larvae are fed with *Brachionus* rotifers until 15 days post hatching. In turn, they are provided at a density of 10–20 rotifers/ml (Burbano et al., 2020; Wullur et al., 2011). Hagiwara et al. (2014) and Rebolledo et al. (2021) suggest that *P. similis* is crucial during the first 7 days post-hatching fish larvae with a very small mouth, then feeding protocols are completed with brachionids.

Prey availability is a determinant factor in the successful rearing of many cultured fish species (Gulbrandsen, 1993; Imentai et al., 2019; Morales-Ventura et al., 2004; Peláez-Rodríguez et al., 2021; Yanes-Roca et al., 2018). During the first feeding stage, fish larvae must have the required and available food for their growth and survivorship (Ma et al., 2013). The availability of prey in the water column can be affected by various physicochemical factors such as temperature, salinity and food (Kim et al., 2020). Culture techniques must ensure an adequate quantity of prey for rearing larvae to avoid high mortalities. Usually, rotifers are cultured in their optimal salinity conditions to achieve high densities in a short time, which in many cases differs from the culture conditions for fish larvae (Fielder et al., 2000; Øie & Olsen, 1993). For example, *P. similis* grows optimally at 15 ppt but transfers to optimal conditions for larval rearing of the silverside *Chirostoma estor estor* (5 ppt) and the seven-banded grouper *Epinephelus septemfasciatus* (34 ppt) (Rebolledo et al., 2021; Wullur et al., 2011). Several strains of *B. plicatilis* have been tested as candidates to feed fish larvae cultured at different salinities; however, in some cases, their availability (mobility and swimming) as prey after rapid salinity changes seems to be short (Fielder et al., 2000; Imentai et al., 2019; Øie & Olsen, 1993).

The relatively wide salinity tolerance of *P. similis* may be advantageous in the marine and freshwater larviculture techniques. Considering this context and that this euryhaline rotifer is a new species for aquaculture, in this study, we evaluate its availability (movement and swimming linear speed) as prey after rapid salinity changes to continue exploring its potential in aquaculture.

2 | MATERIALS AND METHODS

2.1 | Ethics statement

No specific ethical approval is needed for rotifer studies in Mexico. Rotifers were originally isolated from a site that does not belong to any national parks and protected areas.

2.2 | Culture and maintenance

The monogonont rotifer *P. similis* was isolated from resting eggs in the sediment of a shrimp farm (23°09′10.54″N, 106°18′22.84″W) in the northwest Mexico (Román-Reyes et al., 2017). Since then, it has been maintained under laboratory conditions. In our laboratory, *P. similis* is cultured at 15–25 ppt and 25–30°C under natural light. The brackish water is obtained by diluting seawater (Mazatlan Bay, Mex) with freshwater taken from the drinking water network, previously treated as described in Román-Reyes et al. (2017). This Mexican strain of *P. similis* feeds exclusively on the marine microalgae *Nannochloropsis* sp. (~3–5 $\times 10^6$ cells/ml) every 96 h. We have tested providing with other marine microalgae such as *Chaetoceros muelleri*, *C. calcitrans*, *Isochrysis galbana*, *Tetraselmis suecica*, the freshwater microalgae *Chlorella vulgaris* and commercial diets Nanno 3600® and RotiGrow-Plus®; however, the rotifers do not grow as expected.

2.3 | Effect of rapid salinity change on rotifer mobility

Before each bioassay, *Proales* was maintained in synthetic saltwater at 5, 15, 25 and 35 ppt and 25°C for 3 weeks to ensure complete

salinity acclimation. Desired salinities to bioassays were achieved by dissolving Instant Ocean (Aquarium Systems) in distilled water. The use of reconstituted saltwater worked well to assess the effects of salinity in demography and population growth of *P. similis* experimentally (Rebolledo, Nandini, Sarma, et al., 2018). Briefly, we measured the percentage mobility of rotifers after rapid salinity transfer as follows: 5–15, 25 and 35 (T1); 15 to 5, 25 and 35 (T2); 25 to 5, 15 and 35 (T3) and 35 to 5, 15 and 25 ppt (T4). Rotifers were exposed for 1, 15, 30, 60, 120 and 240 min under these conditions. Bioassays were conducted in 24-well sterile polystyrene plates. Twenty individuals (taken at random) were transferred into 1 ml of test medium with the desired salinity (four replicates). Rotifers were not fed during the experiment. Those rotifers that were swimming in the water column were considered mobile individuals. In contrast, immobilized rotifers were those non-swimming individuals and individuals who attached their feet to the bottom of the plates (Øie & Olsen, 1993). Observations were made under a stereomicroscope at established interval times. All experiments and observations were carried out in a temperature-controlled room at 25°C.

2.4 | Effect of rapid salinity change on rotifer swimming

To explore the effects of rapid salinity transfer on swimming speed (SS) of *P. similis*, we used the same experimental design described in Section 2.3 for the mobility bioassays except that we used only three treatments (60, 120 and 240 min) regarding exposure time. We selected this period to ensure swimming activity in most salinity treatments. In this experiment, the swimming speed of *P. similis* in acclimatized conditions was used as a control. Briefly, rotifers were individually (10 replicates for each treatment) transferred into a concave glass microscope slide with about 10 µl of water of the same salinity and temperature level. The swimming speed of the organisms was recorded using a Moticam 10 MP digital camera and the software Motic image plus v. 2.0 (Motic China Group) attached to a dissection microscope (Motic® B3 Series, Motic China Group) at a magnification of 4×. All videos were recorded for 10 s under low-intensity illumination. Next, videos were analysed by the free software KINOVEA 0.9.4 (https://www.kinovea.org/). This software was calibrated using a microscope calibration ruler (1 DIV = 0.1 mm) to measure swimming linear speed in mm s^{-1}.

2.5 | Statistical analysis

The effects of rapid salinity transfer on mobility and swimming linear speed were analysed by one-way analysis of variance (ANOVA). Tukey's multiple comparison tests followed these analyses to discriminate significantly different treatments. Statistical significance was set at $p < 0.05$ for all tests. Furthermore, a two-way ANOVA was used to test the interaction of rapid salinity change and time. Data were expressed as mean ± SD based on 4 and 10 replicate recordings. All statistical analysis and graphs were performed with SIGMAPLOT 11.0 (Systat Software).

3 | RESULTS

3.1 | Effect of rapid salinity change on rotifer mobility

In general, the percent of mobile rotifers in the water column varied according to salinity changes and time. For example, in T1, the total recovery of the mobility was faster at 15 than at 25 and 35 ppt (Table 1). Under a transfer from 5 to 15 ppt, all individuals (100%) were immobilized during the first minute. At 15–240 min, mobility ranged from 93% to 97%, and there was no statistical difference ($p > 0.05$) between these treatments (time), except when compared with 1 min ($p < 0.05$). From 5 to 25 ppt, rotifers were immobilized entirely during the first 30 min; however, there was a substantial increase (41%–81%; $p < 0.05$) in the number of available rotifers at 60–240 min. The percent of mobile rotifers diminished as salinity increased from 5 to 35 ppt. Under this salinity transfer, there was substantial inhibition (100%) on the movement of the individuals during the first 60 min. However, mobility increased significantly ($p < 0.05$) from 11% to 73% at 120 and 240 min respectively.

In T2, a rapid salinity transfer and the time did not significantly affect ($p > 0.05$; one-way ANOVA) the mobility of rotifers; it ranged from 97% to 100% during 1–240 min (Table 1). The mobility recorded for T3 was 55%–96% at 5 ppt; 97%–100% at 15 ppt; 0.0%–93% at 35 ppt and recovered considerable ($p < 0.05$) over time. In this treatment, during the first 15 min, the activity of the organisms recovered fast at 5 and 15 than 35 ppt. After 30 min, we found no significant differences ($p > 0.05$) between the different times and the mobility of the organisms (Table 1). Regarding T4, those individuals transferred at 15 and 25 ppt maintained their mobility at 96%–100% among the different treatments (time) with no significant differences ($p > 0.05$). Rotifers exposed to rapid salinity transfer from 35 to 5 ppt were immobilized during the first 15 min of testing. As time increased, mobility recovered noticeably (45%–97%, $p < 0.05$). A two-way ANOVA showed a significant interaction of rapid salinity change × time (1–240 min) on the percentage of mobility in T1, T3 and T4 ($p < 0.05$) but not in T2 ($p > 0.05$). A second analysis shows that the interaction of rapid salinity change × time at 60–240 min was significant ($p < 0.05$) in T1 and T4 but not in T2 and T3 ($p > 0.05$).

3.2 | Effect of rapid salinity change on rotifer swimming

Swimming linear speed (range and, in parenthesis, mean ± SD; in mm s^{-1}) of *P. similis* at different salinities (control) ranged from 0.50 to 0.64 (0.56 ± 0.05) at 5 ppt; 0.61 to 0.71 (0.65 ± 0.04) at 15 ppt; 0.41 to 0.56 (0.48 ± 0.06) at 25 ppt and 0.32 to 0.45 (0.37 ± 0.04) at 35 ppt (Figure 1). As can be seen, SS were noticeably different according to salinity. Swimming speed was more significant ($p < 0.05$;

TABLE 1 Percent of mobile rotifers (*Proales similis*) in the water column 1–240 min after rapid salinity transfer (T1–T4). The mean ± standard deviation (SD) data is based on four replicates ($n = 20$)

	Time (minutes)					
Salinity (ppt)	**1**	**15**	**30**	**60**	**120**	**240**
5 (T1)						
15	0.0 ± 0.0^{c}	93.7 ± 2.5^{b}	100 ± 0.0^{a}	98.0 ± 2.5^{a}	97.5 ± 2.8^{a}	97.0 ± 2.8^{a}
25	0.0 ± 0.0^{c}	0.0 ± 0.0^{c}	0.0 ± 0.0^{c}	41.2 ± 6.2^{b}	81.2 ± 10.3^{a}	80.0 ± 4.0^{a}
35	0.0 ± 0.0^{c}	0.0 ± 0.0^{c}	0.0 ± 0.0^{c}	0.0 ± 0.0^{c}	11.2 ± 7.5^{b}	73.7 ± 7.5^{a}
15 (T2)						
5	98.7 ± 2.5	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0
25	98.7 ± 2.5	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0
35	97.5 ± 2.8	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0
25 (T3)						
5	55.0 ± 9.7^{c}	77.5 ± 2.8^{b}	87.5 ± 6.4^{ab}	96.2 ± 4.7^{a}	96.2 ± 4.7^{a}	93.7 ± 2.5^{a}
15	97.5 ± 2.8	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0
35	0.0 ± 0.0^{c}	87.5 ± 2.8^{b}	93.7 ± 2.5^{ab}	93.7 ± 6.2^{ab}	97.5 ± 2.8^{a}	93.7 ± 2.5^{ab}
35 (T4)						
5	0.0 ± 0.0^{d}	0.0 ± 0.0^{d}	45.0 ± 5.7^{c}	65 ± 7.0^{bc}	75.0 ± 27.0^{ab}	93.7 ± 4.7^{a}
15	96.2 ± 2.5	100 ± 0.0	100 ± 0.0	98.7 ± 2.5	98.7 ± 2.5	97.5 ± 2.8
25	100 ± 0.0	98.7 ± 2.5	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0

Note: One-way ANOVA with Tukey's post test for multiple comparisons. Identical superscript letters within rows denote a lack of significant differences ($p < 0.05$) only between treatments at each exposure time.

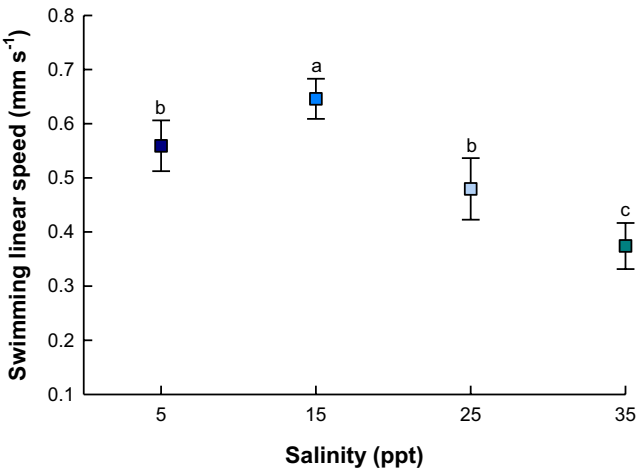

FIGURE 1 Swimming linear speed of *Proales similis* at different salinities (control). Means for all treatments are shown (±SD). One-way ANOVA ($p < 0.05$) with Tukey's post test for multiple comparisons. Values not sharing the same letter are significantly different at $p < 0.05$.

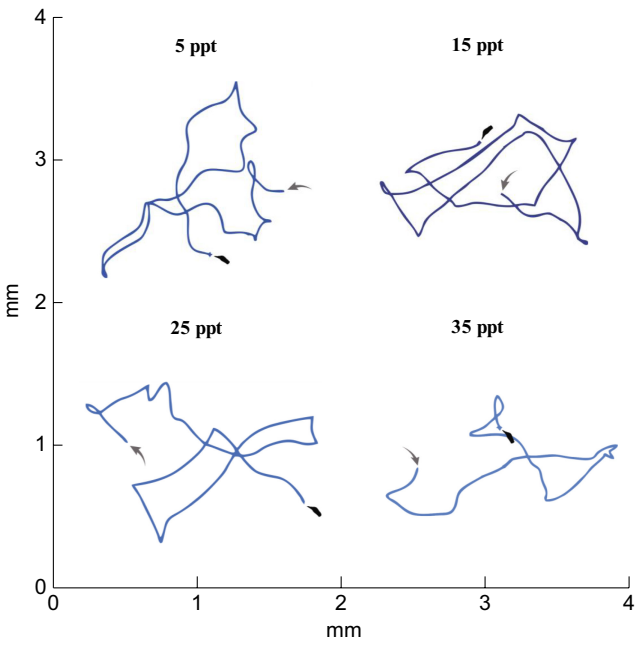

FIGURE 2 Illustration of swimming trajectories recorded for *Proales similis* at different salinities during 10 s. The samples shown are one representative replicate from a total of 10.

one-way ANOVA) at 15 ppt than at 5, 25 and 35 ppt. Statistical analysis showed no significant differences ($p > 0.05$) between 5 and 25 ppt in swimming speed. Statistically, SS was substantially lower as salinity increased to 35 ppt. Swimming trajectories of *P. similis* at different salinities are shown in Figure 2. Rotifers showed similar swimming behaviour at 5, 15, 25 and 35 ppt. The swimming pattern of *P. similis* is helicoidal, alternating with tumbles and events where organisms attach to surfaces with their foot.

The SS registered for rotifers transferred from 5 to 15, 25 and 35 ppt oscillated from 0.20 to 0.68 (0.26 ± 0.05–0.62 ± 0.03) during 60–240 min (Figure 3). The SS of rotifers transferred from 5 to 15 ppt (Figure 3) and the control at 5 ppt (Figure 1) showed no significant differences ($p > 0.05$). Rotifers transferred from 5 to 25 and 35 ppt,

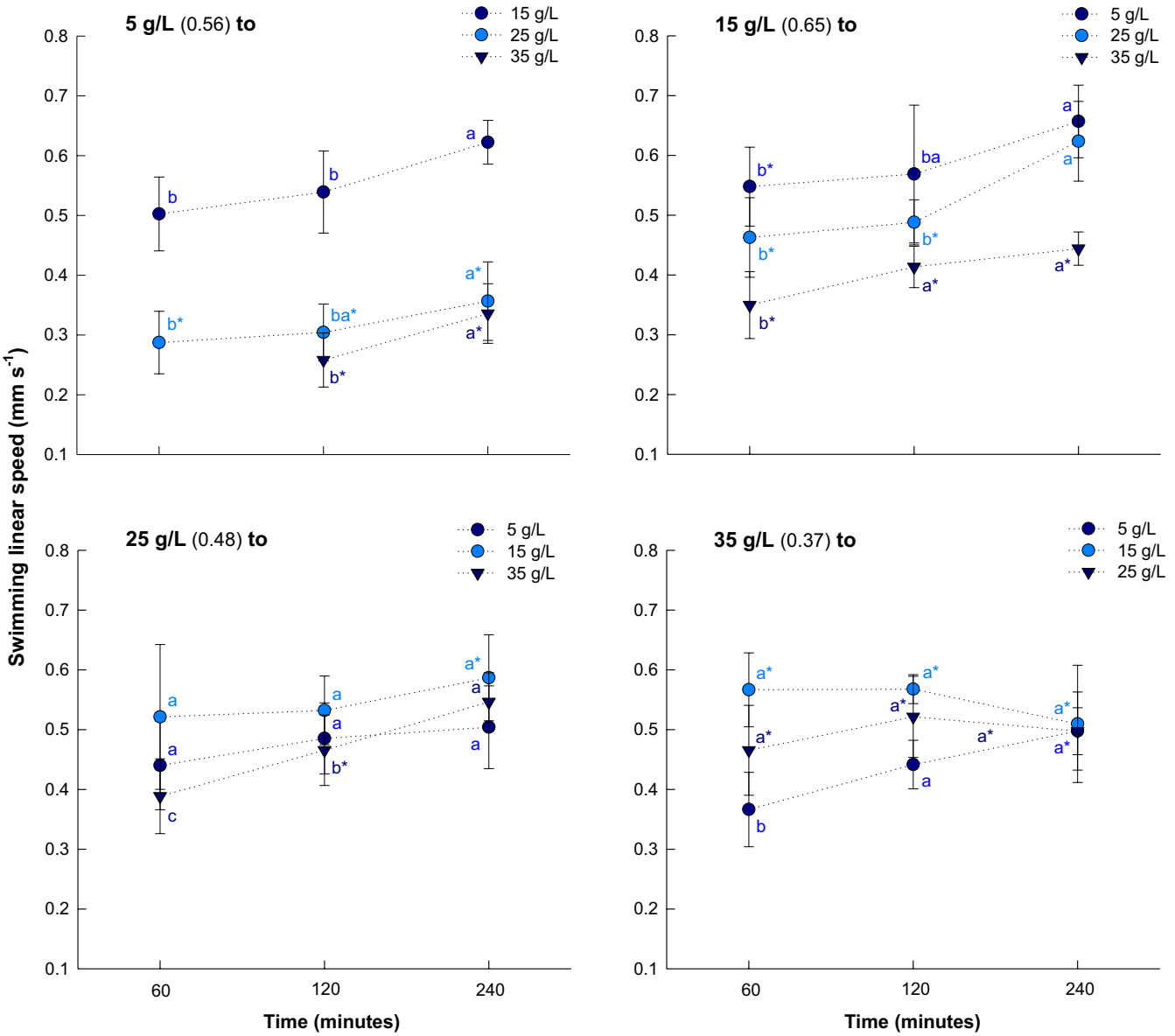

FIGURE 3 Swimming linear speed of *Proales similis* during 60, 120 and 240 min after rapid salinity transfer. Means for all treatments are shown (±SD). One-way ANOVA ($p < 0.05$) with Tukey's post test for multiple comparisons. Values not sharing the same letter are significantly different at $p < 0.05$. The asterisks (*) indicate a significant difference compared with the control mean (in parentheses).

SS improved ($p < 0.05$) with increasing time. SS decreased substantially ($p < 0.05$) when rotifers were transferred from 5 to 25 and 35 ppt (Figure 3) with respect to control at 5 ppt (Figure 1).

Rotifers transferred from 15 to 5, 25 and 35 ppt reached a SS that ranged from 0.22 to 0.76 (0.35 ± 0.06–0.66 ± 0.06) and increased significantly ($p < 0.05$) with time. At 240 min, the SS observed at 5 and 25 ppt (Figure 3) were not statistically different ($p > 0.05$) from those registered in control at 15 ppt (Figure 1). Salinity significantly affected the swimming activity of rotifers transferred from 15 to 35 ppt (Figure 3) with a SS inhibition of about 50% concerning control at 15 ppt. However, the activity of rotifers enhanced as time increased ($p < 0.05$).

The SS of individuals transferred from 25 to 5, 15 and 35 ppt ranged from 0.29 to 0.71 (0.39 ± 0.06–0.59 ± 0.07) and was more significant at 15 ppt than 5 and 35 ppt. Time did not significantly ($p > 0.05$) affect the SS of rotifers transferred at 5 and 15 ppt, but it did at 35 ppt ($p < 0.05$). We observed that in most cases, the salinity changes did not affect the SS of the individuals (Figure 3) compared to SS registered in control at 25 ppt (Figure 1). In 15 ppt at 240 min, the SS was superior to those that reached the control group.

Regarding individuals transferred from 35 to 5, 15 and 25 ppt, the SS ranged from 0.20 to 0.68 (0.37 ± 0.06–0.57 ± 0.06) and was higher at 15 and 25 than at 5 ppt (Figure 3). In most cases, the SS was significantly ($p < 0.05$) or not statistically different ($p > 0.05$) compared to the control at 35 ppt (Figure 1). From 35 to 15 and 25 ppt, SS was reduced slightly at 240 min, but it was not statistically different ($p > 0.05$) at 60- and 120-min. SS improved significantly ($p < 0.05$) at 5 ppt as time increased from 120 a 240 min. Finally, rapid salinity

change × time (60–240) interaction significantly affected the SS in T1 and T4, in turn, resulted not significant in T2 and T3 ($p > 0.05$).

4 | DISCUSSION

For more than 50 years, *B. plicatilis* has been an essential part of the feeding during the larval stages of numerous freshwater and marine fish species (Snell et al., 2019). Currently, *P. similis* is the second rotifer taxon successfully introduced to marine aquaculture (Hagiwara et al., 2014; Kagali et al., 2018; Rebolledo et al., 2021; Wullur et al., 2009). Hitherto, the research on its potential as live food for aquaculture is very scarce. The utilization of *P. similis* cannot be generalized with *B. plicatilis* due to particular characteristics that distinguish them. In this research, we highlight the high tolerance of *P. similis* to rapid changes in salinity. To do this, we consider a salinity range in which a great variety of fish species are reared, including some species from Mexico.

The rotifer *P. similis* showed a higher percentage of mobility (97%–98%) after transfer from 35 to 15 ppt at 60–240 min than *B. plicatilis* (about 7%–18%) and *Brachionus rotundiformis* (4%–22%) exposed to the similar experimental conditions (Fielder et al., 2000). From 35 to 25 ppt, *P. similis* reached 100% mobility at 240 min, while *B. plicatilis* and *B. rotundiformis* about 44% and 55% respectively. When *P. similis* was transferred from 15 and 25 to 5 ppt, the percent of mobile rotifers oscillated from 94% to 100% at 60–120 min, while *B. plicatilis* about 80% following a transfer from 20 to 5 ppt at 100 min (Øie & Olsen, 1993). On the other hand, comparing the results from Imentai et al. (2019), *P. similis* is also more tolerant to salinity transfer than a *B. plicatilis* strain transferred 25 to 4–16 ppt. Rapid salinity changes as 5–35 and 35–5 ppt resulted in *P. similis* immediate immobilization during the first 60 and 15 min respectively. Collectively, these results indicated that even though the osmotic shock negatively affected the mobility of rotifers, they can recover and enhance the activity of salt-sensitive physiological processes over time (period of acclimation; Lowe et al., 2005; Øie & Olsen, 1993). Our findings indicate that *P. similis* can acclimate well to changes in salinity in a short period of time.

Swimming speed is an indicator of culture quality in mass cultures of rotifers (Korstad et al., 1995). Rotifers swim continuously. A ciliated wheel organ called corona generates feeding currents and propulsion (Wallace et al., 2015). This study observed that *P. similis* has a helicoidal swimming pattern like other rotifer taxa (Obertegger et al., 2018). The swimming behaviour of rotifers is affected by changing environmental conditions (Kim et al., 2020). We observed that the swimming speed of *P. similis* was significantly higher at 15 ppt and lower at 35 ppt. In rotifers, swimming requires high energy consumption (Epp & Lewis, 1984). The swimming reduction in *P. similis* at high salinity might be due to the increased metabolic cost of osmoregulation (Lowe et al., 2005).

The SS of *P. similis* registered at 15 ppt was 0.65 mm s^{-1}, which is within that reported for *B. plicatilis* (Garaventa et al., 2010). *P. similis* has a higher SS than freshwater rotifers species such as *Brachionus calyciflorus*, *Cephalodella gibba*, *Epiphanes senta*, *Lecane furcata*, *Lecane luna*, *Lecane pyriformis*, *Lecane hamata* and *Lepadella patella* (0.17–0.54 mm s^{-1}). On the other hand, it is lower than *Asplanchna girodi*, *Euchlanis dilatata* and *Plationus patulus* (0.69–0.98 mm s^{-1}) (Dong et al., 2020; Rico-Martínez & Snell, 1997; Santos-Medrano et al., 2001). Overall, SS of *P. similis* recovered over time and, in some cases, was higher than that observed in controls. Salinity transfers most affected swimming were from 5 to 15, 25 and 35 ppt, and 35 to 5, 15 and 25 ppt. In contrast, the most favourable transfers were from 15 to 5, 15 and 35 ppt, and 25 to 5, 15 and 35 ppt, whose SS improved in the short term (<30 min). The fact that *P. similis* maintains continuous swimming activity (availability) in the water column could increase larval feeding responses that involve search, attack, capture and ingestion, which is a crucial aspect in enhancing the success of larviculture (Conceição et al., 2010; Imentai et al., 2019).

The Mexican strain of *P. similis* was isolated from shrimp ponds where salinity fluctuates between 5 and 68 ppt, and throughout most of the grow-out season, it is above 25 ppt. This strain seems to be more resilient to high salinities than the strain isolated from an estuary (2 ppt) in Okinawa, Japan (Hagiwara & Marcial, 2019). *P. similis* has also been found in hypersaline springs (98 ppt) in the Namib Desert, Namibia (Brain & Koste, 1993), and in inland saline waters (<2 ppt) in the Chihuahuan desert of Mexico (Walsh et al., 2008), which may explain its wide adaptation and tolerance to salinity changes. That *P. similis* can regain mobility and swimming after rapid changes in salinity suggests that it is a hypo-osmoregulator invertebrate like *B. plicatilis* (Lowe et al., 2005). Our results show that prey availability in the water column was more affected when rotifers were transferred from a low (5 ppt) to high (35 ppt) salinity. Meanwhile, it recovered faster when transferred from high (35 ppt) to low (5 ppt) salinity. One explanation indicates that Na+/K+ ATPase activity increases with increasing salinity and reduces as salinity decreases in euryhaline rotifers (Lowe et al., 2005).

Salinity transfer techniques must guarantee survival and fast acclimatization of live food (prey) for optimal larval feeding (Fielder et al., 2000; Hansen et al., 2021; Imentai et al., 2019). The results we present suggest that the most favourable salinities for transferring rotifers were 15 and 25 ppt. Here it was found that in T2 and T3, the effect of different levels of rapid salinity changes does not depend on what level of time is present (two-way ANOVA interaction). Some species, such as *C. estor estor*, are reared at 5–10 ppt and can feed on *P. similis* cultured in the same salinity conditions (Martínez-Palacios et al., 2004; Rebolledo et al., 2021), which does not affect prey availability in the water column. In some cases, when rotifers are cultured at low salinity increases the risk of being contaminated by protozoa, affecting live food production. A culture technique like salinity increases will limit the growth of protozoa contaminants (Liao et al., 2001). Suppose *P. similis* is targeted to feed marine fish larvae such as *E. septemfasciatus* reared above 30 ppt (Hagiwara et al., 2014). In that case, it might be better to culture it at 25 ppt because the osmotic

stress after salinity transfers is lower than other changes in salinity, and availability improves in the short term (<30 min). The fact that *P. similis* are cultured at 35 ppt can ensure the availability of the prey after being transferred to the same or close salinity; however, under these conditions, the growth of rotifers is lower, which can increase operating time and costs. A recent study suggests that the fatty acid composition of marine rotifers is better under their optimal culture conditions (Lee et al., 2022). In this context, we recommend that *P. similis* be cultured at optimal salinity conditions and subsequently transferred to the desired salinities to transfer essential nutrients to larvae.

In Mexico, several fish species have high aquaculture potential (Dávila-Camacho et al., 2019). Unfortunately, the larval survival of many fish species of commercial interest is low to supply the intensive cultures (Alvarez-Lajonchère et al., 2012). Considering the availability of *P. similis* in the laboratory and the field, the Mexican aquaculture sector should begin to include this species in the feeding protocol for some Atherinidae and Lutjanidae family members, to name a few.

5 | CONCLUSIONS

We conclude that *P. similis* has a good acclimation response to a wide range of salinity gradients in the short term (1–240 min). It is suggested that this euryhaline rotifer be cultured at a salinity of 15 and 25 ppt to ensure a higher percentage of prey availability after salinity transfer. Our finding highlights the importance of incorporating *P. similis* into the feeding regimes for fish larvae reared at wide salinity ranges in Mexico and other parts of the world.

AUTHOR CONTRIBUTIONS

Uriel Arreguin Rebolledo: Investigation, Methodology, Formal analysis, Writing—Original Draft, Writing—Review & Editing. G.A Rodríguez-Montes de Oca: Funding acquisition, Resources, Writing—Review & Editing. D. Macías-Velázquez and G.G. Flores-González: Investigation and Methodology. J.C. Román-Reyes: Investigation, Methodology, Funding acquisition, Writing—Review & Editing.

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CONFLICT OF INTEREST

The authors confirm that there are no known conflicts of interest associated with this publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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