Adverse effects of an aquaculture medicine on non-target shrimp populations: extrapolation from lab experiments to demographic endpoints by population modelling

Introduction

Diflubenzuron (DFB) is a commonly used medicine against salmon lice in marine aquaculture. DFB from feed may affect non-target crustaceans such as the Northern shrimp, an economically and ecologically important species. Laboratory experiments have demonstrated that:

- Shrimp exposed to DFB have reduced survival: 60% of control for both adults and larve (Bechmann et al., 2017, 2018).
- Shrimp survival is further reduced by lower pH (7.6) and higher water temperature (10°C), which can be expected for the Norwegian coast towards the end of the century (Wallhead et al. 2017).

Aim: to make the information on mechanistic effects from these experiments more relevant for risk assessment at the population level.

We have developed an age-structured, stochastic population model representing a shrimp population located in a hypothetical Norwegian fjord containing a fish farm (Fig. 2).

A set of model scenarios represent different DFB application schemes and different degrees of exposure to DFB under ambient and future climate conditions.

Model assumptions and scenarios

- The model is run for 100 years × 60 scenarios × 1000 replicate populations.
- Season of DFB application: in autumn, spring, or both.
- The degree of DFB exposure is quantified as the proportion of the population affected: none (0%), low (5%), medium (25%) or high (50%).
- DFB application reduces survival (cf. Table 1) during the season of application.
- Future climate reduces survival (cf. Table 1) in summer for larvae and immature females.
- Environmental fluctuation (Fig. 3c): each year has 20% probability of adverse food conditions for larvae, with survival reduced by 50%.
- Unknown effects of predation and fishing: stochastic variation in adult survival (differs among populations).
- Stochastic variation in fecundity (differs among individuals).
- Density-dependent compensation in juvenile and adult survival, for age classes k ≥ 6:

\[ N_{k+1}(t+1) = \frac{s_k - N_k(t)}{1 + (a - N_k(t))^b} \]

\( t = \) time step
\( N_k = \) no. of individuals in age class \( k \)
\( s_k = \) survival of individuals in age class \( k \)
\( a = 0.0003 \) (related to the carrying capacity)
\( b = 0.5 \) (the degree of compensation)

Results

According to this population model:

- In the worst scenario under ambient climate (Fig. 4c), DFB exposure may reduce the adult shrimp abundance to 32%.
- Combined effects of DFB and changed climate (Fig. 4f) may further reduce the abundance to 28%.
- The probability of decline below a threshold of e.g. 1000 adult individuals (Fig. 5) is:
  - 13% for the ambient control population
  - 38% if DFB is used in spring only, with high exposure of the population
  - 64% if DFB is used in both spring and autumn

Conclusions

The effects of DFB on shrimp populations are strongly affected by:

- The number of DFB applications per year
- The proportion of the population affected by the DFB exposure
- Adverse environmental conditions causing food shortage for larvae, which can be expected more frequently with future climate change.

For more reliable ecological risk estimates for Northern shrimp populations, we need more knowledge on ecological factors affecting the population dynamics:

- Effects of environmental fluctuation on larval survival
- Effects of predation and fishing on adult abundance
- Density dependence: compensating responses to reduced abundance

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References


