Fisheries Research 96 (2009) 216–222

Contents lists available at ScienceDirect

Fisheries Research

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

Demographical analysis of the pink ling *Genypterus blacodes* (Schneider 1801) in the austral demersal fishery: A matrix approach evaluating harvest and non-harvest states

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ARTICLE INFO

Article history:
Received 28 January 2008
Received in revised form 17 November 2008
Accepted 19 November 2008

Keywords:
Ling
Genypterus blacodes
Matrix models
Perturbation analysis
Population growth rate
Population elasticity

ABSTRACT

In this work we model the population dynamics of *Genypterus blacodes* of the demersal fishery on Chilean southern-austral region, using stage structured matrices, from a 17-year time-series of annual age-specific female abundances. For the parameterized matrices obtained, we calculated population growth rates with confidence intervals, net reproductive rate, reproductive value, stable stage structure, and we performed a sensitivity analysis.

We also generated and analyzed an analogous stage structured matrix model for the same population assuming no harvesting. The main results are (1) a negative growth rate for the observed population data; (2) a positive growth rate for the population without the capture effect which is significantly different from the growth rate of the harvested population; (3) the sensitivity analysis revealed that λ is more sensitive to variations in adult survival in the age class 7–10 years; (4) the observed population exhibits a stable stage structure.

1. Introduction

The pink ling (*Genypterus blacodes*) is a demersal species distributed on the coasts of South America, Australia, Tasmania and New Zealand (Chong, 1984; Withell and Wankowski, 1989; Chong and Aguayo, 1990; Horn, 1993; Colman, 1995; Ward et al., 2001; Morioka and Machinandiarena, 2001). This species also named pink cusk-eel (Wiff et al., 2007), golden ling (Paredes and Bravo, 2005) or golden kinglip (Larrain et al., 2002; Seco Pon et al., 2007), is found around the southern tip of South America, between Coquimbo, Chile (30°00′S) along the Pacific Ocean, up to Río Grande in the boundary between Brazil and Uruguay in the Atlantic Ocean.

The austral demersal fishery (ADF) is development in the Chilean southern-austral zone 41°28′–57°00′S from 1997, with a multi-specific character in which diverse resources were extracted simultaneously from approximately 100 species (Aguayo et al., 1986; Arana, 1990), among them the southern hake (*Merluccius australis*) and the pink ling (Ojeda et al., 1986; Pérez, 2000). Both species have been declared in state of "fully exploited", a term that is used to qualify a stock which is probably neither being overexploited nor underexploited and is producing, on average, close to its maximum sustainable yield (Restrepo, 1999). Since the southern hake is the main target period of the fishery, it has been managed through closed seasons during reproduction; these measures affect the whole fishery.

In spite of the apparent stabilisation in the last years, decrease of the pink ling landings in the ADF, as well as other fisheries indicators suggest a decreasing trend in population size. This could be explained by overexploitation due to the lack of biological and ecological knowledge about the main species exploited, including the pink ling.

At present, the knowledge about the ecological processes in this species is fragmentary at best, due to a lack of basic biological and fishery information (Wiff et al., 2007) and previous studies carried out on this species were dedicated to other aspects, but they were not directed towards gaining knowledge on demographical processes of the population.

We studied the population dynamics of *G. blacodes* through the formulation and analysis of a discrete time stage-structured matrix model. This matrix model was parameterized from a

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doi:10.1016/j.fishres.2008.11.006

17-year temporal series of data obtained from the Fishery Development Institute of Chile (Instituto de Fomento Pesquero, IFOP) and we consider that the used methodology can be applied to a more extensive temporal series employing the information available at IFOP.

Specifically, we were interested in estimating the stage-specific survival and fecundity rates, and in calculating the sensitivity of the growth rate to variations in vital rates. We reconstruct the temporal series observed under zero capture assumption and we evaluated the effect of fishery on the *G. blacodes* demographical features. However, a series of assumptions are necessary with respect to the quality of data employed such as the age of the specimens of pink ling obtained from of the sample used has been correctly identified; the abundances obtained from the matrix of capture are well estimated; all individuals within an age class are identical, the stochastic environment changes are not considered on the population dynamic and so on.

In short, the specific aims of this work are (1) to construct and parameterize a matrix model for *G. blacodes* in the ADF, from the available information about the estimated age-specific abundances; (2) to describe the growth of the pink ling population; (3) to carry out a prospective perturbation analysis of the vital rates; (4) to estimate the pink ling population dynamics without the fishing effect and to contrast this with the results obtained from the model of the harvest population.

2. Materials and methods

The information employed in this work was obtained for the fisheries of inner and outer waters of the ADF according to the compiled logbooks. The data of inner waters corresponds mainly to small-scale and industrial longline fishery, and the data of outer waters corresponds to the trawler fishery including factory and freezer vessels (Aránguiz-Acuña and González-Olivares, 2004). Historically, the pink ling has been caught as an incidental species in the ADF where captures are carried out by industrial vessels operating with bottom trawls and longlines as fishing gear (Wiff et al., 2007).

The data was obtained from the indirect estimate of the pink ling abundances by age class through the Sequential Population Analysis (SPA) gauged with the Catch per Unit of Effort (CPUE) (Payá et al., 2000).

The pink ling abundances series of 3 to 14+ years old, estimated in this way for the period 1982–1998 (Fig. 1) was provided by the Chilean Fishery Secretariat (SUBPESCA) and estimated by the Fishery Development Institute (IFOP) on basis of the landed biomass of these commercial fisheries (Aguayo et al., 2000, 2001).

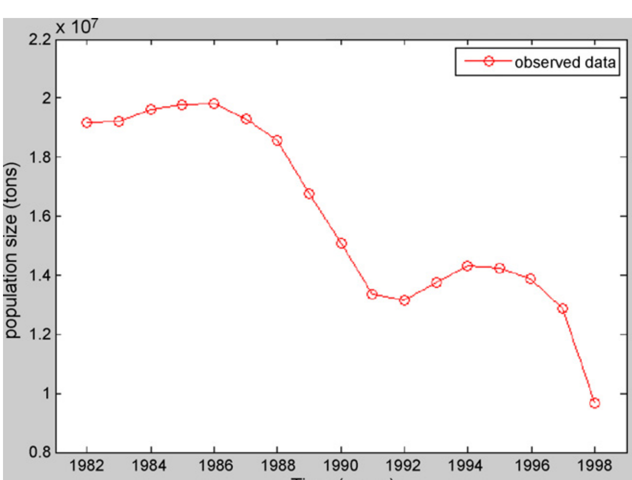

Fig. 1. The female pink ling abundance series of 3 to 14+ years old, estimated for the period 1982–1998.

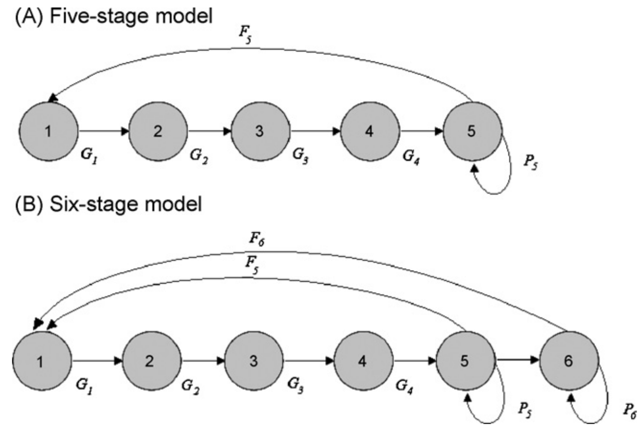

Fig. 2. Life-cycle for the five- and six-stage matrix models.

2.1. Model construction

We developed a stage structured matrix model for the female pink ling (*G. blacodes*) population known as stage-classified matrix model (Caswell, 2001). The matrix model is a discrete model that uses age distributions to project population densities as time progresses (Banks et al., 2007). Mortality is the only mechanism included to remove individuals from the population and a balance between emigration and immigration is assumed.

The beginning of sexual maturity for *G. blacodes* was determined at 7 years old, considering that the 50% age at maturity is 6 years estimated by microscopic observations, and that the contribution to the 3–6-year-old classes is smaller than the 1.4% of the total eggs production in a year (Aguayo et al., 2001).

Models with at least five stages were considered, so that each juvenile age class (3–6 years old) would be represented in a separate stage with a maximum of 12 stages, so that each age group (3–14 years old) would be also represented in a separate stage.

The five-stage model was structured with the following stages: (1) 3-year-old recruits; (2) 4-year-old juveniles; (3) 5-year-old juveniles; (4) 6-year-old juveniles; (5) 7–14-year-old adults. The six-stage model was arranged in a similar way but with stage (5) 7–10-year-old adults and (6) 11–14-year-old adults.

We found that the methodology employed to obtain the coefficients of the projection matrix was not sensitive enough to estimate the fecundity parameters in matrices with more than six stages, i.e., matrices including more than two fertile stages. So, these models were rejected and only the five- and six-stage models were considered.

In vector matrix notation the model employed can be expressed in a general form as

$$x(t+1) = A \cdot x(t) \qquad (1)$$

where $\boldsymbol{A}$ is the transition matrix also known as Leslie matrix, $\boldsymbol{x}(t)$ is the abundance vector at the time t and $\boldsymbol{x}(t+1)$ is the abundance vector at time $t+1$. The life-cycle graphs for five and six stages are shown in Fig. 2.

The transition matrices for the five and six stages are

$$A_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & F_5 \\ G_1 & 0 & 0 & 0 & 0 \\ 0 & G_2 & 0 & 0 & 0 \\ 0 & 0 & G_3 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 \end{pmatrix} \quad \text{and}$$