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Morphological and molecular identification of leptocephali of Taiwanese duckbill conger, *Gavialiceps taiwanensis* (Chen & Weng, 1967) (Family Congridae)

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Abstract

The leptocephali of the Taiwanese duckbill conger are described in detail for the first time based on specimens collected from near the type locality. Morphological and molecular features are employed to compare the leptocephali, juveniles and adults. The morphology of leptocephali can be divided into three stages, with clear metamorphosis of the jaw structure and morphometric proportions. Detailed description and comparison of each leptocephalic stage, juveniles and adults, and the ontogenetic changes of leptocephali are provided.

Key words: Taxonomy, larvae, eel, leptocephalus, Taiwan

Introduction

The eel genus *Gavialiceps*, a member of the conger family Congridae (*sensu* Smith, 1999), is distinguished by having an extremely slender body with a filamentous tail; eye slightly protruding above head profile in lateral view; jaws very long, upper jaw projecting beyond lower jaw anteriorly; rictus extending behind the eye; no pectoral fin, gill openings at lateral side of head; teeth conical, arranged in multiple rows, the inner row of maxillary teeth separated from the outer rows; teeth on mid-line of vomer clearly larger than those on both sides; dorsal fin originating above gill openings, at about the 6th–9th lateral-line pores; trunk length about 1.3–2.8 times head length; preanal lateral-line pores 40–56; and lateral-line pores gradually smaller behind anus (Karmovskaya, 1993; placed under family Muraenesocidae).

The genus currently comprises five species: *G. arabicus* (D'Ancona, 1928) *G. bertelseni* Karmovskaya, 1993, *G. javanicus* Karmovskaya, 1993, *G. taeniola* Alcock, 1889, and *G. taiwanensis* (Chen & Weng, 1967), and is widespread in the Indo-west Pacific ocean.

Chen & Weng (1967) described *Chlopsis taiwanensis* based on 31 specimens collected from off Dong-gang, southwestern Taiwan. The species was assigned to *Gavialiceps*, as a junior synonym of *G. taeniola* by Castle (1977). Karmovskaya (1993) compared the above-mentioned five species and separated *G. taiwanensis* and *G. bertelseni* from the rest three species by having a light body color. Although both *G. taiwanensis* and *G. bertelseni* have a black gill chamber, *G. taiwanensis* has a black gill opening that can be observed externally. As well as this key character, Karmovskaya (1993) also provided 54–55 preanal vertebrae, 6 cephalic lateral-line pores and 73 preanal dorsal-fin rays as diagnostic characters.

Based on our observation, *G. taiwanensis* is very common and the most-abundant eel species in the bycatch of midwater trawls. During the fishing season of Sakura shrimp (*Lucensosergia lucens*) in Taiwan, many midwater fishes, such as lanternfishes, codlets, barracudina and *G. taiwanensis* are collected and sold as aquaculture feed. However, the morphology of its leptocephalus is still unknown.

Recently we collected large numbers of leptocephali caught by midwater trawl which are closely similar to Castle's (1977) description of that of *G. taeniola*. We found clear metamorphosis of the jaw structure, morphometric proportions and patterns of pigmentation among these specimens. A DNA barcoding study is

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conducted to compare these specimens with the juveniles and adults of *G. taiwanensis* in Taiwan. All specimens are proved to be leptocephali of *G. taiwanensis*, and detailed descriptions of the different stages, and of juveniles and adults, are provided here.

Methods and materials

A total 40 leptocephali, 23 juveniles and 42 adults of *G. taiwanensis* were examined. Measurements are direct distance point to point. Total length (TL) is measured from tip of snout to rear end of tail. Head length (HL) is measured from tip of snout to upper end of gill opening. Predorsal length is measured from tip of snout to origin of dorsal fin. Preanal length is measured from tip of snout to origin of anal fin. Snout length is measured from tip of snout to anterior margin of eye. Upper jaw length is measured from tip of snout to posterior end of mouth gape. Eye diameter is horizontal distance of anterior and posterior margins of the eye. Specimens were obtained from the landing place in Dong-gang fishing port, southwestern Taiwan, and were collected mainly by midwater trawl. Specimens were deposited at the National Museum of Marine Biology & Aquarium (NMMB-P) and are listed as follows.

Leptocephali. Stage 1. NMMB-P27898 (1, 150 mm TL), 7 Nov. 2017; NMMB-P27902 (1, 150+), 7 Nov. 2017. NMMBP27897 (1, 132+), 7 Nov. 2017; NMMB-P27909 (1, 149), 6 Dec. 2017; all collected by midwater trawl from off Dong-gang, SW Taiwan. Stage 2. NMMB-P27901 (1, 137+), 7 Nov. 2017; NMMB-P27903 (4, 128+–135), 7 Nov. 2017; NMMB-P27905 (1, 144), 7 Nov. 2017; NMMB-P27908 (1 of 7, 137+), 6 Dec. 2017; all collected by midwater trawl from off Dong-gang, SW Taiwan. Stage 3. NMMB-P27900 (1, 150+), 7 Nov. 2017; NMMB-P27904 (1, 118+), 7 Nov. 2017. NMMB-P27895 (17, 69+–152), 7 Nov. 2017. NMMB-P27906 (1, 127+), 7 Nov. 2017; NMMB-P27908 (4 of 7, 126+–156), 6 Dec. 2017; NMMB-P27910 (1, 141), 6 Dec. 2017; all collected by midwater trawl from off Donggang, SW Taiwan. Unknown stage. NMMB-P27904 (2, 117+–118+ mm TL), 07 Nov. 2017. NMMB-P27908 (2 of 7, 153–155 mm TL), 6 Dec. 2017; all collected by midwater trawl from off Dong-gang, SW Taiwan.

Juveniles. NMMB-P27893 (7, 87.3–103.2 mm PAL), 18 May 2017; NMMB-P27907 (16, 61.3–83.4 mm PAL), 6 Dec. 2017; all collected by midwater trawl from off Dong-gang, SW Taiwan.

Adults. Lectotype. NMMB-P1405 (1, 168 mm PAL), Dong-gang, SW Taiwan, 2 Feb. 1965. Paralectotypes. NMMB-P1360 (2, 154–172 mm PAL) and NMMB-P1410 (1, 192 mm PAL), Dong-gang, SW Taiwan, 4 Mar. 1965. Non-types. NMMB-P7438 (1, 160 mm PAL), Daxi, NE Taiwan, 16 Apr. 2004; NMMB-P7597 (1, 240 mm PAL), Kaohsiung, SW Taiwan, 4 Jul. 2004; NMMB-P8382 (3, 168–173 mm PAL), Dong-gang, SW Taiwan, 16 Mar. 2005; NMMB-P3211 (3, 180–195 mm PAL), Taiwan, 23 May 1983; NMMB-P3210 (3, 201–214 mm PAL), Taiwan. NMMB-P9187 (1, 226 mm PAL), Daxi, NE Taiwan, 8 Sep. 2008; NMMB-P1752 (3, 191–206 mm PAL), Daxi, NE Taiwan, 9 Sep. 2003; NMMB-P10067 (1, 220 mm PAL), Dong-gang, SW Taiwan, 12 Nov. 2009; NMMB-P2814 (2, 172–177 mm PAL), Kaohsiung, SW Taiwan, 10 Nov. 2001; NMMB-P27894 (7, 144–179 mm PAL), Dong-gang, SW Taiwan, Jun. 2017; ASIZP66852 (1, 123 mm PAL), South China Sea, 9 Mar. 2006; ASIZP63824 (1, 171 mm PAL), 11 Sep. 2002. ASIZP67190 (1, 161 mm PAL), Daxi, NE Taiwan, 5 Apr. 2006; ASIZP67182 (1, 154 mm PAL), Daxi, NE Taiwan, 4 Mar. 2006; ASIZP61770 (1, 160 mm PAL), NE Taiwan, 18 May 2001; ASIZP67168 (1, 135 mm PAL), NE Taiwan, 18 May 2001; ASIZP61769 (1, 198 mm PAL), NE Taiwan, 18 May 2001; ASIZP64238 (2, 175–182 mm PAL), NE Taiwan, 26 Aug. 2003; ASIZP66920 (1, 210 mm PAL), South China Sea, 7 Mar. 2006; ASIZP62394 (3, 136–183 mm PAL), SW Taiwan, 10 Nov. 2001.

Abbreviations. TL=total length, PAL=preanal length, PDL=predorsal length, TR=trunk length, BD=body depth, HL=head length, S=snout length, ED=eye diameter, UJ=upper-jaw length, PALL=lateral-line pores before anal-fin origin, PDLL= lateral-line pores before dorsal-fin origin, PAM=preanal myomeres, PDM= predorsal myomeres, TM=total myomeres, PAV=preanal vertebrae, PDV=predorsal vertebrae, TV=total vertebrae.

Genetic analysis. Extractions of genomic DNA and applications of polymerase chain reaction generally followed Tighe *et al.* (2018; this volume). Genomic DNA was eluted in 100 µl of ddH_2O. The DNA barcode 5' region of the COI mtDNA locus was amplified in 5 µl reactions using the FISHF1(5' TCAACCAACCACAAAGACATTGGCAC) and FISHR1 (5' TAGACTTCTGGGTGGCCAAAGAATCA) primers. Cycle-sequence reactions were performed in both directions, using the PCR primers and SuperRed PCR Master Mix Kit's in 2x 12.5 µl reactions run on an Applied Biosystems 2720 Thermal Cycle. Raw trace files were

edited in MEGA 7 program, complementary strands were aligned, edited, and inspected for translation. Consensus sequences were generated and deposited in GenBank. Neighbor joining (NJ) analyses were performed using MEGA7 with the rapid bootstrap inferences (1000 replicates).

GenBank accession numbers and vouchers. *Gavialiceps taiwanensis*: MH414526–MH414538, MH414542 (leptocephali; NMMB-P29518–9, 29590, 29592, 29718–22, 29710–4); MH414539–MH414541 (juveniles; NMMB-P29715–7); and KU942791–KU942793 (adults; ASIZP 67168, 67182, 67190). *Muraenesox cinereus*: KU942798–9 (ASIZP 76195, 79491). *Elops machnata*: KU942721 (ASIZP 79402).

Results

Gavialiceps taiwanensis (Chen & Weng, 1967)

Chlopsis taiwanensis Chen & Weng, 1967:81, fig. 61 (type locality: Tungkang (=Dong-gang), southwestern Taiwan).
Gavialiceps taiwanensis (Chen & Weng, 1967): Karmovskaya, 1993:73. Smith in Randall & Lim, 2000:586. Ho *et al.*, 2010:25. Ho & Shao, 2011:24. Ho *et al.*, 2015a:8. Ho *et al.*, 2015b:150.

Diagnosis. Juveniles and adults with light grayish body color, skin transparent and body white, pale grayish dorsally, white ventrally; gill chamber and gill opening black. Predorsal vertebrae 6–9; preanal vertebrae 46–52; preanal lateral-line pores 46–52; total vertebrae 225+; dorsal-fin rays before origin of anal fin 65–72.

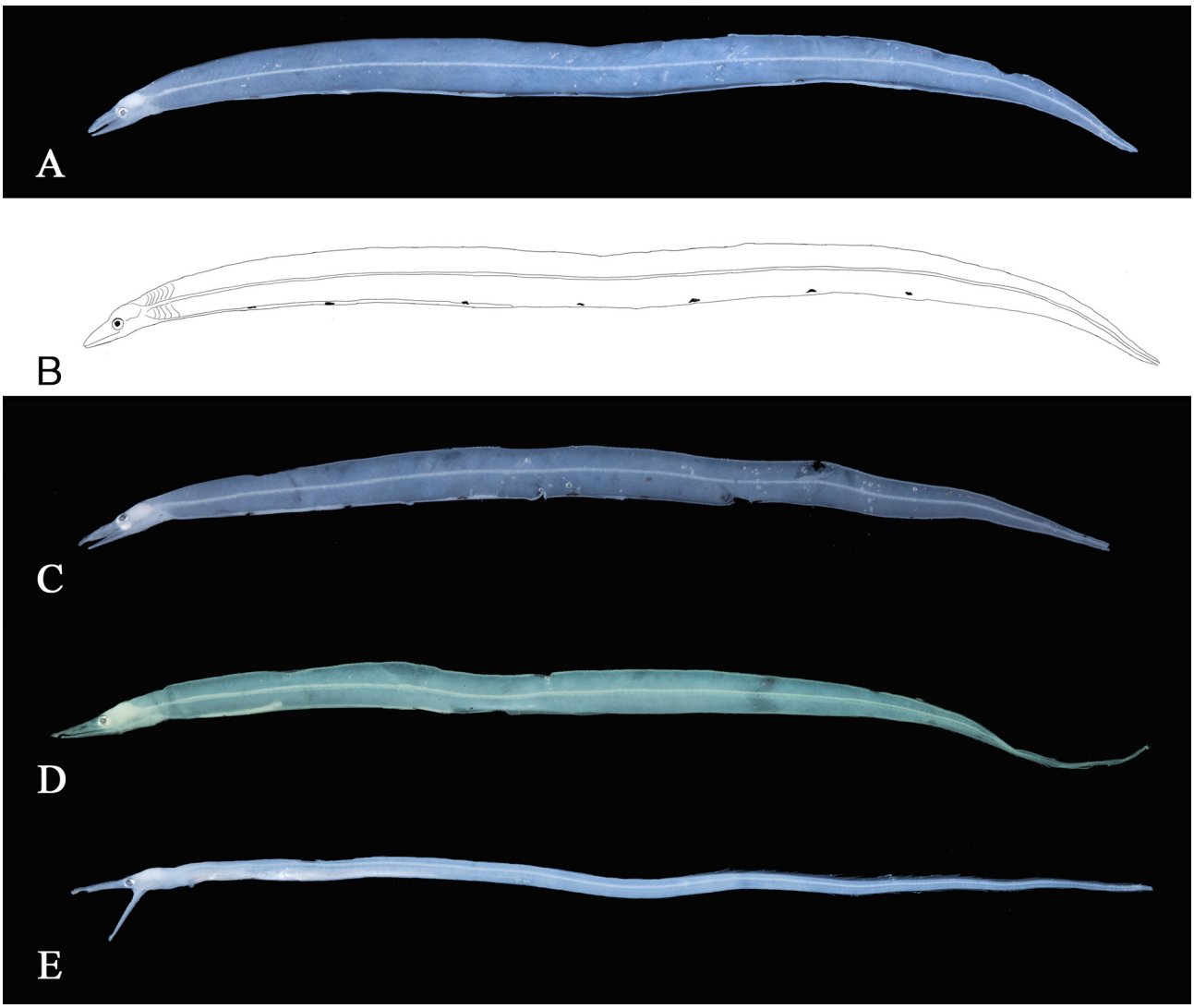

FIGURE 1. General appearance of *G. taiwanensis*. A, B. Stage 1, NMMB-P27898, 150 mm TL. C. Stage 2, NMMB-P27901, 137+ mm TL. D. Stage 3, NMMB-P27900, 144 mm TL E. Juvenile, NMMB-P27907, 72.4 mm PAL.

TABLE 1. Meristics and morphometrics of three leptocephalic stages of *G. taiwanensis*.

	Stage 1	Stage 2	Stage 3
TL (mm)	132+–150+ (n=4)	125+–144 (n=7)	114+–156+ (n=25)
PAL (mm)	86.4–108.3 (n=3)	57.2–109.1 (n=6)	42.2–98.2 (n=22)
TM	173+–203+ (n=2)	164+–227 (n=5)	152+–212+ (n=15)
PDM	66 (n=1)	13–99 (n=3)	8–77 (n=11)
PAM	108–111 (n=2)	58–134 (n=4)	50–123 (n=14)
% TL			
HL	5.1–5.9	5.5–6.0	6.4–8.9
PDL	42.0–51.6	52.1–61.5	10.4–41.4
PAL	57.6–72.7	44.5–80.8	30.2–64.3
TR	51.7–67.5	39.3–75.3	22.5–56.3
% PAL			
PDL	68.7–72.9	35.3–76.1	24.2–71.8
HL	7.1–10.3	6.8–13.9	10.0–27.0
UJ	3.6–5.4	3.9–9.3	5.0–16.0
ED	1.2–1.7	1.2–2.3	1.3–3.3
S	3.2–4.2	3.4–6.5	4.0–12.8
BD	6.0–6.7	5.1–9.9	4.9–14.4
TR	89.7–92.9	86.1–93.2	73.0–90.0
% HL			
ED	15.0–18.3	13.3–19.7	12.4–17.2
S	40.9–45.4	45.4–49.9	40.0–55.9
UJ	49.3–57.3	49.5–66.9	49.8–70.1

Leptocephali with body markedly attenuate, narrow, tape-like, with long and almost filamentous tail; body depth 3.2–4.4% TL; pectoral fin absent; body devoid of pigment, except for row of 5 to 8 large melanophores along ventral margin. Total myomeres up to 227; predorsal myomeres 8–99; and preanal myomeres 50–134.

Description of Stage 1 (Figs. 1A, 1B, 3A, 4A, 5A). Largest specimen examined is 150+ mm TL (n=4). Total myomeres 173+–203+ (n=2); predorsal myomeres 66 (n=1); and preanal myomeres 108–111 (n=2). Head small, head length 5.1–5.9% TL. Tip of snout bluntly pointed, no trace of expansion; extending slightly beyond tip of lower jaw anteriorly. Dorsal fin origin at about middle of body, predorsal length 42.0–51.6% TL. Position of anus variable, slightly behind midpoint of body (57.6% TL) in a 150 mm specimen and at two-thirds of body (72.7% TL) in 149 mm specimen. Eye relatively large, 15.0–18.3% HL; snout relatively short, 40.9–45.4% HL; end of mouth gape below middle of eye, upper-jaw length 49.3–57.3% HL. Complete data provided in Table 1.

Description of Stage 2 (Figs. 1C, 3B, 5B). Largest specimen examined is 144 mm TL (n=7). Total myomeres 164+–227 (n=5); predorsal myomeres 13–99 (n=3); and preanal myomeres 58–134 (n=4). Head small, head length 5.5–6.0% TL. Tip of snout more pointed than those of Stage 1 but no trace of expansion, extending well beyond tip of lower jaw anteriorly. Dorsal fin originating from near nape to behind middle of body, predorsal length 52.1–61.5% TL. Position of anus variable, well behind middle of body, preanal length 44.5–80.8% TL. Eye moderately large, 13.3–19.7% HL; snout slightly longer than that of Stage 1, its length 45.4–49.9% HL; end of mouth gape below middle to posterior margin of eye, upper-jaw length 49.5–66.9% HL. Complete data provided in Table 1.

Description of Stage 3 (Figs. 1D, 3C, 5C). Largest specimen examined is 156+ mm TL (n=25). Total myomeres 152+–212+ (n=15); predorsal myomeres 8–77 (n=11); and preanal myomeres 50–123 (n=14). Head small to moderately large, head length 6.4–8.9% TL. Tip of snout pointed with clear expansion, extending well beyond tip of lower jaw anteriorly, just behind the expansion; a concavity on each side of snout forming a neck-like structure. Tip of lower jaw less expanded than that of upper jaw and not forming neck-like structure. Dorsal fin

originating from near nape to about middle of body, predorsal length 10.4–41.4% TL. Position of anus variable, at anterior third to three-fourths of body, preanal length 30.2–64.3% TL. Eye relatively small, 12.4–17.2% HL; snout slightly slender, 40.0–55.9% HL; end of mouth gape below to slightly behind posterior margin of eye, upper-jaw length 49.8–70.1% HL. Complete data provided in Table 1.

FIGURE 2. General appearance of *G. taiwanensis*. A. Adult, ASIZP 61770, 161.3 mm PAL. B. Adult, 208.1 mm PAL

Description of juveniles (Figs. 1E, 3D, 4B, 5D). Body very slender, trunk somewhat cylindrical, with a filamentous tail; body depth 1.2–2.7% TL. Head slightly shorter, head length 10.0% TL. Dorsal origin above or slightly behind gill opening. No pectoral fin. Anus at anterior two-fifths of the fish, preanal length 41.1% TL. Both jaws markedly slender with a rounded expansion at anterior tip; end of mouth gape well behind posterior margin of eye. Those large melanophores along ventral margin faded or absent; melanophores present along upper margin of vertebrae and dorsal surface of head; dorsal surface of body covered with tiny chromatophores; body less transparent. Complete data provided in Table 2.

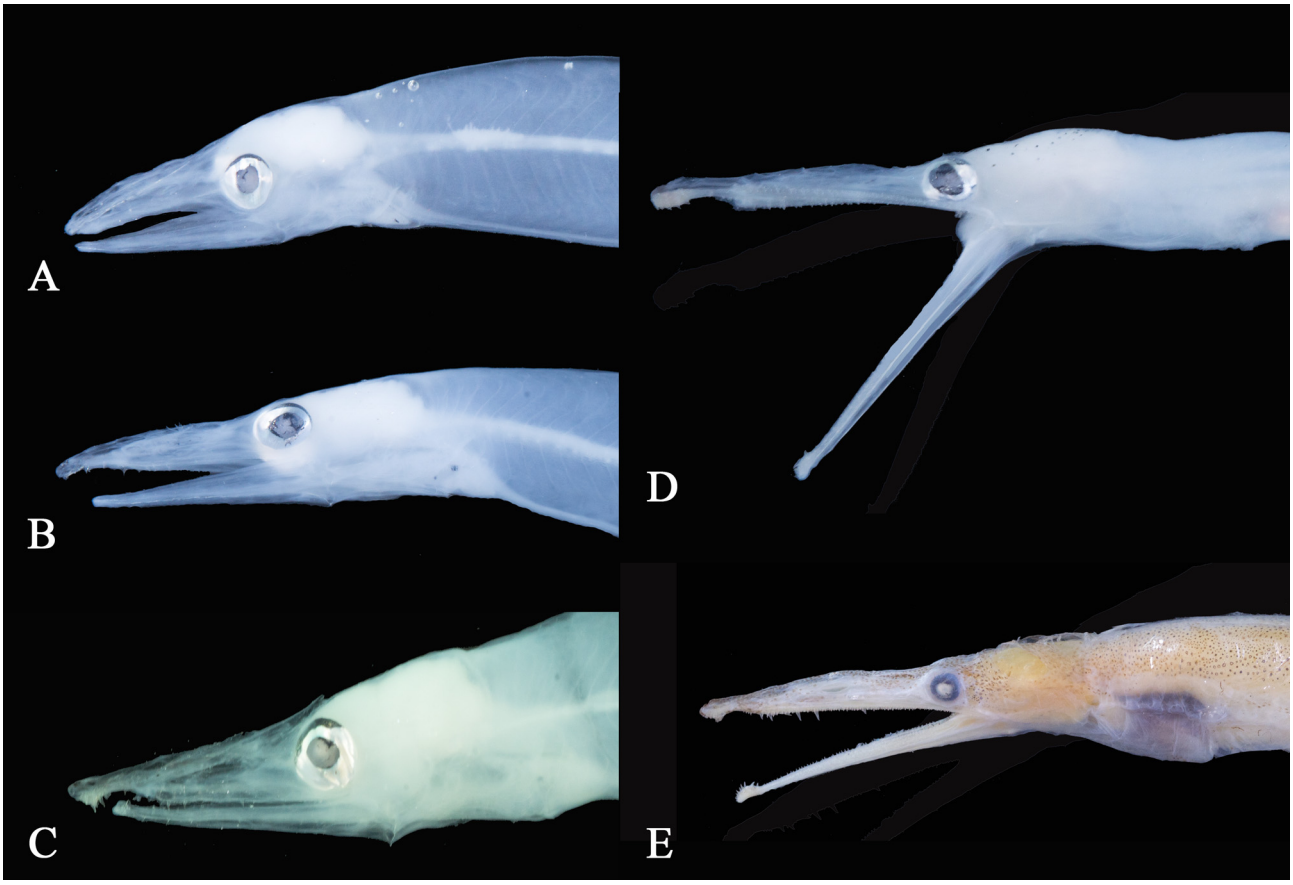

FIGURE 3. Lateral view of head showing jaw development of *G. taiwanensis*. A. Stage 1, NMMB-P27898, 150 mm TL. B. Stage 2, NMMB-P27901, 137+ mm TL. C. Stage 3, NMMB-P27900, 144 mm TL. D. Juvenile, NMMB-P27907, 72.4 mm PAL. E. Adult, ASIZP61770, 161.3 mm PAL.

Description of adults (Figs. 2A, 2B, 3E, 4C, 5E). Total vertebrae 201+–225+ (n=9); predorsal vertebrae 6–9; and preanal vertebrae 47–52; predorsal lateral-line pores 5–7; preanal lateral-line pores 46–52; dorsal-fin rays before vertical through origin of anal fin 65–72. Head small and slender, head length 8.2–11.3% TL. Snout more slender than juveniles. Dorsal-fin origin above gill opening, predorsal length 8.3–11.4% TL. No pectoral fin. Anus at anterior third to before middle of the fish, preanal length 30.3–43.0% TL. Dorsal surface of head and body deep grayish; both upper and lower margins of vertebrae covered by dense melanophores; black color in gill chamber and surfaces of gut become obvious and can be observed in the semi-transparent body. Largest specimen with complete tail examined is 696 mm TL. Complete data provided in Table 2.

Molecular identification

Sequences of 14 leptocephali, 3 juveniles and 3 adults of *G. taiwanensis* were analyzed and compared with 3 outgroups. Figure 6 shows the Neighbor joining cladogram of relationship of all sequences. The K2P distances among leptocephali, juveniles and adults, and outgroups are shown in Table 3 .The ingroup can be separated from the outgroups by having K2P distance 0.279–0.285 (*Muraenesox cinereus*, n=2) and 0.359–0.362 (*Albula glossodonta*, n=1). The ingroup forms a monophyletic group comprising all leptocephali, juveniles and adults and the K2P distances among these sequences are 0.000–0.005. Consequently, they are recognized as the same species, *G. taiwanensis*.

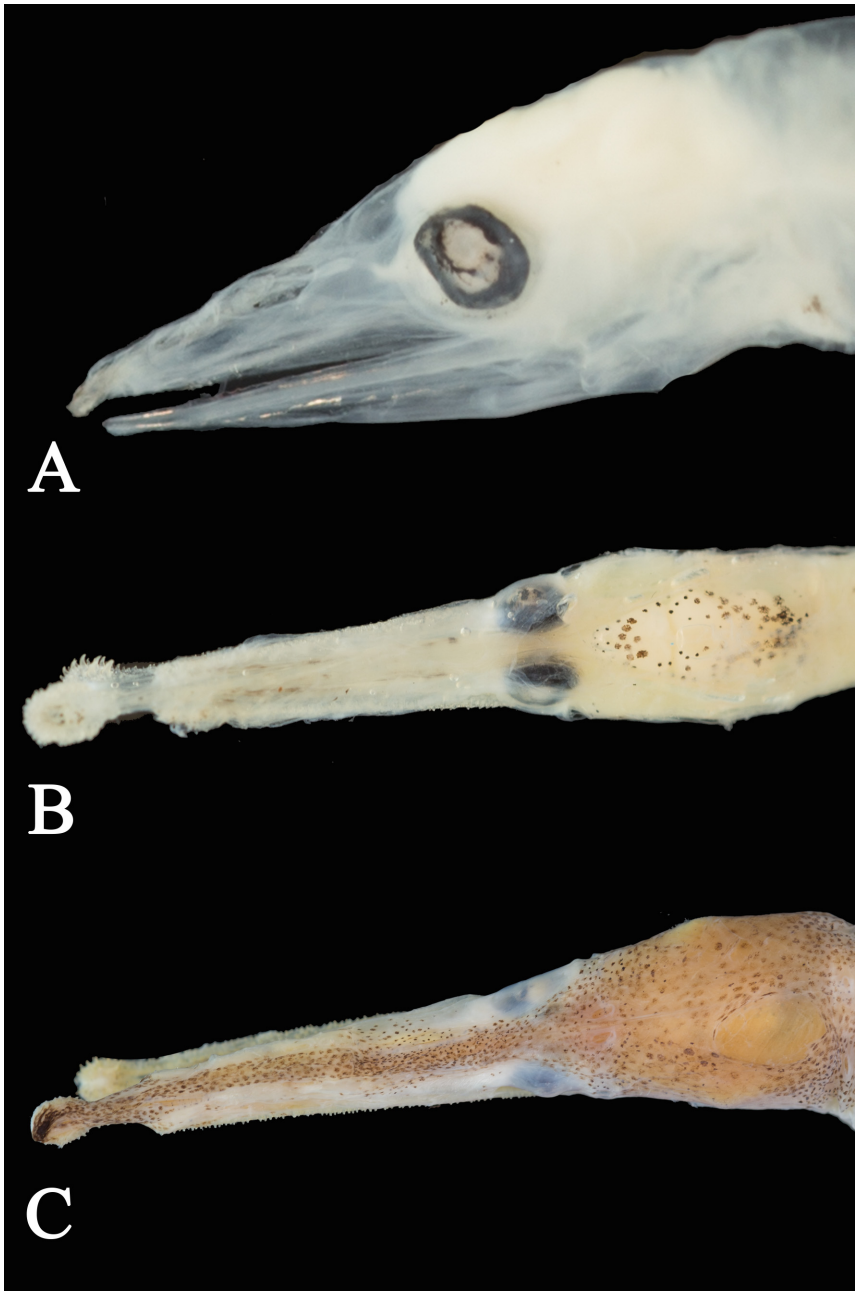

FIGURE 4. Dorsal view of head showing pigmentation of *G. taiwanensis*. A. Leptocephalus, NMMB-P27902, 150+ mm TL. B. Juvenile, NMMB-P27893, 103.2 mm PAL. C. Adult, NMMB-P2814, 172 mm PAL.

Discussion

In general appearance, the leptocephali of *G. taiwanensis* are transparent with 5–8 large black spots along the ventral margin and devoid of pigment elsewhere on the body (Figs. 1A–D, 4A, 5A–C). The snout and jaws gradually becoming longer, with the tip of the snout gradually expanding in Stage 3 (Figs. 3A–C) and after. Juveniles are semi-transparent with the black spots on ventral margin becoming indistinct or disappearing totally (Fig. 5D). The dorsal half of body and snout with pigment accumulating gradually; top of head with a cluster of large chromatophores (Figs. 4B, 5D). In adults, the body becomes less transparent, entirely covered by chromatophores, including the head and lower half of body (Figs. 3E, 4C, 5E). However, those chromatophores are on the skin on the upper half of body and under the transparent skin on lower half of body.

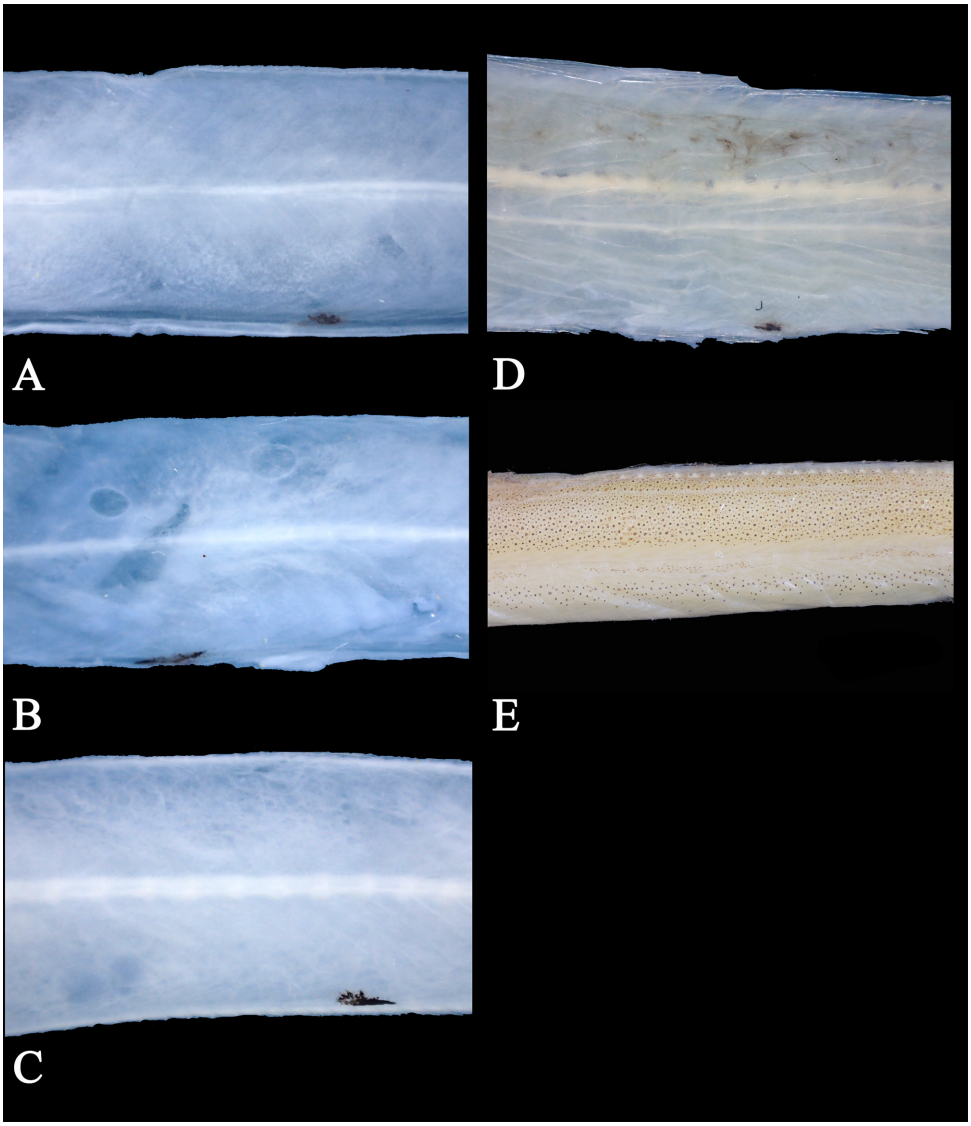

FIGURE 5. Close-up view of lateral side of body showing the pigmentation of *G. taiwanensis*. A. Stage 1, NMMB-P27898, 150 mm TL. B. Stage 2, NMMB-P27901, 137+ mm TL. C. Stage 3, NMMB-P27900, 144 mm TL. D. Juvenile, NMMB-P27893, 95.9 mm PAL. E. Adult, ASIZP 61770, 161.3 mm PAL.

Table 1 shows the meristic and morphometric data of the three growth stages recognized by us. Although the number of total myomeres is a good character to match the leptocephali and their adults, it is not easy to count precisely in *Gavialiceps* because they have a very tapering tail that is easily broken. The largest number of myomeres we counted for a specimen was 227 (Stage 2), whereas the rest have 152+–212+.

The leptocephali usually show dramatic changes in the position of the origins of the vertical fins with growth (Miller, 2009). In most leptocephali of *G. taiwanensis*, the fins begin far behind the middle of the body and gradually move forward with metamorphosis, becoming consistent in juveniles and adults. In Stage 1, the specimens have 66 PDM (n=1) and 108–111 PAM (n=2), whereas the specimens in Stage 2 have 13–99 PDM (n=3) and 58–134 PAM (n=4), and those in Stage 3 have 8–77 PDM (n=11) and 50–123 PAM (n=14). However, these values are highly variable and do not match either PDV or PAV of juveniles and adults. The PDL and PAL of leptocephali of *G. taiwanensis* also reflect these growth changes, e.g. specimens of Stage 3 have relatively small PDL and PAL.

The head length shows a positive trend with growth; specimens of Stage 3 tend to have a longer head compared to the other two stages. The snout length in specimens of Stage 1 is short (40.9–45.4% HL) and becomes longer in the rest.

TABLE 2. Meristic and morphometric data of all specimens examined. *including 4 specimens with unidentified stages.

	Leptocephali	Juveniles	Adults
TL (mm)	114+–156+ (n=40*)	167+–289+ (n=23)	364+–696 (n=42)
PAL (mm)	42.2–109.1 (n=35)	61.3–103.2 (n=19)	116.6–226.0 (n=39)
TV/TM	152+–227 (n=22)	142+–210+ (n=13)	201+–225+ (n=9)
PDV/PDM	8–99	6–7	6–9
PAV/PAM	50–134	46–50	47–52
PDLL	-	-	5–7
PALL	-	-	46–52
% of TL	(n=12)	(n=1)	(n=21)
HL	5.1–8.9	10.0	8.2–11.3
PDL	10.4–61.5	10.1	8.3–11.4
PAL	30.2–80.8	41.1	30.3–43.0
TR	22.5–75.3	31.1	22.1–31.8
% PAL			
HL	6.8–27.0	24.4–30.3	25.6–29.9
PDL	24.2–76.1	24.7–32.2	25.4–29.9
TR	73.0–93.2	69.7–75.6	70.1–74.4
UJ	3.6–16.0	12.9–16.1	12.4–14.9
ED	1.2–3.3	1.7–2.6	1.5–2.5
S	3.2–12.8	10.7–14.2	10.9–13.1
BD	4.9–14.4	3.0–6.7	5.2–10.6
% of HL			
ED	12.4–19.7	5.7–9.7	5.0–8.8
S	40.0–55.9	40.8–48.5	40.2–47.4
UJ	49.3–70.1	48.4–55.7	45.7–54.2

Table 2 shows the comparison of morphometrics and meristics of all leptocephali, juveniles and adults. The largest leptocephalus examined is 156+ mm TL, whereas the smallest juvenile is 167+ mm TL, and the smallest adult is 364+ mm TL. However, the preanal lengths of all juveniles are within the range of that of the leptocephali, whereas adults have a slightly but clearly greater preanal length.

In percentage of TL (% TL). The predorsal and preanal length are much more variable in leptocephali than in juveniles and adults (Fig. 7A–B). The trunk length is relatively large and variable in leptocephali and relatively small and consistent in juveniles and adults (Fig. 7C). The head length is relatively small and variable in leptocephali, whereas that of juveniles and adults is larger and more consistent (Fig. 7D).

In percentage of PAL (%PAL). The predorsal length is relatively large and variable, showing a slightly positive trend with growth in leptocephali, whereas in juveniles and adults it is larger and more consistent (Fig. 8A). The trunk length is variable and generally larger in leptocephali and consistently smaller in juveniles and adults; it also shows a greatly positive trend with growth in leptocephali, whereas in juveniles and adults it is quite consistent (Fig. 8B). The head length is variable and generally smaller in leptocephali than in juveniles and adults; it also shows a negative growth trend in leptocephali, whereas in juveniles and adults it is quite consistent (Fig. 8C).

The snout length (in % PAL) is generally smaller with a negative growth trend in leptocephali, whereas in juveniles and adults it is generally larger and more consistent (Fig. 8D). The upper-jaw length is variable and generally smaller in leptocephali with a greatly negative growth trend, whereas in juveniles and adults it is generally larger and more consistent (Fig. 8E). The eye diameter is variable in leptocephali, with a greatly negative growth trend; it is variable with a narrower range, a slightly negative growth trend in juveniles compared with leptocephali; whereas adults are more consistent (Fig. 8F).

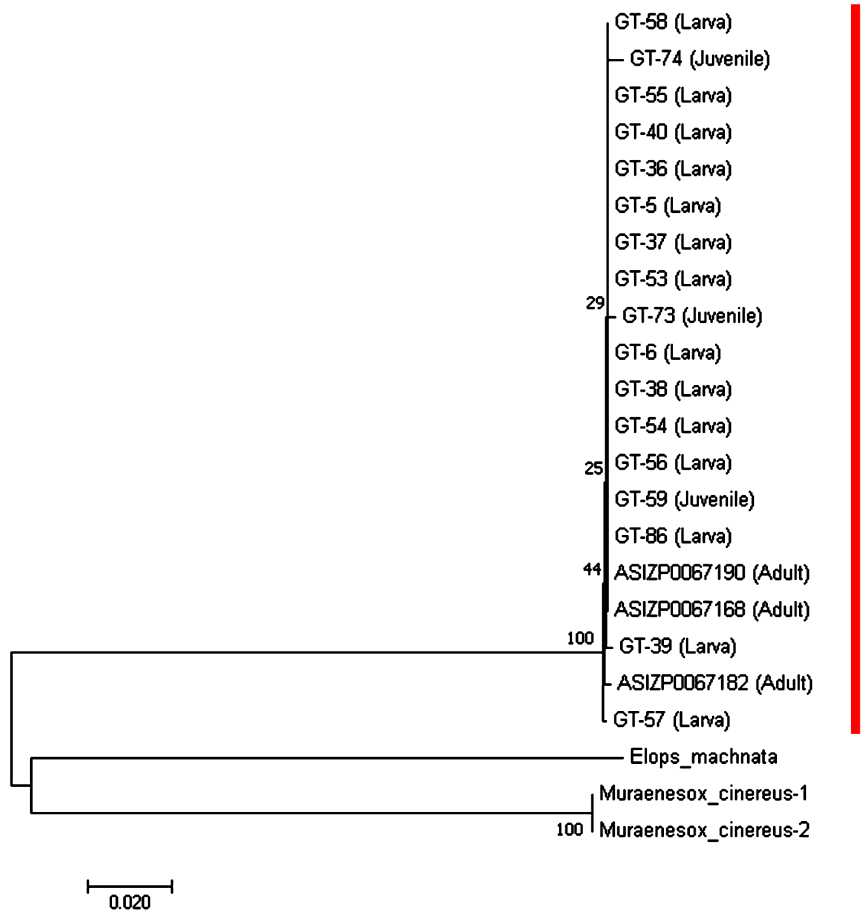

FIGURE 6. Cladogram showing Neighbor-joining (NJ) tree of relationship of *G. taiwanensis* and outgroups based on COI sequences.

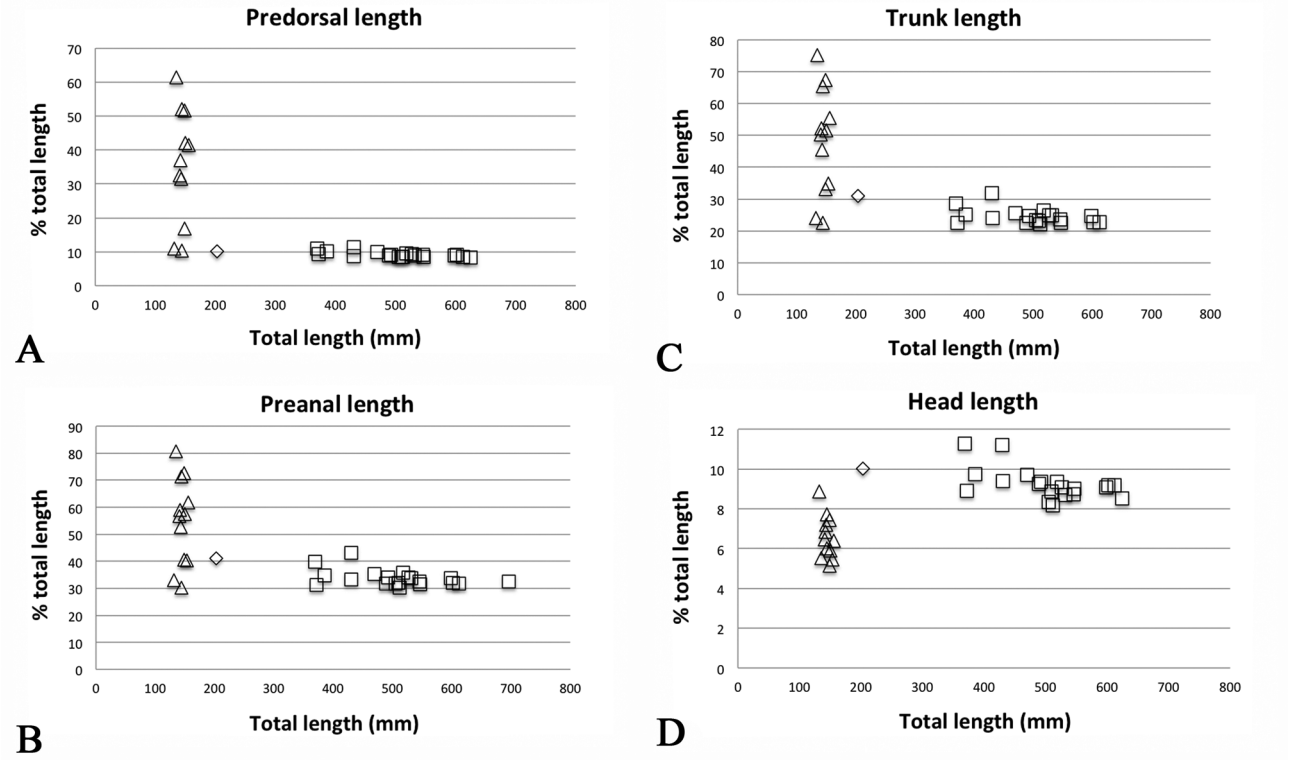

FIGURE 7. Scatter plots of morphometric proportions (in % TL) versus TL of leptocephali (triangles), juveniles (diamonds) and adults (squares) of *G. taiwanensis* showing the growth trend of each proportion.

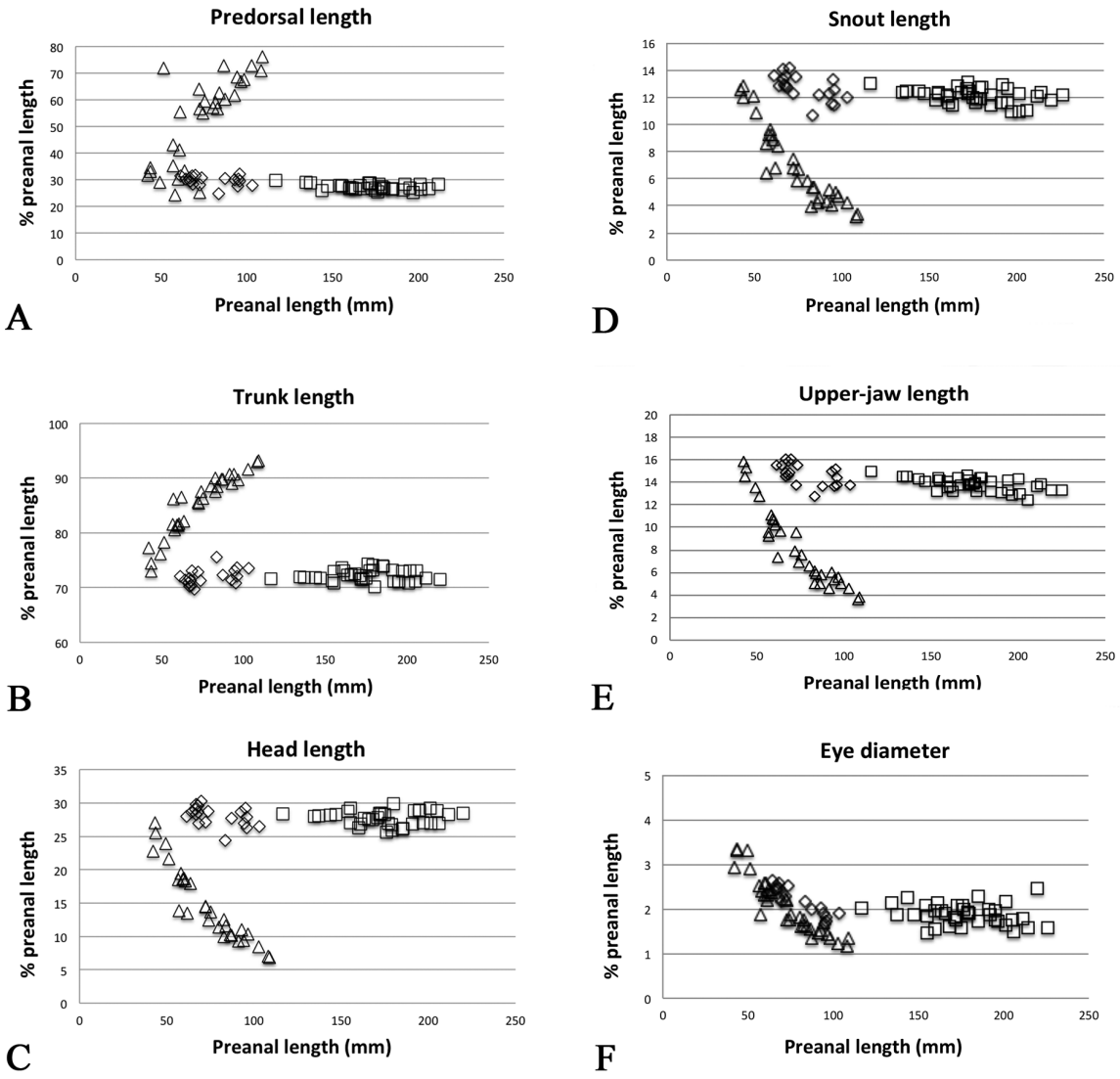

FIGURE 8. Scatter plots of morphometric proportions (in % PAL) versus PAL of leptocephali (triangles), juveniles (diamonds) and adults (squares) of *G. taiwanensis* showing the growth trend of each proportion.

In percentage of HL (% HL). The snout length and upper-jaw length are more variable in leptocephali than in juveniles but no growth trend was found, whereas adults show a slightly negative growth trend (Fig. 9A, 9B). The eye diameter is clearly larger in leptocephali which showing a variable but slightly negative growth trend; that in juveniles is smaller with a slight but clearly negative growth trend; but this is consistently small in adults (Fig. 9C).

Our specimens agree well with *G. taeniola* described by Castle (1977), who included *G. taiwanensis* and *G. arabicus* as junior synonyms of *G. taeniola*. However, Karmovskaya (1993) resurrected these two species. Castle (1977) mentioned that there are small pectoral fins in his specimens, however, it is likely that leptocephali of *G. taiwanensis* do not have pectoral fins as we could not find traces in any of our specimens.

Castle (1977) gave a range of 208–261 total myomeres for his specimens. Karmovskaya (1993) assigned his high myomere-count specimens to an unidentified species and provided the vertebral counts 197–215 for *G. taeniola* (208–215 myomeres, n=4), 220–231 for *G. arabicus* (213–229 myomeres, n=2), 188+ for *G. taiwanensis*, 182+ for *G. bertelseni*, and 155+–210+ for *G. javanicus*. Our specimens have 203+–227 total myomeres (based on 5 complete leptocephali) and 201+–225+ total vertebrae, and these characters are modified accordingly.

Karmovskaya (1993) provided 140–144 PAM for *G. taeniola* and 144 PAM for *G. arabicus*. Our specimens have great variation, ranging from 50 to 134. It is likely the number of PAM changes with the metamorphosis of the leptocephali.

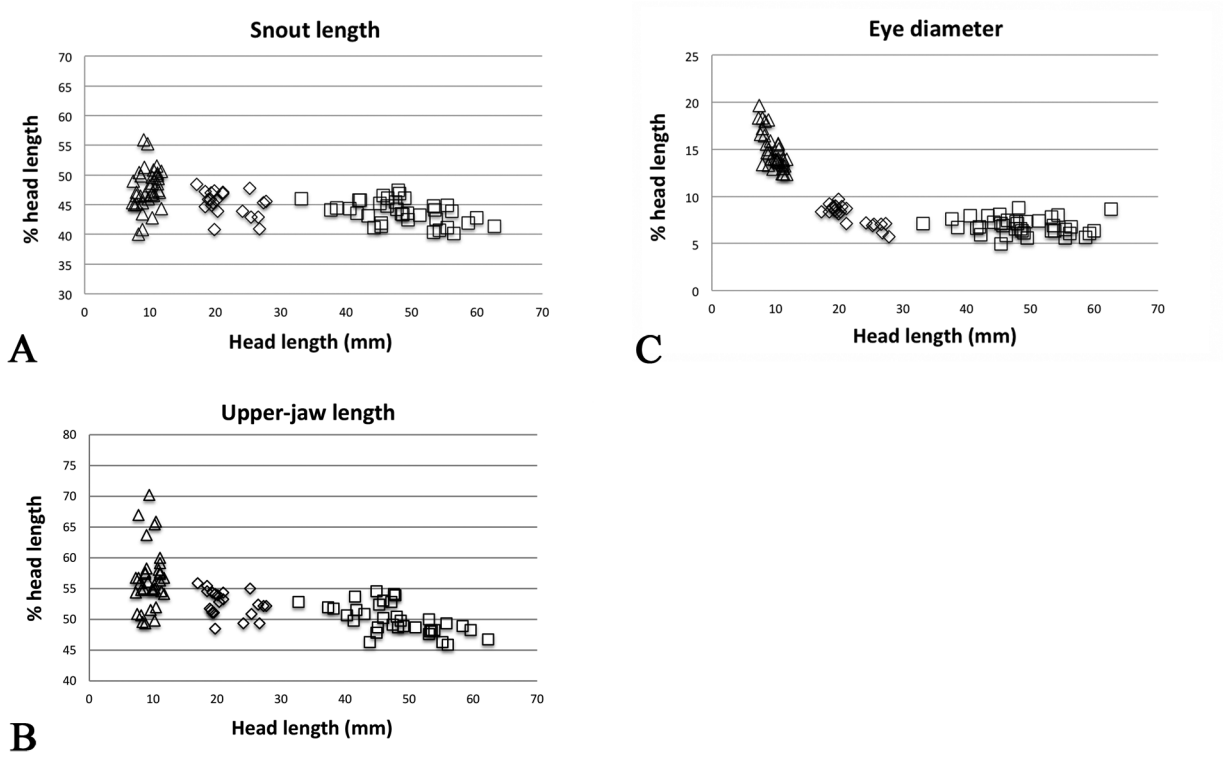

FIGURE 9. Scatter plots of morphometric proportions (in % HL) versus HL of leptocephali (triangles), juveniles (diamonds) and adults (squares) of *G. taiwanensis* showing the growth trend of each proportion.

In summary, the coloration of all leptocephali is fairly consistent (e.g. 5–8 large black spots on ventral margin, devoid of pigment elsewhere), and pigmentation develops gradually in juveniles and adults. In contrast, the body proportions of leptocephali are highly variable and become consistent in juveniles and adults. The proportions of PDL (% PAL) and trunk length (% PAL) show positive growth trends, and head length (% PAL), snout length (% PAL), upper jaw length (% PAL) and eye diameter (% PAL) show strongly negative growth trends in leptocephali. With these dramatic changes, it is impossible to compare their body proportions with the juveniles and adults.

The molecular identification has made it possible to fit leptocephali with the extremely morphological differences to their juveniles and adults. This is the first attempt to study whole series of leptocephali, juveniles and adults of a common eel species in Taiwan using molecular and morphological identification. The results ill provide the fundamental data to study other eel taxa in Taiwan or elsewhere.

TABLE 3. K2P distances among the leptocephali, juveniles and adults of *G. taiwanensis*, and two outgroups.

Taxon	*G. taiwanensis* (leptocephali)	GenBank accession numbers
G. taiwanensis (leptocephali) (n=14)	0.000–0.004	MH414526–414538, 414542
G. taiwanensis (juveniles) (n=3)	0.000–0.005	MH414539–41
G. taiwanensis (adults) (n=3)	0.000–0.005	KU 942791–3
Muraenesox cinereus (n=2)	0.279–0.285	KU942798–9
Elops machnata (n=1)	0.359–0.362	KU942799

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