Zoogeographical and stratigraphical distribution of the genus Zonocyris: supportive evidence for Anatolian Diagonal and description of a new species from Turkey

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Abstract Since its first description from Madagaskar, there are about 16 living (Recent) species of the genus Zonocyris reported from Afrotropical, Neotropical and Palearctic regions. Similarly, there are about 16 fossil with two (sub)species of the genus known from the Early Cretaceous (e.g., India, France, Russia, China, Brazil) to Holocene (e.g., Albania). Among the species, the only species known with fossil and living species is Zonocyris costata. In Turkey, Zonocyris membranae with two subspecies (Z. m. membranae, Z. m. quadricella) is the only fossil species known while living individuals of Z. costata were encountered the southeast Anatolia. Additionally, Zonocyris mardinensis n. sp. is now proposed as a new species which shows clear differences in the soft body parts (e.g., aesthetasc ya in A1, knife-type G2 claw, shapes of clasping organs and hemipenis) and carapace structure (e.g., LV with extension, RV with posterior denticles). Overall, living species reported herein seem to inhabit comparatively warm (15-30°C) within the ranges of slightly acidic to alkaline (pH 6.81-8.44) and low to well oxygenated waters (3.05-18.8 mg/l) where they can tolerate salinity (electrical conductivity 103-1910 µS/cm) values within a limited elevational range (336-991 m). Our results suggest that geographic distribution of the living species of the genus is limited within southern parts of Turkey while fossil forms seem to exhibit much wider distribution in northern parts. Anatolian Diagonal as physical barrier may be considered to play a critical role on separating fossil (east-north regions) and extant (southeast region) species of the genus in Turkey. This is the first supportive evidence provided by the species of the genus Zonocyris that geographic barrier could have played the main role on its distribution.

Key words: Early Cretaceous/ Recent/ Zonocyris/ new species/ ecology/ Anatolian Diagonal/ global distribution

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Introduction

In Turkey, estimated numbers of non-marine ostracods are more than 160 species but this number is certainly an underestimation (Külköylüoğlu et al. 2015). Similarly, Özuluğ et al. (2018) listed about 185 (sub)fossil ostracod species limited to Quaternary period but this number is too a very low estimation to show true ostracod species diversity of the country. Turkey, as a big natural bridge, plays an important role among three continents (Asia, Europe, Africa) providing possible corridors and alternative modes of distribution for many species. This is probably one of the reasons of high species diversity found in the country. In contrast, some parts of the country are known to create ecological and/or geographical barriers for some species’ populations. The Anatolian Diagonal, a NE-SW-directed high mountain belt ranging from south of Gümüşhane-Bayburt in the northeastern to the Kahramanmaraş in the southwestern part of Turkey where it is bifurcated and/or divided into two branches, namely Amanos Mountains and Taurus Mountains, is an example of such eco/geographical barriers for many plant (Davis, 1971; Ekim and Güner, 1986) and animal species (Çiplak et al., 1993; Rokas et al., 2003; Mutun, 2010). It appears that since late Miocene, the diagonal plays critical role for the distribution of many species (Çiplak et al. 1993; Mutun, 2010; Manafzadeh et al., 2016, Meijers et al. 2020). Most recently, Gür (2016) provided a detailed review on the geographical and geological information of the diagonal. Including historical background information supported by the contemporary studies, he found out supportive evidence that the diagonal along with a steep environmental gradient was actually playing a critical role on species distribution coped with especially in seasonal temperature changes in the area. Accordingly, Anatolian Diagonal seems to be responsible for limiting geographical distribution of many animal and plant species at different genetic levels (Çiplak, 2003; Mutun, 2010; Gür, 2016). Previous studies offered evidences about the eco/geographical (and historical as well) role of the diagonal but there is no study on aquatic invertebrates, especially on ostracod species in the region. Hence, the aims of the present study were to 1) compare the distribution of the fossil and live species of the genus Zonocypris worldwide, 2) discuss the first supportive evidence for the role of Anatolian Diagonal by means of using geographical distribution of the genus Zonocypris, and 3) describe a new species of the genus Zonocypris.

Materials and Methods

A total of 17 samples (ca. 200 ml sediment) were collected from different water bodies (Tab. 1) with a standard sized hand-net (150 µm mesh size) and fixed in 70 % of ethanol in 250 ml plastic bottles in situ (Fig. 1). In laboratory, they were washed under tap water and filtered through four different sized sieves (0.5, 1.0, 1.5 and 2.0 mm mesh size) and kept in 70 % ethanol. Ostracod specimens were separated from the sediment and hand-picked under a stereomicroscope (Olympus ACH 1X) with pipets. Adult specimens were dissected in lactophenol solution for the species identification, during which both carapace and soft body parts were examined under Olympus BX-51 light microscope. Carapace and/or valves of the dissected specimens were separated from the soft body parts and kept in the micropaleontological slides. Each slide was numbered with the laboratory catalog number. We primarily used the taxonomic key of Karanovic (2012) and some other earlier sources during the identification. Scanning Electron Microscope (SEM) images acquisition of the carapaces and valves were performed with Carl Zeiss EVO-50 type SEM-EDX at the Department of Geological Engineering, Hacettepe University. We keep the samples and slides at the Limnology Laboratory of Bolu Abant İzzet Baysal University, and they can be available upon request from the first author. Six environmental variables (pH, air (Ta, °C) temperature, water temperature (Tw, °C), dissolved oxygen (DO, mg/L), electrical
conductivity (EC, µS/cm), and salinity (ppt) were measured in situ, during which a YSI-
Professional Plus device was used (for details see Külköylüoğlu et al., 2015).
All specimens collected from the type locality deposited separately in the vials at the Bolu
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Turkey).

Results
Including the new species described herein, total of 16 live (Recent) species of the genus was
reported in here (Tab. 2). Among the species, Z. costata is the only species known from both
fossil and recent reports. The most northern fossil and Recent (live) records of the genus are
so far known from Western Siberia and Turkey, respectively (Figs. 1, 2). The fossil of the
species are generally reported from Miocene to the present while the oldest fossil record
(Zonocypris sp 1) of the genus seem to be listed from Early Cretaceous (ca. 120 Ma) in Brazil
(Do Carmo et al., 2004) (Tab. 3). The youngest fossil record is known from Holocene in
Tanzania, Albania, and Ethiopia (Fig. 2). In Turkey, while the fossil taxa are distributed
above (northern parts) the Anatolian Diagonal, recent living taxa are apparently located below
(southern parts) the diagonal (Fig. 1). Zonocypris mardinensis n. sp. displays several
characteristics (e.g., presence of extension on RV, carapace ornamentation, numbers of setae
on A1 and A2, Mxl, Md-palp, shape of clasping organs, hemipenis etc.) different from the
other species of the genus (see details in Figs. 3-6). Although limited with the current
knowledge, values of some of those ecological variables suggest that the species of the genus
tend to be found in shallow fresh to brackish water bodies where water temperature may
range between 15-30°C in alkaline waters (average pH 7.63) This suggests the fact that the
species appears to prefer warm waters. If this is true, such information can be useful tool for
paleontological studies to estimate past historical conditions of the habitats.

Systematics
Subphylum: Crustacea Pennant, 1777
Class: Ostracoda, Latreille, 1802
Order: Podocopida Sars, 1866
Suborder: Podocopina, Müller, 1894
Superfamily: Cypridacea Baird, 1845
Family: Cyprididae Baird, 1845
Subfamily: Cypridopsinae Kaufmann, 1900
Tribe: Zonocypridini Higuti and Martens 2012
Genus: Zonocypris G.W. Müller, 1898

Diagnosis
In ventral view, carapace globular, ornamented with coarse, concentric ridges. LV
overlapping RV. In dorsal view, posterior end rounded, anterior end pointed. Hinge adont.
Second antenna four segmented with strong claws. Maxillular palp with cylindrical terminal
segment. Uropod absent in males, flagelliform in females.
**Zonocypris mardinensis** n. sp.  
(Figs. 3–6)

**Diagnosis**
Carapace ventrally slightly concave. LV with an extension posteriorly, RV with fine denticles posteriorly. Ridges on carapace surface circular to oval and thinner. Carapace surface with a few (or without) pits. Posterior end of LV with double list. Asthetasc ya on A1 relatively long, G2 claw not knife-type in males, clasping organs asymmetric in T1 and b-d setae absent in male. Mxl-palp with a claw-like seta on the first section, Md with four smooth bunch of setal group, hemipenis short with lobe a rounded, Zenker Organ with ca. 12 whorls. Uropod flagellum like in females, ramus triangular with a subapical posterior seta (Fig. 6G). Genital organ weakly rectangular shape.

Holotype: One male with soft body parts and carapace dissected and sealed in a slide; valves kept in a micropaleontological slides for SEM photography (Collection number: OK-TR-Mardin: 01-02). Collected from type locality by M. Yavuzatmaca, O. Yılmaz, M. Tanyeli on 13 August 2013.

Allotype: One female with soft body parts and carapace dissected and sealed in a slide (OK-TR-Mardin: 03-04); valves kept in a micropaleontological slide for SEM photography.

Paratype: Three adult males (OK-TR-Mardin: 05-07) and three females (OK-TR-Mardin: 08-10) dissected and sealed in slides. Twenty three other individuals (6 males, 11 females, 6 juveniles, 3 broken valves) collected from the type locality were kept in 70% ethanol.

**Type locality:** A shallow (ca. 50 cm) pool in the town Dargeçit, Mardin, Turkey. N 37°35'621" - E041° 43'084", ca. 932 m a.s.l.

**Description of male.** A medium-sized ostracod, with oval shape (mean L = 0.62 mm, H = 0.34 mm, W = 0.37 mm; n = 6). Carapace surface with circular ridges (Figs. 3A, B). LV larger than RV (Fig. 3E). Greatest height near the centre of the carapace. Anterior end slightly more rounded than posterior end. Valves dorsally slightly arched. Four large and one small muscle scars around the center (Fig. 3D). Marginal ends of carapace without tubercles in external view. In dorsal view, carapace ovoid, posteriorly broadened, anteriorly slightly pointing. In internal view, LV posteriorly with an extension part (Fig. 4A), RV posteriorly with row of fine denticles on calcified inner lamella (Fig. 4B). Calcified inner lamella anteriorly wider (about ¼ of carapace length) than posterior end, double inner list prominent posteriorly. Ventral margin slightly concave. Pore canals with thin seta (Fig. 4E). Hinge-like structure with a weak posterodorsal tooth on LV (Fig. 4A, B). Colour of valves opaque to white.

A1 (Fig. 5A): Seven-segmented. First segment ventrally with two well developed long setae slightly plumosed, longer one extending almost the base of the penultimate (6th) segment, shorter reaching to the fifth segment. One dorso-medial seta slightly plumosed on A1 barely reaching to the next segment. Rome or Wouters organs not seen. Second segment broaden with a short dorsal seta about ¼ of the segment. Third segment with a long dorsal-apical smooth seta, reaching end of fifth segment. Fourth segment with two almost equally long smooth dorsal-apical setae and one smooth medium-sized ventral-apical seta extending about to midpoint of sixth segment. Fifth segment with three long dorsal-apical setae and one short
ventral-apical smooth setae. Sixth segment with four unequally long and smooth setae. Terminal segment with two very long smooth setae and ya seta about 1/3 of long setae.

A2 (Fig. 5B): Four-segmented. Basal segment with a well-developed long smooth seta, slightly extending t-setae. Exopodial plate with long and two very short smooth setae. Second (first endopodial) segment well-developed, aesthetasc Y with three lobes and placed near middle of segment. Same segment with one long plumosed posteroproximal seta extending to tips of terminal claws. Five long and one short (slightly plumose barely reaching end of same segment) natatory setae present, long setae extending tips of the claws (Fig. 5C). Penultimate (third) segment with two t-setae in medium size, and two unequally long setae anterodorsally. G1 and G2 claws equal in size and well developed, G3 seta-like about half of the claws. Setae z1 claw-like shorter than G2 and G3, z2 and z3 setae thin (length ratio: z2>z1>z3). Terminal segment with a well-developed GM, Gm about half of GM and seta-like (length ratio: G1=G2>GM>G3>Gm). Seta y3 twice longer than terminal segments.

Md (Fig. 5D): with a well-developed Md-coxa ending with about 8 coxal teeth and two slightly plumose short setae dorsally. Md palp four-segmented. First segment wider than length, with one long and smooth setae, and S1–S2 setae plumose about size of next two segment, alpha seta short about ¼ of S1. Vibratory plate with six (five almost equally long and one shorter) pappose setae. Second segment externally with three smooth setae (two very long reaching tips of terminal claws, one shorter seta about half of others), and four (3+1) medium-sized smooth setae seen internally almost reaching tips of terminal claws, beta seta short and plumose. Penultimate (third) segment with four equally long and smooth extrolateral setae barely reaching tips of terminal claws and four (3 + 1 gamma) equally long and smooth setae intero-distally, two other smooth setae (one long and one short) seen distally. Terminal segment (slightly longer than width) with one very strong and smooth claw in middle, and two almost seta-like claws, one very short seta, all smooth. Claw and setae not fused with terminal segment.

Mxl (Fig.5E): with Mxl palp, three endites and vibratory plate with 14 plumose setae; base of first endite with two unequally long and slightly plumose setae, and with five well developed setae terminally, second endite with three setae and one almost bristle-like seta. Third endite with three claw-like plumose, and two smooth setae. Mxl palp with two segments; first segment with four equally long smooth setae, one claw-like plumose, and one long smooth setae, second (terminal) segment rectangular in shape, with four smooth claw-like setae. Distal segment of Mxl-palp elongated, ca 2x as long as basal width.

Rake-like organ (Fig. 6D): small with about 6-7 very small teeth.

T1 (Figs. 5F, G): Transformed into clasp organs. Left and right palps asymmetric with well-developed fingers. Right finger wide, hook-like, lower part with a long tongueshaped extension and a short a seta (Fig. 5F). Left finger, hook-like and slender, lower part of trunk ending with a long pointing process (Fig. 5G). Vibratory plate with five medium sized plumose setae. One short a seta present, others (b, c, d) setae absent (diagnostic character). Masticatory process with 8 almost equally long smooth setae.

T2 (Fig. 5H): Five-segmented with a medium-sized d2 basal seta, d1 seta absent, e-g setae plumosed (length ratio: e > f > g), g seta half of seta e. Terminal segment with one short h3 and h1 setae (both smooth) and h2 long claw-like.
T3 (Fig. 6A): Three-segmented (penultimate segment undivided). First segment with three slightly plumose (dp > d1=d2) setae; dp seta barely reaching to the end of next segment. Seta e about half of the segment, f seta short about half of seta e. Terminal segment with hook-like pincer organ, h2 short and curved, h3 seta slightly plumose, long about length of penultimate segment.

Zenker organ (Fig. 6B): with 12 whorls of spines, ending with 12-14 corrugated opening.

Hemipenis (Fig. 6C): Lobe a (outer lobe) short with a rounded end. Lobe b (inner lobe) broadly rounded. Medial lobe (lobe h) with nose-shaped expansion directed inwardly.

Etymology. The species is named by adding the suffix -ensis to the type locality (Mardin).

Accompanying taxa. Ilyocypris sp.

**Description of female.** Female similar in shape and size (mean L = 0.59 mm, H = 0.35 mm, W = 0.37 mm; n = 6) to male (Figs. 3C,F,G, 4C,D,E).

A2 (Fig. 6E): Four-segmented. First and second segments similar to male in size and length. This part is at least twice longer in males than females. Second segment with one long (two setae in male) well developed plumose postero proximal seta extending to tips of terminal claws. Penultimate (third) segment with three t-setae (two t-setae in male) in medium size, and two unequally long plumose setae anterodorsally. G1 and G2 claws well developed, G3 seta-like about ⅔ of other claws. G2 very strong knife-shaped (normally shape in male). Setae z1-3 seta-like about length of G2, z3 slightly shorter than z1 and z2. Terminal segment with a smooth GM claw, Gm about z3 seta (length ratio: G1 ≈ G2 > GM ≈ G3 > Gm). T1 (Fig. 6F) normally developed with three endopodial setae (h2 > h1 > h3), h2 seta very long and plumose almost equal to length of all T1. Five short and plumose vibratory setae present in T1, seta a smooth, very short and thin, seta b not seen clearly (b-c-d setae absent in males). Masticatory process short, distally with 8+2 plumose setae. Uropod flagellum like with a triangular ramus and a subapical posterior seta (uropod absent in males) (Fig. 6G). Genital organ smooth weakly rectangular shape (Fig. 6G). Labium (Fig. 6H) wide with short spine-like teeth and medium-sized setae.

**Discussion and Conclusion**

**Paleobiogeography and biogeography of Zonocypris**

Among the fossil taxa of the genus Zonocypris, Z. membranae is the only fossil species reported from late middle?-early late Miocene to early Pleistocene in Turkey and some other countries in Europe, Africa, Asia and Caucasian region including Russia (Siberia, Crimea), Azerbaijan ) and Iran (NW Iran, Tabriz Basin) (Tab. 3). Living populations of the species are not known. In contrast, extant (and fossils as well) populations of Z. costata are common from African countries including Tanzania, Zimbabwe, Mozambique, Kenya, Malawi, and Pliocene forms of Ethiopia, as well as Madagascar (e.g., see Müller, 1898; Sars, 1910; Brehm, 1911; Delachaux, 1919; Klie, 1933; Lindroth, 1953; Fryer, 1957; Carbonel and Peypouquet, 1979) while distribution of fossil species is limited in Europe (see Cabral et al., 2004). According to McKenzie (1971) Z. costata was also known from the Isle Aldabra. Comparing to other species (see e.g., Mischke et al., 2014; Kalbe et al., 2015), Z. costata seems to be the only
species with live and (sub)fossil species known from the world. For example, samples gained from about 100 cm long sediment core from Lake Oloidien (Kenya) located at 1885 m a.s.l. included Z. costata whose live specimens were also known from ponds and lakes in western Uganda and central Kenya (Verschuren, pers. comm., and see details in Rumes et al., 2016). Although the members of the genus, either live or fossil species, are known from many other continents, it is interesting to note that the genus has not been reported from North America, and no fossil forms known from Australia yet.

Biogeographical separation and ecology

Live individuals of Z. costata and Zonocypris spp. are known from six provinces (e.g., Adıyaman, Diyarbakır, Gaziantep, Mardin, Malatya and Hatay) in Turkey where they are all located below the Anatolian Diagonal. Hartmann (1964) was the first to report living females of the species from a river basin in Gaziantep and from ponds near a spring in Malatya (Turkey). Such finding inhere appears to be a good supportive evidence for inquiring the role of the diagonal on species distribution not only for the recent forms but also for the distribution of the fossil forms. As far as we know, this is probably the first report of a non-marine invertebrate species subjected to comparison for both fossil and recent geographical distribution of the members of the genus Zonocypris, meaning that below and above the diagonal. Accordingly, it can be seen that while fossil taxa s are widely distributed above the diagonal, extant (living) taxa are restricted to the areas below it. From the global perspective, this actually corresponds to the northernmost occurrences of the fossil taxa of the genus when living species are much common in southern parts of the world. Up to now, including Z. mardinensis n. sp., there are two (or three) living species of the genus known from Turkey. Schäfer (1952) providing some line drawings of the soft body parts described Z. inconspicua from a pool in the central dry steppe of Turkey but since then the species has not been reported from other parts of the region. Besides, although Schäfer (1952) mentioned about the name “Ilgar-Sea” or “Ilgar Lake”, it should be noted that we have failed to find any water bodies in the region called by Schäfer as “Ilgar Lake”. Therefore, we were not able to find type locality of Z. inconspicua. We are also aware of the fact that repository of the type materials of the species is also not known (Scharf, pers. comm.). Karanovic (2012, p.203) provided coordinates (37°09′N 38°13′E) for Ilgar Lake in Turkey. This coordinate is located in the town of Birecik, Şanlı Urfa (Turkey) that the site is located in the southern part of Anatolian Diagonal. However, because of such uncertainties about the type locality of the lake, presence of Z. inconspicua is not clearly known and deserves further investigation. Considering such clear cut on the species distribution above the diagonal for fossil and below it for living species can be deduced in at least two possible explanations as ecological-geographical and/or temporal-historical ways. In ecological explanation, from the contemporary studies, we know that the species of the genus tend to be found from variety of warm and relatively shallow fresh to brackish aquatic habitats (e.g., littoral zone of lakes, ponds, springs, creeks etc.) located from about sea level up to about 1000 m a.s.l. (this study). The Anatolian Diagonal consisting of high mountain ranges is shown to create a physical barrier for many species (Davis, 1971; Çıplak et al. 2003; Mutun, 2010; Gür, 2016; Manafzadeh et al., 2016; Mutun, pers. comm.). Thus, it is possible that species of the genus have not been able to pass through high mountain ranges and reach to the west-northern parts of Anatolia. Such a barrier basically creates geographical and ecological limits for species dispersion. Synthesis of this view for individual species (i.e., Zonocypris mardinensis n. sp.) may highlight the importance of species ecological tolerances to different aquatic conditions. For example, changes in geographical (e.g., elevation) conditions can eventually be effective on changes in water conditions, simply temperature decreases with increasing elevation.
Thereby, air temperature differences, for example, at high altitudes can be effective on species survival probabilities. During our study, mean values of water temperature and pH where the new species found were about 22°C (15-31°C) and 7.63 (6.81-8.44), respectively. These values are found in accordance with the measurements of Martens et al. (1996) in different shallow water bodies of Verlorenvlei (Western Cape, South Africa) where two other members of the genus (Z. cordata and Z. tuberosa) were found from wet season within the ranges of water temperature (21-27°C), (pH 6.9-7.7), and electrical conductivity (3230-4340 µS/cm). These results imply that the species are not able to tolerate (or prefer) cold waters. If so, these species with such preference for warm waters are not supposed to survive in cold waters at high mountain ranges lined up on the Anatolian Diagonal. In another example, Külköylüoğlu et al. (2015) reported a new species, Gomphocythere besni, from a man-made pool in Adiyaman province located in the south-eastern part of Anatolia, below the diagonal. Species of the genus Gomphocythere are mostly known from Afrotropical region but G. besni is the only species known with the most northern distribution. Besides, there is only one fossil Holocene species G. geareyi Boomer 2010 described from Kahramanmaraş region (Boomer and Gearey, 2010), and later reported from Pleistocene materials of Adiyaman region of Turkey (Karayigit et al., 2016). Similarly, type locality of G. geareyi was also located below the diagonal. Up to now, no other live or fossil of the genus have been reported from western or upper parts of the diagonal. Külköylüoğlu et al. (2015) pointed out that ecological barrier (e.g., temperature differences due to geographical constraints related to the Anatolian Diagonal) could have been played important role on species distribution since species with African origin preferred relatively warm waters and have not been able to pass through the other side of the high mountain ranges of the diagonal. Although these studies favor critical role of the diagonal, due to lack of ecological information about many ostracod species, this view needs to be confirmed with future studies.

In temporal/historical explanation: This is another way to explain limited distribution of the species below (southern parts) and above (northern parts) of the diagonal. It is just a manner of time. Hence, species of the genus Zonocypris have not been able to reach to the northern part of the diagonal. It means that if the conditions are suitable, species may survive above the diagonal. We argue that it is now evidenced that Anatolian Diagonal has been playing critical role on geographical distribution of several (if not many) different taxonomic groups (see above) from south to northern parts of Turkey. Although such studies are diverse, the present study provides the first evidence of the relationship between fossil and live species of the genus Zonocypris along with their historical distribution.

As stated above, the genus seems to be mostly related to warm and shallow fresh to brackish water bodies. Including the new species, total of 16 living (but consider about the situation for Z. inconspicua) and 16 fossil species of the genus is now reported in the present study. Among the species, Z. costata was the only species known from both fossil (from early Miocene) and recent reports. The most northern fossil and living records are known from Western Siberia and Turkey, respectively. The fossil Zonocypris were generally reported from Miocene to the present while the oldest fossil (Zonocypris sp 1) seems to be listed from Early Cretaceous (ca. 120 Ma) in Brazil. The youngest fossil record is known from Holocene in Tanzania, Albania and Ethiopia. Since taxonomic position of this taxon (Zonocypris sp 1) from Brazil has not been confirmed at species level, one may subjectively and cautiously consider excluding the presence of the fossil species from Brazil. Indeed, if this is true, fossil distribution of the species would only be limited within the countries in Africa, Asia and
Europe. This approach based on supportive fossil and recent records may also explain limited geographical distribution of the genus.

**Systematic position**

We propose *Zonocypris mardinensis* n. sp., as a new species because of the following morphological differences from the other species of the genus. Basically, comparisons can be made with the other four sexual (*Z. corrugata*, *Z. costata*, *Z. glabra*, *Z. tuberosa*) species. As shown above in the descriptions, *Z. mardinensis* n. sp. is different from these (and other parthenogenetics) species based on differences in carapace structure (e.g., presence of an extension on LV posteriorly, and fine denticles on RV posteriorly) and soft body parts (e.g., A1 (relatively long aesthetasc ya), A2 (G2 claw normal in males, not knife-type), T1 (clasping organs and absence of b-d setae), Mxl (presence of a claw-like seta on the first section of the Mxl-palp, and a claw-like seta on the third endite), Md (presence of 3+1 smooth bunch of setal group), hemipenis (short and rounded lobe a), Zenker Organ (with ca. 12 whorls). As much as these differences, some other differences can also be found between *Z. mardinensis* n. sp. and *Z. costata*; for instance, ridges are deeper, thicker, and more circular in latter species than the former species. Besides, *Z. costata* is more globular than *Z. mardinensis* n. sp. Extension part is missing on LV of *Z. costata*. Also, *Z. costata* has 17 whorls in Zenker Organ while there are 12 whorls in *Z. mardinensis* n. sp.

*Zonocypris mardinensis* n. sp. has also some differences with the most common fossil species *Z. membranae*: i) *Z. membranae* has fine denticles on the inner calcified lamella of RV located anteriorly and postero-ventrally while such denticles are only located posteriorly in *Z. mardinensis* n. sp.; ii) LV with an extension part posteriorly in *Z. mardinensis* n. sp. This part is missing in *Z. membranae* whose RV (not LV) may have a weakly developed part ventrally; iii) Ridges on carapace surface are circular to oval and thinner in *Z. mardinensis* n. sp. while they are thicker, deeper and much circular in *Z. m. quadricella*. Note that these ridges are also very much thicker in some other fossil forms (cf. *Z. viriensis*, *Z. gujaratensis*, *Z. spirula*, *Z. pseudospirula*). There is no or a few pits may be seen on carapace of *Z. mardinensis* n. sp. while pits are prominent in *Z. m. quadricella* (and in *Z. cordata* whose carapace surface lacks the ridges but is only covered with pits); v) *Z. mardinensis* n. sp. ventrally slightly concave when ventral margin of the carapace is concave in *Z. m. quadricella*; vi) Double inner list present posterior end of LV in *Z. mardinensis* n. sp. This list is not (or if present, weakly developed) present in *Z. membranae*. Including the new species but questioning the taxonomic status of *Z. inconspicua*, there are now possibly 16 living and 15 fossil species of the genus in the world. Based on the current data available, however, the genus, *Zonocypris*, requires more detailed studies due to several issues in lack of ecological, taxonomic and geographical knowledge. Future studies are suggested.
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Fig. 1. Digital Elevation Model (DEM) image showing the distribution of the genus *Zonocypris* in Turkey. Anatolian Diagonal (dashed diagonal) represents high mountain ranges (i.e., eco-geographical barrier) between fossil and living species of the genus.
Fig. 2. Worldwide distribution of the recent (large red star) and fossil (small yellow x) records of the genus *Zonocypris*

(for details see Table 2 and 3)
Fig. 3. Zonocypris mardinensis n. sp. A) external view of RV and B) LV, C) external view of RV, D) internal view of muscle scars, E) dorsal view, carapace, F) ventral view of RV, and G) LV. Male (A, B, D, E), Female (C, F, G). Scale: 50 µm for A, B, C, E, F, and 20 µm for D.
Fig. 4. *Zonocypris mardinensis* n. sp. A) male, internal view of LV and B) RV, C) female, internal view of LV and D) RV, E) pore openings with seta in male, F) posterior end of RV with denticles in female. Scale bar: 55µm for A-D, 45 µm for E, 20 µm for F.
Fig. 5. *Zonocypris mardinensis* n. sp. A) Male, antennule (A1), B) antenna (A2), C) swimming setae detail, D) mandible (Md), E) maxillule (Mx1), F) left clasping organ of T1, G) T1 with right clasping organ, H) second thoracopod (T2, walking leg). Scale: 80 µm for A, B, D, E, H; 40 µm for C, F, G.
Fig. 6. *Zonocypris mardinensis* n. sp. A) third thoracopod (T3, cleaning leg), B) Zenker organ, C) hemipenis, D) rake-like organ, E) antenna (A2), F) first thoracopod (T1), G) uropod or furca with genital lobe of female, H) labium. A-D, male; E-H, female. Scale: 80 µm for A, E, F; 40 µm for B, C, H; 10 µm for D, G.
Table 1. Ecological variables collected from 17 different sampling sites in Turkey where living taxa of genus *Zonocypris* were reported. Type locality of new species is bold and underlined. Abbreviations: (Alt.: Altitude (m), T(a): Air temperature, (°C), T(w): Water temperature (°C), DO: Dissolved oxygen in water (mg/L), EC: Electrical conductivity (μS/cm), Sal: Salinity (ppt). Note that original sampling sites (St. No.) are shown with the numbers nearby the city name. *, *Z. costata*; **, *Z. mardinensis* n. sp.; a, *Zonocypris* sp.; b, *Zonocypris*. cf. sp. Note that *Z. cf. costata* was reported from Malatya by Hartmann (1964) but no measurement of water variables was provided.

| St.No. | St. Type | Alt. | T(a) | T(w) | pH   | DO  | EC  | Sal | Sampling date |
|--------|----------|------|------|------|------|-----|-----|-----|---------------|
| Adiyaman 10* | Spring  | 991  | 40.5 | 15.6 | 7.53 | 6.48 | 565 | 0.34 | 16.07.2012    |
| Gaziantep 11* | Rheocrene sp. | 517  | 40  | 19.8 | 7.23 | 103 | 0.05 | 20.07.2010    |
| Gaziantep 16* | Rheocrene sp. | 527  | 40  | 20.3 | 6.81 | 549 | 0.28 | 20.07.2010    |
| Gaziantep 43* | River    | 336  | 44  | 30.9 | 8.30 | 414 | 0.20 | 23.07.2010    |
| Gaziantep 68* | Creek    | 669  | 43  | 23   | 7.35 | 1910| 0.07 | 29.07.2010    |
| Diyarbakır 23a | Creek    | 832  | 29.1| 18.4 | 7.07 | 7.97 | 476.4 | 0.20 | 18.07.2007    |
| Diyarbakır 79a | Spring   | 754  | 32.6| 21.6 | 8.5  | 247.1| 0.10 | 13.08.2007    |
| Diyarbakır 80a | Water body | 762  | 32.6| 28.6 | 5.72 | 414 | 0.20 | 13.08.2007    |
| Diyarbakır 81a | Water body | 825  | 32.6| 29.2 | 6.75 | 600 | 0.30 | 13.08.2007    |
| Hatay 68* | Creek    | 591  | 31.5| 22.7 | 8.44 | 8.29 | 755 | 0.39 | 07.08.2012    |
| Mardin 4** | Pool     | 932  | 38.9| 18.1 | 7.55 | 9.17 | 401.8| 13.08.2013    |
| Mardin 22a,b | Irrig. chan. | 954  | 30.9| 17.5 | 7.56 | 7.51 | 353.2| 15.08.2013    |
| Mardin 61a,b | Creek    | 785  | 36.7| 21.4 | 7.78 | 8.53 | 699 | 16.08.2013    |
| Mardin 63a,b | Pool     | 941  | 37.8| 20.2 | 8.29 | 18.8 | 484.7| 16.08.2013    |
| Min.    | 336      | 29.1| 15.6| 6.81 | 5.72 | 103 | 0.05 |       |               |
| Max.    | 991      | 44  | 30.9| 8.44 | 18.8 | 1910| 0.39 |       |               |
| Mean    | 749.83   | 40.8| 21.32| 7.63 | 8.01 | 560.73| 0.20 |       |               |

Min. = Minimum, Max. = Maximum, Mean = Average.
Table 2. List of 16 recent (live) and 16 fossil species of the genus *Zonocypris* G.W. Müller, 1898 in the world. Note that details in Discussion for *Z. inconspicua*. * SEM photographs are not clear, possibly belong to different genus. **Considered as synonym to *Z. m. quadricella* by Mazzini *et al.* (2013). ***Modified from Meisch *et al.* (2019).

| Living species*** | Fossil species |
|-------------------|----------------|
| *Zonocypris alveolata* Klie, 1936 | *Zonocypris costata* Vávra, 1897 |
| *Zonocypris calcarata* Klie, 1936 | *Z. digitalis* Babino, 2003 |
| *Zonocypris cordata* Sars, 1924 | *Z. elongata* Schneider, 1963 |
| *Zonocypris corrugata* Rome, 1965 | *Z. expansa* Tian, 1982 |
| *Zonocypris costata* (Vávra, 1897) | *Z. gujarantensis* Bhandari and Colin, 1999 |
| *Zonocypris elegans* G.W. Müller, 1898 | *Z. jintanensis* Chen, 1982* |
| *Zonocypris glabra* Klie, 1944 | *Z. labyrinthicos* Nagari and Khosla, 2007 |
| *Zonocypris inconspicua* Schäfer, 1952 | *Z. maghrebinensis* Helmdach, 1988** |
| *Zonocypris inornata* Klie, 1936 | *Z. mckenziei* (Raghavan *et al.*, 2007) |
| *Zonocypris laevis* Sars, 1910 | *Z. membranae* Livental, 1929 |
| *Zonocypris lata* Rome, 1962 | *Z. oliviformis* Huang, 1979 |
| *Zonocypris peralta* Rome, 1969 | *Z. privis* Zhao (Mei-Yu), 1982 |
| *Zonocypris pilosa* Rome, 1962 | *Z. rippeae* Mostafawi, 1994 |
| *Zonocypris tuberosa* G.W. Müller, 1908 | *Z. spirula* Whatley and Bajpal, 2000 |
| *Zonocypris uniformis* Rome, 1962 | *Z. viriensis* Khosla and Nagori, 2005 |
| *Zonocypris mardinensis* n. sp., this study | *Z. pseudospirula* Khosla *et al.*, 2010 |
Table 3. Zoogeographical and geochronological distribution of the species *Zonocypris*. Note that no records from Eocene. Note to cross-references for 1Witt (2003); 2Reichenbacher *et al.* (2011).

| TAXON                  | GEOLOGICAL AGE                      | LOCATION                  | REFERENCE                  |
|------------------------|-------------------------------------|---------------------------|----------------------------|
| *Zonocypris?* sp.      | Early Cretaceous (Aptian-early Albian) | Araripe Basin/Brasil     | Do Carmo *et al.*, 2004    |
| *Zonocypris? expansa*  | Early Cretaceous (Aptian-Albian)    | NE China                  | Tian and Zhao, 1982        |
| *Zonocypris?* sp.      | Late Cretaceous (late Cenomanian)   | Cedar Canyon/Utah         | Tibert *et al.*, 2009      |
| *Zonocypris* sp.       | Late Cretaceous                      | India                     | Whatley and Bajpai, 2000   |
| *Z. digitalis*         | Late Cretaceous (Campanian)          | Auriol/SE France          | Babinot, 2003              |
| *Z. labyrinthicos*     | Late Cretaceous (Maastrichtian)      | Madhya Pradesh/India      | Nagori and Khosla, 2007    |
| *Z. gujaratensis*      | Late Cretaceous (Maastrichtian)      | Madhya Pradesh/India      | Nagori and Khosla, 2007    |
| *Z. gujaratensis*      | Late Cretaceous (Maastrichtian)      | Madhya Pradesh/India      | Rathore *et al.*, 2017     |
| *Z. spirula*           | Late Cretaceous                      | Gujarat/India             | Khosla and Nagori, 2005    |
| *Z. spirula*           | Late Cretaceous (Maastrichtian)      | Madhya Pradesh/India      | Nagori and Khosla, 2007    |
| *Z. spirula*           | Late Cretaceous (Maastrichtian)      | Gujarat/India             | Khosla *et al.*, 2009b     |
| *Z. viriensis*         | Late Cretaceous (Maastrichtian)      | Gujarat/India             | Khosla *et al.*, 2009b     |
| *Z. gujaratensis*      | Late Cretaceous (late Maastrichtian) | Gujarat/India             | Bhandari and Colin, 1999   |
| *Z. pseudospirula*     | Late Cretaceous                      | Maharashtra/India         | Khosla *et al.*, 2010      |
| *Z. gujaratensis*      | Late Cretaceous (Maastrichtian)      | Madhya Pradesh/India      | Khosla *et al.*, 2011      |
| Species                | Age                      | Region          | Authors                          |
|-----------------------|--------------------------|-----------------|----------------------------------|
| *Z. pseudospirula*    | Late Cretaceous (Maastrichtian) | Madhya Pradesh/India | Khosla et al., 2011 |
| *Z. spirula*          | Late Cretaceous (Maastrichtian) | Madhya Pradesh/India | Khosla et al., 2011 |
| *Z. gujaratensis*     | Late Cretaceous (Maastrichtian) | Madhya Pradesh/India | Kapur et al., 2018 |
| *Z. spirula*          | Early Paleocene          | Madhya Pradesh/India | Khosla et al., 2009; Sharma and Khosla, 2009 |
| *Z. viriensis*        | Early Paleocene          | Madhya Pradesh/India | Khosla et al., 2009; Sharma and Khosla, 2009 |
| *Z. spirula*          | Paleocene?               | Uttar Pradesh/India | Sharma et al., 2008 |
| *Z. jinlanensis*      | Oligocene                | Jiangsu/China   | Hou et al., 1982 |
| *Z. maghrebinensis*   | Middle Miocene (Serravalian) | Maghreb/Morocco | Helmdach, 1988 |
| *Z. membranae*        | Late middle?-early late Miocene | Aşağıçığil Fm./Konya, Turkey | Tuncer, 2020 |
| *Z. membranae* (cf. Paracypretta? sp.) | Late Miocene (early Tortonian) | Kythira Island/Greece | Mostafawi, 1990 |
| *Z. m. quadricella*   | Late Miocene (Tortonian) | Southern Italy | Ligios et al., 2012 |
| *Z. membranae*        | Late Miocene (Tortonian?) | Tabriz/NW Iran | Reichenbacher et al., 2011 |
| *Zonocypris sp.*      | Late Miocene (Tortonian) | Yatağan Basin/Muğla, Turkey | Becker-Platen, 1970 |
| *Z. membranae*        | Late Miocene (middle Pontian) | Romania | Stoica et al., 2013 |
| *Z. membranae*        | Late Miocene (middle Pontian) | Romania | Floroiu et al., 2013 |
| *Z. membranae*        | Late Miocene (Pontian) | Bafra/Samsun, Turkey | Tunoğlu et al., 1997 |
| *Z. m. quadricella*   | Late Miocene             | Tuğlu Fm./Çankırı Basin, Turkey | Mazzini, 2011; Mazzini et al., 2013 |
| Species                | Age                  | Location                          | Authors                |
|------------------------|----------------------|-----------------------------------|------------------------|
| *Z. membranae*         | late Miocene         | Bozkır Section/Çankırı Basin, Turkey | Mazzini, 2011          |
| *Z. membranae*         | late Miocene         | Akkaşdağ Fm./Çankırı-Çorum Basin, Turkey | Kayseri-Özer et al., 2017 |
| *Z. membranae*         | late Miocene-early Pliocene | Manisa, Turkey                     | Witt, 2003             |
| *Z. membranae*         | late Miocene-early Pliocene | Afyon, Turkey                     | Demirer et al., 2017   |
| *Z. membranae*         | late Miocene-Pliocene | Göksöğüt Fm./Isparta, Turkey     | Tuncer et al., 2017; Tuncer, 2020 |
| *Z. membranae*         | early Pliocene (Dacian) | Serbia                            | Krstić, 1993, 1995¹    |
| Z. aff. membranae      | early Pliocene (Dacian) | Silistra, Bulgaria (Romania Boundary) | Jiřiček, 1983          |
| *Zonocypris sp.*       | early Pliocene       | Lake Qinghai/NE Tibetan Plateau | Lu et al., 2017        |
| *Eucypris membranae*   | Pliocene             | Azerbaijan                        | Agalarova, 1956        |
| *Z. m. membranae*      | Pliocene (Levantian) | Bulgaria                          | Stancheva, 1966        |
| *Z. m. quadricella*    | Pliocene (Levantian) | Bulgaria                          | Stancheva, 1966        |
| *Zonocypris sp.*       | Pliocene             | Sivrihisar/Eskişehir, Turkey      | Tunoğlu et al., 1995   |
| *Z. membranae*         | Pliocene             | Turfan/NW China                   | Huang et al., 2004     |
| *Z. membranae* (cf. *Virgatocypris sp.*)* | Pliocene             | Israel                            | Rosenfeld et al., 1981 |
| *Z. membranae*         | Pliocene             | Uzbekistan and Turkmenistan       | Mandelstam and Schneider, 1963 |
| *Z. m. quadricella*    | Pliocene             | Pannonian Plain (Serbia)          | Krstić, 2006           |
| *Z. elongata*          | Pliocene             | Uzbekistan                        | Mandelstam and         |
| Species           | Age                          | Location                | Authors, Year |
|-------------------|------------------------------|-------------------------|---------------|
| *Z. membranae*    | late Pliocene                | Caspian Basin           | Krijgsman *et al.*, 2019 |
| *Zonocypris* sp. | late Pliocene                | Kos and Evia Islands/Greece | Mostafawi, 1988, 1994a |
| *Z. membranae*    | late Pliocene (Dacian-Romanian boundary) | Romania                | Olteanu, 1995¹ |
| *Z. membranae*    | Pliocene-early Pleistocene   | Karapınar/Konya, Turkey | Beker *et al.*, 2008 |
| *Z. membranae*    | Pliocene-early Pleistocene   | Western Siberia         | Kazmina, 1975 |
| *Z. membranae*    | late Pliocene-early Pleistocene (Romanian) | Romania                | Van Baak *et al.*, 2015 |
| *Z. membranae*    | late Pliocene-early Pleistocene (Romanian) | Caspian Basin           | Olteanu and Jipa, 2006 |
| *Z. m. quadricella* | late Pliocene-early Pleistocene (Piacenzian-Gelasian) | Central Italy           | Spadi *et al.*, 2019 |
| *Z. rippeae*      | late Pliocene-late Pleistocene | N-Peloponnes, Griechenland | Mostafawi, 1994b |
| *Z. membranae*    | Pliocene-Pleistocene (Dacian-Romanian) | Caspian Basin/Azerbaijan | Van Baak *et al.*, 2013 |
| *Z. membranae*    | late Pliocene-early Pleistocene (Akchagilian) | Grozny/Chechen Republic | Suzin, 1956² |
| *Z. oliviformis*  | early Pleistocene            | Qinghai/China           | Huang, 1979   |
| *Z. mckenziei*    | early Pleistocene            | India                   | Raghavan *et al.*, 2007 |
| *Z. costata*      | early Pleistocene            | India                   | Raghavan *et al.*, 2007 |
| *Z. membranae*    | early Pleistocene            | Dursunlu Fm./Konya, Turkey | Tuncer, 2020 |
| **Z. costata** | Pleistocene | Kashmir Valley/NW India | Singh, 1977 |
| Z. cf. costata | Pleistocene | Benot Ya’akov Fm./Israel | Kalbe *et al.*, 2015 |
| Z. cf. costata | early-Middle Pleistocene transition | Lake Hula/Israel | Mischke *et al.*, 2014 |
| **Z. membranae** | Late Pleistocene | Western Siberia | Konovalova, 2016 |
| **Zonocypris sp.** | Late Pleistocene | Western Siberia | Konovalova, 2016 |