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SIMULATION OF BIOMASS TRENDS OF EASTERN BLUEFIN TUNA (*THUNNUS THYNNUS*) STOCK UNDER CURRENT MANAGEMENT REGULATIONS

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SUMMARY

Juvenile catches of bluefin tuna (< 30 kg) have fallen considerably due to present regulations for the eastern stock. Considering past catches of juvenile tuna, large numbers of young tuna now survive and may contribute to future spawning stock. We consider the possibility that these measures are maintained for the period 2007-2020 and simulate the biomass output provided by these tuna that have not been and will not be caught. A stochastic matrix projection model was used. The output from the simulation suggest that by 2010, there will be about one million more tuna of ages 1 to 7 than in 2006 with an increase of about 26,000 tons (95% CI 15.795-35.481 tons). By 2020, the population is expected to increase by about 1.6 million of individuals of ages up to 17 years which will imply an increase in biomass of 109.178 tons (95% CI 98.264-118.173 tons) when compared to figures in 2006.

RÉSUMÉ

Les prises des thons rouges juvéniles (< 30 kg) ont considérablement diminué en raison des réglementations actuelles appliquées au stock de l'Est. Si l'on considère les prises de thonidés juvéniles réalisées dans le passé, un grand nombre de juvéniles survivent désormais et peuvent contribuer au futur stock de reproducteurs. Nous considérons que ces mesures sont maintenues pendant la période allant de 2007 à 2010 et nous simulons les résultats de la biomasse de ces thonidés qui n'ont pas été et ne seront pas capturés. Un modèle de projection de matrice stochastique a été utilisé. Les résultats de la simulation donnent à penser qu'il y aura approximativement un million de thonidés supplémentaires d'âges 1 à 7 d'ici à 2010 par rapport à 2006, ce qui représente une augmentation d'environ 26.000 tonnes (95% CI 15.795 - 35.481 tonnes). D'ici à 2020, la population devrait augmenter d'environ 1,6 million de spécimens d'âges allant jusqu'à 17 ans, ce qui impliquera une hausse de la biomasse de 109.178 t (intervalles de confiance de 95 % 98.264 – 118.173 t), si l'on compare ces chiffres avec ceux de 2006.

RESUMEN

Las capturas de juveniles de atún rojo (< 30 kg) han descendido de forma considerable debido a los reglamentos actuales para el stock oriental. En comparación con las capturas de juveniles del pasado, ahora sobreviven muchos juveniles y éstos podrían contribuir al futuro stock reproductor. En el documento se ha considerado la posibilidad de que estas medidas se mantengan para el periodo 2007-2020, y se simularon los resultados de biomasa proporcionados por estos atunes que no han sido ni serán capturados. Se utilizó un modelo de proyección de matriz estocástica. Los resultados de la simulación sugieren que en 2010 habrá en torno a un millón más de atunes de edades 1 a 7 que en 2006, con un incremento de aproximadamente 26.000 t (CI 95% 15.795–35.481 t). Desde ahora hasta 2020, se prevé que la población aumentará en aproximadamente 1,6 millones de ejemplares de edades hasta 17 años, lo que implicará un aumento en la biomasa de 109.178 t (CI 95% 98.264-118.173 t) con respecto a las cifras de 2006.

KEYWORDS

Simulation, stochastic models

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Introduction

The present regulation of captures for the bluefin tuna (*Thynnus thynnus*) at the western and central Mediterranean prohibits the capture of specimens of less than 30 kg since 2007. This resulted in a considerable fall in juvenile catches by European fleets fishing in these areas. It was estimated that about 840 000 less bluefin tunas are now caught annually by European fleets in the central and western Mediterranean (Cort and Martínez 2010). This figure may be much greater if we considered all the fleets of the Mediterranean, for which little information is available. The total quantity corresponding to the three years of regulation coincides with the mean value of the annual recruitment estimated by SCRS for the eastern bluefin tuna stock (Anon. 2009).

The aim of this study was to evaluate the possible effects of such measure in the medium term (2007-2020) on the stock biomass using population projections.

Data and methods

We used matrix population projection models to estimate the potential increase in biomass of the bluefin tuna in case the actual management measures are maintained. Models were based on a pre-breeding census and included seventeen age classes that start from one year old bluefin tunas (Caswell 2001). The initial model started with the juvenile bluefin tunas that spared from the fishery in 2007, the first year after the implementation of present management measures. This included individuals of the cohorts 2003-2006. The estimated number of individuals that were not caught was obtained from reported catches of individuals of those ages (Anon. 2009). We used the mean of the catches as starting population (N_t).

The life cycle used to describe the population dynamics is in **Figure 1**. The model includes an income of new individuals of ages 1 to 4 (individuals not caught by the fishery) in addition to natural mortality and reproduction. The model used is similar to models that incorporate income of individuals from immigration (e.g. Pakanen et al. 2010).

The transitions in the matrix were parameterised with means of yearly survival and fecundity values. The values used for age specific survival probability were according to ICCATs manual (ICCAT 2006; see **Table 1**). The fecundities equal to per capita number of recruits per breeding attempt. The bluefin tuna in the East Atlantic and Mediterranean starts reproduction at the age of three years and 50% maturity is achieved at the age of 4 years (30 kg) (Mather et al. 1995). It is generally assumed that bluefin tuna spawns every year, but electronic tagging experiments, as experiments in captivity, suggest that individual spawning might occur only once every two or three years (Lutcavage *et al.* 1999). Thus, for age 3, the probability of breeding used was 0.1, 05 for age 4 and 0.75. Finally fecundity varies with age and weight. Thus, fecundity terms for the different age groups were calculated with eqn.

$$F_{\mathrm{i}} = Pi*b*w_i$$

where Pi is the breeding probability of age i, b is the mean number of recruits per kg, and w_i is the mean weight of individuals at age i. There is no information of larval survival probability for this species. Data available only obtain estimates of individuals of age 1. The mean number of recruits was obtained from the number of individuals one year old associated with SSB at the next census to estimate her net reproduction (derived from Anon. 2009). Thus this term includes larvae production by kg of reproductive individuals and larval survival.

Because of the uncertainties in most of the demographic data included, a stochastic matrix model was projected. The approach used a stochastic population projection, where the number of individuals at time $t + 1$ is a binomial sample of the number at the previous time t, births were modelled as a Poisson process, and the number or fish spared form catches following a Normal distribution process. A Monte Carlo simulation with 1000 iteration was run. We implemented this simulation using Poptools (Hood 2009).

Results

The mean number of catches of individuals of less than 20 kg is 905172 (extrapolated from inflated catches). The mean number of individuals by age (ages 1 to 4) is in **Table 1**. This amount of individuals is the estimated number bluefin tuna that are not caught and thus will contribute to future biomass of the stock.

There is no information on larval survival for the bluefin tuna (Anon. 2009). Thus we estimated mean fecundity as the number of individuals recruited to the population by kg of SSB (**Table 1**). Although it is most likely that there are density dependent effects in recruitment we did not consider them into the modelling process.

There is a clear increase in biomass if present management regulations are maintained (**Figure 2**). Both determinist and the stochastic models suggest an increase in biomass, although the determinist model suggested an increase up to 400,000 tons of biomass. The output from the simulation suggest that by 2010, there will be about one million more tuna than in 2006 of ages 1 to 7 with an increase of about 26,000 tons (95% CI 15,795-35,481 tons). By 2020, the population is expected to increase by about 1.6 million of individuals of ages up to 17 years which will imply an increase in biomass 109,178 tons (95% CI 98,264 - 118,173 tons).

Discussion/Conclusions

The simulation clearly suggests that present management regulations may result in an increase of the biomass stock for the eastern stock of bluefin tuna if they are mantained. The increase in biomass suggested by the simulation it is accordance with several abundance indices obtained from fisheries, flights and catches in the 2010 in the Mediterranean that suggest an increase in the population, specially of the youngest cohorts.

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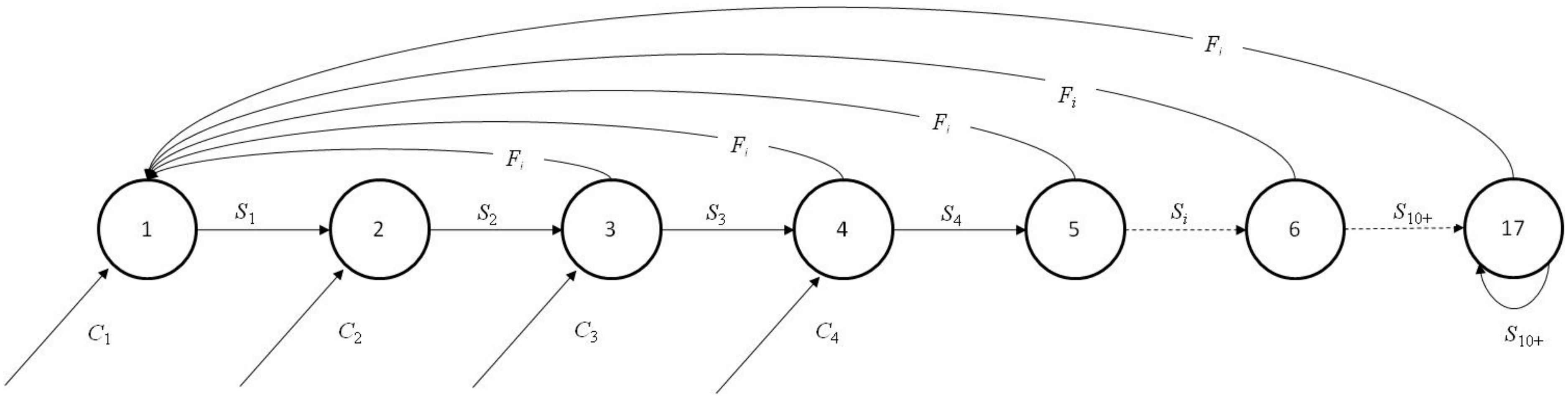
Table 1. Means and standard errors for parameter estimates used in matrices.

Estimates for Fecundity (F)	*Estimate*	*Estimate derived from*
Number recruits/kg of adult (b):	0.012 ± 0.006	Results
Breeding probability age 3 (P_3)	0.1	
Breeding probability age 4(P_4)	0.5	ICCAT 2006
Breeding probability age 5 or older	0.9	ICCAT 2006
Weight at age 1-17 (w_i)		Cort 1990
Survival rate age 1 (S_1)	0.51	Anon. 2009
Survival rate age 2(S_2)	0.76	Anon. 2009
Survival rate age 3(S_3)	0.76	Anon. 2009
Survival rate age 4(S_4)	0.76	Anon. 2009
Survival rate age 5(S_5)	0.76	Anon. 2009
Survival rate age 6(S_6)	0.8	Anon. 2009
Survival rate age 7(S_7)	0.825	Anon. 2009
Survival rate age 8(S_8)	0.85	Anon. 2009
Survival rate age 9(S_9)	0.875	Anon. 2009
Survival rate age 10 or older (S_{10+})	0.9	Anon. 2009
Surplus of individuals of age 1 (C_1)	285424 ± 311928	Results
Surplus of individuals of age 2 (C_2)	369341 ± 213119	Results
Surplus of individuals of age 3 (C_3)	187726 ± 108173	Results
Surplus of individuals of age 4 (C_4)	62682 ± 45162	Results



$$\begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \\ . \\ . \\ N_{17} \end{bmatrix}_{t+1} = \begin{bmatrix} C_1 & 0 & F_3 & F_4 & F_5 & F_6 & F_i & . & F_{17} \\ S_1 + C_2 & 0 & 0 & 0 & 0 & 0 & 0 & . & 0 \\ 0 & S_2 + C_3 & 0 & 0 & 0 & 0 & 0 & . & 0 \\ 0 & 0 & S_3 + C_4 & 0 & 0 & 0 & 0 & . & 0 \\ 0 & 0 & 0 & S_4 & 0 & 0 & 0 & . & 0 \\ 0 & 0 & 0 & 0 & S_5 & 0 & 0 & . & 0 \\ 0 & 0 & 0 & 0 & 0 & S_5 & 0 & . & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & S_i & . & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & S_{10+} & S_{10+} \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \\ . \\ . \\ N_{17} \end{bmatrix}_t$$

Figure 1. Life cycle used in the simulations for the eastern bluefin tuna. N_i, is population size of age class *i*; *Fi*, is fecundity at age *I*; *Si*, represents annual survival at age *i; Ci*, represent the surplus of individuals not caught by the fishery due to present regulations.

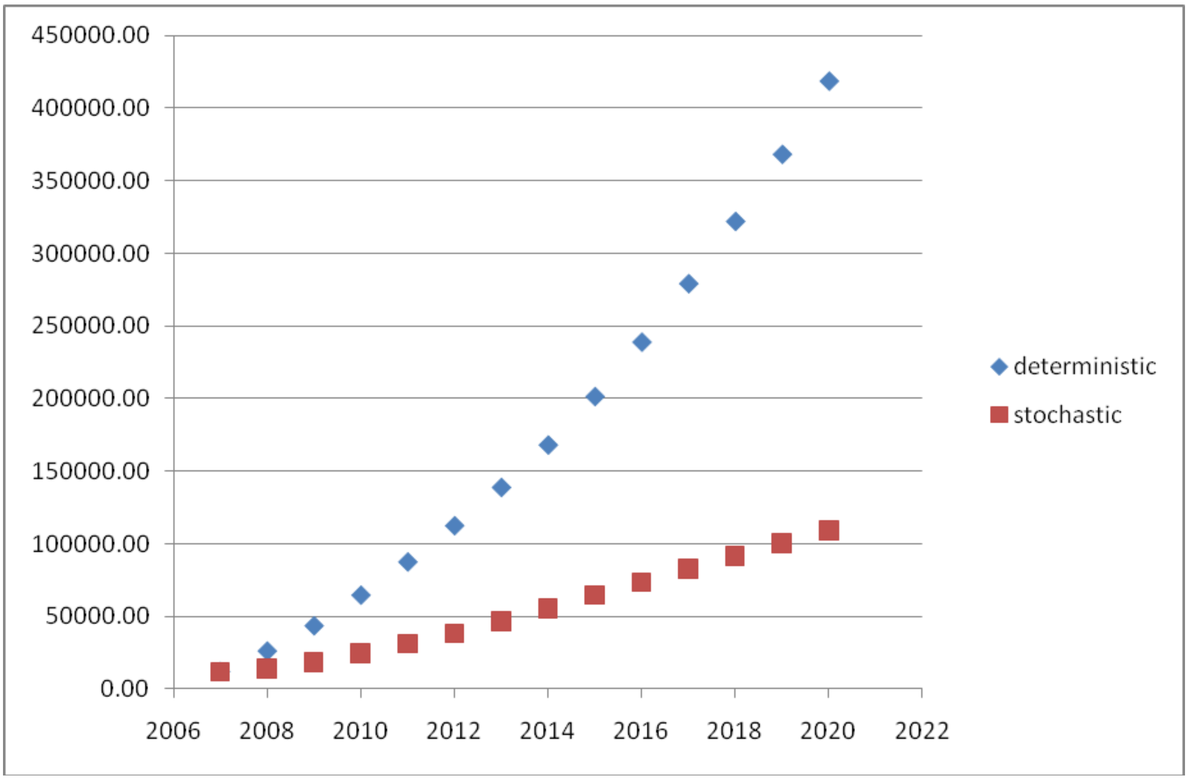


Figure 2. Expected trends in bluefin tuna biomass under an stochastic and a deterministic scenario given that present regulations for the fishery are manteined.