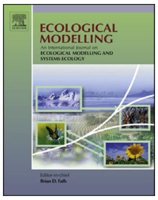
Ecological Modelling 322 (2016) 92–100

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel



Discerning the causes of a decline in a common European fish, the roach (*Rutilus rutilus* L.): A modelling approach

W. Otjacques, F. De Laender, P. Kestemont*

Research Unit in Environmental and Evolutionary Biology, University of Namur, Namur, Belgium

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 1 December 2015
Accepted 7 December 2015
Available online 30 December 2015

Keywords:
Roach stock
Leslie matrix
Bottom-up
Top-down
Large river

ABSTRACT

Stock assessment of roach (*Rutilus rutilus*) in the river Meuse (Belgium), based on two decades of research, indicated a sudden stock decline since the early 2010s. While roach was very abundant during the 1990s and beginning of the 2000s with densities estimated around 3000–3700 fish ha^{-1}, densities dropped below 400 fish ha^{-1} since 2010. A drop in primary production since 2005 and an increase in predation pressure by the Great cormorant (*Phalacrocorax carbo*) between 2000 and 2006 are listed among potential explanations. In the present study, three scenarios were explored using an age-structured Leslie matrix to investigate if bottom-up control (phytoplankton driven), top-down control (predation driven) or a combination of both can explain the observed decline of roach stock. Including only a phytoplankton-dependent reduction of carrying capacity into the model (i.e. bottom-up control) accurately predicted the observed densities. If only predation by wintering populations of Great Cormorant was considered, the model did not predict the observed decline in roach stock. Combining top-down and bottom-up effects into the model resulted in a comparable fit as when including bottom-up effects alone. Taken together, our results suggest that roach decline is mainly driven by phytoplankton decline.

1. Introduction

Species conservation is often reactive and begins after a serious decline in a population is observed. The causes of species decline are pervasive and numerous (Hilderbrand, 2003). Fish populations can be affected by numerous anthropogenic factors such as overfishing, degradation of habitat, eutrophication and chemical pollution (Hanson, 2011). Other factors, such as invasive species (Mack et al., 2000) and climate change (Daufresne and Boët, 2007), can have deep impacts on populations. In these cases, population models can be helpful in determining the sensitiveness of a species to a particular stress (Hanson, 2011).

In the River Meuse (Belgium), a drastic decline in the common fish, the roach (*R. rutilus*), has been observed and quantified by Otjacques et al. (2015). Several stock estimations by mark-recapture have been conducted in the River Meuse, more precisely on the reach of Tailfer (Belgium, 518 km from spring) over the last two decades. The first estimation in 1993 revealed a high stock of roach (density: 3695 ind ha^{-1}; biomass: 200 kg ha^{-1}) (Didier and Micha, 1996). Based on this assessment, the restocking program aiming to support this population subject to capture by sport fishermen was stopped. The study was repeated in 2000, 2001 and 2002, indicating a stable stock (density: 3035–3145 ind ha^{-1}; biomass: 169–175 kg ha^{-1}) (Evrard and Micha, 2003). Following this second study, the restocking program was definitively abandoned. Since 2005, indirect indicators (regular control of fish pass, catch by sport fishermen) suggested a declining trend and a third evaluation was launched in 2010 and 2011. This third fish sampling campaign and stock assessment indicated that roach density was around 300 ind ha^{-1} (Fig. 1). These estimations by mark-recapture have been confirmed by a comparison of catch per unit of effort by gillnet, which revealed a 95% decrease. Moreover, a long term analysis of fish pass data revealed a 90% decrease of roach passages during the same period, thus confirming the trend (Table 1) (Otjacques et al., 2015). Two hypotheses are proposed to explain this sharp decline.

First, since the mid-2000s, a sharp decline in pelagic primary production is observed (Fig. 1). As nutrient levels (C, N and P) remain stable, Pigneur et al. (2014) suggested that this reduction of primary production was not due to the recent increase of sewage treatment plants along the River Meuse but rather to the rapid extension of invasive Asian clams *Corbicula sp.* The loss of 70% of the primary production can create a “bottom-up” effect on fish population (Pigneur et al., 2014) because macrophyte production cannot

---

* Corresponding author.
E-mail address: patrick.kestemont@unamur.be (P. Kestemont).

http://dx.doi.org/10.1016/j.ecolmodel.2015.12.002
0304-3800/

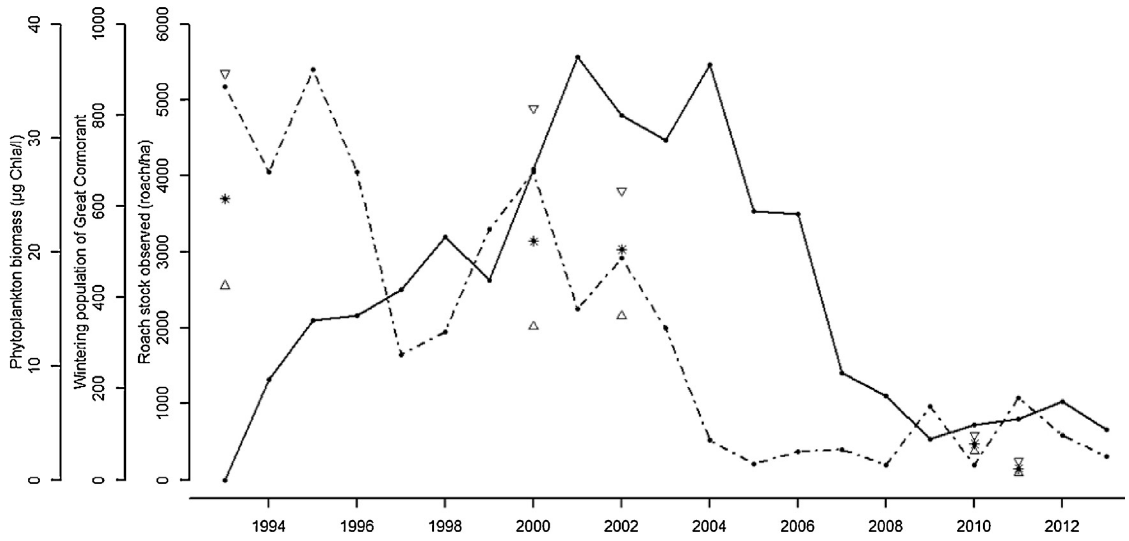


Fig. 1. Evolution of roach stock (* mean (without young of the year); Δ, lower confidence interval; ∇, upper confidence interval), wintering population of Great Cormorant (solid line) and phytoplankton biomass (dotted line) in the reach of Tailfer for the period 1993–2013.

Table 1

Density and biomass estimated by mark-recapture, catch per unit of effort (Gillnet 20 mm, 100 m^2, 30 min of fishing) and roach passages (month^{-1}) in fish pass of Tailfer.

Year	Density (roach ha^{-1})			Biomass (kg ha^{-1})			CPUE			Roach
	LCI 95%	Mean	UCI 95%	LCI 95%	Mean	UCI 95%	LCI 95%	Mean	UCI 95%	passages
1993	2554	3695	5346	138.6	200.6	290.2	9.48	21.29	33.09	873
2000	2021	3145	4892	112.3	174.7	271.8	11.07	19.30	27.53	NA
2002	1950	3035	4719	108.3	168.6	262.2	11.50	17.10	22.70	NA
2010	380	473	590	16.8	20.9	26.0	NA	NA	NA	370
2011	91	149	243	5.7	9.3	15.1	0.36	0.92	1.48	146

counterbalance the loss of primary production by phytoplankton. This is partly because of channelization, disturbing the establishment of macrophytes. Moreover, habitat heterogeneity has been altered for navigation with a deepening of the bed and a reduction of natural banks. These modifications have led to a decrease of biodiversity in the River Meuse (Descy et al., 2009). As these transformations were done in the last century (Micha and Borlée, 1989), they cannot be considered as a direct cause of the recent decrease in roach stocks. However, these alterations can facilitate the spread and the establishment of invasive species potentially dangerous for freshwater fauna and altered macrophyte establishment.

Another hypothesis concerns predation by the Great Cormorant (*Phalacrocorax carbo*). Birds have established a wintering population in Belgium by first colonizing the River Meuse valley in 1991 (Clotuche and Schaeken, 1991) and were first observed in the reach of Tailfer in 1994. This population grew constantly to reach a peak in 2001–2004. Since this historical peak, the wintering population progressively declined along the River Meuse while colonization of small tributaries increased (Fig. 1) (Paquet, 2007, 2011). Thus, top-down effect on roach stock could also be responsible for roach decline, as this species of fish is one of the cormorant's favourite preys in the River Meuse (Evrard and Tarbe, 2002). Fishing pressure by sport fishermen cannot be a cause of the decline as it was very low throughout the duration of this study, with exploitation rates estimated below 50%, which reflects an underutilization of the stock.

In the present study, observed impacts of a reduction in primary production (hypothesis 1) and of predation by the Great Cormorant (hypothesis 2) on the roach are used in an age-structured model. By doing so, we infer which of the two listed hypotheses is most likely to have caused the decline of this fish in the River Meuse. Three scenarios were constructed, one only considering the bottom-up effect, one only including the top-down effect, and a third containing both effects. Population projections of these three scenarios were then compared with observed population trends for different years. Last, an analysis of elasticity has been done to find which population parameters are the most relevant in order to improve management.

2. Materials and methods

2.1. The model

We used a matrix model to calculate population growth of the roach over time (Leslie, 1945). Matrices are written in bold, vectors are written with an arrow, others are single values, products are written by a dot and scalar product is referred by an x:

$$\vec{N}_{t+1} = \boldsymbol{L}\vec{N}_t \tag{1}$$

where the vector $\vec{N}_{t+1}$ contains abundances (females only) of the i age classes at time $t+1$, which is calculated as the product of the Leslie matrix $\boldsymbol{L}$ and the vector $\vec{N}_t$ at time t. The Leslie matrix is written as:

$$\boldsymbol{L} = \begin{vmatrix} F_0 & F_1 & F_2 & \cdots & F_{i=n} \\ S_0 & 0 & 0 & \cdots & 0 \\ 0 & S_1 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & S_{i=n-1} & 0 \end{vmatrix} \tag{2}$$

where the first row shows the fecundity F_i of each age group i (the number of young of the year produced by a female of age i during