Matrix models to assess acute and chronic effects of oil spills on Arctic Calanus populations

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Introduction

A lack of chronic toxicity data generally hampers the adequate assessment of oil spill impacts, which has implications for NEBA-based decison making. To assess toxic impacts at the population level, matrix models may provide a solution by enabling impact simulation of different oil exposure scenarios. This approach was applied to Arctic key-species, including Arctic copepods.

In the Arctic, three herbivorous *Calanus* species co-exist : *C. hyperboreus*, *C. glacialis* and *C. finmarchicus* (Table 1), accounting for 50-80% of the total mesozooplankton biomass (Falk-Petersen 2007, 2009, Søreide et al. 2008). These species are important in transferring primary production to higher trophic levels, mainly fish.

Table 1. Some characteristics of Arctic copepod species

Species	***C. hyperboreus***	***C. glacialis***	*C. finmarchicus*	
Distribution	Arctic, deep water	Arctic, shelf	Atlantic	
Length (mm)	4.5-7	3-4.6	2-3.2	
Lipids (mg)	1-1.8	0.4-0.45	0.04-0.08	
Life span (years)	2-6	2-3	1-2	

Data: Falk-Petersen, 2009. Picture: Soreide, 2012

Methods

Age structured matrix models are constructed taking into account a diapause winter period. After calibration, the model is translated into a "day to day" simulation model enabling the assessment of acute and chronic toxic effects on the population dynamics.

Matrix population models are popular given (1) their direct relationship with empirical field data, (2) their clear link between vital rates (reproduction and survival) and population performance and (3) their relatively low data requirements that make them easy to apply.

Leslie Matrix models for hypothetical *Calanus* species were developed taking into account seasonal events and geographic variation. The models are age structured, and include reproduction and mortality rates.

It is assumed that in relatively mild Arctic regions the life-cycle of *Calanus* sp. lasts two years, and four years in colder regions (Figure 1). Furthermore, it is assumed that during diapause there is no activity; no reproduction and no mortality.

The model described here considers a life-cycle with a generation time of two years (figure 2). We model this population as post-breeding, and thus the two classes $(x_0(\tau),\ x_1(\tau))^T$ represent the just born (0+ to 1 year old), and the older than one year old *Calanus*, with τ in years. The projection in time for this system reads $(x_0(\tau+1),\ x_1(\tau+1))^T = L\ (x_0(\tau),\ x1(\tau))^T$.

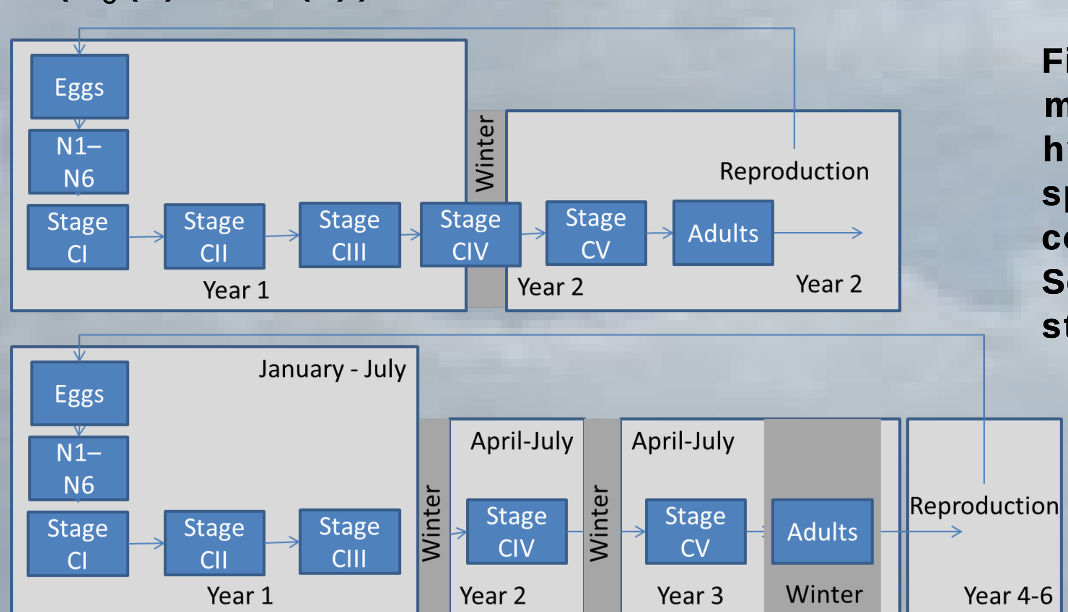

Figure 1. Two (above) and four or more (below) year life cycles of hypothetical Arctic Calanus species for respectively mild and colder Arctic regions, based on Scott et al. (2000). N=naupliar stage, C=copepodite stage.

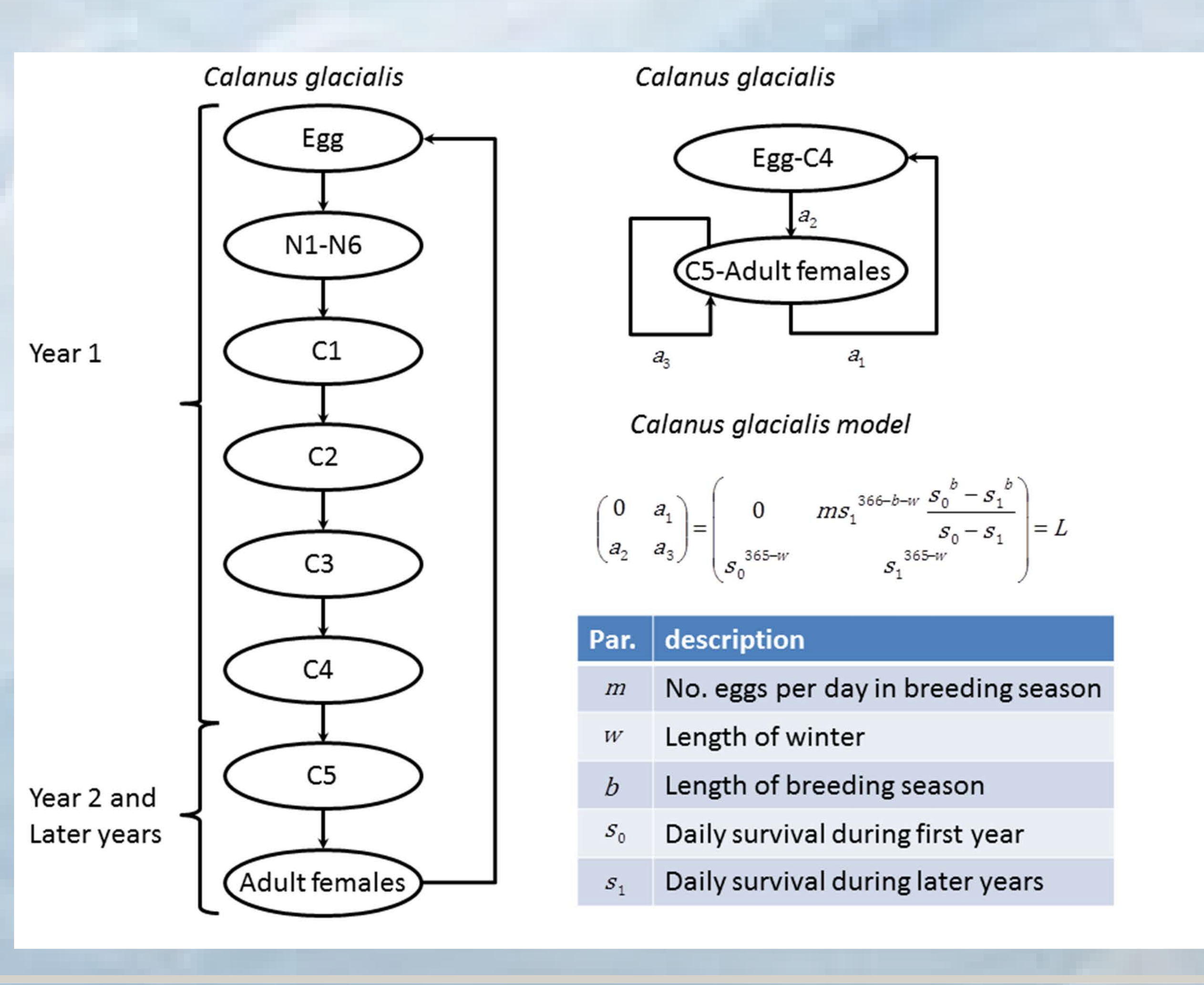

Figure 2. Basic model for *Calanus* with a generation time of two years

Results

With the parameterization as shown in Table 2 the yearly growth factor (=dominant eigenvalue) becomes 1.05. The stable age distribution will be $(x_0,\ x_1)^T = (560,\ 1)^T$. From an elasticity analysis, it appears that the survival rate s_1 had the highest relative influence on the population growth factor (Table 2).

Table 2 Input parameter values, and output of the elasticity analysis (sensitivity and elasticity)

	estimate	sensitivity	elasticity
s_0	0.960	5.36+01	48.7
s_1	0.998	1.39+02	131
M	47	5.72-03	0.25
b	30	4.73-03	0.13
w	185	1.26-02	2.20

The day-to-day simulation model enables the testing of different exposure scenarios on the population level, as exemplified in Figure 3.

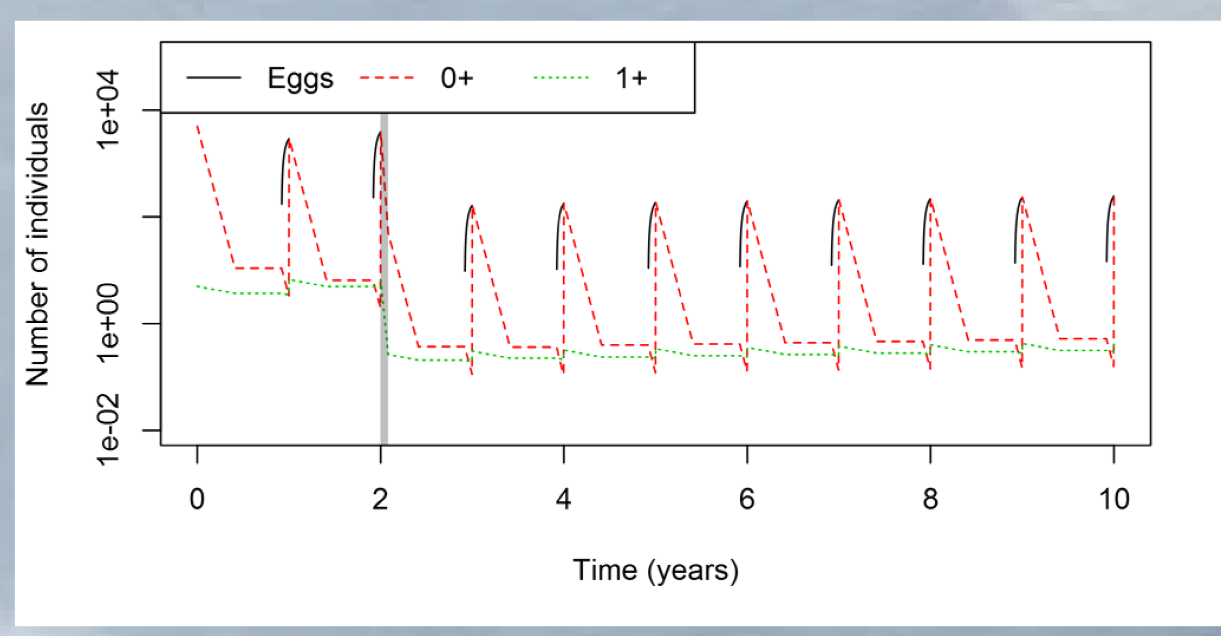

Figure 3 Model output including a 50% reduction of survival rate during a 30 day exposure period just after reproduction (grey bar).

Discussion & Conclusions

- The model input required many extrapolations and assumptions, and parameter values were loosely based on literature data.
- The model enables the inclusion of different seasons, but requires data on field-relevant mortality rates that are not well known.
- Simulations for toxic effects can be implemented by affecting different parameter values at different times of the year.

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