Topic 3: Simulating temperature change scenarios

Motivation: In the last decades we have seen changes in temperature that can be attributed to global climate change. These changes are occurring at an unprecedented rate. Many processes that affect the dynamics of lake organisms are temperature dependent. The goal of this topic is 1) to simulate different temperature change scenarios, 2) to assess the effect these scenarios on the model state variables under two different assumptions regarding the temperature dependence of the growth rate of zooplankton and 3) to reflect about the realism of these model simulations compared to a real lake.

Assignment:

As a baseline use the model 11.4 and implement the following temperature scenarios.

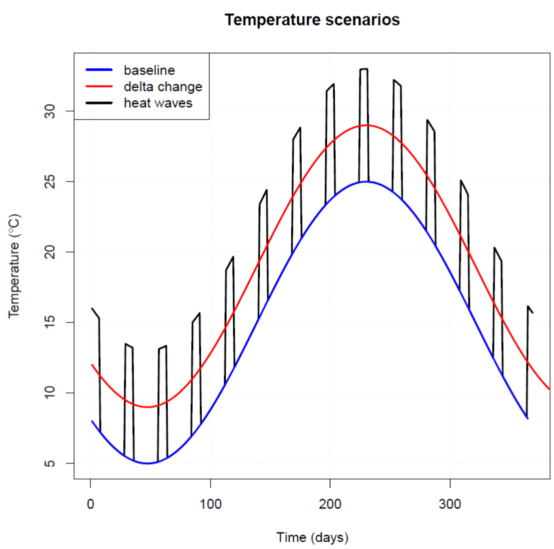

Fig. 1: Temperature scenarios

Scenario 1: Delta Change

Introduce a temperature change scenario where the whole temperature curve shifts upwards by 4°C. Implement this by introducing a new parameter, `delta_T`, and changing the expression for temperature in the environmental conditions of the epilimnion:

```
system.11.4@reactors: [[1]]@cond$T = expression(...)
```

In general, to introduce a new parameter, you can directly add it to the system:

```
system.11.4@param$newparameter <- 42
```

or you can first add it to the parameter list and then update the system:

```
param$newparameter <- 42
system.11.4@param <- param
```

Do the simulation for 2 years and compare it to the baseline scenario.

Scenario 2: Delta change plus sensitive zooplankton

Use the same scenario as nr. 1 and assume that dependence of the growth rate of zooplankton on temperature has an optimum curve.

For this you can use the function `fTR` from the file plots_rates_functions.r. You can access the growth rate of zooplankton directly:

```
system.11.4@reactors[[1]]@processes[5][[1]]@rate <- expression(...)
```

Choose the following parameter values:
`Tmin.ZOO = -10°C; Tmax.ZOO = 29°C; a.ZOO = 0.0334; b.ZOO= 0.8`

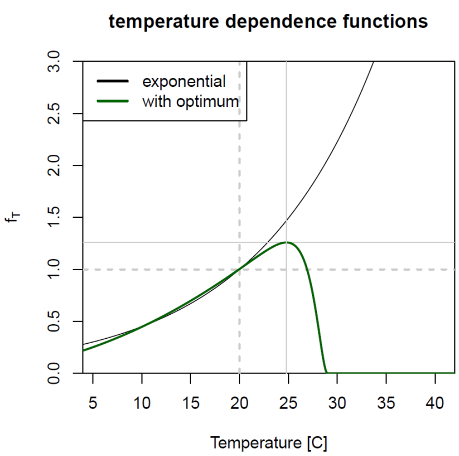

Fig. 2: Temperature dependence functions

Do the simulation for 2 years and compare it to the previous scenarios.

Scenario 3: Heat waves plus sensitive zooplankton

Change the temperature in the epilimnion by simulating heat waves. The heat waves should occurr every 4 weeks, last for 7 days, and increase the temperature by 8 degrees compared to the baseline. Do the simulation for 2 years using the zooplankton growth rate from scenario 2 and compare it to the previous scenarios.

To implement the heat waves, you can use the following function, which is based on the seasonal temperature from scenario 0 and uses three new parameters to add "`hw.magnitude`" °C for "`hw.duration`" days every "`hw.frequency`" days.

```
simulate_heatwave <- function(t, T.min, T.max, t.max,
                              hw.magnitude, hw.duration, hw.frequency) {

  # Calculate day of year (1-365.25)
  day_of_year <- (t-1) %% 365.25 + 1

  # Base sinusoidal pattern with 365.25-day year
  base_temp <- 0.5 * (T.min + T.max) +
```

```
    0.5 * (T.max - T.min) * cos(2 * pi/365.25 * (day_of_year - t.max))

  # Heat wave calculation (timing of the heat wave)
  current_hw <- (t - 1) %% hw.frequency
  is_in_hw <- current_hw < hw.duration

  # Heat wave effect
  hw_effect <- ifelse(is_in_hw, hw.magnitude, 0)

  # Return total temperature for this day
  return(base_temp + hw_effect)
}
```

For all three scenarios plus the baseline, plot the temperature in the epilimnion over time, plot the temperature dependence function of zooplankton over time and plot the results of the model simulations. In addition, do a sensitivity analysis.

Think about the following questions:

1. How do the temperature related changes in zooplankton affect the other state variables?

2. What do you think are the most important shortcomings of this model that might lead to differences to what happens in real lakes?

3. Climate change does not only affect the temperature. What are other aspects that may affect the lake?

4. What happens to the algae when the zooplankton concentrations get very low at high temperatures and release the algae from top-down control? What are possible explanations for this?