学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Consistent ELEFAN estimation of fish stock parameters using median bootstrap estimators: application to *Encrasicholina heteroloba* in Tanzanian coastal waters

（中央値ブートストラップ推定値を用いた一貫したELEFANによる魚類資源パラメータの推定：タンザニア沿岸海域のシロガネアイノコイワシ *Encrasicholina heteroloba* への適用）

General introduction

Fisheries resources are vital to global food security, employment, and livelihoods, particularly in coastal and developing regions. However, approximately 40% of assessed stocks are overfished, and over 80% of the world's fisheries remain data-poor, lacking sufficient information for conventional stock assessment models. Length-based methods such as ELEFAN, which rely on length-frequency data (LFQ) to estimate stock parameters are commonly applied in data-poor fisheries. Although ELEFAN provides point estimates, it does not quantify uncertainty, limiting reliability of its outputs. The incorporation of bootstrap resampling into ELEFAN framework has improved uncertainty quantification, but this approach primarily characterizes variability rather than enhancing the precision or accuracy of the estimates. Given the typically skewed nature of LFQ data, median-based bootstrap estimators may offer improved accuracy. Therefore, this thesis aims to evaluate the use of median bootstrap estimators to reduce variability and achieve consistent ELEFAN estimates providing a practical approach for obtaining reliable fish stock parameter estimates in data-poor fisheries.

Materials and methods

The consistency of the median bootstrap estimators in producing vBGC parameters and BRPs close to their true values was evaluated through simulation. An individual based operating model was used to represent the population dynamics of a typical fish stock, implemented using the 'virtualPop' function in the 'fishdynr' R package. The specified vBGC and length-weight parameters were used to simulate the population and to analytically derive true BRPs. Life history scenarios and selectivity parameters were then applied to generate 12 months of LFQ data consisting of 900 samples per month. The LFQ data was bootstrapped to produce 100 replicate batches, and ELEFAN was run 100 times on each batch. A median estimate of each fish stock parameter was derived from each batch. This procedure was repeated across all life-history scenarios, yielding 100 median bootstrap estimators for each vBGC parameter and BRP. Then consistency of the median bootstrap estimators was subsequently assessed using the median, relative bias (RB), and coefficient of variation (CV).

Stock status of *E. heteroloba* from Tanzanian coastal waters was evaluated using median bootstrap estimators' framework. Data were collected from three sampling sites along the coast, where total length (mm) and weight (g) were recorded using measuring board and digital scale from approximately 100 fish per sampling event over seven fishing days each month, from July 2023 to December 2024. To minimize the influence of outliers, the raw data were statistically cleaned to retain the central 95% of observations suitable for analysis. The cleaned dataset was subsequently bootstrapped and analysed using ELEFAN to estimate stock status parameters. The median

bootstrap estimators' framework was then applied to derive estimates of stock biomass, stocks size, vBGC parameters, BRPs, current fishing mortality, exploitation rate and length at first capture for the *E. heteroloba* stock.

Results and Discussion

The median bootstrap estimators consistently produced parameter estimates that were close to the true values, with CV less than 1.5% and bias of less than 2% in all scenarios for both vBGC parameters, and BRPs. They demonstrated stability and consistency across all simulated life history scenarios and fishing mortality levels. This consistency was further confirmed through sensitivity analyses, in which the performance of the medians bootstrap estimators remained robust across varying fishing mortalities, indicating that they are largely insensitive to changes in fishing pressure. Collectively, these findings suggest that median bootstrap estimators represent a practically effective approach for improving stock assessment in data-poor and data-limited fisheries.

The estimated vBGC parameters of *E. heteroloba* were: L_{∞} = 8.42 cm, K = 2.08, and $\emptyset'$ = 2.19. The BRPs were: $F_{0.1}$ = 1.57, $F_{0.5}$= 1.06, and $F_{\max}$= 3.34. The stock biomass (t) and stock size (N) were 70,725, and 4.37 x 10^{10} respectively. The current length at first capture (L_{curr}), fishing mortality (F_{curr}), and exploitation rate (E_{curr}) were 6.1 cm, 0.85, and 0.40 respectively. These results indicate that the current *E. heteroloba* stock in Tanzanian marine waters is underexploited. To ensure optimal use of the dagaa stock, fishing mortality should be adjusted towards the recommended BRPs.

General discussion

This study demonstrates that using median bootstrap estimators enhances the reliability of fish stock parameters in data-poor and data limited fisheries. Both simulation and empirical results showed consistently low bias in estimates of vBGC parameters, BRPs, and stock status indicators. They reduced variability by approximately an order of magnitude compared to conventional bootstrap resampling estimates approach. By reducing estimates variability, this approach addresses a critical gap in fisheries science and enhances the quality of assessments where conventional methods fall short. Thus, integrating median bootstrap estimators' framework into length-based methods is recommended to strengthens reliable data-limited and data-poor fisheries assessments and to supports sustainable resource use and food security.

General conclusion

This study evaluated the use of median bootstrap estimators in consistently producing accurate fish stock parameters that closely approximate true values, particularly in data-limited or data-poor fisheries. The estimators demonstrated strong performance by substantially reducing bias of parameter estimates through a marked reduction in variability commonly seen in conventional bootstrap resampling estimates. When applied to empirical data, the approach performed well, exhibiting trends consistent with those observed in the simulation scenarios.