

# Evaluating Mortality Using Length-Frequency Data when Growth Parameters are Poorly Known

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## Abstract

A method is presented through which the total mortality undergone by several fish stocks of the same species can be compared when growth parameters are poorly known or unknown. Whereas the estimate of  $Z$  obtained via the length-converted catch curve is highly sensitive to the input parameters  $K$  and  $L_{\infty}$ , the ratio of  $Z$  estimates obtained for different stocks with the same combination of parameters is almost independent of these inputs, at least when the fit of the linear regression is good. The method is tested on simulated data and an application is presented using real data from the Lesser Antilles. It provides the possibility of qualitatively comparing several stocks in situations of scarce biological knowledge.

## Introduction

For decades, assessing tropical fish stocks has been hindered by the difficulty of obtaining reliable estimates of growth parameters. The development of length-frequency analysis (Pauly and Morgan 1987) and the discovery of otolith microstructures (Pannella 1971) represent substantive progress. In spite of these, however, growth parameters are often lacking and still remain a limiting factor for the analysis of mortality using length-frequency data. This is due to the large number of species and the technical skills and financial resources that are necessary for growth studies. In the Caribbean area, for example, more than half of the 300 fish species described by Randall (1983) are caught occasionally and at least 20 species are commonly caught (Munro 1983; Gobert 1992), but only a small number have been the object of growth studies (Claro and Garcia-Arteaga 1994). Moreover, growth parameters obtained in a given location cannot be used without great cau-

tion in other parts of such a wide and diverse region.

Although collecting length-frequency data is within the capabilities of most tropical countries, full use of this information is not always possible due to lack of growth parameters obtained independently. This paper presents a property of the length-converted catch curve (Pauly 1980; Sparre and Venema 1992) which allows estimation of the ratio of total mortality coefficients of two stocks of the same species whose growth parameters are unknown. This property is first shown using simulated data, and then applied to real data collected in the Lesser Antilles.

## Methods

Catch length-frequency distributions were simulated for a population of given growth parameters ( $K$ ,  $L_{\infty}$  and  $t_0$ ) under different fishing mortalities  $F_1$ ,  $F_2$ , etc., corresponding to total mortalities  $Z_1$ ,  $Z_2$ , etc. These distributions were then analyzed using the length-converted catch curve with a set of combinations of arbitrary

growth parameters  $K'(i)$  and  $L_{\infty}'(j)$ ; for each combination  $(i,j)$ , the estimates  $Z'_1(i,j)$ ,  $Z'_2(i,j)$ , etc., estimated the true values  $Z_1$ ,  $Z_2$ , etc., and the ratios  $R_{12}(i,j) = Z_1(i,j)/Z_2(i,j)$ , etc., estimated the true ratios  $R_{12} = Z_1/Z_2$ , etc. The properties of these sets of ratios were studied, and their averages were compared with the true ratio values computed from the input values used in the simulation program.

## Simulation of length-frequency distributions

The program GENEDIS (Boer 1988; Chevallier 1990) simulates the dynamics of a population made of yearly cohorts given input parameters describing growth, natural and fishing mortality, gear selectivity and cohort size at recruitment. The individual growth variability is taken into account by applying a discrete probability density function of  $K$ ,  $L_{\infty}$  and  $t_0$  to the whole cohort, which is thus split into subcohorts of different initial size and following different growth functions. The coefficients of variation of  $K$  and  $L_{\infty}$  were always

given the same value, referred to in the text as  $CV(K \text{ and } L_{\infty})$ . The variability of  $t_0$  was the same in all simulations.

In a first set of simulations, the input growth parameters were kept constant in all the populations and independent of the fishing mortality applied to the stock (Table 1).

A second set of simulations was designed to study the impact of using the same growth parameters for the catch curve analysis of stocks whose real growth function is different owing to density-dependent growth regulation. In the simulations, the growth parameters  $L_{\infty}$  and  $K$  were allowed to vary as the fishing mortality increased, letting  $K$  increase and  $L_{\infty}$  decrease in such a way that the growth performance index  $\phi' = \ln(K) + 2 \ln(L_{\infty})$  (Munro and Pauly 1983) would remain constant. A smaller number of simulations was made, keeping only part of the values of the first set (Table 2).

#### *Estimation of Z by the length-converted catch curve on simulated data*

Length-converted catch curve (Pauly 1980; Sparre and Venema 1992) was applied to the simulated data using the FAO-ICLARM FiSAT software (Gayanilo et al. 1994). In all cases the input value of  $t_0$  was set equal to 0, and the cumulated catch of the year was used. In the first set of simulations  $K'(i)$  ranged from 0.1 to 0.7 by steps of 0.1 and  $L_{\infty}'(j)$  ranged from 36 to 44 by steps of 1 (63 simulations). In the second set  $K'(i)$  ranged from 0.1 to 0.5 by steps of 0.1 and  $L_{\infty}'(j)$  ranged from 36 to 40 by steps of 1 (25 simulations). When possible, the default set of points proposed in FiSAT for the linear regression

Table 1. Input parameters for the first set of simulations.

Constant parameters				
Growth	$K=0.4$	$L_{\infty}=40$	$t_0=-0.01$	$\sigma(t_0)=0.05$
Natural mortality	$M=0.8$			
Selectivity	$L_{50}=20$	$(L_{75}-L_{25})/L_{50}=0.05$		
Number of subcohorts	8 000			
Variable parameters				
Fishing mortality	$F \in \{0.1, 0.2, 0.3, 0.4, 0.5\}$			
Growth variability	$CV(K, L_{\infty}) \in \{0.001, 0.005, 0.01, 0.05, 0.1\}$			

Table 2. Variable input parameters for the second set of simulations.

Variable parameters			
Fishing mortality	$F=0.1$	$F=0.3$	$F=0.5$
Growth parameters	$K=0.4$	$K=0.45$	$K=0.5$
	$L_{\infty}=40$	$L_{\infty}=37.7$	$L_{\infty}=35.77$
Growth variability	$CV(K, L_{\infty}) \in \{0.001, 0.01, 0.1\}$		

was kept, but in many instances it was necessary to select more appropriate points on the descending arm of the catch curve.

#### **Application to Real Data**

In a third set of simulations, real data were processed using the same method. As part of a comparative fishery research project, fishery-independent surveys were conducted on the shelf of three islands of the Lesser Antilles (Martinique, Dominica and Guadeloupe) with standardized unbaited traps. Fishing took place on the East and West shelves of Dominica and of Guadeloupe, and on the East shelf of Martinique; these five areas were coded DE, DW, GE, GW and MA. The method was applied to all species with samples containing more than 100 fish in each of at least two areas; this excluded the area DW, where no sample reached this size. For each sample, 5 to 11 values of  $L_{\infty}$  were chosen within a range containing the maximum recorded length, and  $K$  was allowed to vary between 0.1 and 0.5 by steps of 0.1.

## **Results**

### *Simulations without Density-dependent Growth*

When the real values of  $K$  and  $L_{\infty}$  are used as input to the catch curve,  $Z$  is estimated without bias for low to moderate growth variability. When the CV of the growth parameters exceeds 0.05, the estimate of  $Z$  is negatively biased, and even more so as  $F$  increases (-13% bias for  $F=0.5$  and  $CV(K, L_{\infty})=0.1$ ) (Table 3).

When combinations of arbitrary values of growth parameters are used, the estimates of  $Z$  are highly variable (Table 4), ranging roughly between 0.2 and 3 whereas the true values lie between 0.9 and 1.3. In the absence of previous growth studies, any arbitrary set of values for the growth parameters is therefore likely to lead to a severely biased estimate of  $Z$ .

The individual estimates of  $Z$  are thus highly sensitive to the choice of input growth parameters for the catch curve. However, this is not the case for the ratios of estimated  $Z$  among populations gen-

erated with different mortalities but the same growth parameters. For all combinations of  $F$  and  $CV(K, L_{\infty})$ , the real value is satisfactorily estimated by the mean value of the 63 ratios, with a negative bias most often lower than 5%. This bias is positively related to the true value of the ratio and to the individual growth variability; when  $CV(K, L_{\infty})$  is lower than .01, the bias does not reach 2%, but it can exceed 5% for high values of  $CV(K, L_{\infty})$  and the highest values of the true ratio (Fig. 1). The absence of significant bias in the estimation of the ratios is not subject to the arbitrary choice of growth parameter combinations as the variability of the estimates is very low; the CV computed from the 63 ratios is always lower than 5%, and less than 2% in about half of the cases (Fig. 2).

### Simulations with Density-dependent Growth

Although the changes in the growth function were not negligible ( $K$  ranged from 0.4 to 0.5, and  $L_{\infty}$  from 40 to 35.8), the performance of the method was only moderately affected in most cases (Table 5).

These results suggest that the estimation of a ratio of total mortality coefficients is still possible in quite good conditions when growth patterns are different among stocks; the estimates are often more biased than when growth is constant, but most values of the bias remain lower than  $\pm 5\%$ . The few higher values actually reflect cases of poor fits of the linear regression in the catch curve method. In the same way, the variability of the ratios, as measured by their CV, has increased but remains quite low. In this

Table 3. Estimates of  $Z$  using real growth parameters.

True value	Total mortality coefficient ( $Z$ )				
	0.90	1.00	1.10	1.20	1.30
CV( $K, L_{\infty}$ )=0.001	0.90	1.00	1.10	1.20	1.30
CV( $K, L_{\infty}$ )=0.005	0.90	1.00	1.10	1.20	1.30
CV( $K, L_{\infty}$ )=0.01	0.90	1.00	1.10	1.20	1.30
CV( $K, L_{\infty}$ )=0.05	0.90	0.98	1.07	1.14	1.23
CV( $K, L_{\infty}$ )=0.1	0.86	0.94	1.00	1.07	1.13

Table 4. Summary of estimates of  $Z$  using arbitrary growth parameters.

Growth variability	True value of $Z$	Minimum of $Z'$	Maximum of $Z'$	CV of $Z'$ (%)
CV( $K, L_{\infty}$ )=0.001	0.9 - 1.3	0.17 - 0.22	2.03 - 3.13	53.8 - 56.8
CV( $K, L_{\infty}$ )=0.005	0.9 - 1.3	0.17 - 0.22	1.98 - 3.09	54.5 - 56.7
CV( $K, L_{\infty}$ )=0.01	0.9 - 1.3	0.18 - 0.24	2.04 - 3.00	53.9 - 54.8
CV( $K, L_{\infty}$ )=0.05	0.9 - 1.3	0.18 - 0.24	2.29 - 3.10	55.4 - 55.7
CV( $K, L_{\infty}$ )=0.1	0.9 - 1.3	0.18 - 0.23	1.95 - 2.58	53.0 - 53.3

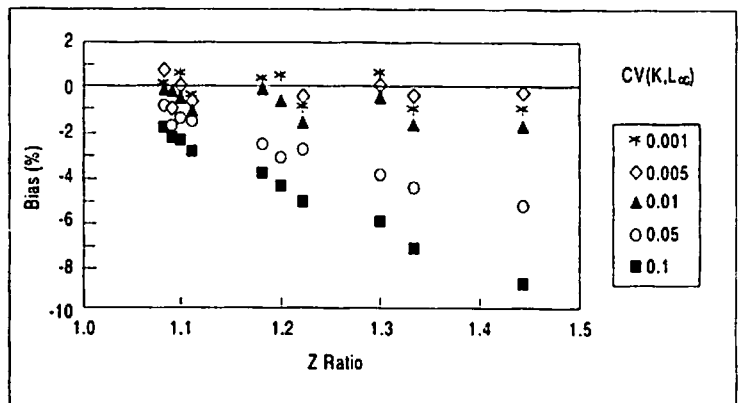


Fig. 1. Relative bias of the estimate of the  $Z$  ratio.

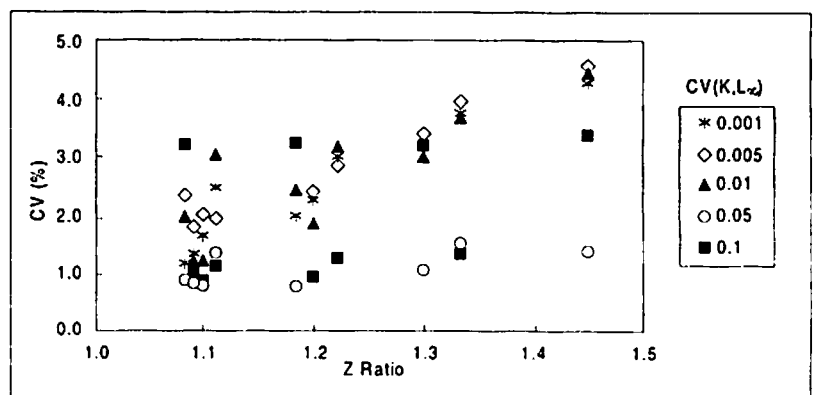


Fig. 2. Coefficients of variation of the estimate of the  $Z$  ratio.

case, at least, it appears that the method is somewhat robust to growth regulation of this magnitude.

### Application to Real Data

In each area, 59 to 111 fish species were caught in the survey, but

**Table 5. Effect of fixed and density-dependent growth on estimation of the Z ratio.**

Growth variability	True value of Z	Bias (%)	Fixed growth		Density-dependent growth	
			Coefficient of variation (%)	Bias (%)	Coefficient of variation (%)	Bias (%)
CV(K, L <sub>-</sub> ) = 0.001	1.22	-0.9	2.9	-0.7	3.5	
	1.44	-1.2	4.2	3.9	2.2	
	1.18	0.1	2.0	4.7	4.8	
CV(K, L <sub>-</sub> ) = 0.01	1.22	-1.7	3.1	1.9	6.4	
	1.44	-1.8	4.3	8.3	5.5	
	1.18	-2.0	2.4	13.0	3.2	
CV(K, L <sub>-</sub> ) = 0.1	1.22	-5.2	1.2	-5.4	2.6	
	1.44	-8.9	3.3	-2.7	7.1	
	1.18	-3.9	3.2	2.9	6.4	

only 16 met the criterion defined (i.e., more than 100 fish caught each in at least two areas to be retained for the analysis). Out of these 16 species, 6 were mentioned in the review of growth studies by Claro and Garcia-Arteaga (1994) and were analyzed via the catch curve method using the given growth parameters. The remaining 10 were analyzed using the method presented here, using a variable number of combinations of growth parameters. The length-frequency data of some species had to be smoothed to allow an acceptable fit by the linear regression.

The distribution of CV of the estimates clearly shows the difference between Z and Z ratios among areas (Fig. 3). Whereas the estimates of Z were always very variable, more than half of the estimates of Z ratios had a low variance (CV ≤ 0.1) (Table 6). For some species, the Z ratio estimates were very variable in all cases (the two *Haemulon* species, for example). This was usually due to a poor fit of the linear regression to the transformed catch curve data, or to the impossibility of an objective selection of points to be kept for the regression.

The comparative analysis of the areas was based on the Z ratios computed for the 6 species for which growth parameters were

available, and for the remaining species on those whose CV was equal or lower than 0.1 (this covered six more species).

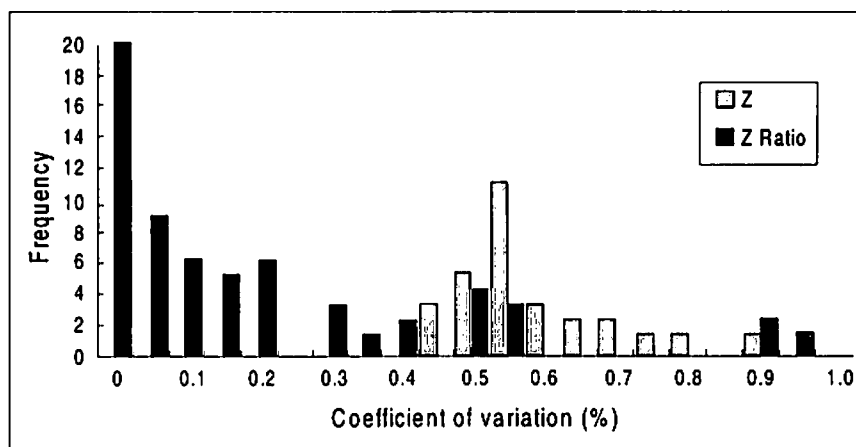
The synthesis of all ratios (Table 7) shows that total mortality in area DE is always lower than anywhere else, in MA it is higher in about 3 out of 4 cases,

and in GE and GW the frequency is intermediate. This leads to the possibility of ranking the areas as follows: DE < GW < GE < MA. This order is consistent with other findings such as average sizes, catch per unit and fishing effort per unit, which were analyzed in this study, and confirms the effect of exploi-

**Table 6. Distribution of the estimates of Z and Z ratios by species.**

Species	Number of combinations	Number of estimates of Z		Number of estimates of Z ratios	
		CV ≤ 0.1	CV > 0.1	CV ≤ 0.1	CV > 0.1
		<i>Holocentrus ascensionis</i>	72	0	4
<i>Holocentrus rufus</i>	55	0	3	6	0
<i>Haemulon flavolineatum</i> (*)	55	0	3	0	6
<i>Myripristis jacobus</i>	30	0	4	6	6
<i>Sparisoma aurorenatum</i>	35	0	4	12	0
<i>Haemulon chrysargyreum</i>	25	0	3	0	6
<i>Gymnothorax moringa</i>	35	0	2	2	0
<i>Lactophrys triqueter</i> (*)	55	0	2	0	2
<i>Dactylopterus volitans</i> (*)	55	0	2	0	2
<i>Rypticus saponaceus</i> (*)	25	0	2	2	0
Total		0	29	34	28

\*Use of frequencies.



**Fig. 3. Overall frequency distribution of estimates of Z and Z ratios.**

Table 7. Summary of comparisons of Z ratios among areas.

Area where Z is lower	Area where Z is greater			
	DE	GE	GW	MA
DE	-	3	3	4
GE	0	-	3	5
GW	0	7	-	5
MA	0	2	2	-
Number of positive comparisons	0	12	8	14
Total number of comparisons	10	20	20	18
% of positive comparisons	0.0	60.0	40.0	77.8

tation on the multispecies demersal resources of the Lesser Antilles.

## Discussion

The simulations presented here show that while the estimation of total mortality coefficients is highly sensitive to the input growth parameters in the length-converted catch curve, the ratio of these coefficients among stocks can be estimated with a fair degree of confidence, even when no more than rough orders of magnitude are available for the growth parameters  $K$  and  $L_{\infty}$ . The ratio method is based on a property of the length-converted catch curve, and thus is subject to all its assumptions (e.g., constancy of  $Z$  above the full selection age, steady-state conditions of the fishery, growth is deterministic without individual growth variability). Various authors have studied the impact of violations of these assumptions (Hampton and Majkowski 1987; Castro and Erzini 1988). In this study, it has been shown that variable individual growth increases the variability of the estimate of the ratio, but that in most cases the variability remains moderate (CV lower than 5%).

The  $Z$  ratio method also requires a new assumption, i.e., that the growth pattern is implicitly identical in the various populations submitted to the catch curve

analysis, since the same set of growth parameters is used to compute the  $Z$  ratio. If total mortality, and thus abundance, is different among stocks, this assumption is likely to be violated, as density-dependent growth has been demonstrated in many fish stocks. This is well documented in temperate species, both pelagic and demersal (Weatherly and Gill 1987; Daan et al. 1990) as well as some tropical pelagic species such as the Peruvian anchoveta (Bakun 1989). Evidence is less clear for tropical demersal species, as many factors interact in complex ways and results are difficult to interpret (Doherty 1982; Forrester 1990). In extensive aquaculture, Lorenzen (1995) could fit a density-dependent model to the observed growth of common carp. Thus, density-dependent growth is likely to be a common feature of fish stocks; the simulations shown here suggest that using the same input growth parameters for stocks whose actual growth patterns are different does not result in highly biased estimates of the ratios of mortality coefficients, at least for the range of growth variation examined. However, while the simulations used variations in  $K$  and  $L_{\infty}$  which were not negligible, comparing them to real density-induced growth variations is not possible for lack of knowledge of their magnitude.

The application to a real data from the Lesser Antilles did not

lead to more than mere qualitative ranking of the fish areas, because the comparison based on different species were not always consistent among two given areas. Thus the frequency of positive comparisons was used as a ranking criterion for areas. In most cases, the linear regression could be fitted fairly well to the catch curve, and this inconsistency is thought to be due to the small size of many samples. However, even with large samples, the ratios of total mortality coefficients would be difficult to interpret quantitatively in terms of stock assessment, since a given  $Z$  ratio could result from many combinations of two fishing mortality coefficients and one possibly two, natural mortality coefficients (which could be common, but could also take different values through density-dependent mechanisms). A possible quantitative application of these  $Z$  ratios could be the surplus modeling approach where total mortality coefficients are used instead of effort data (Csirke and Caddy 1983), modifying it for relative coefficients ( $Z$  ratios) rather than absolute values of  $Z$ . However this approach could not be tested on the data available here.

In situations where biological knowledge is available, this method is more useful as a tool to provide preliminary information on the status of several stocks relative to each other, rather than to contribute to a quantitative stock assessment process. As Pauly (1987) states, length-frequency data are probably the most underutilized type of information on fish and other aquatic resources. This method allows the use of length-frequency information that would not be used otherwise due to lack of detailed biological knowledge, and thus, can be very useful in

many real-world situations. The main reservation to the use of this method deals with the assumption of identical growth parameters between stocks. It should not be used when important differences in growth pattern are likely, for example, when the stocks compared are subject to different environmental conditions.

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