5.2: Population ecotoxicology in laboratory settings

5.2. Population ecotoxicology in laboratory settings

Author: Michiel Kraak

Reviewers: Nico van den Brink and Matthias Liess

Learning objectives:

You should be able to

· motivate the importance of studying ecotoxicology at the population level.

· name the properties of populations, unique to this level of biological organisation.

· explain the implications of age and developmental stage specific sensitivities for population responses to toxicant exposure.

Key words: Population ecotoxicology, density, age structure, population growth rate

Introduction

The motivation to study ecotoxicological effects at the population level is that generally the targets of environmental protection are indeed populations, communities and ecosystems. Additionally, several phenomena are unique to this level, including age specific sensitivity and interaction between individuals. Studying the population level is distinguished from the individual level and lower by a less direct link between the chemical exposure and the observed effects, due to individual variability and several feedback loops, loosening the dose-response relationships. Research at the population level is thus characterized by an increasing level of uncertainty if these processes are not properly addressed and by increasing time and efforts. Hence, it is not surprising that effects at the population are understudied. This is even more the case for investigations on higher levels like meta-populations, communities and ecosystems (see sections on meta-populations, communities and ecosystems). It is thus highly important to obtain data and insights into mechanisms leading to effects at the population level, keeping in mind the relevant interactions with lower and higher levels of organisation.

Properties of populations are unique to this level of biological organization and include social structure (see section on invertebrate community ecotoxicology), genetic composition (see section on genetic variation), density and age structure. This gives room to age and developmental stage specific sensitivities to chemicals. For almost all species, young individuals like neonates or first instars are markedly more sensitive than adults or late instar larvae. This difference may run up to three orders of magnitude and consequently instar specific sensitivities may vary as much as species specific sensitivities (Figure 1). Population developmental stage specific sensitivities have also been reported. Exponentially growing daphnid populations exposed to the insecticide fenvalerate recovered much faster than populations that reached carrying capacity (Pieters and Liess, 2006). Given the age and developmental stage specific sensitivities, the timing of exposure to toxicants in relation to the critical life stage of the organism may seriously affect the extent of the adverse effects, especially in seasonally synchronised populations.

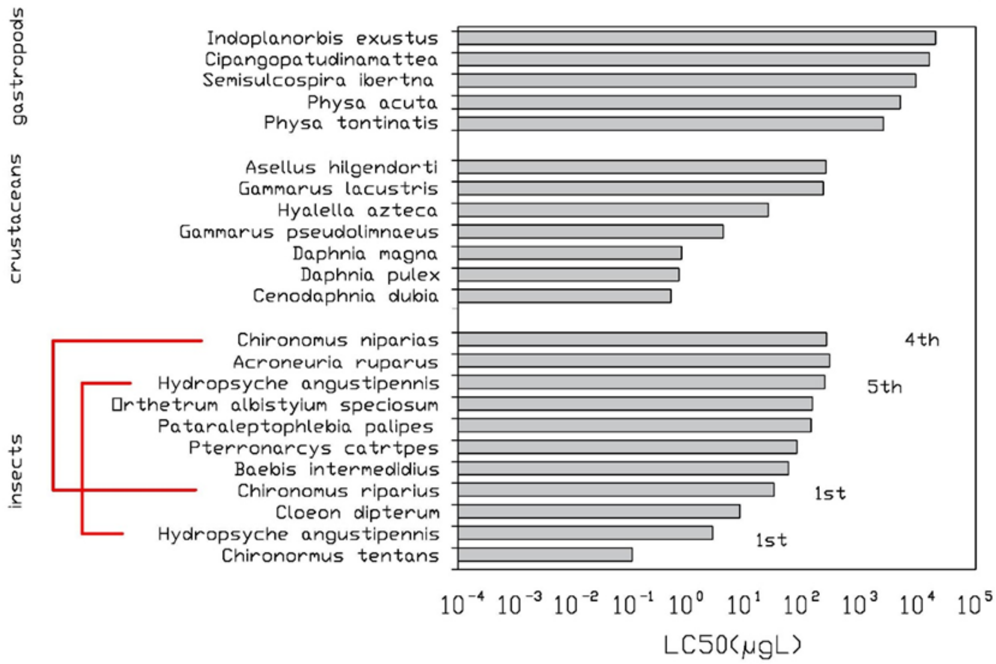

Figure 1. 48h LC50 values of the insecticide diazinon for insects, crustaceans, and gastropods ranked according to sensitivity (according to Stuijfzand et al., 2000), showing that instar specific sensitivities may vary as much as species specific sensitivities. Drawn by Wilma IJzerman. Note: this figure is a draft that still needs correction

A challenging question involved in population ecotoxicology is when a population is considered to be stable or in steady state. In spite of the various types of oscillation all populations depicted in Figure 2 can be considered to be stable. One could even argue that any population that does not go extinct can be considered stable. Hence, a single population could vary considerable in density over time, potentially strongly affecting the impact of exposure to toxicants.

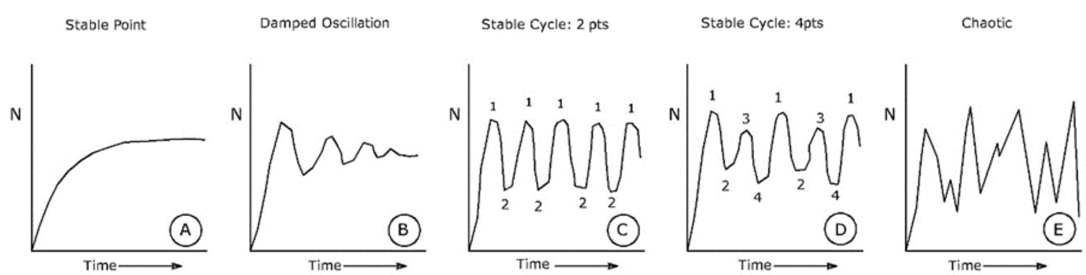

Figure 2. Different types of population development over time. Drawn by Wilma IJzerman.

When populations suffer from starvation and crowding due to high densities and intraspecific competition, they are markedly more sensitive to toxicants, sometimes even up to a factor of 100 (Liess et al., 2016). This may even lead to unforeseen, indirect effects. Relative population growth rate (individual/individual/day) of high density populations of chironomids actually increased upon exposure to Cd, because Cd induced mortality diminished the food shortage for the surviving larvae (Figure 3). Only at the highest Cd exposure population growth rate decreased again. For populations at low densities, the anticipated decrease in population growth rate with increasing Cd concentrations was observed. Yet, at all Cd exposure levels growth rate of low density populations was markedly higher than that of high density populations.

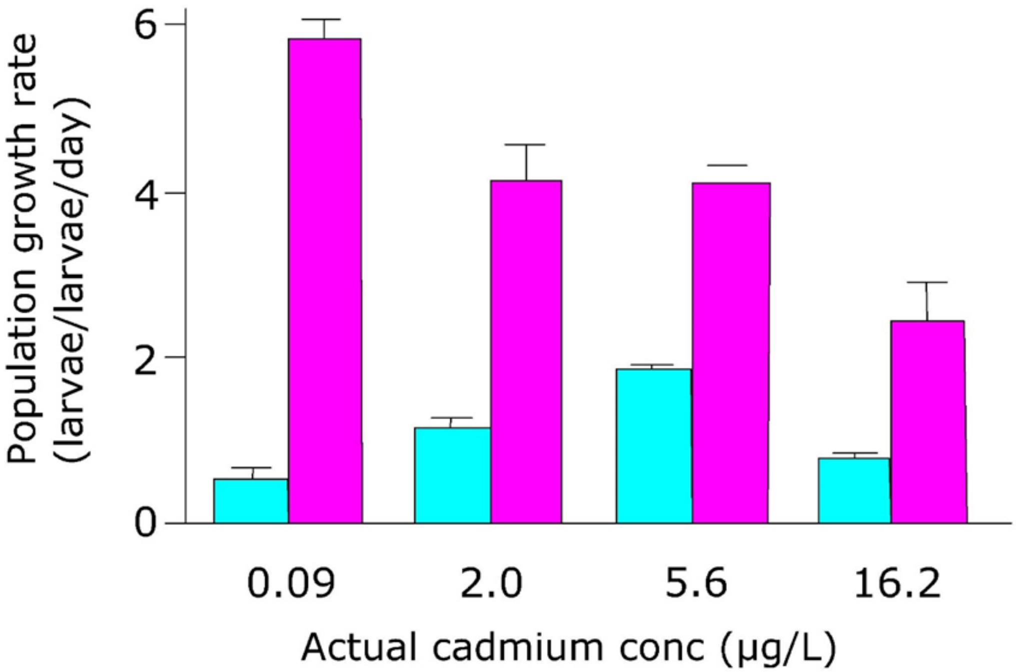

Figure 3. Effects of cadmium exposure and density on population growth rate of Chironomus riparius (according to Postma et al., 1994). Mean values with standard error. Blue bars represent the high larval density and purple bars the low larval density. Redrawn by Wilma IJzerman.

Population ecotoxicity tests

In *chronic* ecotoxicity studies, preferably cohorts of individuals of the same size and age are selected to minimize variation in the outcome of the test, whereas in *population* ecotoxicology the natural heterogenous population composition is taken into account. This does make it harder though to interpret the obtained experimental data. Especially when studying populations of higher organisms in the wild, the increasing time to complete the research due to the long life span of these organisms imposes practical limitations (see section on wildlife population ecotoxicology). In the laboratory, this can be circumvented by selecting test species with relatively short life cycles, like algae, bacteria and zooplankton. For algae, a three or four day test can be considered as a multigeneration experiment and during 21 d female daphnids may release up to three clutches of neonates. These population ecotoxicity tests offer the unique possibility to calculate the ultimate population parameter, the population growth rate (*r*). This is a demographic population parameter, integrating survival, maturity time and reproduction (see section on population modeling). Yet, such chronic experiments are typically performed with cohorts and not with natural populations, making these experiments rather an extension of chronic toxicity tests than true population ecotoxicity tests.

References

Knillmann, S., Stampfli, N.C., Beketov, M.A., Liess, M. (2012). Intraspecific competition increases toxicant effects in outdoor microcosms. Ecotoxicology 21, 1857-1866.

Liess, M., Foit, K., Knillmann, S., Schäfer, R.B., Liess, H.-D. (2016). Predicting the synergy of multiple stress effects. Scientific Reports 6, 32965.

Pieters, B.J., Liess, M. (2006). Population developmental stage determines the recovery potential of *Daphnia magna* populations after fenvalerate application. Environmental Science and Technology 40, 6157-6162.

5.2. Question 1

Motivate the importance of studying ecotoxicology at the population level and higher.

5.2. Question 2

Name the properties of populations that are unique to this level of biological organisation.

5.2. Question 3

Why is it important to understand the implications of age and developmental stage specific sensitivities for population responses to toxicant exposure?

5.2. Question 4

Explain the results observed in Figure 3.