Southward range extension of the goldeye rockfish, *Sebastes thompsoni* (Actinopterygii: Scorpaeniformes: Scorpaenidae), to northern Taiwan

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Abstract

The goldeye rockfish, *Sebastes thompsoni* (Jordan et Hubbs, 1925), is known as a typical cold-water species, occurring from southern Hokkaido to Kagoshima. In the presently reported study, a specimen was collected from the local fishery catch off Keelung, northern Taiwan, which represents the first specimen-based record of the genus in Taiwan. Moreover, the new record of *Sebastes thompsoni* in Taiwan represented the southernmost distribution of the cold-water genus *Sebastes* in the Northern Hemisphere.

Keywords

cold-water fish, DNA barcoding, neighbor-joining, new recorded genus, phylogeny, *Sebastes joyneri*

Introduction

The rockfish genus *Sebastes* Cuvier, 1829 is the most speciose group of the Scorpaenidae, which comprises about 110 species worldwide (Li et al. 2006; Hyde and Vetter 2007; Kai and Nakabo 2013; Nelson et al. 2016). Members of *Sebastes* generally occur in cold-temperate and boreal waters (Wourms 1991; Mecklenburg et al. 2002; Hyde and Vetter 2007), except for four species residing in the North Atlantic and two species being found in the Southern Hemisphere (Chen 1971; Rocha-Olivares et al. 1999; Garabana 2005; Hyde and Vetter 2007). In addition, rockfishes are economically important species, especially in temperate regions (Muto et al. 2018; Wang et al. 2020). The distributions of rockfishes in the Northern Hemisphere are generally present from northern Japan and the waters of Alaska to California (Robins et al. 1980; Wourms 1991).

On an occasional survey in a local fish market (25°7.77′N, 121°44.47′E), a mature female individual of *Sebastes thompsoni* (Jordan et Hubbs, 1925) was obtained in the local catches, which were caught off Keelung, northern Taiwan, by a bottom trawl. Based on the literature records, however, the goldeye rockfish, *S. thompsoni*, was previously known from southern Hokkaido southward to Kochi and Nagasaki at a depth of 80–160 m (Masuda et al. 1984; Nakabo and Kai 2013; Yu and Kim 2018) and from the Korean Peninsula (Kim et al. 2009). Iwatsubo et al. (2015) reported a single specimen of *S. thompsoni* captured by hook-and-line from Yaku-shima Island, Kagoshima Prefecture of Japan, which reveals the southernmost occurrence of the species. Thus, our specimen represents a southward range extension of *S. thompsoni*.

 Members of the *Sebastes* are similar in external appearance between the closely related species (Chen 1985; Muto et al. 2018), hence we performed the molecular
identification of the species using the DNA barcoding of the cytochrome c oxidase I (COI) gene, which is typically indicated as an effective genetic marker for identification of most fish species (Hebert et al. 2003; Ward et al. 2005; Ratnasingham and Hebert 2007; Ward et al. 2009). The identification of our specimen is confirmed as a new record from Taiwan and also the southernmost record for the genus Sebastes in the Northern Hemisphere. We herein describe the Taiwanese specimen in detail.

Methods

Counts and measurements generally followed Kai and Nakabo (2002) and Kai et al. (2011), including the definition of body depths 1 and 2. The last rays of the dorsal and anal fins are divided at their base and were counted as a single ray. Standard length is expressed as SL. Standardization of morphometric data is expressed as a percentage of SL. Measurements were taken by digital and common calipers, based on the length of the measured items, recorded to the nearest 0.1 mm. The terminology of the spines on the head followed Randall and Eschmeyer (2001). Osteological characters were determined by X-radiographs. The specimen was deposited in the Pisces Collection of the National Museum of Marine Biology and Aquarium (NMMB-P), Taiwan.

DNA was extracted from the muscle by the GeneMark Easy Tissue and Cell Genomic DNA Purification Kit, procedures following the manufacturer’s protocol. PCR amplifications were used a 25 μL volume containing 3 μL of 10× Taq Buffer, 2 μL of dNTP mixture at 10 mM each, 1 μL each of forward and reverse primer at 5 μM, 0.125 μL of Pro Taq Plus DNA polymerase (Promega Technology Enterprise, Taiwan), 1 μL of template DNA and the remainder made up with ultrapure water. The portion of COI was amplified using combinations of universal COI primer pairs (Ward et al. 2005): FishF1 (5′-TCAGCCACACAAAGAGATTTGGCA-C3′) and FishR1 (5′-TAGACTTTGCGGCAAAAGATCA-3′). The thermal cycle profiles consisted of an initial denaturation step at 95°C for 4 min, followed by 35 cycles of 94°C for 30 s, 53°C for 30 s and 72°C for 1 min, with a final step at 72°C for 10 min. PCR products were verified in 2% agarose gels and were purified using SAP-Exo Kit (Jena Bioscience). PCR products were sequenced in the forward and reverse directions by a biotechnology company (Genomics, Taiwan), Sebastes atrovirens (Jordan et Gilbert, 1880), Sebastes inermis Cuvier, 1829 and S. thompsoni were selected as the comparative sequences (Chen 1985) that were downloaded from BOLD (the Barcode of Life Data System). K2P (Kimura-2-parameter) model was used for describing the genetic variation of COI gene in the genetic distance and phylogenetic analysis. The phylogenetic relation was reconstructed with the neighbor-joining (NJ) method using MEGA ver. 10.1.1 (Kumar et al. 2018). The branch support value was assessed by the bootstrapping criterion with 1000 replicates.

Results

This study identified the specimen NMMB-P33709 (Figs 1 and 2) as Sebastes thompsoni by morphological and molecular approaches. The counts and proportional measurements of the specimen are listed in Table 1 and described below. Molecular analysis is shown in Fig. 3 and explained. The COI sequence of Sebastes thompsoni (NMMB-P33709) was submitted to GenBank (accession number MZ144755).

Table 1. Morphometric measurements of examined specimen of Sebastes thompsoni from Taiwan (NMMB-P33709).

| Character | Value [%SL] | Value [mm] |
|----------|-------------|------------|
| Standard length | 170.9 |
| Head length | 34.2 |
| Snout length | 8.1 |
| Orbit length | 10.8 |
| Interorbital width | 8.2 |
| Postorbital length | 18.8 |
| Upper jaw length | 14.6 |
| Body depth 1 | 31.2 |
| Body depth 2 | 35.5 |
| Body width | 17.1 |
| Caudal peduncle depth | 10.0 |
| Upper peduncle length | 11.6 |
| Lower peduncle length | 18.1 |
| Pectoral-fin length | 29.2 |
| Pelvic-fin length | 21.9 |
| Dorsal-fin base length | 60.4 |
| Spinous dorsal-fin base length | 32.2 |
| Soft dorsal-fin base length | 24.8 |
| Preanal length | 69.5 |
| Predorsal length | 33.2 |
| Prepelvic length | 40.8 |
| Anal-fin base length | 19.7 |
| Pelvic-to-anal-fin length | 30.6 |
| 1st dorsal-fin spine length | 7.4 |
| 2nd dorsal-fin spine length | 10.4 |
| 3rd dorsal-fin spine length | 14.1 |
| 1st anal-fin spine length | 6.9 |
| 2nd anal-fin spine length | 13.4 |
| 3rd anal-fin spine length | 13.3 |
| Pelvic-fin spine length | 13.3 |
| Gill raker length | 16.1 |

Family Scorpaenidae Risso, 1820
Sebastes Cuvier, 1829

Sebastes thompsoni (Jordan et Hubbs, 1925)

[English name: goldeye rockfish]

Description of the Taiwanese specimen (NMMB-P33709). Dorsal-fin elements XIII, 14; anal-fin elements III, 7; all dorsal- and anal-fin rays branched; pectoral-fin rays 16, lowermost eight rays unbranched; pelvic-fin elements I, 5, all soft rays branched; total caudal-fin rays 37, principal caudal-fin rays 8 + 8 (upper + lower), procurent rays 11 + 10 (upper + lower); pored lateral-line scales 54, not including 3 pored scales extending on to the caudal fin; gill rakers on first gill arch 11 + 27 (upper + lower), all rakers developed; pseudobranchial filaments ca. 40; branchiostegal rays 7; vertebrae 11 + 15 (precaudal + caudal) = 26 (total).
Figure 1. *Sebastes thompsoni*, NMMB-P33709, 170.9 mm SL, off northern Taiwan (fresh specimen).

Figure 2. Preserved condition of *Sebastes thompsoni*, NMMB-P33709. A: After being preserved in 70% of ethanol, B: X-rayograph of the same specimen. It should be noted that the caudal-fin was folded artificially when preserved.
Body relatively deep and compressed. Mouth moderately large, slightly oblique, posterior margin of maxilla not reaching middle level of orbit. Dorsal fin continuous, fourth spine longest, length of remaining spines gradually shorter posteriorly, except last spine (13 th) distinctly longer than penultimate spine; shape of soft portion of dorsal fin triangular, length of soft rays gradually shorter posteriorly. Anal fin with three spines, second and third spine long, subequal in length; shape of soft portion of anal fin triangular, length of soft rays gradually shorter posteriorly. Caudal fin emarginate.

Lower jaw with short symphyseal knob, pointed and protruding anteriorly; upper jaw with band of tiny conical teeth, outermost row larger; lower jaw with band of tiny conical teeth; both jaws without enlarged canines; vomer with V-shaped tooth patch, formed by tiny conical teeth; palatine with two long narrow tooth patches with tiny conical teeth.

Head spines relatively short, except spines on opercle and pre-opercle. Lachrymal with two sharp, developed spines, posterior one slightly longer than anterior; nasal spines present, situated above each anterior nostril; upper margin of orbits with pre-orbital and postorbital spines; pair parietal ridge, posterior end terminating with weak spine; single, short cleithral spine present, located above uppermost edge of opercle membrane; short supra-cleithral spine, located anterior to cleithral spine; opercle with two prominent spines, subequal in length; margin of pre-opercle with five robust and developed spines.

Body mostly covered with tiny ctenoid scales. Head fully scaled, including snout, cheek, lower jaw (dentine and angular surface) and maxilla; scales present on branchiostegal membrane. Dorsal and anal fins scaled; tiny ctenoid scales covering more than half of fin, some scales extending further along fin rays; pectoral fin base with ctenoid scales, scales gradually becoming smaller and extending to fin along fin rays; pelvic fin with scales present along spine and rays, scales becoming cycloid distally; caudal-fin fully scaled, its base covered with relatively larger ctenoid scales, remaining area generally covered with tiny ctenoid scales, distal end of fin covered with tiny cycloid scales.

Color. In fresh condition (Fig. 1), body pale red, dusky along dorsum; five dark-brown irregular transverse bands under base of dorsal fin and caudal peduncle. A faint brown blotch on upper part of opercle. Dorsal fin dusky red with two faint and elongated blotches at base of soft-rayed portion; anal, caudal, and pelvic fins dusky red; pectoral fin reddish. In preserved specimen (Fig. 2A), body, dorsal and caudal fin dusky. Anal and paired fins pale. Transverse bands along dorsum shown in fresh condition remain dark.

Genetics. In the molecular analysis, a total of 22 COI sequences of three species of Sebastes were obtained to reconstruct the neighbor-joining tree (Fig. 3) by the Kimura-2-parameter (K2P) model. The result showed the sequence determined here was placed in the cluster of previously determined sequences of S. thompsoni with a high bootstrap value (99%). The interspecific K2P distance ranged from 1.1% to 5.1% (mean 2.7%). Therefore, the identification of S. thompsoni was further confirmed by the molecular approach.

Discussion

According to several studies of biodiversity of fishes in Taiwan, 62 species of the Scorpaenidae (sensu Smith et al. 2018) were documented in Taiwanese waters (Chen 1981; Shao et al. 2008; Motomura et al. 2011; Shen and Wu 2011; Koeda and Ho 2019). The presently reported specimen (NMMB-P33709) cannot be keyed or classified into the ichthyofauna of Taiwan. Therefore, it represents a new recorded genus and species in Taiwan.

We identified this specimen as the genus Sebastes, based on a combination of characters: weak spines on head and opercular bones; dorsal-fin spines XIII; relatively large body size; and fins were not elongated. In addition, the genus Sebastes can easily be distinguished from most Scorpaenidae species by having a greater number of vertebrae (mostly more than 25), except for Adelosebastes, Hozukius, Sebastolobus, and Trachyscorpia (see Ishida 1994). In this study, the vertebrae count of the specimen (NMMB-P33709) was 26 (Fig. 2) which agreed with the range of Sebastes.

Based on the morphological and molecular evidence, we recognized the specimen (NMMB-P33709) as Sebastes thompsoni in the presently reported study. It was originally described, based on two type specimens collected from Iwate and Osaka in Japan, respectively (Jordan and Hubbs 1925). The presently described specimen (NMMB-P33709) agrees with the original description of S. thompsoni. It could be distinguished from the most related species, Sebastes joyneri Günther, 1878, by three
characters: five dark brown transverse bands on lateral body in *S. thompsoni* (vs. round blotches in *S. joyneri*); a faint blotch on opercle (vs. without); 51–56 pored lateral-line scales (vs. 47–53) (Ida et al. 1982; Masuda et al. 1984; Nakabo and Kai 2013).

The genus *Sebastes* is generally limited to temperate and boreal regions (Chen 1971; Wourms 1991; Rocha-Olivares et al. 1999; Mecklenburg et al. 2002; Garabana 2005; Hyde and Vetter 2007). Hence, the objective record of *Sebastes thompsoni* in Taiwan implied that the distribution of the cold-water fish *Sebastes* extended to the southernmost part in the Northern Hemisphere. However, although *S. joyneri* was listed in Taiwan by Jin (2006), we considered this record as questionable as no voucher specimen is available. In addition, Masuda et al. (1984) indicated that *S. thompsoni* live in colder waters than *S. joyneri*. The potential dispersal mechanism of the southward extension of *S. thompsoni* is uncertain.

A similar case was reported in Koeda and Muto (2019) of another cold-water species, *Pholis fangi* (Wang et Wang, 1935), which was previously only known from the Bohai and Yellow seas. However, a single specimen of *Pholis fangi* was captured by a bottom trawl off Donggang, south-western Taiwan. It represents the first and unexpected case of cold-water species from the Northern Hemisphere with a southward distribution extension to Taiwan. Morphological examination and DNA barcoding analysis highly supports the identification of the specimen. The specimen of *Sebastes thompsoni*, obtained in the presently reported study, is highly similar to the reported case of Koeda and Muto (2019) and yet, it is still uncertain whether the presently described specimen represented a rare local population or a rare dispersal from the Bohai or Yellow Seas.

**Acknowledgments**

We thank C.-H. Chan (NMBA) for the curatorial assistance. We thank Dr H.-C. Ho for critically reading the manuscript. We are grateful to Dr. T.-Y. Liao (NSYSU) for the support of molecular work. This study was partly supported by the National Marine Museum of Biology and Aquarium and National Sun Yat-sen University, Taiwan.

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