



Vivian Moritz

# Climate Change and Global Warming

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## About the Book

Climate change and global warming are two most crucial, environmental concerns of our times. Researchers across the globe are devising methods and strategies to understand these phenomena and deal with them. Different approaches, evaluations, methodologies and advanced studies in this field have been included in this book. It highlights the different strategies and techniques of dealing with climate change and global warming through different case studies and extensive use of examples. This book is a vital tool for all researching or studying climate change and global warming as it gives incredible insights into emerging trends and concepts. It is an essential guide for both academicians and those who wish to pursue this discipline further.

## About the Editor

Vivian Moritz received her master's degree in environmental science from the University of Otago, New Zealand. Her academic interests and expertise lies in climatology, climate change and global warming. She has attended numerous conferences and seminars on the growing concern of global warming; and has presented over 23 papers. Vivian has also published more than 100 articles and papers in leading international scientific journals in the field of environmental science.





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Edited by Vivian Moritz

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## **Climate Change and Global Warming**

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# **Climate Change and Global Warming**



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# PREFACE

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Climate change and global warming are two most crucial, environmental concerns of our times. Researchers across the globe are devising methods and strategies to understand these phenomena and deal with them. Different approaches, evaluations, methodologies and advanced studies in this field have been included in this book. It highlights the different strategies and techniques of dealing with climate change and global warming through different case studies and extensive use of examples. This book is a vital tool for all researching or studying climate change and global warming as it gives incredible insights into emerging trends and concepts. It is an essential guide for both academicians and those who wish to pursue this discipline further.

After months of intensive research and writing, this book is the end result of all who devoted their time and efforts in the initiation and progress of this book. It will surely be a source of reference in enhancing the required knowledge of the new developments in the area. During the course of developing this book, certain measures such as accuracy, authenticity and research focused analytical studies were given preference in order to produce a comprehensive book in the area of study.

This book would not have been possible without the efforts of the authors and the publisher. I extend my sincere thanks to them. Secondly, I express my gratitude to my family and well-wishers. And most importantly, I thank my students for constantly expressing their willingness and curiosity in enhancing their knowledge in the field, which encourages me to take up further research projects for the advancement of the area.

**Editor**





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# The Effect of Simulating Different Intermediate Host Snail Species on the Link between Water Temperature and Schistosomiasis Risk

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## Abstract

**Introduction:** A number of studies have attempted to predict the effects of climate change on schistosomiasis risk. The importance of considering different species of intermediate host snails separately has never previously been explored.

**Methods:** An agent-based model of water temperature and *Biomphalaria pfeifferi* population dynamics and *Schistosoma mansoni* transmission was parameterised to two additional species of snail: *B. glabrata* and *B. alexandrina*.

**Results:** Simulated *B. alexandrina* populations had lower minimum and maximum temperatures for survival than *B. pfeifferi* populations (12.5–29.5°C vs. 14.0–31.5°C). *B. glabrata* populations survived over a smaller range of temperatures than either *B. pfeifferi* or *B. alexandrina* (17.0°C–29.5°C). Infection risk peaked at 16.5°C, 25.0°C and 19.0°C respectively when *B. pfeifferi*, *B. glabrata* and *B. alexandrina* were simulated. For all species, infection risk increased sharply once a minimum temperature was reached.

**Conclusions:** The results from all three species suggest that infection risk may increase dramatically with small increases in temperature in areas at or near the current limits of schistosome transmission. The effect of small increases in temperature in areas where schistosomiasis is currently found will depend both on current temperatures and on the species of snail acting as intermediate host(s) in the area. In most areas where *B. pfeifferi* is the host, infection risk is likely to decrease. In cooler areas where *B. glabrata* is the host, infection risk may increase slightly. In cooler areas where *B. alexandrina* is the host, infection risk may more than double with only 2°C increase in temperature. Our results show that it is crucial to consider the species of intermediate host when attempting to predict the effects of climate change on schistosomiasis.

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## Introduction

Little is known about likely effects of climate change on schistosomiasis transmission[1], however neglecting the issue may have a negative effect on control programs and elimination goals by concentrating resources in the wrong areas. Some empirical studies suggest that increasing temperatures may already be expanding the range of schistosomiasis in Uganda, allowing transmission to occur at increasing altitudes[2–4]. Control programs that do not adapt to the changing distribution of schistosomiasis, and changing intensities of infection in different areas, are unlikely to make efficient use of the limited resources available to them.

Different species of *Biomphalaria* and *Bulinus*, the intermediate hosts of *Schistosoma mansoni* and *S. haematobium* respectively, have very different distributions[5], habitats[6], and temperature requirements[7]. Despite this, previous attempts to develop models of schistosomiasis and temperature and/or predict the effects of climate change on schistosomiasis have largely ignored the issue of different intermediate host species. One model of *S. japonicum*

transmission and climate change in China used data from a single host species only (*Oncomelania hupensis*)[8], however most previous models of *S. mansoni* and *S. haematobium* have been parameterised using data from multiple species, or even genera, of snail[9–12]. To date, the only model parameterised to a single species of *Biomphalaria* or *Bulinus* snail is an agent-based model of water temperature and *Biomphalaria pfeifferi* population dynamics and *S. mansoni* transmission[13].

In this paper, we modify our previously published *B. pfeifferi* model[13] to allow us to simulate two additional species of *S. mansoni* intermediate host snails: *Biomphalaria glabrata* and *Biomphalaria alexandrina*. These species were selected due to the very limited amount of empirical data available on other *Biomphalaria* species[6]. *B. pfeifferi* is the most widespread intermediate host of *S. mansoni* in Africa[5], and can be found in a range of different types of water body including streams[14], lakes[15], reservoirs[16], irrigated areas[17–19], and rice-paddies[20]. *B. alexandrina* is found in North Africa only, in Egypt, north Sudan, and north-west Libya[5,21]. It is very common in the water supply and

drainage networks of the Nile Delta[21,22], and can also be found in springs, streams and the edges of swamps[21]. *B. glabrata* has a widespread distribution in South America and the Caribbean[23], and can be found in pools, marshes, and streams[24].

This study is the first to explore how the population ecology of different species of snail may respond to increasing temperatures, and how this could impact on future schistosomiasis infection risk. It addresses a crucial issue that has been largely ignored in previous modelling efforts, but which nonetheless sits at the forefront of issues to be investigated if adaptation to climate change is to be achieved.

## Methods

### Model description

The model used is described in full in McCreesh and Booth[13]; a brief description is provided here. The model is an agent-based model of snail population dynamics and infection with schistosomes. All temperature sensitive stages of the snail and schistosome lifecycles are represented by agents (snail eggs, juveniles and adults, miracidia, and cercariae), and the model has a time step of one hour. Figure 1 shows a diagram of the model structure. Snails are born into the model as eggs, and develop at a temperature-dependent rate. When snail egg development is complete, they hatch into juvenile snails. Juvenile snails, in turn, develop at a temperature-dependent rate, becoming adult snails when development is complete. Adult snails produce snail eggs at a rate which is dependent on temperature and the number of snails in the model (to account for reduced fecundity at high snail densities). Snail eggs, juveniles and adults die and are removed from the model at a rate which is dependent on temperature and the number of snails in the model.

Miracidia are introduced into the model at a constant rate. They gain biological age at a temperature-dependent rate and die at a rate that depends on their biological age. They infect juvenile and adult snails at a rate that depends on their biological age and the water temperature. Once infected, juvenile and adult snails become prepatent. Their schistosome infections develop at a

temperature-dependent rate, and once development is complete the snails become infectious. Adult snails cease to produce eggs halfway through schistosome development, and infectious snails have increased mortality rates. Once infectious, juvenile and adult snails produce cercariae at a rate which depends on the temperature and the hour of the day. Cercariae gain biological age at a temperature-dependent rate, and die at a biological age dependent rate.

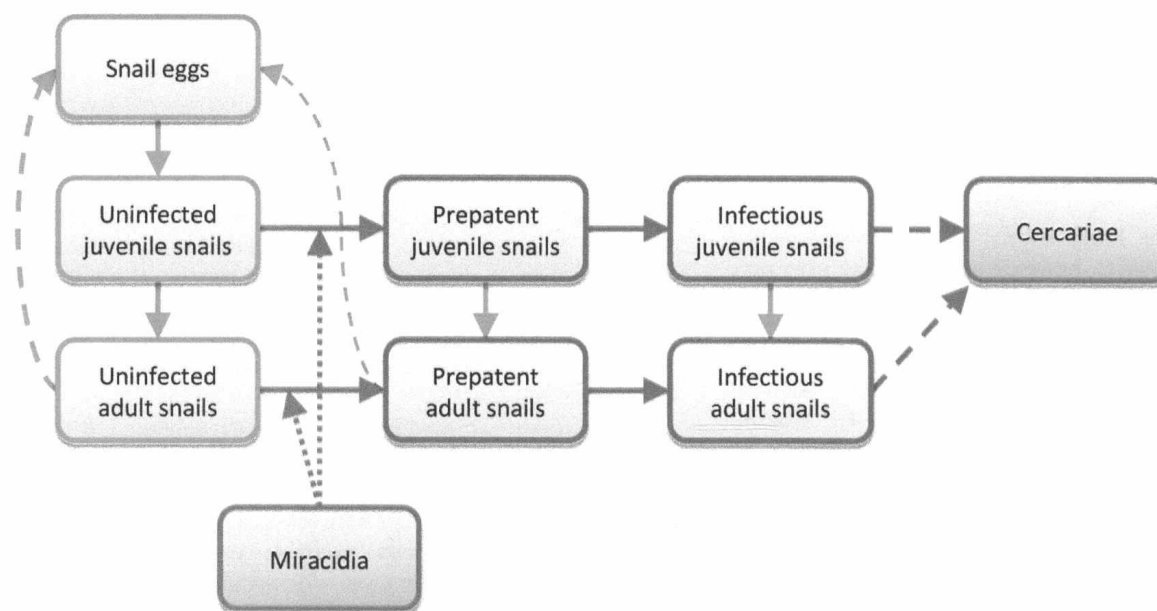
The main output of the model is ‘infection risk’. This is equal to the number of cercariae in the model, adjusted for their decreasing infectiousness with increasing biological age. Humans and adult worms are not simulated, and the rate of miracidia introduction is not linked to the number of cercariae or infection risk. This is because the ‘correct’ linking function would depend on localised factors such as sanitation practices, water contact behaviour, and immunity. Not simulating this link allows the findings of the model to be applied to any area where the relevant intermediate host snail species are found. This issue is discussed in detail in McCreesh and Booth[13].

### Model parameterisation

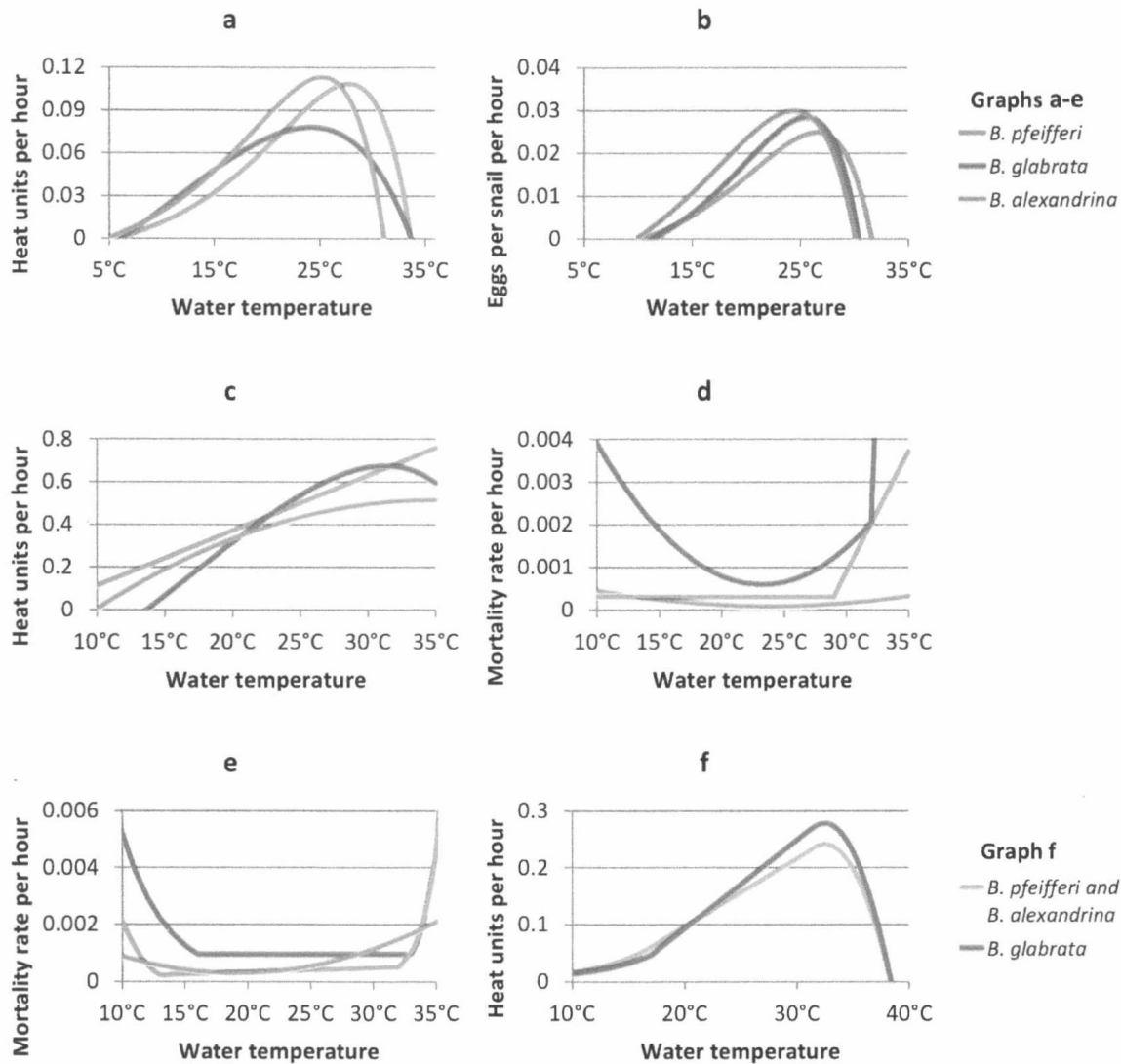
The model was parameterised separately for three different species of *Biomphalaria*: *B. pfeifferi*, *B. glabrata* and *B. alexandrina*, using data from a range of different laboratory experiments and field studies. Details of the model parameterisation to *B. pfeifferi* are given in McCreesh and Booth[13], and details of the model parameterisation to *B. glabrata* and *B. alexandrina* are given in Figures S1–S6, and Tables S1–S3 in Model Parameterisation S1. Figure 2 illustrates values taken by the parameters which vary between snail species in the model: a) the juvenile development rate, b) the egg production rate, c) the egg development rate, d) the egg mortality rate, e) the uninfected and prepatent snail mortality rates, and f) the schistosome development rate.

### Experiments

The model was run separately for *B. pfeifferi*, *B. glabrata* and *B. alexandrina* at all water temperatures at which the simulated snail



**Figure 1. Diagram of the model structure.** Boxes show types of agents. Solid arrows show where agents can change from one type into another. Dashed lines show the production of one type of agent by another. Dotted lines indicate infection. Red outlines and arrows indicate the presence of schistosomes. Agents of all types can die and be removed from the model.



**Figure 2. Comparison of parameters used in models of *B. pfeifferi*, *B. glabrata* and *B. alexandrina*.** a) Juvenile development. Heat units gained per hour. Snails become adults and start producing eggs once they have gained 100 heat units. b) Egg production. Eggs per snail per hour. c) Egg development. Heat units gained per hour. Egg hatch once they have gained 100 heat units. d) Egg mortality rate per hour. e) Uninfected and prepatent snail mortality rate per hour. f) Parasite development within the snail. Heat units gained per hour. Snails become infectious once they have gained 100 heat units. Blue lines show parameters for *B. pfeifferi*, red for *B. glabrata*, green for *B. alexandrina*, and turquoise for both *B. pfeifferi* and *B. alexandrina*.

populations could survive indefinitely, with temperature increasing in 0.5°C increments. Outputs were averaged over a minimum of one year and 200 runs. Outputs were averaged over larger numbers of longer runs when necessary to reduce stochasticity. The number of snails in the model was calculated as the total number of uninfected, prepatent and infectious juvenile and adult snails.

In the models for all three snail species, mortality rates estimated from laboratory data were multiplied by 1.35 to account for increased mortality in natural conditions (see Model Parameterisation S1 for details). Estimates of mortality rates in wild snail populations suggest that mortality rates can be much higher than this in some circumstances however [22,24,25]. The effect of this was explored by further doubling mortality rates for all snails (juvenile and adult; uninfected, prepatent and infectious).

A number of intermediate results were also calculated by temperature for each snail species. These results were calculated from the equations used in the model only, and were designed to

help improve understanding of the overall model results. They were:

- 1) The mean proportion of eggs that hatch, calculated from egg development rates and egg mortality rates
- 2) The mean proportion of juvenile snails that survive to become adults, calculated from juvenile development rates and the uninfected/prepatent mortality rates.
- 3) The mean proportion of infected snails that survive to become infectious, calculated from parasite development rates and the prepatent mortality rates.
- 4) The median lifetime cercaria production of infectious snails, calculated from the cercariae production rates and the infectious snail mortality rates.

As these intermediate results were calculated from the input parameters only, and not from model output, 2) to 4) assume that there is no density-dependent increase in mortality rates. 2) also



assumes that no juvenile snails develop patent infections before becoming adults (which would increase their mortality rate).

## Results

### Snail population dynamics

When the lower mortality rates were simulated, the mean total number of *B. glabrata* in the model was lower than the mean total number of *B. pfeifferi* at all water temperatures, and lower than the number of *B. alexandrina* at all temperatures below 29.5°C (figure 3a). The mean total number of *B. alexandrina* was higher than the number of *B. pfeifferi* at all temperatures below 27.0°C. The maximum mean total number of *B. pfeifferi*, *B. glabrata* and *B. alexandrina* were 1015, 850 and 1284 respectively, at 24.5°C, 23.5°C and 25.0°C. Snail numbers were above 90% of their maximum between 17.0°C and 29.5°C for *B. pfeifferi*, 20.0°C and 28.5°C for *B. glabrata*, and 17.0°C and 25.5°C for *B. alexandrina*. Differences were greater between the maximum mean total number of adult snails in each low mortality rate model, with the *B. pfeifferi* model peaking at 506 adult snails at 26.5°C, the *B. glabrata* model at 145 snails at 24°C, and the *B. alexandrina* model at 661 snails at 20.5°C (figure 3b).

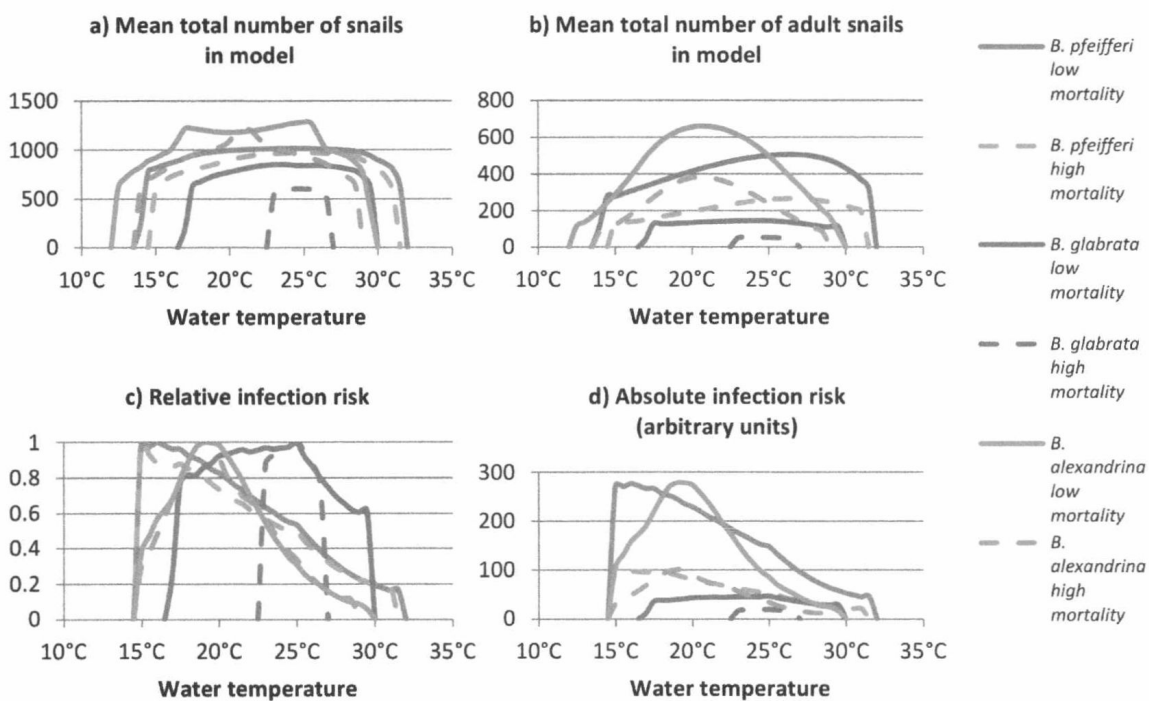
Simulating the higher mortality rates reduced both mean snail and adult snail numbers at all temperatures for all snail species, with the exception of the mean number of *B. alexandrina* at 20.5°C to 21.5°C, where snail numbers were 0.09% to 2.03% higher in the higher mortality scenario. This occurred as a result of the density dependence functions used in the model, and would not necessarily occur in wild snail populations. The presence and magnitude of the dip depends on the density functions used. Reductions in the mean number of snails, over the range of temperatures at which the simulated snail populations could survive indefinitely, varied between 4% and 28% for *B. pfeifferi*, 29% and 36% for *B. glabrata*, and 8% and 28% for *B. alexandrina*.

Reductions in the mean number of adult snails ranged between 47% and 56% for *B. pfeifferi*, 63% and 66% for *B. glabrata*, and 42% and 59% for *B. alexandrina*.

The range of temperatures between which simulated snail populations could survive indefinitely was smallest for *B. glabrata*, with snail populations unable to survive at temperatures outside 17.0°C to 29.5°C, compared to 14.0°C to 31.5°C for *B. pfeifferi*. Simulated *B. alexandrina* populations survived at lower temperatures than either *B. glabrata* or *B. pfeifferi*, with a minimum temperature for survival of 12.5°C, but did not survive as well as *B. pfeifferi* at high temperatures, dying out at temperatures above 29.5°C. Doubling snail mortality rates slightly reduced the range of temperatures at which simulated *B. pfeifferi* and *B. alexandrina* populations could survive indefinitely to 15.0°C to 31.0°C and 14°C to 28.5°C respectively. Doubling mortality rates had a much greater effect on simulated *B. glabrata* populations, reducing the range of temperatures at which they could survive indefinitely to only 23.0 to 26.5°C.

### Infection risk

With the lower mortality rates, infection risk was highest at 16.5°C when *B. pfeifferi* was simulated, at 19.0°C when *B. alexandrina* was simulated, and at 25.0°C when *B. glabrata* was simulated (figure 3c). Either side of these temperatures infection risk fell when simulating all snail species, however infection risk remained high over a wide range of temperatures when *B. glabrata* was the intermediate host snail species. Infection risk remained above 80% of its maximum value at all temperatures between 18°C and 26.5°C in the *B. glabrata* model, between 15°C and 20.5°C in the *B. pfeifferi* model, and between 18°C and 21°C in the *B. alexandrina* model. There was a risk of infection at all temperatures at which simulated *B. glabrata* populations could survive indefinitely. There was no infection risk below 15.0°C in any model, while simulated *B. pfeifferi* and *B. alexandrina* populations



**Figure 3. Number of snails and relative infection risk, with high and low mortality rates.** a) Mean total number of snails in the model. b) Mean total number of adult snails in the model. c) Infection risk, relative to the maximum risk for the same snail species with the same mortality rates. d) Absolute infection risk (arbitrary units). Blue lines show *B. pfeifferi*, red lines show *B. glabrata* and green lines show *B. alexandrina*. Solid lines show results with a low mortality rate and dashed lines with a high mortality rate.