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ANALYSIS OF LENGTH DATA FOR SMALL TUNA

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SUMMARY

*This document presents an analysis of length frequency samples for Atlantic bonito (*Sarda sarda*). Two methods were used, Powell-Wetherall plots to estimate Z and catch curve analysis and age slicing to evaluate vulnerability-at-age.*

RÉSUMÉ

*Le présent document fait état d'une analyse d'échantillons de fréquence des tailles de la bonite à dos rayé (*Sarda sarda*). Deux méthodes ont été appliquées, à savoir des diagrammes de Powell Weatherall afin d'estimer Z et une analyse de la courbe de capture et de découpage des âges pour évaluer la vulnérabilité par âge.*

RESUMEN

*Este documento presenta un análisis de muestras de frecuencias de talla para el bonito del Atlántico (*Sarda sarda*). Se utilizaron dos métodos, gráficos de Powell-Wetherall para estimar Z y análisis de curva de captura y métodos de separación de edades para evaluar la vulnerabilidad por edad.*

KEYWORDS

Length data, small tuna

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Introduction

This document presents an analysis of length frequency samples for Atlantic bonito (*Sarda sarda*). Two methods were used, Powell-Wetherall plots to estimate Z and catch curve analysis and age slicing to evaluate vulnerability-at-age (i.e. selection pattern).

Material and Methods

Data

An example dataset, teleost, is provided as part of the package; this includes values for the Von Bertalanffy (1957) growth equation parameters k the rate at which the rate of growth in length declines and the asymptotic length L_∞, L_{50} the length at which 50% of individuals attain gonadal maturity for the first time and b the exponent of the length weight relationship.

The values and the relationship between them are plotted in **Figure 1**. The data are then summarised using principle components analysis (PCA) in **Figure 2**; the ellipses are the 95% normal probability densities, blue points are scrombidae and the black point is albacore. The first principal axis maximizes the variance, as reflected by its eigenvalue. The second component is orthogonal to the first and maximizes the remaining variance. The first two component account for over 70% of the variance and therefore yield a good approximation of the original variables. They therefore correspond to the interesting dynamics and lower ones to noise. The main features of the data as given by the first component are a contrast between large fish (L_∞), which mature at larger relative size ($L_{50} : L_\infty$) and small fish that mature at relatively small sizes. The second component contrasts thin streamlined species with more sedentary types (i.e. b the exponent of the length weight relationship).

Examples

The examples here are provided to illustrate the use of the package. The code full documentation can be found in the package documentation.

Equilibrium Dynamics

The first example simulates the equilibrium, i.e. the expected, dynamics for a population based on albacore and a fishery that selects mature fish. The equilibrium dynamics were derived by combining spawner per recruit and stock recruitment relationship.

The assumed stock recruitment relationship has a big impact of the dynamics, although there is seldom sufficient information in fish stock data sets to determine either the function form or the parameters of the relationship. Five alternative forms, all with steepness of 0.75 and virgin biomass of 1000, are plotted in **Figure 3**.

Maximum sustainable Yield

Reference points such as MSY and B_{MSY} are found at found at the maxima of the production curves i.e. plots of the equilibrium yield against spawning stock biomass (SSB). These are shown in **Figure 4**

Population Growth Rate

The population growth rate at small population size (*r*) is equivalent to level of exploitation that would drive a population to extinction. Since a population cannot replenish itself if the harvest rate is greater than r. In fisheries terminology r corresponds to a limit harvest rate reference point and can be calculated from the Leslis Matrix (Leslie, 1945).

Global MSY

The maximum potential yield of a cohort is taken at a size (or age) where the gains due to growth are equal to the losses due to natural mortality. Although seldom possible to achieve in practice, calculating the length at which this would occurs (L_{opt}) provide a reference point for growth overfishing.

Density Dependence

To evaluate sustainability requires determining the productivity of a population and its response to perturbation. The stability of a population is strongly influenced by its life history characteristics and the form of density dependence.

Production functions, were therefore calculated for density dependence natural mortality and fecundity and contrasted with the usual assumption made in stock assessment that density dependence only acts in recruitment **Figure 6**. Assuming density dependence in M or fecundity results in an increase in MSY, B_{MSY} and F_{MSY}

Next the response of a population to overfishing is evaluated in **Figure 7** and for rebuilding in **Figure 8**, for density dependence in stock recruitment, natural mortality and fecundity. The response to overfishing is similar across processes, however, rebuilding trajectories depend on the form of density dependence. Predicting recovery trajectories based on time series obtained from a period of increasing exploitation is likely to be problematic.

Stochasticity

Stochasticity has important impacts on population dynamics and can be of various forms, e.g. depending on whether it varies due to annual changes in the environment or by cohort where conditions at an earlier age have an effect on later age classes. Examples of stochastic age effects are shown in **Figure 9** and cohort effects in **Figure 10**.

Next populations were simulated for three levels of fishing mortality (0, 1 and 3 times F_{MSY}) and two selection patterns (corresponding to juvenile or mature age classes) for cohort effects in M and fecundity and autocorrelation in recruitment. The time series of SSB are shown in **Figure 11**. The spectral analysis performed for these time series **Figure 12** shows that all-time series are dominated by low frequencies (i.e. long-term variations) that result from cohort resonant effects, i.e. the propagation of stochastic recruitment into the age-classes and that led to a smoothing of the SSB (see Bjoernstad *et al*., 2004).

Model misspecification

One of the main uncertainties in stock assessment is the difference between models and reality. Therefore we include a model misspecification example, where in the simulated population natural mortality is a random variable, but is assumed to be constant at age in the virtual population analysis used to estimate numbers-at-age **Figure 13**. The effect is to assume that recruitment is more variable than it actually is.

Management Strategy Evaluation

FLife can be used to conduct Management Strategy Evaluation where a simulation model, i.e. operating model, is used to test for example a Harvest Control Rule (HCR). An empirical HCR has been adopted for southern bluefin tuna (SBT) to set Total Allowable Catches (TACs). The HCR is based on year-to-year changes in indices of relative stock abundance. Before the HCR was implemented the HCR parameters had to be tuned to meet management objectives using management strategy evaluation (MSE). **Figure 14** shows an example MSE using an empirical HCR and an Operating Model generated using Flife.

Empirical Methods

Beverton and Holt (1956) developed a method to estimate life history and population parameters length data. Based on which Powell (1979) developed a method, extended by Wetherall *et al*. (1987), to estimate growth and mortality parameters. This assumes that the right hand tail of a length frequency distribution was determined by the asymptotic length L_∞ and the ratio between Z and the growth rate k. Plotting $\overline{L} - L'$ against L' provides an estimate of L_∞ and Z/k, since $L_\infty = -a/b$ and $Z/k = \frac{-1-b}{b}$.

If k is known then it also provides an estimate of Z (**Figure 15**).

Discussion

FLife has many potential uses e.g. for conducting Ecological Risk Assessments, estimating life history parameters from data, development of priors for use in stock assessment, building simulation model based on population and ecological processes and generating Operating Models for use in Management Strategy Evaluation.

The form of density dependence can affect overfishing and rebuilding trajectories. It is, however, difficult to determine whether density dependence is occurring and on what processes it acts using fisheries dataset (Sinclair *et al*., 2002). The main form of density dependence considered in stock assessment models, is the stock recruitment relationship, primarily as it is required to complete the life cycle. Other forms of density dependence may operate and it is necessary to use caution in selecting the type of density dependence, and specifying its parameters (Ginzburg *et al*., 1990).

Trends and fluctuations in populations are determined by complex interactions between extrinsic and intrinsic dynamics. While the dynamics of many marine fish are characterised by age-structured dynamics forced by stochastic recruitment i.e Cohort resonance. The resulting low-frequency fluctuations can potentially mimic or cloak critical variation in abundance linked to environmental change or overexploitation (Bjoernstad *et al*., 2004).

The tools available in FLife can help to develop robust management control rules by building OMs that can be used to evaluate the robustness to uncertainty about ecological processes.

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Table 1. Life history parameters.

	Atlantic	Species	code	lmax	linf	t0	k	l50	l50linf
1	North	Acanthocybium solandri	WAH	200.22	170.10	-1.63	0.38	92.50	0.54
2	North	Auxis rochei	BLT	66.00	45.26	-1.60	0.39	34.40	0.76
3	North	Auxis thazard	FRI	65.00	51.47	-0.83	0.32	34.70	0.67
4	North	Euthynnus alleteratus	LTA	106.68	115.00	-1.71	0.19	43.80	0.38
5	North	Sarda sarda	BOM	97.00	80.60	-1.37	0.36	38.50	0.48
6	North	Scomberomorus cavalla	KGM	158.00	147.40	-0.10	0.12	87.50	0.59
7	North	Scomberomorus maculatus	SSM	80.20	76.00	-2.44	0.18	35.80	0.47
8	North	Scomberomorus regalis	CER	93.98	96.77	-0.10	0.26	38.60	0.40
9	North	Thunnus atlanticus	BLF	104.14	71.40	-0.22	0.70	39.00	0.55
10	South	Acanthocybium solandri	WAH	197.00	170.10	-1.63	0.38	110.00	0.65
11	South	Auxis rochei	BLT	66.00	45.26	-1.60	0.39	34.40	0.76
12	South	Auxis thazard	FRI	65.00	51.47	-0.83	0.32	34.70	0.67
13	South	Euthynnus alleteratus	LTA	100.00	115.00	-1.71	0.19	35.00	0.30
14	South	Sarda sarda	BOM	77.00	74.61	-2.74	0.22	38.00	0.51
15	South	Scomberomorus brasiliensis	BRS	80.00	109.18	-0.41	0.11	42.00	0.38
16	South	Scomberomorus cavalla	KGM	114.80	132.70	-0.10	0.16	70.00	0.53
17	South	Scomberomorus regalis	CER	93.98	96.77	-0.10	0.26	38.60	0.40
18	South	Thunnus atlanticus	BLF	90.00	91.00	-0.22	0.62	51.00	0.56

Table 2. Length based reference points L_{50}, L_{opt} and L_∞

	Species	code	linf	l50	lopt
1	Acanthocybium solandri	WAH	170.10	92.50	160.73
2	Auxis rochei	BLT	45.26	34.40	41.81
3	Auxis thazard	FRI	51.47	34.70	45.68
4	Euthynnus alleteratus	LTA	115.00	43.80	104.72
5	Sarda sarda	BOM	80.60	38.50	74.92
6	Scomberomorus cavalla	KGM	147.40	87.50	138.18
7	Scomberomorus maculatus	SSM	76.00	35.80	70.35
8	Scomberomorus regalis	CER	96.77	38.60	87.69
9	Thunnus atlanticus	BLF	71.40	39.00	67.68
10	Acanthocybium solandri	WAH	170.10	110.00	160.73
11	Auxis rochei	BLT	45.26	34.40	41.81
12	Auxis thazard	FRI	51.47	34.70	45.68
13	Euthynnus alleteratus	LTA	115.00	35.00	104.72
14	Sarda sarda	BOM	74.61	38.00	68.97
15	Scomberomorus brasiliensis	BRS	109.18	42.00	102.51
16	Scomberomorus cavalla	KGM	132.70	70.00	118.80
17	Scomberomorus regalis	CER	96.77	38.60	87.69
18	Thunnus atlanticus	BLF	91.00	51.00	78.64

Table 3. Estimates of L_∞ and Z/k from Powell-Wetherall plots.

	Atlantic	code	zk	linf
1	North	BLF	11.09	229.38
2	North	BLT	2.83	57.52
3	North	BRS	1.28	160.58
4	North	FRI	-15.53	-88.08
5	North	KGM	1.15	158.48
6	North	LTA	17.13	277.62
7	North	WAH	0.79	166.80
8	South	BLF	3.02	109.06
9	South	BLT	0.56	38.88
10	South	FRI	1.27	50.23
11	South	LTA	1.76	66.01
12	South	WAH	0.33	152.85

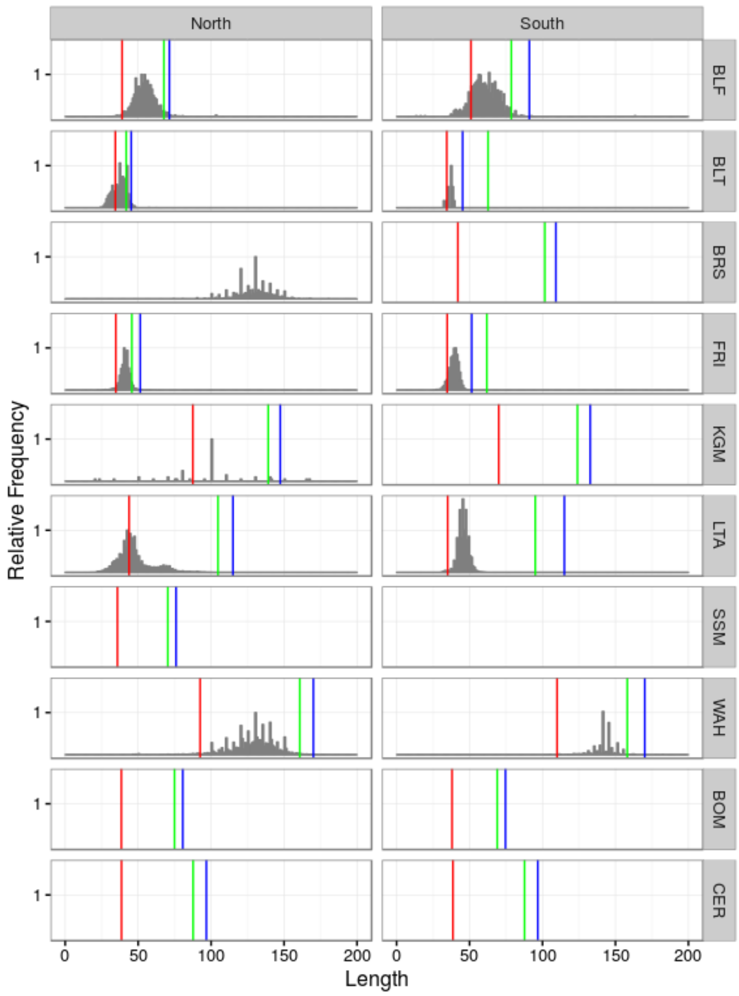

Figure 1. Length frequencies by species and area, L_{50}, (red), L_{opt} (green) and L_∞ (blue).

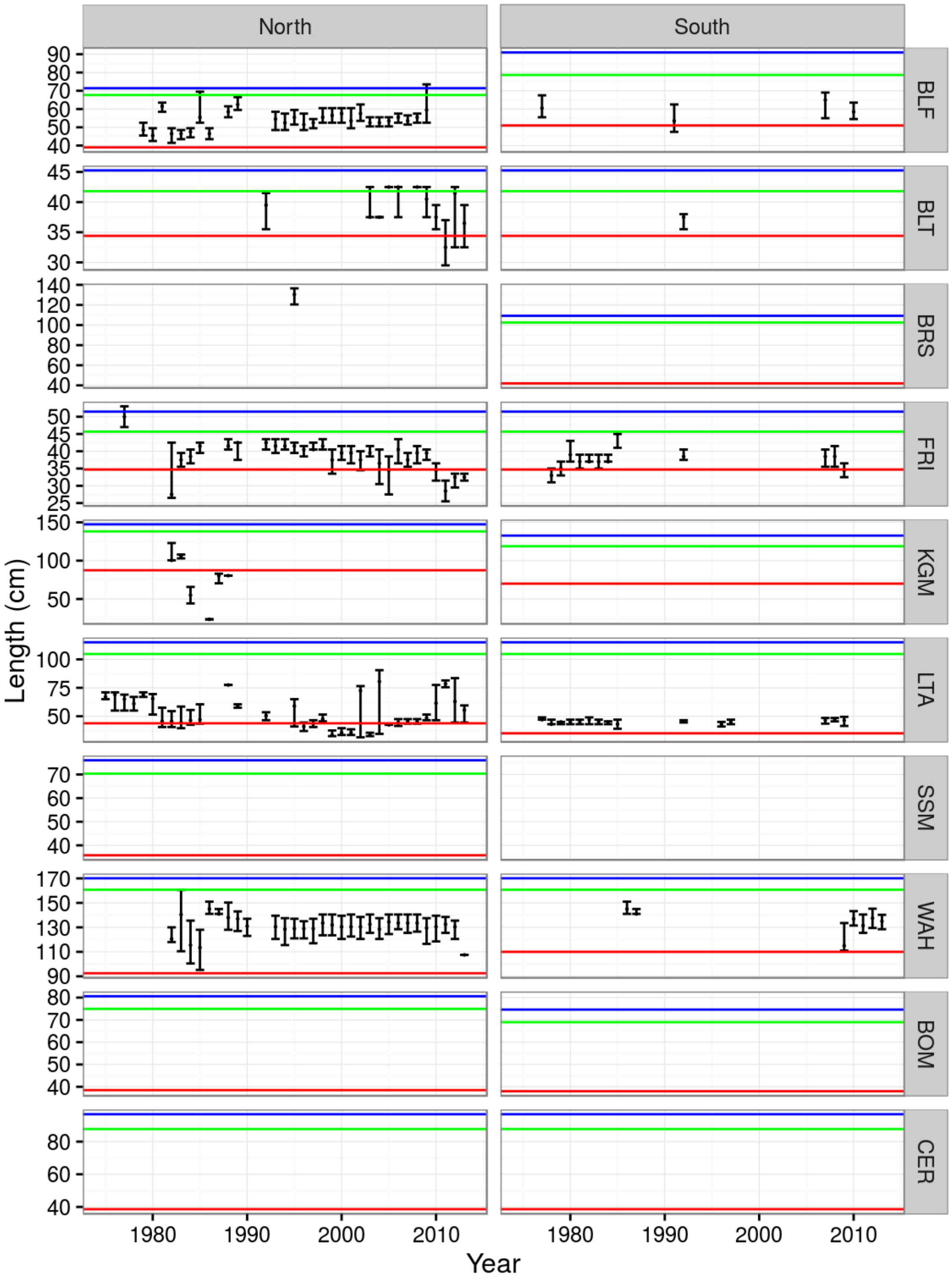

Figure 2. Time series by species and area, bars show the interquartile range, reference lines are L_{50}, (red), L_{opt} (green) and L_{∞} (blue).

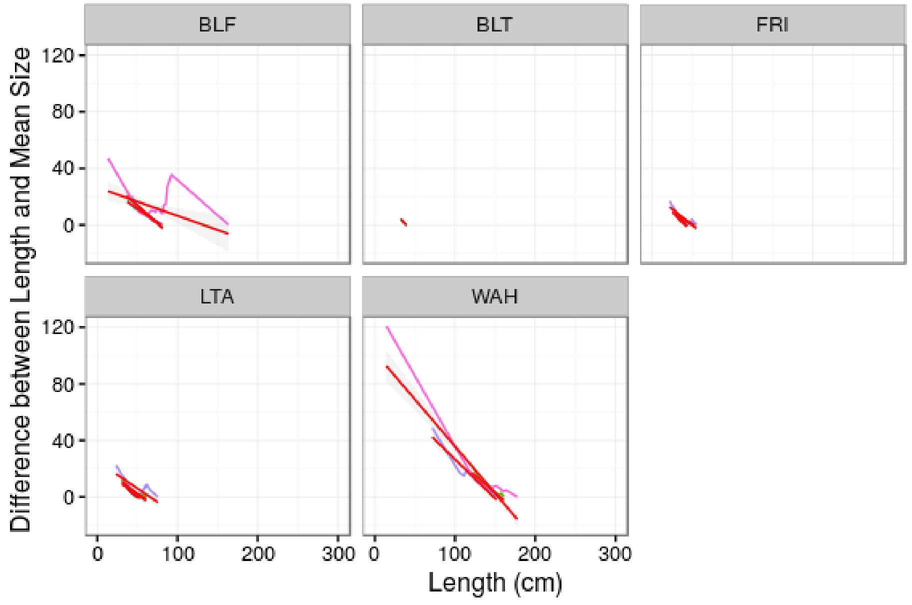

Figure 3a. Powell-Whetherall plots for South Atlantic.

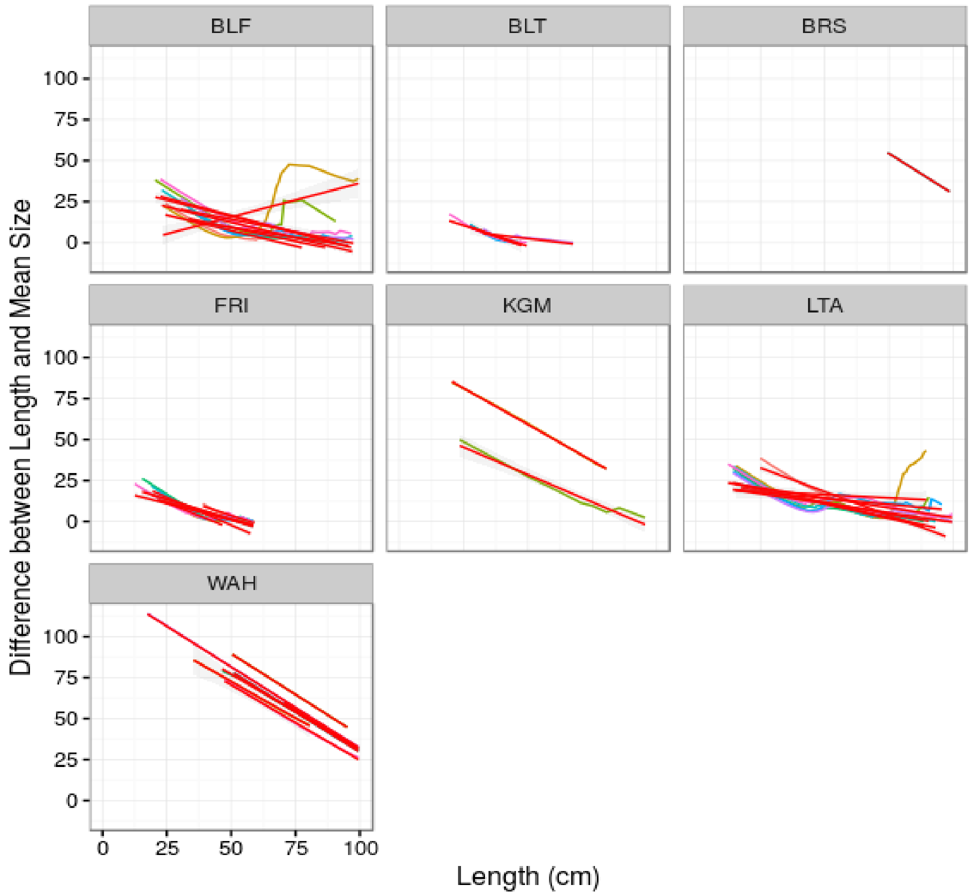

Figure 3b. Powell-Whetherall plots for North Atlantic.