

## Amphipod Diversity in Mussel-Associated Fouling Communities of Aquaculture Nets in Ildır Bay (Aegean Sea, Türkiye)

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**Abstract:** This study investigates the diversity and ecological characteristics of fouling amphipod communities associated with *Mytilus galloprovincialis* on the aquaculture nets of three commercial fish farms in Ildır Bay, located in the Aegean Sea, Türkiye. A total of eight amphipod species, belonging to four families, were identified. These species include representatives from the Caprellidae family (*Caprella dilatata*, *Caprella equilibra* and *Caprella scaura*), Ischyroceridae family (*Erichthonius argenteus*, *Erichthonius brasiliensis* and *Jassa marmorata*), Maeridae family (*Elasmopus rapax*), and Photidae family (*Gammaropsis maculata*). Many recorded species are cryptic (*C. scaura*, *E. brasiliensis*, *E. rapax* and *G. maculata*) or alien (*C. scaura*). The affinity of many of these species for artificial substrates underlines their importance for biofouling monitoring and biodiversity assessments. Comparative analysis with previous Mediterranean-wide studies confirmed the dominance of several taxa across aquaculture sites, while the detection of *E. argenteus* and *E. brasiliensis* suggests regional uniqueness. Notably, no overlap was observed between amphipods inhabiting fouling assemblages and those previously recorded from sediment habitats in the same area, underscoring strong substrate-driven differentiation in community structure. The study emphasizes the ecological importance of multi-habitat sampling for understanding amphipod distribution patterns and highlights the role of aquaculture infrastructure as a facilitator of amphipod colonization. These findings contribute to the expanding knowledge of Mediterranean fouling ecology and establish a baseline for future management of biofouling in aquaculture systems.

**Keywords:** Biofouling, Aquaculture, Cryptic Species, Ildır Bay, Biodiversity

## Ildır Körfezi (Ege Denizi, Türkiye) Akuakültür Ağlarında Midye ile İlişkili Fouling Amfipod Topluluklarının Çeşitliliği

**Özet:** Bu çalışma, Ege Denizi'nde, Ildır Körfezi'nde yer alan üç ticari balık çiftliğinin akuakültür ağlarında *Mytilus galloprovincialis* ile ilişkili fouling amfipod topluluklarının çeşitliliğini ve ekolojik özelliklerini araştırmaktadır. Toplamda dört familyaya ait sekiz amfipod türü teşhis edilmiştir. Bu türler arasında Caprellidae familyasından (*Caprella dilatata*, *Caprella equilibra* ve *Caprella scaura*), Ischyroceridae familyasından (*Erichthonius argenteus*, *Erichthonius brasiliensis* ve *Jassa marmorata*), Maeridae familyasından (*Elasmopus rapax*) ve Photidae familyasından (*Gammaropsis maculata*) temsilciler yer almaktadır. Kaydedilen türlerin birçoğu kriptik (*C. scaura*, *E. brasiliensis*, *E. rapax* ve *G. maculata*) veya yabancı (*C. scaura*) türlerdir. Türlerin bir kısmının yapay substratlara eğilim göstermeleri, bu biofouling izleme ve biyoçeşitlilik değerlendirmeleri açısından önemlerini ortaya koymaktadır. Akdeniz genelindeki önceki çalışmalarla yapılan karşılaştırmalar, birçok taksonun akuakültür alanlarında baskınlığını doğrularken, *E. argenteus* ve *E. brasiliensis*'in tespiti bölgesel özgünlüğe işaret etmektedir. Dikkat çekici olarak, aynı bölgede sediman habitatlarından daha önce kaydedilen amfipodlar ile fouling topluluklarında yaşayan türler arasında hiçbir örtüşme gözlenmemiştir. Bu durum, topluluk yapısında güçlü substrat temelli farklılaşmayı ortaya koymaktadır. Çalışma, amfipod dağılım desenlerini anlamada çoklu habitat örneklemesinin ekolojik önemini vurgulamakta ve akuakültür altyapılarının amfipod kolonizasyonunu kolaylaştırıcı rolüne dikkat çekmektedir. Bu bulgular, Akdeniz'de fouling ekolojisine dair genişleyen bilgi birikimine katkı sağlamakta ve akuakültür sistemlerinde biyo-tutulunun gelecekteki yönetimi için bir temel oluşturmaktadır.

**Anahtar Kelimeler:** Biyofouling, Akuakültür, Kriptik Tür, Ildır Körfezi, Biyoçeşitlilik

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## 1. Introduction

Biofouling is a widespread problem in marine ecosystems, caused by the attachment and growth of diverse organisms, including algae, bivalves, hydroids, sponges, and crustaceans, on submerged surfaces. In aquaculture, fouling organisms colonize nets and cages, obstructing water flow, reducing oxygen availability, and negatively affecting fish health and growth (Fitridge et al., 2012; Fernandez-Gonzalez and Sanchez-Jerez, 2017; Atalah et al., 2020; Giangrande et al., 2020). Over time, thick fouling layers clog meshes, weaken materials, and increase maintenance costs, resulting in significant economic losses for the industry (Greene and Grizzle, 2007; Montalto et al., 2020). In Türkiye, fouling control and net-cleaning are reported to be a significant financial burden for aquaculture facilities (Türkmen, 2022).

Fouling assemblages are taxonomically diverse and structurally complex, typically dominated by sessile invertebrates such as mussels *Mytilus galloprovincialis* Lamarck, 1819, hydroids, sponges, tunicates, and ascidians, along with associated mobile fauna (Sarà et al., 2007; Fernandez-Gonzalez and Sanchez-Jerez, 2017). Among the latter, amphipods—particularly species belonging to Caprellidae and Ischyroceridae—are often abundant in aquaculture environments, sometimes reaching high densities and biomass (Cook et al., 2006; Fernandez-Gonzalez and Sanchez-Jerez, 2017; Ragkousis et al., 2023). Amphipods act as grazers, detritivores, and epibionts, contributing to energy transfer and habitat structuring (Conradi et al., 1997; Scipione, 2013). They frequently inhabit the byssal threads and interstitial spaces created by *M. galloprovincialis*, which provide shelter and microhabitat complexity (Seed and Suchanek, 1992; Çınar et al., 2008).

The ecological importance of amphipods is further underscored by their rapid adaptation to artificial substrates and their sensitivity to environmental changes, which, combined with their role in facilitating non-indigenous species, makes them effective ecological indicators (Conlan, 1994; Giari et al., 2020). Families such as Caprellidae, Ischyroceridae, and Photidae include both native and non-indigenous taxa, many of which are now well established in the Mediterranean Sea (Guerra-García et al., 2011; Ros et al., 2016; Ragkousis et al., 2023). Recent studies have also confirmed the expansion of invasive caprellids along Turkish coasts (Çınar et al., 2021), reinforcing their significance in biofouling dynamics.

Within fouling assemblages, cryptic amphipod species represent a particularly challenging group. The term cryptic refers to species that are morphologically very similar or indistinguishable but genetically distinct, often forming so-called cryptic species complexes (Knowlton, 1993, 2000; Witt et al., 2006; Bickford et al., 2007). These taxa are ecologically significant, as their unnoticed presence can lead to underestimations of biodiversity and misinterpretations of ecological interactions (Lefébure et al., 2006; Havermans, 2016). In fouling ecosystems, cryptic amphipods may occupy different ecological niches despite morphological similarity, influencing trophic dynamics as grazers, detritivores, and habitat modifiers (Lefébure et al., 2006; Costa et al., 2009). Moreover, the detection of cryptic non-indigenous species is crucial, as they can disperse via aquaculture infrastructure and shipping, potentially altering native community structures (Ashton et al., 2007; Ros et al., 2013). Addressing cryptic diversity is therefore essential for accurate taxonomic resolution, biodiversity monitoring, and the effective management of biofouling in aquaculture systems.

Against this background, the present study investigates the diversity, distribution, and ecological associations of amphipods inhabiting *M. galloprovincialis*-dominated fouling assemblages on aquaculture nets from three commercial fish farms in Ildır Bay (Aegean Sea, Türkiye). Specifically, the objectives are to (1) document the amphipod species associated with *M. galloprovincialis*, (2) analyse their spatial distribution patterns and potential biogeographic implications, and (3) address taxonomic challenges, particularly the identification of cryptic and non-indigenous taxa. The findings contribute to Mediterranean fouling ecology by filling existing knowledge gaps and providing a baseline for biofouling management in aquaculture systems.

## 2. Materials and Methods

The present study was conducted in Ildır Bay, located in the Aegean Sea, between the southwest of the Karaburun Peninsula and the northeast of Çeşme. The bay covers an area of approximately 193 km<sup>2</sup> and has a coastline of 68 km (Duman et al., 2018). Surface salinity ranges from 38.4 to 39.4 ‰, and water temperatures fluctuate between 16°C and 24°C throughout the year. Compared to other regions of the Aegean Sea, the hydrography of Ildır Bay is intermediate, being warmer than the North Aegean and cooler than the Southern Aegean (Eronat and Sayın, 2014). This transitional oceanographic character, together with the high level of aquaculture activity in the region, makes Ildır Bay an ideal site for studying biofouling crustaceans and the effects of human activities on habitat structuring.

On June 16, 2017, samples were collected from mussel-fouled cage nets at three commercial fish farms in Ildır Bay: Pınar Incorporated (Inc.), Agromey Inc., and Abaloğlu Inc. (Figure 1). At each farm, one cage net was selected, and random samples of mussels were collected from the 0–3 m depth range. The samples were subsequently sifted through a 0.5 mm mesh and preserved in a 4% seawater–formalin solution.

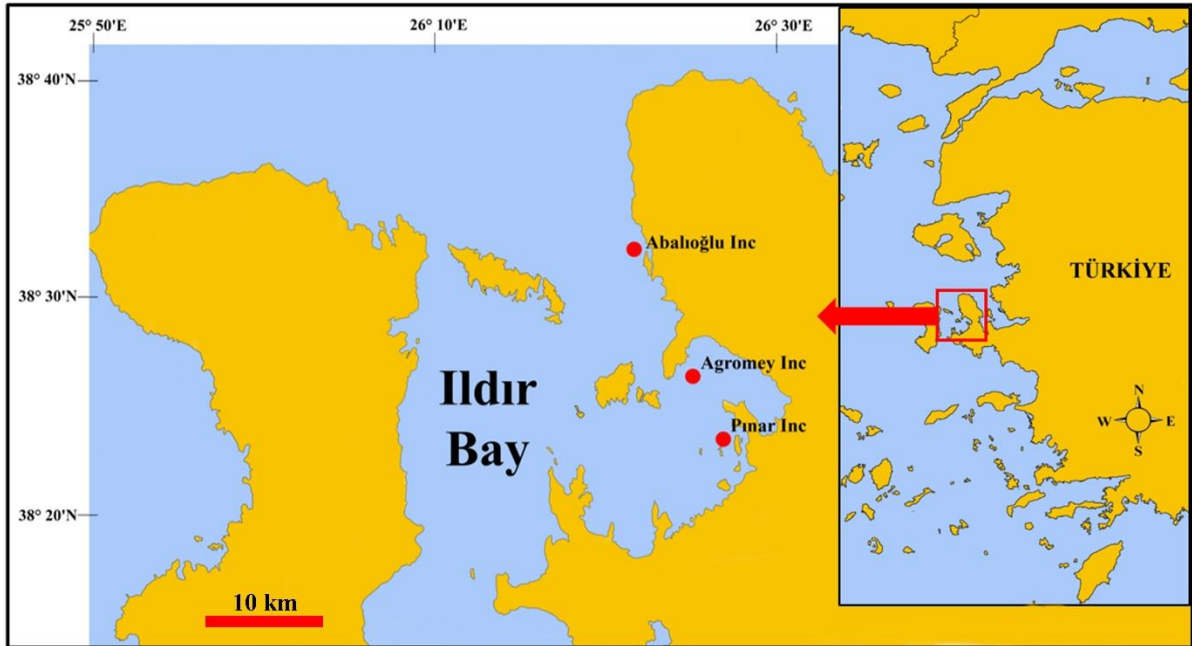


Figure 1. Map of the sampling area with the location of stations.

In the laboratory, specimens were sorted and identified at the species level using a stereomicroscope and a compound microscope. Their current taxonomic status was verified with the World Register of Marine Species (WoRMS, n.d.). The specimens were then preserved in 70% ethanol. Images were captured using an Olympus XOJ60AA camera attached to a stereomicroscope by Özge Özgen. All materials have been deposited in the crustacean collection at the Institute of Marine Sciences and Technology at Dokuz Eylul University.

Species occurrence at each station was determined using the Soyer (1970) frequency index. The index was calculated according to Equation (1):

$$Fi\% = \left( \frac{m}{M} \right) \times 100$$

where  $m$  is the number of samples containing a given species and  $M$  is the total number of samples. Based on Soyer's classification, species were categorized as "Constant" ( $Fi\% \geq 50$ ), "Common" ( $25 \leq Fi\% < 50$ ), or "Rare" ( $Fi\% < 25$ ).

### 3. Results and Discussion

In the present study conducted in Ildır Bay (Aegean Sea), a total of eight amphipod species belonging to four families were identified across the three fish farms surveyed in Ildır Bay (Table 1). Species richness varied among farms, with Pınar Inc. and Agromey Inc. each hosting six species, while Abaloğlu Inc. supported eight species, representing the highest diversity. Members of the family Caprellidae were widespread, with *Caprella equilibra* Say, 1818 occurring at all sites, whereas *Caprella dilatata* Krøyer, 1843 and *Caprella scaura* Templeton, 1836 showed a more restricted distribution. Ischyroceridae species, namely *Erichthonius argenteus* Krapp-Schickel, 1993, *Erichthonius brasiliensis* (Dana, 1853), and *Jassa marmorata* Holmes, 1905, were consistently present across all farms, indicating their strong association with aquaculture fouling habitats. In contrast, *Elasmopus rapax* A. Costa, 1853 (Maeridae) was absent from Pınar Inc., and *Gammaropsis maculata* (Johnston, 1828) (Photidae) was ubiquitous, being recorded at all three sites. These patterns highlight both the shared core assemblage of fouling amphipods in the bay and the site-specific variability that may be linked to local environmental conditions or farming practices.

Table 1. List of amphipod species identified during the study (\*: Alien species)

Species	Pınar Inc.	Agromey Inc.	Abalıoğlu Inc.
<b>Family: Caprellidae Leach, 1814</b>			
<i>Caprella dilatata</i> Krøyer, 1843	+	-	+
<i>Caprella equilibra</i> Say, 1818	+	+	+
* <i>Caprella scaura</i> Templeton, 1836	-	-	+
<b>Family: Ischyroceridae Stebbing, 1899</b>			
<i>Erichthonius argenteus</i> Krapp-Schickel, 1993	+	+	+
<i>Erichthonius brasiliensis</i> (Dana, 1853)	+	+	+
<i>Jassa marmorata</i> Holmes, 1905	+	+	+
<b>Family: Maeridae</b>			
<i>Elasmopus rapax</i> A. Costa, 1853	-	+	+
<b>Family: Photidae</b>			
<i>Gammaropsis maculata</i> (Johnston, 1828)	+	+	+
<b>Total number of species</b>	<b>6</b>	<b>6</b>	<b>8</b>

Based on the Soyer (1970) frequency index, seven of the eight amphipod species identified in the fouling assemblages of Ildır Bay were classified as “Constant,” indicating their widespread occurrence across sampling stations. *Caprella scaura* was categorized as “Common,” reflecting its presence at fewer but still multiple stations (Figure 2).

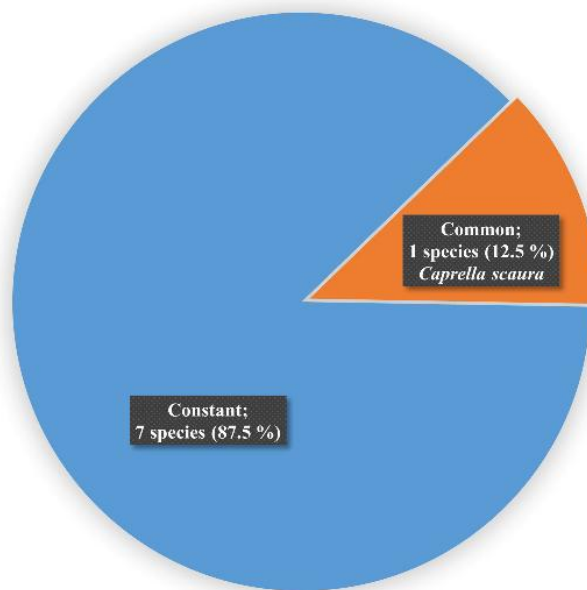


Figure 2. Distribution of amphipod species according to their frequency index categories.

These findings were compared with the Mediterranean-wide survey of Fernandez-Gonzalez and Sanchez-Jerez (2017), which analysed amphipod assemblages from 17 aquaculture sites across the Adriatic Sea and the Western, Central, and Eastern Mediterranean basins. These species were also reported by Fernandez-Gonzalez and Sanchez-Jerez (2017) as dominant fouling amphipods across Mediterranean fish farms, underscoring their wide distribution and ecological tolerance in aquaculture environments.

A key difference between the present study and Fernandez-Gonzalez and Sanchez-Jerez (2017) relates to the recorded *Erichthonius* species. While the Mediterranean-wide survey identified *Erichthonius punctatus* (Spence Bate, 1857) as a dominant amphipod in fish-farm fouling, this species was absent in Ildır Bay. Instead, two congeners were recorded: *E. argenteus* and *E. brasiliensis*, neither of which was reported in the 2017 study. This pattern suggests either a previously overlooked occurrence or a localized distribution in the Eastern Mediterranean. The detection of *E. brasiliensis*, a species more typical of warmer marine environments, highlights the biogeographic distinctiveness of the Aegean amphipod fauna. The absence of *E. punctatus* and the occurrence of alternative *Erichthonius* taxa reflect spatial variability in fouling assemblages, likely influenced by local hydrographic conditions, aquaculture

practices, or methodological differences in sampling.

When compared with the results of Ozaydinli and Bizsel (2020), who investigated benthic crustacean communities from sediment samples in Ildir Bay, apparent differences in amphipod assemblages become evident. In the present study, a total of eight amphipod species were identified in association with artificial substrates. In contrast, Ozaydinli and Bizsel (2020) reported 15 amphipod species from natural sediment habitats. This discrepancy highlights the strong influence of habitat type on amphipod diversity and clearly distinguishes fouling assemblages from sediment-dwelling fauna.

The observed differences in species composition indicate that sedimentary habitats and aquaculture-related artificial structures in Ildir Bay sustain distinct amphipod communities. Environmental factors such as substrate type, hydrodynamic exposure, light availability, and organic matter input are likely key drivers shaping these assemblages. These results highlight the ecological heterogeneity of the bay and emphasize the need for multi-habitat sampling strategies to achieve a more accurate assessment of biodiversity in Mediterranean coastal ecosystems.

To provide a broader understanding, the following section presents detailed accounts of each recorded species, covering diagnostic traits, taxonomic problems, cryptic diversity, and additional remarks. Furthermore, Table 2 summarizes the ecological characteristics, global distribution, depth ranges, and occurrences of the recorded species along the Turkish coasts, providing a broader biogeographic context.

Table 2. Ecological characteristics, global distribution, depth range (DR), and occurrence of the amphipod species identified in this study. An asterisk (+) indicates the presence of the species in the respective Turkish marine region: BS, Black Sea; SM, Sea of Marmara; AS, Aegean Sea; LS: Levantine Sea.

Species	Ecology	Global Distribution	DR (m)	Turkish Seas			
				BS	SM	AS	LS
<i>Caprella dilatata</i>	Artificial substrates, macroalgae, hydroids, and corals; also recorded on sea turtle carapaces	Northern Europe to the Iberian Peninsula, Mediterranean	0-10	-	-	+	-
<i>Caprella equilibra</i>	Artificial substrates, algae, seagrasses, sponges, hydroids, bryozoans, ascidians, corals	Western & Eastern Atlantic, Mediterranean, Pacific Ocean, North & South America	0-50	+	+	+	-
* <i>Caprella scaura</i>	Fouling communities on natural (rocky surfaces, macroalgae, bryozoans, seagrasses) and artificial substrates; common in nutrient-rich environments	Pacific Ocean, Atlantic Ocean, Mediterranean	0-10	-	+	+	-
<i>Erichthonius argenteus</i>	Artificial substrates, mussel beds, photophilic algae, seagrass meadows	Endemic to the Mediterranean	0-10	-	+	+	+
<i>Erichthonius brasiliensis</i>	Artificial substrates, algae, seagrasses, sponges, hydroids, tunicates	Tropical & subtropical Atlantic, Indian Ocean, Mediterranean	0-50	+	+	+	+
<i>Jassa marmorata</i>	Artificial substrates, build silk-like tubes from debris among algae and sponges	North Atlantic, North Sea, Southern Africa, Australia, New Zealand, Argentina, Brazil, Canada, Sea of Japan, Mediterranean	10-50	+	+	+	+
<i>Elasmopus rapax</i>	Artificial substrates, sandy & muddy bottoms, macroalgae, mussel beds	North & South Atlantic, Indian & Pacific Oceans, Red Sea, Mediterranean, North Sea	0-50	-	+	+	+
<i>Gammaropsis maculata</i>	Algal communities, <i>Posidonia oceanica</i> beds, rocky substrates	Northeast Atlantic (Norway–Senegal), Mediterranean	0-250	-	+	+	+

Order: Amphipoda  
 Family: Caprellidae Leach, 1814  
*Caprella dilatata* Krøyer, 1843

Body stout, dorsally smooth. Cephalon with well-developed, prominent rostrum. Pereonites III–IV with auricular pleurae. Gills large, rounded. Antenna I shorter than half body length; in males, peduncular articles I–II swollen, longer than flagellum, bearing sparse setae. Antenna II longer than antenna I, ventral margin with dense long setae. Male gnathopod II with densely setose palm, bearing acute and rectangular projections (Figures 3A, 3B). Female antenna I lacking swelling in peduncular articles; gnathopod II inserted near anterolateral angle of pereonite II; propodus with proximal tooth and palm nearly straight (Figures 3C, 3D) (Ruffo, 1993; Masunari and Takeuchi, 2006). This study detected *C. dilatata* on the net structures of Pınar Inc. and Abalıoğlu Inc. aquaculture

facilities (Table 1).

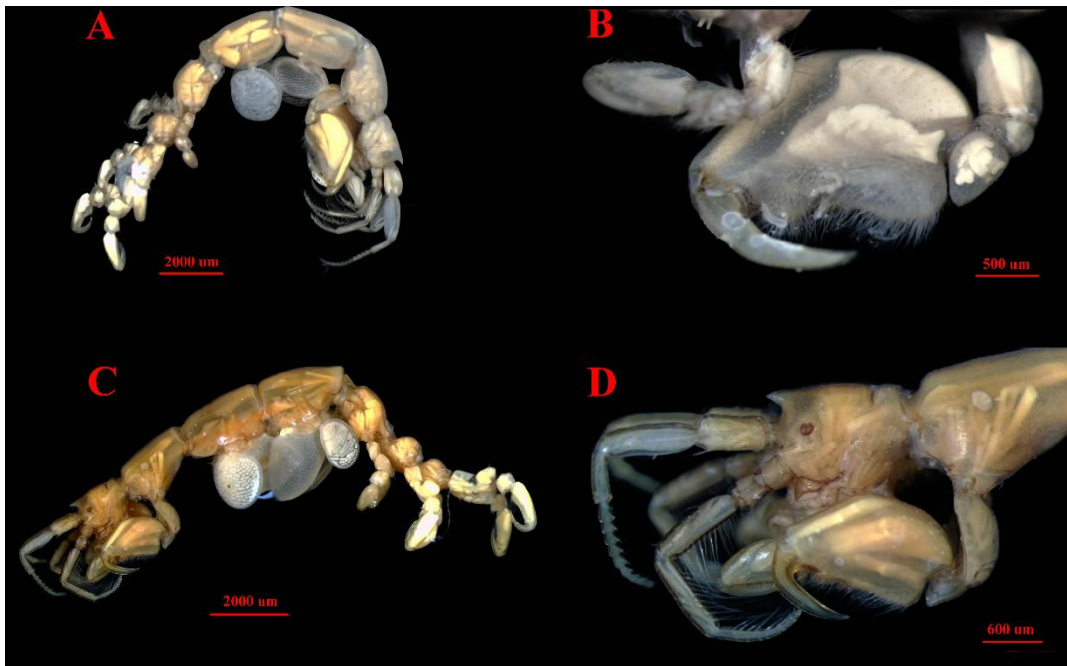


Figure 3. *Caprella dilatata* (A) Lateral view of adult male; (B) Male gnathopod II; (C) Lateral view of adult female; (D) Female cephalic region with antennae I–II and gnathopod II.

Identifying *C. dilatata* can be challenging due to its significant morphological variability, especially in characteristics like dorsal tubercles and spines, which can lead to confusion with similar species. This variability may also account for its underreporting in some areas. However, it is commonly found on artificial structures, particularly in aquaculture environments (McCain, 1964; Masunari and Takeuchi, 2006; Fernandez-Gonzalez and Sanchez-Jerez, 2017), suggesting it is well adapted to artificial habitats and may be more prevalent than previously thought.

#### *Caprella equilibra* Say, 1818

Body slender, smooth, lacking dorsal spines; rostrum short, blunt. Pereonite I elongate; pereonite II with triangular ventral projection between bases of gnathopod II. Male antenna I with swollen segments; antenna II longer, bearing ventral setae. Male gnathopod II enlarged, subchelate; palm smooth; basis robust with denticulate anterior carina (Figure 4A). Female pereonite I length similar to head; pereonite II longest; combined length of pereonites VI–VII shorter than pereonite V (Figure 4B) (McCain, 1968; Ruffo, 1993; Sánchez-Moyano et al., 2015). In this study, the species was found on net structures at all surveyed fish farms, confirming its preference for artificial habitats (Table 1).



Figure 4. *Caprella equilibra* (A) Lateral view of adult male and (B) female.

*Caprella equilibra* is a commonly reported caprellid species, but its native range, particularly in enclosed seas like the Mediterranean, remains unclear. It is considered cryptogenic in this region due to limited historical records and insufficient molecular data (Ragkousis et al., 2023).

*Caprella scaura* Templeton, 1836

Body elongated, slender, without dorsal spines, occipital spine prominent, acute, present in both sexes. Male pereonites I–II elongate; basis of gnathopod II long, subequal in length to pereonite II. Male gnathopod II propodus with palm bearing two strong grasping teeth. Female gnathopod II smaller, palm nearly smooth with reduced grasping spine (Figures 5A and 5B) (Bakır and Katağan, 2011; Martínez and Adarraga, 2008). In the present study, it was found exclusively on cage nets at the Abaloğlu aquaculture facility, with only female individuals observed (Table 1).



Figure 5. *Caprella scaura* (A) Lateral view of adult female; (B) Female cephalic region with antennae I–II.

Recognized as a well-established non-indigenous species (NIS) in the Mediterranean, *C. scaura* has spread rapidly, primarily facilitated by maritime vectors such as hull fouling and ballast water discharge (Guerra-García et al., 2011; Ramalhosa and Canning-Clode, 2015; Ragkousis et al., 2023). Its introduction into the Mediterranean Sea was first documented in the late 1990s from the Venice Lagoon, followed by rapid range expansion along western and southern Mediterranean coasts, including the Iberian Peninsula and Crete (Martínez and Adarraga, 2008; Ros et al., 2014). The species displays considerable morphological variation, which has led to historical confusion and the designation of multiple "formae" (e.g., *C. scaura typica*, *C. scaura hamata*). Recent molecular studies suggest that *C. scaura* sensu lato comprises several cryptic taxa, with Mediterranean populations aligning morphologically with the nominotypical subspecies *C. scaura scaura*, characterized by the absence of dorsal spines and presence of a distinct occipital spine (Krapp et al., 2006; Cabezas et al., 2014).

Family: Ischyroceridae Stebbing, 1899

*Erichthonius argenteus* Krapp-Schickel, 1993

Head with subtriangular, rounded lateral lobes bearing large eyes (Figure 6A). Male gnathopod I smaller than gnathopod II, subchelate, basis lacking knob-like process (Figure 6B). Male gnathopod II carpochelate; basis slender, shorter than carpus; carpus with two prominent distal teeth (Figure 6C). Female gnathopod II with suboval basis; merus rectangular; carpus subtriangular, bearing three posterodistal spines with lateral knobs and dense setae; propodus suboval, broadest near palmar margin (Krapp-Schickel, 1994; Ruffo, 1998; Krapp-Schickel, 2013; Gouillieux et al., 2020). In the present study, *E. argenteus* was recorded on the cage net structures at all three aquaculture facilities examined: Pınar, Agromey, and Abaloğlu (Table 1).

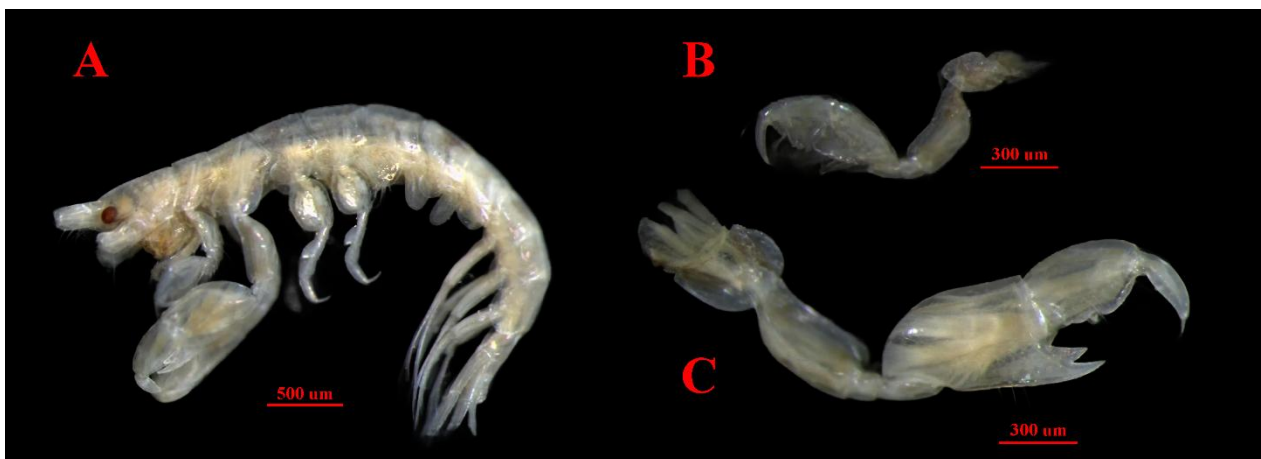


Figure 6. *Erichthonius argenteus* (A) Lateral view of male; (B) Male gnathopod I; (C) Male gnathopod II.

The taxonomy of this species remains challenging due to limited morphological differences between females of related species and variability in male gnathopod II depending on growth stage. These factors have historically led to misidentifications and incorrect synonymizations within the genus. Gouillieux et al. (2020) proposed a more structured grouping of *Erichthonius* species based on coxa II and the shape of male pereopod V, which may help clarify taxonomic distinctions. For *E. argenteus*, the combination of consistent male gnathopod morphology and other appendage features supports its recognition as a distinct and valid species. However, molecular studies are needed to resolve its taxonomic placement within this complex genus fully.

*Erichthonius brasiliensis* (Dana, 1853)

*Erichthonius brasiliensis* differs from *E. argenteus* in the morphology of male gnathopod I: basis with a distinct knob-like projection on the posterior margin, absent in *E. argenteus*. Coxa I is simple in *E. brasiliensis*, whereas in *E. argenteus*, it is subtriangular, bearing a prominent tooth-like sternal process (Figures 7A, 7B, 7C) (Ruffo, 1982, 1998; Gouillieux et al., 2020). In this study, it was found that cage net structures were present at all three aquaculture facilities (Table 1).

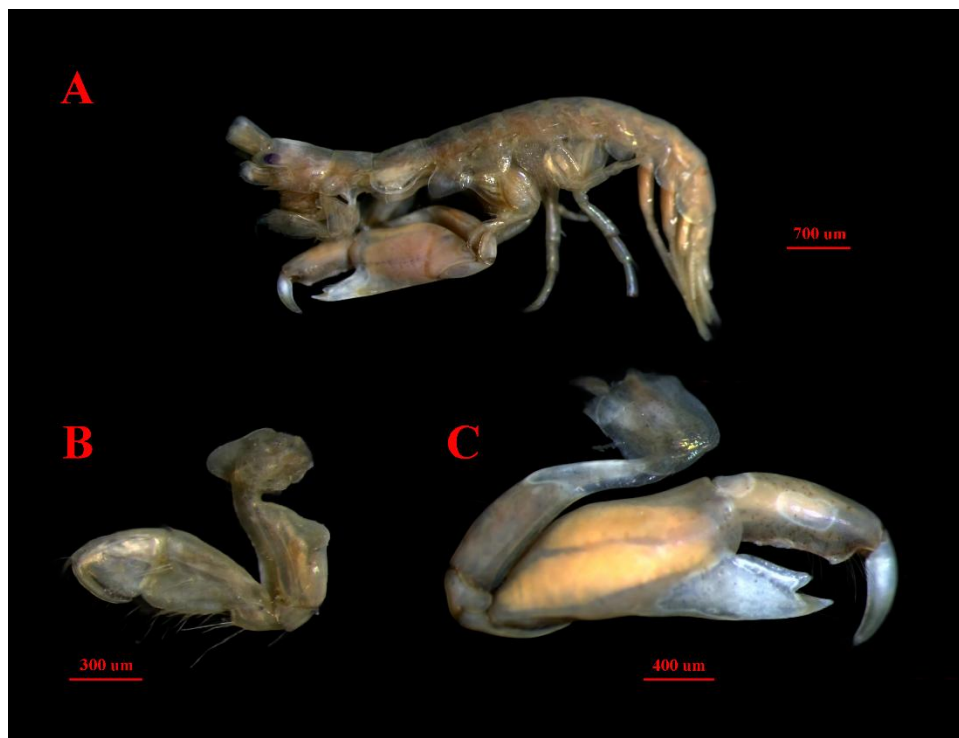


Figure 7. *Erichthonius brasiliensis* (A) Lateral view of male; (B) Male gnathopod I; (C) Male gnathopod II.

The taxonomic history of *E. brasiliensis* is notably complex due to a legacy of misidentifications and synonymizations. As noted by Myers and McGrath (1984), earlier authors, including Greze (1968), incorrectly synonymized *E. brasiliensis* with *E. difformis* due to a lack of access to authentic comparative material, which led to prolonged taxonomic confusion. Furthermore, the name *E. brasiliensis* has not always referred to the same taxon in different regions, particularly within North Atlantic and European literature (Myers and McGrath, 1984; Gouillieux et al., 2020). These inconsistencies highlight the historical reliance on locally limited specimens and emphasize the importance of comparative analysis for accurate taxonomic resolution. In addition, *E. brasiliensis* is frequently confused with many other species within the genus due to its morphological similarities. The limited morphological differences in females and the growth stage-dependent variability of male gnathopod II make the accurate differentiation of this species particularly challenging. Therefore, it is considered that *E. brasiliensis* should be evaluated within the scope of cryptic species.

*Jassa marmorata* Holmes, 1905

Male gnathopod II enlarged; propodus with prominent medial lobe and transverse palm; carpus expanded; posterior margin of propodus with robust setae (Figures 8A, 8B). Antenna I shorter than body, distinctly more robust than antenna II; first peduncular article longer than articles II–III combined (Figures 8A, 8B). Female gnathopod II smaller; propodus narrow, subrectangular, lacking medial lobe; palm oblique with small defining tooth (Figure 8B). Female antennae slender, similar in shape to male but less setose (Ruffo, 1989; Conlan, 1990; Conlan et al., 2021).

In this study, *J. marmorata* was observed on cage nets at the Pınar, Ağrımeş, and Abalıoğlu aquaculture facilities (Table 1).



Figure 8. *Jassa marmorata* (A) Lateral view of male; (B) Male gnathopod II.

This tube-dwelling, detritivorous amphipod is typically found in fouling communities (Ruffo, 1989; Beermann, 2013). Euryhaline in nature, it tolerates a wide range of environmental conditions, including polluted waters, and often forms dense aggregations in coastal habitats, especially near mussel farms (Franz and Mohamed, 1989; Fernandez-Gonzalez and Sanchez-Jerez, 2017).

Recent molecular analyses (Conlan et al., 2021) have confirmed the distinct identity of *J. marmorata* and revealed additional diversity within the *Jassa* genus. Its global distribution, often linked to shipping and aquaculture, suggests a high potential for human-mediated dispersal. In the Mediterranean, *J. marmorata* is well established, particularly in human-altered environments, where it can dominate fouling communities and outcompete native peracarids, highlighting the need for effective biofouling management and biodiversity assessments.

Family: Maeridae Krapp-Schickel, 2008

*Elasmopus rapax* A. Costa, 1853

Body smooth. Lateral cephalic lobes rounded, eyes ovoid. Antenna I nearly half body length; antenna II shorter than antenna I. Male (Figure 9A) gnathopod II palm very oblique, bearing one lateral and two median tubercles or teeth; dactylus long, obtuse-tipped; palmar tubercle shape variable (Figure 9B). Female (Figure 9D) gnathopod II palm oblique, with row of short palmar spines and two lateral spines (Figure 9E).

Pereopods III–IV slender; carpus and propodus with posterior spines; dactylus short. Pereopods V–VII progressively longer; basis ovoid, posterior margin finely crenulate with long or short setae; posterodistal lobe well developed; dactylus nearly half propodus length. Epimeral plates I–III with small posterodistal tooth, posterior margin straight or weakly crenulate (Figure 9C). Uropods I–II stout; uropod I peduncle with two strong distal spines. Uropod III short, stout, just exceeding tip of uropod I; peduncle shorter than rami (Figure 9F) (Ruffo, 1982).

This species shows marked morphological variability, with two distinct forms recognized in the Mediterranean (Ruffo, 1982). Form A males possess long setae on epimeral plates I–III, long posterior setae on the basis of pereopods V–VII, and a telson with very short spines. Form B males, in contrast, have spines on epimeral plates I–III, very short posterior setae on pereopods V–VII, and a telson with long spines. Such polymorphism has contributed to long-standing taxonomic uncertainty within the group.

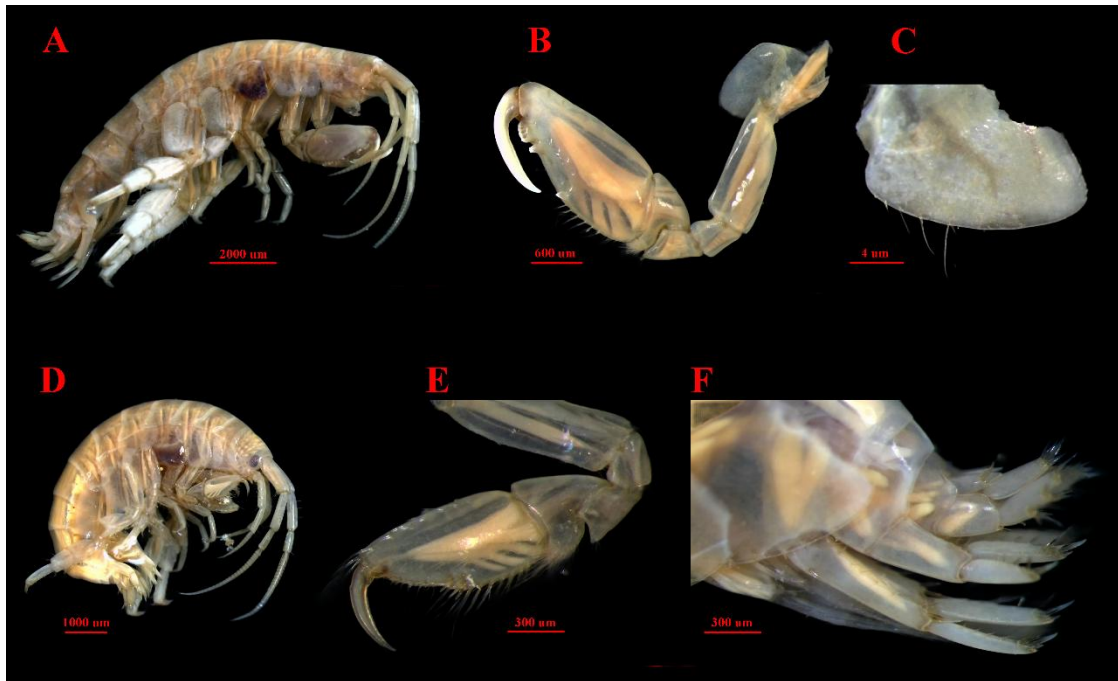


Figure 9. *Elasmopus rapax* (A) Lateral view of male; (B) Male gnathopod II; (C) Male epimeral plate III; (D) Lateral view of female; (E) Female gnathopod II; (F) Female uropods.

As the type species of *Elasmopus*, *E. rapax* also has a complex taxonomic history. The original description lacked detail, and the presumed loss of type material led to widespread misidentifications and an artificially expanded distribution (Hughes and Lowry, 2010). Taxonomic difficulties are further compounded by strong sexual dimorphism, with many diagnostic characters restricted to adult males, and by the fragility of morphological traits during collection. In the Mediterranean, it is considered cryptogenic in areas such as the Italian coast, where it commonly inhabits disturbed, nutrient-rich environments (Ragkousis et al., 2023).

Due to its variability, ecological generalism, and history of misidentification, *E. rapax* should be approached with caution in biogeographic and biodiversity assessments. To clarify species boundaries and address cryptic diversity within the genus, it is essential to employ integrative approaches that combine detailed morphological, molecular, and cytogenetic data.

Family: Photidae Boeck, 1871

*Gammaropsis maculata* (Johnston, 1828)

Head lateral lobes weakly projecting rounded; eyes reniform, partly extending behind antennal insertions. Antenna I slightly exceeding half body length, accessory flagellum well developed; antenna II subequal to antenna I (Figure 10A). Coxa I small, subquadrangular; coxa II larger, subrounded. Gnathopod I with slender basis, carpus slender and longer than propodus, posterior margin strongly convex; dactylus elongate, narrow (Figure 10B). Gnathopod II with carpus less than half length of propodus, palm more than half length of propodus, dactylus stout and curved (Figure 10C). Male gnathopod II with robust basis, carpus large, slightly shorter than propodus, palm bearing three small rounded teeth; female gnathopod II with slender basis, carpus less than half propodus length, palm with two teeth. Pereopods V–VII with robust, subovoid basis, widest proximally. Urosome smooth, lacking dentition. Uropod III with rami subequal, each terminating in a cluster of spines (Krapp-Schickel and Myers, 1979; Ruffo, 1989). In this study, the species was found on the cage nets of all farms surveyed (Table 1).

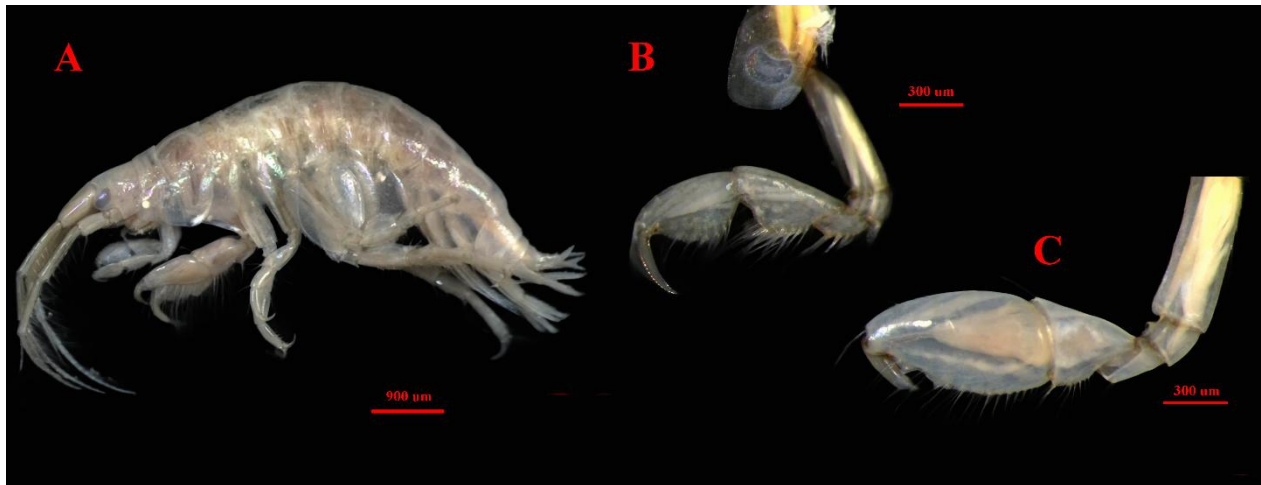


Figure 10. *Gammaropsis maculata* (A) Lateral view of male; (B) Male gnathopod I; (C) Female gnathopod II.

The Mediterranean species of *Gammaropsis* can conveniently be segregated into two groups: Group 'A' with toothed urosome, toothed coxa and long, acute epistome, and Group 'B' (*G. maculata*) with smooth urosome, smooth coxa and short epistome (Krapp-Schickel and Myers, 1979).

It was first described as *Gammarus maculatus* from the Scottish coast. Subsequently, the species was redescribed under several names, including *Eurystheus maculatus* and *Gammaropsis erythrophthalmus*, reflecting long-standing taxonomic confusion (Krapp-Schickel and Myers, 1979; Myers and McGrath, 1982). Much of this uncertainty stems from inconsistent morphological interpretations and overlapping character states with closely related taxa. Within the genus *Gammaropsis*, which is highly diverse in the family Photidae, problems of monophyly and unclear subgeneric boundaries further complicate its taxonomy (Myers, 2009). Moreover, the high degree of morphological similarity among species within the genus often leads to frequent misidentifications, indicating that *Gammaropsis* could represent a cryptic genus. This highlights the necessity of integrative taxonomic approaches combining molecular, morphological, and ecological data to resolve species boundaries and clarify the evolutionary relationships within the group.

#### 4. Conclusion

This study provides the first comprehensive assessment of amphipod assemblages associated with mussel-dominated fouling communities on aquaculture nets in Ildır Bay (Aegean Sea, Türkiye). Eight species were identified, reflecting the ecological complexity and biogeographic relevance of these artificial habitats. The fouling community was characterized by the dominance of widespread species such as *C. dilatata*, *C. equilibra*, *E. argenteus*, *E. brasiliensis*, *J. marmorata*, *E. rapax* and *G. maculata*, all classified as "Constant" according to the Soyer's frequency index, while *C. scaura* was categorized as "Common," indicating its established yet more localized occurrence. The detection of the alien *C. scaura* and several cryptic taxa (*E. brasiliensis*, *E. rapax* and *G. maculata*) highlights the role of aquaculture infrastructure as a dispersal vector and a hotspot for hidden biodiversity. Furthermore, clear compositional differences between fouling assemblages and previously documented sedimentary amphipod communities emphasize the strong influence of substrate type on community structure. These findings demonstrate that artificial substrates in aquaculture environments not only support a distinct and diverse amphipod fauna but also play a key role in shaping local and regional species distributions. In addition to revealing important taxonomic complexities, this study provides a robust ecological baseline for biodiversity monitoring, invasive species management, and the development of more effective biofouling control strategies in Mediterranean aquaculture systems.

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#### 6. Compliance with Ethical Standard

**a) Author Contributions**

Author designed the study, performed the laboratory work, interpreted the data, and prepared the manuscript.

**b) Conflict of Interests**

There is no conflict of interest, according to the authors.

**c) Statement on the Welfare of Animals**

Not relevant.

**d) Statement of Human Rights**

There are no human subjects in this study.

**e) Declaration of Not Using AI**

The author declares that no generative artificial intelligence tools were used in the writing of this manuscript or in the creation of any figures, graphics, tables, or their corresponding captions.

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