Ecology and distribution of calanoid copepods in Sicilian inland waters (Italy)

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Introduction

Sicily covers about 11% of Italian territory, but its inland water bodies store only 1% of national freshwater resources. This percentage includes the water stored in about 30 dam reservoirs, which represents a vital resource for the economy of the island. Its semiarid Mediterranean climate limits water availability in summer months. These environments were studied in the last fifteen years pointing out the effect generated by water-level fluctuations on ecosystem dynamics (NASELLI-FLORES 2003).

Temporary water bodies represent another significant water resource on the island. These freshwater ecosystems, especially in dry regions, not only have a socio-economical and cultural value that includes storage of water for use by local pastoral communities, but contribute to the maintenance of global biological diversity through their exclusive and highly specialized plant and animal communities. Despite that, Sicilian temporary ponds have often been neglected due to their ephemeral character and are now disappearing because of abandonment of traditional life styles and land agricultural use as well as unsustainable land management practices, including permanent flooding and land-filling for agricultural and urban developments. A possible strategy to stop this tendency is increasing the knowledge on the real biological value of these water bodies. To manage this task, a series of samplings representative of the Sicilian territory has been carried out (MARRONE 2003a, b, MARRONE & NASELLI-FLORES 2004). These data, jointly with those present in the literature (MARGARITORA et al. 1982, CALVO et al. 1993), allowed us to organically assess for the first time the consistency of the entomostracan fauna in the island. In this paper we highlight our results concerning the actual knowledge on the distribution of calanoid copepods in Sicily and attempt to highlight the relationships between this distribution and some ecological features of the sampled sites.

Key words: Calanoida, Sicily, distribution, biogeography, Canoco

Methods

Samples were collected from autumn 2000 to spring 2004 in 256 water bodies scattered throughout the Sicilian territory and the small circum-Sicilian islands (southern Italy). The survey incorporated both temporary (78%) and permanent (22%) lentic water bodies, from small rock pools to large artificial reservoirs, ranging from sea level up to 1700 m a.s.l. Even some saline lakes located in the central part of the island, as well as abandoned saltworks were investigated.

A 200-µm mesh hand net was used to sample along shorelines and through vegetation. Open waters were sampled by means of an 80-µm towing net. Smallest environments were sampled by collecting the water with a flask and concentrating the samples on a 200-µm mesh sieve. The size of collected samples strictly depended on the dimensions of the water bodies. Attention was paid to collecting samples in all the microhabitats present.

Samples were fixed *in situ* with 4% buffered formaldehyde and sorted in laboratory under an Optika dissecting microscope. Calanoid copepods were identified according to DUSSART (1967, 1989), EINSLE (1993), KIEFER (1978), PETKVOSKI (1983), RANGA REDDY (1994) and STELLA (1984) and stored in the authors' collection. Individuals were assigned to three arbitrary classes according to their relative abundances and absolute dimensions.

In each site, conductivity, pH and water temperature were recorded using a Hanna Instruments HI-991300 multiprobe. An estimate of the abundance of macrophytes and of the water turbidity was assessed for each site by using three arbitrary qualitative classes. Terrestrial coordinates and altitude were recorded with a GPS Magellan 310. Attention was paid to the geological nature of the substrate and to the landscape context in which the water bodies occurred.

Canonical correspondence analysis (CCA) was undertaken using CANOCO 3.1 (TER BRAAK & VERDONSCHOT 1995). The method allows the contemporary use of quantitative and qualitative variables. The sig-

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Table 1. List of species and their chorological categories (from VIGNA TAGLIANTI et al. 1992, modified).

Species	Chorology
Family PSEUDODIAPTOMIDAE G. O. Sars, 1903	
Calanipeda aquaedulcis Kritschagin, 1873	Turanic-European-Mediterranean
Family DIAPTOMIDAE G. O. Sars, 1903	
Subfamily DIAPTOMINAE Kiefer, 1932	
Diaptomus (*Chaetodiaptomus*) *serbicus* Gjorgjewič, 1907	Eastern-Turanic-European
Diaptomus (*Chaetodiaptomus*) *cyaneus* Gurney, 1909	Mediterranean
Hemidiaptomus (*Hemidiaptomus*) *gurneyi* (Roy, 1927)	Mediterranean
Hemidiaptomus (*Occidodiaptomus*) *ingens* (Gurney, 1909)	West Mediterranean
Copidodiaptomus numidicus (Gurney, 1909)	West Mediterranean
Arctodiaptomus (Arctodiaptomus) stephanidesi (Pesta, 1935)	Eastern-Turanic-European
Arctodiaptomus (*Arctodiaptomus*) *kerkyrensis* (Pesta, 1935)	South-eastern European
Arctodiaptomus (*Rhabdodiaptomus*) *salinus* (Daday, 1885)	Palearctic
Mixodiaptomus kupelwieseri (Brehm, 1907)	South European

nificance with which environmental variables explain the variance of species data was tested using Monte Carlo methods, testing with 99 unrestricted permutations. Variables were considered to be significant when $p < 0.01$.

Results and discussion

Recorded species

Calanoid copepods were found in 65 (37 temporary and 28 permanent) of the 256 studied water bodies. Of the 10 species collected (Table 1), four (*Diaptomus serbicus, Arctodiaptomus kerkyrensis, Hemidiaptomus gurneyi, Hemidiaptomus ingens*) were never recorded before on the island. *D. serbicus* and *H. gurneyi* were previously known in Italy from Latium only (STELLA 1979). Moreover, *H. ingens* and *A. kerkyrensis* were recently recorded for the first time in Italy (LICCHELLI et al. 2003, MARRONE & NASELLI-FLORES 2004).

The most common calanoid occurring in the island (Fig. 1) is *Copidodiaptomus numidicus*, which was collected in about 24% of the 65 sites, where it is the only calanoid present. The occurrence of a single calanoid species per pond is the most common feature in Sicilian water bodies; two or more co-existing species were found in less than 20% of the sites. In particular, permanent water bodies never hosted more than one species.

Calanipeda aquaedulcis, Copidodiaptomus numidicus and *Arctodiaptomus salinus* are the Sicilian calanoid species that show a higher predilection for permanent, large and highly mineralised water bodies. They successfully colonised most of the dam reservoirs built up in the last decades.

When two or more species coexist synchronically in a pond, they show a remarkable difference in size; the most common assemblage is composed by *Hemidiaptomus gurneyi* (replaced in one pond by *H. ingens*), *Diaptomus cyaneus* and a third, smaller species (*Mixodiaptomus kupelwieseri* or *Arctodiaptomus stephanidesi*) in relation to altitude, conductivity and landscape context of the pond. Moreover, in one site it was observed the coexistence of two congeneric species (*D. cyaneus* and *D. serbicus*).

Diaptomus serbicus was collected in four small (8–20 m^2), temporary ponds always lying on a noncarbonatic substratum and located between 680 and 1300 m a.s.l. Sicilian populations represent the south-westernmost records of this species, which is common in the Balkan Peninsula, Armenia and Latium (PETKOVSKI 1983, STELLA 1984, DUSSART & DEFAYE 2002).

Diaptomus cyaneus was collected in 13 water bodies characterised by significant differences in water turbidity, altitude, presence of macrophytes, basin size and substratum nature. The Sicilian sites where it has been collected are always temporary and show conductivity values ranging between 65 and 430 $\mu S\ cm^{-1}$. It is quite

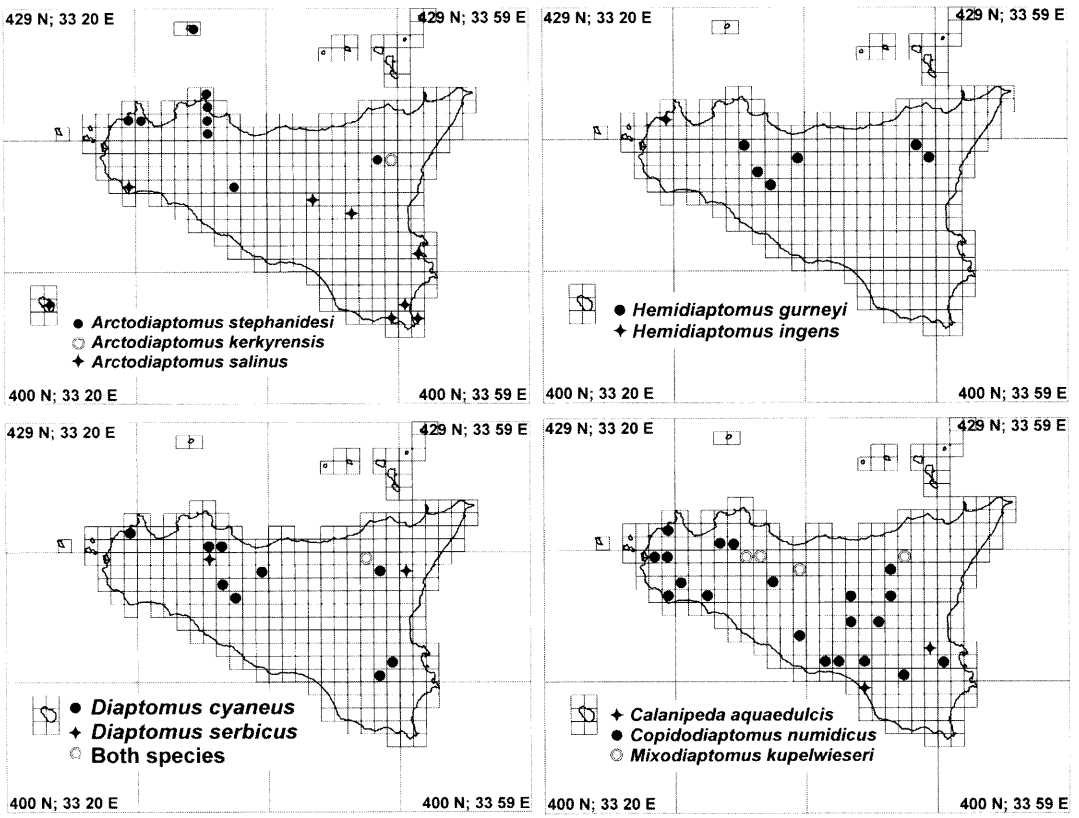

Fig. 1. Distribution maps of calanoid copepods in Sicily.

common along the circum-Mediterranean countries, where it populates both lowland temporary ponds and high altitude permanent ones (STELLA 1984).

Hemidiaptomus gurneyi was collected in eight temporary ponds lying on both siliceous and carbonatic substrates. These environments, distributed along the east-west axis of Sicily, are generally characterised by clear waters, large dimensions (ranging between 300 and 4000 m^2), altitude between 700 and 1300 m a.s.l., a dense macrophyte cover and rather low conductivity values (65–250 $\mu S\ cm^{-1}$).

H. ingens was collected in a single, rather large (about 400 m^2), temporary, macrophyte-rich water body located in the northwestern part of the island. Typical of North African temporary ponds, it has been recorded also in Camargue (DUSSART & DEFAYE 2002) and Corse (CHAMPEAU 1971). Sicilian specimens, along with those collected in Oued Tindja (Tunisia), are morphologically identical to the nomotypical subspecies while the specimens from Algeria, France and Corse lack the setae at the distal end of the endopodite of the male P5, being thus ascribable to the subspecies *H. ingens inermis* (MARRONE & NASELLI-FLORES 2004). These two subspecies are considered synonymous by KIEFER (1973) and DUSSART & DEFAYE (2002).

The small-bodied *Arctodiaptomus stephanidesi* is typical of small and shallow temporary ponds, but in Corfu Island it was also found in permanent water bodies (RANGA REDDY 1994). It is quite insensitive to chemical and physical characteristics of the environments even though it slightly prefers small lowland ponds with intermediate conductivity values. It is an Eastern

Turanic-European taxon, which reaches in Sicily its south-westernmost areal limit.

A. kerkyrensis has been collected in two small (8 m^2 and 40 m^2) and turbid temporary water bodies, located at the edge of a vineyard, on a lavic substratum at the foot of Etna Volcano, 850 m a.s.l. These pools show conductivity values of 490 and 450 µS cm^{-1} respectively. *A. kerkyrensis* was up to now known from Corfu Island, Macedonia, Bulgaria and former Yugoslavia (DUSSART & DEFAYE 2002), where it is typical of lowland astatic swamps and fish ponds (RANGA REDDY 1994). As for the previous species, Sicily represents its south-westernmost areal limit.

Mixodiaptomus kupelwieseri was sampled both in temporary and semi-permanent ponds characterized by rather low conductivity values (50–390 µS cm^{-1}), limpid water, siliceous substratum and at altitude ranging between 600 and 1300 m a.s.l. All the sites lie inside wooded areas, with the exception of two ponds, lying respectively in a cornfield and in a pasture land, both of them near to a wooded area and deforested only in the last decades. *M. kupelwieseri* is typical of central and southern Europe, while in southeastern Europe it coexists with the strictly related *M. lilljeborgi*, which replaces it in Northern Africa (DUSSART 1989, DUSSART & DEFAYE 2002).

Relationships with environmental variables

The eigenvalues for the CCA axes explained almost the 90% of the variance in the species-environment relationship (Table 2). Two distinct tendencies can be observed in Figure 2. One runs horizontally and separates temporary (group C) and permanent (group A and B) water bodies. The first group lies on the left part of the plane and shows a higher species richness (n = 7). The second is located in the right part and collects three species. Temporal dimension is negatively correlated with axis 1 (r = –0.90), whereas permanency is positively related (r = 0.91). These two variables are strictly linked to altitude, area and macrophyte covering. In Sicily, temporary ponds are generally located higher above sea level, have a smaller area and show a richer macrophyte covering compared to permanent environments. The second tendency is vertical and linked to conductivity values and separates environments with conductivity values < 4 mS cm^{-1} (group B) from those with values ranging between 4 mS and 42 mS cm^{-1} (group A). Thus, the permanent water bodies lying on the right part of the plane are ranked according to increasing conductivity values and the species associated reflect this tendency showing *Copidodiaptomus numidicus*, *Calanipeda aquaedulcis* and *Arctodiaptomus salinus* distributed along this gradient.

The group of animals linked to temporary waters seems to be more characteristic of a semi-arid region like Sicily, as confirmed by the higher species richness and diversity of calanoid assemblages. Moreover, a similar tendency has been observed for branchiopods also (MARRONE unpub. data).

Some biogeographical considerations on Sicilian calanoid fauna

Sicily, located in the middle of the Mediterranean basin, hosts taxa belonging to different chorological zones and represents a natural "transition zone" for freshwater taxa (Fig. 3), as documented by NASELLI-FLORES et al. (1998). In particular we highlighted seven chorological groups, with an equilibrated repartition of the taxa among the chorological categories (Table

Table 2. Summary statistics for the first four axes of CCA.

CCA Axes	1	2	3	4
Eigenvalues	0.93	0.59	0.35	0.31
Species-environment correlations	0.97	0.78	0.62	0.59
Cumulative percentage variance				
– of species data	14.4	23.6	29.0	33.0
– of species-environment relation	39.1	63.8	78.5	89.5

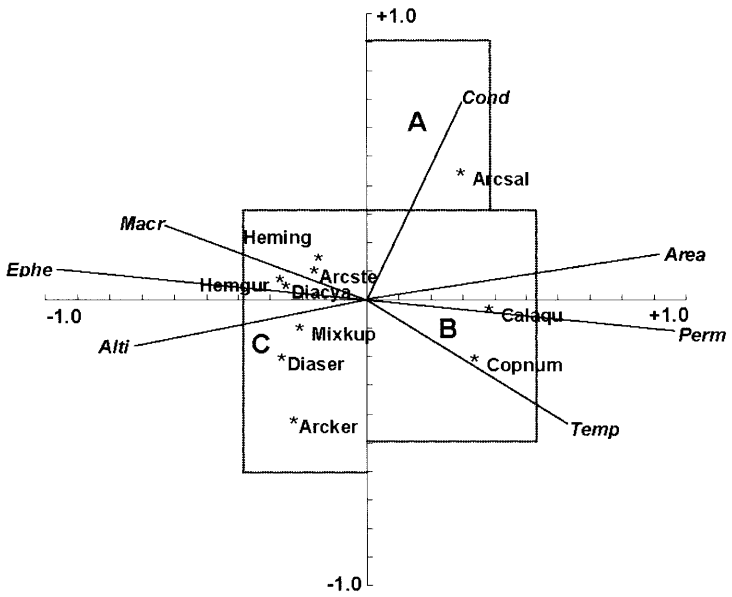

Fig. 2. Ordination triplot of CCA performed on the species-environment relationships in the studied water bodies (grouped as A, B and C). Cond: conductivity; Macr: macrophyte abundance; Ephe: temporaneity; Alt: altitude a.s.l.; Temp: temperature of the water; Perm: permanency; Arcsal: *Arctodiaptomus salinus*; Calaqu: *Calanipeda aquaedulcis*; Copnum: *Copidodiaptomus numidicus*; Arcker: *Arctodiaptomus kerkyrensis*; Diaser: *Diaptomus serbicus*; Mixkup: *Mixodiaptomus kupelwieseri*; Diacya: *Diaptomus cyaneus*; Arcste: *Arctodiaptomus stephanidesi*; Hemgur: *Hemidiaptomus gurneyi*; Heming: *Hemidiaptomus ingens*.

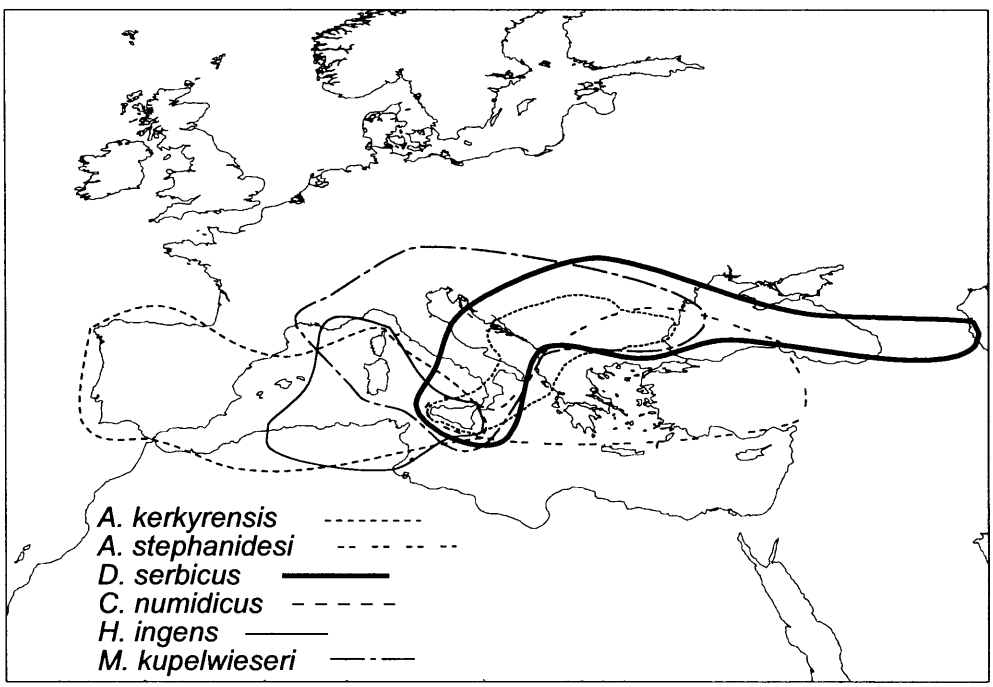

Fig. 3. Updated distribution of some selected species of calanoid copepods in the Mediterranean basin.

1). Three main groups have been singled out: one is composed by the Eastern European elements *D. serbicus, A. stephanidesi* and *A. kerkyrensis*; the second includes Western Mediterranean entities as *H. ingens* and *C. numidicus*; the third one includes Circum-Mediterranean, Palearctic and South European taxa for which Sicily does not represent any geographical limit.

Sicily lacks taxa typical of permanent and poorly mineralised water bodies. Its semi-arid Mediterranean climate limits the development of a perennial surface hydrographic network: most permanent water bodies occurring in Sicily today are artificial, the only exceptions being the coastal brackish ponds and lagoons and some endorheic saline lakes. The construction of several reservoirs and small agriculture ponds favoured the spreading of those euriecious taxa, which naturally occurred in the high mineralised and permanent coastal water bodies. Conversely, those species typical of perennial water bodies in more temperate climates are absent on the island. Noteworthy is the absence of the genus *Eudiaptomus*, which is common in peninsular Italy, Europe and Asia but rare along a latitudinal gradient. Accordingly, also the genus *Metadiaptomus*, common in sub-Saharian Africa as well as in Maghreb (DUSSART 1984), has been never recorded on the island. All Sicilian species are present in Europe and nearly a half of them (*M. kupelwieseri, A. stephanidesi, A. kerkyrensis* and *D. serbicus*) are absent from North Africa.

In this way, Sicilian calanoids show the greatest affinity with the European and temperate fauna. Nevertheless, Sicilian fauna is impoverished by the absence of many northern elements, and this lack is not balanced by the ingression of typical African ones.

Note: When the present paper was already in press, the Paradiaptominae (Calanoida, Diaptomidae) species *Metadiaptomus chevreuxi* (GUERNE & RICHARD 1894) was collected in a temporary pool in Favignana Island (Egadi Archipelago, Western Sicily). This finding, described in MARRONE & NASELLI-FLORES 2005, constitutes the first record of a representative of the Paradiaptominae subfamily in Italy.

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