Topic 2: Introducing a contamination with an insecticide and explore coexistence between two groups of zooplankton that differ regarding their sensitivity to the insecticide.

Introduce an insecticide (e.g. Diazinon) in the inflow to the lake that has sub-lethal effects on the growth of zooplankton. The inflow concentrations have a seasonal pattern according to the application period of the substance (see Fig. 1).

Introduce a second population of zooplankton that has the same composition and processes as the already existing zooplankton population but has a different half-saturation constant regarding food and a different sensitivity to the insecticide (described in more detail below). Note that you have to change the food-limitation term to a Monod-equation instead of a linear dependency. Note that this will change the unit of the parameter k.gro.ZOO from m^3/gALG/d to 1/d.

To model the toxic effect on the growth of both zooplankton populations, you can include a factor f_{tox} in the growth rate (see equation below). f_{tox} describes a concentration-effect relationship with a logistic equation, such that increasing concentrations of the toxicant, C, causes a decrease in the growth rate.

$$f_{tox} = \frac{1}{1+\left(\frac{C}{EC50}\right)^{slope}}$$

The parameter EC50 determines at which concentration the growth is reduced by 50%. The parameter "slope" determines the slope of the concentration-response curve.

As a rough estimate of the input of Diazinon into the lake with the inflow, you can use the following function:

```
inpPest <- function(t,C.max=10)
{
  xinp <- NULL
  xinp[1] <- 0
  xinp[2] <- 61  # 1. March
  xinp[3] <- 92  # 1. April
  xinp[4] <- 183 # 1. July
  xinp[5] <- 214 # 1. August
  xinp[6] <- 365
  yinp <- c(C.max/5,C.max/5,C.max,C.max,C.max/5,C.max/5)
  yout <- approx(x=xinp,y=yinp,xout=t%%365)$y
  return(yout)
}
```

The function `inpPest` needs a time vector *t* as well as `C.max`, which describes the inflow concentration of Diazinon during the agricultural application period (April – June) and assumes a concentration of Diazinon of 20% of `C.max` outside the application period, e.g. from applications in households (Fig. 1). (Note that the default of this parameter is set to 10 here, but it will be overwritten when you call the function with a different parameter value as argument.)

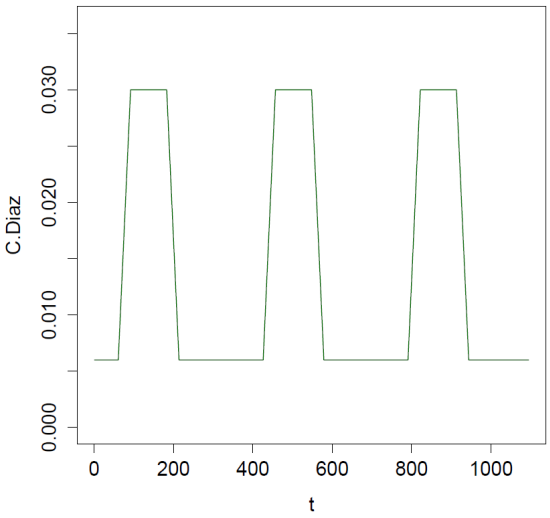

Fig. 1: Diazinon inflow concentrations in µg/L over time, using a `C.max` of 0.03 µg/L.

Since Diazinon is quite stable under normal temperature and pH conditions, you can neglect here the degradation of the substance.

Parameter values:

For the slope of the concentration-effect curve, you can assume a value of 2.5 for both zooplankton populations. For the EC50, you can assume a value of 0.5 µg/L for one zooplankton population, which is realistic based on short-term exposure experiments in the lab. Assume an EC50 value that is four times lower value for the second population. This value is still approx. ten times higher than the environmental quality standard for Diazinon[1] (12 ng/L) that is considered to be protective.

A realistic `C.max` for the river discharging into Greifensee would be 0.03 µg/L based on weakly composite samples from 2010. As initial concentration, you can assume 0.006 µg/L, which corresponds to the assumed input concentration outside the agricultural application period. For the half-saturation constant regarding food, you can choose a value 0.5 gDM/m^3 for the less sensitive zooplankton population and a lower value for the more sensitive population. Try to find out, for which parameter value you can achieve long-term coexistence (i.e., 3 years or longer) of the two populations.

How does the level of `C.max` affect the density and coexistence of the two zooplankton populations? A sensitivity analysis may help you find out.

Finally, think about the most important shortcomings of this model that might lead to differences to what happens in real lakes.

[1] https://www.oekotoxzentrum.ch/expertenservice/qualitaetskriterien/qualitaetskriterienvorschlaege-oekotoxzentrum/