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ESTIMATING THE PRODUCTIVITY OF ATLANTIC BLUEFIN TUNA FROM VALIDATED SCIENTIFIC DATA

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SUMMARY

Estimating the productivity of an exploited marine species is not an easy or a trivial task. In the case of Atlantic bluefin tuna, the productivity can hardly be estimated from the natural mortality rates or the stock recruitment relationships because the former have never been estimated for this species from scientific data, but only "guesstimated", while the latter remain highly uncertain for both the eastern stock (BFTE) and the western stock (BFTW). To get a better idea of bluefin tuna productivity, we thus applied the approach by Jennings et al. (1998) who proposed a surrogate of r, r', named the potential rate of population increase. We compared this parameter and age-at-maturity (and to some extent the individual growth curves) of 25 species displaying contrasting life history traits. The results indicate that the potential rate of population increase of BFTW is significantly lower than this of BFTE. BFTW productivity displays a rather low productivity while BFTE productivity is at a medium level.

RÉSUMÉ

L'estimation de la productivité des populations marines exploitées n'est pas chose aisée. Dans le cas du thon rouge Atlantique, la productivité peut difficilement être estimée à partir des taux de mortalité naturelle ou des relations stock-recrutement, car ces taux n'ont jamais été estimés pour cette espèce à partir de données scientifiques, mais simplement approximés à partir de sources extérieures, alors que les relations stock-recrutement sont très incertaines tant pour le stock Est (BFTE) que pour le stock Ouest (BFTW). Aussi, pour avoir une meilleure idée de la productivité du thon rouge, nous avons utilisé l'approche de Jennings et al. (1998) qui proposait une approximation de r, r', comme taux de croissance potentiel de la population. Nous avons comparé ce paramètre avec l'âge à maturité (et en partie les courbes de croissance individuelle) de 25 espèces présentant des traits de cycle de vie contrastés. Les résultats indiquent que le taux de croissance potentiel de la population du BFTW est significativement plus bas que celui du BFTE. La productivité du BFTW est assez basse alors que celle du BFTE se situe à un niveau moyen.

RESUMEN

La estimación de la productividad de una especie marina explotada no es una tarea sencilla o trivial. En el caso del atún rojo del Atlántico, la productividad apenas puede estimarse partiendo de las tasas de mortalidad natural o de las relaciones stock-reclutamiento porque nunca se han estimado dichas tasas para esta especie a partir de datos científicos, sino que siempre se ha realizado una aproximación, mientras que la relación stock-reclutamiento conlleva una gran incertidumbre tanto para el stock oriental (BFTE) como para el occidental (BFTW). Para obtener una visión más completa de la productividad del atún rojo, se aplicó el enfoque de Jennings et al (1998) que proponía una aproximación de r; r' como tasa de crecimiento potencial de la población. Se comparó este parámetro con la edad de madurez (y en cierta medida con las curvas de crecimiento individual) de 25 ejemplares que presentaban rasgos de ciclo vital que contrastaban. Los resultados indican que las tasas de crecimiento potencial de la población de BFTW son notablemente inferiores que las de BFTE. La productividad del BFTW es bastante baja, mientras que la del BFTE se sitúa en un nivel intermedio.

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KEYWORDS

Thunnus thynnus, population growth rate, fecundity, maturity, CITES criteria

1. Introduction

In 2009, the SCRS has to develop concise scientific advice on the condition of Atlantic bluefin tuna with respect to the biological criteria applied for listing commercially-exploited aquatic species under CITES Appendices I and II. This scientific evaluation is limited to the biological criteria. In the case of Atlantic bluefin tuna (*Thunnus thynnus*), a key point will be related to the estimation of the population decline in the past (see CITES Res. 9.24). The way to evaluate such decline is dependent on several factors (see Annex 5 of the above document), among which the productivity of the species:

"A general guideline for a marked historical extent of decline is a percentage decline to 5%-30% of the baseline, depending on the biology and productivity of the species. Productivity is the maximum percentage growth rate of a population. It is a complex function of reproductive biology, fecundity, individual growth rates, natural mortality, age at maturity and longevity. More-productive species tend to have high fecundity, rapid individual growth rates and high turnover of generations."

Application of decline for commercially exploited aquatic species for CITES is stated as follow (same document):

"*In marine and large freshwater bodies, a narrower range of 5-20% is deemed to be more appropriate in most cases, with a range of 5-10% being applicable for species with high productivity, 10-15% for species with medium productivity and 15-20% for species with low productivity. Nevertheless some species may fall outside this range. Low productivity is correlated with low mortality rate and high productivity with high mortality. One possible guideline for indexing productivity is the natural mortality rate, with the range 0.2-0.5 per year indicating medium productivity."*

2. Natural mortality and stock recruitment approaches

Estimating the productivity of an exploited marine species, especially of a large pelagic species such as bluefin tuna, is not an easy or a trivial task because of the lack of data for key biological processes. For instance, the productivity may be approximated from the natural mortality (M) or the stock recruitment relationship (especially the slope of the curve), but both are particularly problematic to estimate empirically for Atlantic bluefin tuna.

M for Atlantic bluefin tuna (M_{BFT}) has never been estimated from scientific data although some attempts have been tried in the past, using tagging data. As for many other exploited fish stocks, M_{BFT} has thus been "guesstimated" for modelling purposes (i.e. VPA) and assumed to be constant over all the ages, first at the 0.18 per year (close to the "magic" 0.2 annual value used for many demersal fish stocks) and then at 0.14. In 1998, the group that assessed the status of the eastern stock decided to use the age-specific M vector estimated from tagging data for the southern bluefin tuna, *Thunnus maccoyii* (Anon. 1999). Therefore, M_{BFT} values currently used are an either assumption derived from other life history characteristics (western stock) or borrowed from a similar species (eastern stock). M_{BFT} thus can hardly be used to estimate BFT productivity.

Stock recruitment relationship has been modelled for both the eastern and western stocks using a Beverton and Holt (BH) relationship (Beverton and Holt 1957) because overcompensation is unlikely for pelagic fish. However, for both stocks, the goodness of fit has always been unsatisfactory and led to strong residual patterns (see the document "Projections for Eastern Atlantic and Mediterranean Bluefin" by L.T Kell). For the eastern stock, significant temporal changes in the maximum recruitment level have always been estimated from VPA, i.e. at about 1,500,000 recruits in the 1970s and 3,350,000 recruits in the 1990s. However, the lowest recruitment levels correspond to the largest SSB values while the highest recruitment values correspond to medium to low SSB. This point together with the lack of low to very low SSB did not allow estimating correctly both the slope and the asymptote of the BH relationship (Anon. 1999). For that reason, the Committee has considered in 2008 different scenarios, including 3 different slopes and 2 different asymptotes, as being equally probable (Anon. 2009). For the western stock, if there is better support to estimate the slope of the BH relationship (being a 2-line model or not), there has been large uncertainty regarding the asymptote for 2 to 3 decades, so that the Committee considers 2 levels of recruitment, known as the "low" and "high" recruitment scenario (Anon. 1999; 2003; 2007; 2009). The stock-recruitment relationship remains thus highly uncertain for both stocks, so that alternative approaches have to be investigated to estimate BFT productivity.

3. Population growth rates

Calculating the intrinsic rate of increase (r) would imply, in theory, data for egg production and cohort generation time (or lifespan) under unfished condition. However, this is rarely, if ever, the case and the *r* is most often estimated through surplus production model and thus using data from a time period when the stock is under fishery exploitation which might bias (overestimate) this value. Regarding BFT, surplus production has rarely been fitted because of the long life span of the species and numerous age-classes. However, following the demographic method to construct Bayesian prior for the intrinsic rate of increase in the Schaefer model proposed by McAllister *et al.* (2001), Ravier (2003) estimated a prior for *r* of the East Atlantic and Mediterranean BFT at 0.34. Using the same methodology, McAllister *et al.* (2000) estimated both the prior and posterior of *r* for the North Atlantic swordfish at 0.4, a value rather close to the one estimated for BFT.

There are other values of *r* estimated for different species through different surplus production models, but, as the models and/or assumptions and data sources may be significantly different, they must be compared with great care. In order to carry out a comparison among species and thus get a better idea of BFT productivity, we applied the approach by Jennings *et al.* (1998) who proposed a surrogate of *r, r'*, that the authors named the potential rate of population increase. This parameter is estimated as follows:

$r' = \log(\text{fecundity at } L_{50}) / A_{50}$

where L_{50} and A_{50} are the mean length and the mean age at which 50% of the stock attained maturity, respectively.

We compiled the life history traits information for a range of exploited fish species from the North Atlantic and Mediterranean Sea that display contrasting life history and then computed *r'* for each species **(Table 1)**. All the biological information is coming from published scientific documentation, i.e. published articles (e.g., Fromentin and Fonteneau 2001; Denney *et al.* 2002) or scientific reports from ICES and ICCAT working groups.

The potential rate of population increase (*r'*) of the western BFT (BFTW) is clearly lower than this of the eastern BFT (BFTE). For the former, *r'* is comparable to this of the Barent Sea cod (CODbs), a relatively slow growing species, but it is significantly higher than the very low growing species that are orange roughy and arctic sebastes. In contrast, the *r'* of BFTE is comparable to this of albacore (ALB) and not much lower than this of bigeye tuna (BET). It is also close to the productivity of swordfish (SWO), plaice (PLAI), North Sea cod and saithe (CODns, SAI) and Mediterranean hake (HAK). Note that the comparison of *r'* is relatively consistent with the comparison of *r* based on McAllister *et al.* (2001) calculations (see above). In both cases, the productivity of BFTE seems to be rather close to that of the North Atlantic swordfish.

When compared across a range of marine fish species, the BFTW productivity (according to *r'*) thus displays a rather low productivity while BFTE productivity is, in a comparative perspective, at a medium level. This difference between the two stocks is obviously due to strong difference in age-at-maturity, i.e. 4 years (BFTE) against 8 years (BFTW). The comparison of the age-at-maturity of the same 25 exploited species gives a similar picture **(Figure 2)**. BFTW displays an age-at-maturity close to this of the slow growing species while BFTE age-at-maturity is in between, similar as this is hake, albacore, bigeye tuna, Norwegian-spring herring and North Sea cod.

4. Growth

Comparing individual growth estimated through the von Bertalanffy function could be also of interest, as individual growth may be seen as an indicator of the population productivity. As, the estimations of the 3 parameters of the von Bertalanffy equation are usually strongly correlated, it is difficult to compare one given parameter, such as K, across species. Therefore, we directly compared the individual growth curves of a sub-sample of the above list, both in absolute and relative values **(Figure 3)**.

We directly compared the growth curves on relative scales, i.e., Age divided by the maximum age of the given species and the length-at-age divided by the maximum length of the given species (i.e. $L\infty$ from the von

Bertallanffy equations), because it would have been difficult to compare them on absolute scales. On a relative scale, all the growth curves are roughly similar and this of BFT is in between **(Figure 3)**. This point may actually reflect an universal law according to the bio-energetic and physiological constraints of any living animal (Kooijman 2000). Taking maximum size and age into account is indeed important, as the fecundity is proportional to the weight and there are considerable differences among species. At its maximum age, an anchovy is about 0.03kg and can emit about 200,000 eggs while a BFT of 180 kg and 400 kg (still common in the current catch) can emit 20 and 45 millions eggs, respectively (Rodriguez-Roda 1967). In other words, the comparison of individual growth curves is difficult to interpret without referring to other key biological parameters, such as sex ratio, fecundity and lifespan.

5**. Conclusion**

According the CITES criteria about the productivity of commercially exploited aquatic species (see Introduction), BFTW may be seen in the higher range of the species displaying a low productivity while BFTE displays a medium productivity. For conservative purposes, the threshold of 15%, which corresponds to the highest range for low productivity species and to the lowest range for medium productivity, may be thus seen as the most appropriate benchmark against which to compare the extent of historical decline.

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Table 1. Comparative table of F_{50} (fecundity at L_{50}), A_{50} and *r'* of 25 Atlantic fish species.

Order	Species	Stock	Acronyms	F50 (nb eggs)	A50	Lmax	r'
Beryciform	*Hoplostethus atlanticus*	Atlantic Orange roughy	ORAN	42695	27.50	NA	0.1684
Clupeiform	*Clupea harengus*	Norwegian-spring spawning Herring	HERnss	30077	4.00	40	1.1196
Clupeiform	*Clupea harengus*	Baltic Herring	HERbal	30077	1.80	40	2.4879
Clupeiform	*Engraulis encrasicolus*	Iberian Anchovy	ANCH	94190	1.00	20	4.9740
Clupeiform	*Sardina pilchardus*	Mediterranean Sardine	SARD	156525	1.00	25	5.1946
Gadiform	*Gadus morhua*	Barent Sea cod	CODbs	3660000	7.10	135	0.9244
Gadiform	*Gadus morhua*	Icelandic Cod	CODis	2418000	6.00	135	1.0639
Gadiform	*Gadus morhua*	North Sea Cod	Codns	1642000	3.80	135	1.6356
Gadiform	*Melanogrammus aeglefinus*	North Sea Haddock	HADD	148216	2.52	100	2.0542
Gadiform	*Merlangius merlangus*	Whiting	WHIT	107700	1.50	45	3.3548
Gadiform	*Merlucius merlucius*	Mediterranean hake	HAK	253500	4.10	100	1.3180
Gadiform	*Pollachius virens*	North Sea Saithe	SAI	1405952	4.70	130	1.3081
Perciform	*kKatsuwonus pelamis*	Atlantic Skipjack	SKJ	256932	1.50	75	3.6065
Perciform	*Scomber scombrus*	Northeast Atlantic Mackerel	MACK	104300	2.00	50	2.5091
Perciform	*Thunnus alalunga*	North Atlantic Albacore	ALB	2462113	4.50	120	1.4203
Perciform	*Thunnus albacares*	Atlantic Yellowfin	YFT	2462113	2.80	170	2.2826
Perciform	*Thunnus obesus*	Atlantic Bigeye	BET	4274343	3.50	180	1.8945
Perciform	*Thunnus thynnus*	Western Bluefin	BFTW	5000000	8.00	295	0.8374
Perciform	*Thunnus thynnus*	Eastern Bluefin	BFTE	1439404	4.00	295	1.5395
Perciform	*Xiphias gladius*	North Atlantic swordfish	SWO	1847101	5.00	290	1.2533
Pleuronectiform	*Pleuronectes americanus*	Georges Bank winterfounder	WFLO	191650	2.00	60	2.6413
Pleuronectiform	*Pleuronectes platessa*	English channel Plaice	PLAI	50559	2.90	100	1.6210
Pleuronectiform	*Reinhardtius hyppoglossoides*	Greenland halibut	HAL	28075	6.80	100	0.6542
Pleuronectiform	*Solea solea*	English channel Sole	SOLE	163994	2.35	70	2.2191
Scorpaeniform	*Sebastes mentella*	Arctic Sebaste	SEB	5391	11.00	NA	0.3392

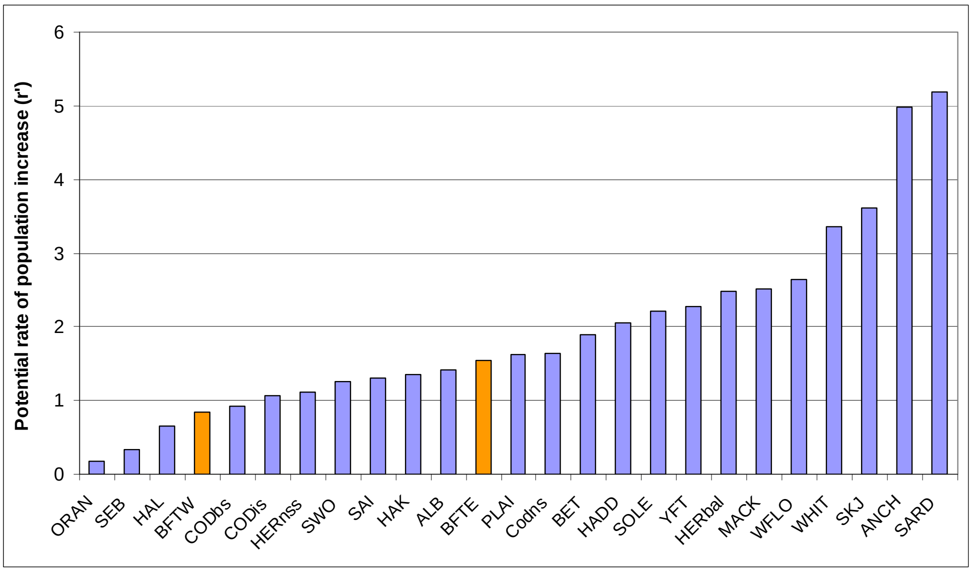

Figure 1. Histogram of the potential rate of population increase (r') in ascending order.

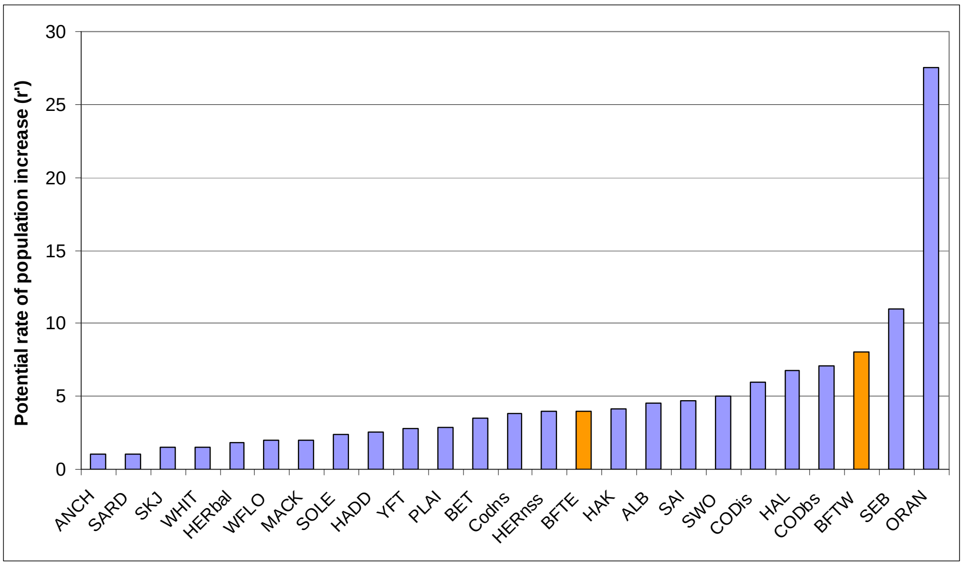

Figure 2. Histogram of the age-at-maturity (A_{50}) of the same set of species in ascending order.

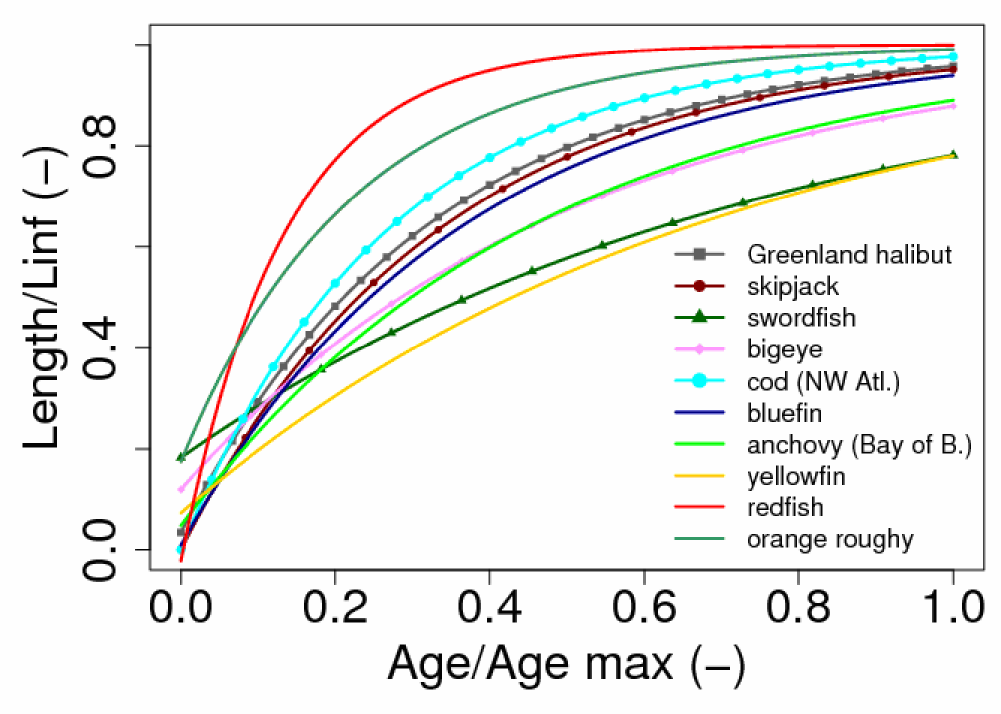

Figure 3. Relative growth curves of 10 species displaying contrasting life history.