Short Paper

Logistic regression analysis applied to cannibalism in the giant grouper *Epinephelus lanceolatus* fry

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The giant grouper *Epinephelus lanceolatus* is a highly valued finfish. In past years, some propagation techniques such as induced spawning and sexual reversal were achieved. However, for hatcheries, the seed production is still unstable, and mass mortality often occurs. Serious intracohort cannibalism is one of the reasons for this.¹ This fish exhibits type II cannibalism,² and this type of cannibalism usually begins when growth heterogeneity among the fish appears.² For hatcheries, routine size grading is the most commonly used method to prevent this type of cannibalism.³

To establish an effective grading method, Hseu *et al.*² developed a cannibal-prey length relationship from morphometric measurements for giant grouper fry:

$$\text{Total length}_{\text{prey}} = 0.83 \text{ Total length}_{\text{cannibal}} - 2.48.$$

According to the equation, approximately 30% is a threshold in total length (TL) difference to use for grading giant grouper fry.² Hseu *et al.*² also carried out pairwise experiments to verify the reliability of the above equation. The threshold was supported by pairwise experiments with 136 pairs;² Hseu *et al.* found that 33 of 36 cannibalism incidents occurred only when the prey was of an equal or smaller size than that predicted by the equation.² In aquaculture practice with this species, it is therefore

suggested that when the length of larger fry exceeds that of smaller fry by more than 30%, the potential cannibals should be removed.² From the above experiment, a critical threshold was obtained in TL at which to grade giant grouper, but Hseu *et al.* had no idea about the cannibalism rates of grouper under different cannibal-prey length ratios. Since the regression variable (whether or not an incident occurs) is binary, a logistic regression model was therefore used to analyze the effect of covariates on the probability of occurrence.⁴

The morphometric measurements and pairwise experiments of giant grouper fry have been described in detailed by Hseu *et al.*² In their experiment, Hseu *et al.*² used 136 cannibal-prey pairs of varying size ratios. Before the experiment, fish from large (cannibal)- and small (prey)-size groups were chosen and separated into individual nets. The small and large fishes used in the experiment were 23.3–46.7 and 30.3–68.4 mm in TL, respectively. After careful measurement, size ratios of between 1.20 and 1.80 were established for the pairs. Both sizes of fish were starved for 1 day. When the experiment began, the two sizes of fish were anesthetized with 400 µL/L 2-phenoxyethanol, and their TL were carefully measured to the nearest 0.05 mm. Each pair of fish was co-cultured in a glass aquarium (30 × 15 × 28 cm) containing 10 L of sea water. After 24 h, the predation result of each trial was recorded.

Three covariates (cannibal-to-prey length ratio, TL_{prey} , TL_{cannibal}) are considered for logistic

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Fig. 1 Relationship between estimated probability of cannibalism and cannibalism/prey length ratio, where prey's total lengths ranged from 34.5 to 35 mm. Non-cannibalism (●); cannibalism (△); 95% confidence interval (★).

regression. Based on the stepwise procedures,⁴ only ratio and TL_{prey} were included in the model. The estimated parameters were 7.187 (estimated standard error [SE] = 1.715) and -0.126 (estimated SE = 0.046) for ratio and TL_{prey} , respectively. Based on Wald χ^2 -test,⁴ both parameters were significantly different from zero, with a P -value of less than 0.001 for ratio and that of 0.006 for TL_{prey} . The estimated probability of cannibalism was given as follows:

$$P(\text{occurrence}|\text{ratio}, TL_{\text{prey}}) = \frac{e^{-7.217+7.187\text{ratio}-0.126TL_{\text{prey}}}}{1+e^{-7.217+7.187\text{ratio}-0.126TL_{\text{prey}}}} \quad (1)$$

In order to assess the goodness-of-fit of the model, the test proposed by Hosmer and Lemeshow⁵ was considered. They proposed a Person statistic comparison of the observed data and fitted counts for 10 groups, which were partitioned using the estimated probability of occurrence.⁵ In this present study, the Hosmer-Lemeshow test, with a P -value of 0.356, indicated that the model (1) fitted adequately (Figure 1).

The probability of cannibalism of grouper under different TL_{prey} and cannibal-prey size ratios was estimate with model (1) (Fig. 2), and showed the following: First, if given a TL_{prey} constant, the probability of cannibalism increases with the increase of the cannibal-prey size ratios; second, if given a cannibal-prey size ratio constant, it could be found that larger (in TL) preys are more difficult to ingest than the smaller ones. For piscivorous fish, mouth width (MW) relative to body depth (BD) determines whether prey can be ingested. This relationship of prey BD to cannibal MW sets an upper morphological limit on the maximum prey size

Fig. 2 Estimated logistic curve for cannibalism in giant grouper with different prey's total length (TL) against cannibal-prey length ratios. The value above each curve is the prey's TL .

available to piscivorous fish.⁶ In the giant grouper, the limit at which a cannibal can successfully engulf a prey is c. 1.3; compared to other fish, this limit is very low.² The logistic regression model in this study indicated that in advance grading is very important, especially in the early stage of larviculture.^{2,3} When TL_{prey} was 10 mm, even cannibal-prey size ratio was 1.5, the probability of cannibalism would be 0.8. The potential cannibals should therefore be removed before the cannibal-prey size ratio and TL_{cannibal} reaching the threshold.

The predicted model indicated that when being offered different sizes of prey, the cannibal grouper prefers smaller prey. In our cultural and laboratory experience, cannibal groupers do swallow smaller prey when given a choice. Similar situations were reported in other studies with different cannibal fishes such as the yellow perch *Perca flavescens*,⁷ Arctic charr *Salvelinus alpinus*,⁸ pike *Esox lucius*,⁹ and dorada *Brycon moorei*.¹⁰ Handling time may be a major consideration for grouper cannibalism. The risk of falling prey or of kleptoparasitism (i.e. the stealing of food items from other foragers)⁹ can be reduced. The grouper can successfully get food through cannibalism.

The logistic regression model can help us to estimate and prevent the cannibalism during larviculture. Routine grading seems the most effective method, although it consumes labor and time. However, from this present study and previous observations,^{2,3} it could be found that cannibalism gradually declines or even disappears when the grouper grow up to 5–6 cm.

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