# List of Figures

**Figure 1.1.** Temperature- and *P*CO2-dependent routine metabolic rates of *M. menidia* embryos and larvae. 38

**Figure 1.2.** The effect of *P*CO2 on *Q*10 of routine metabolic rates in *M. menidia* embryos and larvae. 39

**Figure 1.3.** Oxygen- and *P*CO2-dependent routine metabolic rates of *M. menidia* embryos and larvae. 40

**Figure 1.4.** Conceptual diagram of the relationship between *P*O2 and routine metabolic rate of *M. menidia* embryos in ambient and elevated *P*CO2. 41

**Figure 2.1.** Experiment 1 and 2 mean pCO2 levels for each treatment 72

**Figure 2.2.** Whole-body routine metabolic rates of *M. menidia* embryos and mass-specific metabolic rates of larvae as a function of pCO2 73

**Figure 2.3.** Examples of a typical MO2-O2 curve, one with a sudden transient increase in MO2 at low oxygen, and one with full oxyconformity, with fitted breakpoint regressions 74

**Figure 2.4.** Critical oxygen levels of *M. menidia* offspring in response to pCO2 treatments at the embryo, 2dph larval, and 5dph larval stages 75

**Figure 3.1.** Microscope images of an *M. menidia* embryo, hatchling, and 10-mm larva with ionocytes stained dark purple 104

**Figure 3.2.** Frequency distribution of ionocyte densities at the embryo (skin and yolk sac) and hatchling stages 105

**Figure 3.3.** Embryo yolk sac and skin ionocyte density means plotted with respect to temperature and pCO2 106

**Figure 3.4.** Hatchling and 10-mm larvae ionocyte density means plotted with respect to temperature and pCO2107

**Figure 3.5.** Metabolic rates of embryos and hatchlings plotted with respect to ionocyte density and treatment temperature 108

**Figure 4.1.** The DEBkiss model with stage-specific survival parameters 146

**Figure 4.2.** Predicted and observed data for the fitted DEBkiss model of *M. menidia* 147

**Figure 4.3.** The effect of dissolved oxygen on correction factor *c* and *c1* 148

**Figure 4.4.** Simulated effect of changing assimilation rate on the state variables 149

**Figure 4.5.** Simulated effect of changing maintenance rate on the state variables 150

**Figure 4.6.** Simulated effect of changing mortality rates on the state variables 151

**Figure 4.7.** Best fit of DEBkiss model to experimental data from four oxygen levels, showing early life data only 152

**Figure S4.1.** Best fit of DEBkiss model to experimental data from four oxygen levels, showing full life data **196**

# List of Tables

**Table 1.1.** Overview of target levels for pCO2, temperature, and oxygen for six experiments in which respirometry was conducted on *M. menidia* embryos and larvae **42**

**Table 1.2.** Age at sampling and mean routine metabolic rates of *M. menidia* embryos and larvae across pCO2, temperature, and oxygen treatments 43

**Table 2.1.** Target and mean pH, pCO2, and temperature levels in two experiments 76

**Table 2.2.** Mean routine MO2 and Pcrit for *M. menidia* embryos and larvae reared in three pCO2 treatments 77

**Table 2.3.** Percentages of *M. menidia* offspring in which full oxyconformity or a low-oxygen increase in MO2 occurred 78

**Table 3.1.** Spawning dates, target temperature, target pCO2 levels, and stages sampled in each experiment 109

**Table 3.2.** Mean, standard error, sample size, and age at sampling for ionocyte density of embryos in each treatment 110

**Table 3.3.** Mean, standard error, sample size, and age at sampling for ionocyte density of larvae in each treatment 111

**Table 3.4.** Linear model coefficients and p-values for ionocyte density 112

**Table 3.5.** Comparison of ionocyte density results with previously reported effects of pCO2 and temperature on growth and survival of fish from the same experiments 113

**Table 4.1.** DEBkiss parameters, their abbreviations, and their fixed or estimated values from fitting to full life data 153

**Table 4.2.** Fluxes, state variables, and differential equations in the DEBkiss model 154

**Table 4.3.** Mean survival rates, hatch time, and lengths of *M. menidia* from different oxygen treatments in Cross et al. (2019) 155

**Table 4.4.** Summary of impacts of altering each DEBkiss parameter on predicted data for total length, time to hatching, and survival 156

**Table 4.5.** The estimate *Z* value and AICc when the correction factors were applied to each parameter or combination of parameters 157

**Table 4.6.** The value of DEBkiss parameters that best reproduce the hypoxia effects observed experimentally, calculated for each DO treatment level 158

**Table S1.1.** Treatment conditions and carbon chemistry for CO2 × temperature experiments shown as mean measured levels for each corresponding target treatment 191

**Table S1.2.** Treatment conditions and carbon chemistry for CO2 × oxygen experiments shown as mean measured levels for each corresponding target treatment 192

**Table S1.3.** Linear regression model results for metabolic rates of *M. menidia* embryos and larvae 193

**Table S1.4.** Bootstrapped means and 95% confidence intervals sampled from Q10 values calculated using metabolic rates of *M. menidia* embryos and larvae across three CO2 and two temperature treatments 194

**Table S2.1.** Mean measured water quality parameters for two experiments 195