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Size at maturity of splendid alfonsino (*Beryx splendens*) from the Emperor seamounts

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Abstract

Analysis of splendid alfonsino data collected by NPFC members for the purpose of determining spawning season, maturity stages, and size at maturity for stock fish around the Emperor seamounts. To mitigate sampling bias and maturity stage inconsistencies in the existing data set, we calculated maturity using the gonadosomatic index (GSI) of female alfonsino using the gonometric method described in Flores et al (2019). Based on this test, we found a $GSI_{cut\text{-}off}$ score of 0.51 and *k* coefficient of 0.67 for Japanese data, however, both Korean and Russian data was not applicable for this analysis. Based on our gonometric results, FL_{50} was 282.1 mm among fish sampled by fishery trawl and 265.5 mm for fish sampled by fishery gillnet. Further analyses on size and maturity revealed that the difference between gears is likely to be a result of different gear selectivity, and that different seamounts host alfonsino with different size and size at maturity. While we believe the gonometric method can potentially function as an accurate yet cheap way to determine stock maturity, it is currently in the preliminary phase of testing and so we cannot recommend it for use in stock management.

Introduction

The splendid alfonsino *Beryx splendens* Lowe 1834 is a regionally important stock species targeted by deepwater fisheries (Shotton 2016). Generally caught over seamounts at depths between 200 to 800 meters, splendid alfonsino are demersal and can be found in temperate and tropical waters worldwide (Nishizawa and Sawada 2022). Despite its wide distribution and value to fisheries, in the northwestern part of the

Convention Area several key components of its life history such as size at maturity and reproductive timing have yet to be determined, making management of stock in this region difficult. For populations along the Emperor Seamount area, attempts were made to determine alfonsino reproductive season and maturity size, with mixed results. Part of the challenge in collecting natural history data on demersal fish like alfonsino, is the depth at which they tend to spawn, making sampling expensive and labor intensive. Additionally, splendid alfonsino are batch spawners which further blurs estimates of reproductive timing between seasons (Fitzhugh et al 2012). Coupled with these challenges, a lack of methodological consistency between Members has made it difficult to determine reproductive timing and maturity. Even though the shared data is impressive in scope, including nearly 25,000 specimens collected over 50 years, currently there is a lack of consistent sample collection methods or maturity stage categorization. Sample data, for example, was collected using trawling and gill nets of varying sizes, with some rod fishing surveys mixed in, introducing sampling bias to the average size of collected specimens (Nishizawa and Sawada 2022). Maturity stage indices on the other hand, have been determined by both macroscopic and microscopic criteria and broken into categories that differ between Members, with Korea using a macroscopic 5 stage scale, Russia using a macroscopic 6 stage scale, and Japan using a microscopic 7 stage scale. As a result of these methodological differences, comparing data from the regional organizations that fish in the Emperor seamount chain has proven difficult, and hampers development of precise management policies.

In this report we attempt to create a common methodology that separates immature and mature fish by applying the so called “gonometric” method (Flores et al. 2019). Less time consuming and costly than microscopic estimates of fish maturity, but able to maintain a comparable degree of accuracy, the gonometric method ties the gonadosomatic index (GSI) of individuals to maturity stage. Determined by histological analysis, logistic regression is used to create a $GSI_{cut\text{-}off}$ value that allows for the separation of mature and immature individuals. Utilizing this method, we will estimate the size at maturity of alfonsino from the Emperor seamounts to construct maturity ogives and determine if this method is broadly applicable for NPFC estimations of target fish maturity. Because this analysis detected a considerable difference in size at maturity between samples from trawl fishery and from gillnet fishery, we also analyzed the cause of this difference.

Materials and Methods

Beryx splendens shared data includes fork length (FL, mm), total mass (M_T, g), and gonad mass (M_G, g) for 24865 individuals (10237 females, 10007 males, and 4621 immature/unknown). The reproductive condition of samples was determined using differing macroscopic (Korea and Russian) and microscopic (Japan) maturation stage criteria. Japanese maturity criteria followed a 7-stage cycle based on histological examination of gonad development. Histological analyses were performed using 115 ovaries collected by Japan between April and October. Ovaries were embedded in paraffin wax, sectioned into 7−8 μm thick slices and stained with hematoxylin and eosin. We characterized the gonad development to determine the different maturity stages according to the criteria developed by Lehodey et al. (1997), consisting of chromatin nucleus, peri nucleolus, yolk vesicle, early yolk, late yolk, maturation, and spawning. For the gonometric analysis, currently only Japanese data is being considered since GSI was only recorded for immature fish by Korea, and Russian samples were taken prior to gonad weight being recorded in their sampling methodology. The samples used for gonometric analysis were Japanese samples collected between 2013 to 2022 from Colahan, Kammu, Kinmei, Koko, Northern Koko, and Yuryaku seamounts, using fishery and survey gillnets, trawls, or fishing rods (table.1). Due to fishing gear having a significant effect on ogive results, we limited gear types to "fishery trawl" and "fishery gillnet" data since these are the largest sources of samples for their respective gear types, allowing us to avoid unnecessary variables in our logistic regression model. GSI was calculated using the M_G relative to M_T for each female specimen: GSI = $100M_g(M_T - M_g)^{-1}$, and was used to calculate the $GSI_{cut\text{-}off}$ values with logistic regression following the gonometric method as described by Flores et al. (2019). GSI values above the $GSI_{cut\text{-}off}$ were classified as mature, while GSI values below the $GSI_{cut\text{-}off}$ were classified as immature. Size at maturity was represented as FL_{50}, the size (fork length, FL) at which 50% of a population is mature, and was estimated by generalized linear mixed model (GLMM) in R (R Core Team 2023) using the R package glmmTMB (Brooks et al 2017), with maturity used as the response variable, FL as the explanatory variable, and month, year, and seamount as random effects, assuming binomial error structure. Given the difference among estimated FL_{50} among samples from different fisheries suggested by a previous study (Nishizawa and Sawada 2022), we analyzed data from trawl fisheries and from gillnet fisheries separately and excluded data from surveys.

The effect of gear type and seamount on FL was calculated using data from all Members in an ANOVA, with FL as the response variable and seamount and gear type used as explanatory variables. To avoid using gear and seamount categories with few or no samples, only fishery gillnet and fishery trawl data was used for gear type, while Colahan, Kinmei, Milwaukee data were the only seamounts used. Based on our ANOVA results, it was possible that fork length and maturity of alfonsino differed depending on the seamount they were caught at and the type of fishing gear (trawl or gillnet) used. To examine the effects of seamount and gear type on fork length and maturity of splendid alfonsino, causal pathway diagrams were created and analyzed by piecewiseSEM based on the following three hypotheses and tested for goodness-of-fit ($\chi^2 = 149.8, p \leq 0.01, df = 1$). Hypothesis 1; The fork length of splendid alfonsino caught with gill nets will be larger than that of splendid alfonsino caught with trawl nets. Hypothesis 2; There may be differences in fork length among seamounts. Hypothesis 3; There may be differences in the proportion of mature stock in each seamount.

Results and Discussion

Our gonometric analysis of Japanese samples found a $GSI_{cut\text{-}off}$ score and kappa (k) coefficient of 0.51 and 0.67, respectively. Based on this $GSI_{cut\text{-}off}$ result, our GLMM analysis found a significant relationship between FL for trawl and gillnet samples, with $p \leq 0.01$ in both fisheries. Unexpectedly, trawled fish had a larger FL_{50} than gillnets (282.1 mm and 265.5 mm, respectively) and a narrower regression curve (fig.1ab).

This result is considerably smaller than previously observed using methods based on histological data, which found an FL_{50} of 299.1 mm for Japanese specimens (Nishizawa and Sawada 2022). While the cause of this result has not yet been determined, it is possibly related to seasonal changes in mature alfonsino aggregations and the use of either trawling or gillnetting across different seasons.

As a result of our unexpected size at maturity results for different gear types, further analyses into the relationships between these variables and FL were performed. Based on our ANOVA results, gear type and seamount had a significant effect on alfonsino FL (seamount: $F(2/448286) = 3280, p \leq 0.01$; and gear: $F(1/6057283) = 8864, p \leq 0.01$). piecewise SEM found that seamounts had a significant effect on alfonsino FL ($p \leq 0.01$) and maturity $p \leq 0.01$), gear type did not affect maturity directly ($p \leq 0.05$) but only indirectly through its effect on FL ($p \leq 0.01$) (fig.2). These results suggest that the difference between estimates using samples from different gear types may be the result of different catch size composition (gear selectivity), and different seamounts may host populations with different FL composition and different size at maturity. It is therefore preferable to analyze FL and maturity incorporating gear and seamount whenever the necessary data is available. Based on this result, when considering factors to be added as explanatory variables in future, using SEM to determine valid candidates is an effective means of doing so.

While still in testing, the gonometric method appears to have promise, even if we are unable to apply it to a larger dataset due to differences between NPFC members in their recording of gonad weight. For management purposes we cannot yet recommend this method yet as it requires further testing and a single estimate for size at maturity before practical application for stock management can be considered. Going forward, more work will be necessary to account for the sampling bias caused by fishing gear with differing size selectivity of catch.

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Table 1 – Japanese collection data for splendid alfonsino by seamount and gear-type. Only seamount with available GSI data were selected for gonometric analysis.

Seamount	Fishery Trawl	Fishery Gillnet	Survey Trawl	Survey Gillnet	Fishing Rod
Colahan	233	321	683	0	12
Kammu	821	46	227	94	0
Kinmei	10	464	0	0	0
Koko	1511	0	72	0	0
Northern Koko	244	0	0	0	0
Yuryaku	520	149	0	112	0

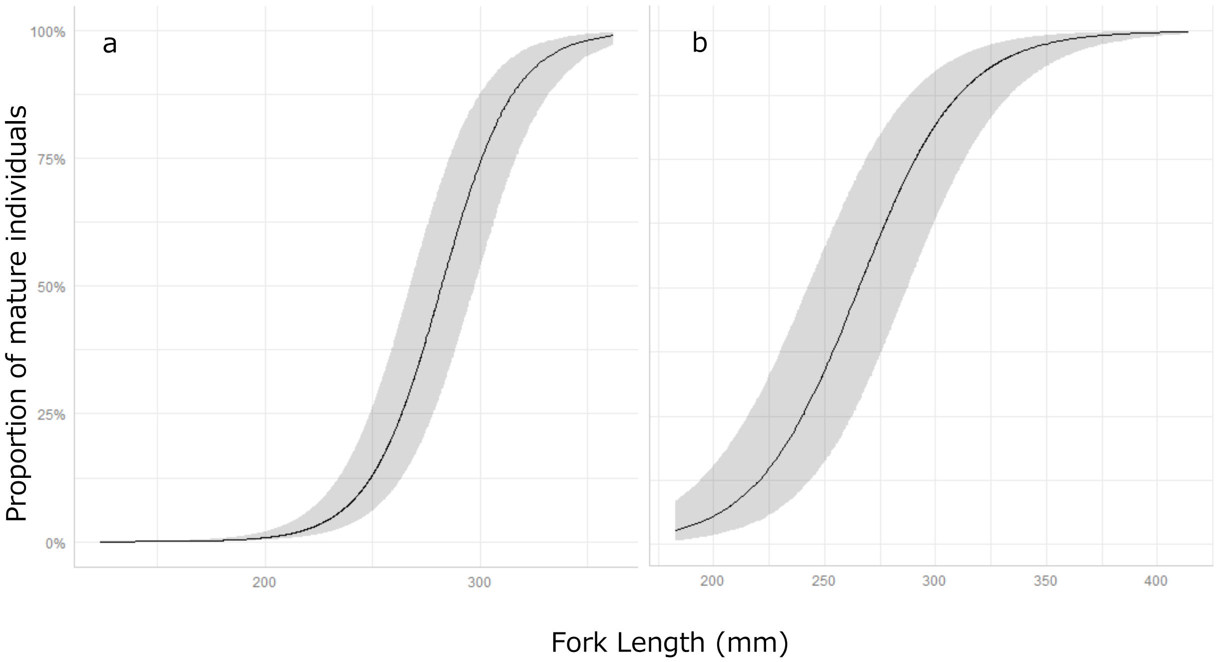

Fig. 1ab – Predicted probability of maturity in glmmTMB for fishery trawl (a) and fishery gillnet (b) using month, year, and seamount as random effects.

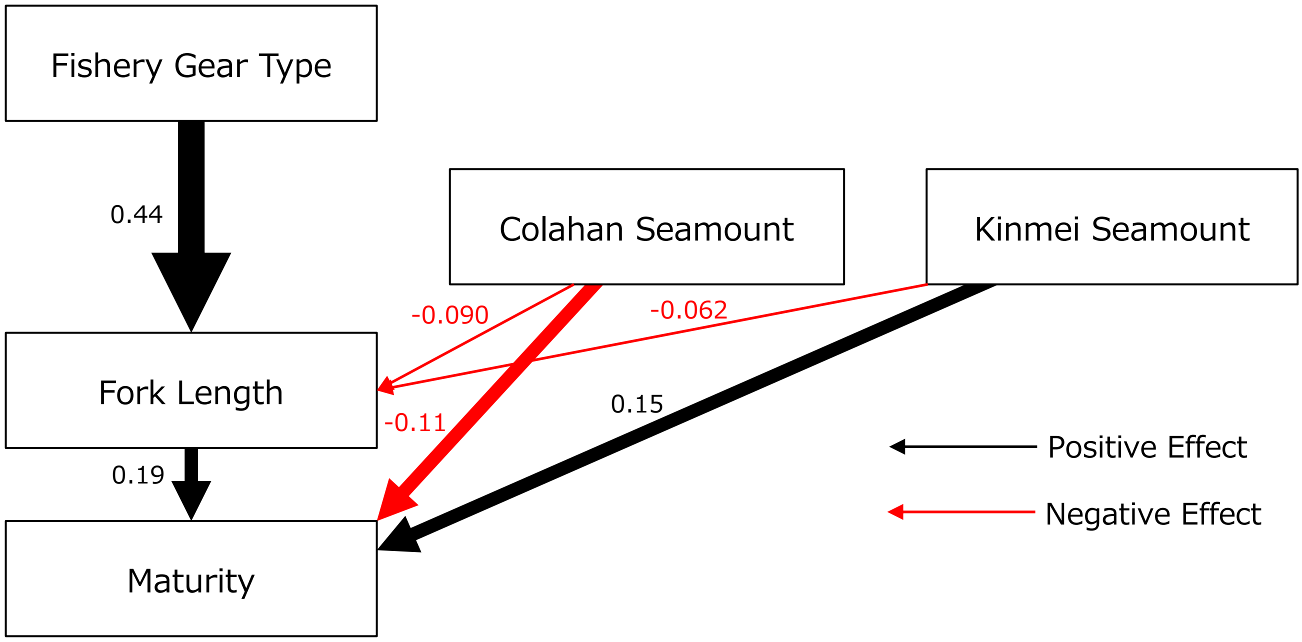

Fig. 2 – Result of causal pathways analysis by piecewiseSEM. Thicker arrows indicate stronger causal relationships. Displayed values represent the regression coefficients. Dummy variables were set to 0 for gillnets in gear type and 0 for Milwaukee in the location.