Effect of Duckweed (*Lemna minor*) on the Growth of Damselfly Larvae (*Ischnura verticalis*) Under Environmental Stress

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Abstract

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Yasmine Hoballah

Freshwater ecosystems are increasingly threatened by interacting anthropogenic stressors such as nutrient enrichment and pollution, which can alter water chemistry and disrupt aquatic communities. In such environments, positive species interactions may help buffer the effects of environmental stress by modifying local abiotic conditions. Aquatic macrophytes, including duckweed (Lemnaceae), can influence physicochemical properties of freshwater systems through nutrient uptake and metabolic processes, potentially affecting other organisms inhabiting the same environment. Despite the extensive study of duckweed for applications such as bioremediation and biofuel, its indirect ecological effects on co-occurring organisms remain poorly understood. Whether duckweed influences the growth performance of aquatic insect larvae through modifications of water chemistry has not previously been tested. To address this, three laboratory experiments were conducted to examine how duckweed (*Lemna minor*) influences the growth of damselfly larvae (*Ischnura verticalis*) under different environmental conditions. The first experiment tested the effect of duckweed on pH, dissolved oxygen, and conductivity of the water. The second experiment examined how feeding (artemia input) influenced these parameters. The third experiment tested the effect of duckweed on larval growth and survival under different temperature and water trophic status. Overall, duckweed had a positive effect on larval growth and no effect on survival. The effect of duckweed on water chemistry parameters was stronger under significant organic matter input (feeding). These findings highlight the importance of considering indirect species interactions in freshwater ecosystems and suggest that the ecological effects of duckweed may depend strongly on environmental context.

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Contribution of Authors

As the first author, I was responsible for the data collection, data analysis, and the writing of this thesis. I also contributed to the design of the study.

As my thesis supervisor, Dr. Rassim Khelifa was responsible for the conception of the study, provided mentorship and support, assisted with the sampling and statistical analysis, and revised my thesis.

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1. Introduction

Freshwater ecosystems support a disproportionate share of global biodiversity (Stendera et al., 2012); yet are among the most threatened ecosystems due to their increasing exposure to multiple interacting anthropogenic stressors (Dudgeon et al., 2006). Land-use change, nutrient enrichment, and chemical pollution are important drivers of environmental change in freshwater systems (Birk et al., 2020). For example, inputs of nitrogen, phosphorus, and organic contaminants can substantially degrade water quality and alter nutrient stoichiometry (N:P ratios). These imbalances can often promote eutrophication and the proliferation of algal blooms, which can disrupt ecosystem functioning by altering oxygen dynamics, light availability, and nutrient cycling (Jeppesen et al., 2015). These changes can cascade through aquatic food webs and negatively affect the growth, survival, and interactions of freshwater organisms (Woodward et al., 2010). As a result, freshwater biodiversity has significantly declined in recent decades (Stendera et al., 2012). Understanding how these interactive stressors affect freshwater communities is therefore essential for ecosystem management and restoration strategies.

Species coexist within complex communities where they potentially influence each other through negative interactions (e.g. competition, predation) and positive interactions (e.g. facilitation, mutualism). Positive interactions in particular can help mitigate the impact of environmental stressors on more vulnerable species, playing a crucial role in maintaining biodiversity in harsher environments (e.g. Shantz et al., 2023). Facilitation has been extensively documented within the same taxonomic groups, particularly in plant-plant interactions where some species mitigate the effect of environmental stressors for others (Brooker et al., 2008; Zhang & Shao, 2013). However, facilitation can also occur across taxonomic groups (Lortie et al., 2016), such as plant-animal interactions, i.e., plants can reduce environmental stress experienced by animal communities and improve habitat suitability. Consistent with this idea, studies have reported that the presence of plants can be associated with greater insect richness, abundance, and diversity (Chen et al., 2021; Molenda et al., 2012), suggesting that plant-mediated environmental changes can have important cascading effects on higher trophic levels.

Macrophytes are not only indicators of water quality but also an important ecosystem component capable of modifying local physicochemical environments in freshwater ecosystems. Through their growth and metabolism, they can alter key water parameters such as pH, temperature, dissolved oxygen, conductivity, and nutrient concentrations, which influences overall water chemistry (Manolaki & Papastergiadou, 2013). They can also affect the dynamics of organic matter and pollutants, as many species actively absorb nutrients and contaminants from the water (Rodríguez et al., 2012). For example, studies have shown that macrophytes such as *Eichhornia crassipes* and *Lemna minor* can improve water quality by reducing organic pollution, suspended solids, nitrogen, and phosphate concentrations sometimes within a few weeks of growth (Mishra et al., 2013; Dalu & Ndamba, 2003). Furthermore, floating plants can affect physicochemical

conditions by forming sometimes dense surface layers that can influence oxygen and temperature profiles in the water column. As a result, macrophyte-dominated systems often exhibit more stable pH, temperature, and dissolved oxygen dynamics than systems without (Caicedo et al., 2002). Duckweed species are macrophytes that can strongly influence water quality due to their rapid growth and high capacity for nutrient cycling (Moreno Castro et al., 2025; Saha et al., 2015).

Duckweeds (Lemnaceae) are among the smallest and fastest-growing flowering plants and are widely distributed across freshwater ecosystems worldwide (Ziegler et al., 2015). Their rapid asexual reproduction allows them to form dense floating mats that can quickly cover the water surface (Landolt, 1986). Like other macrophytes, they can reduce water turbidity and lower biochemical oxygen demand (BOD) and chemical oxygen demand (COD), thereby improving overall water quality (Gupta & Prakash, 2013). Widely used in ecotoxicological assays (Laird & Barks, 2018), duckweed can act as an efficient nutrient sink by rapidly assimilating dissolved nitrogen and phosphorus from the water column, with reported removal efficiencies exceeding 90% for some compounds under nutrient-rich conditions (Alaerts et al., 1996). In addition to these biogeochemical roles, duckweed plays an important role in aquatic food webs, serving as a food source for numerous herbivores including insects, fish, and waterfowl (Gülçin et al., 2010). Duckweed can also provide habitat and refuge for aquatic organisms. For instance, larvae of the duckweed moth (*Cataclysta lemnata*), beyond feeding on the plant, also use duckweed as material to construct protective cases for shelter (Van Der Heide et al., 2006). Together, these ecological functions highlight the importance of duckweed as a multifunctional component of freshwater ecosystems. Such changes to habitat structure and water conditions can also indirectly influence the growth and survival of other aquatic organisms, including predatory insects such as damselfly larvae.

Damselfly larvae are ecologically important mesopredators in freshwater food webs (Johnson, 1991), where they consume smaller invertebrates and vertebrates while also serving as prey for larger invertebrates and fish (Corbet, 1999). As a result, stress-induced changes can propagate through aquatic food webs and even influence adjacent terrestrial ecosystems after adult emergence (Varg et al., 2022). Larval growth and development are highly plastic and influenced by multiple environmental factors (Johansson et al., 2001). For instance, abiotic factors such as temperature can influence growth performance (Raczyński et al., 2022). Warming and contaminants can interact to reduce growth rate and increase mortality, with effects varying among populations and environmental conditions (Dinh Van et al., 2014). In the context of increasing anthropogenic stressors in freshwater ecosystems, these traits make damselfly larvae ecologically relevant model organisms for studying how environmental conditions influence growth and fitness in freshwater ecosystems.

Research on duckweed has largely focused on its applied potential (Lewis, 1995; Ekperusi et al., 2019; Cui & Cheng, 2015) with comparatively little attention given to its ecological interactions or indirect effects on co-occurring organisms such as damselfly larvae. In particular, very few studies have examined how duckweed-mediated changes in environmental conditions influence the performance of other organisms (but see Lanthemann & Van Moorsel, 2022; Lürig et al., 2021), and none have investigated these effects on damselfly larvae. Because duckweed can alter physicochemical properties of aquatic habitats, they may influence the growth, development, and behavior or organisms that inhabit the same environment (Gupta & Prakash, 2013; Lürig et al., 2021). However, the environmental effects of duckweed are unlikely to be constant, as they may vary depending on surrounding environmental conditions like temperature or dissolved organic matter (Shen et al., 2024). Consequently, the influence of duckweed on co-occurring organisms is likely to be context dependent. Damselfly larvae, which develop in shallow freshwater habitats, and are known to exhibit different growth responses depending on environmental conditions, frequently occur in systems where duckweed is present. Yet, the role of duckweed in shaping growth responses of aquatic insect larvae such as damselflies remains largely unexplored.

To address this knowledge gap, this thesis investigated how duckweed influences the growth of damselfly larvae under different temperatures and nutrient conditions. To do so, three experiments were conducted. The first experiment examined the effect of duckweed on key water chemistry parameters (pH, dissolved oxygen, and conductivity). Based on previous studies, I hypothesize that the presence of duckweed would result in a smaller increase in pH and conductivity compared to treatments without duckweed (Caicedo et al., 2002; Moreno Castro et al., 2025). I also hypothesize that the presence of duckweed will have lower dissolved oxygen levels due to plant respiration. The second experiment tested how the addition of food (artemia) influences water chemistry, as larval feeding in the subsequent growth experiment may itself modify physicochemical conditions. I hypothesize that feeding would result in a smaller increase of dissolved oxygen and pH due to microbial respiration and the decomposition of organic matter (Ficke et al., 2007, Freitas et al., 2023). I also predict that conductivity would increase in feeding treatments, which is consistent with other studies (Freitas et al., 2023). Finally, the third experiment evaluated the effect of duckweed presence on larval growth and survival. I hypothesize that duckweed would have a positive effect on larval growth. Although relatively few studies have examined the effects of macrophytes on aquatic insects, existing work suggests positive effects of macrophytes at the community level (Misteli et al., 2022). I therefore predict that these benefits may also extend to individual growth. This is partially supported by a study done by Vilenica et al. (2022) where macrophyte-rich habitats had higher values of adult body size than macrophyte-poor habitats. In contrast, I do not expect duckweed to influence larval survival in our experiment because damselfly larvae naturally occur in habitats both with and without duckweed, meaning that its absence is not lethal to the insect. Previous studies linking

macrophytes to increased survival primarily attribute this effect to the refuge and habitat complexity they provide against predators (Grutters et al., 2015), which were absent in our experimental design.

2. Methods

2.1 Duckweed effect on water chemistry

2.1.1 *Lemna minor* culture: *Lemna minor* is a small, free-floating freshwater macrophyte (1–8 mm in size) commonly found in ponds and slow-moving streams (Landolt, 1986). We obtained the plant from the University of Waterloo (CPCC 490) which was shipped in 25 mL tubes. Upon arrival to our laboratory (Concordia University, Loyola campus), individuals were transferred to a 50 L aquarium containing sterile, diluted Hoagland's media. Cultures were maintained under five LED light strips at an intensity of 30 μmol m^{-2} s^{-1} with a 16:8 light:dark photoperiod at a constant temperature of 20°C.

2.1.2 Experimental design: To assess the effects of *Lemna minor* presence, temperature, and trophic status on water chemistry parameters, I conducted a full factorial design (2 × 2 × 3) which included two temperature treatments (20 °C and 24 °C), two duckweed treatments (presence or absence), and three trophic status (oligotrophic, mesotrophic, and eutrophic). This resulted in 12 treatment combinations, each replicated three times, for a total of 36 experimental units (Figure 1).

2.1.3 Experimental procedure: To control for temperature, the experiment was conducted in two climate-controlled chambers set to 20°C and 24°C (16:8 h light-dark photoperiod, light intensity 70 μmol $m^{-2}s^{-1}$). For treatments with duckweed, 30 fronds (leaves) were added per jar at the beginning of the experiment. The absence of duckweed (control) was simulated using artificial duckweed (approx. 2 cm^2 leaf area × 2.4 cm root depth floating plastic duckweed, WishLotus). Trophic status (oligotrophic, mesotrophic, and eutrophic) were determined using the LakePulse dataset (LakePulse, 2023) based on the average total phosphorus concentrations. Values for waterbodies classified as mesotrophic and mesoeutrophic in the dataset were combined when defining our mesotrophic category to ensure sufficient difference between the oligotrophic and the mesotrophic treatments. Mean phosphorus concentrations were 0.008 mg L^{-1} (oligotrophic), 0.018 mg L^{-1} (mesotrophic), and 0.057 mg L^{-1} (eutrophic). I used these concentrations to prepare our trophic status treatments by mixing Miracle-Gro organic fertilizer (N:P:K = 10:1:6) with bottled spring water. Organic fertilizer was filtered through a fine-mesh strainer prior to mixing with water to prevent clumps in the solutions. Jars were covered with a transparent cup to limit evaporation and allow for visual monitoring. Jars were randomly positioned within the chambers at the start of the experiment.

2.1.4 Measurements: To assess the temporal pattern of water chemistry across all our treatments, pH, temperature (°C), Dissolved oxygen (%), and conductivity (µS/cm) were measured mostly weekly using a HI9829-10041 Hanna multiparameter probe for seven weeks.

2.2 Feeding effect on water chemistry

2.2.1 Experimental design: To assess the effects of feeding, *Lemna minor* presence, temperature, and trophic status on water chemistry parameters, I conducted a full factorial design ($2 \times 2 \times 2 \times 3$) which included two temperature treatments (20 °C and 24 °C), two feeding treatments (feeding or no feeding), two duckweed treatments (presence or absence), and three trophic status (oligotrophic, mesotrophic, and eutrophic). This resulted in 24 treatment combinations, each replicated three times, for a total of 72 experimental units.

2.2.2 Experimental procedure: Experiment 2 had the same experimental procedure as Experiment 1 except for feeding. Feeding treatments received a daily drop of artemia, which contained on average 60 artemia nauplii, which represents *ad libitum* feeding.

2.2.3 Measurements: I assessed the temporal pattern of water chemistry across all our treatments using the same parameters (pH, dissolved oxygen, and conductivity) and instrument as Experiment 1 for nine weeks mostly weekly.

2.3 Duckweed effect on larval growth

2.3.1 *Ischnura verticalis* sampling: This species is a widespread damselfly in North America that typically reproduces in freshwater ponds and other lentic habitats (Corbet, 1999). Adult females were collected from the Lachine Canal (Montréal, Canada; 45.451933, −73.625635) using hand nets and transported live to the laboratory in 25 mL plastic zip bags in a cooler. To induce oviposition in the laboratory, females were placed in containers (14.5 × 9 × 6.5 cm) lined with delicate task wipes moistened with aged water. Egg laying was checked daily, and eggs were collected and transferred to containers (14.5 × 9 × 6.5 cm) filled with aged water. Upon hatching, larvae were reared in groups of 50 – 100 individuals for the first eight weeks of their development under laboratory conditions (20 °C). They were provided with strips of 15 × 5 cm mesh fabric to increase habitat complexity and reduce the risks of cannibalism. Larvae were fed artemia nauplii daily (AAA Brine Shrimp Eggs Hatch – 453 g, Aquarium Direct). After eight weeks from hatching, individuals were randomly selected and distributed across treatments of Experiment 3.

2.3.2 Experimental design: To assess the effects of *Lemna minor* presence, temperature, and trophic status on *Ischnura verticalis* larval growth, I conducted a full factorial design ($2 \times 2 \times 3$) which included two temperature treatments (20 °C and 24 °C), two duckweed treatments (presence or absence), and three trophic status (oligotrophic, mesotrophic, and eutrophic). This

resulted in 12 treatment combinations, each replicated ten times, for a total of 120 experimental units. For this experiment, each experimental unit (jar) contained a single larva randomly selected.

2.3.3 Experimental procedure: Experiment 3 had the same experimental procedure as Experiment 1, except for the addition of a larva per jar. Each larva was randomly selected from the rearing population and assigned to a treatment. A 20 × 2.5 cm rigid mesh grid was added to each jar to provide a perching substrate for emergence. Similar to Experiment 2, all the jars received a daily drop of artemia to feed the larvae.

2.3.4 Measurements: To estimate growth rate, larval weight was measured approximately every five weeks on four different occasions. To take the weight measurement, larvae were temporarily removed from jars and placed in 30 mL cups. Individuals were gently dried using delicate task wipes to remove excess moisture, weighted on an analytical balance (Mettler Toledo Standard MA Analytical balance) to the nearest 0.1 mg, and returned to their respective jars. Larval emergences were monitored daily. Upon emergence, adults were collected, placed in 25 mL plastic zip bags, and stored at −3 °C.

2.4 Statistical analysis

All statistical analyses were performed in R (version 4.4.2) using the RStudio interface (version 2024.09.1+394). Bayesian linear mixed-effects models were fitted using the package brms following a model selection procedure. To validate the models, I performed convergence diagnostics, which showed a good convergence of the four chains across all models. R-hat was below 1.05 for all parameter estimates, indicating that all chains have mixed and converged properly.

2.4.1 Effect of duckweed on water chemistry: Models were built for each response variable: pH, conductivity, and dissolved oxygen. Each model included the fixed effect time, temperature, duckweed, and trophic status. Interaction terms were included when biologically relevant. In the pH model, the interaction between time and temperature was included and in the conductivity model, the interaction between time and duckweed was included. For the pH and dissolved oxygen models, polynomial terms of time were included to capture non-linear temporal trends. Specifically, a quadratic term of time was included in the pH model, and both a quadratic and fourth-order terms were included in the dissolved oxygen model. For all models, experimental units (jars) were included as a random effect. Models were fitted using a Gaussian error distribution and run for 8000 iterations with an adapt_delta of 0.95 and a maximum tree depth of 15 to ensure proper convergence. Default priors were used for all models. Model predictions and associated 95% prediction intervals were obtained using the ggeffects package and visualized using the ggplot2 package. Raw observations were overlaid on the predicted plots.

2.4.2 Effect of feeding on water chemistry: Bayesian linear mixed-effects models were fitted using the package brms. Models were built for each response variable: pH, conductivity, and dissolved oxygen. Each model included the fixed effect time, temperature, duckweed, artemia, and trophic status. Interaction terms were included when biologically relevant. In the pH model, interactions between duckweed and time, duckweed and temperature, time and artemia, and time and temperature were included. In the conductivity model, interactions between duckweed and time, duckweed and artemia, time and artemia, and time and temperature were included. In the dissolved oxygen model, interactions between duckweed and time, time and artemia, and time and temperature were included. A quadratic term of time interacting with temperature and artemia was included in all three models. For all models, experimental units (jars) were included as a random effect. Model fitting and visualization are the same as the previous experiment.

2.4.3 Effect of duckweed on larval growth: Bayesian linear mixed-effects models were fitted using the package brms. Models were built for each response variable: larval growth and mortality. The growth model included the fixed effects time, temperature, duckweed, and trophic status. For this model, an interaction term between time, temperature, and duckweed as well as a quadratic term of time interacting with duckweed was included. Experimental units were included as a random effect. In contrast, the mortality model included the fixed effects duckweed, temperature, and trophic status. Model fitting and visualization are the same as the two previous experiments except for the growth model. On the other hand, the mortality model was fitted using a Bernoulli error distribution. To visualize larval mortality, a bar graph of mortality proportions per treatment was generated from the raw data.

3. Results

3.1 Duckweed effect on water chemistry

3.1.1 Effect on pH: There was no effect of duckweed presence on water pH (posterior mean = −0.017, 95% CI [−0.0426, 0.0092]). However, there was an increase of pH over time (posterior mean = 0.008, 95% CI [0.0070, 0.0097]), with a deceleration after 28 days as indicated by the negative quadratic effect of time (posterior mean = −0.0001, 95% CI [−0.0001, −0.0001]). Temperature had a positive effect on pH (posterior mean = 0.054, 95% CI [0.0223, 0.0848]), and this difference in pH increased over time, as revealed by the time and temperature interaction (posterior mean = 0.001, 95% CI [0.0007 – 0.0021]). There was no effect of trophic status on pH (Figure 2, Table 1).

3.1.2 Effect on conductivity: Conductivity increased over time (posterior mean = 1.414, 95% CI [1.0041, 1.8176]). There was no evidence of an initial effect of duckweed on conductivity (posterior mean = −6.420, 95% CI [−29.16, 15.78]), however, a positive interaction between duckweed and time was observed (posterior mean = 0.634, 95% CI [0.1658, 1.1069]), indicating

that conductivity increased more rapidly over time in the presence of duckweed. There was also a positive effect of temperature (posterior mean = 84.336, 95% CI [61.9593, 107.0129]), which increased over time, as shown by the time and temperature interaction (posterior mean = 0.920, 95% CI [0.4504, 1.4022]). There was no evidence of an effect of trophic status on conductivity (Figure 3, Table 2).

3.1.3 Effect on dissolved oxygen: Dissolved oxygen exhibited an increasing pattern over time (posterior mean = 4.176, 95% CI [3.4998, 4.8396]), with some noticeable fluctuations as indicated by the positive quadratic term (posterior mean = 13.528, 95% CI [10.4371, 16.6221]), and negative order-four time term (posterior mean = −6.678, 95% CI [−7.9375, −5.4233]). Temperature had a negative effect on dissolved oxygen (posterior mean = −1.843, 95% CI [−3.2246, −0.4881]), indicating lower oxygen levels at higher temperatures. In contrast, there was no evidence of duckweed (posterior mean = 0.698, 95% CI [−0.7019, 2.0634]) and trophic status effects (Table 3) on dissolved oxygen (Figure 4).

3.2 Feeding effect on water chemistry

3.2.1 Effect on pH: There was an initial difference in pH between feeding and non-feeding treatments (posterior mean = 0.117, 95% CI [0.0324, 0.201]), with the effect of feeding increasing pH over time (posterior mean = −0.011, 95% CI [−0.0169, −0.005]). pH increased over time (posterior mean = 0.018, 95% CI [0.0134, 0.0218]), with a deceleration as indicated by the negative quadratic effect of time (posterior mean = −0.0002, 95% CI [−0.0002, −0.0001]). The interaction between time and the presence of duckweed was positive (posterior mean = 0.0013, 95% CI [0.0002, 0.0024]). The negative interaction between temperature and non-feeding (posterior mean = −0.1335, 95% CI [−0.2546, −0.0131]), together with the three-way interaction between time, temperature, and non-feeding (posterior mean = 0.010, 95% CI [0.0018, 0.0187]), suggests that the temporal effect of feeding on pH depended on temperature. Trophic status showed no clear effects on pH across all treatments (Figure 5, Table 4).

3.2.2 Effect on conductivity: Conductivity increased over time (posterior mean = 3.455, 95% CI [2.4109, 4.5102]). The interaction between non-feeding and the quadratic term of time was positive (posterior mean = 0.0281, 95% CI [0.0062, 0.0504]). The negative interaction between time and non-feeding (posterior mean = −3.856, 95% CI [−5.3075, −2.401]) indicated that conductivity increased faster over time in feeding treatments. Duckweed had a negative initial effect on conductivity (posterior mean = −31.159, 95% CI [−51.0343, −11.6313]) and, from the time and duckweed interaction, reduced the rate of increase over time (posterior mean = −0.7373, 95% CI [−1.0061, −0.4682]). A strong positive interaction between duckweed and non-feeding (posterior mean = 48.63, 95% CI [23.5735, 74.0104]) indicated that the effect of duckweed on conductivity depended on feeding conditions. Conductivity increased faster at

higher temperature over time (posterior mean = 1.569, 95% CI [0.1164, 3.0406]). There was no clear effect of trophic status on conductivity (Figure 6, Table 5).

3.2.3 Effect on dissolved oxygen: Dissolved oxygen increased over time (posterior mean = 0.7576, 95% CI [0.6059, 0.9095]), with most treatments exhibiting a nonlinear pattern, as is shown by the quadratic term of time (posterior mean = −0.0088, 95% CI [−0.0111, −0.0066]), except for the 24 °C feeding treatment, as revealed by the negative interaction between the quadratic term of time, non-feeding and temperature (posterior mean = −0.0079, 95% CI [−0.0093, −0.0065]). The interaction between non-feeding and time had a positive effect (posterior mean = 0.2384, 95% CI [0.0695, 0.4103]), which indicated that dissolved oxygen initially increased more rapidly over time without feeding. This implies that feeding initially reduced the rate of increase in dissolved oxygen over time. Duckweed had a positive effect over time (posterior mean = 0.0797, 95% CI [0.0350, 0.1250]), indicating faster increases in dissolved oxygen when duckweed is present. Higher temperature reduced the rate of increase in dissolved oxygen over time (posterior mean = −0.2020, 95% CI [−0.3752, −0.0314]). Trophic status showed no clear influence on dissolved oxygen regardless of feeding treatment (Figure 7, Table 6).

3.3 Duckweed effect on larval growth

3.3.1 Effect on larval growth: Larval weight increased over time (posterior mean = 0.0043, 95% CI [0.0033, 0.0054]) and this increase was more pronounced at a higher temperature, as shown by the time and temperature interaction (posterior mean = 0.0037, 95% CI [0.0008, 0.0043]). Duckweed presence also had a positive effect on larval growth (posterior mean = 0.0026, 95% CI [0.0004, 0.005]). Trophic status showed no clear effect on larval growth (Figure 8, Table 7).

3.3.2 Effect on larval mortality: None of the predictors showed a clear effect on larval mortality. Duckweed presence (posterior mean = 0.1516, 95% CI [−0.5997, 0.9119]), temperature (posterior mean = −0.3006, 95% CI [−1.073, 0.4548]), and trophic status all had credible intervals overlapping zero, indicating no influence on mortality (Figure 9, Table 8).

4. Discussion

This study aimed to investigate how duckweed can influence water chemistry and, indirectly, the growth and survival of damselfly larvae under different stressful environmental conditions. More specifically, we examined how duckweed, temperature, trophic status, and feeding affected pH, conductivity, and dissolved oxygen, and whether these changes translated into effects on larval growth and mortality. Overall, water chemistry changed substantially over time across

experiments, with temperature consistently influencing all measured parameters. Duckweed effects were variable and context dependent. In the first experiment, duckweed had little effect on pH and dissolved oxygen but increased conductivity over time, whereas in the feeding experiment it increased pH and dissolved oxygen while reducing conductivity. Feeding also strongly altered water chemistry dynamics, likely through its effects on nutrient availability and biological activity. Despite trophic status having little influence on measured physicochemical variables throughout the experiments, duckweed positively affected larval growth, suggesting that its influence on aquatic insects may occur through changes in environmental conditions. In contrast, duckweed did not affect larval mortality. Together, these findings suggest that the effects of duckweed on freshwater systems are highly dependent on environmental context and may indirectly benefit aquatic insects through modifications of water chemistry.

4.1 Duckweed effect on water chemistry

4.1.1 Effect on pH: pH increased over time, with a deceleration towards the end of the experiment. pH is primarily controlled by CO_2 dynamics. Therefore, since external environmental factors were removed by conducting the experiments in controlled climate chambers, changes in pH are most likely related to biological activities that affect CO_2 concentrations in the water (Hasler et al., 2018). The overall increase in pH is likely a result of photosynthesis by autotrophs (e.g. algae), which remove CO_2 from the water (Wetzel, 2001).

Temperature influenced pH dynamics over time, with a higher temperature resulting in a faster increase in pH. This pattern contrasts with many observations in freshwater systems, where higher temperatures are often associated with lower pH values due to temperature-driven changes on CO_2 solubility (Diamond & Akinfiev, 2003) and increased respiration and decomposition rates (Monroy et al., 2023). However, higher temperatures can also stimulate biological activity, including photosynthesis, which, as stated above, can increase pH by lowering CO_2 levels. Such effects have been reported in previous studies (Coles & Jones, 2000; Pniewski & Sylwestrzak, 2018). In this experiment, decomposition, which releases CO_2, may have remained relatively low, allowing the net effect of warming to be an increase in pH driven by more CO_2 uptake.

Duckweed did not affect pH, contrary to our initial hypothesis. As a floating plant, duckweed likely has a smaller influence on CO_2 dynamics through photosynthesis compared with other aquatic autotrophs. Although duckweed can contribute to CO_2 exchange with the water, as reported for other floating macrophytes such as *Salvinia molesta* and *Eichhornia crassipes* (Sale et al., 1985), most of its gas exchange occurs directly with the atmosphere through dorsal stomata. Duckweed can also influence CO_2 dynamics by forming dense mats at the water surface that limit gas exchange between the air and the water (Ceschin et al., 2019). In our experiment,

however, duckweed density was not high enough to fully cover the surface, which likely explains why no detectable effect on pH was observed.

Similarly, trophic status did not affect pH. In our experiment, other factors such as time and temperature likely played a larger role in regulating CO_2 dynamics. Therefore, the differences in fertilizer concentrations among trophic treatments may not have been large enough to drive changes in biological processes influencing pH as strongly as other variables in our experiment.

4.1.2 Effect on conductivity: Conductivity increased over time for all treatments, indicating a progressive accumulation of dissolved ions in the water. Initially, there was no difference in conductivity between duckweed treatments within each temperature level. However, the presence of duckweed accelerated the increase of conductivity over time. This pattern contradicts the initial hypothesis that duckweed would decrease conductivity and is inconsistent with findings reporting reductions in electrical conductivity in the presence of duckweed and other macrophytes [*Eichhornia crassipes*] (e.g. Moreno Castro et al., 2025). The observation that duckweed increases conductivity suggests that this parameter was influenced by processes associated with the plant. One possible explanation for the increase observed here is greater microbial activity associated with the duckweed microbiome (including its rhizosphere), which is context dependent (Bunyoo et al., 2022). Bacterial metabolism can release dissolved ions (Federle & Schwab, 1989) into the water, which may contribute to the increase in conductivity observed in the duckweed treatment.

Temperature also had an effect on conductivity, with higher temperatures associated with higher conductivity values over time. This pattern is consistent with established relationships between temperature and electrical conductivity in freshwater systems. As temperature increases, water viscosity decreases, allowing ions to move more freely, which increases conductivity (Hayashi, 2004).

There was no effect of water trophic status on conductivity. This result can be explained by the fact that most dissolved ions came from the bottled spring water used as the base for our media rather than from the fertilizer added to create the trophic status in the jars. For instance, if we calculate the total dissolved solids (TDS) for each trophic status, the values differ very little among trophic status treatments. The estimated maximum TDS is 290.80 ppm for the oligotrophic treatment, 291.81 ppm for the mesotrophic treatment, and 295.73 ppm for the eutrophic treatment. Because TDS can be used as a proxy for conductivity (Rusydi, 2018), the small differences in TDS among treatments likely explain why trophic status did not significantly affect conductivity.

4.1.3 Effect on dissolved oxygen: Time had a non-linear effect on dissolved oxygen, with an overall increasing pattern accompanied by some noticeable fluctuations. Temporal variability is consistent with observations from freshwater systems, where dissolved oxygen can vary

substantially over short time periods due to biological processes such as photosynthesis and respiration (Williams et al., 2000). These processes, which are driven by plant, algae and microbial activity, can lead to periodic increases and decreases in oxygen concentrations, explaining the fluctuations observed over time in this experiment.

Temperature also had an effect on dissolved oxygen, with higher temperature associated with lower oxygen concentrations. This pattern is consistent with established physical relationship between temperature and oxygen solubility in water. As water temperature increases, the oxygen solubility decreases, leading to lower dissolved oxygen levels in warmer aquatic environments (Woolway et al., 2022).

Duckweed did not affect dissolved oxygen. As stated above for the duckweed effect on pH, duckweed has likely a limited direct influence on oxygen release in the water column because, as a floating plant, its stomata are located on the upper surface. As a result, most gas exchange occurs with the atmosphere rather than with the water, which could explain the lack of effect seen here.

Similarly, trophic status did not influence dissolved oxygen. In natural systems, nutrient enrichment typically affects dissolved oxygen indirectly through its influence on algal growth. Increased nutrient availability can stimulate algal production, which may initially increase oxygen through photosynthesis but later decrease oxygen through respiration and the decomposition of algal biomass (Zhang et al., 2025). In our experiment, the absence of an observed trophic-status effect on dissolved oxygen likely suggests that algal biomass remained low or did not differ much among treatments. As a result, the differences in nutrient levels among trophic status may not have been large enough to generate differences in algal biomass and, in turn, translate into measurable differences in oxygen concentrations.

4.2 Feeding effect on water chemistry

4.2.1 Effect on pH: The temporal dynamics of pH were feeding and temperature dependent despite temporal temperature effect not having an effect on its own. Feeding represented a substantial input of organic matter and nutrients into the system, which most likely stimulated biological activity. As artemia decompose, microbial processes can release nutrients essential for primary producers such as algae (Deng et al., 2023). This process could have increased algal photosynthesis and thus have contributed to the rise in pH observed over time. Because metabolic processes accelerate with temperature, warmer conditions may have further enhanced this activity, leading to a faster increase in pH under higher temperature treatments. This result contradicts the initial hypothesis, which predicted that microbial respiration and organic matter decomposition would be the primary drivers of pH dynamics, whereas the observed pattern suggests that photosynthesis played a more important role.

Duckweed also had a positive effect on pH, with higher pH values observed when it was present. This contrasts with the previous experiment, where duckweed had no detectable effect on pH. One possible explanation is that visibly more algae were present in the second experiment than in the first experiment. Under these conditions, competition for nutrients among duckweed, algae, and microbes may have shifted the balance between photosynthesis and respiration toward photosynthesis. By taking up nutrients from the water column, duckweed may lower nutrient availability for microbial growth, potentially reducing decomposition and respiration. As a result, photosynthetic activity by algae may have become relatively more important in the system. Increased photosynthesis would consume more CO_2 from the water, leading to higher pH values. This suggests that the positive effect of duckweed on pH observed here likely reflects conditions in which the presence of duckweed promoted photosynthesis more than in treatments without duckweed.

There was no effect of water trophic status on pH. As in the first experiment, other factors such as time, temperature, feeding, and duckweed may have been more important in CO_2 dynamic regulation. Therefore, trophic status may not have been such an important driver in processes affecting pH, leading to an undetectable effect.

4.2.2 Effect on Conductivity: Conductivity increased over time across treatments, with the curvature of the trajectory depending on feeding conditions, and increased faster in feeding treatments. This pattern is consistent with the relationship between nutrient enrichment (dead artemia) and conductivity, as nutrient inputs can increase the concentration of dissolved ions in the water, and therefore increase conductivity values (Nürnberg, 1996).

The presence of duckweed reduced the rate of conductivity increase throughout the experiment, and this effect depended on feeding treatments. This result is consistent with the initial hypothesis and with previous findings showing that, despite an overall increase in conductivity, treatments with duckweed experienced a smaller increase than treatments without duckweed (Sarkheil & Safari, 2020). This is consistent with the ability to uptake excess nutrients from the water column (Cheng & Stomp, 2009), which would reduce conductivity values. This pattern may appear to contrast with the results of the first experiment. However, under conditions of continuous nutrient input through daily feeding, the duckweed-associated microbiome may have altered nutrient processing differently than in treatments without duckweed. For example, a study on duckweed (*Landoltia punctata*) has shown that microbial activity associated with duckweed can vary depending on environmental conditions [nutrient stress] (Bunyoo et al., 2026). This study suggests that the duckweed microbiome can adapt to its environment, leading to changes in microbial activity and community structure. As such, this could result in different responses under different conditions. Together, the results of both experiments suggest that the influence of duckweed on water chemistry may depend on environmental context, including nutrient regime

and species interactions. This supports the idea that the effects of duckweed on aquatic environments are highly context dependent (Shen et al., 2024).

Similar to the previous experiment, there was no effect of water trophic status on conductivity, indicating that ion concentrations did not differ among trophic treatments. This is to be expected, since we used the same trophic status solutions for all experiments.

4.2.3 Effect on dissolved oxygen: Both feeding and higher temperature reduced the rate of increase in dissolved oxygen. The negative effect of temperature on dissolved oxygen is consistent with the well-established physical relationship between temperature and oxygen solubility, as warmer water holds less dissolved oxygen (Woolway et al., 2022). The effect of feeding may be explained by nutrient enrichment altering biological processes in the system. Increased nutrient availability can stimulate algal production, which may initially increase oxygen through photosynthesis but later reduce oxygen through respiration and the decomposition of organic matter (Zhang et al., 2025; Zhang et al., 2017). These opposing processes may explain the observed pattern in dissolved oxygen, where the increase in dissolved oxygen slowed over time for most treatments. On the other hand, the 24 °C feeding treatment not showing a deceleration in dissolved oxygen may reflect higher photosynthetic activity under warmer conditions (Yvon-Durocher et al., 2015). Because temperature accelerates metabolic processes, higher temperature paired with continuous nutrient input (feeding) may have promoted photosynthesis sufficiently to offset the effect of respiration and decomposition on dissolved oxygen.

In contrast, dissolved oxygen increased more rapidly in the presence of duckweed. Consistent with the effect observed for pH, the presence of duckweed in this system seems to have promoted photosynthesis. This is likely due to competitive interactions for nutrients between duckweed and microorganisms, which could reduce microbial respiration and result in relatively greater photosynthetic activity when duckweed is present.

4.3 Duckweed effect on larval growth

4.3.1 Effect on larval growth: Larval weight increased more over time at higher temperature. This pattern is consistent with previous studies on odonates, which show that growth rate increases with temperature until an optimal temperature for growth (T_{opt}) is reached. In multiple damselfly species [*Ischnura elegans, Lestes disjunctus, Coenagrion mercuriale,* and *Enallagma vesperum*], it has been recorded that the optimal temperature for growth is at least 24 °C (Carbonell & Stoks, 2020; Suhling, 2015). Thus, larvae at 24 °C acquired mass faster than at 20 °C.

The presence of duckweed had a positive effect on larval growth. In this experiment, larvae were fed *ad libitum*, and much of the added artemia accumulated in the jars. This likely created

conditions similar to those observed in the feeding treatments of the second experiment. Under similar nutrient-rich conditions, duckweed may have modified water chemistry by increasing pH, reducing conductivity, and increasing dissolved oxygen relative to control treatments. A reduction in conductivity may be a reflection of excess nutrients being filtered out of the water column by duckweed, which could potentially reduce osmotic stress on larvae. An increase in dissolved oxygen could potentially allow larvae to sustain higher metabolic rates. Damselfly larvae are known to tolerate a relatively wide pH range (Corbet, 1999). Therefore, moderate increases in pH may not be detrimental if values remain within their tolerance limits. These changes in environmental conditions may have created a more favorable environment for larval growth, which could explain the positive effect of duckweed observed in this experiment.

My findings provide evidence of a positive effect of a macrophyte on life history traits of an aquatic insect, which is an understudied aspect in freshwater ecosystems. To the best of my knowledge, no study has examined the effect of duckweed on life history traits of odonates through changes in water chemistry. However, one study has reported that macrophytes can benefit mosquito larvae by removing pesticides from the water, highlighting the potential of these plants to indirectly benefit the fitness of aquatic insects (Gomes et al., 2022). More generally, positive effects of macrophytes have been reported at the community level through increased abundance and richness of insects. However, these effects are typically attributed to more direct mechanisms, such as increased habitat structure and complexity, rather than indirect mechanisms like changes in water chemistry. (Vilenica et al., 2022; Da Silva Araujo et al., 2023).

4.3.2 Effect on larval mortality:

Temperature did not affect larval mortality, which is consistent with previous studies reporting no effect of the higher temperature on survival in *Ischnura* species (Baker & Feltmate, 1987, Raczyński et al., 2022). This is to be expected, since the higher temperature used in this experiment likely remained within the larvae's optimal temperature range (Suhling, 2015).

Similarly, the presence of duckweed did not influence mortality across all treatments, even though it affected growth. This result is not surprising, as growth is generally more sensitive to suboptimal environmental conditions than survival. In this case, duckweed may change water chemistry parameters, creating conditions that favor larval growth. However, these changes may not be strong enough to influence mortality. Differences in responses among life-history traits are not uncommon in odonates, where environmental factors can affect growth or development without necessarily altering survival (e.g., Plaistow & Siva-Jothy, 1999).

4.4 Limitations

A few limitations of this study should be considered when interpreting the results. First, the experiments were conducted under controlled conditions in climate chambers. While this approach has clear advantages as it allows individual mechanisms to be isolated and analyzed, it may not fully reflect the complexity of natural freshwater ecosystems. Natural systems include additional environmental variability, species interactions, and spatial heterogeneity that may influence how aquatic plants affect water chemistry and organism performance, which cannot be replicated in laboratory experiments.

Second, the study focused on a limited set of physicochemical variables (pH, dissolved oxygen, and conductivity). Although these parameters represent important aspects of water chemistry, other variables such as specific nutrient concentrations, particularly nitrogen and phosphorus, and their temporal dynamics may have helped clarify the mechanisms underlying the patterns observed in this study. Including additional chemical variables could help determine more precisely how duckweed modifies environmental conditions and how these changes influence aquatic organisms.

5. Conclusion

The results of this study suggest that macrophytes such as duckweed can facilitate aquatic insects by mitigating the effect of environmental stressors. While duckweed alone had relatively little influence on water chemistry, its presence under different nutrient enrichment conditions was associated with increased larval growth, suggesting that its context-dependent functional role can be beneficial for life-history traits of co-occurring organisms.

Future research should further investigate plant-mediated facilitation under different types of environmental stress. It would be valuable to test whether similar facilitative effects occur in other aquatic insect species or taxa, as responses may vary depending on the organism studied. Additionally, studies could examine whether other macrophytes or mixed plant communities provide similar buffering effects, and whether these effects are consistent across different types of stressors such as temperature increases, nutrient enrichment, or pollution. Including additional environmental variables, particularly nutrient concentrations such as nitrogen and phosphorus, would also help clarify the mechanisms through which plants mitigate stress. Expanding research in this direction would improve our understanding of how facilitation shapes community dynamics in freshwater ecosystems under global change.

This study suggests that aquatic plants such as duckweed could be used in applied conservation and ecosystem management as natural tools to mitigate environmental stressors and support

aquatic organisms. By acting as a nutrient sink and modifying water chemistry, duckweed may help buffer the negative effects of nutrient enrichment and organic pollution, thereby improving conditions for sensitive species. This is particularly relevant in freshwater systems increasingly impacted by anthropogenic stressors. Incorporating aquatic plants into restoration or management strategies could enhance ecosystem resilience by promoting facilitative interactions that support biodiversity. Given that duckweed is fast-growing, widely distributed, and inexpensive to implement, it represents a practical and accessible approach to improving water quality while simultaneously benefiting aquatic communities. However, these benefits are likely contingent on careful management of duckweed growth, as dense surface mats can restrict gas exchange and potentially lead to hypoxia.

Table 1. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, and trophic status on water pH.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat
Intercept	8.487	0.017	8.4537	8.5204	1.000
Time	0.008	0.001	0.007	0.0097	1.001
$Time^2$	-0.000	0.000	-0.0001	-0.0001	1.001
Temperature[24°]	0.054	0.016	0.0223	0.0848	1.001
Duckweed[D]	-0.017	0.013	-0.0426	0.0092	1.000
Trophic_Status[M]	-0.008	0.016	-0.0392	0.0239	1.001
Trophic_Status[O]	-0.018	0.016	-0.0498	0.0129	1.001
Time:Temperature[24°]	0.001	0.000	0.0007	0.0021	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_Status[M] and Trophic_Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table 2. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, and trophic status on water conductivity.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat
Intercept	499.390	12.049	475.7041	523.1844	1.001
Time	1.414	0.209	1.0041	1.8176	1.000

Temperature[24°]	84.336	11.464	61.9593	107.0129	1.001
Duckweed[D]	-6.420	11.293	-29.1562	15.7812	1.002
Trophic_ Status[M]	-14.104	12.113	-37.7643	9.2643	1.001
Trophic_ Status[O]	-3.827	12.064	-27.5882	20.1715	1.001
Time:Duckweed[D]	0.634	0.239	0.1658	1.1069	1.000
Time:Temperature[24°]	0.920	0.242	0.4504	1.4022	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table 3. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, and trophic status on water dissolved oxygen (DO).

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat
Intercept	48.306	0.967	46.414	50.168	1.000
Time	4.176	0.346	3.4998	4.8396	1.000
$Time^2$	13.528	1.581	10.4371	16.6221	1.000
$Time^4$	-6.678	0.644	-7.9375	-5.4233	1.000
Temperature[24°]	-1.843	0.698	-3.2246	-0.4881	1.000
Duckweed[D]	0.698	0.705	-0.7019	2.0634	1.000
Trophic_Status[M]	1.012	0.866	-0.6728	2.712	1.000
Trophic_ Status[O]	-0.629	0.858	-2.2969	1.0735	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table 4. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, feeding, and trophic status on water pH.

Parameter	Estimate	Est.Error	l-95% CI	u-95%	Rhat
Intercept	8.248	0.035	8.1793	8.3173	1.000
Time	0.018	0.002	0.0134	0.0218	1.001
Temperature[24°]	0.075	0.046	-0.0148	0.1653	1.001
Duckweed[D]	-0.026	0.028	-0.0815	0.0284	1.000
$Time^2$	-0.0002	0.000	-0.0002	-0.0001	1.001
Artemia[A]	0.117	0.043	0.0324	0.201	1.001
Trophic_ Status[M]	-0.007	0.018	-0.0427	0.029	1.001
Trophic_ Status[O]	-0.034	0.018	-0.0697	0.0022	1.000
Time: Duckweed[D]	0.001	0.001	0.0002	0.0024	1.001
Temperature[24°]:Duckweed[D]	0.024	0.030	-0.033	0.0838	1.000
Temperature[24°]: $Time^2$	0.000	0.000	0.0001	0.0003	1.001
$Time^2$:Artemia[A]	0.000	0.000	0.0000	0.0002	1.001
Temperature[24°]:Artemia[A]	-0.134	0.061	-0.2546	-0.0131	1.001
Time:Artemia[A]	-0.011	0.003	-0.0169	-0.005	1.001
Time:Temperature[24°]	-0.004	0.003	-0.0101	0.0018	1.001
Temperature[24°]:$Time^2$:Artemia[A]	0.000	0.000	-0.0004	-0.0001	1.001
Time:Temperature[24°]:Artemia[A]	0.010	0.004	0.0018	0.0187	1.001

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table 5. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, feeding, and trophic status on water conductivity.

Parameter	Estimate	Est.Error	l-95% CI	u-95%	Rhat
Intercept	445.877	11.473	423.2716	468.274	1.000
Time	3.455	0.529	2.4109	4.5102	1.001
Duckweed[D]	-31.159	10.011	-51.0343	-11.6313	1.000
Temperature[24°]	8.853	13.161	-16.4609	34.7917	1.001
Artemia[A]	-14.361	14.655	-43.1011	14.3042	1.000
$Time^2$	-0.001	0.008	-0.0164	0.0152	1.001
Trophic_ Status[M]	-5.129	7.899	-20.6075	10.4351	1.001
Trophic_ Status[O]	5.175	7.704	-9.8002	20.7161	1.000
Time:Duckweed[D]	-0.737	0.138	-1.0061	-0.4682	1.000
Duckweed[D]:Artemia[A]	48.627	12.819	23.5735	74.0104	1.001
Temperature[24°]:$Time^2$	-0.005	0.011	-0.0277	0.0168	1.001
Artemia[A]: $Time^2$	0.028	0.011	0.0062	0.0504	1.001
Temperature[24°]:Artemia[A]	-9.437	18.662	-46.2803	26.9342	1.001
Time:Artemia[A]	-3.856	0.746	-5.3075	-2.401	1.001
Time:Temperature[24°]	1.569	0.744	0.1164	3.0406	1.001
Temperature[24°]:Artemia[A]:$Time^2$	-0.004	0.016	-0.0356	0.0273	1.001
Time:Temperature[24°]:Artemia[A]	1.782	1.055	-0.3056	3.8528	1.001

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table 6. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, feeding, and trophic status on water dissolved oxygen (DO).

Parameter	Estimate	Est.Error	l-95% CI	u-95%	Rhat
Intercept	28.745	1.438	25.9489	31.5581	1.000
Time	0.758	0.077	0.6059	0.9095	1.000
Temperature[24°]	0.195	1.592	-2.9043	3.3439	1.000
Duckweed[D]	-0.346	1.054	-2.4051	1.7324	1.000
$Time^2$	-0.009	0.001	-0.0111	-0.0066	1.000
Artemia[A]	-1.515	1.586	-4.64	1.5828	1.000
Trophic_ Status[M]	-0.192	0.937	-2.0404	1.6663	1.001
Trophic_ Status[O]	-0.680	0.935	-2.516	1.16	1.001
Time: Duckweed[D]	0.080	0.023	0.035	0.125	1.000
Temperature[24°]:$Time^2$	0.013	0.001	0.0099	0.0153	1.000
$Time^2$:Artemia[A]	-0.003	0.001	-0.0052	0.0002	1.000
Temperature[24°]:Artemia[A]	-0.321	1.810	-3.9038	3.2336	1.000
Time:Artemia[A]	0.238	0.087	0.0695	0.4103	1.000
Time:Temperature[24°]	-0.202	0.087	-0.3752	-0.0314	1.000
Temperature[24°]:$Time^2$:Artemia[A]	-0.008	0.001	-0.0093	-0.0065	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table 7. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, and trophic status on larval growth.

Parameter	Estimate	Est.Error	l-95%	u-95%	Rhat
Intercept	0.010	0.001	0.008	0.0118	1.000
Time	0.004	0.001	0.0033	0.0054	1.000
Temperature[24°]	0.003	0.001	0.0005	0.0045	1.000
Duckweed[D]	0.003	0.001	0.0004	0.005	1.000
$Time^2$	-0.001	0.001	-0.0015	0.0004	1.000
Trophic_ Status[M]	0.001	0.001	-0.0008	0.0025	1.000
Trophic_ Status[O]	0.001	0.001	-0.001	0.0022	1.001
Time:Temperature[24°]	0.0037	0.001	0.0008	0.0043	1.000
Time: Duckweed[D]	0.002	0.001	0.00003	0.0032	1.000
Temperature[24°]:Duckweed[D]	0.003	0.002	0.0002	0.0059	1.000
Duckweed[D]:$Time^2$	-0.0006	0.0007	-0.0020	0.0008	1.000
Time:Temperature[24°]:Duckweed[D]	-0.001	0.001	-0.002	0.0008	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table 8. Summary of the Bayesian linear mixed-effects model testing the effects of time, temperature, duckweed, and trophic status on larval mortality.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat
Intercept	-0.351	0.428	-1.2074	0.4627	1.000
Duckweed[D]	0.152	0.388	-0.5997	0.9119	1.000
Temperature[24°]	-0.301	0.388	-1.073	0.4548	1.000
Trophic_ Status[M]	0.221	0.467	-0.6953	1.1334	1.001
Trophic_ Status[O]	-0.464	0.487	-1.4278	0.4682	1.000

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

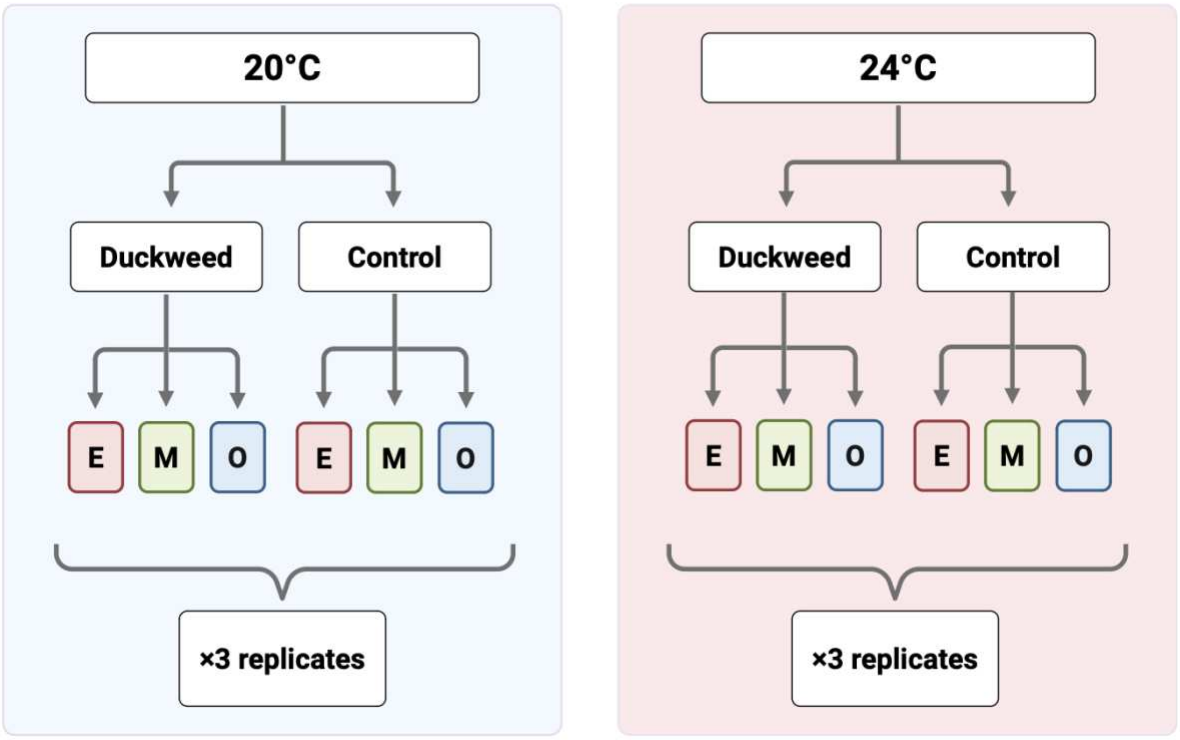

Figure 1. Experimental design for Experiment 1. This design included two temperatures (20 °C and 24 °C), two duckweed treatments (presence or absence), and three trophic status (O = oligotrophic, M = mesotrophic, and E = eutrophic). In total, the experiment included 12 treatments with three replicates.

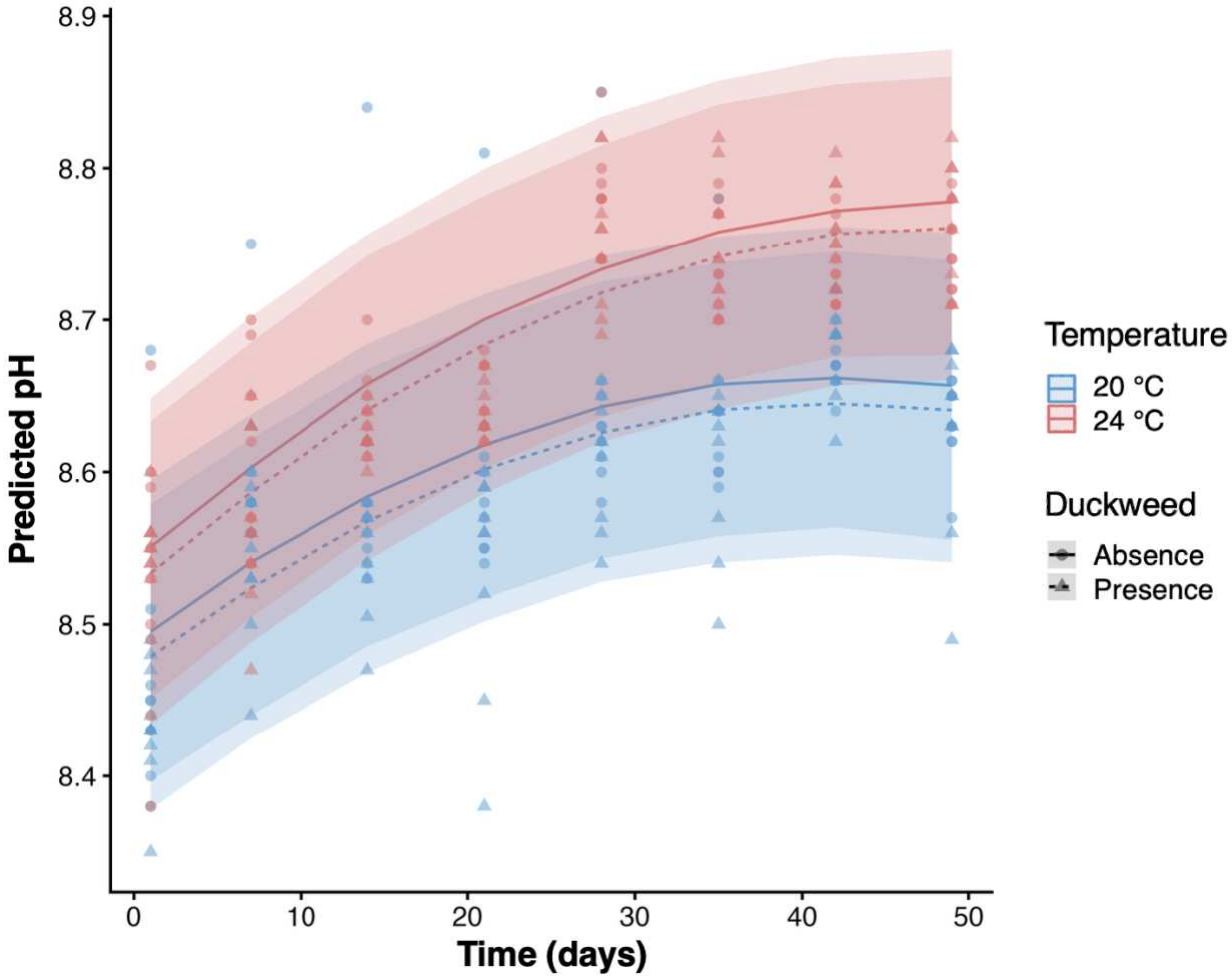

Figure 2. Changes in water pH over time under different temperature and duckweed treatments. Points represent raw observations. Lines show model-predicted conductivity values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

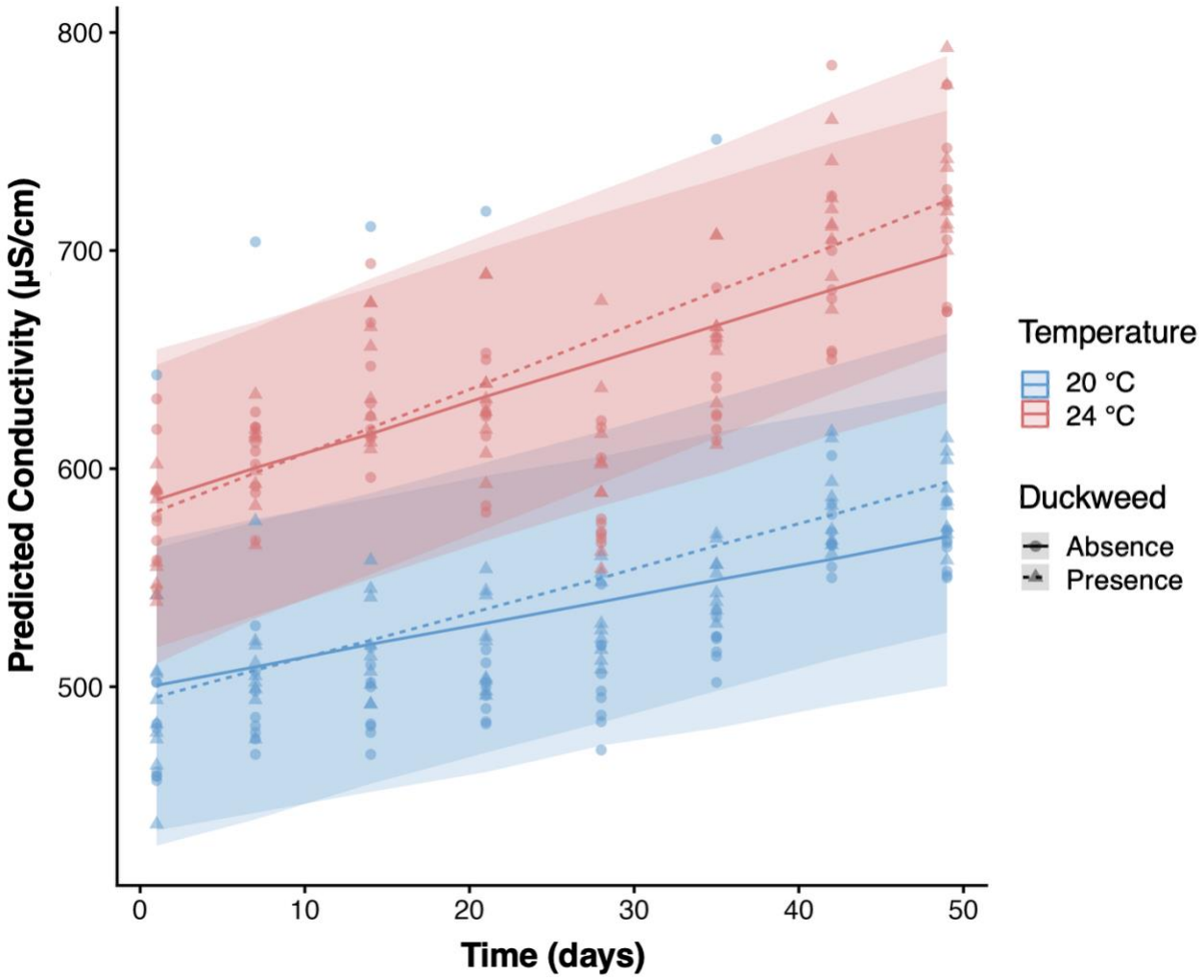

Figure 3. Changes in water conductivity (µS/cm) over time under different temperature and duckweed treatments. Points represent raw observations. Lines show model-predicted conductivity values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

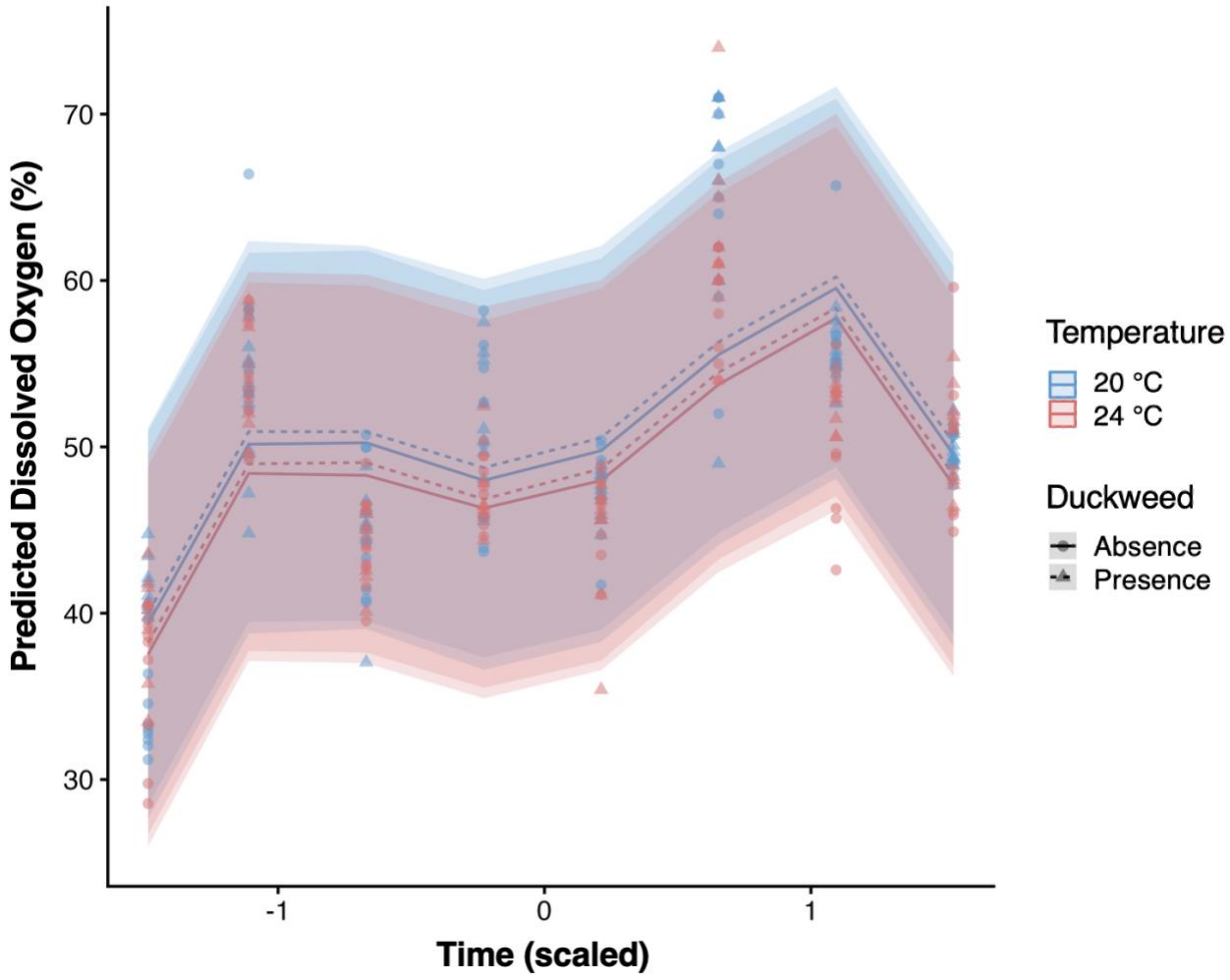

Figure 4. Changes in water dissolved oxygen (%) over time under different temperature and duckweed treatments. Points represent raw observations. Lines show model-predicted conductivity values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

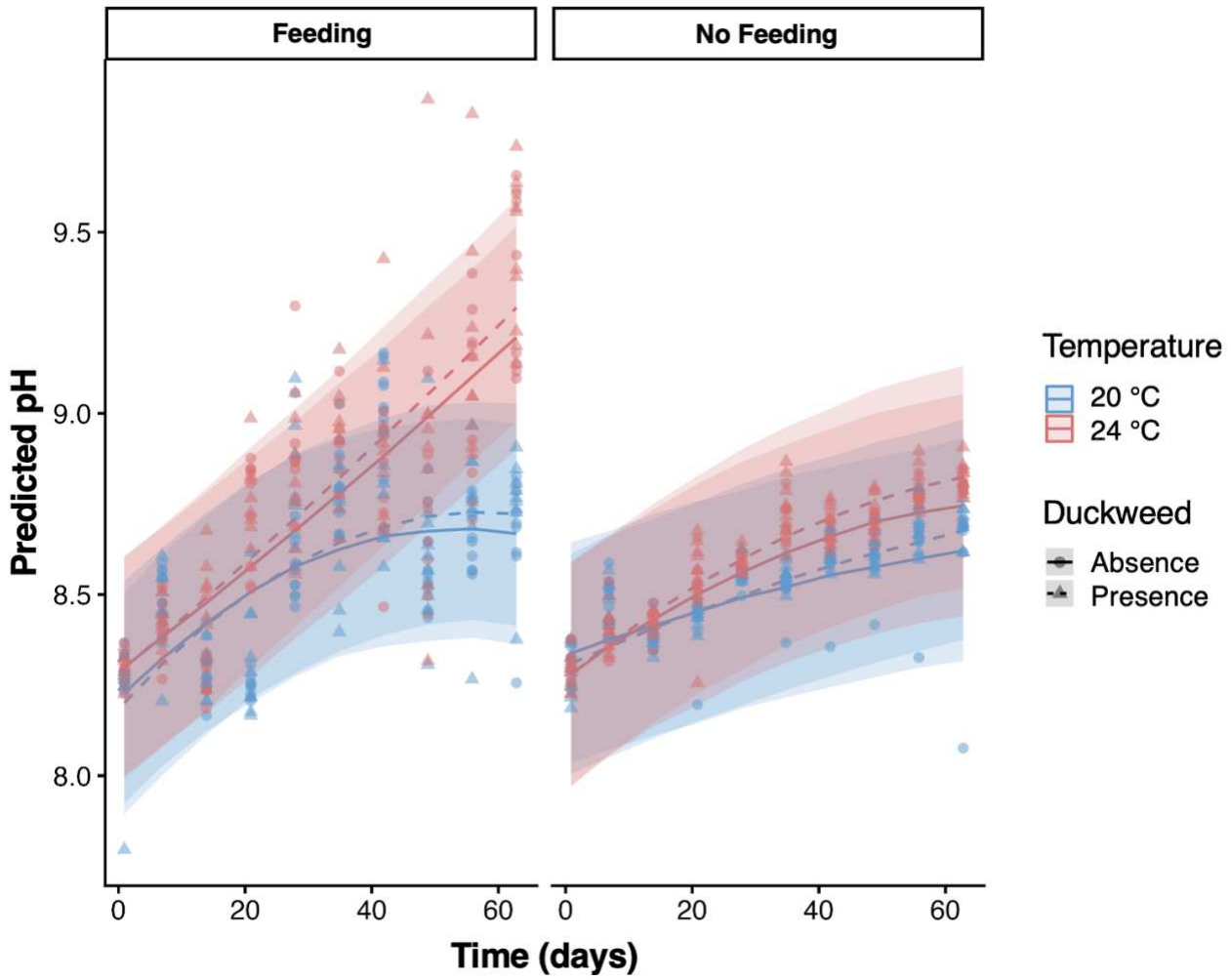

Figure 5. Changes in water pH over time under different temperature and duckweed treatments for the two feeding treatments, A (feeding) and N (no feeding). Points represent raw observations. Lines show model-predicted pH values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

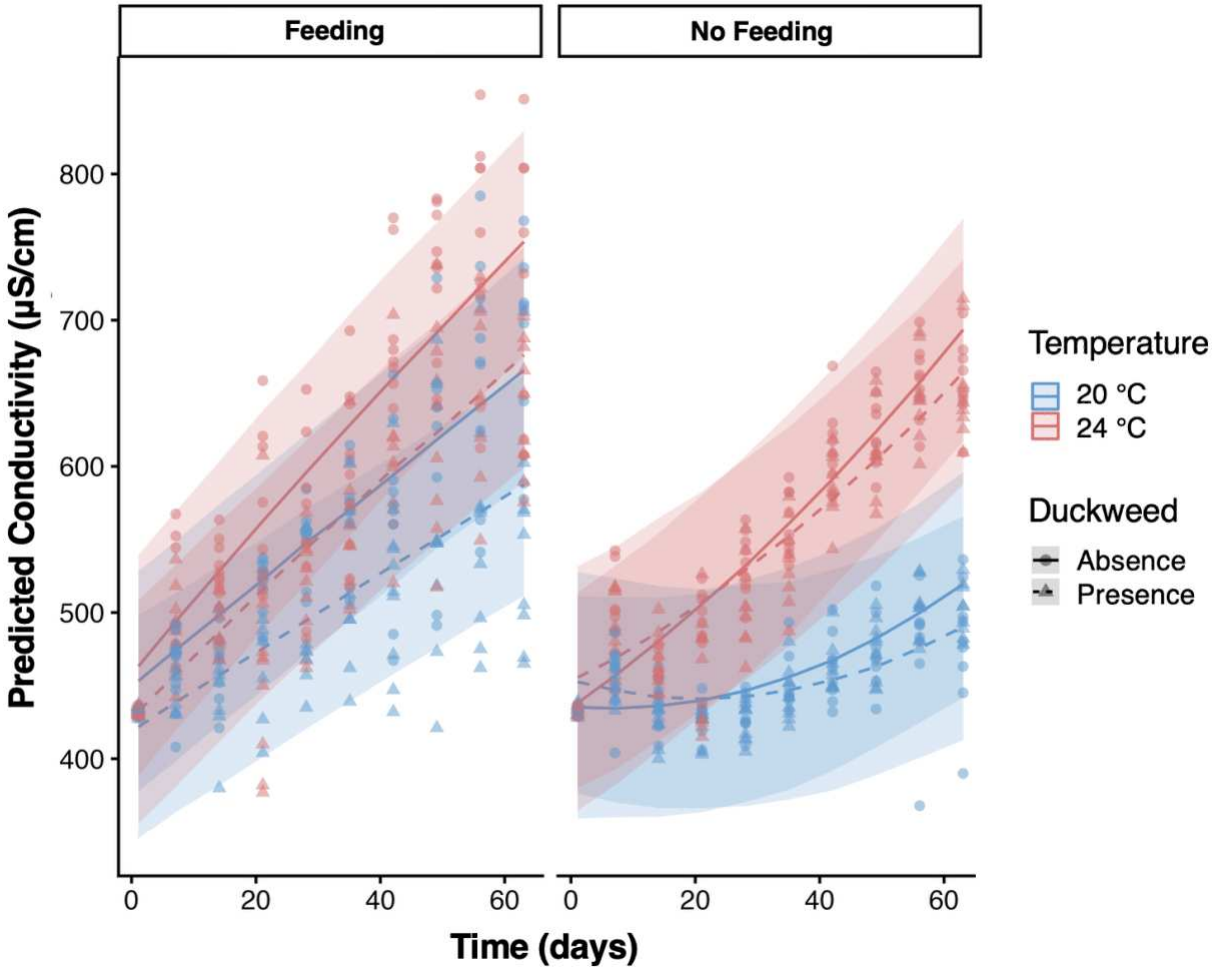

Figure 6. Changes in water conductivity (µS/cm) over time under different temperature and duckweed treatments for the two feeding treatments, A (feeding) and N (no feeding). Points represent raw observations. Lines show model-predicted pH values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

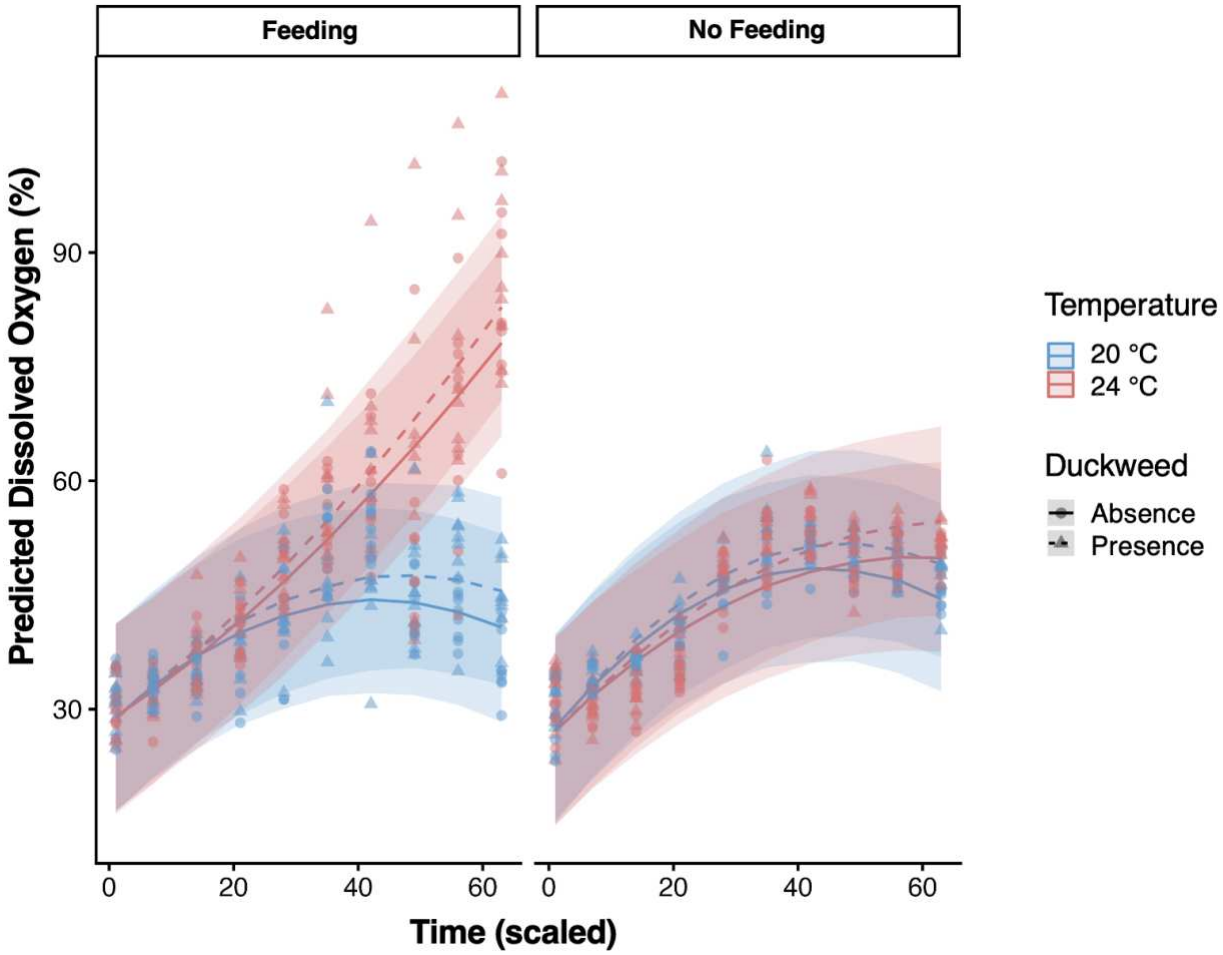

Figure 7. Changes in water dissolved oxygen (%) over time under different temperature and duckweed treatments for the two feeding treatments, A (feeding) and N (no feeding). Points represent raw observations. Lines show model-predicted pH values from the Bayesian linear mixed-effects model, with shaded areas representing 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

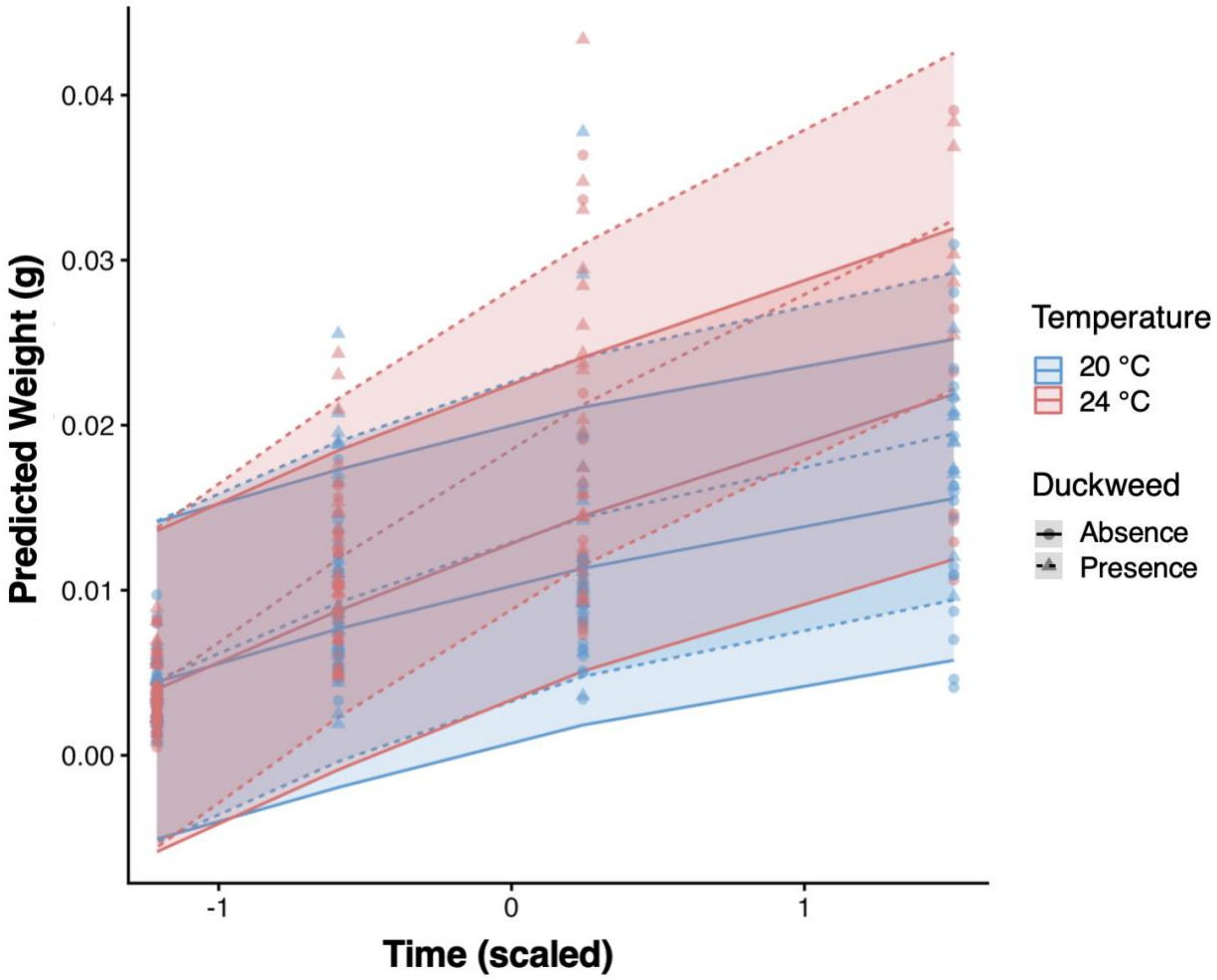

Figure 8. Predicted damselfly larval weight (g) over time under different temperature and duckweed treatments. Solid lines represent model-predicted values from the Bayesian linear mixed-effects model. Shaded areas represent 95% prediction intervals. Blue lines correspond to the 20 °C treatment and red lines correspond to the 24 °C treatment. Solid lines represent absence of duckweed, and dashed lines represent the presence of duckweed.

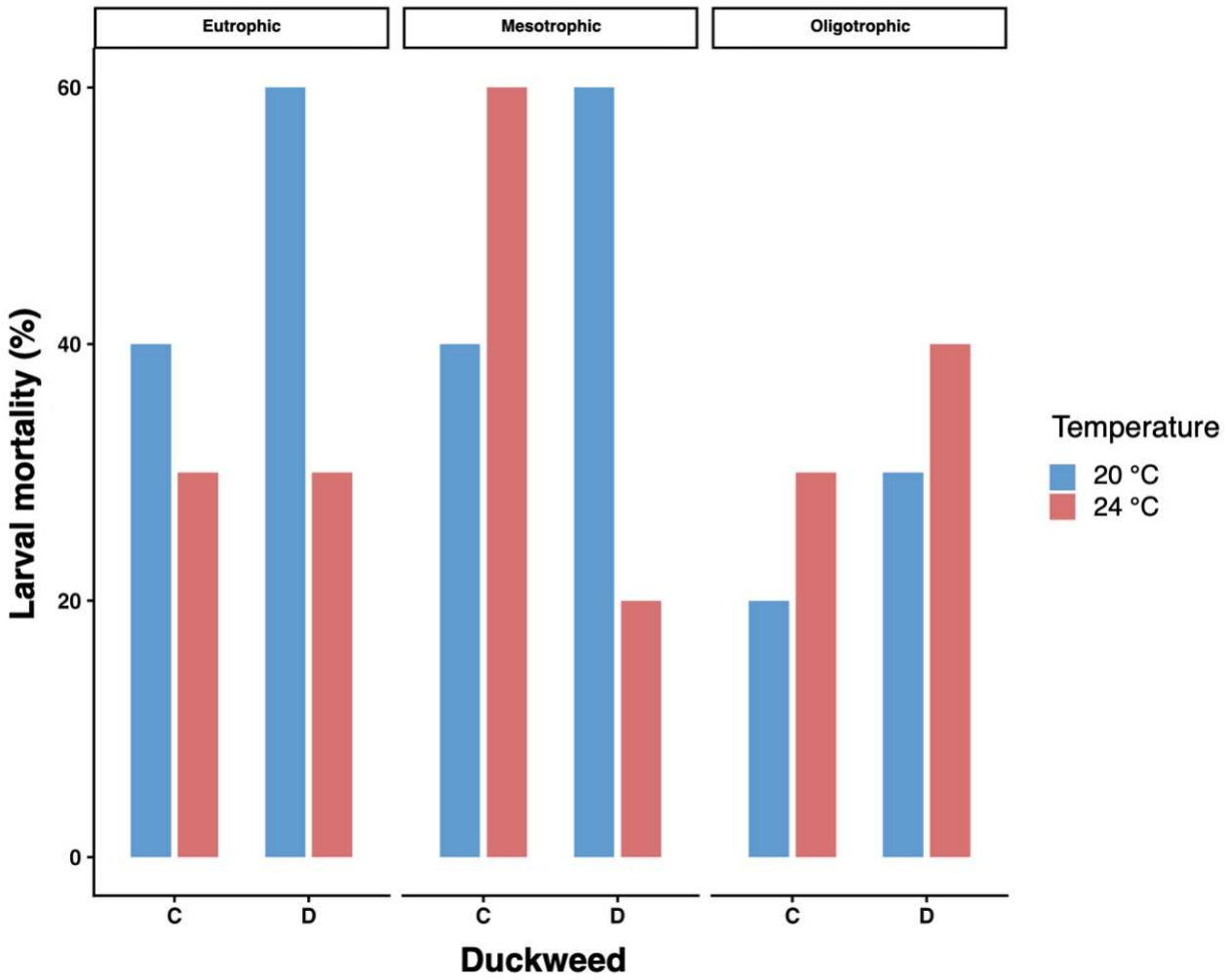

Figure 9. Percentage of larval mortality of *Ischnura verticalis* for different temperature, duckweed, and water trophic status treatments. Bars represent presence (D) and absence (C) of duckweed.

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Appendix A

A.1 Formula specifications for the model testing the effect of duckweed on pH.

pH ~ time + I(time^2) + Temperature + Duckweed + Trophic_State +Temperature * time +(1|Unique_ID)

A.2 Formula specifications for the model testing the effect of duckweed on conductivity.

Conductivity ~ time + Temperature + Duckweed + Trophic_State + time * Duckweed + time * Temperature +(1|Unique_ID)

A.3 Formula specifications for the model testing the effect of duckweed on dissolved oxygen.

DO ~ Time + I(Time^2) + I(Time^4) + Temperature + Duckweed + Trophic_State + (1 | Unique_ID)

A.4 Formula specifications for the model testing the effect of feeding on pH.

pH ~ time + Temperature + Duckweed * time + Duckweed * Temperature + I(time^2) * Temperature * artemia + time * artemia * Temperature + Duckweed + Trophic_State + artemia + (1|Unique_ID)

A.5 Formula specifications for the model testing the effect of feeding on conductivity.

Conductivity ~ time + Duckweed * time + Temperature +Duckweed * artemia + I(time^2) * Temperature * artemia + time * artemia * Temperature + Duckweed + Trophic_State + artemia + (1|Unique_ID)

A.6 Formula specifications for the model testing the effect of feeding on dissolved oxygen.

DO ~ time + Temperature + Duckweed * time + I(time^2) * Temperature * artemia + time * artemia + time * Temperature + Duckweed + Trophic_State + artemia + (1|Unique_ID)

A.7 Formula specifications for the model testing the effect of duckweed on larval growth.

Weight ~ time * Temperature * Duckweed + I(time^2) + I(time^2) * Duckweed + Temperature + Duckweed + Trophic_State + time * Temperature + time * Duckweed + (1|Unique_ID)

A.8 Formula specifications for the model testing the effect of duckweed on larval mortality.

Mortality_Larvae ~ Duckweed + Temperature + Trophic_State

Appendix B

Table B.1. Full summary output of the Bayesian linear mixed-effects model testing the effect of duckweed on pH.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	8.487	0.017	8.4537	8.5204	1.000	5931	8824
Time	0.008	0.001	0.007	0.0097	1.001	19905	11356
$Time^2$	-0.000	0.000	-0.0001	-0.0001	1.001	18252	10905
Temperature[24°]	0.054	0.016	0.0223	0.0848	1.001	6661	10565
Duckweed[D]	-0.017	0.013	-0.0426	0.0092	1.000	5514	7224
Trophic_Status[M]	-0.008	0.016	-0.0392	0.0239	1.001	5008	7781
Trophic_Status[O]	-0.018	0.016	-0.0498	0.0129	1.001	5105	7135
Time:Temperature[24°]	0.001	0.000	0.0007	0.0021	1.000	23365	13290

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_Status[M] and Trophic_Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table B.2. Full summary output of the Bayesian linear mixed-effects model testing the effect of duckweed on conductivity.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	499.390	12.049	475.7041	523.1844	1.001	5099	7337
Time	1.414	0.209	1.0041	1.8176	1.000	9244	11698
Temperature[24°]	84.336	11.464	61.9593	107.0129	1.001	5355	7892
Duckweed[D]	-6.420	11.293	-29.1562	15.7812	1.002	5186	7687
Trophic_ Status[M]	-14.104	12.113	-37.7643	9.2643	1.001	4909	7416
Trophic_ Status[O]	-3.827	12.064	-27.5882	20.1715	1.001	4754	6895
Time:Duckweed[D]	0.634	0.239	0.1658	1.1069	1.000	11270	10658
Time:Temperature[24°]	0.920	0.242	0.4504	1.4022	1.000	11038	11803

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table B.3. Full summary output of the Bayesian linear mixed-effects model testing the effect of duckweed on dissolved oxygen.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	48.306	0.967	46.414	50.168	1.000	19265	13710
Time	4.176	0.346	3.4998	4.8396	1.000	29630	11479
$Time^2$	13.528	1.581	10.4371	16.6221	1.000	13759	11682
$Time^4$	-6.678	0.644	-7.9375	-5.4233	1.000	13610	11494
Temperature[24°]	-1.843	0.698	-3.2246	-0.4881	1.000	28066	11585
Duckweed[D]	0.698	0.705	-0.7019	2.0634	1.000	28811	11648
Trophic_Status[M]	1.012	0.866	-0.6728	2.712	1.000	21247	12507
Trophic_ Status[O]	-0.629	0.858	-2.2969	1.0735	1.000	20590	13426

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Table B.4. Full summary output of the Bayesian linear mixed-effects model testing the effect of feeding on pH.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	8.248	0.035	8.1793	8.3173	1.000	5636	9798
Time	0.018	0.002	0.0134	0.0218	1.001	5899	9271
Temperature[24°]	0.075	0.046	-0.0148	0.1653	1.001	4603	8253
Duckweed[D]	-0.026	0.028	-0.0815	0.0284	1.000	8627	11110
$Time^2$	-0.0002	0.000	-0.0002	-0.0001	1.001	6766	10460
Artemia[A]	0.117	0.043	0.0324	0.201	1.001	4947	8410
Trophic_ Status[M]	-0.007	0.018	-0.0427	0.029	1.001	7560	10825
Trophic_ Status[O]	-0.034	0.018	-0.0697	0.0022	1.000	7589	10122
Time: Duckweed[D]	0.001	0.001	0.0002	0.0024	1.001	24276	13128
Temperature[24°]:Duckweed[D]	0.024	0.030	-0.033	0.0838	1.000	6736	9174
Temperature[24°]: $Time^2$	0.000	0.000	0.0001	0.0003	1.001	5969	9280
$Time^2$:Artemia[A]	0.000	0.000	0.0000	0.0002	1.001	6067	9982
Temperature[24°]:Artemia[A]	-0.134	0.061	-0.2546	-0.0131	1.001	4382	7523
Time:Artemia[A]	-0.011	0.003	-0.0169	-0.005	1.001	5170	8968
Time:Temperature[24°]	-0.004	0.003	-0.0101	0.0018	1.001	5107	8289
Temperature[24°]:$Time^2$:Artemia[A]	0.000	0.000	-0.0004	-0.0001	1.001	5763	8160
Time:Temperature[24°]:Artemia[A]	0.010	0.004	0.0018	0.0187	1.001	4864	7643

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table B.5. Full summary output of the Bayesian linear mixed-effects model testing the effect of feeding on conductivity.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	445.877	11.473	423.2716	468.274	1.000	5877	8869
Time	3.455	0.529	2.4109	4.5102	1.001	5825	9310
Duckweed[D]	-31.159	10.011	-51.0343	-11.6313	1.000	6561	9429
Temperature[24°]	8.853	13.161	-16.4609	34.7917	1.001	6000	9204
Artemia[A]	-14.361	14.655	-43.1011	14.3042	1.000	5548	8569
$Time^2$	-0.001	0.008	-0.0164	0.0152	1.001	6002	9342
Trophic_ Status[M]	-5.129	7.899	-20.6075	10.4351	1.001	6476	9433
Trophic_ Status[O]	5.175	7.704	-9.8002	20.7161	1.000	6601	9228
Time:Duckweed[D]	-0.737	0.138	-1.0061	-0.4682	1.000	25277	11353
Duckweed[D]:Artemia[A]	48.627	12.819	23.5735	74.0104	1.001	5575	9063
Temperature[24°]:$Time^2$	-0.005	0.011	-0.0277	0.0168	1.001	5712	9212
Artemia[A]: $Time^2$	0.028	0.011	0.0062	0.0504	1.001	5662	8849
Temperature[24°]:Artemia[A]	-9.437	18.662	-46.2803	26.9342	1.001	5697	8017
Time:Artemia[A]	-3.856	0.746	-5.3075	-2.401	1.001	5589	9123
Time:Temperature[24°]	1.569	0.744	0.1164	3.0406	1.001	5479	8878
Temperature[24°]:Artemia[A]:$Time^2$	-0.004	0.016	-0.0356	0.0273	1.001	5551	8319
Time:Temperature[24°]:Artemia[A]	1.782	1.055	-0.3056	3.8528	1.001	5324	8472

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table B.6. Full summary output of the Bayesian linear mixed-effects model testing the effect of feeding on dissolved oxygen.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	28.745	1.438	25.9489	31.5581	1.000	6319	9478
Time	0.758	0.077	0.6059	0.9095	1.000	7696	10029
Temperature[24°]	0.195	1.592	-2.9043	3.3439	1.000	6133	9496
Duckweed[D]	-0.346	1.054	-2.4051	1.7324	1.000	8148	10244
$Time^2$	-0.009	0.001	-0.0111	-0.0066	1.000	7990	10787
Artemia[A]	-1.515	1.586	-4.64	1.5828	1.000	7204	9509
Trophic_ Status[M]	-0.192	0.937	-2.0404	1.6663	1.001	6571	9179
Trophic_ Status[O]	-0.680	0.935	-2.516	1.16	1.001	5917	9060
Time: Duckweed[D]	0.080	0.023	0.035	0.125	1.000	12372	10466
Temperature[24°]:$Time^2$	0.013	0.001	0.0099	0.0153	1.000	8939	11036
$Time^2$:Artemia[A]	-0.003	0.001	-0.0052	0.0002	1.000	9623	11058
Temperature[24°]:Artemia[A]	-0.321	1.810	-3.9038	3.2336	1.000	6563	9407
Time:Artemia[A]	0.238	0.087	0.0695	0.4103	1.000	8959	10605
Time:Temperature[24°]	-0.202	0.087	-0.3752	-0.0314	1.000	8299	10150
Temperature[24°]:$Time^2$:Artemia[A]	-0.008	0.001	-0.0093	-0.0065	1.000	17611	12553

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table B.7. Full summary output of the Bayesian linear mixed-effects model testing the effect of duckweed on larval growth.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	0.010	0.001	0.008	0.0118	1.000	14985	13523
Time	0.004	0.001	0.0033	0.0054	1.000	17763	14587
Temperature[24°]	0.003	0.001	0.0005	0.0045	1.000	13459	13053
Duckweed[D]	0.003	0.001	0.0004	0.005	1.000	14924	13364
$Time^2$	-0.001	0.001	-0.0015	0.0004	1.000	19309	14240
Trophic_ Status[M]	0.001	0.001	-0.0008	0.0025	1.000	15482	13785
Trophic_ Status[O]	0.001	0.001	-0.001	0.0022	1.001	14963	14626
Time:Temperature[24°]	0.0037	0.001	0.0008	0.0043	1.000	19974	14096
Time: Duckweed[D]	0.002	0.001	0.00003	0.0032	1.000	19311	14696
Temperature[24°]:Duckweed[D]	0.003	0.002	0.0002	0.0059	1.000	13252	11883
Duckweed[D]:$Time^2$	-0.0006	0.0007	-0.0020	0.0008	1.000	22141	12549
Time:Temperature[24°]:Duckweed[D]	-0.001	0.001	-0.002	0.0008	1.000	21627	13619

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status. Artemia[A] represents the absence of feeding relative to feeding Artemia (P).

Table B.8. Full summary output of the Bayesian linear mixed-effects model testing the effect of duckweed on larval mortality.

Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.351	0.428	-1.2074	0.4627	1.000	17773	11938
Duckweed[D]	0.152	0.388	-0.5997	0.9119	1.000	20151	11457
Temperature[24°]	-0.301	0.388	-1.073	0.4548	1.000	19504	12858
Trophic_ Status[M]	0.221	0.467	-0.6953	1.1334	1.001	15296	11997
Trophic_ Status[O]	-0.464	0.487	-1.4278	0.4682	1.000	15232	12548

Note. Temperature[24°] represents the effect of 24 °C relative to the reference level of 20 °C. Duckweed[D] indicates the presence of duckweed relative to the absence of duckweed (C). Trophic_ Status[M] and Trophic_ Status[O] represent mesotrophic and oligotrophic status, respectively, relative to eutrophic status.

Appendix C

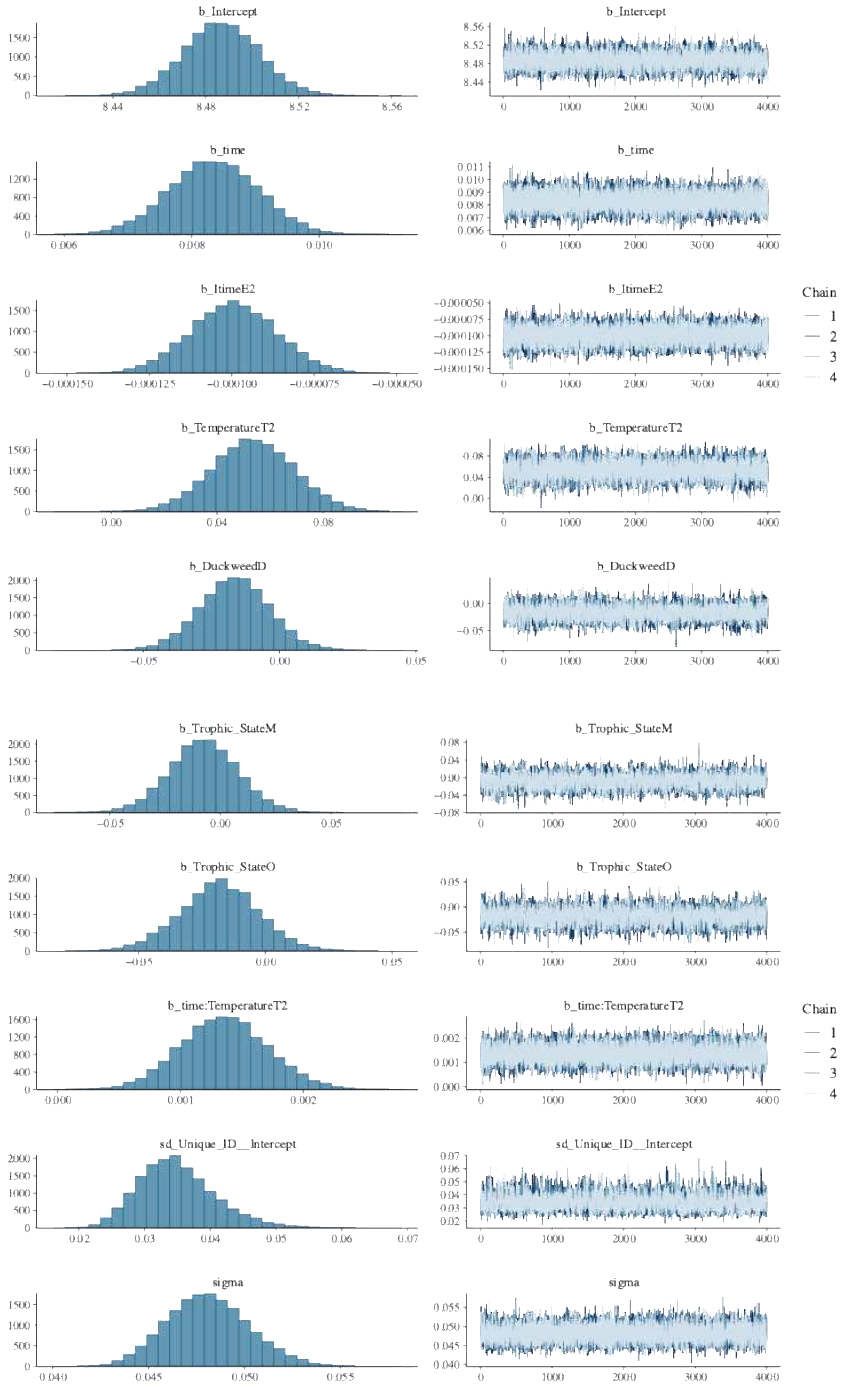


Figure C.1. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of duckweed on pH.

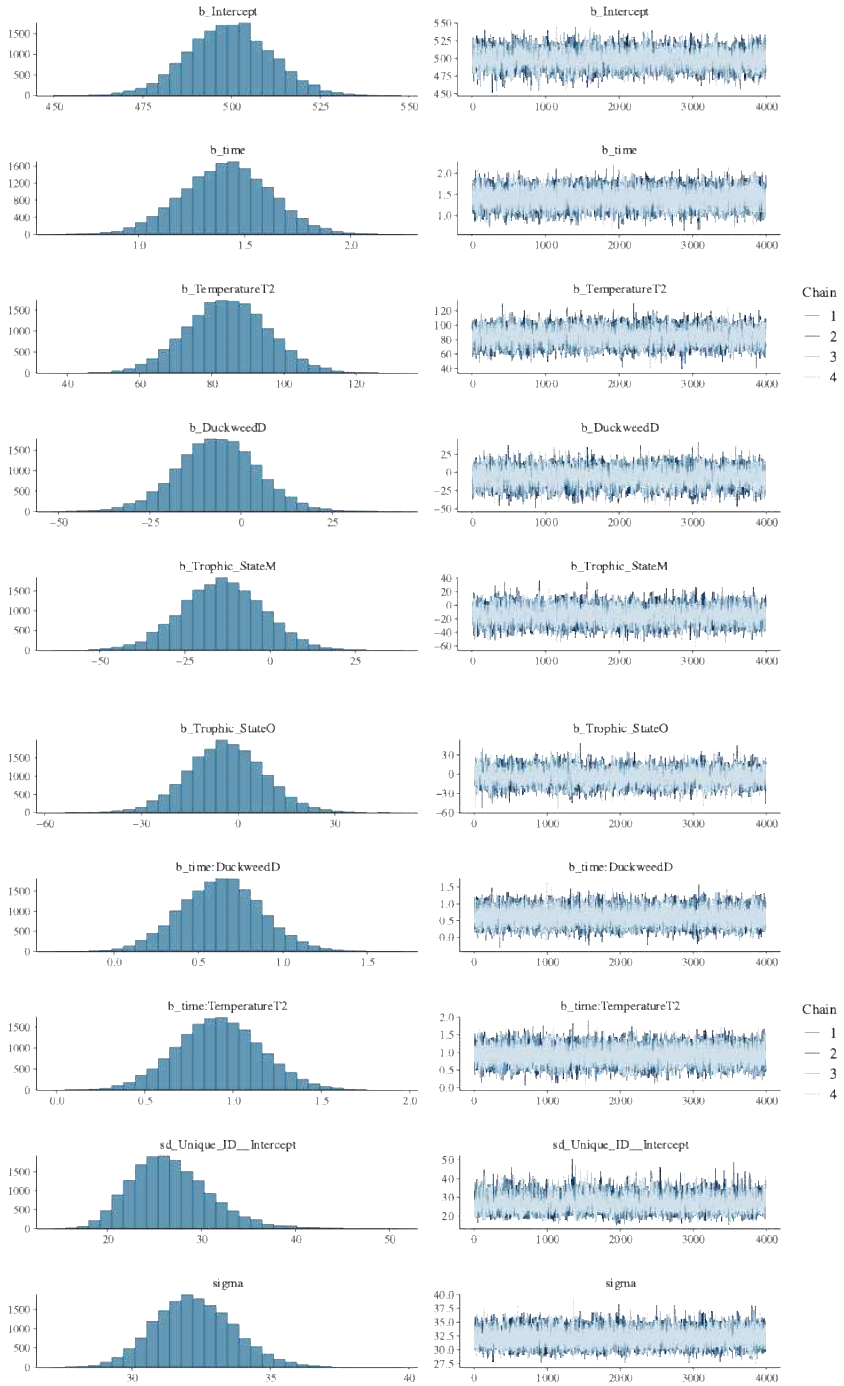


Figure C.2. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of duckweed on conductivity.

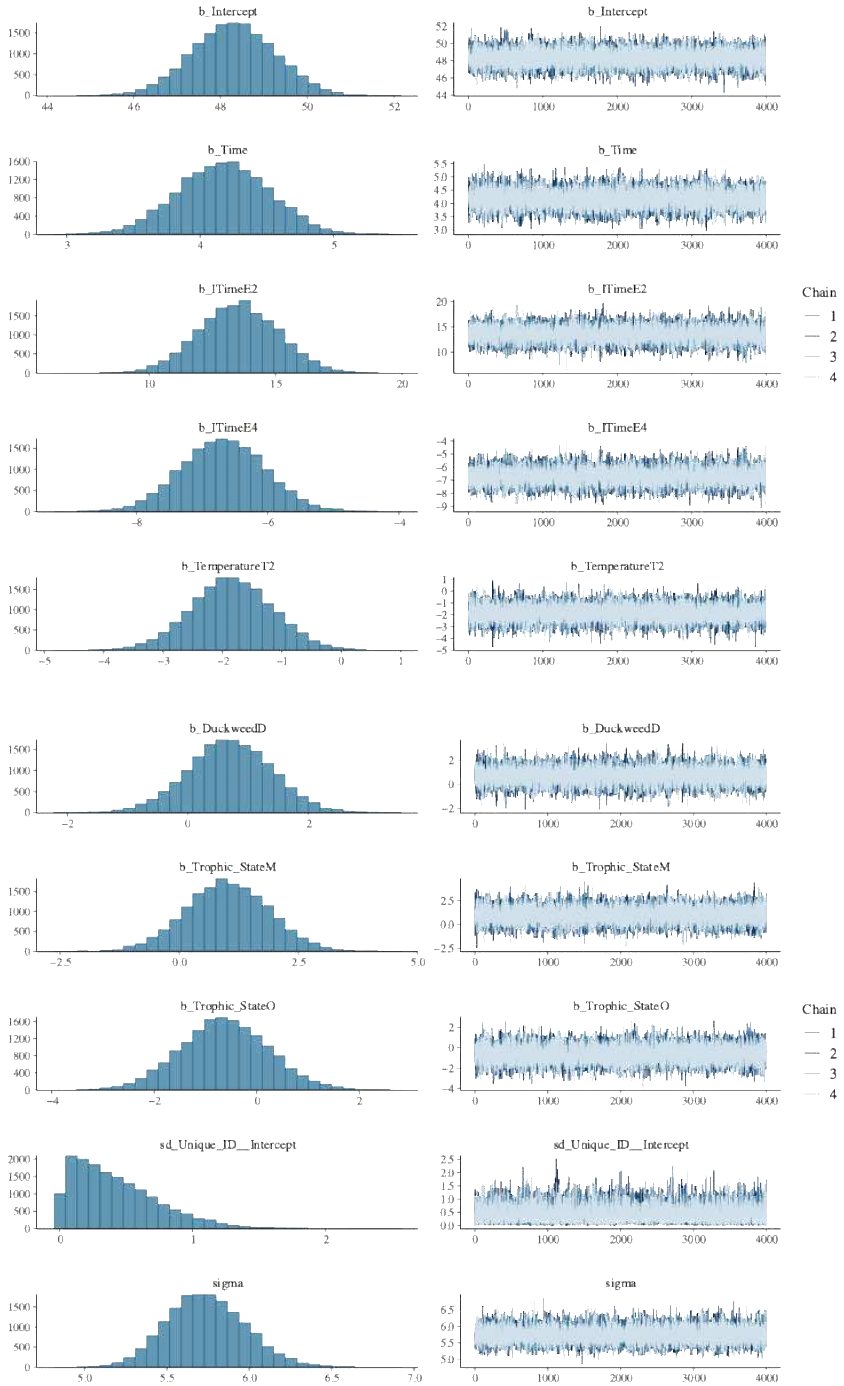
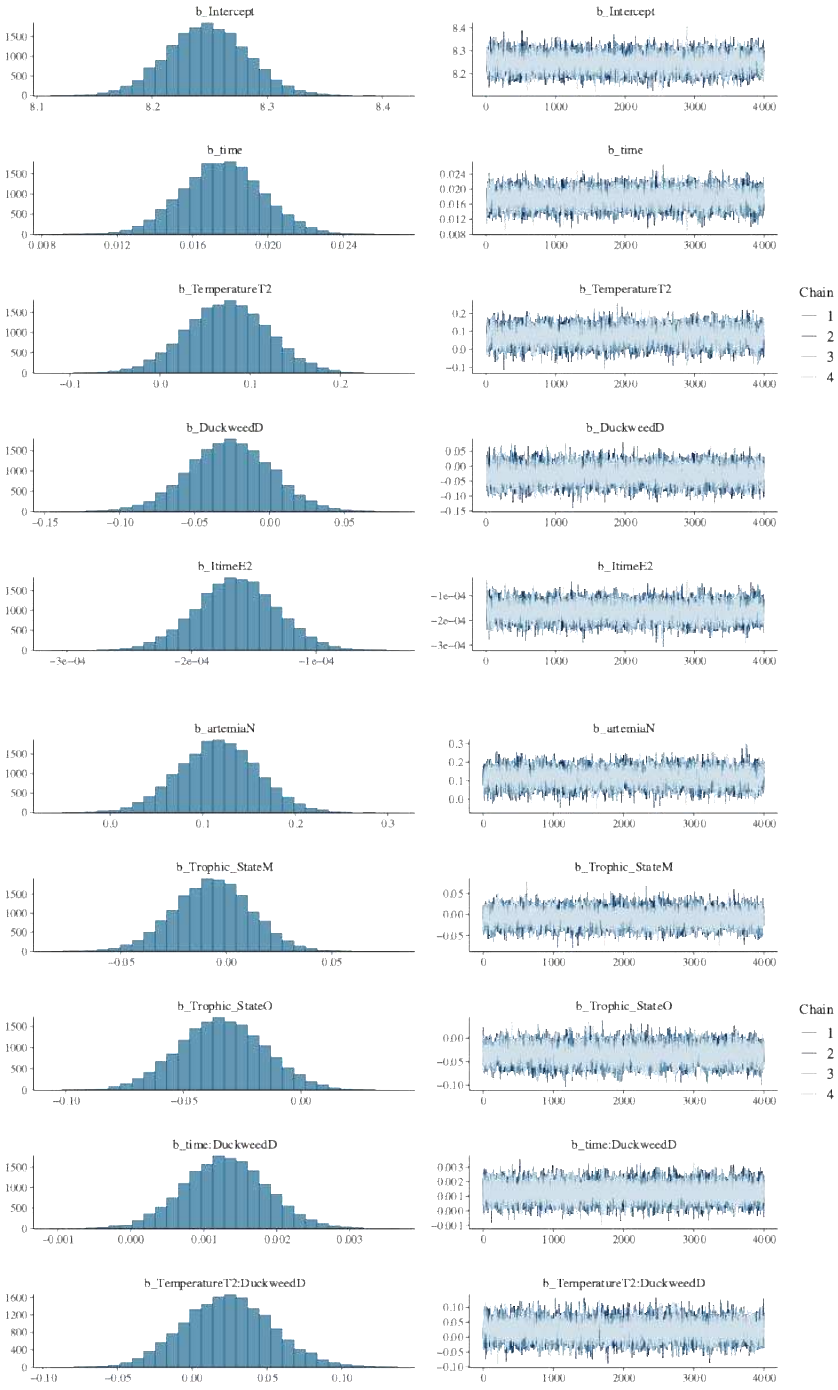


Figure C.3. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of duckweed on dissolved oxygen.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b_Intercept
b_time
b_time
b_TemperatureT2
b_TemperatureT2
b_DuckweedD
b_DuckweedD
b_ItimeE2
b_ItimeE2
b_artemiaN
b_artemiaN
b_Trophic_StateM
b_Trophic_StateM
b_Trophic_StateO
b_Trophic_StateO
b_time:DuckweedD
b_time:DuckweedD
b_TemperatureT2:DuckweedD
b_TemperatureT2:DuckweedD
Chain
1
2
3
4

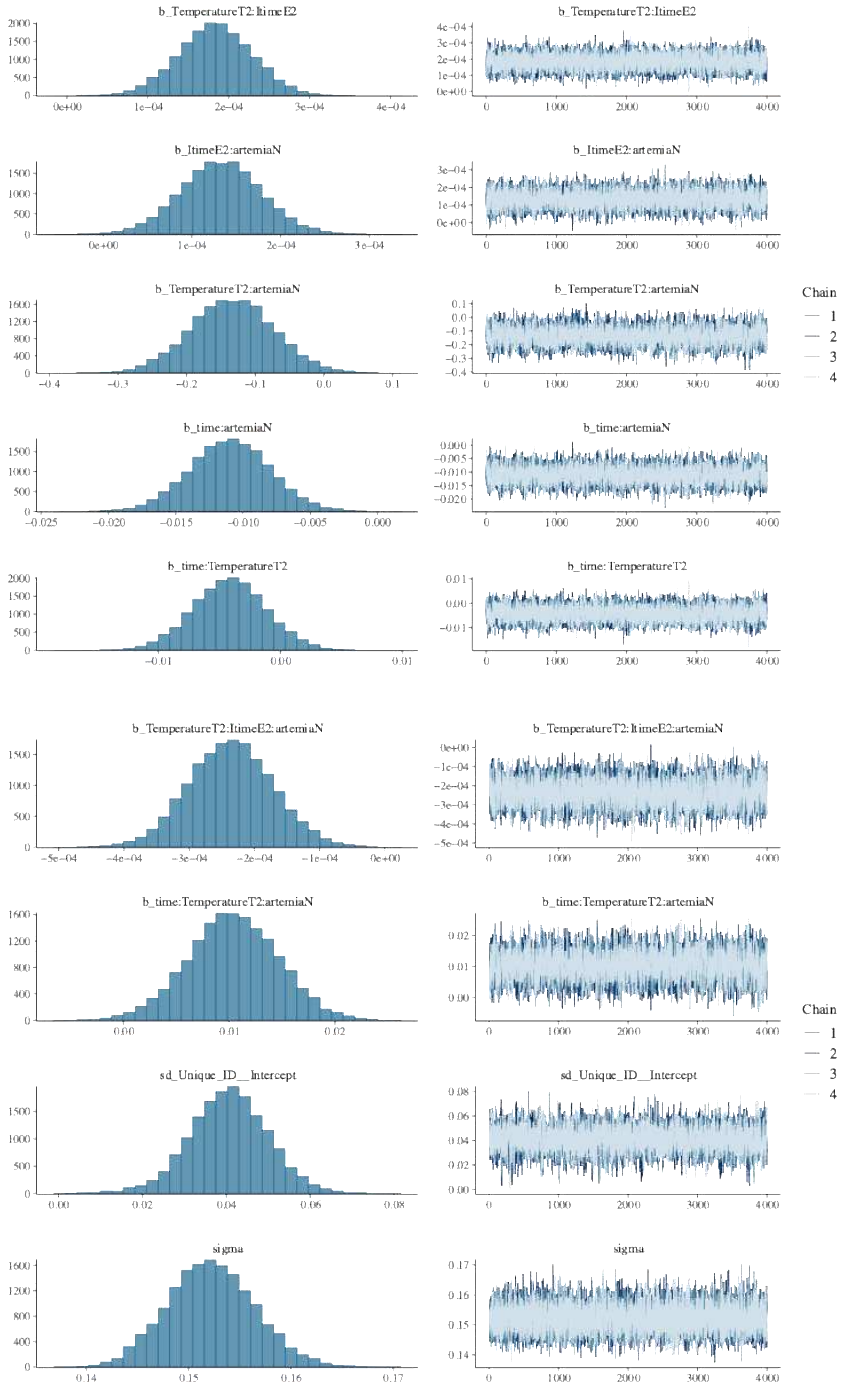
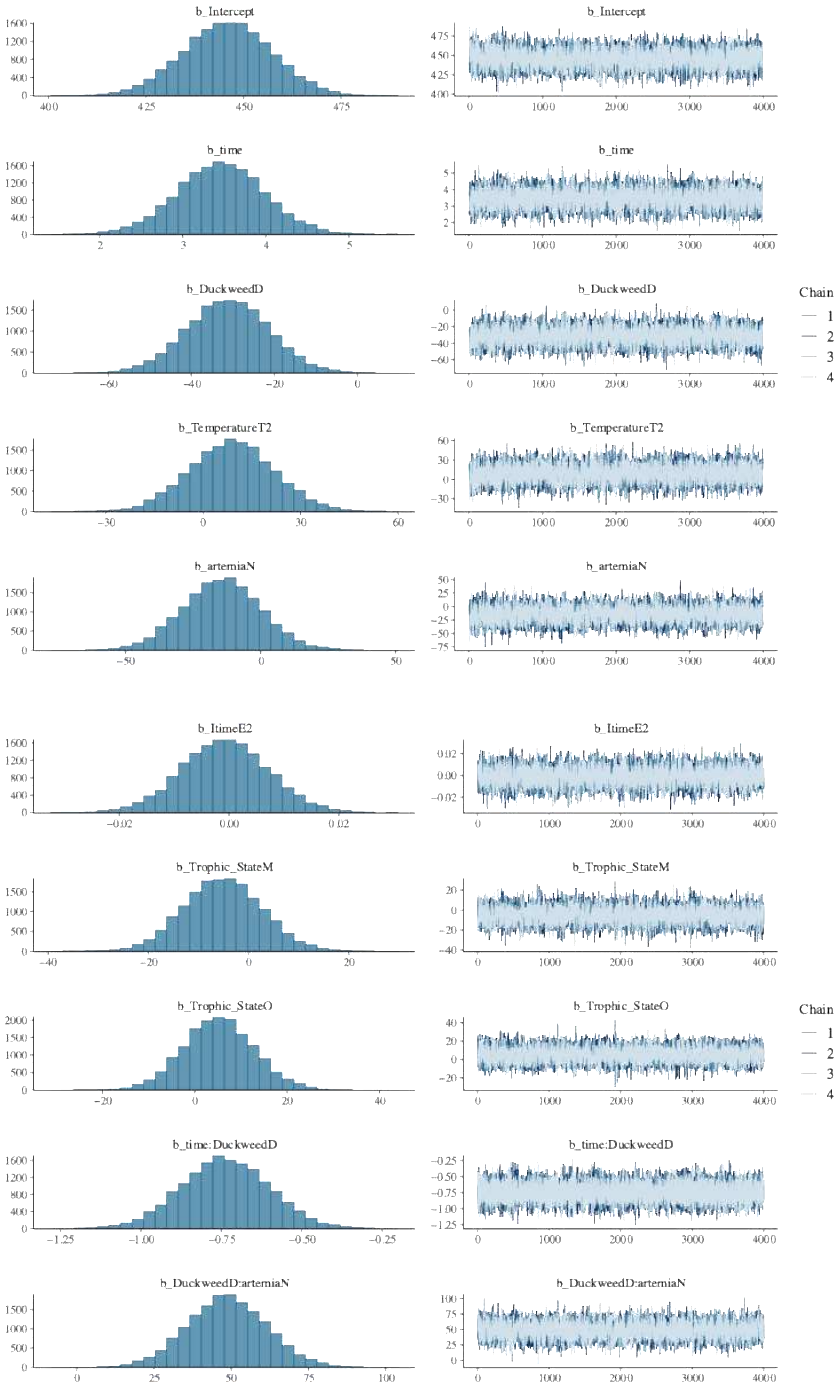


Figure C.4. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of feeding on pH.


b_Intercept
b_Intercept
b_time
b_time
b_DuckweedD
b_DuckweedD
b_TemperatureT2
b_TemperatureT2
b_arteniaN
b_arteniaN
b_ItimeE2
b_ItimeE2
b_Trophic_StateM
b_Trophic_StateM
b_Trophic_StateO
b_Trophic_StateO
b_time:DuckweedD
b_time:DuckweedD
b_DuckweedD:arteniaN
b_DuckweedD:arteniaN
Chain
1
2
3
4

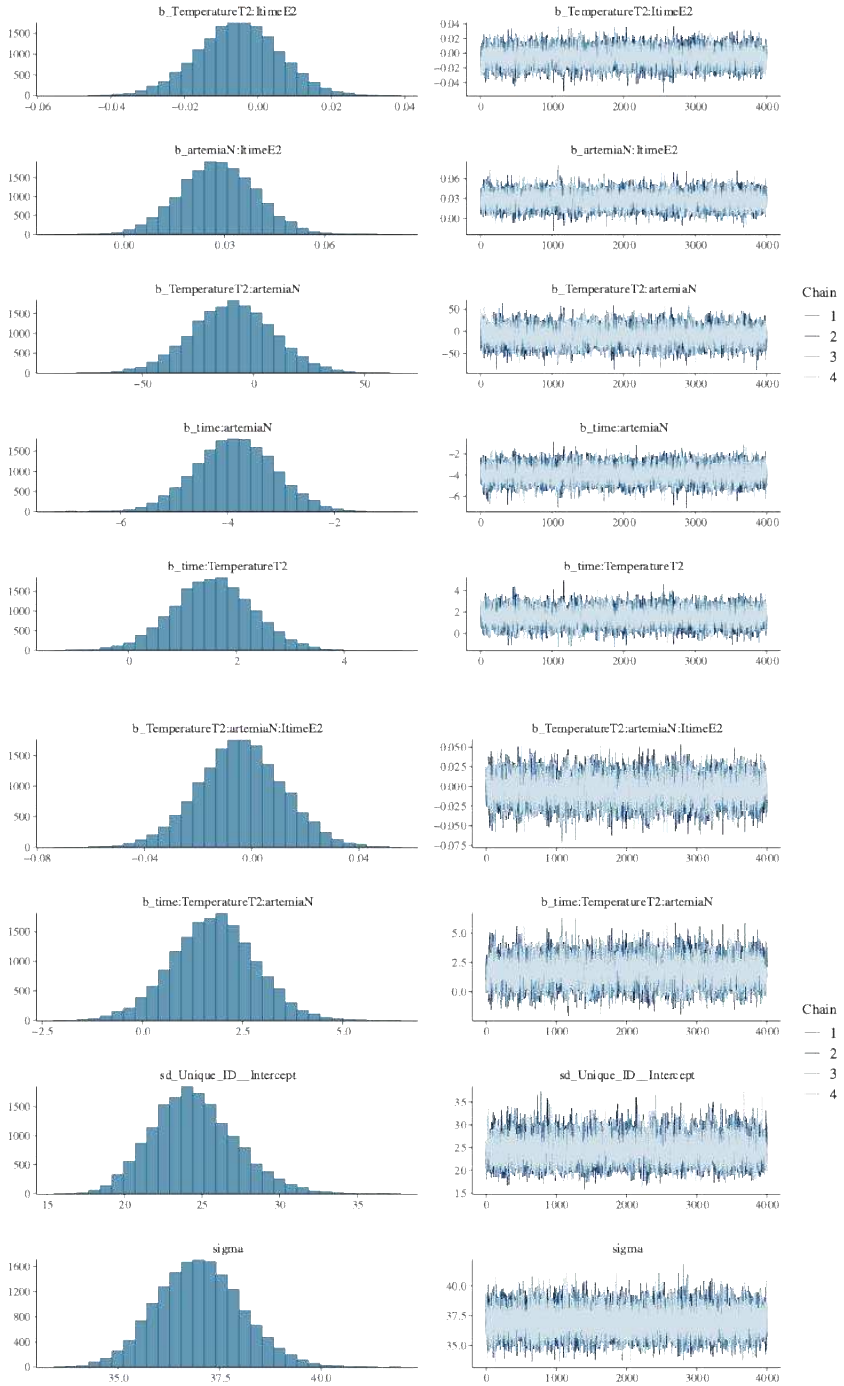
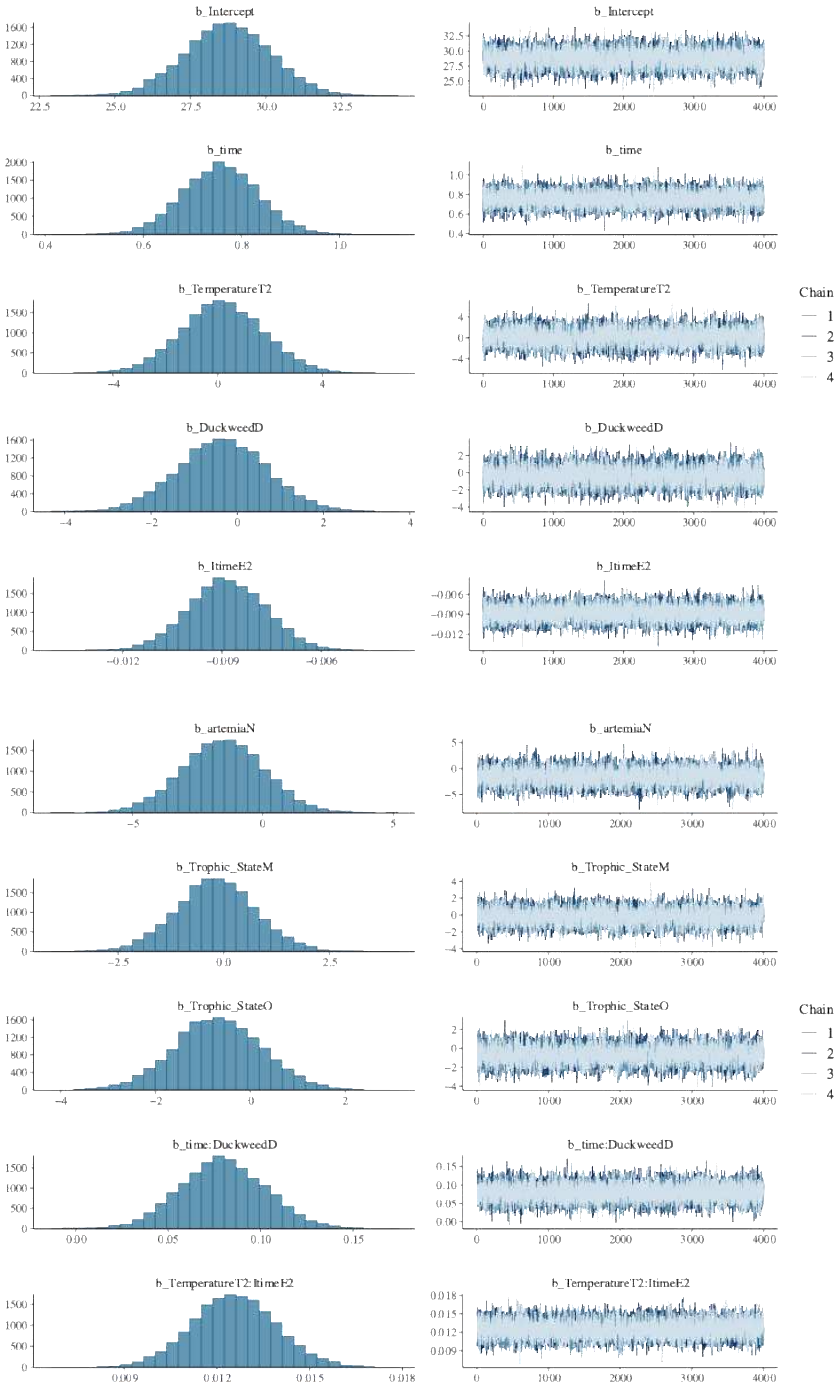


Figure C.5. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of feeding on conductivity.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b_time
b_TemperatureT2
b_DuckweedD
b_ItimeE2
b_artemiaN
b_Trophic_StateM
b_Trophic_StateO
b_time:DuckweedD
b_TemperatureT2:ItimeE2
Chain
1
2
3
4

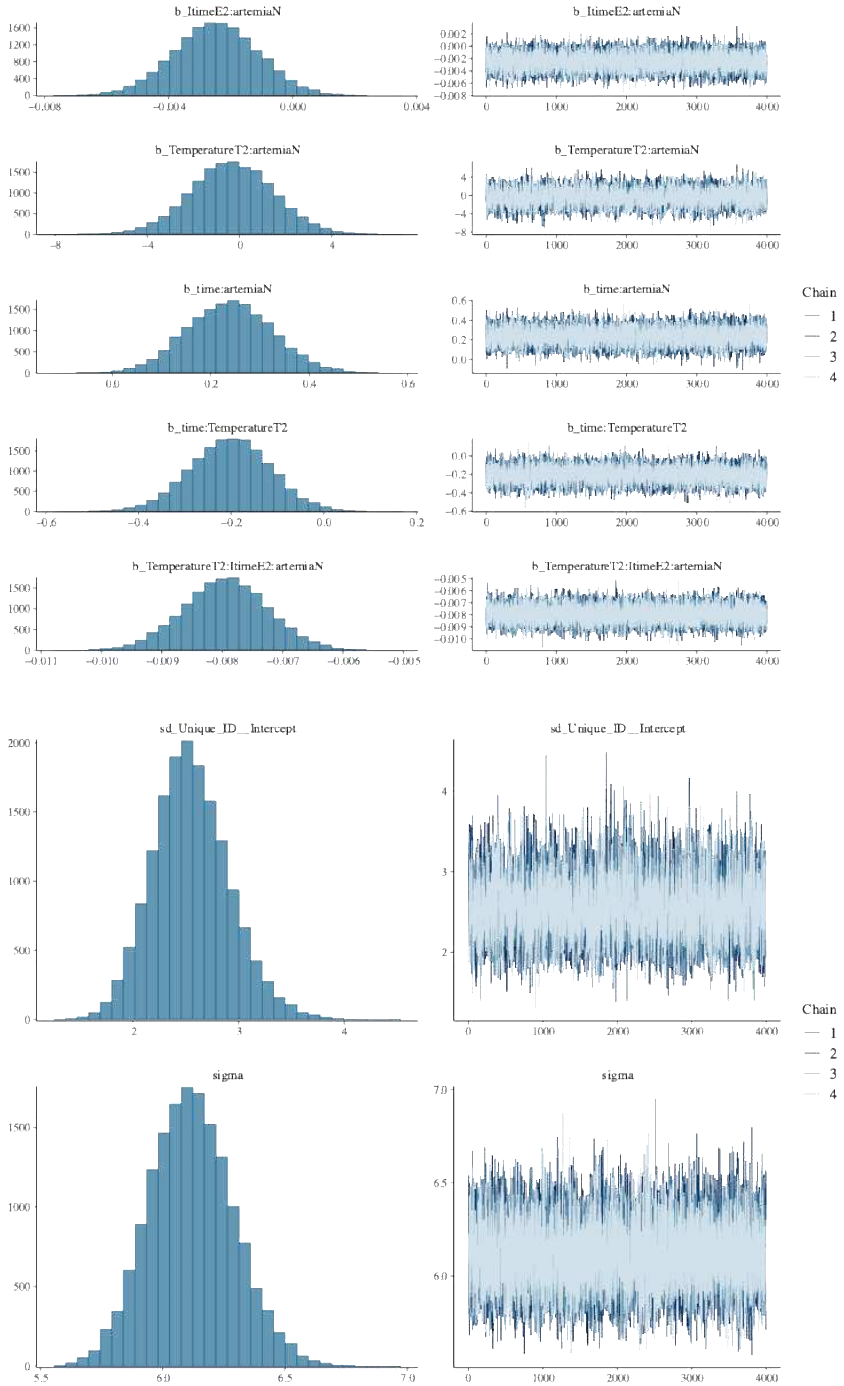
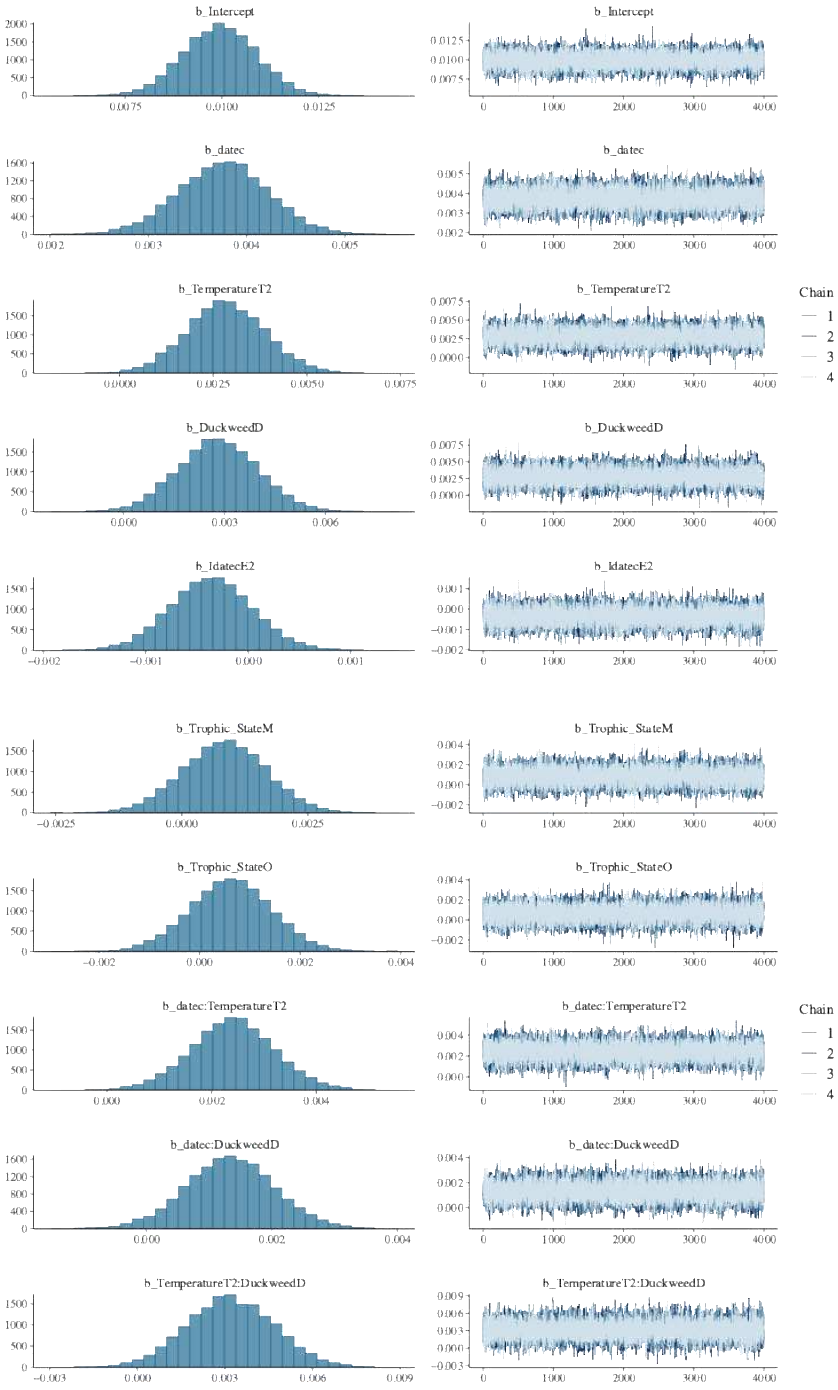


Figure C.6. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of feeding on dissolved oxygen.


b_Intercept
b_Intercept
b_datec
b_datec
b_TemperatureT2
b_TemperatureT2
b_DuckweedD
b_DuckweedD
b_IdatecE2
b_IdatecE2
b_Trophic_StateM
b_Trophic_StateM
b_Trophic_StateO
b_Trophic_StateO
b_datec:TemperatureT2
b_datec:TemperatureT2
b_datec:DuckweedD
b_datec:DuckweedD
b_TemperatureT2:DuckweedD
b_TemperatureT2:DuckweedD
Chain
1
2
3
4

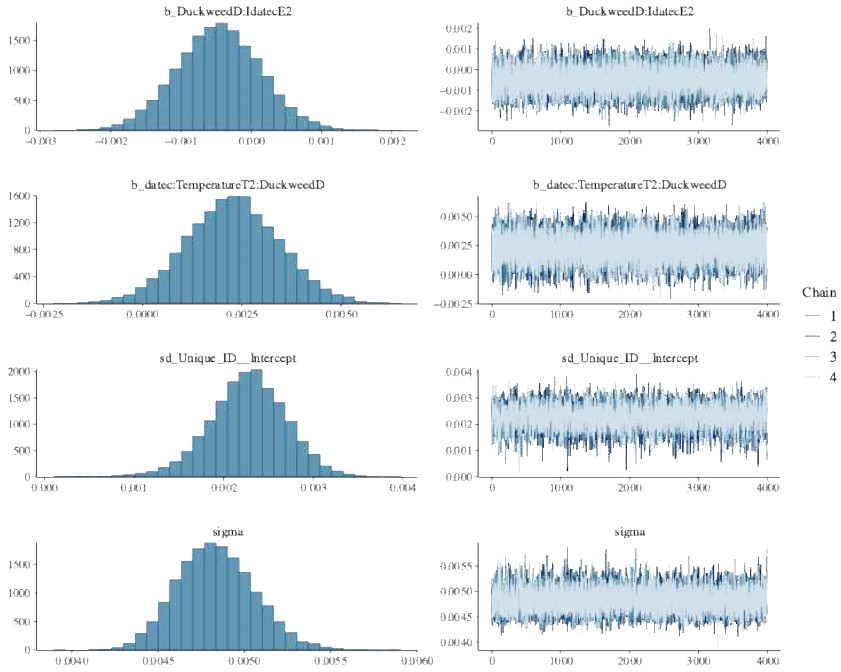


Figure C.7. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of duckweed on larval growth.

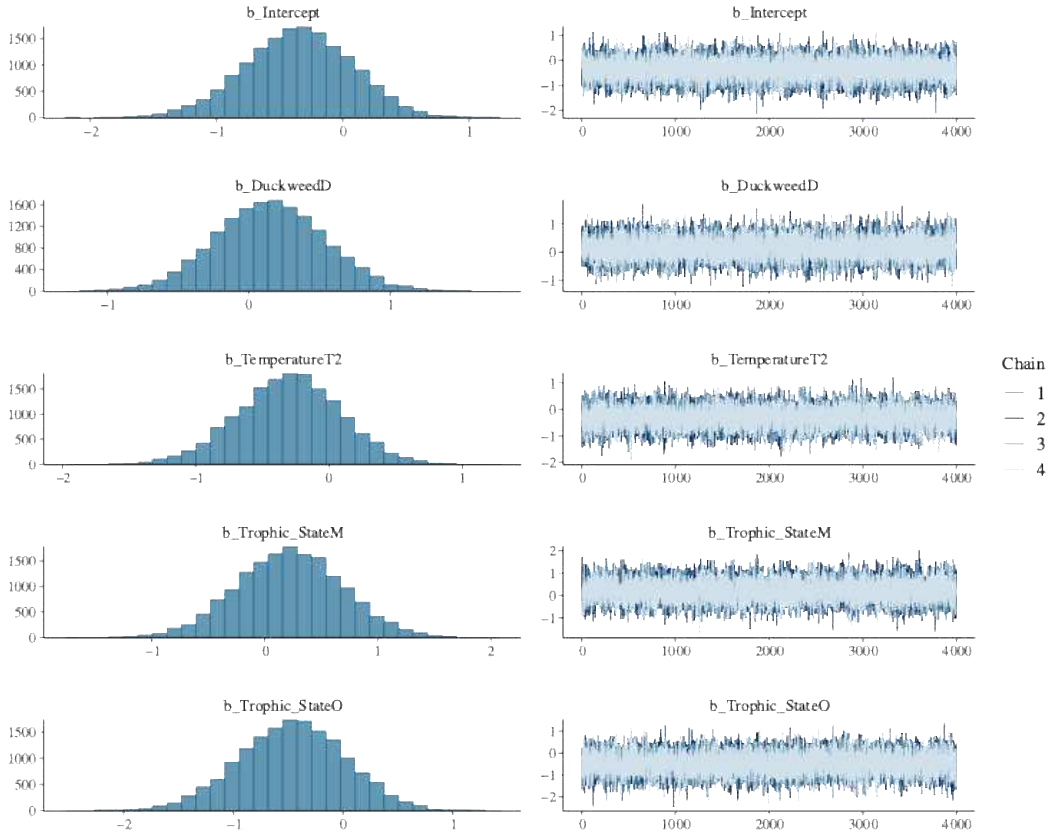


Figure C.8. MCMC diagnostic plots for the Bayesian linear mixed-effects model testing the effect of duckweed on larval mortality.