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# $NZ_{50}$ A NEW METRIC FOR MAXIMUM SIZE IN THE CATCH: AN EXAMPLE WITH BLUE MARLIN

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*SUMMARY*

*Diagnostics are important for evaluating the robustness of models used to estimate stock status and for understanding how uncertainties propagate through into advice. Diagnostics also make the stock assessment process more transparent and help to identify where more knowledge and better data are required. Here we adopt a generic strategy to conduct a preliminary stock assessment for North Atlantic albacore, based on five steps. The steps are to i) agree in advance hypotheses to test; ii) check for convergence; iii) identify violation of assumptions; iv) use simulation methods such as the jack knife or bootstrap to identify problems with the data and model specifications; and v) conduct hindcasting to evaluate prediction ability.*

*RÉSUMÉ*

*Des diagnostics sont importants pour évaluer la solidité des modèles utilisés pour estimer l'état des stocks et pour comprendre la façon dont les incertitudes se propagent dans l'avis. Les diagnostics rendent également le processus d'évaluation des stocks plus transparent et contribuent à identifier les domaines qui nécessitent plus de connaissances et de meilleures données. Une stratégie générique a été adoptée dans le présent cas pour réaliser une évaluation préliminaire du stock de germon de l'Atlantique Nord en suivant cinq étapes. Ces étapes étaient les suivantes : i) convenir à l'avance des hypothèses à tester ; ii) vérifier la convergence ; iii) identifier la non-application des hypothèses ; iv) utiliser des méthodes, telles que l'eustachage (« jack knife ») ou le bootstrap pour identifier les problèmes avec les données et les spécifications du modèle ; et v) réaliser des simulations rétrospectives pour évaluer la capacité prédictive.*

*RESUMEN*

*Los diagnósticos son importantes para evaluar la robustez de los modelos utilizados para estimar el estado del stock y para comprender el modo en que las incertidumbres se propagan a través del asesoramiento. Los diagnósticos también hacen que el proceso de evaluación de stock sea más transparente y contribuyen a identificar dónde se requieren más conocimientos y mejores datos. Aquí, se ha adoptado una estrategia genérica para realizar una evaluación preliminar del stock de atún blanco del Atlántico norte, basada en cinco pasos. Estos pasos son: i) acordar previamente la hipótesis que se tiene que probar, ii) comprobar la convergencia; iii) identificar los supuestos que no se cumplen; iv) utilizar métodos de simulación como jack knife o bootstrap para identificar problemas con los datos y especificaciones del modelo y v) realizar una simulación retrospectiva para evaluar la capacidad predictiva.*

*KEYWORDS*

*Biometrics, stock assessment, population structure, population dynamics, fishery management, biological reference points, blue marlin*

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## 1. Introduction

The size distribution of the catch is an important characteristic of a population considered in stock assessments. Fishing tends to progressively reduce the abundance of older, larger fish in the population which reduces their availability to fishermen. The mean and maximum sizes are readily understood indicators of population health by fishermen and managers alike. The mean is clearly defined and easily understood, but the properties of the maximum size in a set of observations make this variable a less suitable reference parameter to be included in the stock assessment process. This is because the value of the maximum varies with the number of observations in the sample. A new metric, $NZ_{50}$, is presented that is a useful measure of size distributions applicable to the quantification of variation in maximum size in the catch. The concept is applied to estimate $L_{NZ50,N}$, the smallest maximum size that would be expected in a set of observations based on the number of observations (*N*) and the size distribution of the sample of the catch from a hypothetical population of blue marlin (*Makaira nigricans*).

## 2. Methods

The likely maximum observed value in a sample of size observations depends on the joint probability for the number of observations and the cumulative frequency distribution (cdf) of sizes within the population from which the sample was drawn. Consequently, both variables must be involved in metrics to quantify maximum size. To characterize the effect of observation numbers, I proposed a new metric, $NZ_{50}$ (Goodyear 2015). $NZ_{50}$ is the least number of observations required of a random sample to include one or more individuals ≥ a specified size in 50% of such samples (the smallest number of observations which will include fish at least that big half the time). Monty Carlo methods are employed to estimate the cumulative distribution of sample maximum probability values as a function of the numbers of observations. Here, this was done by drawing $10^6$ sets of samples from 1 up to 100,000 random observations from a standard uniform distribution. The random numbers were drawn using the FORTRAN intrinsic function RANDOM_NUMBER() which provides uniformly distributed pseudorandom numbers within the range $0 < 1$ with a period of approximately $10^{18}$, thus minimizing any effects of intrinsic patterns in the random number sequences. The uniform distribution was employed so that every possible value had an equal probability of being "sampled" in a random set of observations. This procedure provided a cumulative frequency distribution of maximum probability levels observed for each number of observations in a sample. The cumulative distribution of the medians from each of these sample maximum probability value distributions by sample size gives an estimate of the cdf (*p*) for $NZ_{50}$. Here, I extend the method to estimate the smallest maximum size likely to be observed in a sample using a cumulative length-frequency distribution from a hypothetical blue marlin population taken from Goodyear (2015). The value of *p* from the cumulative probability of $NZ_{50}$ was used to estimate the smallest maximum size likely to be observed in a sample of size *N* ($L_{NZ50,N}$). This was accomplished by conjoining the probability value (*p*) for the sample size (*N*) from the cumulative $NZ_{50}$ distribution with the corresponding value of the cumulative probability (*r*) of length (Lower Jaw Fork Length, LJFL). to interpolate the length at $NZ_{50}$, $L_{NZ50,N}$ (**Figure 1**).

## 3. Results

The median value for the smallest maximum observed probability *p* in samples increases from 0.5 asymptotically toward 1.0 as $NZ_{50}$ approaches very large sample sizes (**Figure 2**). This reflects the stochastic nature of sampling because there is always a chance of not including the largest possible fish in a random sample of the catch. A very large sample could census the catch, but since the catch is a sample drawn from the larger biological population, it may not include the largest fish in that larger population. At $NZ_{50} = 1$, the value of *p* from the cumulative probability distribution is 0.5. This characteristic simply reflects the fact that on half the occasions that there is only one fish in a sample, it will be equal or larger than the median of the sampled population. Accordingly, the size at $NZ_{50}$ is the median size in the population when the samples consist of a single observation each.

I illustrate an application of $NZ_{50}$ to estimate the smallest maximum size likely to be observed in a sample of size *N* ($L_{NZ50,N}$) with the cumulative length-frequency distribution of catch from a hypothetical blue marlin stock. The hypothetical blue marlin catch was from a population using a fishing mortality rate selected to reduce it by 50% from its unfished abundance (by number), and an assumed natural mortality rate M=0.1 (from Goodyear 2015). Other important features of the hypothetical stock included constant recruitment, sex-specific, von Bertalanffy growth partitioned into 2001 growth morphs for each sex, monthly time increments within a maximum age of 100 years, and entry to the fishable stock at 100 cm LJFL. Fishing was constant at F=0.1 for marlin ≥ 100 cm LJFL at the beginning of a month but otherwise F did not vary by sex, or age. This model provided just over 2.1 million discrete size bins of population abundances and catches. The catches at size were accumulated into a cumulative length frequency in 1 cm intervals (**Figure 3**). The smallest maximum sizes that would be expected to be observed in at least 50% of samples for several sample size options in the range of 1 to 100,000 were estimated using the approach illustrated in **Figure 1**. The resulting estimates of $L_{NZ_{50},N}$ are presented in **Table 1**. By increasing sample sizes from 1 to 50, the expected smallest maximum size in a sample increased more than 100 cm from 218 cm to 322 cm LJFL. The gain in $L_{NZ50,N}$ declines with increasing $NZ_{50}$ . For example, $L_{NZ_{50},N}$ increased only 1.5% ( 6 cm) from 401 to 407 cm LJFL when sample numbers from the hypothetical population were increased from 50,000 to 100,000 observations (**Table 1**).

## 4. Discussion

A common theme in finfish fisheries is that the abundance of large fish declines when a fishery develops. The availability these fish is often of special interest to both recreational and commercial fishermen. The reduced abundance of large individuals is partly from the decline in population numbers resulting from fishing removals. More important, but sometimes less appreciated, is a progressive reduction in numbers at the oldest ages where the larger sizes predominate. This phenomenon results from their accumulated exposure to risk of capture (a "catch-curve" effect). The latter effect is best known because it causes a downward shift in the mean size of the catch. If the population is not overfished, neither its overall reduced abundance relative to the unfished state nor the change in mean size reflect how profoundly the abundance of large fish can actually change with fishing. $NZ_{50}$ is a direct measure of the magnitude of the reduced availability of these large fish. Its use recasts the magnitudes and changes in magnitudes of probabilities in the cumulative size distributions into different metrics that are easier to visualize.

Goodyear (2015) showed that at large maximum-size threshold levels, $NZ_{50}$ was particularly sensitive to changes in fishing. This sensitivity was consistent across different natural mortality assumptions. An average 350 cm LJFL Blue Marlin weighs about 470 kg or slightly more than 1000 lb which is a notable size among recreational fishermen (a "grander"). At $M$=0.1, the inclusion of a 350 cm marlin in half of samples would require slightly more than 200 individuals per sample before fishing. That value nearly triples to more than 600 when fishing reduces the surviving population per recruit by 50%. The increase is more than 1,000% if fishing reduces the population to 25% of its unfished state. This sensitivity makes such measures relatively good indicators of population status, and also sensitive indicators of changes in fishing rates. They are much more responsive than mean size, and will resist the rapid fluctuations that might accompany strong variations in year-class strength that can cause annual changes in mean sizes. In general, maximum size metrics based on the frequency of occurrence of individuals above some threshold defined for large fish, such as $NZ_{50}$, will generally be superior to the maximums observed in a sample (or set of samples) as a biological reference criterion because of the stochastic nature of individual observations.

Because samples must consist of integer values, the $p$ distribution for $NZ_{50}$ is inherently discrete. This feature is important for low sample sizes where $NZ_{50}$ is constant over a range of increasing $p$. This trait diminishes as $p$ increases and the distribution begins to approach that of a continuous distribution. Nonetheless, herein all estimates of $NZ_{50}$, corresponding values of $p$, and hence estimates of $L_{NZ_{50},N}$ are only approximations. Their accuracy and precision are based on the quantity of random draws and the robustness of the random number generator used in the construction of $NZ_{50}$. The cumulative probability ($r$) of samples from a length distribution will also be discrete, either from intentional binning the data, or because of the truncations inherent in the measurements. The discrete nature of the distributions should not themselves be issues because estimates arise their upper tails. These are the regions used by the methods described here to quantify aspects of the occurrences of the very largest individuals in the catch or underlying population. Inspection of the size data may demonstrate that a fit to an arbitrary continuous model may be useful, but this should be done with care so that the relative magnitudes of values in the upper tail of the size distribution are not unduly influenced by the more numerous observations near the middle of the size distribution.

In addition to assessing the status of stocks, $NZ_{50}$, or a similar measure could be a helpful metric for judging stock recovery for fisheries already depleted by fishing. Landing limits implemented by management authorities can obfuscate estimates of changes in abundance based on catch or even catch per unit effort. In many circumstances, the frequencies of the largest specimens in the catch will be more informative for judging stock recovery than are the average sizes, especially when catch restrictions limit landings of small fish (e.g., if minimum sizes are imposed). Specimens which were once rare events should become larger and more numerous as stocks rebuild from excessive fishing. It should be possible to build distributions for test metrics based on sample sizes and observed maxima to allow for confidence statements about differences between maximum sizes in samples for different stock conditions. Explicit treatment of reference levels for the largest fish in the catch would be a useful adjunct to the standard reference points, $B/B_{MSY}$ and $F/F_{MSY}$, and should be a routine part of stock assessments.

**Acknowledgements**

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**Literature cited**

Goodyear, C. P. 2015a. Understanding maximum size in the catch: Atlantic blue marlin as an example. Transactions of the American Fisheries Society, 144:274-282.

**Table 1.** Medians of maximum probabilities (*p*) in the cumulative distribution of observation maxima in samples, and corresponding smallest expected maximum lengths, $L_{NZ_{50},N}$ (lower jaw fork lengths, LJFL), that would occur in half of samples at the indicated sample sizes (*N*). The cumulative distribution of sizes in the catch were from the hypothetical blue marlin population at *M*=0.1 and fishing levels which reduced the population size in number to one half the unfished abundance (from Goodyear 2015).

| ***Sample size (N)*** | ***Probability (p)*** | | ***$L_{NZ50,N}$*** |
|---|---|---|---|
| | ***Median*** | ***ln(median)*** | ***LJFL(cm)*** |
| 1 | 0.5000 | -6.91824E-01 | 218 |
| 5 | 0.8707 | -1.38496E-01 | 273 |
| 10 | 0.9329 | -6.94493E-02 | 292 |
| 25 | 0.9726 | -2.77748E-02 | 311 |
| 50 | 0.9862 | -1.38808E-02 | 322 |
| 100 | 0.9931 | -6.91415E-03 | 330 |
| 250 | 0.9972 | -2.77412E-03 | 341 |
| 500 | 0.9986 | -1.38382E-03 | 348 |
| 1,000 | 0.9993 | -6.94147E-04 | 363 |
| 2,500 | 0.9997 | -2.77252E-04 | 373 |
| 5,000 | >0.9999 | -1.38613E-04 | 379 |
| 10,000 | >0.9999 | -6.92830E-05 | 387 |
| 25,000 | >0.9999 | -2.77319E-05 | 395 |
| 50,000 | >0.9999 | -1.38805E-05 | 401 |
| 100,000 | >0.9999 | -6.90252E-06 | 407 |

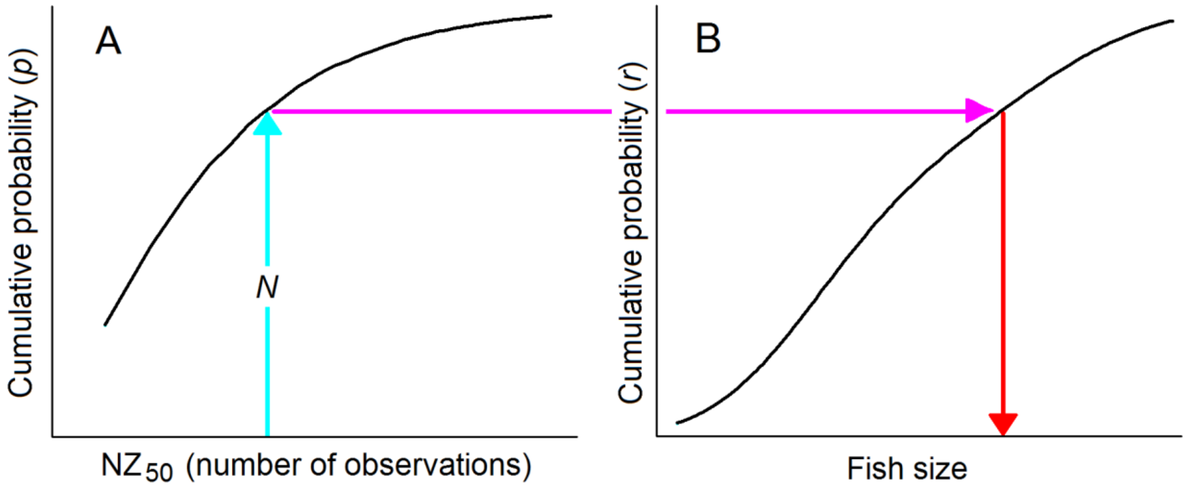


**Figure 1.** Illustration of the method used to determine the median maximum length ($L_{NZ_{50},N}$) at $NZ_{50}$ from a length-frequency distribution for a specified sample size (*N*). First, the probability (*p*) for $NZ_{50}$ is determined for the sample size of interest (Panel A). That *p* value is then used to index the probability (*r*) of length in the cumulative length distribution (Panel B) to obtain $L_{NZ_{50},N}$ for the sample size.

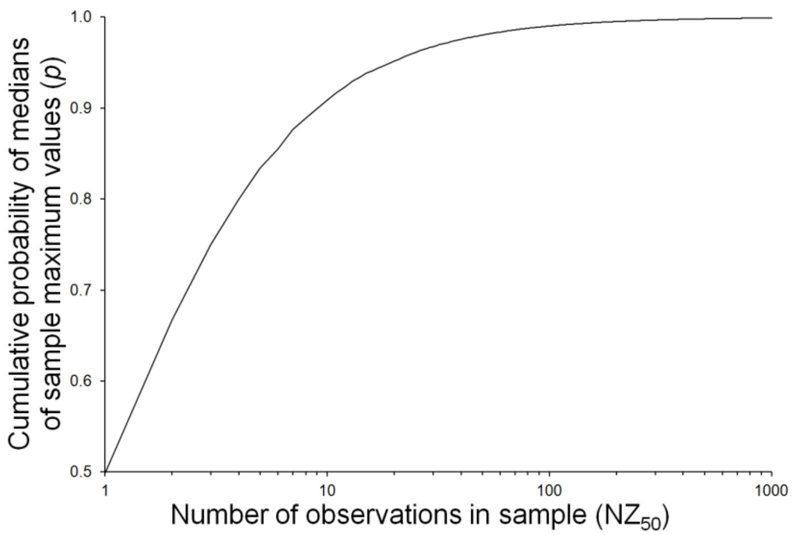


**Figure 2.** Medians of maximum probabilities (*p*) in the cumulative distribution of observation maxima in samples by numbers of observations in the sample ($NZ_{50}$).

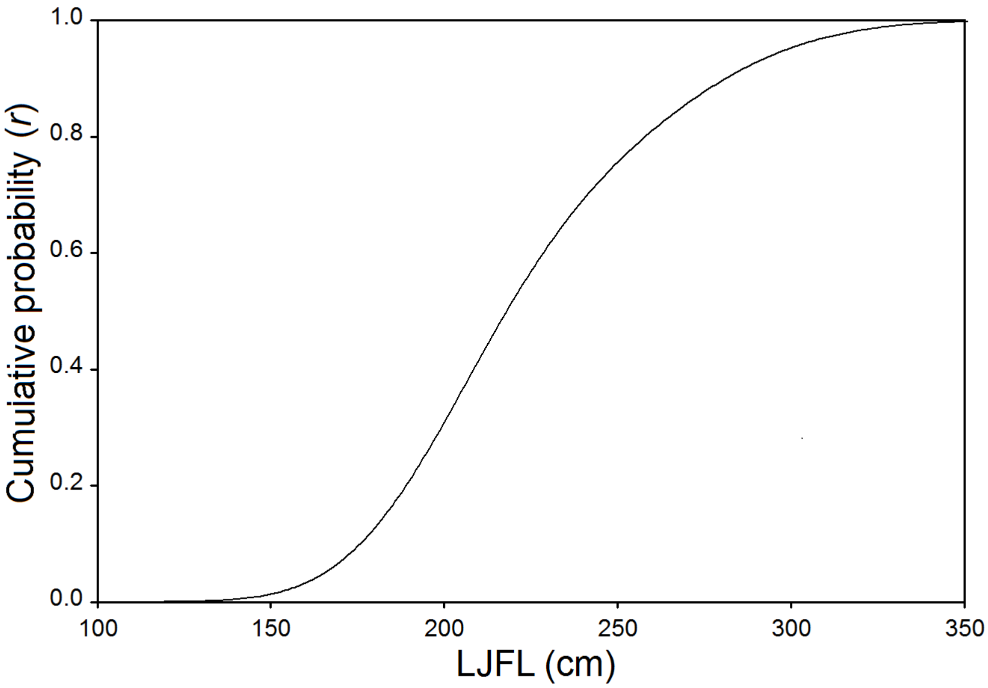


**Figure 3.** Cumulative probability distribution ($r$) of blue marlin sizes (lower jaw fork length, LJFL) in the catch from a hypothetical blue marlin population fished at a rate to reduce the population size to 0.5 of its unfished number assuming natural mortality $M$ = 0.1 (from Goodyear 2015).