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Observations on the burrows and burrowing behaviour of *Brachynotus gemmellari* and on the burrows of several other species occurring on *Squilla* grounds off Ancona, Central Adriatic*

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SUMMARY: The paper presents information on the burrows of a number of species that occur on *Squilla* grounds in the coastal Adriatic off Ancona, Italy. The burrows and burrowing behaviour of *Brachynotus gemmellari* are described for the first time. For *Upogebia tipica, Solecurtus strigilatus* and *Gobius niger,* the observations add to sparse burrow information in the literature. Little is known of the burrows of Echiura in the Mediterranean: those of two species are briefly described from surface features.

Key words: Burrows, Adriatic, *Brachynotus gemmellari, Upogebia tipica, Solecurtus strigilatus, Gobius niger, Maxmuelleria gigas, Thalassema thalassemum.*

RESUMEN: OBSERVACIONES SOBRE LAS MADRIGUERAS Y COMPORTAMIENTO ENTERRADOR DE *BRACHYNOTUS GEMMELLARI* Y OTRAS ESPECIES DE LOS FONDOS DE *SQUILLA* EN ANCONA ADRIÁTICO CENTRAL. – Este trabajo presenta información sobre las madrigueras de diversas especies presentes en los fondos de *Squilla* en las costas de Ancona, Italia, en el Adriático central. Se describen por vez primera las madrigueras y el comportamiento excavador de *Brachynotus gemmellari*. En el caso de *Upogebia tipica, Solecurtus strigilatus* y *Gobius niger,* las presentes observaciones se añaden a información dispersa sobre las madrigueras de *Echiura* en el Mediterráneo: se describen brevemente las de dos especies a partir de características de la superfície.

Palabras clave: Madrigueras, *Brachynotus gemmellari, Upogebia tipica, Solecurtus strigilatus, Gobius niger, Maxmuelleria gigas, Thalassema thalassemum.*

INTRODUCTION

The observations reported in this paper are by-products of work on the stomatopod *Squilla mantis* (L.) which is reported elsewhere (Atkinson *et al.*, in press). In coastal Adriatic waters off Ancona, Italy, our observations using SCUBA diving and underwater television showed the sea bed of *Squilla* grounds to be highly burrowed. The burrows of large *S. mantis* were large and distinctive with two circular openings, one larger than the other, sometimes more than a metre apart (Pervesler and Dworschak, 1985; Atkinson *et al.*, in press). The burrows of small *S. mantis* had the same basic pattern (Manfrin and Piccinetti, 1970; Atkinson *et al.*, in press), but were less conspicuous. Numerous small burrows, formed by a variety of species, occurred on the grounds and the present paper reports on some of these.

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Our work is the first report on the burrowing behaviour and burrows of the small grapsid crab *Brachynotus gemmellari* (Rizza) for which ecological information is sparse (Froglia and Manning, 1978). For the thalassinidean shrimp *Upogebia tipica* (Nardo), to our knowledge, only Dworschak (1987a) has commented on burrow structure. We add to the literature on the burrows of the tellinacean bivalve *Solecurtus strigilatus* (L.) (Bromley and Asgaard, 1986; Dworschak, 1987b), and present information on opportunistic burrow dwelling by the black goby, *Gobius niger* L., adding to observations of this in Scottish waters (Atkinson and Taylor, 1991; Nickell *et al*., 1995b; Marrs *et al*., 1996). We also briefly report on burrows attributed to the echiurans *Maxmuelleria gigas* (M. Müller) and *Thalassema thalassemum* (Pallas) and on the occurrence of several other burrowers recognized by the appearance of their burrows at the sediment surface.

MATERIAL AND METHODS

Fieldwork was conducted using SCUBA equipment at two sites close to Ancona during July 1994. One site was off Falconara, 2 miles from the shore (43º 39.2´N, 13º 26.4´E), at a depth of 13 metres. The other site was opposite the mouth of the River Esino, 2.7 miles from the shore (43º 41.14´N, 13º 23.61´E), at a depth of 15 m. The substratum at the former site was well-compacted silty sand. The substratum at the latter site was muddier (sandy mud) due to the fluvial influence of the Esino River. Sediment analysis at these sites, determined following Folk (1974), is reported in full in Atkinson *et al*. (in press). The CNR research vessel ´Salvatore Lo Bianco´ was anchored on station and provided all necessary support facilities. A small boat (4m GRP dory) was deployed from the research vessel to support the diving operations. Dive sites were marked with surface buoys and swim lines were set out from their anchorage point to guide the divers on the bottom.

Burrows were cast using polyester resin, following the method of Atkinson and Chapman (1984). The resin (POL11, Industria Chimica Adriatica) was mixed with liquid peroxide catalyst (U100) (0.4% by volume - larger amounts resulted in the resin setting too soon after mixing) and poured into burrows by the divers using plastic watering cans. Casts were recovered a day later. They were subsequently photographed and measured.

Brachynotus gemmellari were collected by hand and brought to the laboratory. One specimen was placed in a glass tank containing sediment from the collection site. Burrowing activity was observed and photographed.

Underwater television (UWTV) (Simrad Osprey) was deployed on *Squilla mantis* grounds off Ancona during other studies: on 14th April 1994 from 43º 49.46´N, 13º 21.68´E to 43º 49.21´N, 13º 21.15´E, depth 29 m, on 9th May 1995, at depths from 18 m to 29 m (several transects between 43º 45.2´N, 13º 22.9´E and 43º 48.9´N, 13º 23.2´E) and again on 26th April 1996, at depths from 17-29 m (several transects between 43º 50.10´N, 13º 19.50´E and 43º 46.83´N, 13º 18.32´E). These grounds were clayey silts and silty clays, becoming muddier with increasing depth (Annovi and Fontana, 1978). Some previously unreported information on the burrows observed is included in the present paper.

Burrow terminology follows Frey (1973) and Atkinson and Taylor (1988).

RESULTS

Brachynotus gemmellari (Rizza)

This species was abundant at both dive sites and characteristically occurred in simple burrows. Typically, these were shallow excavations with a single opening and a short horizontal tunnel. Some burrows were U-shaped with two openings. A typical example is illustrated in Fig.1a where a crab can be seen in its burrow against the glass wall of a laboratory aquarium. Fig.1b illustrates another such burrow (centre left), this time photographed in the field. The crab is visible at the burrow opening, partly obscured by a sea urchin test. Polyester resin casts of three such burrows, taken in the field, are shown in Fig 1c. In each case the occupant was entrapped in the resin, confirming the identity of the burrow. For the burrows illustrated in Fig.1c, from left to right, burrow depths were 40, 74 and 70mm, respectively; crater (opening at surface) diameters (minimum and maximum) were ca 60 x 60 mm, 75 x 75 mm and 50 x 75 mm, respectively; tunnel diameters near the end of the burrows were (width x height) 16 x 9 mm, 19 x 10 mm and 22 x 14 mm, respectively; lengths along the outer curve of the burrows were ca 110 mm, 90 mm and 150 mm, respectively; burrow volumes were 44 ml, 78 ml and 72 ml, respectively, and the capapace

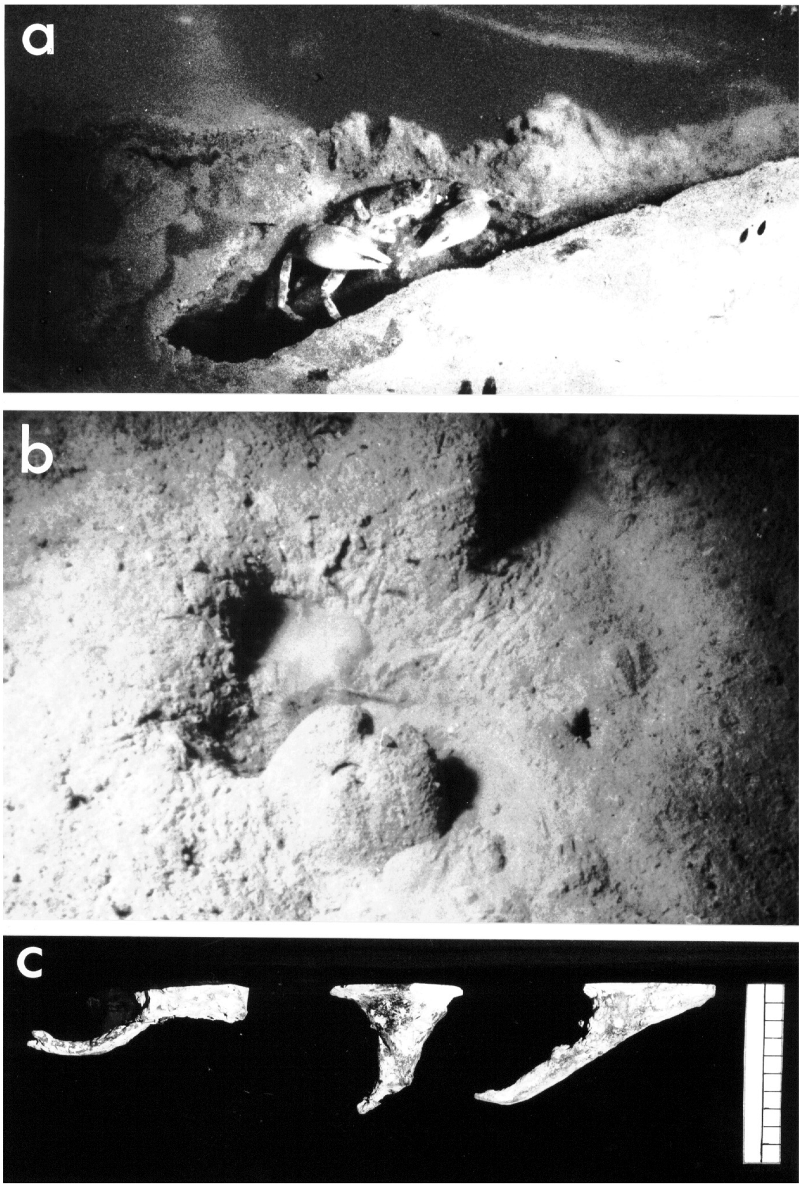

FIG. 1. – a) *Brachynotus gemmellari* within its burrow (tunnel diameter ca 15 mm) against the glass wall of a laboratory aquarium; b) another such burrow (centre left), this time photographed in the field. The crab is partly visible at the burrow opening, behind a sea urchin test (diameter ca 50 mm); c) polyester resin casts of three individual burrows of *B. gemmellari,* taken in the field, scale bar 10 cm.

widths of the occupant crabs were 17 mm, 7 mm and 14 mm, respectively. A fourth burrow cast, almost identical in structure to the cast on the right of Fig.1c, is not illustrated. The dimensions of this burrow were: depth 82 mm, crater diameter 87 x 100 mm, tunnel diameter 23 x 14 mm, length along outer curve of tunnel ca 170 mm and volume 167 ml. The occupant crab was seen leaving the burrow prior to casting and was not captured.

Evidence from the burrow casts and field and aquarium observations suggested that depth of sediment penetration was usually less than 10 cm.

The crab burrowed readily in the laboratory. Boli of mud were excavated with the chelipeds and the second and third pereiopods. Sediment was carried from the excavation between the folded chelipeds and supported beneath by the second and third pereiopods of the trailing (in-burrow) side of the crab. Sediment dropped at the burrow mouth was swept away by the chelipeds, mainly by the propodus of the leading cheliped. Periodically, the crab turned round at the surface, and re-entered the burrow with the previously trailing side leading. In the laboratory aquarium, which was held under conditions of subdued natural lighting, most burrowing activity occurred at night.

When not engaged in burrowing activity, the crab was either inactive or engaged in feeding activity. Two types of feeding activity were observed, deposit feeding and scavenging. The former consisted of lifting sediment to the mouthparts with the chelae as in Fig.1a. Such behaviour occurred both within and outside of the burrow. Scavenging consisted of feeding on small pieces of fish which were introduced into the aquarium. These were either consumed at the sediment surface or were carried into the burrow and consumed there. Predatory behaviour was not investigated.

Brachynotus gemmellari appeared to be restricted to inshore *Squilla* grounds. It was abundant at the dive sites (depths 13 and 15 m) and, using UWTV, appeared to be present at ca 18 m (based on appearance of burrows and brief sight of a crab which was probably this species).

Upogebia tipica (Nardo)

Burrows attributable to this species occurred at both dive sites, but visual impressions were that they were more numerous at the muddier site. Similar burrows were also discernible using UWTV on *Squilla* grounds off Ancona throughout the depth range examined (18-29 m). They were recognizable as small burrow openings occuring in pairs or sometimes three, four or more openings in a loose cluster, with each cluster presumed to belong to an individual burrow.

The burrow cast illustrated in Fig. 2 comprised two connected burrows, each containing an embedded specimen of *U. tipica*. Each component burrow was basically U-shaped: one U-shaped component had shaft diameters of 14 and 15 mm, respectively, narrowing at the surface to 10 mm and 6 mm, respectively, while the other had shaft diameters each of 11 mm, narrowing at the surface to 6 mm, indicating occupants of differing size. The smaller specimen was female: the sex of the larger specimen could not be determined. The U-shaped burrow section occupied by the larger animal extended to a depth of 126 mm, with surface openings 21 mm apart; that of the smaller animal extended to a depth of 107 mm, with surface openings 58 mm apart. A branch tunnel extended downwards from the base of each U-shaped section, to a maximum depth of 165 mm. The two U-shaped burrows were joined by a horizontal branch tunnel between their bases. Distinctive dilations (10 in total) were present at the base of the shafts and below these where the burrows branched or changed direction, so that these dilations occurred at two horizons in the burrow complex (Fig. 2). The volume of this compound burrow was 143 ml.

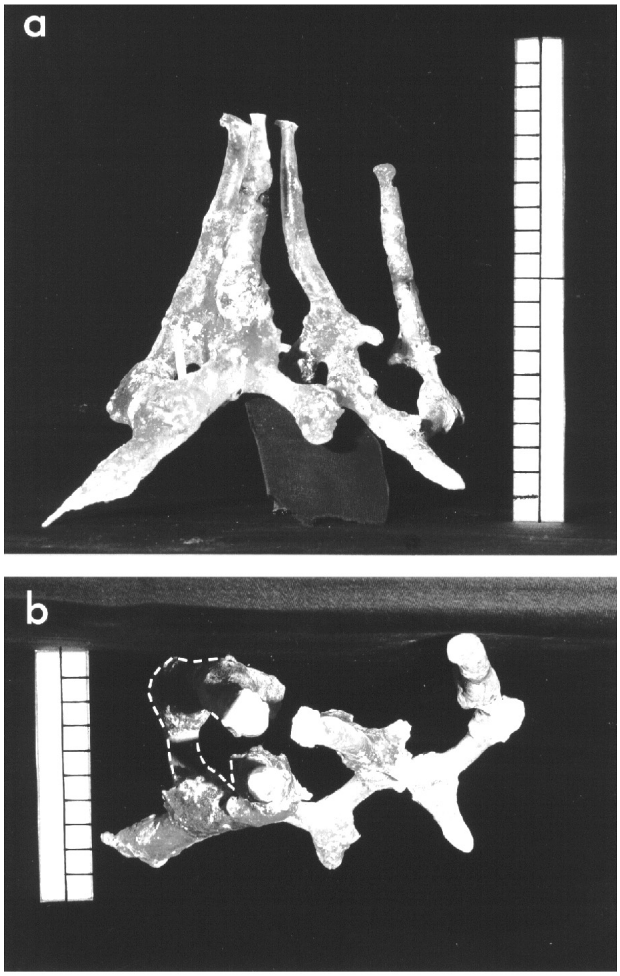

FIG. 2. – Polyester resin cast of two connected burrows, each containing an embedded specimen of *Upogebia tipica;* a) side view, scale bar 20 cm, b) plan view, scale bar 10 cm. White dashes outline the parts of the burrow that are obscured by shadow.

Solecurtus strigilatus (L.)

The paired holes formed by the siphons of *Solecurtus* spp. appeared to be abundant on the *Squilla* grounds off Ancona that were investigated by diving and underwater TV, occurring throughout the depth range examined (13-29 m). The siphons were often visible at the surface. The species responsible for the two burrows cast with resin was *Solecurtus strigilatus*. *S. multistriatus* (Scacchi) is also known from the area and has similar burrows and surface features (Dworschak, 1987b).

The larger of the two burrows cast is illustrated in Fig. 3a,b. It penetrated the sediment to a maximum depth of 28 cm and was 75 cm long (along curve of burrow). One siphonal opening was 7 mm in diameter, the other 9 mm in diameter: siphonal shaft lengths were around 85 mm and cross sections were circular. The burrow section immediately below the siphonal shafts was laterally flattened (35x23 mm, greater dimension in same plane as siphons as illustrated in Fig. 3a). Below this (depth 136 mm), the burrow narrowed and the plane of greatest width rotated through 90º. Thus, in the principally horizontal part of the burrow the cross section showed tunnel width to be greater than tunnel height (width 27-32 mm, height 20-22 mm). Burrow volume was 317 ml. The second burrow which was cast had a maximum depth of around 17 cm and a length along the curve of the burrow of 38 cm. Only one siphon shaft (length 30 mm) was fully cast: this had a diameter of 9 mm. The cross sectional dimensions of the lower section of the burrow were width 31 mm, height 22 mm. Burrow volume was 150 ml.

Gobius niger L.

Gobius niger was abundant at the dive sites and was frequently observed by UWTV on *Squilla* grounds throughout the depth range examined (17-29 m). At the dive sites, several fish were observed in burrow openings and others were seen to enter burrows when disturbed. One such burrow was cast with polyester resin and is illustrated in Fig. 3c. The burrow is amphora-shaped: the opening is elliptical in cross section (67 x 58 mm), the narrow neck is almost circular in cross section (26 x 28 mm) and the dilated terminal chamber is elliptical in cross section (54 x 44 mm), but the maximum dimension is rotated 90º from that at the opening. Maximum depth is 123 mm and burrow volume 138 ml. Shell fragments adhere to the cast margin at the plane of the sediment surface, probably representing burrow ejecta.

UWTV observations revealed that *G. niger* was present throughout the depth range investigated (17-29m) and was abundant at the shallow end of this depth range. Many of the fish observed were associated with burrows and, on a number of occasions, male and female fish entered the same burrow when disturbed by the camera sledge. From their size and general appearance, some of these burrows appeared to be those of *Squilla mantis*.

Echiura

Another distinctive burrow was seen in increasing numbers as the ground became muddier with increasing depth. It was most frequently recognized as a funnel-shaped opening (narrowing to 1-2 cm diameter) within a large sediment mound (up to ca 30 cm across and ca 15 cm high). The burrow descended steeply from the opening. Sometimes spills of grey-coloured sediment ejecta were present around the hole in the mound. Occasionally there were marks (shallow grooves up to ca 30 cm long) radiating from the opening, like spokes from a hub. Most radiating traces were seen around holes which were not associated with mounds. On several occasions, during the night, the causative agent was seen - the elongate (ca 30 cm), spatulate green proboscis of an echiuran worm. The echiuran was not caught, but the species responsible is almost certainly *Maxmuelleria gigas* (see Discussion).

The proboscis of a second echiuran species was commonly seen during night time observations. This was orange-brown in colour, narrow and up to ca 20 cm in length. Each proboscis extended from a small hole (ca 5 mm diameter) in flat sediment. Small sediment mounds (ca 10 cm high and 15 cm in basal diameter) were occasionally seen nearby, and may have been associated with the echiuran, but this remains speculative. Size and colour suggest that the species is *Thalassema thalassemum* (see Discussion).

Other species

Using the UWTV, the burrows of a number of other species were recognized from their distinctive configurations (see discussion) and, in some cases, the presence of the occupant at the mud surface. These included the burrows of the thalassinidean *Callianassa subterranea* (Montagu), the crab *Goneplax rhomboides* (L.), the stomatopod *Squilla mantis* (L.) and the gobiid fish *Lesueurigobius friesii* (Malm), all of which were occasionally seen on the sediment surface beside their burrows.

A common burrow type consisted of two rings of holes spaced ca 20-30 cm apart, each ring, about 10 cm in diameter, consisting of normally 4-7 holes around a low cone of sediment with an apical hole. This burrow type was described from observations in the Clyde Sea area, Scotland, by Tuck and Atkinson (1995), but the species responsible has not been established.

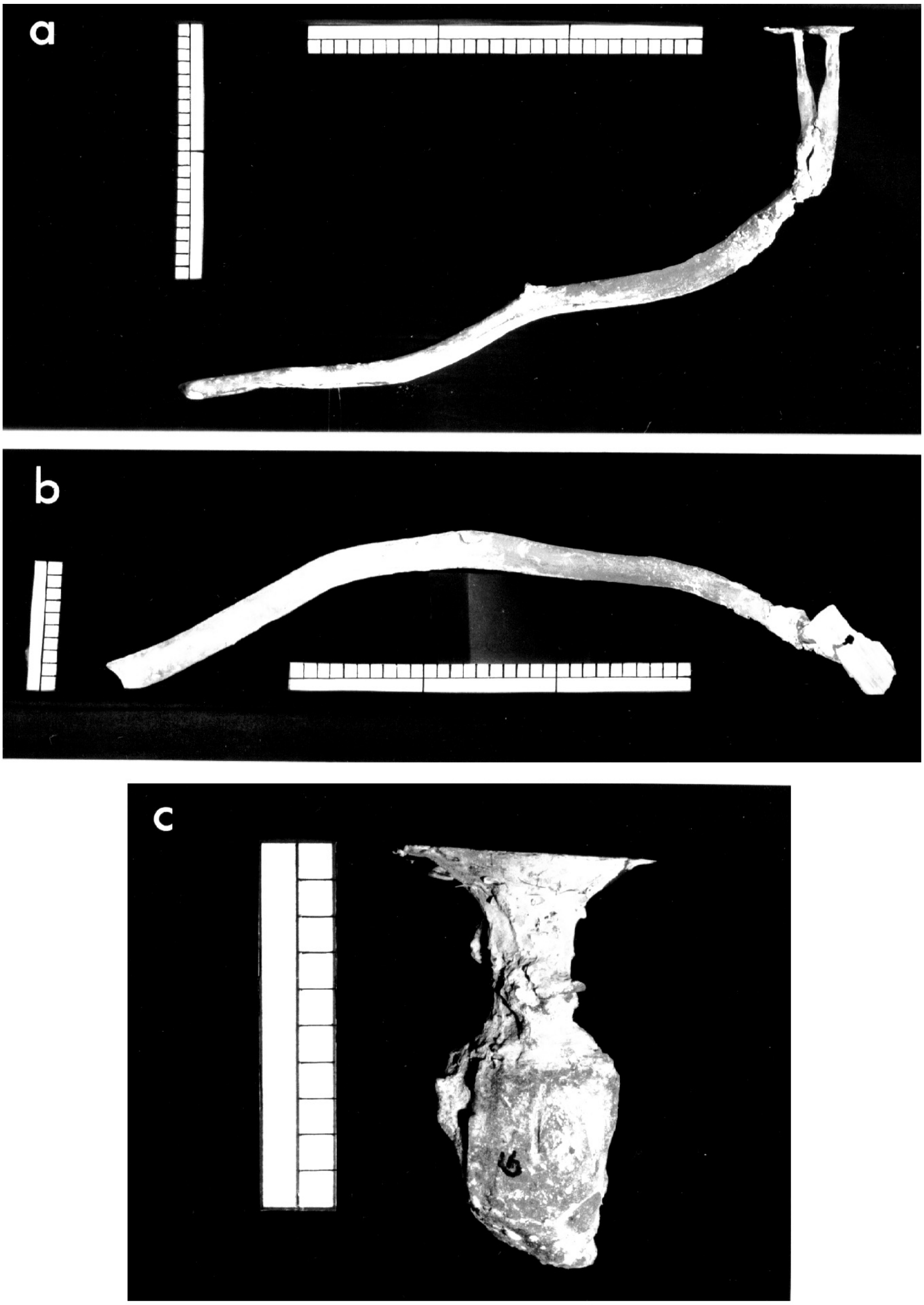

FIG. 3. – a) side view, and b) plan view of polyester resin cast of the burrow of *Solecurtus strigilatus,* horizontal scale bar 30 cm, vertical scale bars (a) 20 cm, (b) 10 cm; c) polyester resin cast of burrow occupied by *Gobius niger,* scale bar 10 cm.

The swimming crab *Liocarcinus vernalis* (Risso) was abundant at the dive sites. It concealed itself by burying in the superficial sediment and did not occupy burrows. *Liocarcinus* spp. and *B. gemmellari* are amongst the commonest constituents found in the stomachs of *S. mantis* (Froglia and Giannini, 1989).

DISCUSSION

Muddy substrata are often heavily burrowed. During the last 25 years, with the application of SCUBA techniques, substantial progress has been made in identifying the species responsible for such burrows and describing their burrow morphologies (see reviews in Dworschak, 1983; Atkinson and Taylor, 1988, 1991; Bromley, 1990; Nickell *et al.* 1995a,b). Many, however, await elucidation and description, and for some the available information is scarce.

The small grapsid crab *Brachynotus gemmellari,* though first described in 1839 (as *Cleistotoma gemmellari;* Rizza, 1839), was later erroneously synonomized with *Brachynotus sexdentatus* (Risso), until Froglia and Manning (1978) clarified its independent status. The species is reported to occur on muddy sands and sandy muds, usually sublittorally at depths of 4-21 m, probably throughout the Mediterranean (Froglia and Manning, 1978). The known distribution of *B. gemmellari* was recently extended westwards by Guerao *et al.* (1995) who reported it from the Ebro delta and described larval development under laboratory conditions. Little is known of its biology: the occurrence of the species in simple burrows has not previously been reported. The two obvious strategies for a small crab to avoid predation are burial in the substratum or burrow occupancy. At the sites examined, the latter strategy was widespread. The former strategy is also likely to occur, but was not observed. It has, however, been observed in the closely related *B. sexdentatus* on a sandy substratum in the Gulf of Tunis (C. Froglia, pers. obs.).

Several species of upogebiid mud shrimp occur in the Mediterranean. The species list is under revision because of confusion between several similar species. *Upogebia tipica* and *U. pusilla* (Petagna) are very similar and, according to Dworschak (1992), have been confused in the past so that records are unreliable. Dworschak (1992) states that *U. tipica* is confined to the Mediterranean, whereas *U. pusilla* also occurs in the Atlantic. He states that the former occurs in muddy substrata at depths below 9 m, whereas the latter occurs intertidally and down to around 6m. The present SCUBA observations of *U. tipica* at 13 m and 15 m depth, and UWTV observations (of burrow openings consistent in size and configuration with those observed at the dive sites) at 17-29 m depth, are consistent with this.

The burrows of upogebiids all have a similar morphology, but species-specific differences may be apparent (Dworschak, 1983; 1987a). The burrows of *U. tipica* had turning chambers at two levels in the shafts of the U-shaped component of the burrow, a feature also noticed by Dworschak (pers. comm.). This may be characteristic of this species: it has not been reported for the burrows of *U. pusilla* or other upogebiids (Dworschak, 1983). The two burrows of *U. tipica* that were cast in the present work were joined. Dworschak (1987b) illustrated two burrows of *U. tipica* which were joined by an escape burrow of the bivalve *Solecurtus multistriatus*. These two burrows show upper and lower turning chambers in their shafts and the bivalve is implicated in the junction of these burrows. More material needs to be examined in order to assess whether joined burrows are a normal occurrence rather than the result of a chance encounter, and to fully describe the burrow structure of this species.

The bivalve *Solecurtus strigilatus* appears to be abundant in inshore sediments in the Adriatic, judging from SCUBA and TV observations of their siphons or of the paired holes when the siphons are withdrawn. Other species of the same genus also occur and may be indistinguishable from them without resin casting. Dworschak (1987b) provides a detailed description of the burrows of *S. strigilatus* and *S. multistriatus*. Our findings are consistent with his.

Gobius niger appears to be an opportunistic burrow-dweller. In the muddy sediments of shallow Scottish sea lochs, it is regularly seen in upper part of the burrows of the thalassinidean mud-shrimp *Callianassa subterranea* and the echiuran *Maxmuelleria lankesteri* (Herdman) (Atkinson, 1987; Atkinson and Taylor, 1991; Nickell and Atkinson, 1995). The upper portion of a shaft is enlarged by the fish to form a chamber. The species will also invade the deserted burrows of the Norway lobster *Nephrops norvegicus* (L.) and, on the basis of recent observations, may construct its own U-shaped burrows (Marrs *et al.*, 1996). Even then, it probably uses parts of the burrows of other species as starting points in most cases At the Adriatic sites investigated, *G. niger* appeared to be using burrows in an opportunistic manner. Some fish were seen on the sediment surface without any obvious association with a burrow, others used natural cover (stones, debris), but burrow occupancy was common. The burrow which was cast appeared to be a modified component of a burrow shaft originally constructed by *Squilla mantis*.

Dr P. Dworschak showed one of us (RJAA) two photographs of *G. niger* occupying burrows in muddy sediment in the northern Adriatic. From these grounds, Pervesler and Dworschak (1995) briefly commented on ´burrows of *Gobius* sp. - which seem to be abandoned burrows of other animals (e.g. *Squilla*)´, a comment which, on the evidence of their photographs, relates to *G. niger* and is consistent with our observations.

The opportunistic use of shelters by *Gobius niger* is well known to Adriatic artisanal and sport fishermen. During the reproductive season (spring), empty cans are attached to long-lines set on the bottom near-shore and inspected daily. Each can has been prepared by having its top removed and is then is partly squeezed to restrict its aperture. The can bottom is perforated with a few small holes to facilitate water flow at hauling, Adult black gobies use the cans as a nests, but are unable to leave them quickly when they are hauled and are thus caught.

In most cases, the species whose burrows were inferred from structure were collected or seen either by SCUBA divers or had been trawled in the area using the research vessel. Proboscides consistent with *Maxmuelleria* sp. had been observed using UWTV, but no animals were collected. Referring to Stephen and Edmonds (1972), the most likely candidate is *M. gigas*, about which almost nothing is known. Clearly, more information on this species and its burrows would be advantageous. Traces attributable to this species were also seen beyond the *Squilla* grounds on the muddier *Nephrops* grounds at around 70 m depth. In Scottish waters, *Maxmuelleria lankesteri*, is restricted to soft muds (Hughes *et al*., 1996). Proboscides and burrow features consistent with the entity assigned to *M. gigas* were seen on fine muddy grounds and on coarser sandy mud grounds. By analogy with *M. lankesteri* (see Nickell *et al*., 1995a, b; Hughes *et al*., 1993, 1994, 1996a, b), the species is likely to occupy a large (can be 2 m long in *M. lankesteri*), U-shaped burrow which therefore has two surface openings. The sediment mound is at the opening that is principally exhalant, the stellate feeding traces at the opening which is principally inhalant.

The commonest echiuran on the coarser grounds, however, was the one that, on proboscis characteristics, conformed to the description of *Thalassema thalassemum*. This species is recorded from the Mediterranean (Stephen and Edmonds, 1972), but little is known of its ecology. Nickell and Atkinson (1994), in aquarium observations in Scotland, noted that the species occupied a burrow with two openings (around 20-25 cm apart), one predominantly inhalant and the other predominantly exhalant. Small mounds of sediment, rich in faecal pellets, built up around the openings. Others have found the species occupying cavities in clinker and rock (Cuénot, 1922; Wilkie, 1990), so the habitat utilization is variable. The *Echiura* are a little-studied group: the discovery of new species is likely as was the case recently in the Azores (Rogers and Nash, 1996). Collection of specimens from Adriatic grounds is therefore a high priority.

As information on burrow structure accumulates, the identity of the occupants can be established with increasing confidence from the size, shape and configuration of openings and burrow-associated traces such as tracks and trails. Thus, the burrows of the crab *Goneplax rhomboides* can often be distinguished by their shallow angle and characteristic recurved grooves at burrow openings (Rice and Chapman, 1971; Atkinson, 1974, 1986); those of the thalassinidean *Callianassa subterranea* by one or more vertical (inhalant) shafts, usually with funnel-like openings, and an associated small mound of sediment ejecta (usually dark, i.e. reduced) marking the site of the exhalant shaft which is usually partially blocked by pelletized sediment (Witbaard and Duineveld, 1989; Atkinson and Nash 1990; Nickell and Atkinson, 1995); the gobiid fish *Lesueurigobius friesii* by small, shallow, U- or T-shaped burrows (with 2 or 3 openings) (Rice and Johnstone, 1972); and echiurans of the genus *Maxmuelleria* by large ejecta mounds around the burrow opening which is functionally exhalant and stellate feeding traces, caused by proboscis activity, around an opening which is functionally inhalant (Hughes *et al*. 1994; Nickell *et al*. 1995a). Thus, we feel that the burrows of these animals were recognized with confidence, at least in the cases where such diagnostic features were clearly visible. In the case the echiuran thought to be *Thalassema thalassemum,* this identification was based on the appearance of the proboscis. It is unlikely that the small burrow of this species would be correctly assigned without the proboscis being visible.

Improved recognition of burrow types on *S. mantis grounds* will help reduce errors when assigning burrows to *S. mantis* and help prepare the way for stock assessment of *S. mantis* using underwater television.

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