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Importance of piscivory for growth and survival in early life stages of Pacific bluefin tuna observed by rearing experiments

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Introduction

Survival in early life stages of fishes is considered to be the main cause of interannual variability in their recruitment [1]. Growth of larvae and juveniles is one of the most important factors for their survival and subsequent recruitment successes as reported for various fish species because bigger and/or faster growing larvae have a higher tolerance to starvation and a higher ability to escape from predators than smaller and/or slower growing larvae e.g. [2-4]. Accordingly, studies on growth performance of larvae and juveniles can contribute to the understanding of mechanisms and factors leading to the variability of recruitment.

Pacific bluefin tuna (PBT) *Thunnus orientalis* is distributed widely in the North Pacific Ocean and is one of the most important fisheries species in Japan. Artificial mass culture of PBT has been explored since the 1990s to promote aquaculture and stock enhancement. The most remarkable work in this process is the success of aquaculture for whole life cycle of PBT by Kindai University in 2002 [5]. From this period, rearing techniques for PBT larvae have been remarkably developed for the last decade in various facilities and enable us to investigate details of eco-physiological traits in early life stages of PBT.

On the other hand, ecological information on the late larval to early juvenile stages of wild PBT in the field are extremely few although ecological studies on the early larval stage (< 10 mm in body length, BL) have been reported. Late larval-early juvenile stages (ca. 10-20 mmBL) are important periods for mass culture process. Laboratory-reared PBT shows a shift of feeding habit from zooplanktivory to piscivory in these stages and changes in their subsequent growth performances. However, details on the shift of feeding habit and growth performance in wild PBT in the field are still unknown, which could be a key mechanism regulating their recruitment success in the field.

Our group have conducted a series of rearing experiments and reported the relationships between piscivory and growth of laboratory-reared PBT larvae. The objective of the present study is to review our findings on the relationships between piscivory and growth of laboratory-reared PBT larvae and to discuss the potential importance of piscivory for growth and survival in early life stages of PBT in fields based on the results of rearing experiments.

Materials and methods

We conducted three designs of rearing experiments. Details of the experiments were described in the respective references.

Firstly, we examined the influence of piscivory on growth of hatchery-reared PBT larvae by prey switch experiment [6]. PBT larvae were reared under two different feeding regimes: a group fed only rotifers, and a group switched their prey from rotifers to yolk-sac larvae (YSL) of spangled emperor, *Lethrinus nebulosus* at 15 days after hatching (DAH) [6].

Secondly, we investigated the influence of the timing of the prey switch from rotifers to YSL on the growth and its variations of PBT larvae [7]. Four periods prior to the prey switch were conducted on 17, 20, 23, 26 DAH and a non-switched group and the growth of PBT larvae was compared among the groups of different periods prior to the prey switch.

Thirdly, we collected various size of hatchery-reared PBT larvae from actual hatchery tanks from onset of feeding of YSL to 7 days after feeding of YSL [6,8]. Then, we analyzed their nitrogen stable isotope ($\delta^{15}N$) and increments of sagittal otolith of collected PBT larvae, which were used as indices of nutritional and growth histories, respectively [6,8]. In addition, the nutritional and growth histories of live and dead PBT larvae collected from the same hatchery tank were compared [9].

Results and Discussion

First experiment: influence of piscivory on growth rate
PBT tuna larvae fed on yolk-sac larvae showed significantly higher growth rates than larvae fed only on rotifers. Body weight increase of PBT larvae fed YSL rapidly increased up to 40 fold to the initial weight on 9 days after the prey switch. These results suggest that piscivory strongly influenced on the growth PBT larvae and could induce growth variation in PBT larvae by individual differences in the availability of YSL.

Second experiment: influence of timing of piscivory on growth
Average BL of PBT larvae which had their prey switched on 17, 20, 23, 26 DAH at the end of experiment (29 DAH) were 27.27, 23.38, 17.23 and 13.45 mm, respectively. That of the non-switched (only rotifer) group was 9.25 mm. These results indicate that earlier prey switch induced a larger body length in PBT larvae. This experiment showed that earlier prey switch to piscivory induced larger body lengths in PBT larvae and suggests that timing of piscivory is also a key factor in the growth variation that develops in PBT larvae.

Third experiments: relationship between piscivory and growth variation
The values of $\delta^{15}N$ of rotifers and YSL of spangled emperor were 0.2 and 12.9‰, respectively [10]. The $\delta^{15}N$ values of PBT larvae varied after the feeding of YSL. The $\delta^{15}N$ values of larger PBT larvae collected after the feeding of YSL were significantly higher than those of the smaller PBT larvae and those of the smaller PBT larvae did not markedly change. This result indicates that larger larvae utilized YSL rapidly after the feeding of YSL and they subsequently showed a rapid increase in growth. Conversely, smaller PBT larvae could depend largely on rotifers rather than the yolk-sac larvae. Their growth variation of PBT larvae is strongly related to the differences in the utilization of YSL.

The otolith radius (OR) from the core to the increment corresponding to the first feeding on YSL was used as the index of larval BL at the first feeding on YSL. Relationships between OR and the values of $\delta^{15}N$ of various sized PBT larvae showed a positive correlation, indicating that the larvae with larger OR values had higher values of $\delta^{15}N$ (ca.10‰). This result suggests that BL at the initial YSL feeding stage affected the utilization of prey larvae and consequently the somatic growth of PBT larvae. This result may also suggest that small growth variations in the zooplanktivorous stage induce large growth variations after the onset of piscivory.

The $\delta^{15}N$ values of the live larvae were significantly higher than the dead larvae, suggesting that the live larvae rapidly utilized prey fish larvae but the dead fish had depended more on rotifers relative to the live fish. The growth trajectories based on otolith increments were compared between the live and dead tuna larvae, and indicated that the live fish showed significantly faster growth trajectories than dead fish. Our results suggest that faster growing larvae at the onset of piscivory could survive in the mass culture tank of PBT, and were characterized by growth selective mortality.

Conclusion

Our studies revealed that the onset of piscivory strongly influenced the growth performance and growth variation in early life stages of laboratory-reared PBT. It has been reported that field-caught PBT larvae smaller than 10 mm BL showed growth selective survival process which were faster growing PBT larvae could have a higher possibility of survival than slower growing larvae [11]. Although these findings were observed in PBT larvae larger than 10 mm BL by rearing experiments, we conclude that timing of piscivory and prey availability in relation to piscivory in the field could potentially influence the growth and survival of wild PBT larvae larger than 10 mm BL and consequently play important roles in recruitment processes of PBT.

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