Bright, M., P.C. Dworschak & M. Stachowitsch (Eds.) 2002: The Vienna School of Marine Biology: A Tribute to Jörg Ott. Facultas Universitätsverlag, Wien: 63-71

The burrows of *Callianassa candida* (Olivi 1792) and *C. whitei* Sakai 1999 (Crustacea: Decapoda: Thalassinidea)

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Keywords: Burrows, Callianassidae, *Callianassa candida, Callianassa whitei*, Adriatic Sea

Abstract. Resin casts of the burrows of the thalassinidean decapods *Callianassa candida* and *C. whitei* were made in situ in the Lagoon of Grado, Italy, and the Bay of Kuvi, Croatia, respectively. Burrows of *C. candida* on tidal flats are irregularly branched; those of *C. whitei* from sand under stones consist of series of U-shaped sections. The functional morphology of the burrows is discussed.

Introduction

Callianassid shrimps are one of the most common infauna elements in marine intertidal and subtidal sediments. Their bioturbating activities generate both considerable disturbances to ambient sediments and subsequent effects on benthic community structure (Posey, 1986; Tamaki, 1988, 1994; Ziebis *et al.*, 1996a,b; Rowden *et al.*, 1998).

Nine species of the family Callianassidae are known to occur in the Mediterranean (d'Udekem d'Acoz, 1999; Sakai, 1999). Four species can be found in higher numbers: *Callianassa subterranea* (Montagu 1808) in deeper muddy bottoms (d'Udekem d'Acoz, 1999), *C. truncata* Giard & Bonnier 1890 in shallow sublitoral sediments (Ziebis *et al.*, 1996a,b; Abed-Navandi & Dworschak, 1997) and *C. tyrrhena* (Petagna 1792) and *C. candida* (Olivi 1792) in tidal flats (Dworschak, 1992, 1998, 2000).

Callianassa candida (Olivi 1792) is also known as *C. pontica* Czerniavsky, 1884 or *C. pestae* (*pestai*) de Man 1928. So far, it has been reported from the Mediterranean and the Black Sea. This species can often be found together with *C. tyrrhena* (Petagna, 1792) and *Upogebia pusilla* (Petagna 1792) in the same habitat, but occurs higher in relation to tidal level and in more muddy sediments. In addition, this species has also been found in sandy silt or mud in 6 to 9 m depth (Thessalou-Legakis & Zenetos 1985; Dworschak, 1987, 1992; d'Udekem d'Acoz, 1999).

Callianassa whitei Sakai 1999 was recently recognized as a separate species. It has been confused earlier with *C. candida* (e.g. Dworschak, 1992) and occurs in the Mediterranean in coarse sand or mud under stones from the intertidal to the shallow subtidal.

Material and Methods

Specimens of *C. candida* were were recovered with the aid of a yabby pump (Manning, 1975), those of *C. whitei* by digging. Casts of burrows were made using an epoxy resin (CIBA-GEIGY Araldite GY 257, with hardener HY 830 and HY 850, 25:7:8 parts by weight)(for further details see Dworschak, 1983).

The investigations were carried out at the following locations in the northern Adriatic Sea:

1) A tidal flat in the eastern part of the Lagoon of Grado, Italy (Fig. 1a); for further details see Dworschak (1987b). Here, hole counts and resin casts were made in July, October and December 1978 (see also Dworschak, 1983, 1987).

2) A tidal flat at Lido di Staranzano, S of Monfalcone, Italy. Here, hole counts were made in May 1983; for further details see Dworschak (1987).

3) The Bay of San Pol is situated 10 km S of Rovinj, Croatia (Fig. 1c). In its middle is a pebbled beach; the southern part formed by a boulder field and rocks. Three layers of boulders and cobbles (total thickness: 20 - 30 cm) lie on gravelly sand with a median diameter of 1784 µm, 50 % sand, 2.8 % silt and clay. The sediment's organic content ranged from 0.84% to 1.11% (loss on ignition). Here, hole counts were made in October 1982.

4) The Bay of Kuvi, 2 km S of Rovinj (Croatia) is bordered by rocks. Fine muddy sediments under and between boulders form the intertidal. Here, two resin casts of *C. whitei* burrows were made in July 1983.

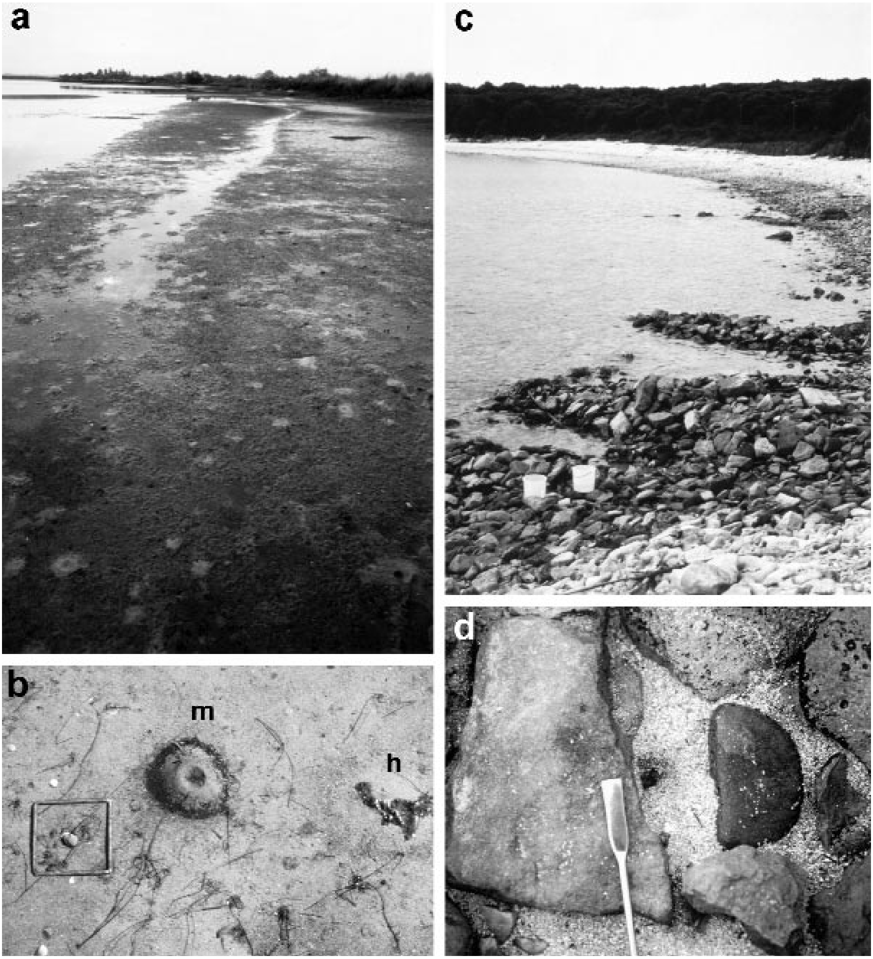

Fig. 1. *Callianassa candida*; a: habitat, tidal flat during low tide at the Lagoon of Grado; b: burrow openings mound (m) and concealed hole (h), Lido di Staranzano, frame is 10 × 10 cm. *Callianassa whitei*: c: habitat, boulder field during low tide at San Pol; d: burrow opening in sand under stones (area is 16.6 × 14.4 cm).

Results

Callianassa candida

On the sediment surface, burrows of *C. candida* are characterised by mounds (2-3 cm high, 7-15 cm diameter at their base) which are closed during low tide. The sediment of the mounds differs in colour from that of the surface; the mounds are often surrounded by fecal pellets (Fig. 1b). The second opening in 15 to 20 cm distance from the mound is simple and often blocked.

At Grado, burrow openings usually occurred in the upper intertidal in densities between 0.55 and 2.25 mounds·(10 $m^2)^{-1}$. At Lido di Staranzano, mounds could be found only in the upper zone in a density of 0.7 mounds (10 $m^2)^{-1}$ (see Dworschak, 1987).

Burrows are irregularly branched and apparently have at least two openings. Several enlarged chambers with irregular elliptical cross-sections are linked by other segments with more regular circular cross-sections. Measurements of the segments, chambers, their numbers and the dimensions of the burrows are summarised in Table 1.

Cast #770912 (Fig. 2a) has two openings. Below the mound the burrow turns to the horizontal in a depth of 5 cm. Here the burrow branches, one branch into a long (ca. 80 cm) irregular tunnel with several chambers and blind side tunnels. The second leads down to a chamber, from which another tunnel (17 cm long)

Table 1. Measurements and characteristics of resin casts of *C. candida* and *C. whitei* burrows.

	C. candida		*C. whitei*	
cast #	770912	770914	8307/1	8307/2
mean segment diameter [mm]	17.0	17.8	15.4	13.5
mean segment length between turning chambers [mm]	56.1	74.0	41.9	64.2
number of turning chambers	16	14	9	7
mean turning chamber width [mm]	31.1	35.5	42.8	27.1
mean turning chamber height [mm]	23.4	28.2	25.3	20.7
mean number of branches from chambers	2.4	2.9	1.7	2.6
mean number of blind branches	0.4	1	0.3	0.4
burrow length [cm]	205	248	102	112
horizontal extension [cm]	125	55	30	30
burrow depth [cm]	25	65	>28	>20
burrow volume [cm^3]	473	696	350	155
burrow surface area [cm^2]	1051	1392	605	356

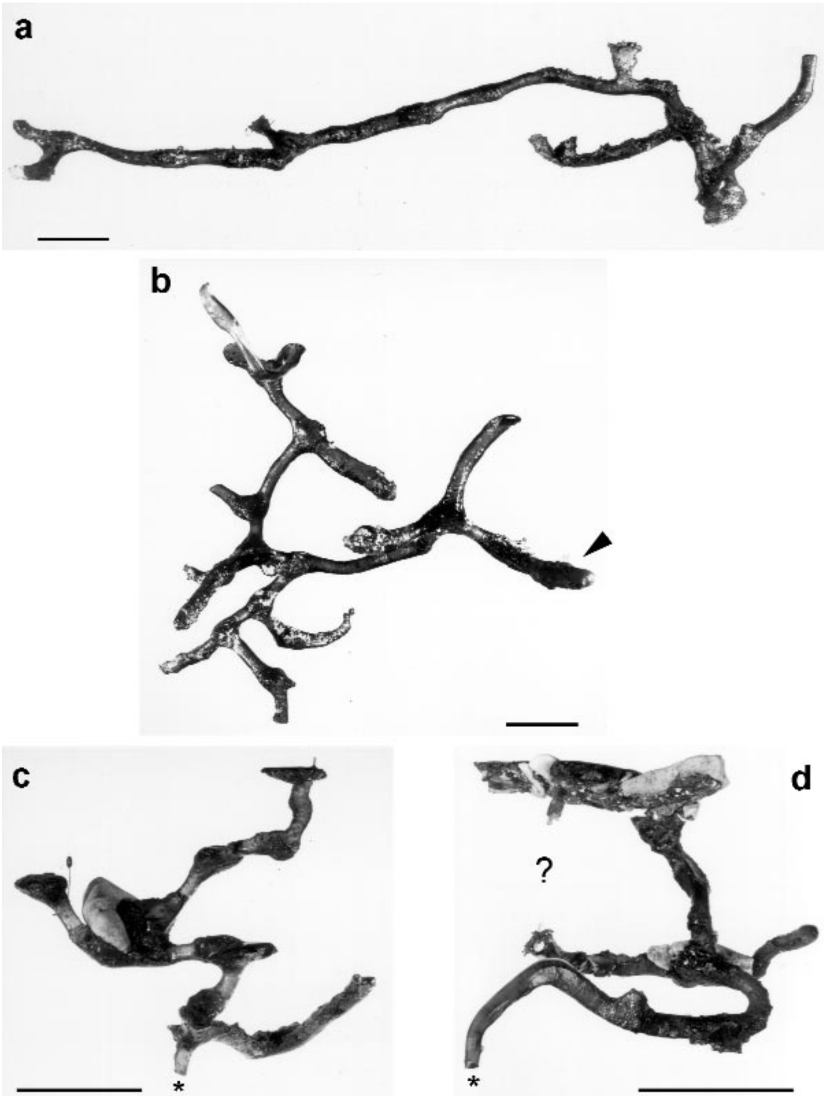

Fig. 2. Burrows of *Callianassa candida*, Lagoon of Grado, Italy; a: resin cast #770912; b: resin cast #770914, arrow shows position where animal was entombed. Burrows of *C. whitei*, Bay of Kuvi, Croatia; c: resin cast #8307/1; d: resin cast #8307/2. All in side view, scale is 10 cm. * indicates position where cast was broken off.

branches off at a depth of 11 cm. Another short shaft leads to another chamber, from which one branch leads to the second opening and another branch reaches the depth of 25 cm and then turns upwards before it ends blindly.

Cast #770914 (Fig. 2b) was incompletely filled in its upper part. In a depth of ca. 15 cm, gently sloping tunnels with chambers and blind tunnels lead in form of a spiral down to a depth of ca 35 cm. Here, one branch (to the right in Fig. 2b) leads further down to a total depth of 65 cm; the other branch forms a tunnel which connects to further chambers and connecting segments and blind tunnels. One specimen of the shrimp was entombed here (see arrow in Fig. 2b); it has a total length of ca 60 mm.

The burrow wall, as judged by resin casts, is smooth, especially in sections with regular diameter; chambers are rougher. The wall appears oxidized as observed by digging because it has the same colour as the sediment surface compared to black or grey reduced sediment.

Callianassa whitei

Burrow openings of *C. whitei* in sand under stones are simple holes with a diameter between 0.8 and 1.5 cm (Fig. 1d); they reach a density of up to 12 holes$\cdot m^{-2}$.

Burrows of *C. whitei* also seem to have at least two openings. The two casts made in Kuvi Bay are incomplete; especially the deeper parts could not be retreived as they led under larger boulders embedded in the sediment. The burrows also show enlarged chambers with irregular cross-sections and segments with more regular circular cross-sections. Due to embedded stones, some chambers have triangular to rectangular cross-sections and some tunnels are flattened.

In cast #8307/1, a short tunnel leads from the opening to a depth of 8 cm, where the burrow turns towards the horizontal. With two chambers and two gently inclined segments it leads to a very irregular chamber in 17 cm depth (embedded stone in Fig. 2c). One short side branch leads to another wide chamber in this depth. From this chamber, a short shaft leads to the next level in 23 cm depth, where a longer irregular T-shaped tunnel branches off. From this level, another shaft (* in Fig. 2c) led to greater depth but could not be retrieved.

In cast #8307/2, a trifurcation is visible just below the sediment surface near the opening. A winding shaft leads down to a depth of 11 cm. Here, an irregular tunnel with two blindly ending tunnels branches off. At one end, a shaft (? in Fig. 2d) - temporarily blocked or incompletely filled - led to the second opening, 9 cm apart from the first. The other branch turns down and continues as a tunnel in 15 cm depth, then leading down as a shaft (* in Fig. 2d) to greater depth; this part could not be retreived further.

In the habitat of *C. whitei*, fine material (red clay of terrigenous origin - terra rossa) is concentrated around burrows of the shrimp; it has an organic content of 3.3 to 3.5% which is higher than that of the ambient sediment (see above).

Discussion

The burrow opening of *C. candida* can easily be recognised and can be distinguished easily from that of the syntopic *Upogebia pusilla* (see Dworschak, 1983). Although both thalassinids overlap in distribution, *C. candida* was found almost exclusively in a narrow band near the midwater line. The openings are also different from those of *Callianassa tyrrhena* (see Dworschak, 2001), occurring also at Lido di Staranzano and overlapping with *Upogebia pusilla* near the low water line. The burrows of *C. candida* also differ considerably from those of *C. tyrrhena*. The latter show a much more regular pattern, consisting of a shallow U and a spiral shaft with several chambers which are often filled with seagrass debris (Dworschak, 2001). Burrow casts of *C. candida* made in the Lagoon of Venice are very similar to those presented here (A. Rowden, pers. comm. 1996).

The habitat of *C. whitei* differs from that of most other callianassid species. Only a few species are known to occur in intertidal boulder fields: *Neotrypaea biffari* (as *Callianassa affinis*) in California (MacGinitie & MacGinitie, 1968) and *Nihonotrypaea petalura* (Tamaki *et al.*, 1999). These species occur in much lower densities than their congeners in sandy or muddy tidal flats (Tamaki *et al.*, 1999).

As information on feeding habits in burrowing shrimp is scarce, the mode of feeding is often derived from burrow shape. One such classification was presented by Griffis & Suchanek (1991), who recognised 5 types of shrimp burrows. According to this scheme, burrows of *C. candida* – with mounds on the sediment surface and no seagrass inside – would fall into type 2, thus indicating deposit feeding. Burrows of *C. whitei* show no mounds, have no seagrass inside and are mainly a simple "Y"; they would fall into type 5 and indicate suspension feeding. Using the alternative approach of Nickell & Atkinson (1995), a surface mound would indicate deposit feeding in *C. candida* and the U or Y shape suspension feeding, while *C. whitei* would be classified as a suspension feeder only. Recent observations in aquaria have shown that feeding mode is not always clear-cut, the animals having a great plasticity in their feeding mode (Nickell & Atkinson, 1991; Coelho *et al.*, 2000).

Acknowledgements

Financial support was given by project P5059 of the Fonds zur Förderung der wissenschaftliche Forschung in Österreich.

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