



## The freshwater snake eel genus *Lamnostoma* (Anguilliformes: Ophichthidae) in Taiwan, with description of a new species

YUNG-CHIEH CHIU<sup>1</sup>, KWANG-TSAO SHAO<sup>2</sup>, SHIH-PIN HUANG<sup>3</sup> & HONG-MING CHEN<sup>1,4,5</sup>

<sup>1</sup>Department of Aquaculture, National Taiwan Ocean University, Keelung 202, Taiwan

<sup>2</sup>Institute of Marine Biology, National Taiwan Ocean University, Keelung 202, Taiwan

<sup>3</sup>Biodiversity Research Center, Academia Sinica, Taipei 115, Taiwan

<sup>4</sup>Center of Excellence for the Oceans, National Taiwan Ocean University, Keelung 202, Taiwan

<sup>5</sup>Corresponding author. E-mail: [hmchen@mail.ntou.edu.tw](mailto:hmchen@mail.ntou.edu.tw)

### Abstract

A review of the freshwater ophichthid eel genus *Lamnostoma* from Taiwan is provided with three species recognized. *Lamnostoma mindora* has been recorded in previous literature and its presence is confirmed. Two specimens of *Lamnostoma polyophthalmum* represent the first record in Taiwan. A new species, *Lamnostoma taiwanense* sp. nov., is described on the basis of two specimens collected from northeastern Taiwan. It can be distinguished by having 3 preopercular pores, higher number of teeth on lower jaw, and a series of white spots with hill-shaped papillae along the head. A key to all known species of *Lamnostoma* is provided.

**Key words:** Anguilliformes, Ophichthidae, *Lamnostoma*, new species, Taiwan

### Introduction

Snake eels, family Ophichthidae is the most diverse family of Anguilliformes fishes, comprising about 59 genera and 319 species that are widely distributed around the tropical and subtropical water regions of the world (Nelson *et al.*, 2016). So far, 19 genera and 60 species of ophichthid eels have been recorded in Taiwan (Ho *et al.*, 2015; Shao, 2017).

Except for *Lamnostoma*, ophichthid eels normally occupy various marine habitats, including intertidal wetlands, mid waters and reefs, where they burrow in sand and mud substrates. Although some species are found at depths of 1,300 m or deeper region, most usually inhabit waters with depths less than 100 m (McCosker *et al.*, 2012). Snake eels are often caught by the bottom trawl fishery in Taiwan, and are also trapped in the estuaries area and downstream stretches of rivers.

Species of *Lamnostoma* were collected from brackish water or in the lower reaches of rivers close to estuaries. Previous studies (Chang & Tsai, 2003, 2004) pointed out that the bottom dwelling habit of *Lamnostoma mindora* could be the reason why *Lamnostoma* species are rarely found and recorded in previous surveys.

The obvious benthic preference observed in a live specimen of *Lamnostoma polyophthalmum* kept in an aquarium by the first author resembles the case of *L. mindora* reported previously (Chang & Tsai, 2004).

Hatooka & Yoshino (1998) reported 2 rare ophichthid species of the genus *Lamnostoma* from western Pacific, including a single specimen of *L. mindora* collected from eastern Taiwan that was the first record of both genus and species, as well as the 4<sup>th</sup> specimen worldwide. Subsequently, Chang & Tsai (2003) presented a 5<sup>th</sup> example of *L. mindora* from the southwest of Taiwan, and declared that *L. taylori* to be a valid species; Chang & Tsai (2004) reported another 9 specimens, and provided brief ecological information. In this study we present information about 11 more specimens of *L. mindora*, 3 specimens of *L. polyophthalmum*, and 2 specimens of a new species along with additional descriptive details about these species.

Currently five species of *Lamnostoma* are considered valid (Kottelat, 2013; van der Laan, 2016), including

*Lamnostoma kampeni* (Weber & de Beaufort, 1916), *Lamnostoma mindora* (Jordan & Richardson, 1908), *Lamnostoma orientalis* (McClelland, 1844), *Lamnostoma polyopthalmum* (Bleeker, 1853), and *Lamnostoma taylori* (Herre, 1923). Recently, McCosker (personal communication) who examined holotype specimens of three of the nominal species, and concluded that *L. kampeni* is a junior synonym of *L. mindora*. In addition, *L. taylori* was considered to be a junior synonym of *L. mindora* by Hatooka & Yoshina (1998). And as a holotype was not designated in the original description of *L. orientalis* and the syntypes appear to have been lost, the validity of *L. orientalis* is controversial.

The results of a taxonomic study of the genus *Lamnostoma* carried out in Taiwan are reported below. Two specimens of *Lamnostoma polyopthalmum* collected in northeastern Taiwan represent a new record for Taiwan. In addition, two specimens of *Lamnostoma* collected in northeastern Taiwan are described as a new species based on morphological features.

## Materials and methods

Abbreviations and terms used in diagnosis and descriptions follow McCosker (1977) and McCosker *et al.* (1989), with the addition of dorsal-fin origin (DFO), anterior nostril (AN), and posterior nostril (PN). The body contains the head and trunk when comparing body and tail lengths.

Counts and measurements generally follow Böhlke (1989) and McCosker *et al.* (1989). Measurements are straight-line and obtained with a 600 mm ruler; 1 mm gradations were used for total length (TL), tail length (Tail), trunk length (TR), head length (HL), predorsal length (PD), preanal length (PA), and distance between dorsal fin origin and upper margin of gill opening (DGW). A dial caliper, recorded to the nearest 0.1 mm, were used for body depth at gill opening (DGO), body depth at anus (DA), interorbital width (IOW), eye diameter (ED), snout length (S), ventral width between gill opening (VG; “isthmus” in Böhlke, 1989), upper jaw length (UJ), lower jaw length (LJ), and gill opening diameter (GO).

Terminology of cephalic and lateral-line pores generally follows McCosker *et al.* (1989). Supraorbital pores (SO) are expressed as ethmoidal pore + pores in the supraorbital canal; infraorbital pores (IO) are expressed as pores along the upper jaw + those in the vertical part of the canal behind the eye (the postorbital pores), however, the last pore on the upper jaw is included as part of the postorbital pore series; the preoperculo-mandibular pores (POM) include pores on the lower jaw (mandibular pores) and preopercular canal (preopercular pores, POP, counted from the lowest and recorded as pop<sup>1</sup>, etc.); the supratemporal pores (ST) are pores on the dorsolateral side of the head pore anterior to the lateral-line pores, and the upper temporal pore (TP) from lateral view labeled as tp<sup>2</sup> when the number of ST up to five. Frontal pore (F) is the pore on the transverse frontal commissure. Lateral-line pores (LL) are expressed as pre-gill-opening lateral-line pores (PGLL), predorsal lateral-line pores (PDLL), preanal lateral-line pores (PALL), and total lateral-line pores (TLL).

Vertebral counts (hypural included) were taken from radiographs. Mean vertebral formula (MVF) follows Böhlke (1982) and is expressed as the average of predorsal vertebrae (PDV), preanal vertebrae (PAV), total vertebrae (TV). Vertebral counts when only a single specimen was available are presented as a vertebral formula (VF).

Clearing and staining for studying skeletal features of lateral-line series on the head generally followed Dingerkus & Uhler (1977).

All examined specimens were deposited in the collections of the Laboratory of Aquatic Ecology, Department of Aquaculture, National Taiwan Ocean University (TOU-AE) and Biodiversity Research Center, Academia Sinica, Taiwan (ASIZP).

## Key to species of *Lamnostoma*

- 1a. Eyes placed about 1/3 upper jaw from snout tip; gill opening lateral, anterior duplicate gill membrane absent; distance between dorsal fin origin and upper margin of gill opening 10.5–26.5% HL; no papilla on both of nostrils; 2 rows of white spots on lateral side of head meeting above gill opening and becoming a single row posteriorly, and forming a “Y”.....  
..... *Lamnostoma mindora* (Jordan & Richardson, 1908)
- 1b. Eyes placed near the midpoint of upper jaw; gill opening ventral, anterior duplicate gill membrane present; distance between

- dorsal fin origin and upper margin of gill opening more than 23.3% HL; both of nostrils with a slim papilla along the anterior margin; 2 rows of white spots on lateral side of head not meeting, but arranged in parallel arched rows . . . . . 2
- 2a. Head about 12.4–12.7% TL . . . . . *Lamnostoma orientalis* (McClelland, 1844)
- 2b. Head less than 12.4% TL . . . . . 3
- 3a. Ventral width between gill opening about 6.5–6.9% HL; 2 preopercular pores; 33–41 teeth on lower jaw; lateral white spots on head without hill-shaped papilla, indistinct ventrally . . . . . *Lamnostoma polyophthalmum* (Bleeker, 1853)
- 3b. Ventral width between gill opening about 8.0–9.1% HL; 3 preopercular pores; 47–49 teeth on lower jaw; lateral white spots on head in the form of a series of hill-shaped papilla, all spots distinct . . . . . *Lamnostoma taiwanense* sp. nov.

## Taxonomy

### Genus *Lamnostoma* Kaup, 1856

*Lamnostoma* Kaup, 1856a: 49. Type species: *L. pictum* Kaup, 1856 = *Dalophis orientalis* McClelland, 1844 = *Lamnostoma orientalis* (McClelland, 1844).

*Anguisurus* Kaup, 1856a: 24. Kaup, 1856b: 50. Type species: *A. punctulatus* Kaup, 1856 = *Dalophis orientalis* McClelland, 1844 = *Lamnostoma orientalis* (McClelland, 1844).

**Diagnosis.** Body stout, cylindrical, and slightly longer than tail; vent near midpoint of TL; snout pointed and slightly slender; eye small to moderate; anterior nostril slightly tubular, ear-shaped, with a cutaneous adjunct on its inner edge, its posterior nostril rim produced into a flap; gill opening lateral or oblique; dorsal fin origin above or behind gill opening;  $tp^2$  absent and  $pop^3$  sometimes present; teeth pointed, and recurved, those in jaws uniserial or biserial, intermaxillary and vomerine teeth largest and widely spaced. Coloration generally darker dorsally, with a continuous band of spots across the neck dorsally.

**Remarks.** *Lamnostoma orientalis* was initially assigned to the genus *Dalophis*; however, the species can be clearly separated from the genus *Dalophis* McClelland, 1844 by a combination of characters with the *Dalophis* eels having a tail that is longer than the head and trunk and the dorsal fin origin before the gill opening. The genus *Anguisurus* Kaup, 1856 was considered to be a junior synonym of *Lamnostoma* by McCosker (1977). In this study, we revise the diagnosis of the genus *Lamnostoma* to include the presence of 3 preopercular pores in at least one species, our new species *Lamnostoma taiwanense*.

### *Lamnostoma mindora* (Jordan & Richardson, 1908)

#### 明多羅龍口蛇鰻

Common name: Mindora Snake Eel

Figures 1A–1C, 2A–2B, 7A; Table 1

*Caecula mindora* Jordan & Richardson, 1908: 239 (holotype: CAS-SU 20209; type locality: Mindoro Island, Philippines); Herre, 1923: 183.

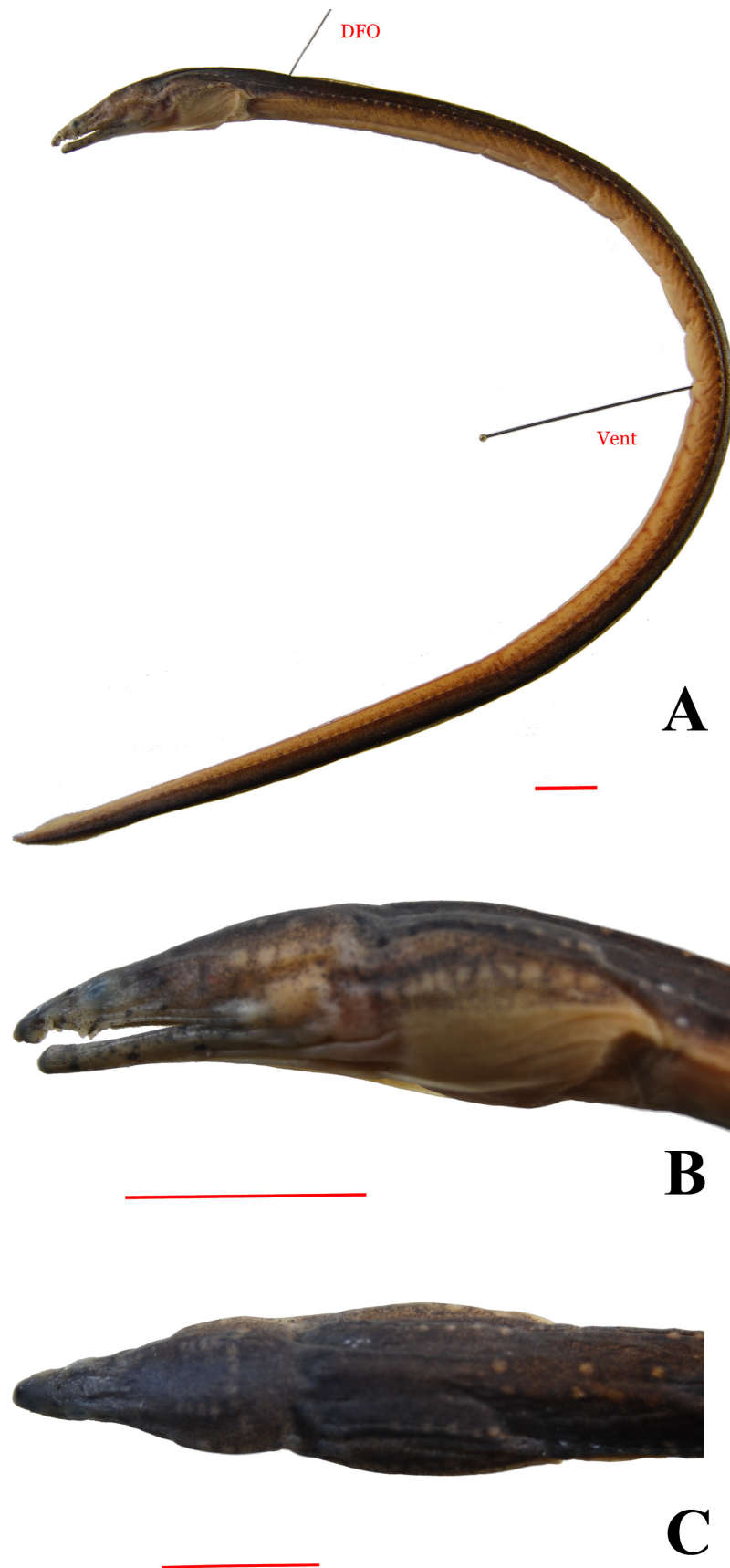
*Sphagebranchus mindora* (Jordan & Richardson, 1908): Weber & de Beaufort, 1916: 322.

*Lamnostoma mindora* (Jordan & Richardson, 1908): McCosker, 1977: 69; Séret & Dingerkus, 1992: 169; Chen & Fang, 2002: 75; Chiu, 2014: 15; McCosker, 2014: 339; Ho *et al.*, 2015: 168; Miesen *et al.*, 2016: 81.

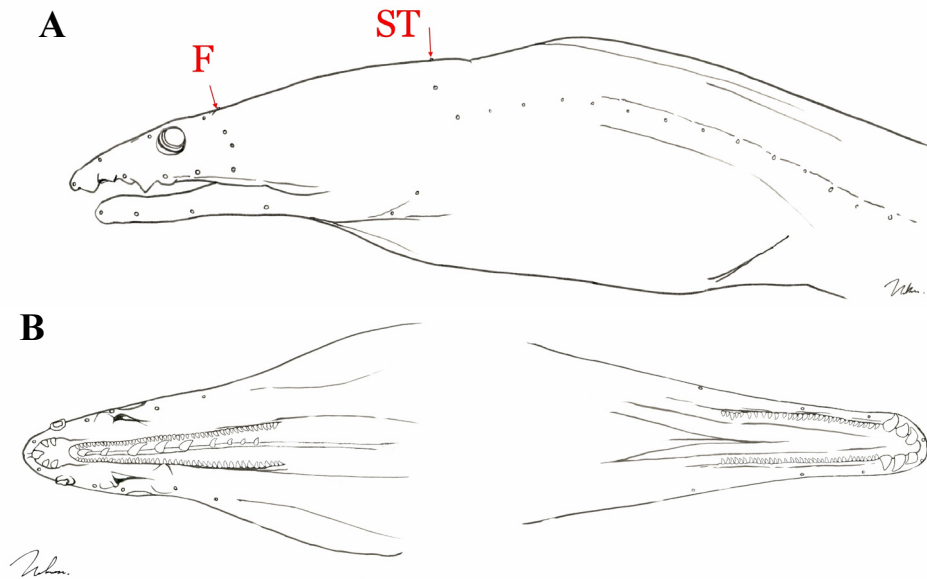
*Lamnostoma midorum* (Jordan & Richardson, 1908): Hatooka & Yoshino, 1998: 25; Chang & Tsai, 2003: 77; Chang & Tsai, 2004: 51, 52, 54, 55.

**Specimens examined.** TOU-AE 7087 (287 mm TL), sex unknown, Xiu-gu-luan River, eastern of Taiwan, 2008; ASIZP 62051 (251–272 mm TL), 2 specimens, sex unknown, Hua-lien River, Hua-lien county, eastern of Taiwan, 5 Oct. 1999, coll. J.-L. Huang; ASIZP 75026 (182–428 mm TL), 5 specimens, sex unknown, Yi-lang county, northeastern of Taiwan, 10 Jan. 2008, coll. H.-C Ho; ASIZP 80724 (312 mm TL), sex unknown, Mei-lun River, eastern of Taiwan, 1 Jul. 2009, coll. S.-P. Huang; ASIZP 80725 (266 mm TL), sex unknown, Mei-lun River, eastern of Taiwan, 1 Jul. 2009, coll. S.-P. Huang; ASIZP 80726 (319 mm TL), sex unknown, Lin-bien River, southwestern of Taiwan, 14 Dec. 2005, coll. S.-P. Huang.

**Diagnosis.** Eye situated about 1/3 length of upper jaw from snout tip; 2 preopercular pores; gill opening lateral, without anterior duplicate gill membrane; distance between dorsal-fin origin and upper margin of gill opening 10.5–26.5% HL; no papilla on both of nostrils; 2 rows of white spots on lateral side of head meeting above gill opening and becoming single row posteriorly, and forming a “Y”.



**FIGURE 1.** *Lamnostoma mindora* (Jordan and Richardson, 1908), TOU-AE 7087, 287 mm TL. A. Lateral view of the whole body. B. Left view of head. C. Top view of head. Bar = 10 mm. Abbreviation: DFO, dorsal fin origin.



**FIGURE 2.** *Lamnostoma mindora* (Jordan and Richardson, 1908), TOU-AE 7087, 287 mm TL. A. Lateral view of head showing the arrangement of cephalic pores. B. Illustration of dentition. Abbreviation: F, frontal pore; ST, supratemporal pores.

**Description.** Head moderately slender, slightly flat dorsally after the eyes; snout relatively blunt at tip; eye placed near 1/3 of upper jaw length from the tip of snout; no papilla on both of nostrils; gill opening lateral without anterior duplicate gill membrane.

Body moderately elongated; tail longer than head and trunk, vent situated before the midpoint of total length; HL 11.3–12.8% TL, TR 33.0–36.3% TL, Tail 51.9–56.1% TL; distance between dorsal fin origin and gill opening about 17.7–26.5% HL.

Teeth on jaws uniserial and conical, comprising intermaxillary 5, maxillary 37–46 on each side, vomerine 7–9, dentary 32–35 on each side.

Cephalic pores: SO 1 + 3, IO 4 + 2, POM 4 + 2, ST 3, F 1. Lateral-line pores: PGLL 10, PDLL 13–15, PALL 57–66, TLL 128–135.

MVF: 14–59.1–146.7 (n = 11). PDV 13–16, PAV 54–61, TV 141–150.

Coloration in 75% EtOH dark dorsally, yellowish to brownish on belly, all fins pale; all sensing pores black. Two rows of white spots on lateral side of head meeting above gill opening and becoming single row posteriorly, forming a “Y” (Figure 7A).

**Distribution.** Philippines (type locality), Java, Indonesia (Kottelat, 2013), eastern Taiwan (Hatooka & Yoshino, 1998) and southwestern Taiwan (Chang & Tsai, 2003, 2004).

**Remarks.** This species has the longest tail relative to total length among species of the genus *Lamnostoma*. Both nostrils lacking a flap, the posterior nostril is placed between the 2<sup>nd</sup> and 3<sup>rd</sup> IO pore and has the appearance of an inverted triangle in lateral view; its snout is moderately elongate. The morphological characters described above generally agree with the description in Hatooka & Yoshino (1998) and Chang & Tsai (2003) (Table 1). The first Taiwanese record of *Lamnostoma mindora* was mentioned in Hatooka & Yoshino (1998) and based on a specimen collected from the Xiu-gu-luan River in eastern Taiwan. Subsequently, this species was also found in southwestern Taiwan (Chang & Tsai, 2003, 2004), all specimens having been collected from downstream parts of rivers.

McCosker (personal communication) suggested that *Lamnostoma kampeni* may be a junior synonym of *L. mindora* based on its morphometric composition, which is within the range of individual variation. The holotype specimen of another nominal species, *L. taylori* was destroyed during WWII. Hatooka & Yoshino (1998) considered *L. taylori* to be a junior synonym of *L. mindora* based on the key presented in Herre (1923), which differ slightly in body depth (25–30 times in TL in *L. mindora* vs. about 18 times in *L. taylori*).

***Lamnostoma polyophthalmum* (Bleeker, 1853)**

多斑龍口蛇鰻

Common name: Ocellated Snake Eel

Figures 3A–3C, 4A–4B, 7B; Table 1

*Dalophis polyophthalmus* Bleeker, 1853: 299 (holotype: BMNH 1867.11.28.310; type locality: Priaman, Indonesia; poor condition).

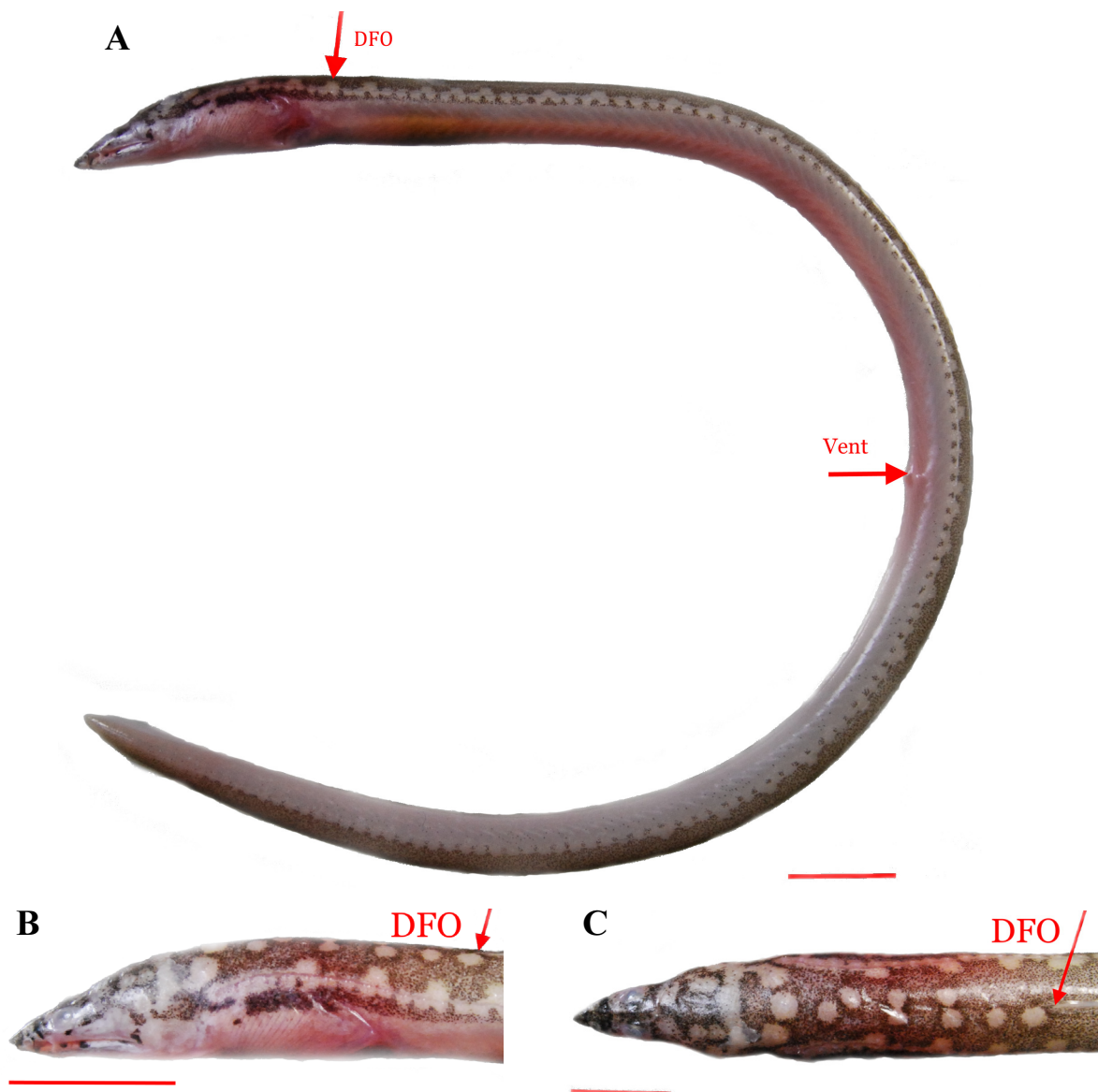
*Anguisurus punctulatus* Kaup, 1856a: 24; Kaup, 1856b: 50 (syntype whereabouts unknown; type locality: Java, Indonesia).

*Sphagebranchus polyophthalmus* (Bleeker, 1853): Weber & de Beaufort, 1916: 320.

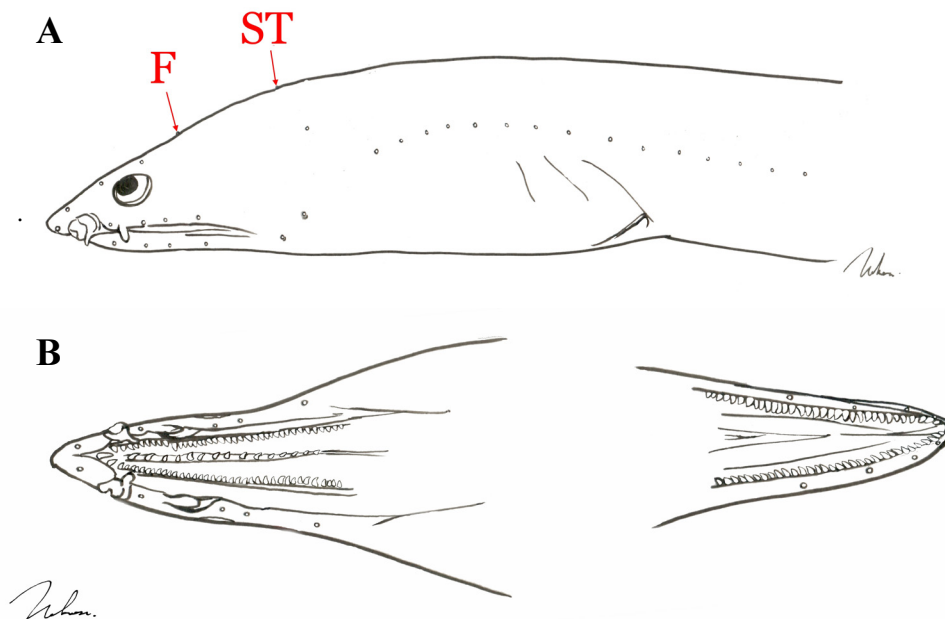
*Lamnostoma orientalis* (McClelland, 1844): McCosker & Castle, 1986: 179 (not of McClelland).

*Lamnostoma polyophthalmum* (Bleeker, 1853): Hatooka & Yoshino, 1998: 22; Chang & Tsai, 2003: 76; Kottelat, 2013: 44; Hatooka, 2013: 269.

*Lamnostoma polyophthalma* (Bleeker, 1853): Fricke *et al.*, 2014: 22.



**FIGURE 3.** *Lamnostoma polyophthalmum* (Bleeker, 1853), TOU-AE 7226, 209 mm TL. A. Lateral view of the whole body. B. Left view of head. C. Top view of head. Bar = 10 mm. Abbreviation: DFO, dorsal fin origin.



**FIGURE 4.** *Lamnostoma polyophthalmum* (Bleeker, 1853), TOU-AE 7226, 209 mm TL. A. Lateral view of head showing the arrangement of cephalic pores. B. Illustration of dentition. Abbreviation: F, frontal pore; ST, supratemporal pores.

**Specimens examined.** TOU-AE 7226 (209 mm TL), sex unknown, downstream of Long-long River, Gong-liao, New Taipei city, catch net, coll. J.-C. Dai. TOU-AE 7235 (304 mm TL), sex unknown, collected together with TOU-AE 7226. **Other locality.** ASIZP 0062047 (415 mm TL), sex unknown, Ryukyu Islands, Okinawa prefecture, Japan, 1 May 2000, unknown collector.

**Diagnosis.** Gill opening ventral; ventral width between gill opening 6.5–6.9% HL; two POP; 33–41 teeth on lower jaw; lateral white spots on head without hill-shaped papilla, very faint ventrally.

**Description.** Head moderately slender cylindrical and uncompressed; snout sharp, pointed, not elongate; posterior margin of anterior nostril and the anterior edge of posterior nostril with a slim labial papilla obvious in lateral view, posterior a hole situated at the interspace between the 1<sup>st</sup> and 2<sup>nd</sup> IO pore; gill opening ventral.

Body moderately elongated, tail shorter than head and trunk, vent placed behind midpoint of total length. HL 9.9–10.1% TL, TR 40.2–43.4% TL, Tail 45.3–49.8% TL; distance between dorsal fin origin and gill opening about 23.3–33.3% HL, ventral width between gill opening 6.5–6.9% HL.

Teeth on both jaws uniserial and conical, comprising intermaxillary 5, maxillary 36–41 on each of side, vomerine 12–15, dentary 33–41 on each of side.

Cephalic pores: SO 1 + 3, IO 4 + 2, POM 4 + 2, ST 3, F 1. Lateral-line pores: PGLL 8, PDL 15, PALL 65–66, TLL 127–129.

MVF: 12.5–63–136.5. This species has the highest number of preanal vertebrae among species of the genus *Lamnostoma*.

**Coloration:** Body dark dorsally, whitish to yellowish ventrally; patterns of white spots on lateral of head arranged in arch, 2 rows of spots not meeting, lower row very faint ventrally (Figure 7B), numerous white spots on head, each corresponding with a sensory pore, and extending posteriorly along lateral-line with another not associated with a pore spot above it for 4–5 lateral-line pores, not continuous past vent.

All the morphological characters of specimens examined generally agree with the description in Hatooka & Yoshino (1998) and Chang & Tsai (2003) except for larger eyes (Table 1).

**Distribution.** This species is known from Indonesia (Bleeker, 1853; Kaup, 1856b), Luzon in the Philippines (Herre, 1953), Japan (Hatooka & Yoshino, 1998) and northern Taiwan.

**Remarks.** Although the holotype of this species is damaged, a careful examination was performed by Dr. Hibino and his morphological data provided herein. Additional morphological data obtained from other non-type specimens by Dr. McCosker (personal communication) and as reported by Hatooka & Yoshino (1998) are also

presented. Based on this information *Lamnostoma polyophthalmum* is very similar to *L. orientalis* (McClelland, 1844), but a type specimen and more adequate description of the later are still required. Hatooka & Yoshino (1998) indicated the distance between the dorsal fin origin and gill opening (DGW in this study) is the only difference to distinguish these two species, and they pointed out the *L. orientalis* in McCosker & Castle (1986) is the same species with *L. polyophthalmum*. The two specimens listed above provide the first record from the species from Taiwan.

***Lamnostoma taiwanense* sp. nov. Chiu, Huang & Shao**

**臺灣龍口蛇鰻**

Common name: Taiwan Snake Eel

Figures 5A–5C, 6A–6B, 7C, 8, 9A–9C; Table 1

**Holotype.** TOU-AE 7152 (354 mm TL), mature female with ca. 1.0 mm egg diameter in belly, Juan-wei, Yi-lan county, northeastern Taiwan, 2 Jul. 2014, coll. N.-C. Hsu.

**Paratype.** ASIZP 74900 (323 mm TL), sex unknown, Lan-yang River, Yi-lan county, northeastern Taiwan, 6 Sep. 2006, coll. S.-C. Lee.

**Measurements of the holotype.** TL 354 mm. HL 35 mm, PD length 47 mm, TR 152 mm, Tail 168 mm, DGO 11.4 mm, IOW 1.4 mm, UJ 12.6 mm, LJ 10.6 mm, ED 2.0 mm, S 5.2 mm, ventral width between gill opening 2.8 mm.

**Diagnosis.** The 3<sup>rd</sup> POP present, arranged in a triangle; lower jaw with 47–49 teeth; white spots on lateral sides of head forming parallel arches, not meeting posteriorly and lower arch clearly displayed each spot with a hill-shaped papilla; others arranged along lateral-line and extending to tail tip with series of additional non-pore spots above lateral-line each separated by 5–6 lateral-line pores.

**Description.** Head cylindrical, uncompressed; Snout relatively long, sharp, with lip present. Eye situated above middle of upper jaw. Posterior margin of anterior nostril and anterior end of posterior nostril with slender labial papilla; posterior nostril situated within midpoint of 1<sup>st</sup> and 2<sup>nd</sup> IO pore and the posterior edge of eye. Gill opening wide, ventral, anterior duplicate gill membrane present.

Body moderately stout. Tail slightly shorter than body, comparatively stout relative to other congeners. Vent placed after midpoint of body. HL 9.9–10.2% TL, TR 42.1–42.9 % TL, tail 47.5–47.7% TL; distance between dorsal fin origin and gill opening about 30.3–34.3% HL, ventral width between gill opening 8.0–9.1% HL. All fins low, pale, unspotted.

Teeth on both jaws uniserial, sharp, recurved, conical and pointed: teeth on intermaxilla (5) and vomer (13 in holotype and 14 in paratype) bigger than others, teeth on maxilla 41–50 on each side, and 47–49 on each side of lower jaw, strongly recurved.

Cephalic pores: SO 1 + 4, IO 4 + 2, POM 4 + 3, ST 3, F 1. Lateral-line pores: PGLL 10, PDLL 15, PALL 65, TLL 129.

Vertebral counts: 14 before dorsal fin origin, 64 before vent, total 138.

Coloration: deep brownish dorsally, becoming whitish below rictus, the 2<sup>nd</sup> row of white spots (lower one on the head) distinct; lateral white spots on head with series of hill-shaped papilla, and clearly displayed completely; numerous white spots, one on each lateral-line pore, with additional spots above lateral-line each separated by 5–6 pores along full length of body.

**Size.** The maximum size attains to 354 mm TL.

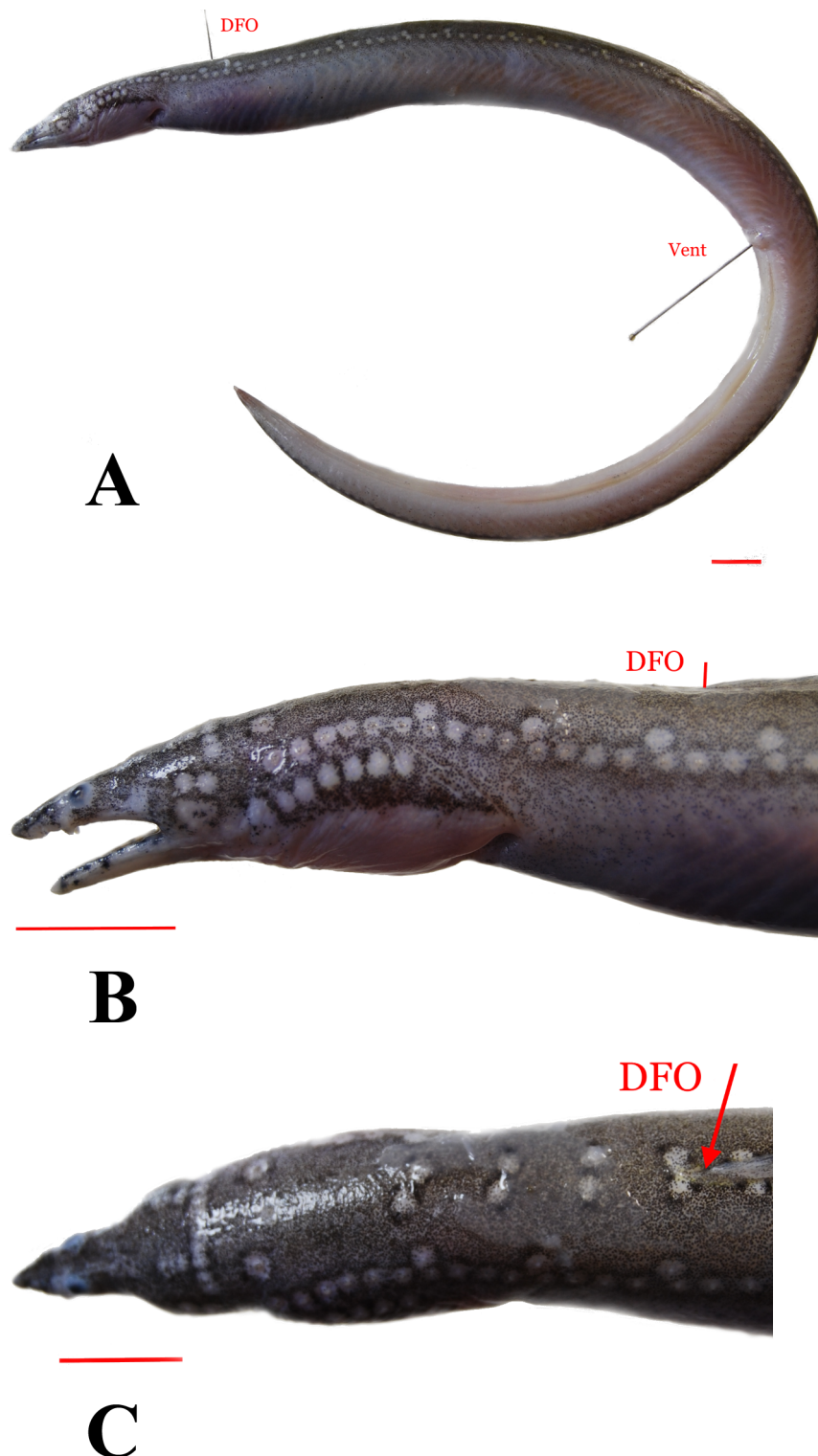
**Etymology.** The specific name recognizes the type locality, Taiwan.

**Distribution.** Only known from the mouth of Lan-yang River in northeastern Taiwan.

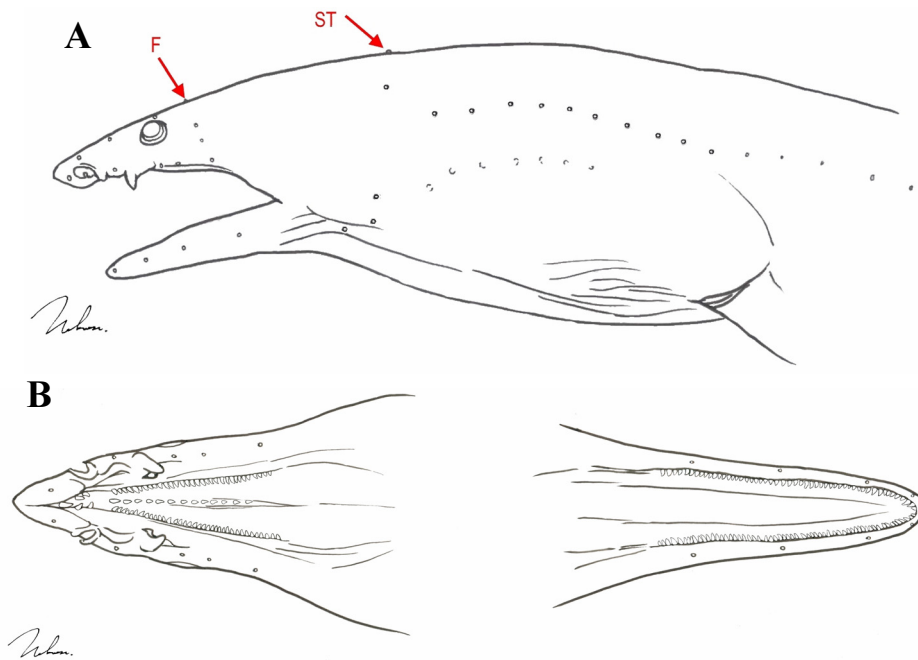
**Remarks.** Compared with the five valid species of the genus *Lamnostoma*, *L. taiwanense* can be distinguished by having three preopercular pores, the third which is absent in all other congeners. This new species is most similar to *Lamnostoma polyophthalmum* in having a similar combination of morphological features of that include the lateral-line, mean vertebral formula, and head coloration; *Lamnostoma taiwanense* differs from *L. polyophthalmum* in having the third POP, a higher number of teeth on the lower jaw (47–49), a slightly shorter tail, a longer snout in relation to the head length, and a concentration of dense fine melanin along the ventral side of the body from the lower jaw to the belly (Figure 8). The white spots on the lateral side of the head of the new species



looks like a second row of lateral-line pores, however, the position of the true lateral-line, the lower row of white spots along the head are on a series of hill-shaped papillae which stain with alcian blue and alizarin red-S (Figure 9A–9C). The presence of papillae coinciding with the 2<sup>nd</sup> row of lateral white spots may also be an important diagnostic morphological feature.



**FIGURE 5.** *Lamnostoma taiwanense* sp. nov., holotype, TOU-AE 7152, 354 mm TL. A. Lateral view of the whole body. B. Left view of head. C. Top view of head. Bar = 10 mm. Abbreviation: DFO, dorsal fin origin.



**FIGURE 6.** *Lamnostoma taiwanense* sp. nov., holotype, TOU-AE 7152, 354 mm TL. A. Lateral view of head showing the arrangement of cephalic pores. B. Illustration of dentition. Abbreviation: F, frontal pore; ST, supratemporal pores.

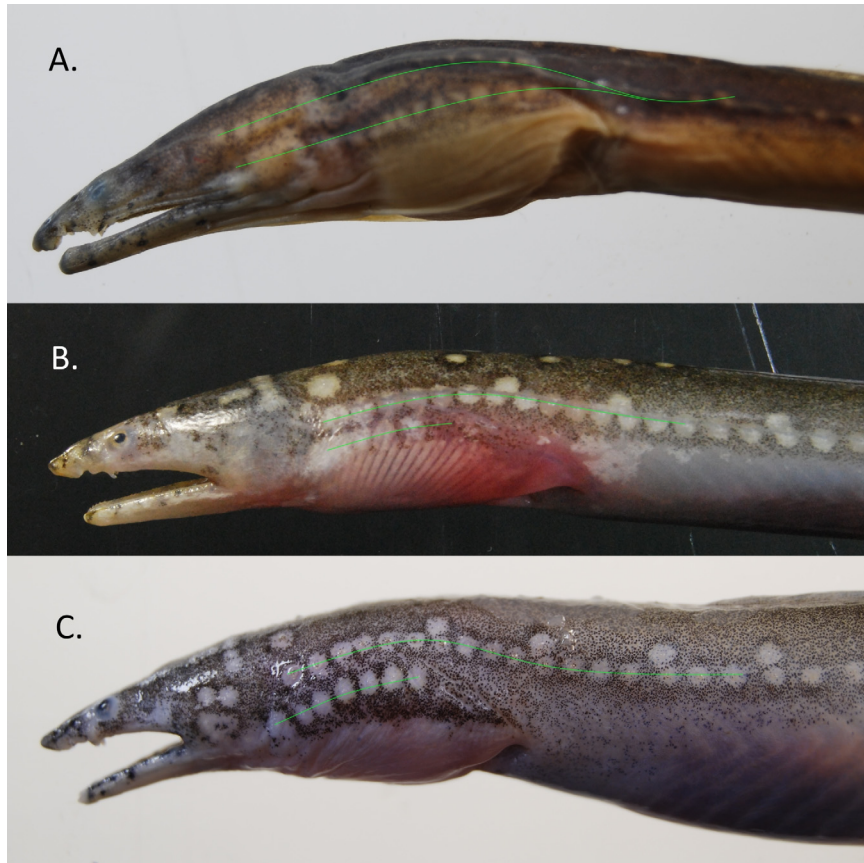
**Discussion.** The distribution of cephalic papillae is also a useful morphological feature for identifying gobies and sleepers (Huang *et al.*, 2016; Nakabo, 2013). Many species of fresh and brackish water fishes are included in the red data book of fish in Taiwan (Chen *et al.*, 2012). In this study, the complete taxonomic survey of freshwater eels is beneficial for understanding their diversity and distribution in Taiwan, and it may be an important reference for future changes to the conservation act.

### Acknowledgments

We give great thanks to John E. McCosker (California Academy of Sciences, U. S.) and Yusuke Hibino (Mie University, Japan) for their helpful comments on the draft. Thanks to Nai-Chung Hsu (National Taiwan University), Yi-Hua Yang (National Taiwan Ocean University) and Jia-Chi Dai (a fisherman) for collecting the research materials used in this study. Thanks to Pai-Lei Lin (Academia Sinica, Taiwan) for curatorial assistant. Thanks to Pei-Chi Chung (National Taiwan Ocean University, Taiwan) for translation of German literature. Thanks to Yu-Ming Shih and Shih-Kai Huang (Academia Sinica, Taiwan) for their assistance with transferring important literature. Thanks to Martin F. Gomon (Museum Victoria, Australia) and James Lin for their help in revising grammar and sentences in the draft. We express our gratitude to Hsuan-Ching Ho for his invitation to the special project. We also appreciate the Biodiversity Research Museum, Academia Sinica for providing great assistance in the examination of specimens. This study is supported by National Taiwan Ocean University (NTOU) and Biodiversity Research Center, Academia Sinica.

**TABLE 1.** Measurements (%) and counts for *Lamnostoma* species from Taiwan. Data source: a, specimens collected from Taiwan in this study; b, Chang & Tsai, 2003; c, collected from Japan; d, data of holotype, BMNH1867.11.28.310; e, from Hatooka & Yoshino, 1998.

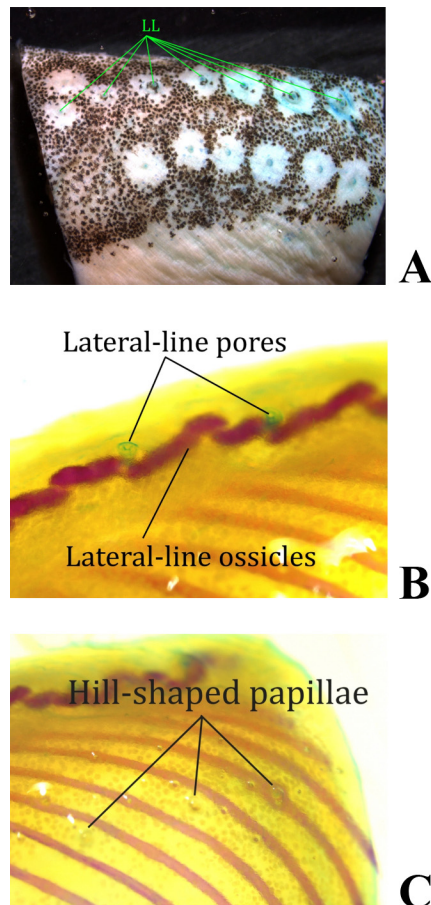
Species	<i>L. mindora</i>				<i>L. polyophthalmum</i>				<i>L. taiwanense</i> sp. nov.				
	11	1	2	1	1	1	12	1	1	1	1	1	1
Number	182–428	354	209–304	415	324	194–291	354	323	323–354				
TL(mm)													
Type	-				Holotype		Holotype	Paratype					
Source	a	b	a	c	d	e		a					
	Mean		Range	Mean		Range	Mean						Mean
HL/TL	11.9	11.3	9.9–10.0	10.0	10.6	9.8–11.8	11.3	10.2	10.1				
PA/TL	46.3	42.9	50.2–52.0	51.1	52.8	51–55	52.4	52.3	52.4				
Tail/TL	53.7	57.1	48.0–49.8	48.9	48.1	-	-	47.5	47.6				
DGO/TL	3.0	4.1	2.8–3.0	2.9	2.7	2.6–3.6	3.1	3.2	3.2				
PD/TL	14.2	14.3	12.2–13.4	12.8	13.7	12.9–14.2	13.7	13.3	13.3				
DGW/HL	20.1	-	23.3–33.3	28.3	29.40	19.9–31.2	24.4	34.30	32.30				
IOW/HL	5.4	-	5.4–7.1	6.3	3.6	3.5–6.6	4.6	4.1	4.8				
VG/HL	11.0	-	6.5–6.9	6.7	-	-	-	8.0	8.5				
UJ/HL	35.3	43.9	39.8–43.3	41.5	-	34–40	37.1	35.9	30.4				
LJ/HL	32.4	-	33.0–36.2	36.2	-	-	-	30.2	30.4				
Snout/HL	12.3	13.9	14.8–16.0	15.4	13.33	14.2–17	15.4	14.7	14.7				
E/HL	5.6	5.1	5.4–7.4	7.4	4.63	3.8–5.7	4.8	5.8	6.5				
SO	1+3	4	1+3	1+3	-	-	-	1+3	1+3				
IO	4+2	6	4+2	4+2	-	-	-	4+2	4+2				
POM	4+2	4+?	4+2	4+2	-	-	-	4+3	4+3				
ST	3	3	3	3	-	-	-	3	3				
F	1	-	1	1	-	-	-	1	1				
PGLL	10.0	-	8	8	10	-	-	10	8				
PDLL	14.5	-	15	15	-	10–12	10.7	15	13				
PALL	59.8	-	65–66	65.5	65	63–67	65	64	66				
TLL	131.3	141.0	127–129	128	-	-	-	134	132				
PDV	14.1	-	12–13	12.5	17	14–16	14.7	14	14				
PAV	59.1	-	62–64	63	66	63–68	65.4	64	64				
TV	146.7	-	135–138	136.5	138	-	-	138	138				



**FIGURE 7.** Lateral view of head of three *Lamnostoma* species in this study. A. *L. mindora*. White spots forming a “Y”; B. *L. polyophthalmum*. Spots arranged in an arch, the two rows of spots not meeting posteriorly the lower very faint ventrally. C. *L. taiwanense* **sp. nov.** Lower spots on a series of hill-shaped papillae, all spots clearly defined.



**FIGURE 8.** *Lamnostoma taiwanense* **sp. nov.**, paratype, ASIZP 74900, 323 mm TL. Dense-fine melanin along ventral side of body. Bar = 10 mm.



**FIGURE 9.** *Lamnostoma taiwanense* sp. nov., holotype, TOU-AE 7152, 354 mm TL. A. Right side of lateral-line pores on head. B. Same tissue as A. cleared and stained. C. Lower row of white spots along the head on a series of hill-shaped papillae.

## References

- Bleeker, P. (1853) Diagnostische beschrijvingen van nieuwe of weinig bekende vischsoorten van Sumatra. Tiental V-X. *Natuurkundig Tijdschrift voor Nederlandsch Indië*, 4 (2), 243–302.
- Böhlke, E.B. (1982) Vertebral formulae of type specimen of eels (Pisces: Anguilliformes), *Proceeding of Academy of Nature Science of Philadelphia*, 134, 31–49.
- Böhlke, E.B., (1989) Methods and terminology. In: Böhlke, E.B. (Ed.), *Fishes of the Western North Atlantic. Volume One—Orders Anguilliformes and Saccopharyngiformes*. Sears Foundation for Marine Research, New Haven, pp. 1–7.
- Bucol, A.A., Menes, C.C., Linaugo, J.D. & Pacalioga, J.O. (2010) The Anguilliform Eels (Pisces: Anguilliformes) of Bago River and Adjacent Waters in Negros Occidental, Philippines, *Silliman Journal*, 51 (1), 89–103.
- Chang, S.-T. & Tsai, C.-F. (2003) Notes on the Mindoro snake eel *Lamnostoma mindorum* (Jordan and Richardson) (Ophichthidae: Pisces) in the Western Pacific. *Endemic Species Research*, 5 (2), 73–81.
- Chang, S.-T. & Tsai, C.-F. (2004) The Mindoro snake eel *Lamnostoma mindora* (Jordan and Richardson) of the Hsiukulan River in the Eastern Taiwan. *Endemic Species Research*, 6 (1), 51–55.
- Chen, I.-S. & Fang, L.-S. (2002) *The inland water fishes of Taitung, Taiwan*. National Museum of Marine Biology and Aquarium, Taitung, 200 pp. [in Chinese]
- Chen, I.-S., Tzeng, C.-S. & Shao, K.-T. (2012) *Red Data Book of Freshwater Fishes in Taiwan*. Forestry Bureau, COA, Executive Yuan, Taipei, 242 pp. [in Chinese]
- Chiu, Y.-C. (2014) *Preliminary Taxonomic Studies of Snake Eels (Anguilliformes: Ophichthidae) from Taiwan*. Master thesis of Department of Aquaculture, National Taiwan Ocean University, Keelung, 118 pp. [in Chinese]
- Chiu, Y.-C., Lin, J. & Chen, H.-M. (2013) One New Record Genus and Three New Record Species of Snake Eels (Ophichthidae: Anguilliformes) From Taiwan, *Journal of Marine Science and Technology*, 21 (Supplement), 201–206. <http://dx.doi.org/10.6119/JMST-013-1220-10>
- Dingerkus, G. & Uhler, L.D. (1977) Enzyme clearing of alcian blue stained whole small vertebrates for demonstration of cartilage. *Stain Technology*, 52, 222–232.

<https://doi.org/10.3109/10520297709116780>

- Fricke, R., Allen, G.R., Andréfouët, S., Chen W.-J., Hamel, M.A., Laboute, P., Mana, R., Tan, H.-H. & Uyeno, D. (2014) Checklist of the marine and estuarine Fishes of Madang District, Papua New Guinea, western Pacific Ocean, with 820 new records. *Zootaxa*, 3832 (1), 1–247.  
<https://doi.org/10.11646/zootaxa.3832.1.1>
- Friedrich, W.M., Fabian, D., Sebastian, H., Renny, K.H. & Fabian, H. (2016) An annotated checklist of the inland fishes of Sulawesi. *Bonn zoological Bulletin*, 64 (2), 77–106.
- Hatooka, K. (2013) Ophichthidae. In: Nakabo, T. (Ed.), *Fishes of Japan with Pictorial Keys to the Species. 3<sup>rd</sup> Edition*. Tokai University Press, Tokyo, pp. 266–277. [in Japanese]
- Hatooka, K. & Yoshino, T. (1998) Two rare ophichthid species of the genus *Lamnostoma* (Pisces: Anguilliformes) from the Western Pacific. *Bulletin of the Osaka Museum of Natural History*, 52, 21–30.
- Herre, A.W.C.T. (1923) A review of the eels of the Philippine Archipelago. *The Philippine Journal of Science*, 23 (2), 123–236.
- Herre, A.W.C.T. (1953) Check list of Philippine fishes. *Research Report, Fish and Wildlife Service*, 20, 1–977.
- Ho, H.-C., Smith, D.G., McCosker, J.E., Hibino, Y., Loh, K.-H., Tighe, K.A. & Shao, K.T. (2015) Annotated checklist of eels (orders Anguilliformes and Saccopharyngiformes) from Taiwan. *Zootaxa*, 4060 (1), 140–189.  
<https://doi.org/10.11646/zootaxa.4060.1.16>
- Huang, S.-P., Chen, I.-S., Jang-Liaw, N.-H., Shao, K.-T., Yung, M.-N. (2016) Complete mitochondrial genome reveals a new phylogenetic perspective of brackish water goby *Mugilogobius* group (Teleostei: Gobiidae: Gobiionellinae). *Zoological Science*, 33 (5), 566–574.  
<https://doi.org/10.2108/zs150154>
- Jordan, D.S. & Richardson, R.E. (1908) Fishes from islands of the Philippine Archipelago, *Bulletin of the Bureau of Fisheries*, 27, 233–287. [for 1907]
- Kaup, J.J. (1856a) *Catalogue of the apodal fish in the collection of the British Museum*, London, 163 pp.
- Kaup, J.J. (1856b) Uebersicht der Aale. *Archiv für Naturgeschichte*, 22 (1), 41–77.  
<https://doi.org/10.5962/bhl.part.11240>
- Kottelat, M. (2013) The fishes of the inland waters of southeast Asia: a catalogue and core bibliography of the fishes known to occur in fresh waters, mangroves and estuaries. *The raffles bulletin of zoology*, 27 (Supplement), 1–663.
- Lin, C.-J. (2007) *Freshwater fishes and shrimps of Taiwan*. Commonwealth Publishing Group, Taipei, 239 pp. [in Chinese]
- McClelland, J. (1844) Apodal fishes of Bengal. *Calcutta Journal of Natural History*, 5 (18), 151–226.
- McCosker, J.E. (1977) The Osteology, Classification, and Relationships of the Eel Family Ophichthidae. *Proceeding of California Academy Sciences California Academy of Sciences, Series 4*, 41 (1), 1–123.
- McCosker, J.E., Allen, G.R., Hoese, D.F., Gates, J.E. & Bray, D.J. (2006) Ophichthidae. In: Hoese, D.F., Bray, D.J., Paxton, J.R. & Allen, G.R. (Eds.), *Zoological Catalogue of Australian. Vol. 35. Fishes. Parts 1–3*. CSIRO Publishing, Collingwood, pp. 264–277.
- McCosker, J.E., Böhlke, E.B. & Böhlke, J.E. (1989) Family Ophichthidae. In: Böhlke, E.B. (Ed.), *Fishes of the Western North Atlantic. Part 9. Vol. 1*. Yale University, New Haven, pp. 254–412.
- McCosker, J.E., Boseto, D. & Jenkins, A. (2007) Redescription of *Yirrkala gjellerupi*, a poorly known freshwater Indo-Pacific snake eel (Anguilliformes: Ophichthidae), *Pacific Science*, 61 (1), 141–144.  
<https://doi.org/10.1353/psc.2007.0009>
- McCosker, J.E. & Castle, P.H.J. (1986) Family 42: Ophichthidae. In: Smith, M.M. & Heemstra, P.C. (Eds.), *Smith's Sea Fishes*. Macmillan South Africa, Johannesburg, pp. 176–186.
- McCosker, J.E., Ide, S. & Endo, H. (2012) Three new species of Ophichthid eels (Anguilliformes: Ophichthidae) from Japan, *Bulletin of the National Museum of Natural Science, Series A*, 6 (Supplement), 1–16.
- McCosker, J.E. & Randall, J.E. (2001) Revision of the snake-eel genus *Brachysomophis* (Anguilliformes: Ophichthidae), with description of two new species and comments on the species of *Mystriophis*. *Indo-Pacific Fishes*, 33, 1–32.
- Miesen, F.W., Droppelmann, F., Hüllen, S., Hadiaty, R.K. & Herder, F. (2015) An annotated checklist of the inland fishes of Sulawesi, *Bonn zoological Bulletin*, 64 (2), 77–106.
- Nakabo, T. (2013) *Fishes of Japan with Pictorial Keys to the Species. Vol. II. Third Edition*. Tokai University Press, Tokyo, 864 pp. [in Japanese]
- Nelson, J.S., Grande, T.C. & Wilson, M.V.H. (2016) *Fishes of the World. 5<sup>th</sup> Edition*. John Wiley & Sons, Hoboken, N.J., 752 pp.  
<https://doi.org/10.1002/9781119174844>
- Nichols, J.T. (1955) Results of the Archbold expeditions. No. 71. Two new freshwater fishes from New Guinea. *American Museum Novitates*, 1735, 1–6.
- Randall, J.E. & Lim, K.K.P. (2000) A checklist of the fishes of the South China Sea, *The Raffles Bulletin of Zoology*, 8 (Supplement), 569–667.
- Séret, B. & Dingerkus, G. (1992) First record of the rare snake-eel *Lamnostoma kampeni* (Teleostei: Anguilliformes, Ophichthidae) from a river in northeastern New Caledonia. *Cybium*, 16 (2), 169–170.
- Shao, K.-T. (2017) Taiwan Fish Database. WWW Web electronic publication. Available from: <http://fishdb.sinica.edu.tw> (accessed 12 January 2017)
- Shao, K.-T., Ho, H.-C., Lin, P.-L., Lee, P.-F., Lee, M.-Y., Tsai, C.-Y., Liao, Y.-C., Lin, Y.-C., Chen, J.-P. & Yeh, H.-M. (2008) A

checklist of the fishes of Southern Taiwan, Northern South China Sea, *The Raffles Bulletin of Zoology*, 19 (Supplement), 233–271.

van der Laan, R. (2016) Freshwater Fish List (Online): an alphabetic scientific name list of the world's freshwater fishes and an overview of the scientific names used in the aquarium literature, 19 Edition, ISBN: 2468–9157. Available from: [https://www.researchgate.net/publication/308901824\\_Freshwater\\_Fish\\_List\\_19th\\_Edition\\_October\\_2016](https://www.researchgate.net/publication/308901824_Freshwater_Fish_List_19th_Edition_October_2016) (accessed 6 October 2016)

Weber, M. & de Beaufort, L.F. (1916) *The fishes of the Indo-Australian Archipelago. III. Ostariophysi: II Cyprinoidea, Apodes, Synbranchi*. E. J. Brill, Leiden, 455 pp.