

Article

Discovery of *Anchimolgus jejuicus* n. sp. (Copepoda, Cyclopoida, Anchimolgidae) Associated with the Scleractinian Coral *Alveopora japonica* Eguchi (Cnidaria) off Jeju Island, Korea: Systematics and Ecological Insights

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Abstract

A new species of copepod, *Anchimolgus jejuicus* n. sp., is described based on specimens collected from the external washings of the scleractinian coral *Alveopora japonica* Eguchi, 1965, off Jeju Island, Korea. The new species closely resembles *A. multidentatus* Kim, 2003, associated with *Alveopora catalai* Wells, 1968, from New Caledonia in having similar body lengths and similar shapes of the antennae, mouth organs, and swimming legs. However, the new species can be distinguished from the New Caledonian species by the shorter female caudal ramus, which is 1.70 times longer than wide; by the shorter third endopodal segment of the female antenna, which is 3.35 times longer than wide; by the reduced second spine of the distal lash of the maxilla, which is less than half as long as the first spine; by the relatively shorter inner distal spine of the second endopodal segment of female leg 4, which is 1.56 times longer than the outer spine; by the shorter exopodal segment of female leg 5, which is 3.39 times longer than wide; and by the exopod of male leg 5 armed with one spine and one seta. The present paper reports the northernmost distribution area of the genus *Anchimolgus*, near the latitude of 33°24' N off Jeju Island. In addition, the recent rapid increase in populations of the host coral *Alveopora japonica* around Jeju Island—likely driven by climate change—highlights the significant ecological consequences for both the scleractinian coral and its newly discovered symbiotic copepod.

Keywords: copepod symbiont; taxonomy; external association; scleractinian coral; Jeju Island



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1. Introduction

Copepods are small crustaceans found throughout aquatic environments worldwide, with over 12,500 species described [1]. About half of these species are free-living, and the other half are symbiotic. Free-living copepods are important components of aquatic ecosystems, both in numbers and biomass, as planktonic, benthic, or interstitial organisms. They are dominant members of the zooplankton community in pelagic water. Symbiotic copepods are found on most major invertebrate groups, including sponges, cnidarians, polychaetes, crustaceans, echinoderms, and tunicates. The relationship between parasitic copepods and their fish host is well known, and parasitic copepods such as sea lice (family Caligidae) are known to have serious negative effects on fish. Most copepods symbiotic

with invertebrates are probably parasitic, but the precise natures of the relationships with invertebrate hosts have yet to be elucidated [2], except for a few copepods that are lethal to commercially important mussels and scallops. Similarly, little is known about the biological relationships between symbiotic copepods and scleractinian corals. Because of this, most researchers of symbiotic copepods use the neutral term “associates” to refer to these symbiotic copepods [2].

The copepod family Anchimolgidae Humes and Boxshall, 1996, currently comprises 32 genera, and all members of this family are associates of scleractinian corals [3,4]. *Anchimoligus*, the largest genus of the family, consists of 37 known species [5] distributed in the tropical seas, including Indonesia, New Caledonia, the east coast of Australia, and Madagascar [6–9]. Major host genera of *Anchimoligus* species include *Galaxea*, *Goniopora*, *Favia*, *Pavona*, and *Fungia*.

Corals (Cnidaria) are major hosts of associated copepods [10]. In Korea, the scleractinian coral *Alveopora japonica* Eguchi, 1965, has recently thrived in shallow subtidal hard bottoms around Jeju Island [11–14]. While examining the washings of the coral *A. japonica* collected from the west coast of Jeju Island, we unexpectedly found a new species of the genus *Anchimoligus*, which is to be described herein.

2. Materials and Methods

In October 2012, extensive beds of *A. japonica* were observed at the sampling site near Biyangdo, northwest of Jeju Island, South Korea, where they formed dense, nearly monospecific carpets at depths of 10–17 m. These stands were interspersed with the regionally endemic kelp *Ecklonia cava* (Figure 1).

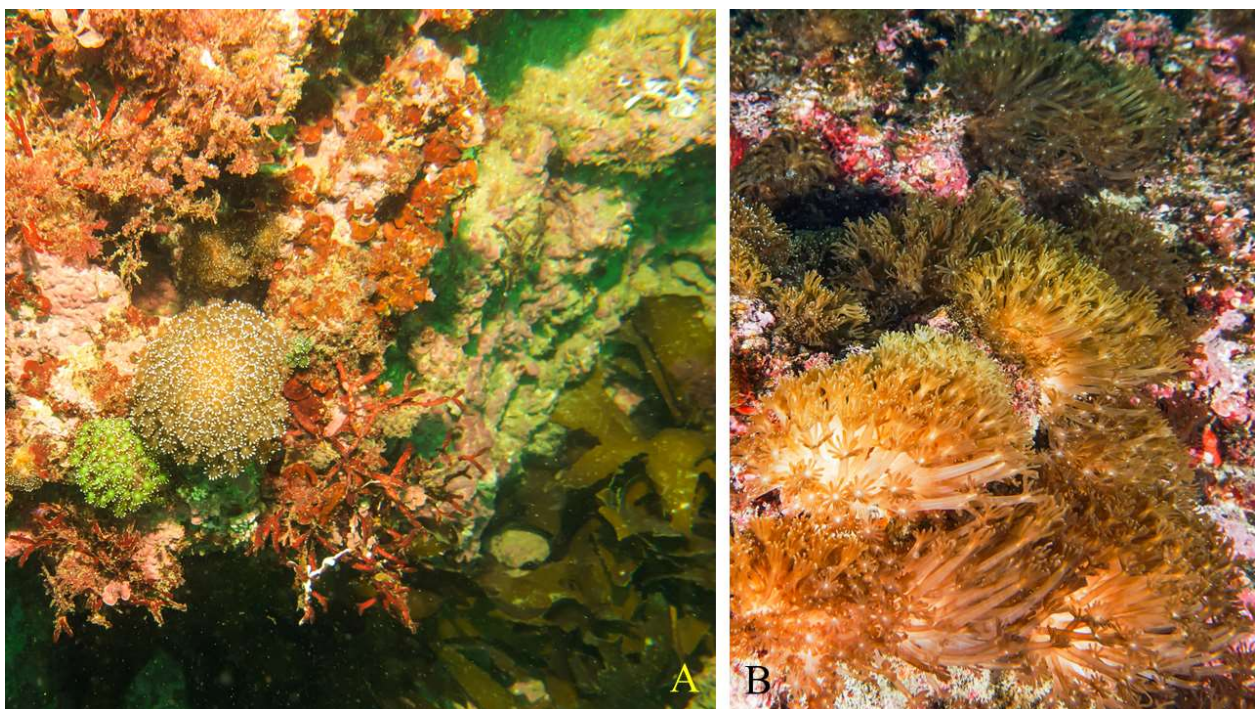


Figure 1. The scleractinian coral *Alveopora japonica* Eguchi, 1968, around Jeju Island, South Korea, showing colonies in association with red algae, including *Peyssonelia capensis*, *Actinotrichia fragilis*, and crustose coralline algae ((A), Seongsan-Ilchulbong, 28 July 2022), and live colonies with extended, waving tentacles ((B), Geumneung, near the sampling locality at Biyangdo, 23 September 2016).

A recent observation shows that this scleractinian coral is now the dominant taxon at 15 m at this site, covering up to 67% of the benthic substrate on an estimated area of >1 ha [11]. On 14 June 2023, samples of the coral host, *Alveopora japonica*, were collected

by Drs. Taewon Jung and Jong Guk Kim of the Honam National Institute of Biological Resources, using SCUBA diving at a depth of 20 m near Biyangdo, Jeju Island (33°24'19.3'' N, 126°12'17.0'' E).

The collected coral samples were fixed with 80% ethanol, and copepods dislodged from the corals were sorted out. Before microscopic observation, selected copepod specimens were immersed in lactic acid for several minutes to make them clean and relaxed. Dissections and microscopic observations were performed using the reversed slide method of Humes and Gooding [15]. Drawings were made with a drawing apparatus equipped on the microscope. The lengths of the appendage segments of copepod specimens are the average of the longest and shortest margins. The terminology adopted in this paper mainly follows Huys and Boxshall [16] and Humes and Boxshall [3]. The dissected paratype of *Anchimolgus multidentatus* Kim, 2003, was carefully re-examined and measured for a detailed comparison with the new species. Type specimens have been deposited in the Honam National Institute of Biological Resources (NNIBR), Mokpo, Korea.

3. Taxonomic Description

Class Copepoda Milne Edwards, 1840

Order Cyclopoida Burmeister, 1834

Family Anchimolgidae Humes and Boxshall, 1996

Genus *Anchimolgus* Humes and Stock, 1972

(Korean name: Dol-san-ho-no-beol-le)

Anchimolgus jejuicus n. sp.

(Korean name: Je-ju-dol-san-ho-no-beol-le)

(Figures 2–4)

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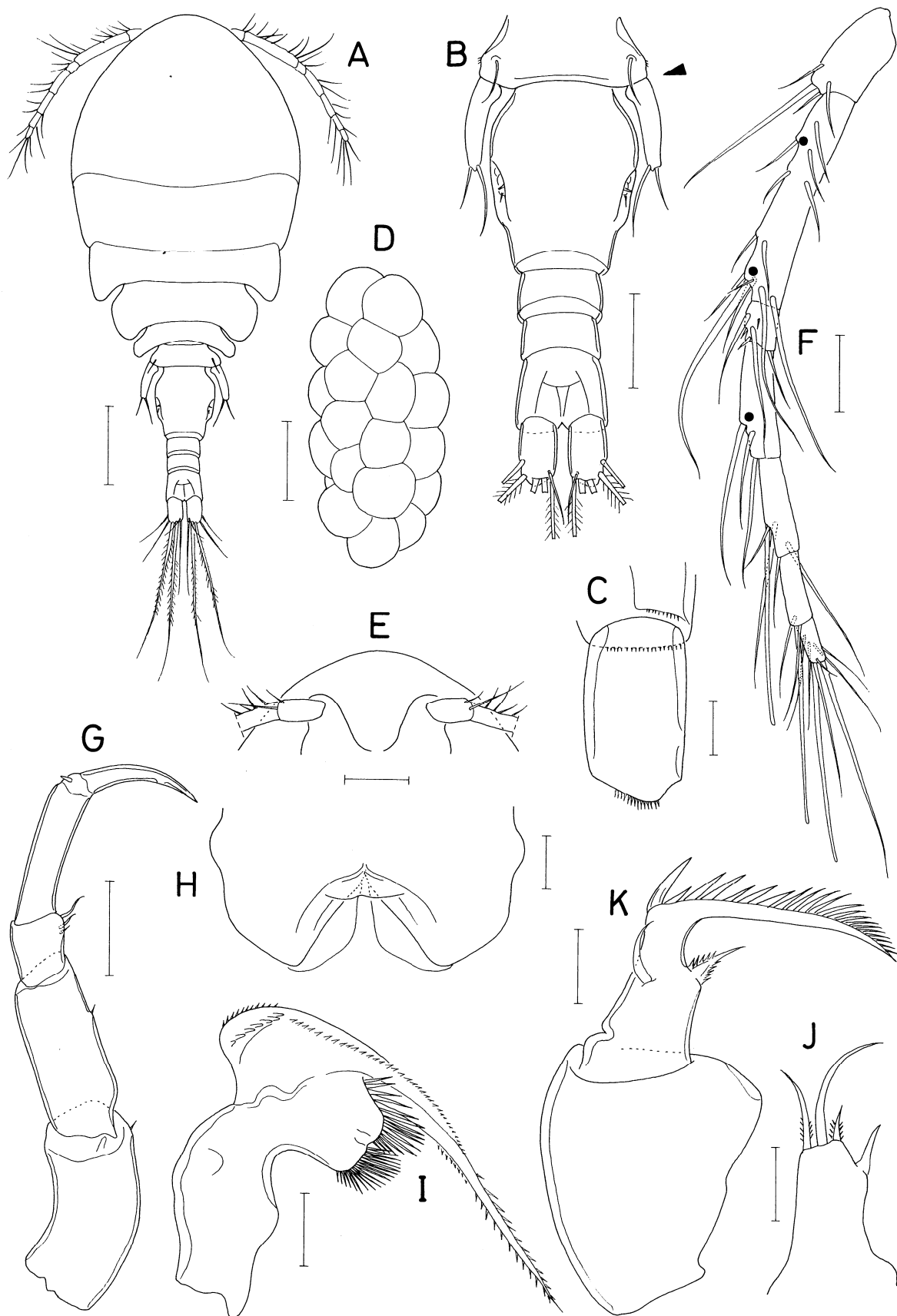


Figure 2. *Anchimolgus jejuicus* n. sp., female. (A) Habitus, dorsal; (B) urosome, dorsal (arrowhead indicates leg 5); (C) right caudal ramus, dorsal; (D) egg sac; (E) rostral area; (F) antennule; (G) antenna; (H) labrum; (I) mandible; (J) maxillule; (K) maxilla. Scale bars: (A,D) 0.2 mm; (B,E) 0.1 mm; (C,H–K) 0.02 mm; (F,G) 0.05 mm.

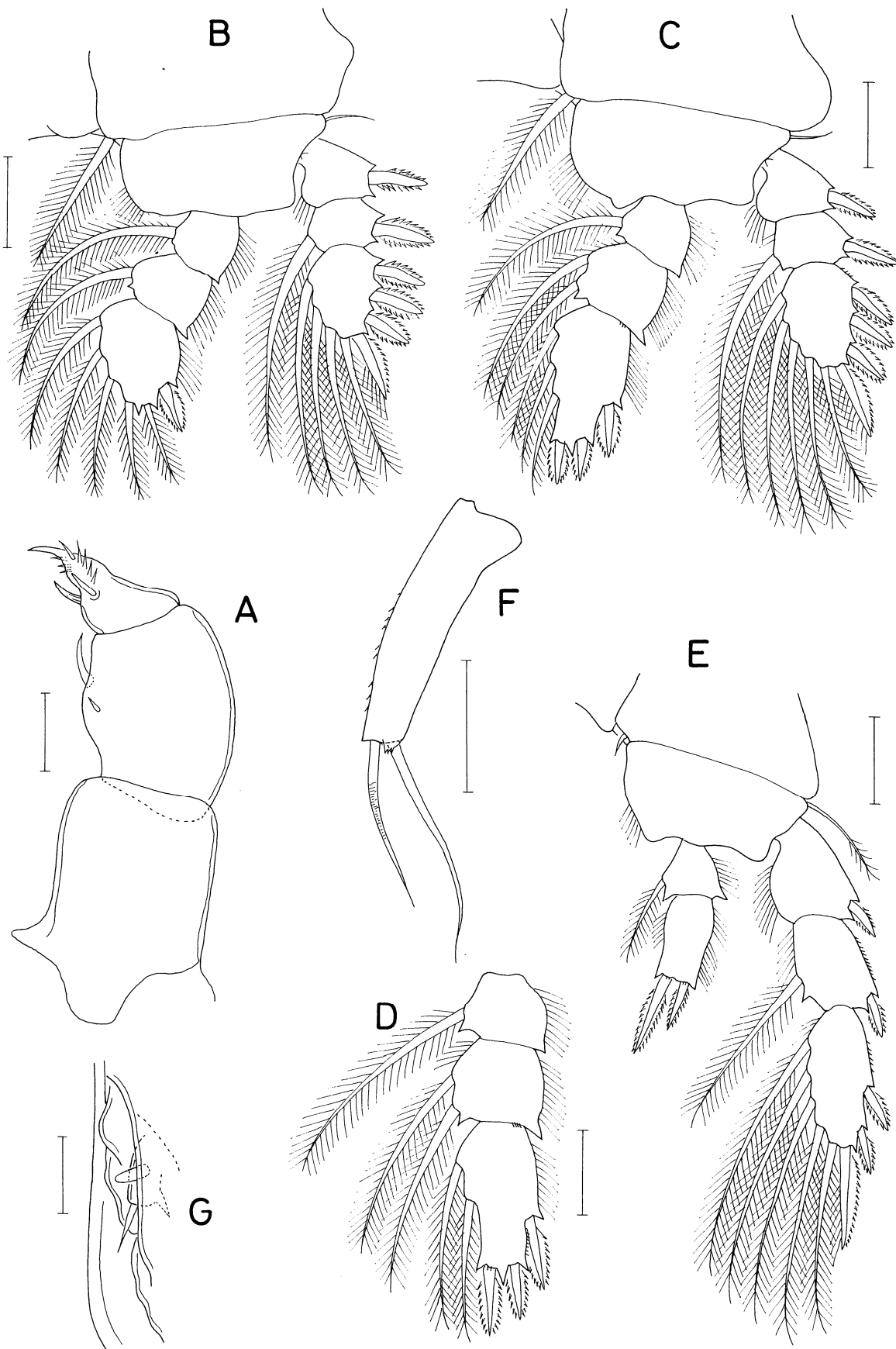


Figure 3. *Anchimolgus jejuicus* n. sp., female. (A) Maxilliped; (B) leg 1; (C) leg 2; (D) endopod of leg 3; (E) leg 4; (F) exopod of leg 5; (G) left genital aperture, dorsal. Scale bars: (A,G) 0.02 mm; (B–F) 0.05 mm.

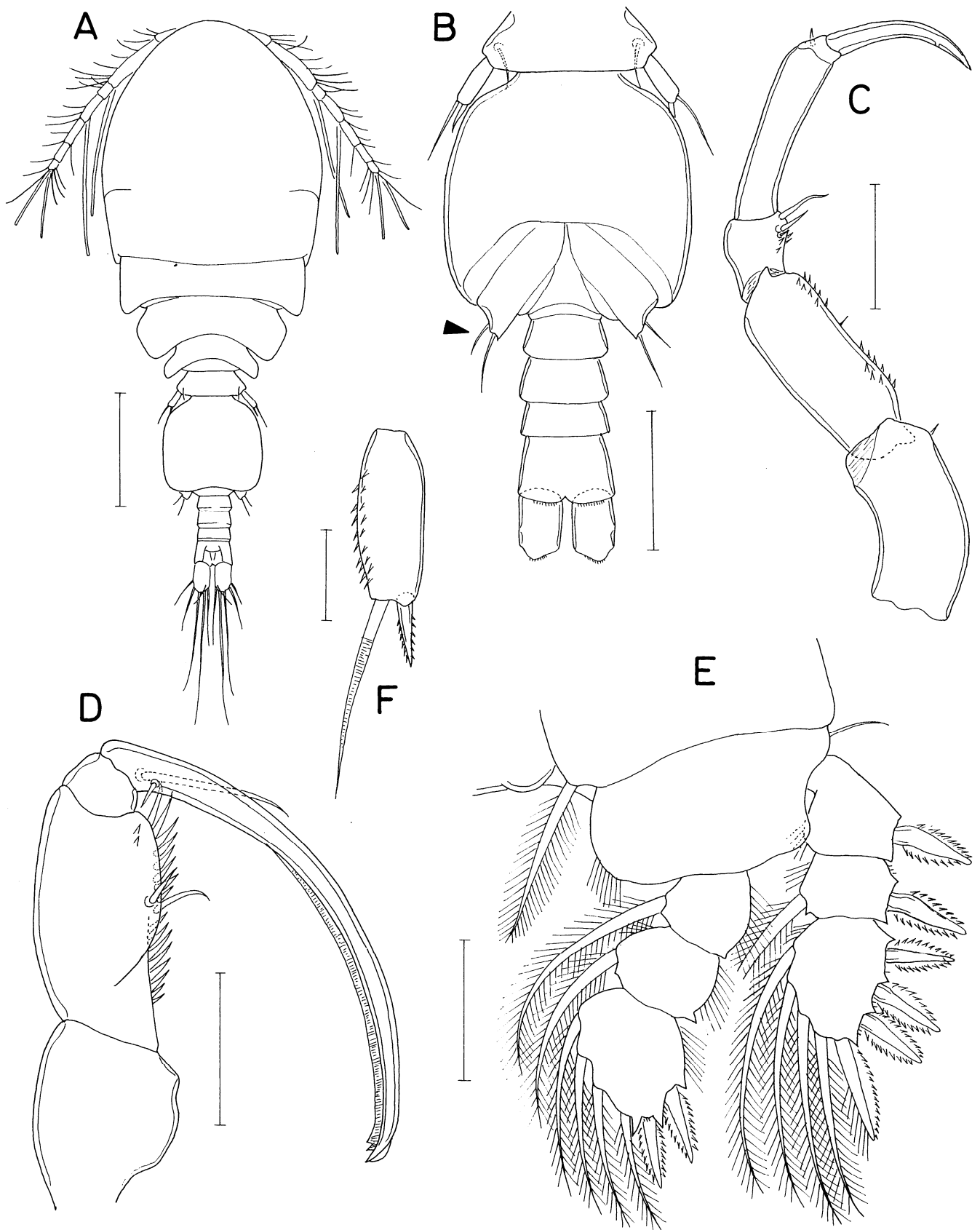


Figure 4. *Anchimolgus jejuicus* n. sp., male. (A) Habitus, dorsal; (B) urosome, ventral (arrowhead indicates leg 6); (C) antenna; (D) maxilliped; (E) leg 1; (F) exopod of leg 5. Scale bars: (A) 0.2 mm; (B) 0.1 mm; (C–E) 0.05 mm; (F) 0.02 mm.

Type material. Holotype (intact ♀; HNIBR IV7751), intact paratypes (15 ♀♀, 10 ♂♂; HNIBR IV7752), and dissected paratypes (2 ♀♀, 1 ♂) from washings of fifteen colonies of the scleractinian coral *Alveopora japonica* Eguchi, 1965; Biyangdo, Jeju Island (33°24′19.3″ N, 126°12′17.0″ E); depth 20 m; collected by Tae Won Jung and Jong Guk Kim; 14 June 2023. Intact type specimens have been deposited in the Honam National Institute of Biological Resources (HNIBR), Mokpo, Korea. Dissected paratypes and voucher specimens (3 ♀♀, 10 ♂♂) are retained in the collection of I.-H. Kim.

Etymology. The name is derived from “Jeju Island”, where the type locality is located.

Female. Body (Figure 2A) rather stout. Mean body length 1.24 mm (1.16–1.36 mm), based on 10 specimens. Body length of figured and described specimen 1.33 mm. Prosome 867 × 594 µm. All prosomal somites with rounded lateral corners. Cephalothorax as long as wide, with dorsal suture line between cephalosome and first pedigerous somite. Urosome (Figure 2B) five-segmented. Fifth pedigerous somite 180 µm wide, with several minute spinules at lateral apex. Genital double somite 1.23 times longer than wide (193 × 157 µm), widest at anterior third; genital apertures positioned laterally at about 60% region of double-somite length. Three free abdominal somites, 45 × 91, 36 × 84, and 73 × 96 µm, respectively. Anal somite with minute spinules along posterior margin (Figure 2C). Caudal ramus (Figure 2C) 1.70 times longer than wide (68 × 40 µm), slightly shorter than anal somite, armed with six setae and ornamented with minute spinules on posteroventral margin; setae II and VII naked, other four setae pinnate. Egg sac 782 × 364 µm; each egg 150 µm in diameter.

Rostrum (Figure 2E) with indistinctly rounded apex. Antennule (Figure 2F) 444 µm long, seven-segmented; armature formula 4, 13, 6, 3, 4 + aesthetasc, 2 + aesthetasc, and 7 + aesthetasc; third and last segments shortest; all setae naked; aesthetascs thin, setiform. Antenna (Figure 2G) four-segmented, consisting of coxobasis and three-segmented endopod; armature formula 1, 1, 3, 1 + claw; setae small, rudimentary; third endopodal segment 3.35 times longer than wide (77 × 23 µm); terminal claw arched, 64 µm long, shorter than third endopodal segment.

Labrum (Figure 2H) broad, with broad posterior lobes; each lobe bearing broad membranous flange along its inner margin. Mandible (Figure 2I) with distinct inner notch; inner margin slightly bilobed, with thin spinules on proximal lobe and thicker spinules on distal lobe; outer side of gnathobase strongly protruded, bearing marginal row of minute spinules and row of about seven small digitiform processes near margin of protruded region; distal lash elongated, spinulose along both margins. Maxillule (Figure 2J) lobate, bearing one inner and three distal setae; shortest innermost and outermost spinulose; middle one of three distal setae longest, naked. Maxilla (Figure 2K) two-segmented; syncoxa (first segment) broad, unarmed; basis (distal segment) bearing elongated distal lash and two setae; distal lash with about 20 spines along its distal (outer) margin, first spine distinctly longer than other spines, second spine less than half as long as first spine, much smaller than other proximal spines; seta I (inner seta) short, broad, strongly tapering, with several spinules along margins; seta II curved, naked. Maxilliped (Figure 3A) three-segmented, consisting of syncoxa, basis, and endopod; syncoxa unarmed; basis with two very unequal setae, distal one 3 times longer than proximal one; basis bearing one small spine, one seta, and two subdistal rows of three to five small spinules and terminating in slender, spiniform process.

Legs 1 (Figure 3B), 2 (Figure 3C), and 3 with three-segmented rami. Leg 3 similar to leg 2, except for bearing three spines and two setae on third endopodal segment (Figure 3D). Leg 4 (Figure 3E) with three-segmented exopod and two-segmented endopod. Inner coxal seta well-developed in legs 1–3, but vestigial in leg 4. Outer seta of basis small, naked in legs 1–3, but longer and pinnate in leg 4. All spines on legs 1–4 with serrate margins. Leg 4

endopod with second segment of $51 \times 29 \mu\text{m}$; its two distal spines 32 (outer) and $50 \mu\text{m}$ (inner), respectively. Armature formula for legs 1–4 is shown in the Table 1.

Table 1. Armature formula of legs 1–4 in *Anchimolgus jejuicus* n. sp.

	Coxa	Basis	Exopod	Endopod
Leg 1	0–1	1–0	I-0; I-1; III, I, 4	0–1; 0–1; I, 1, 4
Leg 2	0–1	1–0	I-0; I-1; III, I, 5	0–1; 0–2; I, II, 3
Leg 3	0–1	1–0	I-0; I-1; III, I, 5	0–1; 0–2; I, II, 2
Leg 4	0–1	1–0	I-0; I-1; II, I, 5	0–1; 0, II, 0

Leg 5 (Figure 2B) consisting of dorsolateral seta and free exopod; exopodal segment (Figure 3F) 3.39 times longer than wide ($95 \times 28 \mu\text{m}$; width measured at proximal expanded region), $23 \mu\text{m}$ wide in midway, bearing prominent inner proximal inflation, distally one small serrate lamella and two naked setae (outer one $87 \mu\text{m}$ long and inner one $64 \mu\text{m}$ long), and ornamented with several minute spinules on outer margin. Leg 6 (Figure 3G) represented by two small setae (one blunt and one attenuated) and one toothlike process on genital operculum.

Male. Body (Figure 4A) similar to that of female. Body length of figured and described specimen 1.02 mm. Prosome $630 \times 395 \mu\text{m}$. Cephalothorax 1.28 times longer than wide, with obscure dorsal suture line. Urosome (Figure 4B) six-segmented. Fifth pedigerous somite $124 \mu\text{m}$ wide. Genital somite roughly quadrangular $179 \times 180 \mu\text{m}$, with rounded corners and well-developed genital operculum. Four abdominal somites, 27×62 , 31×64 , 25×64 , and $42 \times 71 \mu\text{m}$, respectively. Caudal ramus 1.69 times longer than wide ($54 \times 32 \mu\text{m}$), armed as in female.

Rostrum as in female. Antennule with three additional aesthetascs, two on second segment and one on fourth at places indicated by dark dots in Figure 2F. Antenna (Figure 4C) armed as in female, but with additional spinules on inner margin of first and second endopodal segments; third endopodal segment 3.95 times longer than wide ($75 \times 19 \mu\text{m}$).

Labrum, mandible, maxillule, and maxilla as in female. Maxilliped (Figure 4D) consisting of syncoxa, basis, endopod, and terminal claw; syncoxa and small endopod unarmed; basis with two naked, unequal setae, one row of spinules along inner margin, two small subdistal teeth; terminal claw arched, elongated, as long as remaining part of maxilliped, with two very unequal setae proximally, fringed with membrane along concave margin.

Leg 1 (Figure 4E) with two spines and four setae (formula I, I, 4) on third endopodal segment. Legs 2–4 as in female. Exopodal segment of leg 5 (Figure 4F) 2.53 times longer than wide ($38 \times 15 \mu\text{m}$), lacking proximal expansion, bearing spinules on outer surface, armed distally with one seta ($45 \mu\text{m}$ long) and one spinulose spine ($15 \mu\text{m}$ long). Leg 6 (Figure 4B) represented by two thin setae on genital operculum.

4. Discussion

4.1. Species Characterization

Species of the genus *Anchimolgus* can be divided into two groups: the digitatus group and the contractus group. In the digitatus group, which consists of 25 known species, including the type species, *A. digitatus* (Humes and Ho, 1968), the third endopodal segment (terminal segment) of the antenna is shorter than or as long as the second endopodal segment (third segment). In the contractus group, which consists of 12 known species, including *A. contractus* Humes, 1979, the third endopodal segment of the antenna is longer than the second segment. *Anchimolgus jejuicus* n. sp. belongs to the contractus group, as the third endopodal segment of its antenna is much longer than the second endopodal segment. Within the contractus group, the new species most closely resembles *A. multidentatus*

Kim, 2003, which was described as an associate of *Alveopora catalai* Wells, 1969, from New Caledonia [7], as both species have similar body lengths and similar shapes of the antennae, mouth organs, and swimming legs. Moreover, since the two copepod species are the only species associated with coral hosts of the genus *Alveopora*, they were initially thought to be the same species.

A careful comparison of specimens of *A. jejuicus* n. sp. and the original description and preserved female specimen of *A. multidentatus* has led to the conclusion that they are not the same species (Table 2; Figure 5). The morphological differences between the two species lies in the details, as follows: (1) the female caudal ramus of *A. jejuicus* n. sp. is 1.70 times longer than wide ($68 \times 40 \mu\text{m}$), while it is 2.02 times longer than wide ($85 \times 42 \mu\text{m}$) in *A. multidentatus*; (2) the third endopodal segment of the antenna of *A. jejuicus* n. sp. is 3.35 times longer than wide ($77 \times 23 \mu\text{m}$) and 1.20 times longer than the terminal claw, while it is 3.96 times longer than wide ($95 \times 24 \mu\text{m}$ in measured dissected paratype) and 1.48 times longer than the terminal claw in *A. multidentatus* (Figure 5); (3) the second spine (indicated by the arrowhead in Figure 5) of the distal lash of the maxilla of *A. jejuicus* n. sp. is distinctly reduced, while it is only slightly shorter than the first spine in *A. multidentatus*; (4) the inner distal spine ($50 \mu\text{m}$ long) of the second endopodal segment of female leg 4 of *A. jejuicus* n. sp. is 1.56 times longer than the outer spine ($32 \mu\text{m}$ long), while the inner spine ($64 \mu\text{m}$ long) is 2.13 times longer than the outer spine ($30 \mu\text{m}$ long) in *A. multidentatus*; (5) the exopodal segment of female leg 5 of *A. jejuicus* n. sp. is 3.39 times longer than wide ($95 \times 28 \mu\text{m}$), while it is more elongated, 3.83 times longer than wide ($115 \times 30 \mu\text{m}$), and abruptly narrowed along the distal quarter, with more and larger spinules on the outer surface in *A. multidentatus*; and (6) the exopod of male leg 5 of *A. jejuicus* n. sp. is armed with one spine and one seta, while it is armed with two setae in *A. multidentatus*.

Table 2. Morphological differences between *Anchinolagus multidentatus* Kim and *A. jejuicus* n. sp.

Characteristics	<i>A. multidentatus</i>	<i>A. jejuicus</i> n. sp.
Length/width ratio of ♀caudal ramus	2.20:1	1.70:1
Length/width ratio of third endopodal segment of ♀ leg 2	3.96:1	3.35:1
Second spine of distal lash of maxilla	Slightly smaller than first spine	Much smaller than first spine
Inner distal spine on second endopodal segment of leg 4	2.13 times longer than outer spine	1.56 times longer than outer spine
Length/width ratio of exopodal segment of ♀leg 4	3.83:1	3.39:1
Armature of exopodal segment of ♂leg 5	2 setae	1 spine + 1 seta
Hosts	<i>Alveopora catalai</i>	<i>Alveopora japonica</i>
Known distribution	New Caledonia	Jeju Island (Korea)

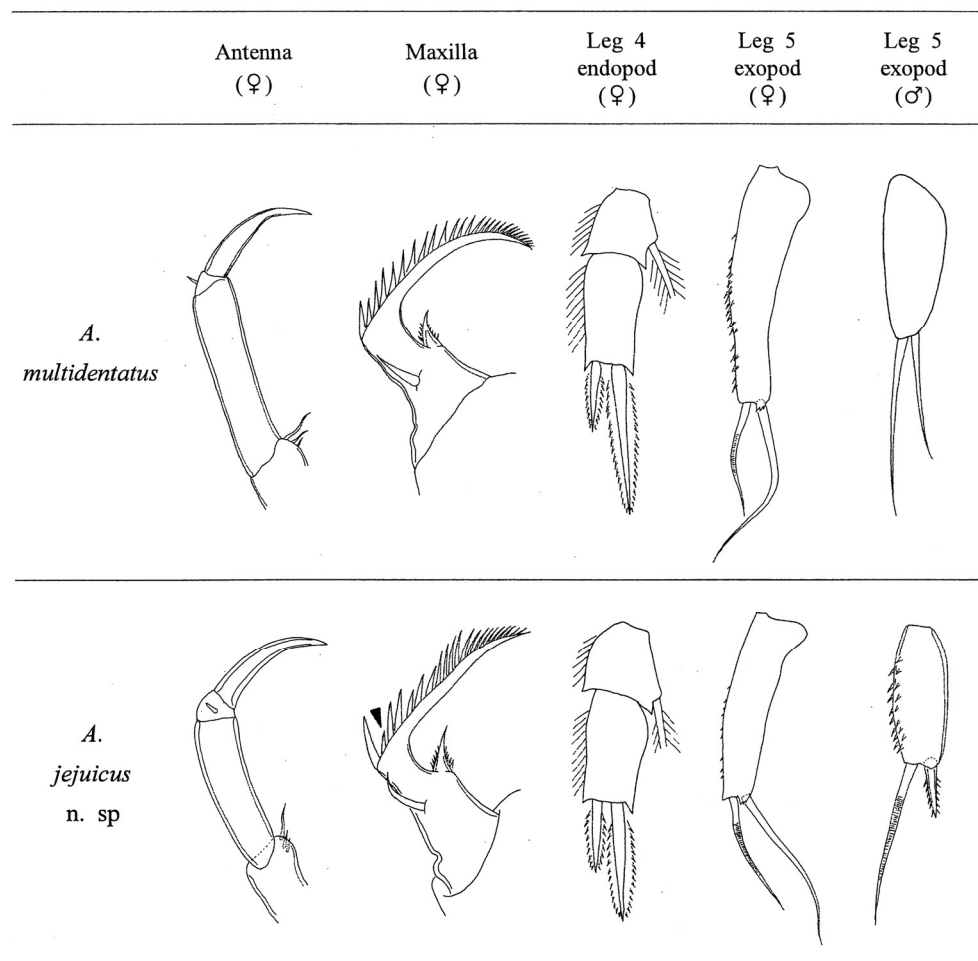


Figure 5. Comparison of five appendages between *Anchimolgus multidentatus* Kim and *A. jejuicus* n. sp. Arrowhead indicates the reduced second spine on the distal lash. The exopod of male leg 5 of *A. multidentatus* is redrawn from the original description.

4.2. Ecological Implications of the Discovery of the Symbiotic Copepod *Anchimolgus jejuicus* n. sp. on the Scleractinian Coral *Alveopora japonica* from Jeju Island

The discovery of *A. jejuicus* in *A. japonica* colonies at Jeju Island highlights the under-explored diversity of temperate coral–copepod symbioses in the Northwest Pacific. Corals form complex ecosystems, creating intricate microhabitats that host diverse organisms, yet the associated invertebrate communities remain poorly studied despite their critical role in maintaining coral ecosystem function [17].

Copepods, in particular, are a diverse group of crustaceans that have evolved intimate, often obligate, associations with scleractinian corals throughout evolutionary history [17–19]. However, our understanding of their ecology and interactions with host corals remains limited. It is often unclear whether they act as parasites that negatively affect host fitness or as commensal symbionts with negligible impacts on coral health [2,16]. Many species exhibit strict host specificity, while others are generalists [19,20]. Functionally, coral-associated copepods have been categorized as endosymbionts [19,21,22], gall-inducers [23,24], or ectoparasites [17,25]. Globally, 148 scleractinian coral species host 363 copepod symbionts, including 141 species in the family Anchimolgidae, which comprises 32 genera all associated with scleractinian corals [25]. *Anchimolgus*, the largest genus in the family with 37 described species, is distributed across tropical Indo-Pacific regions. Prior to this study, its northernmost record was from Dongsha Atoll (20°40' N) in the South China Sea [26]. The present discovery of *A. jejuicus* at Jeju Island (33°24' N)

therefore extends the known range of the genus substantially northward (Figure 6). We presume that *A. jejuicus* n. sp. may have come with its host species *A. japonica*, and its ecological role and interactions within the host environment remain to be elucidated through further investigation.

The host coral *A. japonica* is one of the principal reef-framework builders in the Indo-Pacific [27], and its ecology in this high-latitude setting warrants particular attention. Seven zooxanthellate scleractinian species occur around Jeju Island [28], among which *A. japonica* is endemic to Korea and Japan, inhabiting subtropical to temperate waters of the northwestern Pacific, including Taiwan, Japan, and Jeju Island [27–29]. However, molecular analyses of its symbiotic dinoflagellates (Symbiodiniaceae), based on ITS and 23S rDNA sequences, suggest the existence of three cryptic lineages in the region, with Taiwanese populations forming a distinct clade [13]. According to the georeferenced records from the Global Biodiversity Information Facility (GBIF) [30], the species' latitudinal distribution extends from 30°24' N (Tanegashima, Kagoshima Prefecture) to 36°06' N (Shimane Prefecture, Japan), including Jeju Island, Korea. This range corresponds to sea surface temperatures of 20–24 °C, as inferred from time-averaged SST data (2003–2023) (Figure 6).

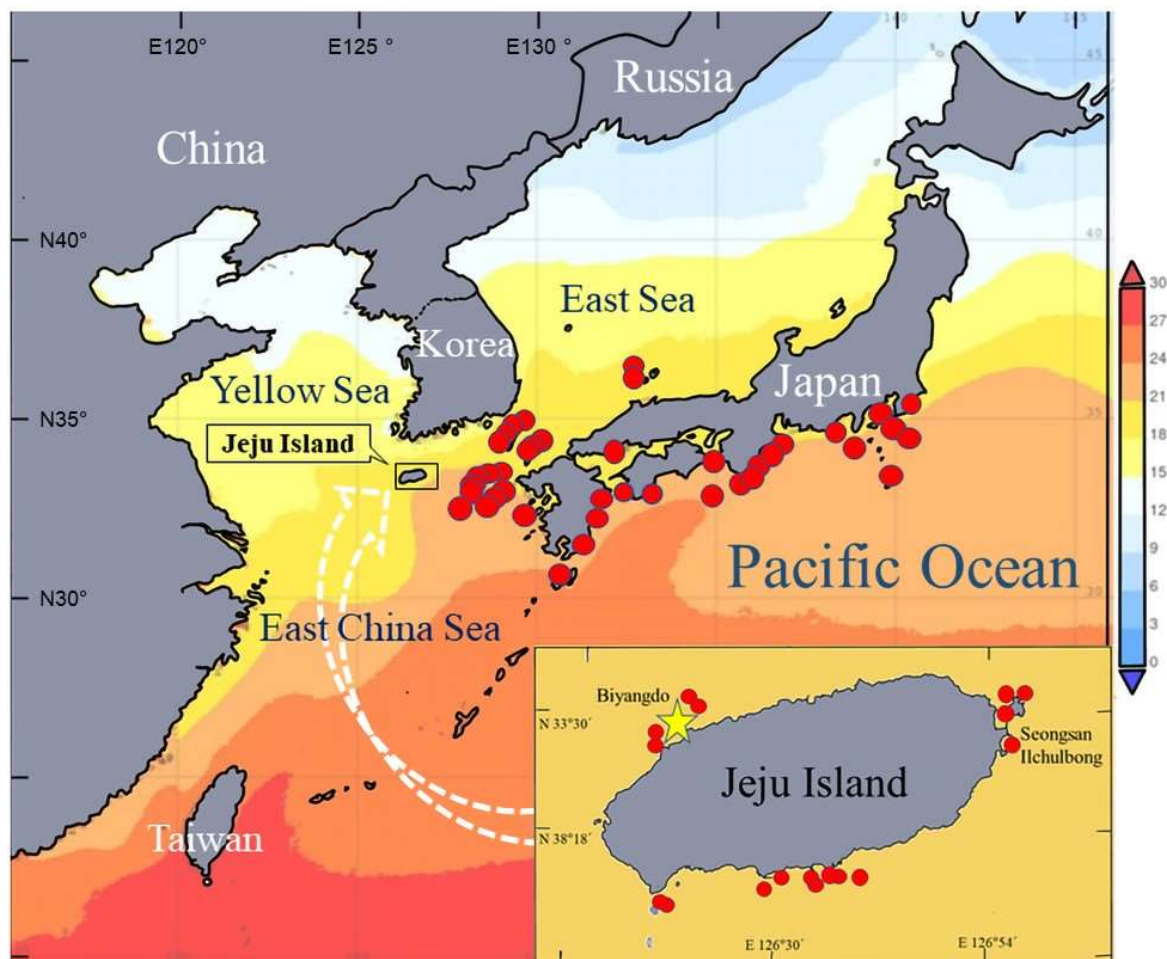


Figure 6. Sampling locality of *Anchimolgus jejuicus* n. sp. off Jeju Island (★) and distribution of its host coral *Alveopora japonica* (●) in the surrounding seas of the Northwest Pacific, based on 75 georeferenced records from the Global Biodiversity Information Facility [30]. The time-averaged sea surface temperature (°C; August 2003–August 2023; see legend on the right) for the regional seas was derived from satellite remote-sensing datasets provided by the NASA Giovanni Data System. Inset: distribution of *A. japonica* around Jeju Island, including the sampling site at Biyangdo.

Since its first report at Jeju Island in 1973 [31], *A. japonica* has opportunistically expanded into areas vacated by the decline of kelp forests, showing marked population growth over the past two decades, likely driven by climate change and anthropogenic impacts [11,12,14,32–34]. Colonies are typically submassive to hemispherical, 2–3 cm in diameter, with occasional specimens exceeding 10 cm. Polyps extend during the day, bear 12 tentacles, and exhibit pale brown to green coloration with white or cream tips [28] (Figure 1). The species shows seasonal recruitment, with peak reproductive activity in late summer to early fall (September–October), coinciding with elevated seawater temperatures. On Jeju Island, larval release of this brooding coral occurs during this period [32]. Local populations are characterized by a mean colony size of 30 cm², a density of ~120 colonies m⁻², a slow growth rate (4.8 mm year⁻¹), and a short lifespan of 12–13 years [12]. Frequent typhoons uproot kelp [35], creating barren substrata suitable for coral colonization [36].

In shallow rocky subtidal zones, high-density stands of *A. japonica* function as ecosystem engineers [37], directly and indirectly modifying and maintaining habitats. This activity generates structurally distinct environments—often described as “submarine tropical islands”—that support elevated biodiversity. Although early colonization may temporarily reduce local species diversity, mature *A. japonica* stands develop into biodiversity hotspots. For instance, a recent survey documented 34 species of epibenthic mollusks (20 bivalves and 14 gastropods) within 1 m² plots of *A. japonica* habitat, many of which exhibit tropical–subtropical affinities [38].

The occurrence of *A. jejuicus* n. sp. at Jeju Island therefore represents not only a significant poleward extension of the genus but also a biogeographic shift consistent with broader trends in marine taxa under contemporary ocean warming. Rising sea surface temperatures in the northwestern Pacific are facilitating the poleward expansion of tropical and subtropical species into higher-latitude environments, where they are increasingly establishing stable populations in habitats that were previously unsuitable.

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Data Availability Statement: Designated type specimens are available for loan to copepod specialists for re-examination from the Honam National Institute of Biological Resources, Mokpo, Korea.

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Conflicts of Interest: The authors declare no conflict of interest.

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