

Taxonomical review of *Auxis* (Scombridae, Pisces) larvae using collections around Tosa Bay, Japan

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Abstract: Larvae of *Auxis* collected around Tosa Bay from May 2002 to May 2018 could be distinguished into two types primarily by the pigmentation patterns on the caudal peduncle. Type-A *Auxis* larvae possess a row of pigmentation along the midlateral line in all larval stages, while type-B does not. Little morphometric differentiation was found until the flexion stage in both types, but at the postflexion type-A showed significantly larger head [36.8% BL (mean)], larger mouth (24.1%), shorter vent to anal-fin length (17.7%) and deeper body (27.8%) than type-B (34.8, 21.5, 19.0, 25.9%, respectively). These observed differences indicate the validity of the pigmentation row in distinguishing *Auxis* larvae. Between the two types, type-B larvae ($n = 795$) were more abundant than type-A ($n = 21$) in Tosa Bay. Based on this distribution pattern and shallower body depth, type-B larvae could be considered as *A. rochei* and type-A with a deeper body as *A. thazard*.

Keywords : *Auxis* larvae, pigmentation and morphometry, Tosa Bay

1. Introduction

Auxis is a commercially important fish with widespread distribution in tropical to temperate waters (COLLETE and NAUEN, 1983). It is represented by four species, *A. brachydorax*, *A. eudorax*, *A. rochei* and *A. thazard* (FRICKE *et al.*, 2018). The latter two species are cosmopolitan in distribution, while the former two species have been recorded only in the eastern Pacific and are previously considered as subspecies of *A. thazard* and *A. rochei*, respectively (COLLETTE and AADLAND, 1996). Around Japanese waters, both *A. rochei* and *A. thazard* are widely distributed, with the former dominating fisheries catches

throughout the year (HOTTA, 1955; OKACHI, 1958; MOHRI *et al.*, 2016), half of which are landed from Tosa Bay (OCHIAI and TANAKA, 1998; NIYYA, 2001). This demonstrates the importance of Tosa Bay in the reproduction of pelagic fishes in southwestern Japan (KINOSHITA, 2006).

Global capture production of *Auxis* from 2010–2015 showed a general increasing trend, with an annual average of ca. 457 kt (FAO, 2018a). However, in Japan *Auxis* capture production continue to decline from ca. 29 kt in 2010 to ca. 16 kt in 2015 (FAO, 2018b). To manage fisheries resources sustainably, precise identification (FISCHER, 2013) and information on the early life histories that has considerable influence on population dynamics (SPONAUGLE and COWEN, 1997) should be acquired. Currently, identification of

the larvae of the two cosmopolitan *Auxis* species is still problematic. MATSUMOTO (1959) classified *Auxis* larvae into two types using pigmentation patterns of the caudal peduncle region, and JONES (1963) speculated that these types I and II may be *A. thazard* and *A. rochei*, respectively. However, because of the lack of detailed morphometric examinations, both works are inconclusive.

There is little available information on the early life history of *Auxis* in Japan. Most of the information are limited to collection records based on ichthyoplankton studies (YOKOTA *et al.*, 1961; YABE and UEYANAGI, 1962; HATTORI, 1964; MATSUDA, 1969; FUKUDA, 1984; FUNAKOSHI, 1993; ZHONG, 2002). Artificially reared larvae and juveniles of both *Auxis* species were reported in HARADA *et al.* (1973a, b), but their papers never describe their ontogeny. To date, only NISHIKAWA (2014) described an uncertain species of *Auxis*, which may probably be any of the two types observed by MATSUMOTO (1959). This study aims to differentiate the early developmental stages of *Auxis* larvae collected around Tosa Bay, Japan based on pigmentation patterns and morphometric trends. Detailed descriptions of pigmentation and morphometric patterns are also provided to determine which characters are most useful in separating *Auxis* even at early developmental stages.

2. Materials and methods

Fish larvae were collected in waters of Tosa Bay (32° 42'–33° 25' N, 132° 52'–133° 38' E) from May 2002 to May 2018, primarily by towing obliquely from near the bottom to the surface with a larva net (1.3 m mouth diameter with 0.5 mm mesh aperture) and a modified IKMT (1.5 m² mouth opening with 2 mm and 0.5 mm mesh apertures in the anterior part and cod end, respectively). All samples collected were preserved in 10% formalin solution. Fishes were

immediately sorted and transferred to 80% ethanol. *Auxis* larvae were identified following MATSUMOTO (1959), NISHIKAWA and RIMMER (1987) and NISHIKAWA (2014). Larvae of *Auxis* can be distinguished from other scombrids containing the same number of myomeres (39) such as *Thunnus*, *Euthynnus* and *Gymnosarda* based on the pigmentation patterns on the caudal peduncle, chleithral symphysis, front of the anus and tip of the lower jaw.

After identification, the body lengths (BL: notochord length in preflexion and flexion larvae, and standard length in postflexion larvae) and other various measurements such as eye diameter, body depth, snout, upper jaw, pre-anal, head and vent to anal-fin (VAFL) lengths were made following LEIS and CARSON-EWART (2000) by developmental stages (KENDALL *et al.*, 1984). A total of 642 preflexion (2.3–4.6 mm BL), 140 flexion (4.7–7.1 mm) and 34 postflexion (5.5–7.9 mm) larvae of *Auxis* were collected and representative samples were used to describe the different developmental stages.

Morphometric data were evaluated for heterogeneity of variances using ANCOVA. A representative series of specimens used in this study were deposited in the Usa Institute of Marine Biology, Kochi University (UKU-449000–449005).

3. Results

Types of larvae

Specimens were classified into two types primarily using pigmentation patterns. Type-A specimens possessed a distinct row of melanophores along the midlateral line of the caudal peduncle, while type-B did not. Both types occurred almost simultaneously in spring to autumn, with type-B larvae outnumbering type-A on all occasions (Fig. 1). A total of three preflexion (4.1–4.3 mm BL), three flexion (4.8–5.5 mm) and 15 postflexion larvae (5.5–7.9 mm) of type-A,

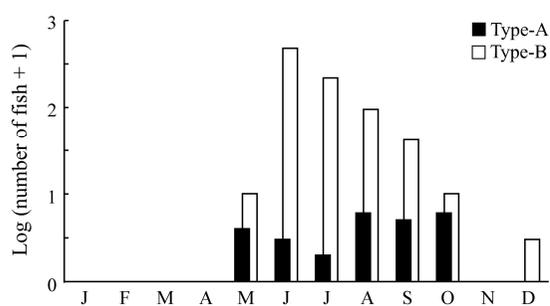


Fig. 1 Seasonal abundance of types -A and -B *Auxis* larvae collected in Tosa Bay from May 2002 to May 2018.

while 639 preflexion (2.3–4.6 mm), 137 flexion (4.7–7.1 mm) and 19 postflexion larvae (5.6–7.6 mm) of type-B were collected (Fig. 2).

General morphology

Both types containing 39 myomeres are laterally compressed with an elongate body tapering gradually towards the caudal end. The abdominal sac is triangular and protrudes ventrally be-

low the body outline. In both types, the pre-anal (ca. 40–48% BL), head (ca. 26–37%), upper jaw (ca. 16–24%) and snout (ca. 7–14%) lengths and body depth (ca. 24–28%) increase with body length (Fig. 3a, b, d). Eye diameter hardly changes with BL (ca. 11–12%) (Fig. 3e), while the VAFL becomes shorter (ca. 22–17%) (Fig. 3c) from preflexion to postflexion. However, at the postflexion stage, significant differences between the two types were observed, with type-A having a larger head [36.8% BL vs 34.8% (means) in type-B, $p < 0.05$], longer upper jaw (24.1% vs 21.5%, $p < 0.05$), shorter VAFL (17.7% vs 19.0%, $p < 0.01$) and deeper body (27.8% vs 25.9%, $p < 0.01$) than type-B (Fig. 3f, g, h). Correspondingly, the snout and pre-anal body length in type-A (14% and 48%) are also longer than type-B (13% and 47%, respectively), but these were not significant.

Fin formation

Notochord flexion begins at 4.8 mm BL in

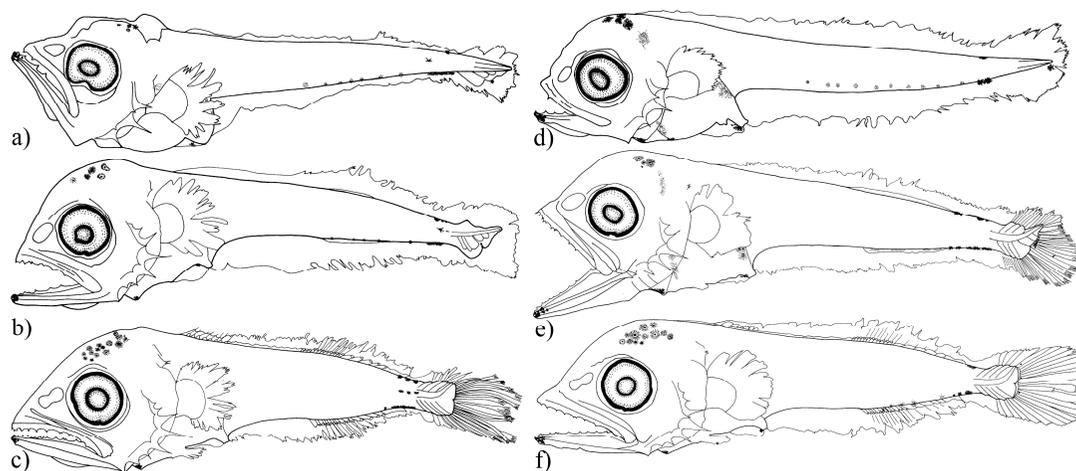


Fig. 2 Developmental stages of types -A (a-c) and -B (d-f) *Auxis* larvae from Tosa Bay. (a) 4.3 mm BL preflexion larva (UKU-449000); (b) 5.4 mm BL flexion larva (UKU-449001); (c) 6.8 mm BL postflexion larva (UKU-449002); (d) 5.0 mm BL preflexion larva (UKU-449003); (e) 6.9 mm BL flexion larva (UKU-449004); (f) 7.5 mm BL postflexion larva (UKU-449005). Note: Fig. 2a was derived from the right side body of the larva due to damage on the left side.

type-A and at 4.7–5.2 mm in type-B, and is completed at 5.5 and 6.9 mm, respectively (Fig. 2e). The hypurals start to appear in late preflexion larvae measuring 4.3 mm in type-A (Fig. 2a) and in 4.6–5.2 mm in type-B, with incipient rays formed subsequently. The pelvic bud occurs in 4.8 mm flexion larva in type-A and in 5.1 mm flexion larvae in type-B, with rays starting to develop at 6.5 and 7 mm postflexion larvae, respectively. The second dorsal- and anal-fin anlagen first appear in 4.8 mm flexion larvae of type-A and in 5.2 mm flexion larvae of type-B, and their incipient fin rays begin to differentiate in 5.5 and 6 mm flexion larvae, respectively. The first dorsal-fin anlagen are found in late flexion larvae measuring 5.5 mm in type-A and 7 mm in type-B, with incipient spines starting to form in 6.6 and 7.3 mm postflexion larvae, respectively. The 7.9 mm postflexion larva of type-A was the largest in both types, and showed full complements of first dorsal (XI), second dorsal (11 + 7 finlets), anal (11 + 7 finlets), pelvic (I + 5) and caudal (9 + 8) fins (pectoral fin, unknown due to damage).

Head spination and dentition

In both types, two and three spines are initially present on the inner and outer preopercle, with the outer spine at the angle being the longest (Fig. 2a, d). The number of inner and outer spines increase gradually to three and seven, respectively, by postflexion stage in both types (Fig. 2c, f). One small spine starts to form on the posttemporal in 5.4 mm BL flexion larvae (Fig. 2b), increasing to two in ca. 6 mm flexion larvae in both types (Fig. 2c, 2e). The small and conical teeth are already present in both jaws in the smallest larvae at 4.1 mm in type-A and 2.3 mm in type-B, gradually increasing their number with development thereafter (Fig. 2).

Pigmentation

Three distinct rows of melanophores (middorsal, midlateral and midventral) are present on the caudal peduncle in type-A (Fig. 2a-c), while one or two rows only in type-B, along the midventral and or middorsal (Fig. 2d-f), which is sometimes absent in preflexion and flexion larvae. The rows on the caudal peduncle become denser with growth in both types, and the three rows of type-A form a transverse band (Fig. 2a-c). The internal melanophores arranged along the anal-fin anlagen are more numerous in preflexion type-B larvae (6–13) than in type-A (5–8) (Fig. 2a, c), and their number decreased, although variable, to 1–5 in type-A (Fig. 2c) and 3–6 in type-B at postflexion (Fig. 2f). Small melanophores at the tip of the lower jaw and large branched melanophores over the head are present in all stages in both types, becoming more obvious with growth (Fig. 2). Melanophores on the triangular abdominal sac are internally developed, being heavier along the anterior and dorsal surfaces from flexion larvae (Fig. 2). A conspicuous melanophore at the cleithral symphysis (Fig. 2b-f) is present in most specimens, but sometimes absent in type-A preflexion larvae (Fig. 2a) and in any stage of type-B larvae. A single melanophore just in front the tip of the anus and/or the anterior finfold (Fig. 2a, b, d, e, f) irregularly appears in any stage in both types.

4. Discussion

The midlateral row of melanophores on the caudal peduncle is the most consistent feature distinguishing all larval stages of type-A from type-B. Both types closely resemble MATSUMOTO'S (1959) types I and II larvae, respectively from unspecified waters of the Pacific, Atlantic and Indian Oceans, based on pigmentation patterns. Although MATSUMOTO (1959) mentioned the extreme inconsistency of the midlateral pigments

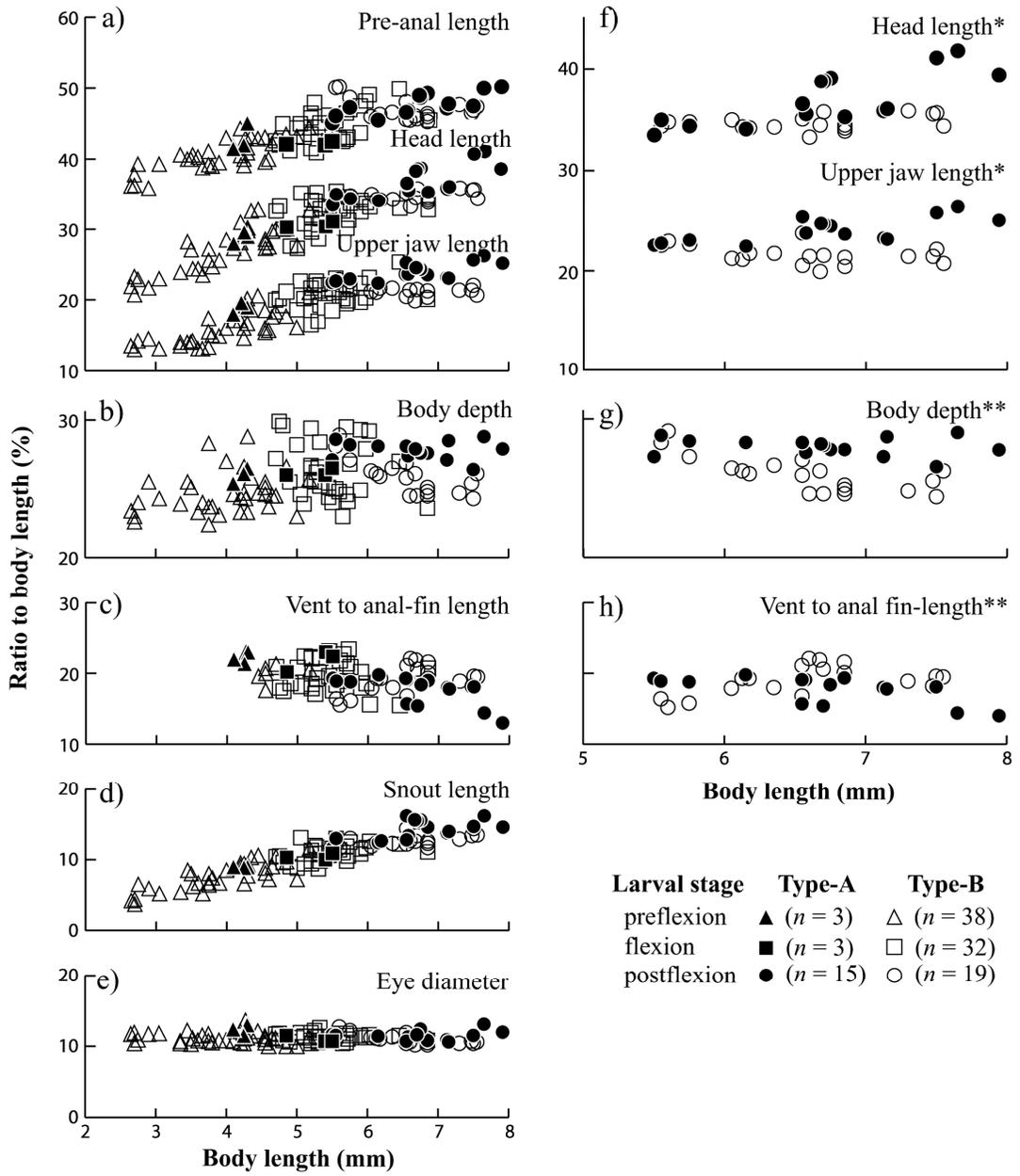


Fig. 3 Changes in the ratio of the different morphometrics measured to body length of *Auxis* types -A and -B larvae covering all larval stages (left: a-e), and upon attaining postflexion stage (right: f-h). ** and * indicate significant differences between the two types with p value < 0.01 and < 0.05, respectively.

in type I larvae (a row of 1–5 melanophores on one side of the body but absent on the other side on the same larvae), our type-A specimens have the pigments on both sides, except for the 4.3 mm BL preflexion larva (Fig. 2a). This specimen had a damaged caudal peduncle on the other side, hence, the presence or absence of the pigment row is uncertain. Nevertheless, we are convinced that this specimen possessed the pigment because the other two preflexion type-A larvae (4.1 and 4.3 mm BL, with deformed bodies) have the pigment row on both sides.

The morphological features of both types -A and -B are very similar in the early larval stages. Differences are recognizable only at the postflexion stage, with type-A larvae showing a larger head, larger mouth, shorter VAFL and deeper body than type-B (Fig. 3). These results indicate the validity of the pigmentation row on the midlateral line in typing the entire larval stages of *Auxis*, probably until the juvenile stage.

The body depths of juvenile and adult *A. rochei* are shallower than in *A. thazard* (COLLETTE and AADLAND, 1996; NAKABO and DOIUCHI, 2013). In Tosa Bay, *A. rochei* are captured more abundantly than *A. thazard* (OCHIAI and TANAKA, 1998; NIHYA, 2011). In this study, the shallower-bodied type-B larvae predominated the deeper-bodied type-A larvae. Based on these facts, type-B larvae can be considered as *A. rochei* and type-A larvae as *A. thazard*. Our opinion corroborates with JONES (1963) speculations based on a limited morphometric examination (eight specimens) that the stouter type of *Auxis* larvae from Indian waters may be a *A. thazard* [= type I of MATSUMOTO (1959)] and the less stout or elongate type may be *A. rochei* [= type II of MATSUMOTO (1959)]. Furthermore, the photographs, although unclear, of the artificially reared preflexion larvae of *A. thazard* and *A. rochei* have three and two rows of pigmentation on

the caudal peduncle, respectively (HARADA *et al.*, 1973b, a). Accordingly, based on the results of this study, the three postflexion *Auxis* larvae observed in NISHIKAWA (2014) can be identified as *A. thazard*, but the smallest preflexion larva is not *Auxis* because of the absence of pigmentation rows on the midventral, middorsal and/or midlateral lines of the caudal peduncle which are distinguishing characteristics of *Auxis* even in early preflexion larvae. This preflexion specimen is probably *Euthynnus* (NISHIKAWA, 2014), which has 1–3 pigment spots on the ventral edge of the tail and shares the same characters with *Auxis*; such as 39 myomeres, strong preopercular spines and pigmentations at the tip of the lower jaw, cleithral symphysis and tip of anus. In the near future, molecular studies examining the two types of *Auxis* larvae should be conducted to clarify their identifications.

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