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A Quick Method to Identify Engraulid Fish Larvae in the Tanshui River Estuary of Northern Taiwan

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Abstract

Five species of larval engraulids, *Engraulis japonica* Schlegel, *Encrasicholina punctifer* Fowler, *E. heteroloba* (Ruppell), *Stolephorus insularis* Hardenberg, and *Thryssa dussumieri* (Valenciennes), were found in coastal waters off the Tanshui River Estuary, northern Taiwan during the period from May 1992 through November 1993. Their sizes ranged between 8 and 46 mm SL. Comparing the meristics, morphometrics, and pigmentations of the 5 species, we found pigment patterns on the ventral side of the larvae that can be used as a key character to discriminate these species.

Key words: larval engraulid, species identification, meristics, morphometrics, pigmentation, Tanshui River Estuary.

INTRODUCTION

Engraulid larvae are the dominant components of the larval fish community in coastal waters of Taiwan (Chen 1985, 1986; Chen and Huang, 1985; Huang *et al.*, 1985; Tzeng and Wang, 1986, 1992; Wang *et al.*, 1991; Wang and Hwang, 1992). The larvae of engraulids and clupeids are named "bull-ard" in Taiwanese. They are harvested for local consumers and greatly contributing to coastal fisheries (Shen, 1971; Cheng, 1980; Chen, 1984; Young *et al.*, 1992). The amount of engraulid larvae constitutes ca. 75% of the total bull-ard catch (Cheng, 1980; Wang and Tzeng, 1997). Due to its economic importance, several studies have been conducted on species composition (Liu and Shen, 1957; Shen, 1971; Cheng, 1980), feeding habits (Chern and Tzeng, 1993, 1994), growth (Huang and Chiu, 1996), fluctuation of the catch (Tsai *et al.*, 1996), and fishery oceanography (e.g., Lee *et al.*, 1990, 1995, 1996). However, due to the difficulty in classification of the larvae, the community structure and population dynamics of engraulids have been little studied (Tzeng and Wang, 1992, 1993, 1997; Wang and Tzeng, 1997).

There are 5 genera and 12 species of engraulids in the coastal waters of Taiwan are revised (Young *et al.*, 1994). Species of adult engraulids are classified mainly based on the numbers of pre- or post-pelvic scutes (Shen, 1984; Chen and Yu, 1986; Whitehead *et al.*, 1988; Nakabo, 1993; Shen *et al.*, 1993; Young *et al.*, 1994). However, these characters are lacking in larvae and thus not applicable to the larval stage of engraulids.

Chen (1987), Yu and Chiu (1994), and Young *et al.* (1995) tried to identify the species of engraulid larvae by meristics, morphometrics, and pigmentation. Their works have a combination of these characters. However, counting meristics and measuring morphometrics are time consuming and difficult when dealing with large numbers of samples (Powles and Markle, 1984). This paper attempts to evaluate the merits and defects of the method of meristics, morphometrics, and pigmenta-

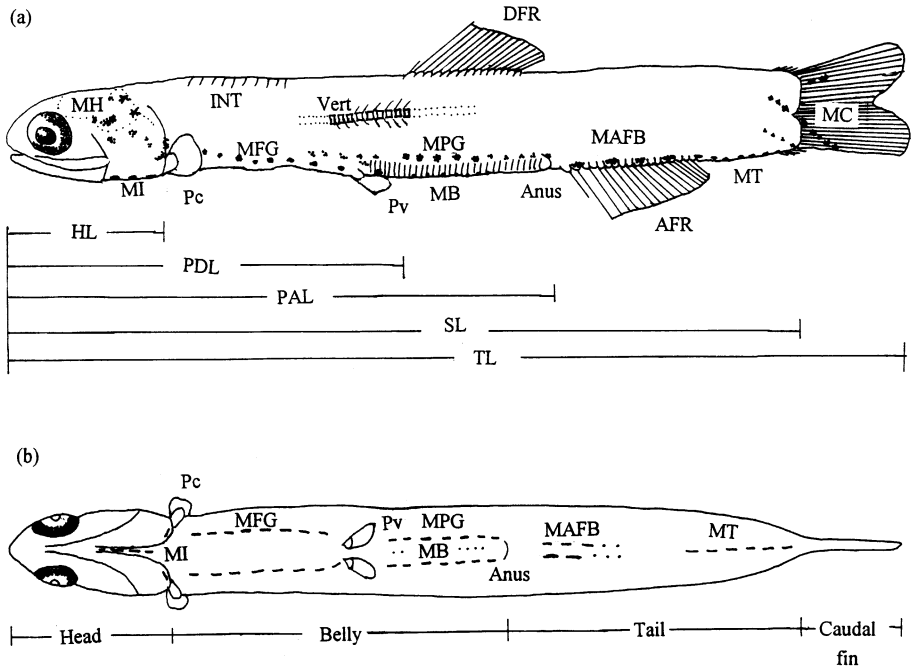

Figure 1. Measurement of pigmentation, meristics, and morphometrics of engraulid larvae: (a) lateral view, (b) ventral view. MAFB, MB, MC, MFG, MH ,MI, MPG, and MT denote the melanophores appearing on anal fin base, belly, caudal fin, dorsolateral side of fore gut, head, isthmus, dorsolateral side of posterior gut, and tail, respectively. AFR and DFR, INT, Pc, Pv, and Vert denote the anal and dorsal fin rays, interneurals, pectoral fin, pelvic fin, and vertebrae, respectively. HL, PAL, PDL, SL, and TL denote the head, preanal, predorsal fin, standard, and total lengths, respectively.

tion, and to establish a simple key to identify species of engraulid larvae.

MATERIALS AND METHODS

Collection of fish larvae

Engraulid larvae were collected from the fishing grounds in coastal waters off the Tanshui River Estuary as in a previous study (Wang and Tzeng, 1997). A commercial set-net was set against the tidal current, to catch the larvae in the estuary during the fishing season from May 1992 to November 1993. The structure and dimension of the net were the same as that of the previous study (Wang and Tzeng, 1997). About 10 g of wet-weight larvae were randomly selected from each daily catch in the fishing season. The larvae were preserved in 95% alcohol and used for species identification.

Identification of fish larvae

Engraulid larvae were separated from fishes of other families by meristic characters and external morphology (Leis and Rennis, 1983; Wang, 1987; Okiyama, 1988; Leis and Trnski, 1989). Then standard lengths of the larvae were measured and their melanophores were examined and photographed. To identify the species of engraulid larvae, approximately 600 specimens were stained to examine meristics and morphometrics. The measurements of melanophores include the items of head (MH), isthmus (MI), anterior part of gut (MFG), posterior of gut (MPG), belly (MB), anal fin base (MAFB), tail (MT), and caudal fin (MC) (Fig. 1a, b). Measurements of meristics including numbers of total vertebrae (TV), vertebrae before anus (VBA), interneurals (INT), and dorsal and anal fin rays (DFR and AFR) (Fig.

Table 1. Homogeneity test for the standard lengths of the 5 species of engraulid larvae collected in coastal waters off the Tanshui River Estuary. Species sharing the same letter are in the same homogeneous group.

Species	Sample size	Standard length (mm)		Homogeneous group
		Range	Mean ± S.D.	
Stolephorus insularis	131	8 ~ 24	15.2 ± 3.9	a
Thryssa dussumieri	937	8 ~ 32	16.4 ± 4.6	a
Encrasicholina heteroloba	1233	10 ~ 46	18.2 ± 4.2	b
Engraulis japonica	1268	10 ~ 38	21.6 ± 4.4	c
Encrasicholina punctifer	1645	12 ~ 44	24.8 ± 4.2	d

1a) were counted under a stereomicroscope. Morphometric characters of larvae, including total length (TL), standard length (SL), head length (HL), predorsal fin length (PDL), and preanal length (PAL) (Fig. 1a), were measured to the nearest 0.1 mm by profile projector at 10× magnification.

The staining method of larvae is modified from that of Potthoff (1984). The staining process includes 5 steps. 1) Larvae were preserved with alcohol and put in an acidified alcian blue solution to stain cartilage for 1 day. 2) Larvae were transferred to a saturated sodium borate solution for 12 h for neutralization. 3) After neutralization, the bones of larvae were stained with alizarin red and cleared with 1% KOH solution, lasting for only a few minutes. 4) When vertebrae were nearly clearly seen, larvae were transferred to a solution of 60% glycerin and 40% of 1% KOH for few days to destain the muscle. 5) Finally, stained larvae were preserved in pure glycerin. The bleaching process described by Potthoff (1984) was neglected to maintain the pigments of the larvae.

Data analysis

The normality of frequency distribution of standard length was tested by χ^2, and the significant test of difference in mean standard length and mean meristic count among species was conducted by Scheffe's multiple comparison test. The regressions of morphometric characters on standard length were fitted with linear regression. The differences in slope and adjusted mean of the regression lines among species were determined by analysis of covariance (ANCOVA) (Steel and Torrie, 1980).

RESULTS

Length frequency distribution

Five species of engraulid larvae were identified, and their length frequency distributions are shown in Figure 2. Standard lengths of *Engraulis japonica* Schlegel ranged between 10 and 38 mm (21.6 ± 4.4 mm, mean ± standard deviation), *Encrasicholina punctifer* Fowler, 12 and 44 mm (24.8 ± 4.2 mm), *E. heteroloba* (Ruppell), 10 and 46 mm (18.2 ± 4.2 mm), *Stolephorus insularis* Hardenberg, 8 and 24 mm (15.2 ± 3.9 mm), and *Thryssa dussumieri* (Valenciennes), 8 and 32 mm (16.4 ± 4.6 mm). Scheffe's multiple comparison test indicated that the differences of mean standard length among the 5 species were *S. insularis* = *T. dussumieri* < *E. heteroloba* < *E. japonica* < *E. punctifer* (Table 1).

Morphological descriptions

The degrees of ossification of the 5 species of engraulid larvae are shown in Figure 3. Vertebrae and fin rays, when ossified, were stained red. Dorsal, anal, and caudal fin bases and interneurals which remained cartilagenous were stained blue. Skulls appeared either red or blue or in combination, indicating that skulls were in the process of calcifying from cartilage to bone. The relative position of the dorsal fin

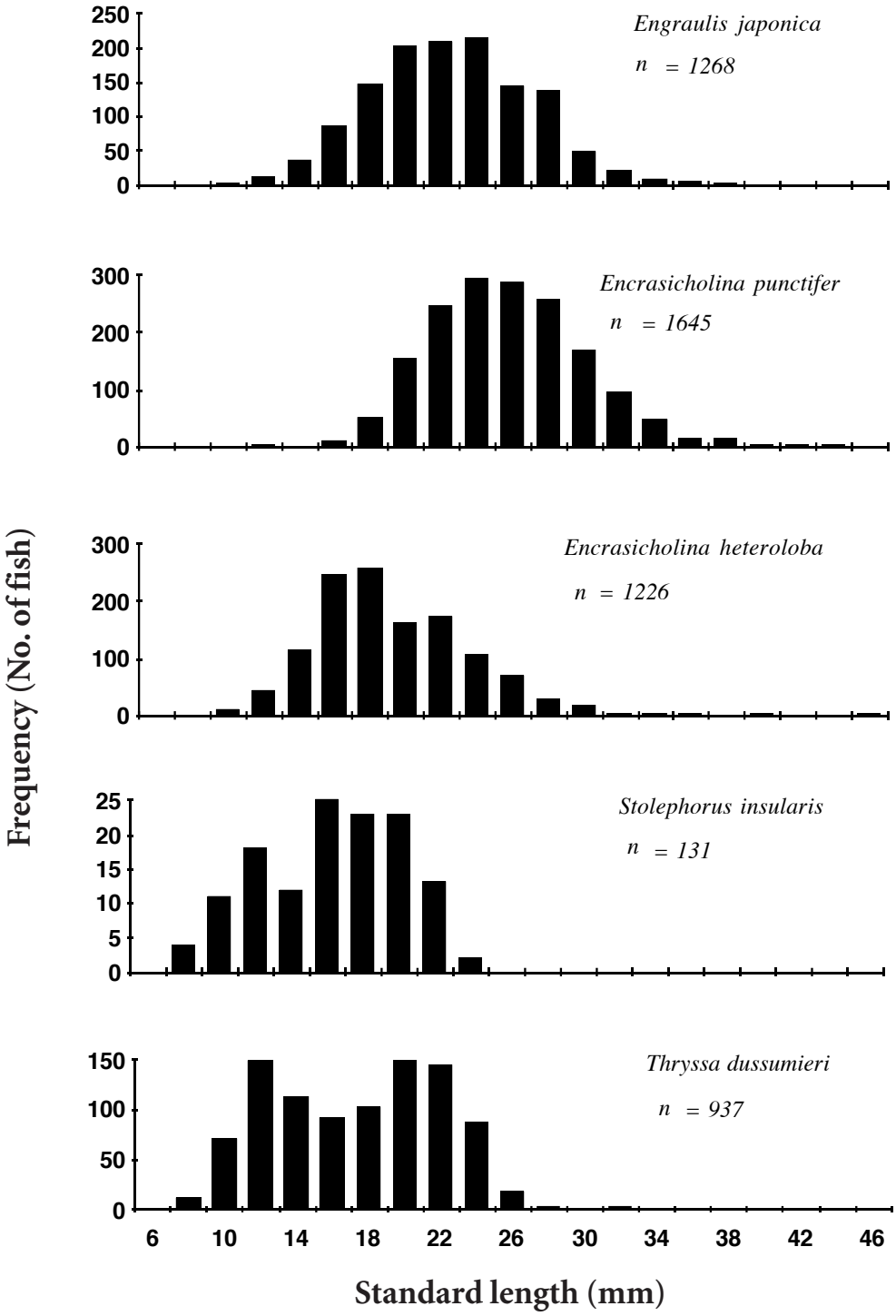

Figure 2. Length frequency distributions of engraulid larvae collected by a commercial set-net in coastal waters off the Tanshui River Estuary, northern Taiwan, April 1992 to November 1993.

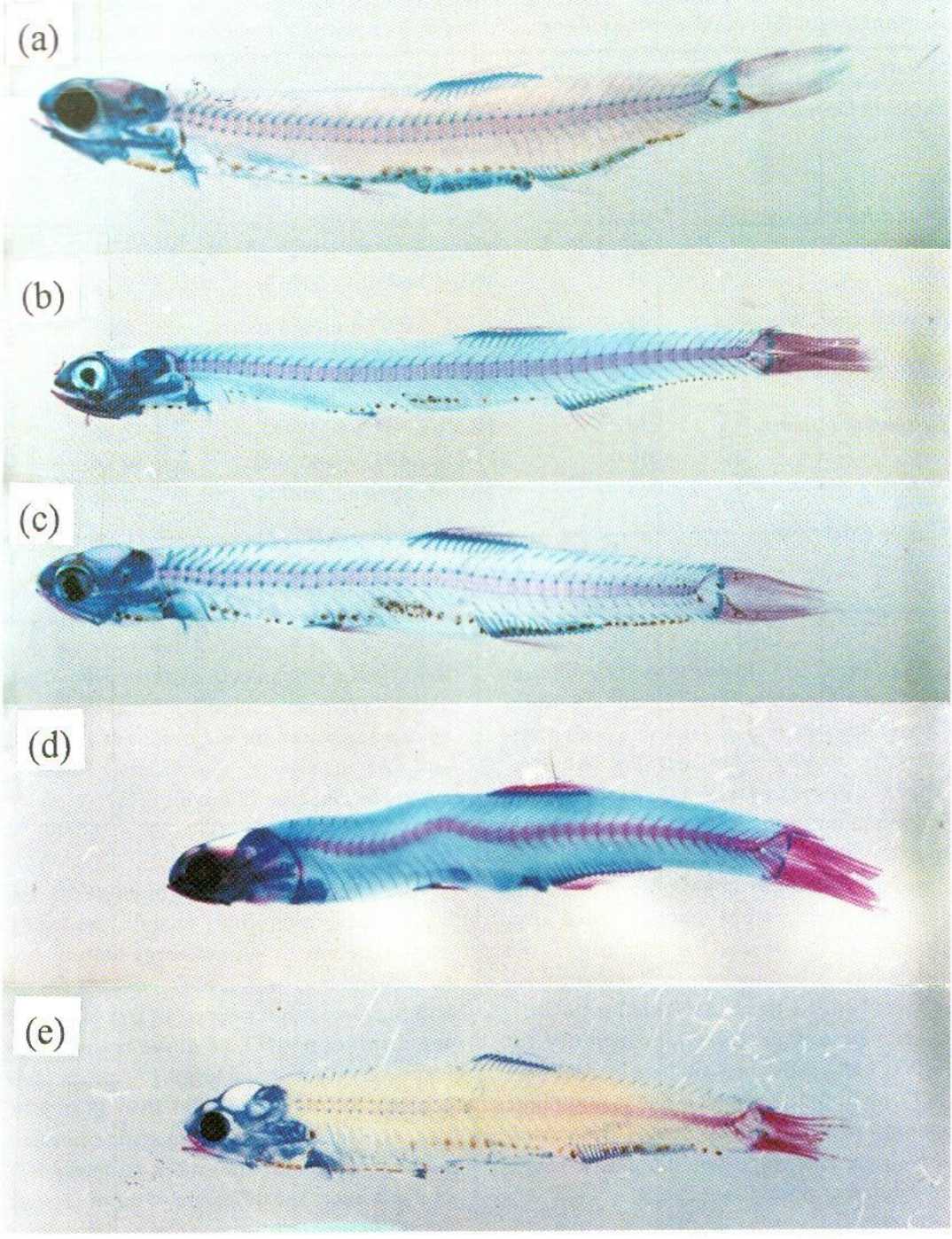

Figure 3. External and internal morphological features of stained engraulid larvae: (a) *Engraulis japonica*, 22.0 mm TL, (b) *Encrasicholina punctifer*, 21.4 mm TL, (c) *E. heteroloba*, 22.9 mm TL, (d) *Stolephorus insularis*, 21.1 mm TL, and (e) *Thryssa dussumieri*, 21.5 mm TL.

Table 2. Regressions of head length (HL), predorsal fin length (PDL), and preanal length (PAL) on standard length (SL) of the 5 species of engraulid larvae. R^2, square of correlation coefficient.

Species	Sample size	Regression	R^2
Engraulis japonica	57	HL = 0.0677 + 0.1904 SL	0.93
	51	PDL = 2.3869 + 0.4593 SL	0.84
	57	PAL = 1.6556 + 0.6165 SL	0.96
Encrasicholina punctifer	31	HL = -1.2268 + 0.2623 SL	0.93
	31	PDL = 3.7925 + 0.3893 SL	0.91
	31	PAL = 3.4004 + 0.5210 SL	0.98
Encrasicholina heteroloba	49	HL = -1.0977 + 0.2642 SL	0.93
	49	PDL = 3.8225 + 0.3683 SL	0.89
	49	PAL = 1.2696 + 0.5901 SL	0.96
Stolephorus insularis	30	HL= -0.8347 + 0.2579 SL	0.96
	30	PDL = 2.4762 + 0.4020 SL	0.86
	30	PAL = 1.8842 + 0.5010 SL	0.92
Thryssa dussumieri	49	HL = -1.1106 + 0.2752 SL	0.74
	45	PDL = 3.9239 + 0.3221 SL	0.88
	47	PAL = 3.1260 + 0.5293 SL	0.94

(DF) and anal fin (AF) was apparently different among the 5 species. They did not overlap in *Thryssa dussumieri* (Fig. 3a), overlapped 4 vertebrae in *Stolephorus insularis* (Fig. 3b), overlapped approximately 1-2 vertebrae in *Encrasicholina punctifer* (Fig. 3c), overlapped approximately 2-4 vertebrae in *E. heteroloba* (Fig. 3d), and approximately 1-3 vertebrae in *Engraulis japonica* but they seperated after growth (Fig. 3e). After staining, the melanophores became brown in color, which appeared in the head (MH), isthmus (MI), anterior part of gut (MFG), posterior of gut (MPG), belly (MB), anal fin base (MAFB), tail (MT), and caudal fin (MC). The melanophore patterns, meristic counts, and relative growth of body parts in proportion to standard length were different among the 5 species.

Morphometric characters

The regressions of head length (HL), predorsal length (PDL), and preanal length (PAL) on standard length (SL) were significant for all 5 species of engraulid larvae (R^2 = 0.75 ~ 0.98). Slopes and intercept of the regression lines of the 5 species were calculated respectively (Table 2). ANCOVA analysis indicated that slopes and adjusted means of the regressions of HL, PDL, and PAL on SL were significantly different among the 5 species (Table 3).

Meristic characters

The 5 meristic characters of engraulid larvae, dorsal fin rays (DFR), anal fin rays (AFR), total vertebrae (TV), vertebrae before anus (VBA), and interneurals (INT), did not change with standard length beyond 12 mm SL, except the number of INT of *E. japonica* which increased with standard length but also became constant at the length larger than 18 mm SL (Fig. 4). This indicates that meristic characters were already stable in this study, except for INT of *E. japonica*. The difference of mean meristic counts among the 5 species were determined by Scheffe's multiple comparison (Table 4). The number of DFR, *T. dussumieri* (Td) < *E. heteroloba* (Eh) = *E. punctifer* (Ep) < *E. japonica* (Ej) = *S. insularis* (Si) (Table 4a); AFR, Ep < Ej = Eh < Si < Td (Table 4b); INT, Td < Eh = Si < Ep < Ej (Table 4c); TV, Td = Si < Eh < Ep

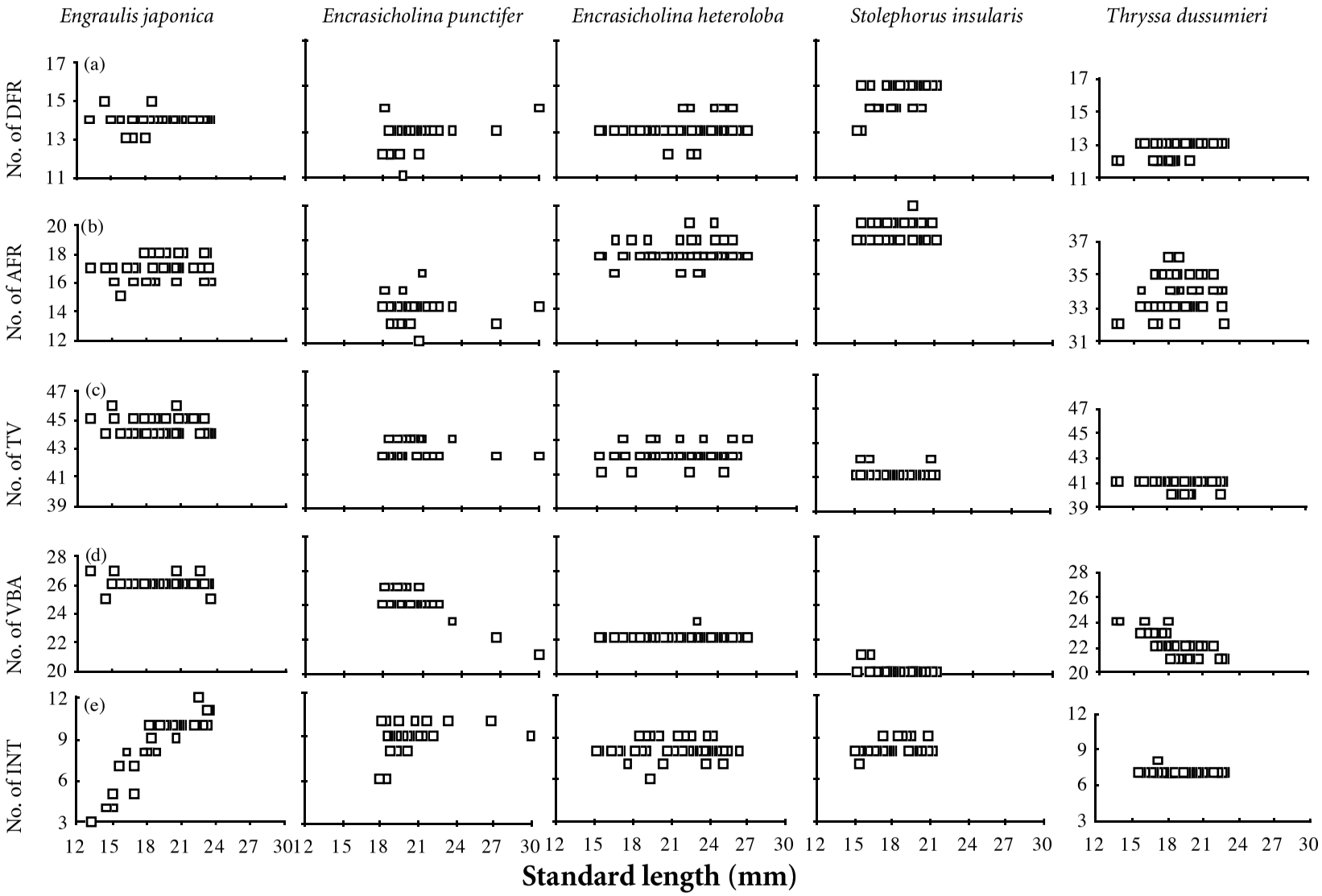

Figure 4. Counts of the 5 meristic characters vs. standard length of the 5 species of engraulid larvae collected in coastal waters off the Tanshui River Estuary: (a) dorsal fin rays, (b) anal fin rays, (c) vertebrae, (d) vertebrae before anus, and (e) interneurals.

Table 3. ANCOVA of the regression of head length (HL), predorsal fin length (PDL), and preanal lengh (PAL) on standard length (SL) among 5 species of engraulid larvae. (d.f.: degree of freedom; TA, TB: *t*-values for testing the difference in intercepts and slopes between regression lines; Significance level, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$).

Species	HL - SL			PDL - SL			PAL - SL		
pair	d.f.	TA	TB	d.f.	TA	TB	d.f.	TA	TB
Ej - Ep	85	-1.7670	-3.5955***	79	-0.8403	2.0334*	85	1.9205	3.5245***
Ej - Eh	103	-5.8306***	-4.4991***	97	4.1767***	3.2162**	103	12.8164***	1.1842
Ej - Si	84	-7.2390***	-2.6701**	78	11.4356***	1.3192	84	25.1665***	3.0801**
Ej - Td	106	-9.9459***	-4.4341***	93	13.8444***	4.0135***	101	3.0070**	3.3603**
Ep - Eh	77	-3.6645***	-0.0975	77	4.7942***	0.6349	77	9.9985***	-2.6559*
Ep - Si	58	-4.3164***	0.1634	58	9.9334***	-0.2723	58	18.3845***	0.2698
Ep - Td	77	-6.3426***	-0.5954	73	12.4167***	1.7590	75	0.6042	-0.2861
Eh - Si	76	-1.4055	0.2562	76	6.2881***	-0.7952	73	10.6933***	2.3683*
Eh - Td	95	-2.9292**	-0.5998	91	8.2244***	1.4114	93	-9.5228***	2.4488*
Si - Td	76	-1.1659	-0.6515	72	0.6148	1.7183	74	-21.7907***	-0.5090

Ej: *Engraulis japonica* Ep: *Encrasicholina punctifer* Eh: *Encrasicholina heteroloba*
Si: *Stolephorus insularis* Td: *Thryssa dussumieri*

< Ej (Table 4d); and VBA, Si < Td < Eh < Ep < Ej (Table 4e). Apparently, the number of VBA was most reliable to discriminate the 5 engraulid species.

Patterns of pigmentations

The pigment patterns of the engraulid larvae when viewed laterally were classified into 3 types (Fig. 5). Type I was for *T. dussumieri*, with several rows of melanophores on the top of the auditory vesicle and inner part of the opercles (MH), in the isthmus (MI), both dorsolateral side of fore- and post-gut (MFG and MPG), belly (MB), ventral part of the tail extending from the origin of anal fin to caudal fin bases (MAFB and MT), and lower part of the caudal fin extending to the peduncle (MC; Fig. 5a). Type II for *S. insularis* was similar to type I, except with fewer melanophores, MPG and MB absent, and MC not extending from the caudal fin to the peduncle (Fig. 5b). Type III included 3 species, *E. punctifer*, *E. heteroloba*, and *E. japonica* and was also similar to type I, but lacked MB (Fig. 5c-e). When the larvae of type III were greater than 20 mm TL, an additional row of melanophores appeared in the dorsal part of the gut and in the mid-lateral part of the posterior half of the body, respectively. This means that the pigment patterns shown on the lateral side of the body can not easily distinguish *E. punctifer*, *E. heteroloba*, and *E. japonica*.

On the other hand, pigment patterns on the ventral side of the body were completely different among the 5 species and this enables them to be distinguished from one another. *T. dussumieri* presents a row of melanophores on the belly (MB), but the other 4 species lack MB (Fig. 6a). *S. insularis* lacks MB and melanophores in both dorsolateral sides of post-gut (MPG) (Fig. 6b). The melanophores in the anal fin base (MAFB) are symmetrical in *E. punctifer* (Fig. 6c), but asymmetrical in both *E. heteroloba* and *E. japonica*. The MAFB in the former of the 2 species is spot shaped (Fig 6d) and in the latter species is a bar-like shape (Fig. 6e). This indicates that pigment patterns appearing on the ventral side are more reliable and can be used as a distinct character to discriminate theses 5 larval engraulid species. A practical key for quick identification of these 5 larvae is presented below:

Table 4. Homogeneity test for the 5 meristic characters (a ~ e) of the 5 species of engraulid larvae collected in coastal waters off the Tanshui River Estuary. Species sharing the same letter are in the same homogeneous group.

(a)

Species	Sample size	No. of dorsal fin rays Range	Mean ± S.D.	Homogeneous group
Thryssa dussumieri	54	12 ~ 13	12.7 ± 0.1	a
Encrasicholina heteroloba	90	12 ~ 14	13.1 ± 0.1	b
Encrasicholina punctifer	167	11 ~ 15	13.2 ± 0.0	b
Engraulis japonica	138	13 ~ 16	14.2 ± 0.0	c
Stolephorus insularis	30	13 ~ 15	14.5 ± 0.1	c

(b)

Species	Sample size	No. of anal fin rays Range	Mean ± S.D.	Homogeneous group
Encrasicholina punctifer	167	12 ~ 17	14.2 ± 0.1	a
Engraulis japonica	138	15 ~ 19	17.0 ± 0.1	b
Encrasicholina heteroloba	90	15 ~ 20	17.2 ± 0.1	b
Stolephorus insularis	30	18 ~ 20	18.5 ± 0.1	c
Thryssa dussumieri	54	32 ~ 36	34.0 ± 0.1	d

(c)

Species	Sample size	No. of interneurals Range	Mean ± S.D.	Homogeneous group
Thryssa dussumieri	54	7 ~ 8	7.0 ± 0.1	a
Encrasicholina heteroloba	90	4 ~ 9	7.8 ± 0.2	b
Stolephorus insularis	30	7 ~ 9	8.2 ± 0.1	b
Encrasicholina punctifer	167	6 ~ 10	9.0 ± 0.1	c
Engraulis japonica	138	3 ~ 12	9.7 ± 0.0	d

(d)

Species	Sample size	No. of vertebrae Range	Mean ± S.D.	Homogeneous group
Thryssa dussumieri	54	40 ~ 41	40.9 ± 0.0	a
Stolephorus insularis	30	41 ~ 42	41.1 ± 0.0	a
Encrasicholina heteroloba	90	41 ~ 44	42.0 ± 0.1	b
Encrasicholina punctifer	167	41 ~ 44	42.3 ± 0.0	c
Engraulis japonica	138	43 ~ 46	44.9 ± 0.0	d

(e)

Species	Sample size	No. of vertebrae before anus Range	Mean ± S.D.	Homogeneous group
Stolephorus insularis	30	20 ~ 21	20.2 ± 0.1	a
Thryssa dussumieri	54	21 ~ 24	22.0 ± 0.1	b
Encrasicholina heteroloba	90	22 ~ 25	22.4 ± 0.1	c
Encrasicholina punctifer	167	21 ~ 27	24.0 ± 0.1	d
Engraulis japonica	138	25 ~ 27	26.0 ± 0.0	e

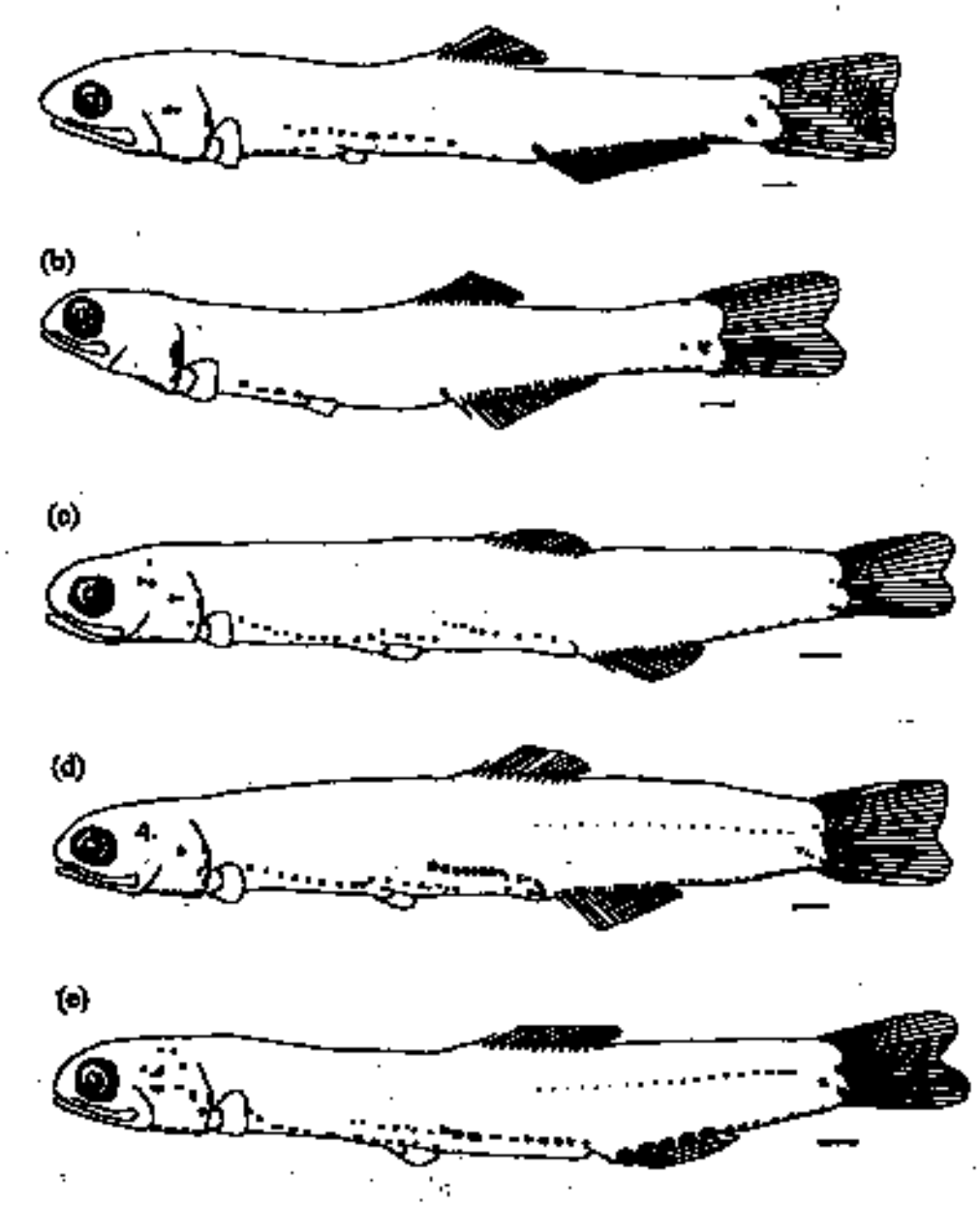

Figure 5. Schemata of the lateral-view pigment patterns of the 5 species of engraulid larvae: (a) *Thryssa dussumieri*, (b) *Stolephorus insularis*, (c) *Encrasicholina punctifer*, (d) *E. heteroloba*, and (e) *Engraulis japonica*. Scale bar = 1 mm.

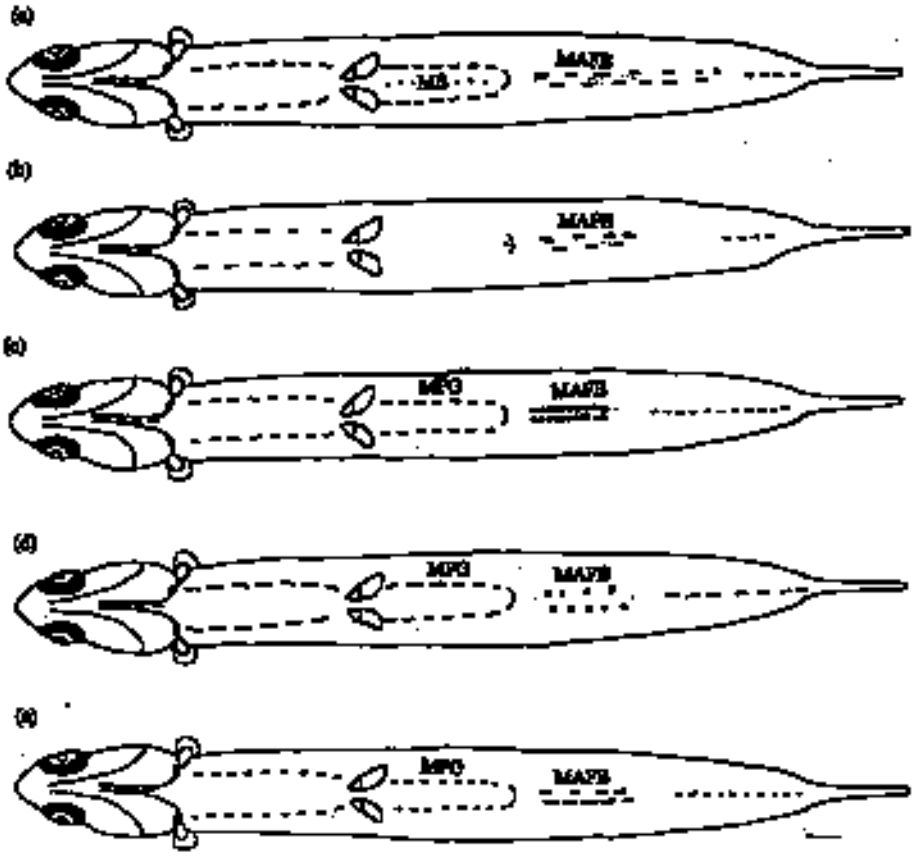

Figure 6. Schemata of the ventral-view pigment patterns of the 5 species of engraulid larvae: (a) *Thryssa dussumieri*, (b) *Stolephorus insularis*, (c) *Encrasicholina punctifer*, (d) *E. heteroloba*, and (e) *Engraulis japonica*. Scale bar = 1 mm.

Key to species of engraulid larvae

1a With melanophores on the belly (MB)
D. 12-13, A. 32-36, Vertebrae 40-41 ..... *Thryssa dussumieri*
1b Without melanophores on the belly 2
2a Without melanophores on both dorsolateral sides of post gut (MPG)
D. 13-15, A. 18-20, Vertebrae 41-42 ..... *Stolephorus insularis*
2b With melanophores on both dorsolateral sides of post gut 3
3a Melanophores on both sides of anal fin base (MAFB) are symmetrical
D. 11-15, A. 12-17, Vertebrae 41-44 ..... *Encrasicholina punctifer*
3b Melanophores on both sides of anal fin base asymmetrical 4
4a Melanophores on both sides of anal fin base small spots
D. 12-14, A. 15-20, Vertebrae 41-44 ..... *Encrasicholina heteroloba*
4b Melanophores on both sides of anal fin base a bar-like shape
D. 13-16, A. 15-19, Vertebrae 43-46 ..... *Engraulis japonica*

DISCUSSION

Five species of larval engraulids, *Engraulis japonica*, *Encrasicholina punctifer*, *E. heteroloba*, *Stolephorus insularis*, and *Thryssa dussumieri*, were found in coastal waters off the Tanshui River Estuary, northern Taiwan. The mean meristic counts are significantly different among the 5 species (Table 2), indicating that these species can be discriminated by meristic characters. Similar results were also reported by McGowan and Berry (1984), Chen (1987), Yu and Chiu (1994), and Young *et al.* (1995). However, we found that meristic counts largely overlapped among the 5 species of engraulid larvae as did results by Shen (1959). Meanwhile, meristic counts are unstable during the early developmental stage, e.g., interneurals of *E. japonica* (Fig. 4). Accordingly, meristic counts alone can not be used to clarify the species status of engraulid larvae. In addition, internal meristic characters, such as vertebrae, can not be seen without staining. Numbers of vertebrae before the anus were different among the 5 species.

The slope and adjusted mean of the linear regressions of morphometric characters relative to standard length were significantly different among the 5 species of engraulid larvae (Table 4). This indicates that the species can be discriminated by morphometric characters. However, variation in morphometric parameters in larval fishes is high because of ontogenetic changes in body shape, and damage or distortions caused during collection, and shrinkage (Leis and Rennis, 1983). A significant shift of dorsal and anal fins in the engraulid larvae was reported, and this may lead to the inconsistency in body proportions during different development stages. This phenomenon was named "iwashi type metamorphosis" (Okiyama, 1979b). Thus, morphometrics is a conditional character in the discrimination of engraulid larvae.

Pigment patterns on the ventral side of the body are quite different among the 5 species of engraulid larvae (Fig. 3). Pigments on fish body constitute a more versatile taxonomic character than meristics because pigmentation can be used over a greater range in larval size and can be easily recognized (Okiyama, 1979a; Kendall *et al.*, 1984). Several successful applications have been reported on larval identification with pigmentation, e.g., notacanthiforms and anguilliforms (Smith, 1979; Castle, 1984), clupeids (Ditty *et al.*, 1994), melanostomiids, gonostomatids, synodontids, paralepidids (Ozawa, 1986), exocoetids (Chen, 1987), tunas (Ueyanagi, 1969), and istiophorids (Ueyanagi, 1974). However, due to the greater variation in pigmentation during metamorphosis in apogonids and gobiids, or pigments easily lost during fixation, such as in labrids and bothids (Leis and Rennis, 1983; Okiyama, 1988; Leis

and Trnski, 1989), the uses of pigmentation need to be confirmed before being applied.

In conclusion, the 5 species of engraulid larvae in coastal waters off the Tanshui River Estuary can be quickly identified by their ventral-view pigment patterns.

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REFERENCES

Castle, P. H. J. (1984) Notacanthiformes and anguilliformes: development. In *Ontogeny and systematics of fishes.* H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr. and S. L. Richardson, eds. Spec. Publ. No. 1, Amer. Soc. Ichthyol. Herpetol. pp. 62-93.

Chen, C. C. and C. C. Huang (1985) Reports on fish larvae research. COA Fish. Ser. 2, 279 pp. (In Chinese)

Chen, C. H. (1987) Studies of the early life history of flying fishes (family Exocoetidae) in the northwestern Pacific. Taiwan Mus. Spec. Publ. Ser. 7, 203 pp. (in Chinese)

Chen, C. S. (1985) Occurrence of fish larvae in the Kau-Ping River Estuary. J. Fish. Soc. Taiwan 12: 1-20. (In Chinese)

Chen, C. S. (1986) Occurrence of fish larvae in the estuary of Jwo-Shoei River. J. Fish. Soc. Taiwan 13: 11-20. (In Chinese)

Chen, J. T. F. and M. J. Yu (1986) A synopsis of the vertebrates of Taiwan. Taiwan Commercial Book Co., Taipei, pp. 267-277. (In Chinese)

Cheng, T. S. (1980) Study and investigation of bull-ard and anchovy fisheries in coastal waters of Taiwan. Bull. Taiwan Fish. Res. Inst. 32: 219-233. (In Chinese)

Chen, T. S. (1984) The suitable fishing season of larval anchovy in Fang-Liao and Lin-Yuan by studying on maturity and spawning of anchovy *Stolephorus zollingeri* (Bleeker). Bull. Taiwan Fish. Res. Inst. 37: 59-66. (In Chinese)

Chen, T. S. (1987) Identification of Engraulid larval fish. Bull. Taiwan Fish. Res. Inst. 42: 77-89. (In Chinese)

Chern, Y. T. and W. N. Tzeng (1993) Feeding strategy of *Encrasicholina punctifer* and *Stolephorus insularis* larvae in the estuary of Tanshui River, Taiwan -I. Ontogenetic dietary shifts and morphological correlation. J. Fish. Soc. Taiwan 20: 313-328. (In Chinese)

Chern, Y. T. and W. N. Tzeng (1994) Feeding strategy of two larval anchovies, *Encrasicholina punctifer* and *Stolephorus insularis*, in the Tanshui River estuary, Taiwan -II. Prey selectivity and interspecific feeding competition. J. Fish. Soc. Taiwan 21: 33-48. (In Chinese)

Ditty, J. G., E. D. Houde and R. F. Shaw (1994) Egg and larval development of Spanish sardine, *Sardinella aurita* (Family Clupeidae), with a synopsis of characters to identify clupeid larvae from the northern Gulf of Mexico. Bull. Mar. Sci. 54: 367-380.

Huang, C. C., W. N. Tzeng and S. C. Lee (1985) Preliminary survey on larval fishes of Yen-Liao Bay, northeastern Taiwan. Bull. Inst. Zool., Academia Sinica 24: 147-154.

Huang, J. B. and T. S. Chiu (1996) Daily growth and length distribution of larval Japanese anchovy (*Engraulis japonica*) in the neritic waters off northeastern Taiwan. Acta Zool. Taiwanica 7: 29-41.

Kendall, A. W. Jr., E. H. Ahlstrom and H. G. Moser (1984) Early life history stages of fishes and their characters. In *Ontogeny and*

systematics of fishes. H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr. and S. L. Richardson, eds. Spec. Publ. No. 1, Amer. Soc. Ichthyol. Herpetol. pp. 11-22.

Lee, M. A., K. T. Lee and H. C. Ou (1990) The larval anchovy fishing ground formation in relation to osmotic pressure changes of the coastal waters along southern Taiwan. J. Fish. Soc. Taiwan 17: 233-245

Lee, M. A., K. T. Lee and G. Y. Shiah (1995) Environmental factors associated with the formation of larval anchovy fishing grounds in the coastal waters of southwest Taiwan. Mar. Biol. 121: 621-625

Lee, M. A., S. C. Chou, K. T. Lee and P. C. Lee (1996) Distribution of fish larvae in relation to pycnocline in the coastal waters of Tan-Shui, Taiwan. J. Fish. Soc. Taiwan 23: 195-206

Leis, J. M. and D. S. Rennis (1983) The larvae of Indo-Pacific coral reef fishes. New South Wales Univ. Press, Kensington, 269 pp.

Leis, J. M. and T. Trnski (1989) The larvae of Indo-Pacific shorefishes. Univ. Hawaii Press, Honolulu, 371 pp.

Liu, F. H. and S. C. Shen (1957) A preliminary report on the activity of wen-fishes (herring-like fishes) along the coast of Taiwan. Rep. Inst. Fish. Biol., Natl. Taiwan Univ. 1: 24-38. (In Chinese)

McGowan, M. F. and F. H. Berry (1984) Clupeiformes: development and relationships. In *Ontogeny and systematics of fishes.* H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr. and S. L. Richardson, eds. Spec. Publ. No. 1, Amer. Soc. Ichthyol. Herpetol. pp. 108-126.

Nakabo, T. (1993) Fishes of Japan with pictorial keys to the species. Tokai Univ. Press, Tokyo, 1474 pp. (In Japanese)

Okiyama, M. (1979a) Manuals for the larval fish taxonomy. (2) General aspects of larval characters that aid identification. Kaiyo to Seibutsu (Ocean and its life) 1(2): 53-59. (In Japanese)

Okiyama, M. (1979b) Manuals for the larval fish taxonomy. (3) Metamorphosis of the clupeoid fishes and problems of larval convergence. Kaiyo to Seibutsu (Ocean and its life) 1(3): 61-66. (In Japanese)

Okiyama, M. (ed) (1988) An atlas of the early stage fishes in Japan. Tokai Univ Press, Tokyo, 1154 pp. (In Japanese)

Ozawa, T. (1986) Studies on the oceanic ichthyoplankton in the western North Pacific. Kyushu Univ. Press, Fukuoka, 430 pp.

Potthoff, T. (1984) Clearing and staining techniques. In *Ontogeny and systematics of fishes.* H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr. and S. L. Richardson, eds. Spec. Publ. No. 1, Amer. Soc. Ichthyol. Herpetol. pp. 35-37.

Powles, H. and D. F. Markle (1984) Identification of larvae. In *Ontogeny and systematics of fishes.* H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr. and S. L. Richardson, eds. Spec. Publ. No. 1, Amer. Soc. Ichthyol. Herpetol. pp. 31-33.

Shen, S. S. (1959) Anchovies found in Taiwan. Rep. Inst. Fish. Biol., Natl. Taiwan Univ. 1: 24-33.

Shen, S. S. (1971) Preliminary report on the study of wen-yü resources of Taiwan. ACTA Oceanographica Taiwanica 1: 101-126.

Shen, S. C. (1984) Synopsis of fishes of Taiwan. Southern Materials Center Inc., Taipei, pp. 96-101.

Shen, S. C., S. C. Lee, K. T. Shao, H. K. Mok, C. T. Chen and C. H. Chen (1993) Fishes of

Taiwan. Dept. Zool., Natl. Taiwan Univ. 960 pp.

Smith, D. G. (1979) Guide to the leptocephali (Elopiformes, Anguilliformes and Notacanthiformes). NOAA Tech. Rep. NMFS Circ. 424.

Steel, R. G. D. and J. H. Torrie (1980) Principles and procedures of statistics. McGraw-Hill, Aukland, 633 pp.

Tsai, C. F., P. Y. Chen, M. A. Lee, K. Y. Hsia and K. T. Lee (1996) Effects of fishing effort on stock size and catch of larval anchovy in coastal waters of southwestern Taiwan. Fish. Res. 28: 71-83.

Tzeng, W. N. and Y. T. Wang (1986) Seasonal occurrence, abundance and diversity of larval fishes in the Shuang-hsi River estuary, northeastern Taiwan. Na. Sci. Council Monograph Ser. 14: 135-154. (In Chinese)

Tzeng, W. N. and Y. T. Wang (1992) Structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan. Mar. Biol. 113: 481-490.

Tzeng, W. N. and Y. T. Wang (1993) Hydrography and distribution dynamics of larval and juvenile fishes in the coastal waters of Tanshui River estuary, Taiwan, with reference to estuarine larval transport. Mar. Biol. 116: 205-217.

Tzeng, W. N. and Y. T. Wang (1997) Movement of fish larvae with tidal flux in the Tanshui River Estuary, northern Taiwan. Zool. Studies 36: 179-185

Ueyanagi, S. (1969) Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga*. Bull. Far Seas Fish. Res. Lab. 2: 177-256. (in Japanese)

Ueyanagi, S. (1974) On an additional diagnostic character for the identification of billfish larvae with some notes on the variations in pigmentation. NOAA Tech. Rep. NMFS Circ. 675: 73-78.

Wang, S. B. and P. P. Hwang (1992) Occurrence of fish larvae and juveniles in Tan-Shui estuary, northern Taiwan. J. Fish. Soc. Taiwan 19: 173-182.

Wang Y. T. (1987) Studies on the eggs, larvae and juveniles of fishes in the estuaries of Tansui and Shuang-hsi Rivers, northern Taiwan. MSc Thesis, Inst. Mar. Sci., Chinese Culture Univ., 306 pp. (In Chinese)

Wang, Y. T., W. N. Tzeng and S. C. Lee (1991) A preliminary study on species composition and seasonal abundance of fish eggs and larvae from the coastal waters adjacent to the Tansui River estuary, Taiwan (1984-1985). J. Fish. Soc. Taiwan 18: 7-20.

Wang, Y. T. and W. N. Tzeng (1997) Temporal succession and spatial segregation of clupeoid larvae in the coastal waters off the Tanshui River Estuary, northern Taiwan. Mar. Biol. 129: 23-32.

Whitehead, P. J. P., G. J. Nelson and T. Wongratana (1988) FAO species catalogue, Vol. 7 Clupeoid fishes of the world (suborder Clupeoidei), Part 2 - Engraulididae. FAO, Rome, 579 pp.

Young, S. S., C. C. Chen and T. S. Chiu (1992) Resource characteristics of young herring-like fish in the I-Lan Bay area - Fishing season, major species and size variation. J. Fish. Soc. Taiwan 19: 273-281.

Young, S. S., T. S. Chiu and S. C. Shen (1994) A revision of the family Engraulidae (Pisces) from Taiwan. Zool. Studies 33: 217-227.

Young, S. S., T. S. Chiu and S. S. Shen (1995) Taxonomic description and distribution of larval anchovy (Engraulidae) occurred in the waters around Taiwan. Acta Zoologica Taiwanica 6: 33-60.

Yu, P. T. and T. S. Chiu (1994) Fishery target species of larval anchovy fishery in the western central Taiwan. J. Fish. Soc. Taiwan 21(3): 227-239.

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