Plankton Benthos Res 12(1): 66–70, 2017

Plankton & Benthos Research

Note

First record of the doliolid genus *Paradoliopsis* in the Pacific Ocean

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Received 7 December 2015; Accepted 1 November 2016 Responsible Editor: Mary Grossmann

Abstract: A doliolid species belonging to the genus *Paradoliopsis* was photographed by an Autonomous Visual Plankton Recorder (AVPR) off the eastern seaboard of Japan in October 2014 at 493–512 m depth. Two *Paradoliopsis* gonozooids were also captured on the video record of the ROV *Crambon* at 372–373 m depth during the same cruise. This is the first record of this genus from the Pacific Ocean, and although it resembles the sole described species in this genus, *P. harbisoni* Godeaux, 1996, some aspects of its morphology suggest it may be an as-yet-undescribed species.

Key words: doliolid, gonophorozooid, Visual Plankton Recorder, first record, biogeography

During Cruise KS-14-18 of the R/V *Shinsei Maru* from 26 September–6 October 2014, deployments of an Autonomous Visual Plankton Recorder (AVPR) and the Remotely-Operated Vehicle *Crambon* off the coast of north-eastern Japan recorded a species of the doliopsid doliolid genus *Paradoliopsis* Godeaux, 1996 for the first time outside of the North Atlantic Ocean.

In situ photographs of three individual doliolids with a distinctive anatomy were taken by the AVPR between 1–3 Oct 2014, at depths between 478–512 m (Fig. 1). Although the resolution of the images was not particularly high, it was obvious that these individuals belonged to the same species, each imaged from a different angle. In the individual in Fig. 1C, approximated 8–9 mm in length, the wide-open buccal and atrial siphons are visible. The body length was slightly longer than high, the atrial siphon was long, the buccal siphon wide, and the buccal vestibule was capacious. The endostyle was visible on the ventral side, along with two associated pigmented structures at either end in the individuals in Figs. 1B and C. No stolon was visible. The peripharyngeal bands, extending from the anterior end of the endostyle in the ventral mid-line of the zooid, were also evident (Fig. 1B, C). Conspicuous red-orange and yellow-gold pigmentation existed in the U-shaped digestive canals, which also contained three to four black fecal pellets. The numerous slits of the branchial septa in the gill were visible and the gills were colorless throughout their extent. The dorsal neural ganglion was evident and slightly pigmented (see Fig. 1B, C). The above characters are congruent with these animals being gonozooids and/or gonophorozooids of the genus *Paradoliopsis*. They more closely resemble *P. harbisoni* Godeaux, 1996, than any other *Doliposis*-like doliolid (see Table 3 in Godeaux & Harbison, 2003), although several differences were noted. The buccal siphon was approximately 35–40% of the height of the zooid rather than 70% as reported for the single known representative of the genus, *P. harbisoni*, and the gills were not completely vertical. Because the present animals were less than 1 cm in length, while the description of *P. harbisoni* is based on individuals of 2.2 and 2.5 cm in length, it is possible that these morphological differences may just be growth-related and they can thus be thought referable to *P. harbisoni*. However, because all observed individuals were of a similar size, it is possible that these animals actually belong to an as-yet undescribed species in the genus *Paradoliopsis*.

Two deployments of the AVPR were made during the cruise—on the nights of the 1st and 3rd of October. The field of view was set to 43 mm by 43 mm with a pixel resolution of 48 μm pixel^{-1}. On 1 October 2014, the VPR was deployed to a maximum depth of 720 m at a ship speed vs water of 0.5 knots and a wire reel-out speed of 0.5 m/s. On 3 October, ship speed was kept stable at 1 knot vs water and wire reel-out and reel-in speeds were 0.5 m/s with a maximum depth reached of 1000 m. Gonozooids (gonophorozooids?) of doliopsids belonging to the genus *Paradoliopsis* were photographed by the AVPR on 1 October at 493 m depth (Fig. 1A,

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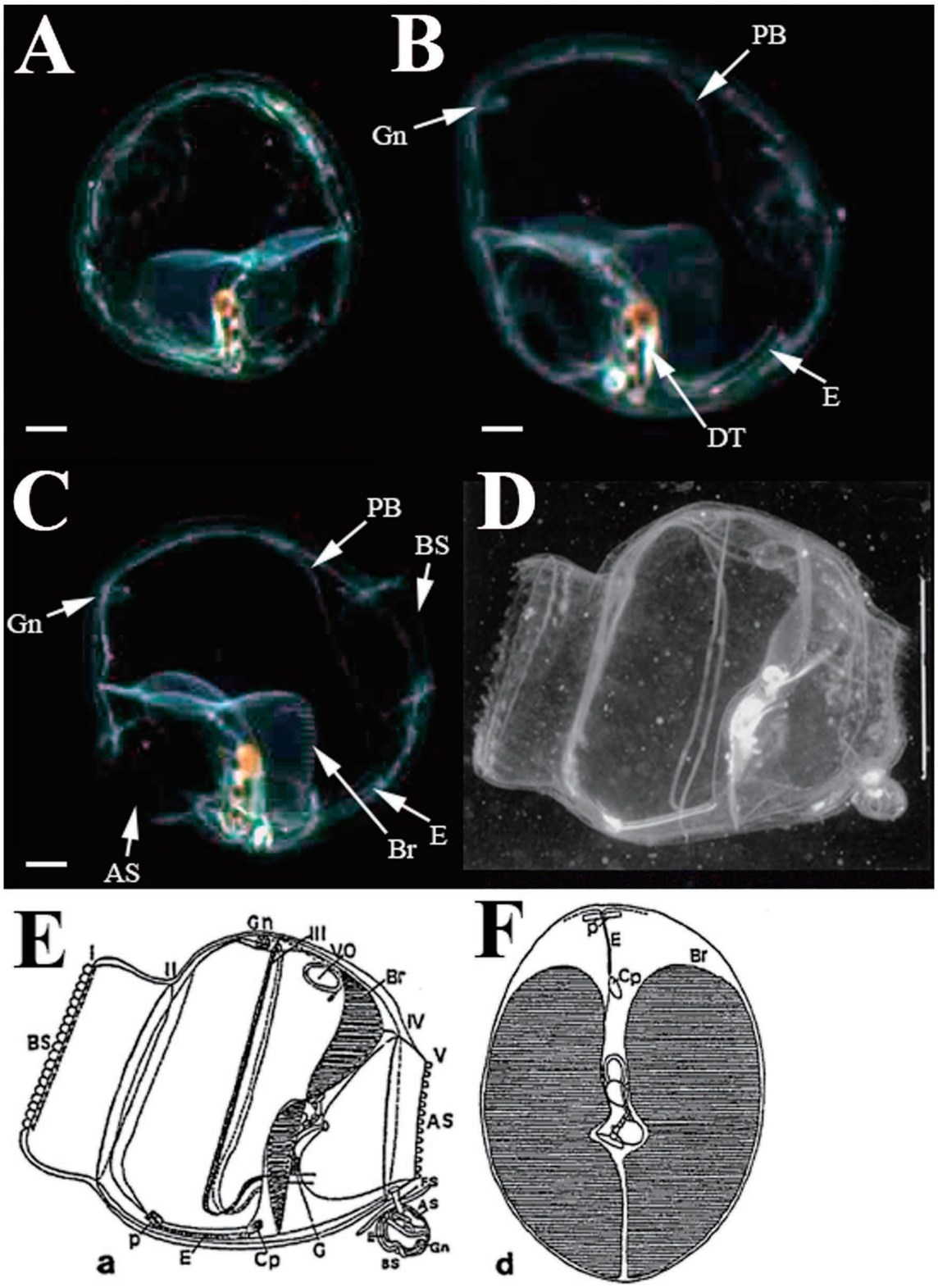

Fig. 1. Posterior (A: 1 Oct 2014, 11:34:05, 493.4 m), right lateral with endostyle rotated out of the page ca. 45° (B: 3 Oct 2014, 11:22:25, 477.7 m), and right lateral with endostyle rotated into the page ca. 40° and buccal siphon pitched upward ca. 30° (C: 3 Oct 2014, 11:57:43, 511.9 m) views of gonozooids/gonophorozooids of the *Paradoliopsis* species photographed by the Autonomous Visual Plankton Recorder (AVPR). The buccal (BS) and atrial (AS) siphons, peripharyngeal bands (PB), endostyle (E) with white pigments, the digestive tract (DT), neural ganglion (Gn), and the numerous gill slits of the branchial septum (Br) are labelled; scale bars for A–C: 1 mm. A black and white photograph (D: scale bar 1 cm) and line drawings in left lateral (E) and frontal (F) views of *Paradoliopsis harbisoni* Godeaux, 1996, reproduced from Godeaux & Harbison (2003), are also presented for comparison.

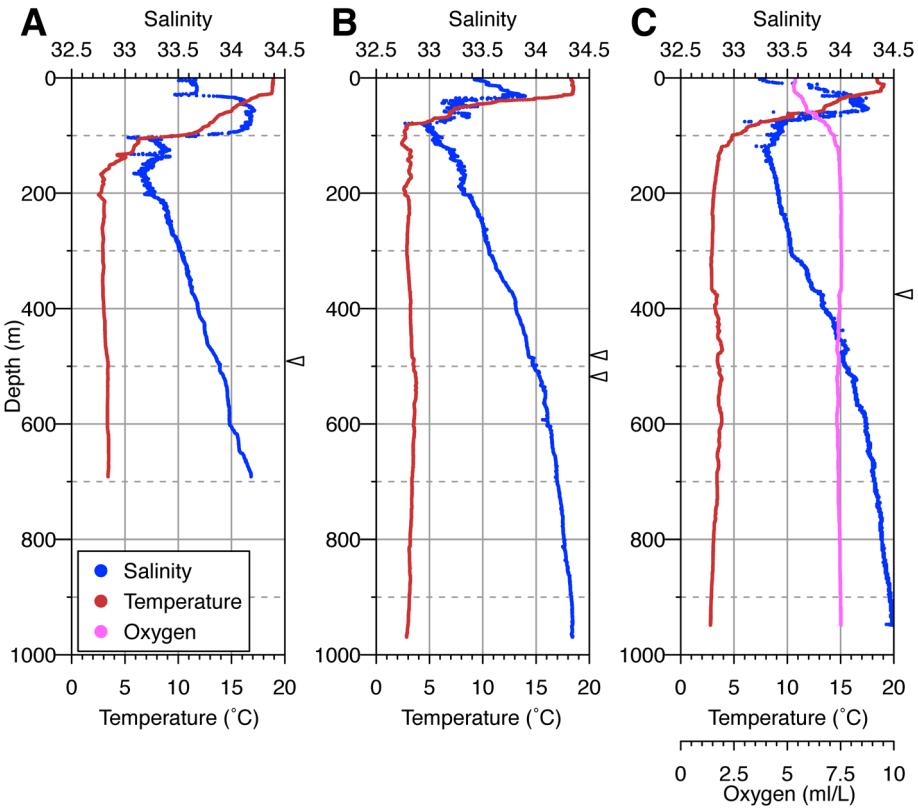

Fig. 2. CTD profiles from the AVPR deployments on 1 October (A) and 3 October (B) 2014, and the ROV *Crambon* dive on 4 October (C). Depths at which *Paradoliopsis* was observed are indicated by open triangles.

temperature 3.4°C, salinity 33.93, 38°59.62′N 142°16.45′E) and on 3 October 2014 at 478 m (Fig. 1B, temperature 3.4°C, salinity 33.87) and 512 m (Fig. 1C, temperature 3.6°C, salinity 34.03, 38°53.88′N 142°30.09′E) depth. Two doliolids with the same gross morphology as the present material were also captured on the video record of the ROV *Crambon* at 372–373 m depth (temperature 3.2°C, salinity 33.79, dissolved oxygen 7.5 mL/L, 38°36.51′N 142°24.51′E) during a dive to 948 m depth on the morning of 4 October. CTD profiles from the AVPR and ROV *Crambon* deployments are shown in Fig. 2.

During the ROV *Crambon* dive, the cold-water indicator species *Aglantha digitale* (O.F. Müller, 1776) was observed between 204–338 m, shallower than the depth at which *Paradoliopsis* was observed. According to the water mass classification scheme of Hanawa and Mitsudera (1987) for water masses of the Sanriku Coast, the water mass occurring below 300 m depth, in which *Paradoliopsis* was observed, was the cold lower-layer water system (Fig. 3). This water mass occurred just below the depths at which the cold, low salinity waters of the Oyashio Current prevailed (Fig. 3), and its origin was supposed by Hanawa and Mitsudera (1987) to be Kuroshio waters cooled by air-sea interaction for waters above salinity 34.0 and derived from Oyashio waters when salinity was lower than 34. The presence of the Oyashio-associated *A. digitale* in the shallower layers of this water mass during the ROV *Crambon* dive lends support to this hypothesis. *Paradoliopsis* was observed in waters both higher and lower than 34.0 salinity (Fig. 3).

Paradoliopsis, specifically *P. harbisoni*, has been recorded in the literature only off the Atlantic coast of North America, specifically over George's Bank (40°02′N, 69°02′W) and in the Bahamas (24°31′N, 83°45′W) at 735–739 m depth in both locations, and at temperatures ranging between 4.8°C and 5.7°C (Godeaux & Harbison 2003). The present observations are only the second of the genus, extending its known biogeographical distribution, but are both colder (3.2°C) and shallower (372 m) than previous records. It remains unclear whether the present observations are referable to a second, as-yet-undescribed, species that prefers colder and/or shallower waters, or whether these observations of smaller zooids would extend the known habitat preferences for *P. harbisoni*.

The size distribution of marine snow particles at the depths at which *Paradoliopsis* occurred were analyzed (Fig. 3) according to the methods of Lindsay et al. (2014), where the minimum measured dimension of particles was 144 μm in order to filter out compression artefacts and other "noise". These data are presented as histograms of minimum Feret's diameter (shortest dimension) vs particle number (Fig. 3). Minimum feret size was investigated because, as elongated particles generally align in flow with their long axes parallel to flow streamlines, this will determine whether the particles could be trapped within the feeding filter of the doliolid zooids. Although the pore widths of the mucous feeding filter of these zooids is as yet unknown, in most doliolids they are usually

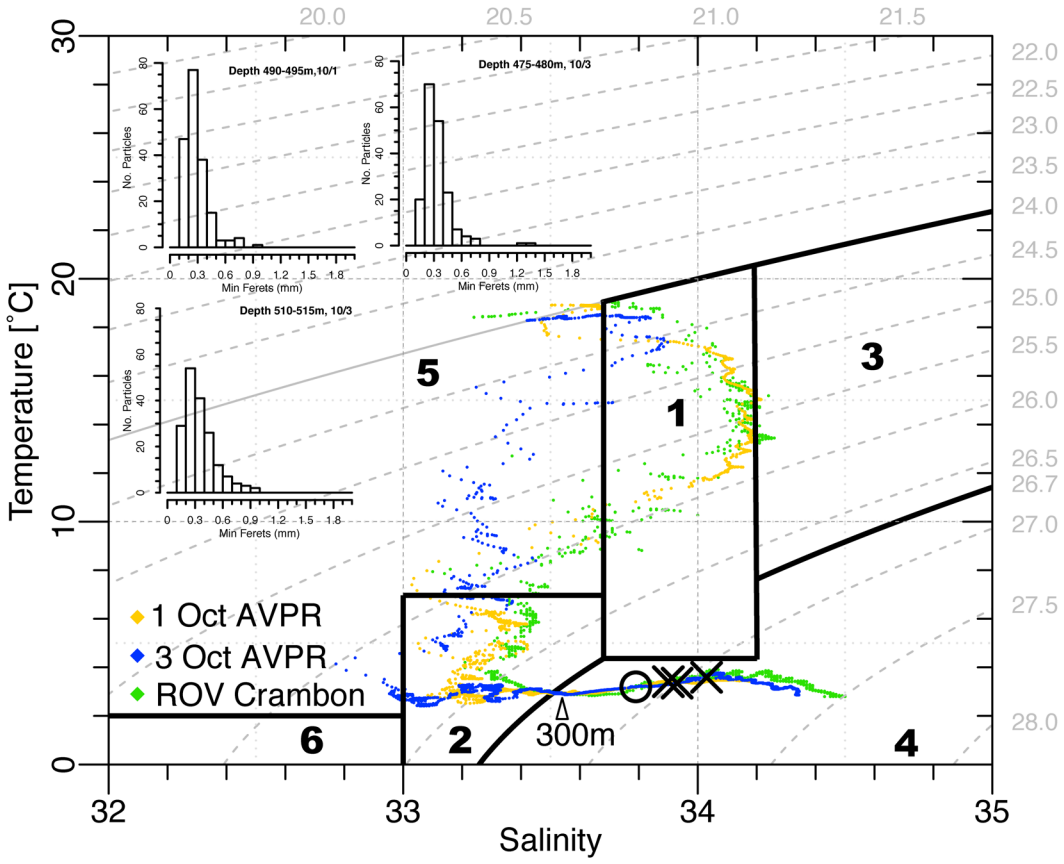

Fig. 3. T–S diagram based on CTD data from the two Autonomous Visual Plankton Recorder (AVPR) tows and the ROV *Crambon* dive, with the six water systems off the Sanriku Coast, according to Hanawa & Mitsudera (1987), overlaid: 1. the Tsugaru Warm Current water system; 2. the Oyashio water system; 3. the Kuroshio water system; 4. the cold lower-layer water system; 5. the surface layer water system; 6. the Coastal Oyashio water system. Open circles and crosses represent *Paradoliopsis* observations during the ROV *Crambon* and AVPR surveys, respectively. Marine snow particle size (minimum Feret's diameter >144 μm) histograms, for the depths at which *Paradoliopsis* was observed with the AVPR, are inserted top left.

from 0.2–5 μm (Bone et al. 2003). Consequently, these zooids would therefore be able to consume almost the entire range of particles present at the depths at which they were observed (Fig. 3), including particles that were too small to be imaged with the AVPR, but with the possible exception of the larger particles (e.g. >1 mm), which may clog the feeding filter.

A VPR has been successfully used to elucidate *in situ* associations between doliolids, specifically *Dolioletta gegenbauri* (Uljanin, 1884), and sapphirinid copepods (Takahashi et al. 2015a), and to characterize a surface bloom of *D. gegenbauri* doliolids in the Oyashio-Kuroshio frontal region (Takahashi et al. 2015b), but the present report is the first to identify a deep sea doliolid to putative species level using VPR images and to characterize the marine snow particle field upon which it may feed, at the same depths.

Development of an imaging system able to be deployed to mesopelagic depths and taking higher resolution images than the AVPR (1024×1024 pixels) will certainly enable new discoveries of fragile zooplankton, their ecology and their environment in the future. Existing net samples and net samples collected into the future from the present survey area should be (re-) examined to locate specimens for a taxonomic study to unequivocally determine the specific identity of these *Paradoliopsis* zooids.

Acknowledgements

We are grateful to the reviewers for critical and constructive comments on the manuscript. This study is a contribution to the Census of Marine Zooplankton (CMarZ), an ocean realm field project of the Census of Marine Life, the International Network for Scientific Investigations of Deep-Sea Ecosystems (INDEEP), and the Deep Ocean Stewardship Initiative (DOSI). This work was partially funded by Japan Society for the Promotion of Science (JSPS) KAKENHI, grant number 24248032, JST grant CREST and research project funds for "Tohoku Ecosystem-Associated Marine Sciences", from the Ministry of Education, Culture, Sports, Science and Technology.

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