A new species of amphidromous goby, *Stiphodon alcedo*, from the Ryukyu Archipelago (Gobiidae: Sicydiinae)

by

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ABSTRACT. - A new goby species, *Stiphodon alcedo*, is described from 27 specimens collected in Okinawa and Iriomote Islands of the Ryukyu Archipelago, Japan. This species can be distinguished from its congeners by having a pointed, but not filamentous, first dorsal fin in males, nine soft-rays in the second dorsal fin, 15-17 rays in the pectoral fin, the number of teeth, and unique sexually dimorphic colouration. The new species is considered to have recently colonised the islands where it has established small populations, and is considered to have originated from regions to the south of the archipelago, with larvae occasionally being transported northward by the Kuroshio Current.

RÉSUMÉ. - Une nouvelle espèce de gobie amphidrome de l'archipel des Ryukyu, *Stiphodon alcedo* (Gobiidae : Sicydiinae).

Stiphodon alcedo est une nouvelle espèce décrite à partir de 27 spécimens collectés à Okinawa et Iriomote dans l'archipel des Ryukyu au Japon. Elle se distingue des autres espèces du genre par plusieurs caractères dont une première dorsale pointue mais non filamenteuse chez le mâle, 9 rayons mous à la seconde dorsale, 15-17 rayons à la pectorale, un nombre de dents différent et une coloration unique aussi bien chez les mâles que chez les femelles. Il est suggéré que cette nouvelle espèce a récemment colonisé ces îles et y a établi de petites populations. Ces populations sont peut-être plus importantes dans les régions du sud et les larves ont pu occasionnellement être transportées par le courant du Kuroshio.

Key words. - *Stiphodon* - Ryukyu Archipelago - New species - Amphidromy - Larval dispersal - Kuroshio Current.

The sicydiine gobies of the genus *Stiphodon* Weber, 1895 are distributed in tropical and subtropical freshwater streams from Sri Lanka and the western coast of Sumatra in the Indian Ocean to southern Japan, Australia, and French Polynesia (Watson, 1995). Of these gobies, only the life history of *Stiphodon percnopterygionus* Watson & Chen, 1998 from the Ryukyu Archipelago has been studied to date. This species has the following characteristics: it is amphidromous; it produces small pyriform eggs that are laid on the undersurface of stones in freshwater streams (Yamasaki and Tachihara, 2006); newly hatched larvae, which are small (1.2-1.3 mm in notochord length) and poorly developed, migrate downstream to the sea shortly after hatching at dusk where they develop as pelagic larvae for 2.5-5 months; the pelagic larvae may sometimes be dispersed to distant islands before migrating up to freshwater streams at 13-14 mm in standard length (SL) for further growth and reproduction (Yamasaki *et al*., 2007; Maeda and Tachihara, 2010). Although details of the life histories of the other *Stiphodon* species have not yet been clarified, all sicydiine gobies are generally considered to be amphidromous (Keith *et al*., 2009).

Watson and Chen (1998) reviewed the taxonomy of the genus *Stiphodon* from the Ryukyu Archipelago in southern Japan to clarify the disarray that previously existed within the genus. They described two new species, *S. imperiorientis* Watson & Chen, 1998 and *S. percnopterygionus* Watson & Chen, 1998, from the Ryukyu Archipelago (with the latter species also found in southern Taiwan and Micronesia), and proved that *S. atropurpureus* (Herre, 1927) also occurs in the Ryukyu Archipelago. Based on a single record from Yaku Island in the northern Ryukyu Archipelago (Fig. 1), Yonezawa and Iwata (2001) added a fourth species, *S. surrufus* Watson & Kottelat, 1995 to the list of species distributed on the islands. Here we describe a new species, *Stiphodon alcedo*, from the islands of Okinawa and Iriomote in the Ryukyu Archipelago (Fig. 1). The archipelago is located in the northwest Pacific Ocean, along the path of the strong, warm Kuroshio Current which runs from the southwest to the northeast. The dispersal and colonisation of *Stiphodon* larvae along the Kuroshio Current are also discussed, given their role in the occurrence of this new species in the Ryukyu Archipelago.

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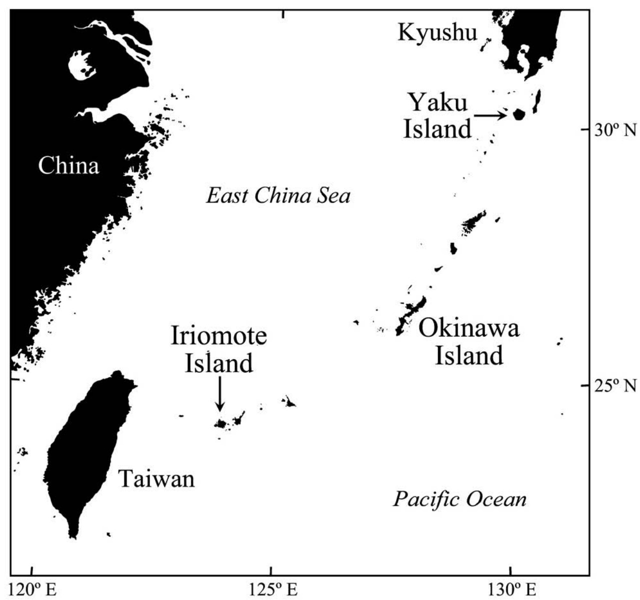

Figure 1. - Map of the Ryukyu Archipelago showing Okinawa and Iriomote Islands where the holotype and paratypes of *Stiphodon alcedo* were collected.

MATERIAL AND METHODS

All measurements and counts were taken from the right side of the fish, unless the right side was damaged. For example, characters related to the pectoral fin were described using the left side when the right pectoral fin was removed for mitochondrial DNA analysis. Measurements were made point-to-point with a dial calliper or a divider under a stereomicroscope to the nearest 0.1 mm and expressed as a percentage of SL. The measurements and counts followed Nakabo (2002), with the following modifications: SL, head length, snout length, and predorsal length were measured to the anterior point of the protruding snout; body depths were measured at the origins of the pelvic and the anal fins; length of caudal peduncle was measured from the posterior end of the second dorsal- and also from the anal-fin bases to the midpoint of the caudal-fin base; first and second dorsal- and anal-fin lengths were measured from the origin of each fin to the farthermost point when the fin was depressed; interval between the first and second dorsal-fin bases was measured from the posterior end of the first dorsal-fin base to the second dorsal-fin origin; preanal length was measured from the snout tip to the anal-fin origin; anus to anal-fin length was measured from the centre of the anus to the anal-fin origin; scales in longitudinal row were counted from the middle of the posterior end of the hypurals to behind the pectoral-fin base (this did not include the scales above the pectoral-fin base, because they did not form a contiguous row with the scales on the lateral midline of the trunk and tail, of which the anterior end was behind the pectoral-fin base); however, in *S. surrufus*, which lacks scales on the anterior trunk, scales in the longitudinal row were counted from the middle of the posterior end of the hypurals to the most anterior scale along the lateral midline; scales in transverse series back were counted along a diagonal line extending posteriorly and ventrally from the first scale anterior to the second dorsal fin, including one scale on the dorsal midline and another small scale at the anal-fin base; scales in transverse series forward were counted along a diagonal line extending anteriorly and ventrally from the first scale anterior to the second dorsal fin to the centre of the belly, and included a scale on the dorsal midline; scales in transverse series in the caudal peduncle were counted along a vertical line around the narrowest point of the caudal peduncle in a zigzag manner, and included scales on the dorsal and ventral midlines. Teeth counts of the upper and lower jaws were taken from the right of the symphysis, with terms used in dentition following Watson (2008). Vertebrae were counted from radiographs. Abbreviations pertaining to the cephalic sensory pore system followed Akihito *et al.* in Nakabo (2002). Abbreviations used to represent collections and institutions cited follow Leviton *et al.* (1985), except BLIH (Biological Laboratory, Imperial Household, Tokyo, Japan), CMK (collection of M. Kottelat, Cornol, Switzerland), KPM-NI (Kanagawa Prefectural Museum of Natural History, Kanagawa, Japan), and ZRC (Raffles Museum of Biodiversity Research, National University of Singapore). Colour in life was described based on underwater observations and photographs taken in streams on Okinawa and Iriomote Islands. The localities were given at the island scale to protect the sites where the new species was discovered from overexploitation by ornamental fish dealers, aquarium hobbyists, and researchers.

Comparative material

The new species was compared to *Stiphodon* specimens from the Ryukyu Archipelago, Japan (Okinawa, Iriomote, and Yaku Islands; Fig. 1), the Philippines (Cebu, Negros, Leyte, Culion, Busuanga, and Palawan Islands), and Palau (Babelthuap Island). Measurements in brackets are SL (mm).

Stiphodon imperiorientis Watson & Chen, 1998. - NSMT-P 48063 (holotype), male (48.5); Iriomote; 2 Sept. 1986. BLIH 19810202 (paratype), male (43.0); Iriomote; 10 Jul. 1981. BLIH 19860400 (paratype), male (44.1); same data as holotype. BLIH 19950002, 19950028 (paratypes), 2 males (37.9, 43.5); Iriomote; 4 Nov. 1995. URM-P 3205, 3206 (paratypes), 2 males (41.8, 47.5); Iriomote; 4 Jun. 1982. URM-P 4823-4825 (paratypes), 2 males (50.9, 50.9), female (52.0); Iriomote; 13 Sept. 1982. OMNH-P 34657, male (32.0); Okinawa; 29 Jul. 2008. OMNH-P 34937, male (29.3); Okinawa; 15 Nov. 2008. OMNH-P 35471, male (48.2); Iriomote; 28 Jul. 1997. OMNH-P 35472, male (39.5); Iriomote; 8 Aug. 2000. URM-P 32169-32171, 2 males (45.2, 49.7), female (47.3); Iriomote; 29-30 July 1994. URM-P 36457, male (39.4); Iriomote; 20 Aug. 1996. URM-P 46079, male (30.6); Okinawa; 27 Oct. 2006.

Stiphodon pulchellus (Herre, 1927). - CAS-SU 26360 (neotype designated by Maeda *et al.*, 2011b), male (50.5); Negros; 15 Jun. 1931. CAS-SU 26359, 6 males (45.5-59.9), 3 females (49.6-54.2); Culion; 19 Apr. 1931. CAS-SU 26362, female (55.2); Culion; 28 Apr. 1931. CAS-SU 38618, male (37.7), 2 females (42.9, 50.6); Busuanga; 21 Jun. 1940. CAS-SU 38622, male (48.0); Busuanga; 24 Jun. 1940. CAS-SU 69760, 69898, 2 males (34.6, 57.5), female (48.2); same data as neotype. CMK 9986, 2 males (36.0, 42.7), 4 females (23.2-45.3); Leyte; 9 Jul. 1993. NSMT-P 45093, male (51.2); Palawan; 13 Nov. 1988. ZRC 38396, 38397, 2 males (49.8, 50.2), 2 females (24.7, 53.5); Leyte; 6 Jul. 1993. ZRC 38396 is a holotype of *S. olivaceus* Watson & Kottelat, 1995 and CMK 9986 and ZRC 38397 are paratypes of *S. olivaceus*. We consider that *S. olivaceus* is a junior synonym of *S. pulchellus* as proposed by Maeda *et al*. (2011b).

Stiphodon pelewensis Herre, 1936. - OMNH-P 34791, 34792, 35269, 35270, 2 males (30.4, 31.4), 2 females (33.4, 37.3); Babelthuap; 17 Aug. 2008.

Stiphodon atropurpureus (Herre, 1927). - ZRC 38392 (neotype), male (33.1); Leyte; 29 Jun. 1993. URM-P 45067-45070, 45075-45080, 4 males (32.4-37.5), 6 females (21.8-37.9); Cebu; 28 Aug. 2007. URM-P 46058, 46059, male (33.6), female (42.2); Okinawa; 13 Dec. 2006. URM-P 46060-46063, 2 males (24.3, 24.5), 2 females (32.3, 36.0); Okinawa; 10 Nov. 2008. URM-P 46064, 46065, male (30.2), female (36.0); Okinawa; 29 Nov. 2009.

Stiphodon percnopterygionus Watson & Chen, 1998. - NSMT-P 49671 (holotype), male (27.9); Iriomote; 1 Jun. 1980. URM-P 4349, 2 males (32.4, 32.6), female (36.8); Iriomote; 10 Sept. 1982. URM-P 4350, male (36.9), female (41.5); Iriomote; 13 Sept. 1982. URM-P 34003, male (31.2), 2 females (35.1, 37.6); Iriomote; 15 Jul. 1995. URM-P 46041, male (20.5); Okinawa; 27 Oct. 2006. URM-P 46042, 46043, male (28.3), female (30.5); Okinawa; 13 Dec. 2006. URM-P 46044-46046, 3 females (24.4-32.7); Okinawa; 26 Dec. 2006. URM-P 46047-46053, 3 males (24.9-27.1), 4 females (28.2-31.7); Okinawa; 10 Nov. 2008. URM-P 46054, 46055, male (25.6), female (31.5); Okinawa; 24 Nov. 2008. URM-P 46056, female (32.0); Okinawa; 29 Nov. 2009. URM-P 46057, female (38.2); Iriomote; 5 Jul. 2010.

Stiphodon surrufus Watson & Kottelat, 1995. - ZRC 38394 (holotype), male (20.0); Leyte; 25 Jun. 1993. ZRC 38395 (paratypes), male (21.0), female (21.0); Leyte; 23 Mar. 1991. NSMT-P 61273, male (18.7); Yaku; 6 Feb. 2000.

Mitochondrial DNA analysis

Total genomic DNA of 17 *Stiphodon alcedo* specimens, 32 congeneric specimens (two *S. imperiorientis*, 16 *S. atropurpureus*, 14 *S. percnopterygionus*), and one outgroup species, *Sicyopterus japonicus* (KPM-NI 0015468; Chiba, Japan; 25 Sept. 1997) was extracted from the right pectoral fin. DNA extraction, gene amplification, and sequencing of a part of the mitochondrial NADH dehydrogenase subunit 5 (ND5) gene (ca. 1 kbp) were performed according to Mukai *et al*. (2005). All sequences are available from GenBank/EMBL/DDBJ under accession numbers AB613050 (holotype), AB613044-AB613058 (paratypes), AB613026-AB613043 and AB613059-AB613069 (congeneric specimens), and AB613024 (outgroup). Genetic distances were calculated using PAUP*4.0b10 (Swofford, 2002). The complete mitochondrial DNA sequence of a paratype (NSMT-P 103605) was determined following Miya and Nishida (1999).

Stiphodon alcedo, new species

New Japanese name: Hisui-bouzu-haze

(Tabs I-II, Figs 2-9)

Material examined

Twenty-seven specimens collected on Okinawa and Iriomote Islands, Ryukyu Archipelago, Japan (Fig. 1), by K. Maeda using a hand net, totalling 15 males, 12 females, size range of 26.0-47.9 mm SL, largest male 43.4 mm SL, largest female 47.9 mm SL.

Holotype. - NSMT-P 103600, female (30.8); Okinawa; 10 Nov. 2008.

Paratypes. - BLIH 20110001, male (29.7); Okinawa; 27 Oct. 2006. BLIH 20110002, female (33.2); Okinawa; 13 Dec. 2006. BLIH 20110003, female (47.9); Iriomote; 20 Oct. 2009. BLIH 20110004, male (40.3); Iriomote; 5 Jul. 2010. NSMT-P 103601-103603, 2 males (27.9, 30.2), female (32.5); same data as holotype. NSMT-P 103604, female (33.5); Okinawa; 5 Nov. 2006. NSMT-P 103605, male (30.1); Okinawa; 13 Dec. 2006. NSMT-P 103606, female (45.6); Iriomote; 20 Oct. 2009. NSMT-P 103607, 103608, male (36.2), female (42.1); Okinawa; 29 Nov. 2009. NSMT-P 103609, male (39.7); Iriomote; 5 Jul. 2010. URM-P 46066, male (30.1); Okinawa; 27 Oct. 2006. URM-P 46067, female (34.2); Okinawa; 13 Dec. 2006. URM-P 46068, 46069, male (29.4), female (29.6); Okinawa; 24 Nov. 2008. URM-P 46070, 46071, male (34.4), female (37.2); Okinawa; 27 Sept. 2009. URM-P 46072, male (38.8); Okinawa; 7 Nov. 2009. URM-P 46073, male (35.4); Iriomote; 9 Nov. 2009. URM-P 46074, male (31.7); Iriomote; 10 Nov. 2009. URM-P 46075-46078, 2 males (28.5, 43.4), 2 females (26.0, 44.9); Okinawa; 3 Sept. 2010.

Diagnosis

Dorsal fins, usually VI-I, 9. Male having pointed, but not filamentous, first dorsal fin with elongate spines 4 and 5, posterior tip of fin usually extending to base of soft-rays 2-5 of second dorsal fin. Pectoral fin rays 15-17 (mode 16). Premaxillary teeth 32-40. Dentary with 32-45 horizontal teeth. Female having two black longitudinal bands laterally on body arranged with a larger interval between two bands; lower band composed of 8-11 regular blotches, upper band thin and pale. All fins of female usually with faint markings. Non-nuptial coloured male having a dark brown longitudinal band just below lateral midline; nuptial coloured male

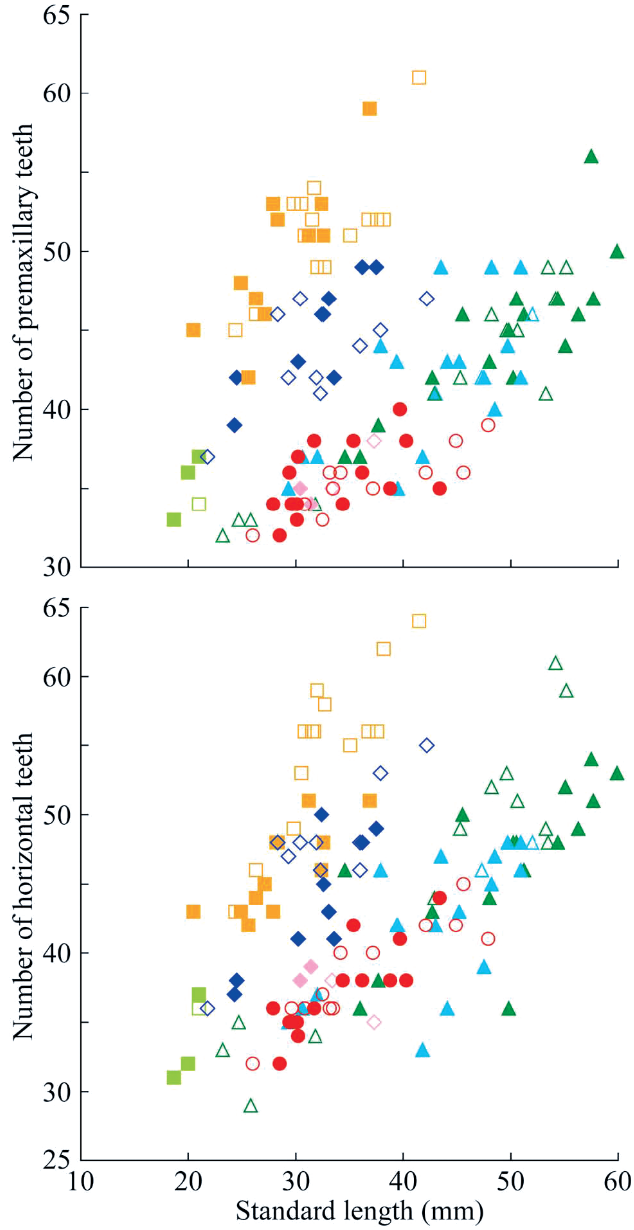

Figure 2. - Number of premaxillary and horizontal dentary teeth of *Stiphodon alcedo* (red circles), *S. imperiorientis* (light blue triangles), *S. pulchellus* (green triangles), *S. pelewensis* (pink squares), *S. atropurpureus* (blue squares), *S. percnopterygionus* (orange squares), and *S. surrufus* (light green squares). Solid and open symbols represent males and females, respectively. A premaxillary tooth count of one *S. percnopterygionus* female (28.2 mm SL) was excluded because the count was exceptionally small (8).

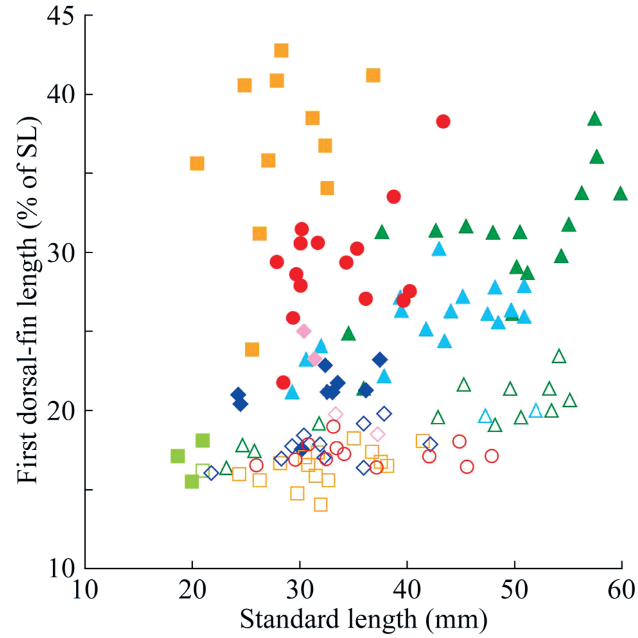

Figure 3. - First dorsal-fin length (% of standard length) of *Stiphodon alcedo* (red circles), *S. imperiorientis* (light blue triangles), *S. pulchellus* (green triangles), *S. pelewensis* (pink squares), *S. atropurpureus* (blue squares), *S. percnopterygionus* (orange squares), and *S. surrufus* (light green squares). Solid and open symbols represent males and females, respectively.

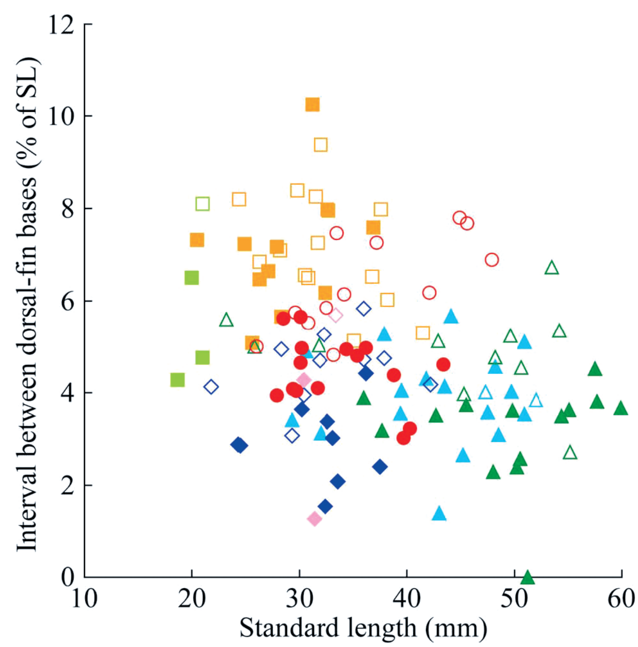

Figure 4. - Interval between first and second dorsal-fin bases (% of standard length) of *Stiphodon alcedo* (red circles), *S. imperiorientis* (light blue triangles), *S. pulchellus* (green triangles), *S. pelewensis* (pink squares), *S. atropurpureus* (blue squares), *S. percnopterygionus* (orange squares), and *S. surrufus* (light green squares). Solid and open symbols represent males and females, respectively.

lacking this band, and having blackish or sometimes orange body, metallic turquoise laterally on head, metallic turquoise spot on upper pectoral-fin base when alive. Pectoral-fin rays in male often having 1-6 somewhat obscure black spots.

Description

Morphometric measurements are given in table I. Body elongate, cylindrical anteriorly and somewhat compressed posteriorly. Head somewhat depressed with a round snout protruding beyond upper lip. Anterior nostril short tubular, posterior nostril not tubular. Mouth inferior with upper jaw projecting beyond lower jaw. Upper lip thick with small, medial cleft and crenulated with tiny fimbriate projections. Premaxillary teeth 32-40, fine and tricuspid. Dentary with recurved conical to canine-like symphyseal teeth, number of teeth usually 2-3 (range 1-5) in males, usually none in females (1 in a case with teeth); dentary with a row of unicuspid horizontal teeth enclosed in a fleshy sheath, number of teeth (32-45) similar or slightly more numerous than premaxillary teeth. Larger fish having more premaxillary and horizontal teeth (Fig. 2).

Dorsal fins VI-I, 9 (n = 25) or VI-I, 10 (n = 2); in female, first dorsal fin almost semicircular and spine 3 or 4 longest; in male, first dorsal fin forming parallelogram or triangular with spines 4 and 5 elongate but not filamentous. Most posterior points of first dorsal fin of male extending to base of soft-rays 2-5 of second dorsal fin when depressed, except in a smaller male (28.5 mm SL) having a shorter first dorsal fin extending to base of spine of second dorsal fin; larger males having longer first dorsal fin than smaller males (Fig. 3). Female having larger interval between first and second dorsal-fin bases (4.8-7.8% of SL) than male (3.0-5.6% of SL) (Fig. 4). Anal fin I, 10, below second dorsal fin. In female, anterior rays (usually soft-ray 2) longest in second dorsal and anal fins; in male, most posterior rays longer than anterior rays. Caudal fin with 13 (n = 4), 14 (n = 17), 15 (n = 6) branched rays within 17 segmented rays, posterior margin rounded or somewhat truncated, male with somewhat larger fin than female (length of longest ray 23.9-28.8% of SL in male, 20.7-25.0% of SL in female; Tab. I).

Table I. - Morphometric measurements of *Stiphodon alcedo* expressed as a percentage of standard length. D_1: first dorsal fin; D_2: second dorsal fin; A: anal fin; C: caudal fin; P_1: pectoral fin; P_2: pelvic fin.

	Holotype	Paratypes	
Sex	Female	Female	Male
Number of specimens measured	1	11	15
Standard length (mm)	30.8	26.0-47.9	27.9-43.4
Head length	24.4	22.5-25.0	22.8-25.3
Snout length	8.1	7.9-10.5	7.3-9.5
Eye diameter	5.8	4.5-6.2	5.2-6.1
Postorbital length of head	11.0	9.9-12.0	10.3-11.9
Upper jaw length	7.5	7.6-10.0	7.8-9.0
Body depth at P_2 origin	15.9	13.7-15.4	14.2-17.3
Body depth at A origin	18.2	15.4-17.6	15.1-18.3
Depth of caudal peduncle	11.4	10.5-12.0	11.3-12.6
Length of caudal peduncle from A base	18.8	15.6-20.4	17.5-20.4
Length of caudal peduncle from D_2 base	21.1	19.6-21.9	19.2-22.5
Predorsal length	36.7	33.8-37.3	32.7-35.9
Length of D_1 base	17.9	16.0-18.1	16.8-19.3
D_1 length	17.9	16.4-19.0	21.8-38.2
Length of longest spine of D_1	12.0	11.0-13.1	15.8-30.9
Interval between D_1 and D_2 bases	5.5	4.8-7.8	3.0-5.6
Length of D_2 base	23.4	23.0-24.7	23.9-27.2
D_2 length	29.5	28.7-30.7	33.7-43.6
Length of longest ray of D_2	13.0	11.6-13.2	13.6-21.2
Preanal length	59.1	57.7-61.6	54.1-58.7
Length of A base	25.3	23.0-25.7	26.7-29.1
A length	31.8	29.2-31.6	35.4-42.8
Length of longest ray of A	11.7	10.0-11.7	12.2-16.9
Anus to A length	4.2	3.3-4.8	2.7-4.5
Length of longest ray of P_1	21.1	18.8-22.0	21.0-25.8
Length of longest ray of C	24.4	20.7-25.0	23.9-28.8
P_2 length	15.6	14.2-16.2	14.7-16.6

Table II. - Counts of soft-rays in second dorsal and pectoral fins, and scales in longitudinal row of *Stiphodon alcedo* and congeners from the Ryukyu Archipelago, the Philippines, and Palau.

	Second dorsal-fin ray			Pectoral-fin ray				
	8	9	10	13	14	15	16	17
S. alcedo		25	2			5	19	3
S. imperiorientis		18	1			15	4	
S. pulchellus	1	26	2		2	19	8	
S. pelewensis		3	1		1	3		
S. atropurpureus		19			1	15	3	
S. percnopterygionus		2	24	1	23	2		
S. surrufus		4			4			

	Scales in longitudinal row																	
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
S. alcedo														9	9	8	1	
S. imperiorientis														3	9	4	2	1
S. pulchellus														4	8	7	8	2
S. pelewensis															1	3		
S. atropurpureus													5	8	6			
S. percnopterygionus											1	7	9	4	5			
S. surrufus	1	1				2												

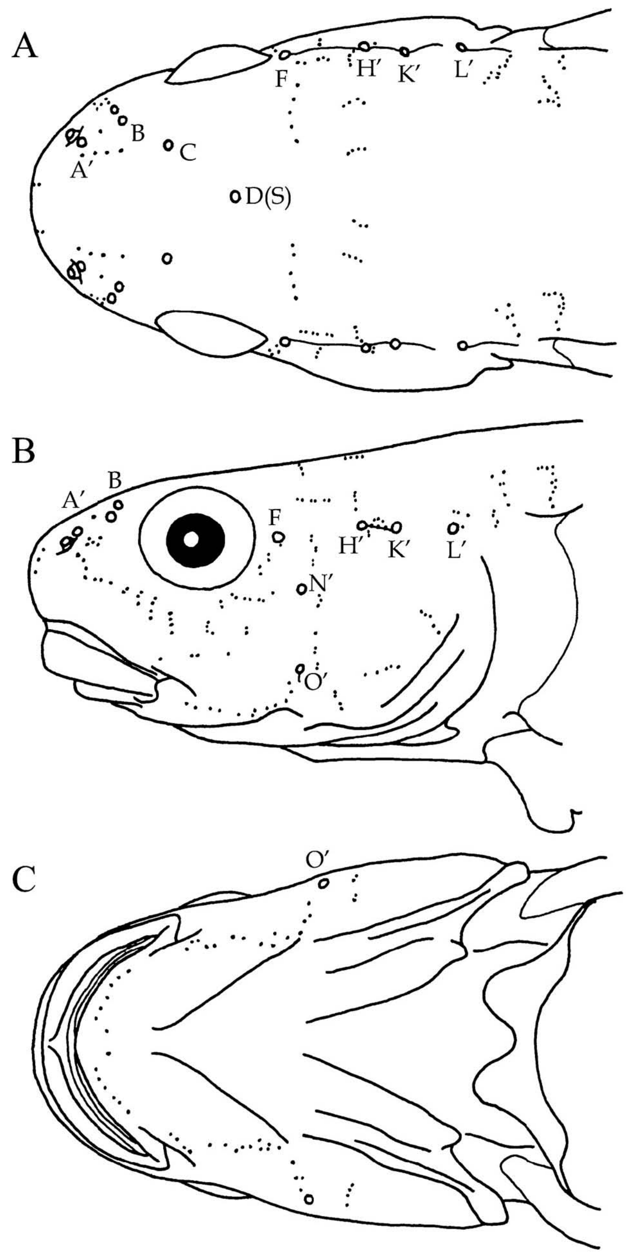

Figure 5. - Diagrammatic illustration of head showing arrangement of the cephalic sensory pores and cutaneous sensory papillae in *Stiphodon alcedo* (BLIH 20110001); **A**: Dorsal view; **B**: Lateral view; **C**: Ventral view.

Pectoral fin with 15-17 rays (Tab. II), male with somewhat larger fin than female (length of longest ray 21.0-25.8% of SL in male, 18.8-22.0% of SL in female; Tab. I). Pelvic fin I, 5, paired fins joined together to form a strong cup-like disk with fleshy frenum. Number of vertebrae 10+15 (n = 1), 10+16 (n = 25), 10+17 (n = 1).

Scales in longitudinal row 30-33 (Tab. II); scales in transverse series back 10 (n = 2), 11 (n = 25); scales in transverse series forward 13 (n = 4), 14 (n = 19), 15 (n = 3), 16 (n = 1); scales in transverse series in caudal peduncle 9 (n = 23), 10 (n = 4). More predorsal scales in female (9-16) than in male (7-13). Ctenoid scales covering lateral sides of trunk and almost entire tail. Cycloid scales dorsally on trunk and head, posterior to pectoral-fin base, on belly between middle of pelvic fin to origin of anal fin, along second dorsal- and anal-fin base, along dorsal and ventral midline in caudal peduncle (often with ctenoid scales), and caudal-fin base. Pectoral-fin base naked, except in two females with two cycloid scales laterally on pectoral-fin base.

Urogenital papilla in male rectangular or somewhat rounded with two small projections at both sides of tip, often some tiny projections between the two projections; female similar but tip projections more pronounced and posterior edge almost smooth.

Cephalic sensory pore system always A, B, C, D, F, H, K, L, N, and O; pore D singular, all others paired (Fig. 5). Oculoscapular canal separated into anterior and posterior canals between pores H and K. Cutaneous sensory papillae developed over lateral and dorsal surface of head (Fig. 5).

Colour in preservation

Sexual dichromatism well developed with males showing conspicuous nuptial colour during courtship.

Non-nuptial coloured males (Fig. 6A). - Background of body and head pale brown; dark brown longitudinal band extending from behind pectoral-fin base along and just below lateral midline to posterior end of caudal peduncle, band often composed of 9 or 10 obscure blackish blotches at regular intervals along posterior trunk and entire tail. Dorsum somewhat dusky with 1, 3, and 5 whitish blotches on head, trunk, and tail, respectively. Belly whitish. Snout, infraorbital and opercular regions, upper lip blackish; head pale brown ventrally. Black patch on middle and upper part of pectoral-fin base. First dorsal-fin membranes pale grey, first spine with 3-4 black spots, other spines with 0-4 obscure black spots. Second dorsal-fin membranes greyish, spine with 3-4 black spots, soft-rays with 2-5 obscure black spots with translucent spots between each black spot. Anal-fin membranes greyish, spine with 0-3 obscure black spots, soft-rays without spots and paler than fin membranes. Caudal fin dusky with 5-7 translucent transverse bars; distal margin of fin transparent, upper part with wider margin; black blotch at centre of proximal part of fin. Black patch on pectoral-fin base spread to proximal part of rays 6-10 and adjacent membranes; other membranes of pectoral fin transparent; pectoral-fin rays with somewhat obscure black spots, but spots usually invisible in smaller males and sometimes invisible even in larger males, number of spots on longest rays (ray 7 and/or 8) 0-6. Black transverse band across middle part of pelvic-fin rays, fin membranes, and frenum, forming a black ring (in ventral view); inside of ring pale brown, outside of ring transparent except around soft-ray 5, which has blackish edge.

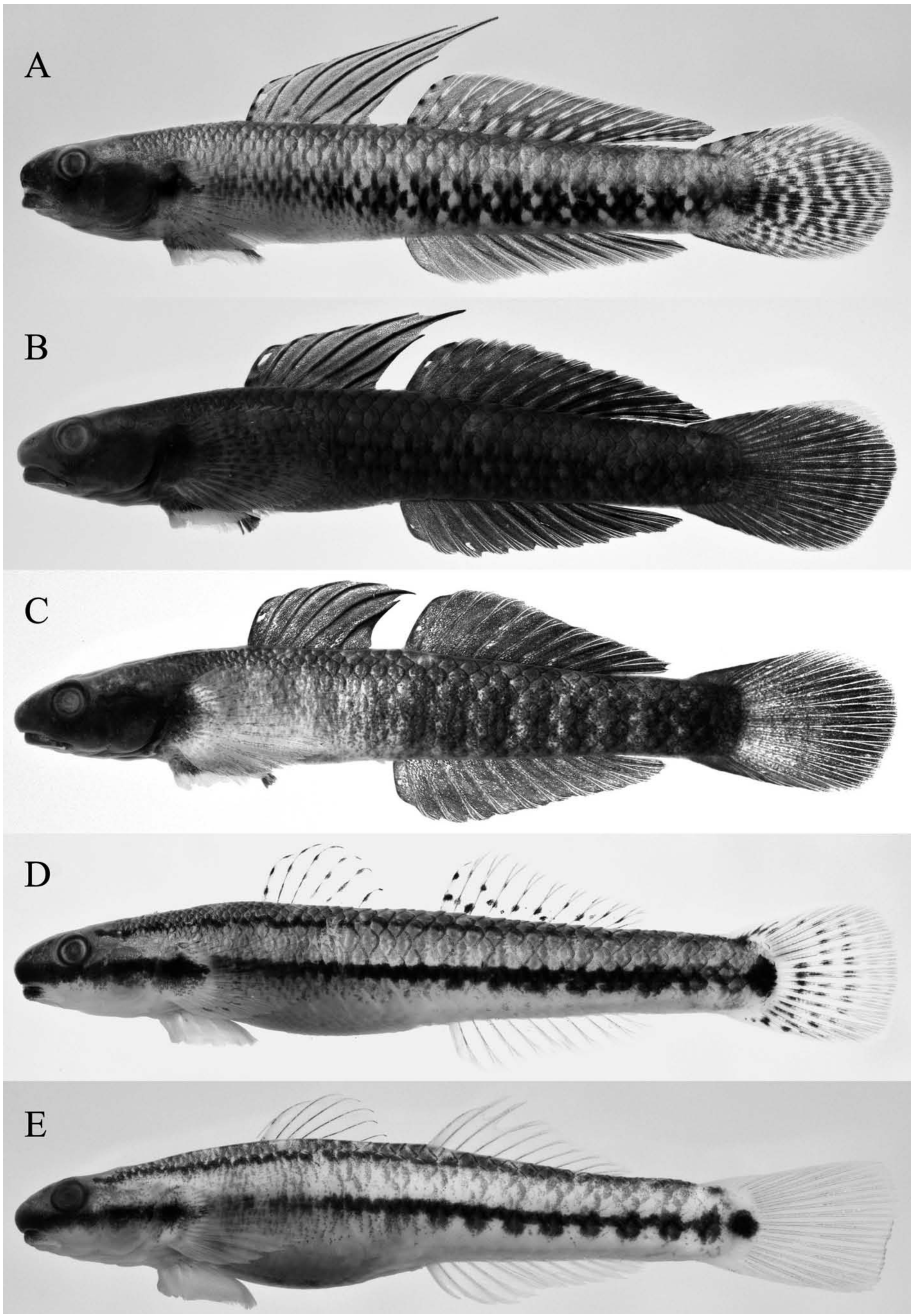

Figure 6. - Preserved specimens of *Stiphodon alcedo*. **A**: Non-nuptial coloured male (43.4 mm SL, URM-P 46078, paratype); **B-C**: Nuptial coloured males (**B**: 38.8 mm SL, URM-P 46072, paratype; **C**: 29.4 mm SL, URM-P 46069, paratype); **D-E**: Females (**D**: 45.6 mm SL, NSMT-P 103606, paratype; **E**: 30.8 mm SL, NSMT-P 103600, holotype).

Nuptial coloured males (Fig. 6B, C). - Head, trunk, and tail blackish, but belly usually whitish grey; 3 and 8 pale grey transverse bars laterally on trunk and tail, respectively (Fig. 6C), but bars sometimes indistinguishable (Fig. 6B); arrangement of whitish blotches along dorsal midline similar to those of non-nuptial coloured males. Dorsal, anal, and caudal fins dusky brown without clear markings. Margin of caudal fin transparent; proximal part of caudal fin of small specimens (< 30 mm SL) sometimes pale brown (Fig. 6C). Colour of pectoral and pelvic fins similar to those in non-nuptial coloured males.

Females (Fig. 6D, E). - Background of body and head pale cream; black longitudinal band extending from snout to below eye and to middle of pectoral-fin base, band continuing from behind pectoral-fin base to posterior end of caudal peduncle through a position somewhat lower than lateral midline (e.g., located on lower half of 6th scale and upper half of 7th scale in transverse series back), band composed of 0-3 obscure black blotches on trunk and 8 black regular spacing blotches on tail (Fig. 6E), but blotches sometimes indistinct and forming disheveled band (Fig. 6D). Another black longitudinal band from behind eye extending dorsolaterally to base of upper procurrent caudal-fin rays, this band thinner and often paler than lower lateral band and sometimes obscure; distance between two longitudinal bands 29-38% of body depth at origin of anal fin (Fig. 7). Dorsum between upper lateral bands pale brown with 1, 3, and 5 pale cream bars on head, trunk, and tail, respectively. Snout usually with U-shaped black band detached from both eyes, irregular black markings sometimes scattered between eyes. First dorsal-fin membranes transparent, first spine with 1-4 black spots, other spines usually dusky without clear markings (Fig. 6E), but sometimes with 2-4 black spots in larger females (Fig. 6D). Second dorsal-fin membranes transparent, spine usually with 1-3 black spots, soft-rays usually dusky without clear markings (Fig. 6E), but sometimes with 1-2 black spots in larger females (Fig. 6D). Anal fin usually without pigment, but sometimes with irregular pale grey pigments in fin membranes. Black blotch at centre of proximal part of caudal fin, remainder of fin usually without markings and with only faint black pigments on rays (Fig. 6E), occasionally with 2-3 transverse bars formed by black spots on rays in larger females (Fig. 6D). Black lateral band on pectoral-fin base spreading to proximal part of pectoral-fin rays 6-8 and adjacent membranes; other parts of pectoral fin usually without clear markings, but occasionally with 1-2 black spots on rays in larger females. Pelvic fin translucent without pigment.

Colour in life

Non-nuptial coloured males (Fig. 8A, B). - Body colour and markings similar to preserved specimens, but head and body pale reddish brown dorsally; dusky or black lateral band extending from snout through infraorbital and opercular regions to centre of pectoral-fin base; pale pearl blue or gold band dorsally along this lateral band on snout and opercular region; upper pectoral-fin base with pale pearl blue or gold spot. Markings of fins similar to preserved specimens, but second dorsal, anal, and caudal fins with a shiny white margin; second dorsal fin with white spots between blackish spots along spine and rays; caudal fin with 5-7 whitish transverse bars; distal area of pelvic fin white.

Nuptial coloured males (Fig. 8C-F). - Body colour showing considerable variation, but lateral area of head and upper and lower lips always brilliant metallic turquoise, dorsum of head always black, pectoral-fin base always black with brilliant metallic turquoise spot on upper part. Background of body usually black. 4 and 8 metallic turquoise transverse bars laterally on trunk and tail, respectively, but bars sometimes indistinguishable due to totally blackish body. Dorsum with 1, 3, and 5 metallic turquoise or gold blotches on head, trunk, and tail, respectively. Belly whitish ventrally and sometimes orange laterally. Markings of fins similar to those of preserved specimens, but second dorsal, anal, and caudal fins blackish with shiny white margin; pectoral fin usually

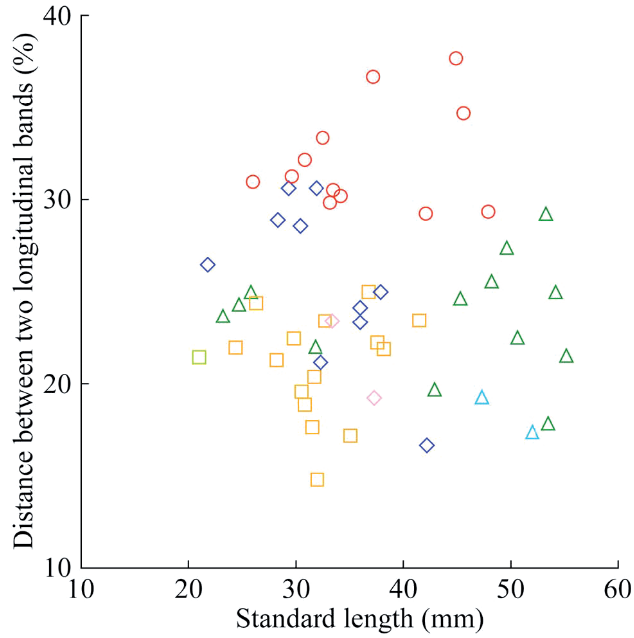

Figure 7. - Distance between two black longitudinal bands above the origin of the anal fin (% of body depth at origin of anal fin) in females of *Stiphodon alcedo* (red circles), *S. imperiorientis* (light blue triangles), *S. pulchellus* (green triangles), *S. pelewensis* (pink squares), *S. atropurpureus* (blue squares), and *S. percnopterygionus* (orange squares).

lacking white marking, but occasionally with faint bluish-white spots between black spots along rays; distal area of pelvic fin white. Smaller males (< 30 mm SL) often with orange on trunk and tail, first and second dorsal, anal, and caudal fins (Fig. 8F). While resting on perch during courtship, colour changes rapidly and appears similar to non-nuptial coloured males, having paler background and occurrence of a black longitudinal band.

Females (Fig. 8G, H). - Background of body and fins pale yellowish-brown. Markings similar to preserved specimens, but gold on snout, opercular region, and upper pectoral-fin base. Fins lacking white marking.

Etymology

The new species is named from the Latin *alcedo*, meaning kingfisher, as the metallic turquoise on the head and body and the orange around the belly of the nuptial coloured male is similar to the plumage of the kingfisher, *Alcedo atthis*. The new specific name is a noun in apposition.

MtDNA phylogeny

The complete mitochondrial DNA sequence (16,505 bp) of a paratype specimen (NSMT-P 103605) is available from the DNA Data Bank of Japan (DDBJ) (http://www.ddbj.nig.ac.jp/) under the accession number AB613000. Since the genome content, gene order, and L- and H- strand coding of each gene were identical to those obtained for other teleost

Figure 8. - Live *Stiphodon alcedo* in streams of the Ryukyu Archipelago (photo by K. Maeda). **A-B**: Non-nuptial coloured males (**A**: ca. 37 mm SL, Iriomote Island, 5 Jul. 2010; **B**: ca. 43 mm SL, Okinawa Island, 29 Aug. 2010); **C-F**: Nuptial coloured males (**C**: ca. 30 mm SL, Okinawa Island, 27 Nov. 2006; **D**: ca. 32 mm SL, Okinawa Island, 10 Nov. 2006; **E**: ca. 29 mm SL, Okinawa Island, 15 Nov. 2008; **F**: ca. 28 mm SL, Okinawa Island, 15 Nov. 2008); **G-H**: Females (**G**: ca. 30 mm SL, Okinawa Island, 20 Jan. 2008; **H**: ca. 32 mm SL, Okinawa Island, 6 Nov. 2008).

fishes reported by Miya *et al*. (2003), we were able to identify 13 protein-encoding genes, two rRNA-encoding genes, and 22 tRNA-encoding genes, in addition to the control region (D-loop). The gene location data for the mitochondrial genome of *Stiphodon alcedo* has been deposited in the DDBJ.

A total of 1,004 bp for nucleotide sequences of the mitochondrial ND5 gene was determined for 17 *S. alcedo* specimens, 32 specimens belonging to three other *Stiphodon* species, and one *Sicyopterus japonicus* specimen. The nucleotide sequences of two *S. alcedo* specimens (holotype NSMT-P 103600 and paratype NSMT-P 103609) and four

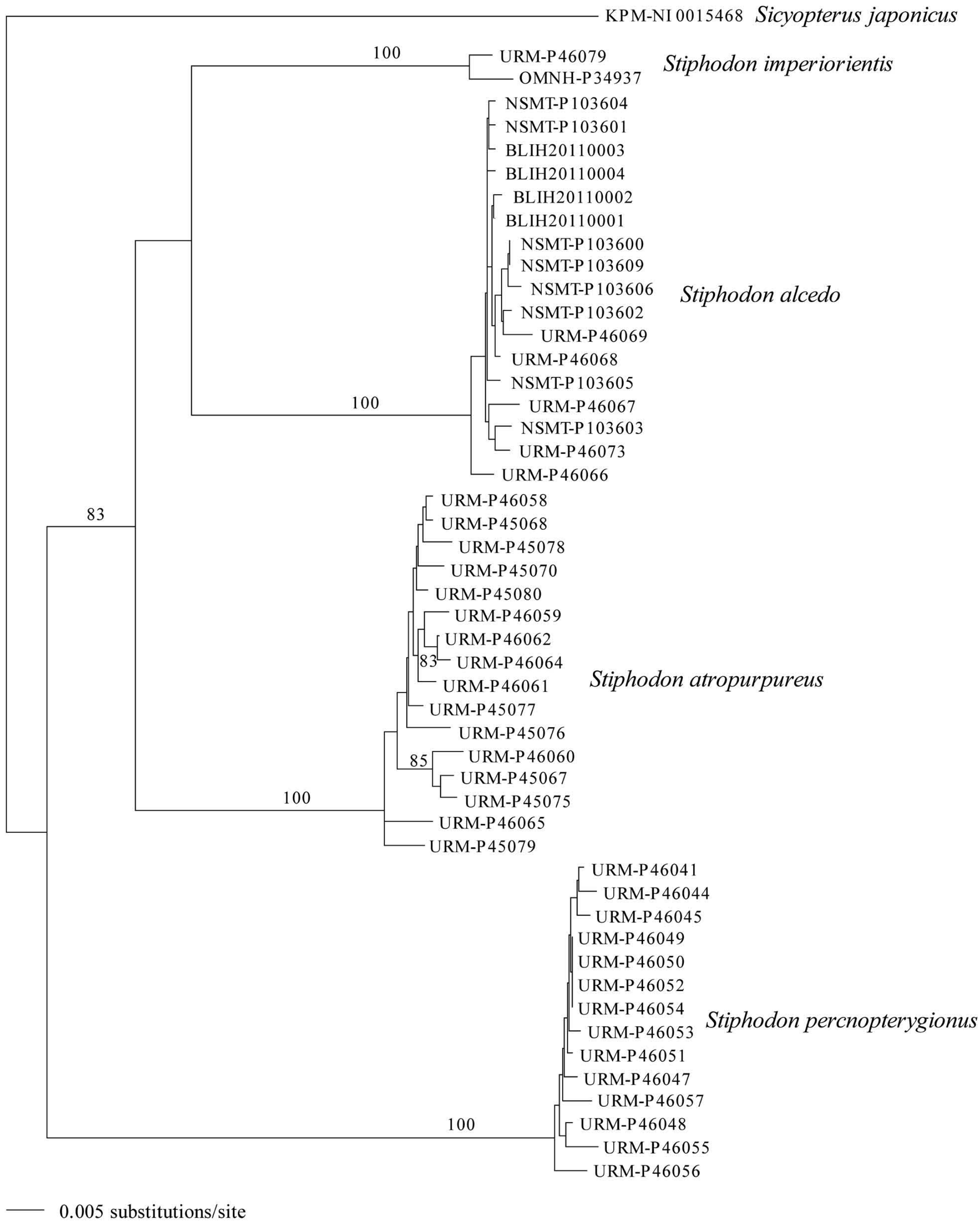

Figure 9. - Neighbour-joining tree based on genetic distances estimated from partial mitochondrial NADH dehydrogenase subunit 5 (ND5) gene sequences (1,004 bp) in four *Stiphodon* species including type specimens of *S. alcedo* and a related genus (*Sicyopterus*). Distances are based on Kimura's two-parameter model and calculated using PAUP*4.0b10 (Swofford, 2002). Numbers adjacent to internal branches indicate bootstrap probabilities (> 80%) based on 1,000 pseudoreplicates.

S. percnopterygionus specimens (URM-P 46049, 46050, 46052, and 46054) had the same haplotypes, respectively (DDBJ accession number AB613050 and AB613064). A neighbour-joining tree showed that all 17 nucleotide sequences of *S. alcedo* comprised a monophyletic group (Fig. 9). Intraspecific nucleotide sequence differences were small (*p* distance 0.00-1.00% in *S. alcedo*, 0.20-1.49% in *S. atropurpureus*, and 0.00-1.00% in *S. percnopterygionus*), with those among the four *Stiphodon* species being remarkably higher (*p* distance 7.47-12.95%; Tab. III). Among these species, *S. alcedo* grouped relatively close to *S. imperiorientis* in the phylogenetic tree.

Table III. - Averages pairwise sequence differences (%: *p* distance) of partial ND5 gene among species of gobies. Ranges in *p* distances are shown in parenthesis.

	S. japonicus	*S. imperiorientis*	*S. alcedo*	*S. atropurpureus*
Sicyopterus japonicus	-			
Stiphodon imperiorientis	12.60 (12.55-12.65)			
S. alcedo	13.07 (12.55-13.25)	7.89 (7.47-8.47)		
S. atropurpureus	12.76 (12.45-12.95)	9.14 (8.57-9.76)	8.52 (8.17-9.26)	
S. percnopterygionus	14.29 (14.04-14.54)	11.43 (10.96-11.95)	12.44 (11.95-12.95)	11.22 (10.66-11.75)

Comparison

The morphology of *Stiphodon alcedo* was compared to those of six northwestern Pacific *Stiphodon* species. The second dorsal-fin ray count of *S. alcedo* (usually I, 9) was the same as in other species examined in this study, except for *S. percnopterygionus* (usually I, 10) (Tab. II). While the mode of the pectoral-fin ray count of *S. alcedo* (16) was higher than that observed in all of other species examined in this study, with the range (15-17) almost overlapping with those of *S. imperiorientis*, *S. pulchellus*, *S. pelewensis*, and *S. atropurpureus* (Tab. II). The scale counts in longitudinal row of *S. alcedo* (30-33) were similar to those of *S. imperiorientis*, *S. pulchellus*, and *S. pelewensis* and higher than those of *S. atropurpureus*, *S. percnopterygionus*, and *S. surrufus* (Tab. II). The number of premaxillary teeth and horizontal teeth in the dentary of all species increased with body size (Fig. 2). Teeth counts of *S. alcedo* were lower than those of *S. atropurpureus* and *S. percnopterygionus*, and similar to those of *S. imperiorientis*, *S. pulchellus*, and *S. pelewensis* when compared within the same size class (Fig. 2). Males of *S. alcedo* had a pointed first dorsal fin and differed from the males of *S. atropurpureus* and *S. surrufus*, which had a round first dorsal fin. The first dorsal fins of male *S. imperiorientis*, *S. pulchellus*, *S. pelewensis*, and *S. percnopterygionus* were also pointed, but the first dorsal fin of male *S. alcedo* was longer than that of *S. imperiorientis*, *S. pulchellus*, and *S. pelewensis*, but shorter than that of *S. percnopterygionus* (Fig. 3). The interval between the first and second dorsal-fin bases of *S. alcedo* females was longer than that of *S. imperiorientis*, *S. pulchellus*, and *S. atropurpureus*, but smaller than that of *S. percnopterygionus* (Fig. 4). Taken together, *S. alcedo* can be distinguished from *S. atropurpureus*, *S. percnopterygionus*, and *S. surrufus* through a combination of pectoral-fin ray and teeth counts and the shape of male first dorsal fin, while the ranges of most meristic and morphometric characters in *S. alcedo* generally overlapped with those observed in *S. imperiorientis*, *S. pulchellus*, and *S. pelewensis*. On the other hand, the colours and markings of both male and female *S. alcedo* were markedly different from all *Stiphodon* species examined. In particular, the dark brown longitudinal band just under the lateral midline of non-nuptial coloured males and the arrangement and composition of the two, black, longitudinal bands in the female (i.e., in *S. alcedo*, the lower band was missing from the 5th scale in the transverse series back, but was present on the lower part of this scale in all other species examined, increasing the distance between the longitudinal bands in *S. alcedo* as shown in Fig. 7, a lower band composed of 8-11 regular blotches, and a thin, paler coloured upper band) are unique to this species. The relatively faint fin markings of *S. alcedo* males and females also differed from those in several other species (*S. imperiorientis* males and females, *S. pulchellus* males, and *S. pelewensis* males, which always have distinctive black spots on the pectoral-fin rays; and *S. atropurpureus* females have conspicuous black spots on their dorsal and caudal fins with a black longitudinal band along the distal margin of anal fin).

A combination of pectoral-fin ray count (15-17), second dorsal-fin ray count (I, 9), relatively low premaxillary teeth count (32-40 in specimens measuring 26.0-47.9 mm SL), and pointed but not filamentous first dorsal fin in males distinguishes the new species from all other *Stiphodon* species, except *S. ornatus* Meinken, 1974, *S. atratus* Watson, 1996, and *S. weberi* Watson, Allen & Kottelat, 1998, as well as *S. imperiorientis*, *S. pulchellus*, and *S. pelewensis*. However, according to descriptions in Watson (1994, 1996) and Watson *et al*. (1998), *S. alcedo* can be distinguished from *S. ornatus*, *S. atratus*, and *S. weberi* by the unique arrangement and composition of the lateral longitudinal bands in females described above; faint female fin markings (*vs*. well-defined markings on the second dorsal-, caudal- or pectoral-fin rays); no or 1-6 inconspicuous black spots without clear white spots on male pectoral-fin rays (*vs*. having alternately arranged rows of black and white spots on rays); uniform intensity of lateral blotches on the tails of males and the caudal peduncle never being whitish (*vs*. blackish blotches along lateral midline often prominent below second dorsal fin with whitish caudal peduncle in *S. ornatus* and *S. atratus*; often with two broad black bars below first and second dorsal fins in *S. weberi*).

Remarks

The female specimen (OMNH-P 15609) described as *Stiphodon atropurpureus* by Suzuki *et al.* (2001) was a female *S. alcedo*. An illustration of a female *S. atropurpureus* in Nakabo (2002) was based on the same specimen (Y. Ikeda, pers. comm.) and we conclude that this was also *S. alcedo*. That specimen was collected on Iriomote Island in 1999 (T. Suzuki, pers. comm.).

We selected a female specimen as holotype of the new species, although the majority of holotypes in this genus are male. The markings on the body and fins of *S. alcedo* females are unique to this species and stable even after preservation, while some of the characteristics of male colouration, especially nuptial males, disappeared after preservation. Based on these characteristics, we determined that a female specimen would be well suited for use as the holotype for this species.

Ecology

Adult and juvenile *Stiphodon alcedo* were observed in freshwater streams where they usually inhabited pools. They often shoaled with conspecific individuals and the congeners *S. percnopterygionus* and *S. atropurpureus*, and occasionally with *S. imperiorientis*. We suppose that the spawning season of the new species is from October to December (autumn and early winter), at least on Okinawa Island, because nuptial coloured males and courtship displays were observed only during these three months. The water temperature decreases during this season, and the males were observed to become inactive and assume non-nuptial colours before the beginning of the coldest season (Jan.-Feb.), retaining the non-nuptial colouration throughout the spring and summer. This spawning season is considerably shorter than that of its sympatric congener, *S. percnopterygionus*, which spawns from spring to early winter (May-December) on Okinawa Island (Yamasaki and Tachihara, 2006). The spawning season of *S. alcedo* is unique among freshwater and estuarine fish on Okinawa Island, which generally spawn from spring to autumn, from spring to summer, in winter, or throughout the year (Maeda *et al.*, 2008; Maeda and Tachihara, 2010). Spawning of *S. alcedo* was observed in a stream on Okinawa Island on 27 October 2006; an egg mass, tended by a male (30.1 mm SL; URM-P 46066), was found on the undersurface of a stone, and a gravid female (ca. 30 mm SL) was observed around the site the day before the eggs were discovered. The smaller, orange nuptial males (ca. 28-30 mm SL) also exhibited active courtship displays, suggesting that *S. alcedo* mature at 28-30 mm SL and spawn in the first season after recruitment.

Distribution

The new species has only been found in four streams on Okinawa Island and in two streams on Iriomote Island. Larger populations of approximately 30 individuals have occasionally been observed along the 200 to 400 m stream reaches on Okinawa Island, but such levels of abundance were not sustained. The populations sometimes became depleted or disappeared from some of the streams in winter. All specimens of the new species examined in the present study were collected during or after 2006. Although the freshwater fish fauna of the islands comprising the Ryukyu Archipelago have been explored since the early 20th century (Sakai *et al.*, 2001), except for one female collected in 1999 (OMNH-P 15609, see remarks), no specimens or photographs of this species are known prior to 2006. The absence of any sightings before this time implies that the populations of *Stiphodon alcedo* may have increased recently in the Ryukyu Archipelago.

It has been suggested that the Kuroshio Current frequently transports the pelagic larvae of some amphidromous, catadromous, and estuarine fish species, and that, in doing so, the current facilitates the colonisation of streams on the islands along the current (Maeda *et al.*, 2007, 2011a; Yamasaki *et al.*, 2007; Iida *et al.*, 2010: Shinoda *et al.*, in press). In addition to common migrants (e.g., *Eleotris acanthopoma* and *Sicyopterus japonicus*), it is likely that vagrant species have also colonised the Ryukyu Archipelago, and the discovery of *S. surrufus* on Yaku Island (Yonezawa and Iwata, 2001) is considered to be a typical example of such a colonisation event. The extant populations of *S. alcedo* in the Ryukyu Archipelago may have originated on islands near the origin of the Kuroshio Current. The new species on Okinawa and Iriomote Islands may have established small, local populations either by self-recruitment through local reproduction or by continuous colonisation from regions to the south. The relatively low abundance of this species is likely to be regulated by the environment and/or competition with congeners and other lotic species. For example, the relatively low winter water temperatures on these subtropical islands may be unsuitable, and preferred habitats may be already occupied by *S. percnopterygionus*, a dominant species in streams of the archipelago (Watson and Chen, 1998).

Thus, even though the new goby species has only been found on Okinawa and Iriomote Islands, it may not be endemic to the Ryukyu Archipelago. Indeed, it is possible that this species is well represented in river systems further south, such as those along east coast of Luzon in the Philippines, which is in close geographical proximity to the origin of the Kuroshio Current. The area is likely to have an abundance of suitable habitats and is largely unexplored. Other peripheral regions (e.g., Taiwan, Visayas, Mariana Islands, Palau, and South China) have been surveyed, and only the other *Stiphodon* species have been reported from these regions to date (Herre, 1934, 1936; Watson and Kottelat, 1995; Watson and Chen, 1998; Donaldson and Myers, 2002; Nip, 2010).

The genus *Stiphodon* has undergone considerable diversification in the insular tropical and subtropical streams of the areas in which it occurs, and species-specific distributions are known to occur (Keith *et al.*, 2009). The speciation events and extant distributions of the species belonging to this genus are considered to be the result of repeated colonisation events, of which *S. alcedo* may be a recent example. The establishment, success, decline, and extinction of local populations are all affected by habitat preference and interspecific competition, as well as by geographic and oceanographic changes. The distribution of this genus is thus likely to change in the future, particularly if global warming affects the survival of tropical stragglers, such as *S. alcedo* in the Ryukyu Archipelago. It is therefore important to monitor the fluctuations of these populations in the future.

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