

## The genus *Owenia* (Annelida: Polychaeta) in the Persian Gulf, with description of *Owenia persica* sp. nov.

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### Abstract

Examination of a collection of Polychaeta from the Iranian coast of the Persian Gulf results in recognition of a new species of *Owenia*, namely *O. persica* sp. nov. This is an oculate oweniid (thorax width 0.27–1.17 mm) in which the collar edge is not rectilinear but presents an angle of 150° with an anterior opening. Hooks on the first abdominal segment are aligned at 45°. In lateral view, the upper teeth of the hooks' head are clearly separated from the shaft; there is no discontinuity between the teeth, nuchal curve and shaft. The scales of the capillary chaetae are oval, with a long, loose transition between sections a and b, and short ( $a+b = 8.05$  mm; ratio  $(a+b)/d = 7.76$ ). The description of *Owenia persica* sp. nov. contributes to the growing evidence that the cosmopolitan *Owenia fusiformis* sensu lato is, in fact, a complex of species. Two previous reports of *O. fusiformis* Delle Chiaje from the Gulf are shown to be misidentifications: the specimens from Kuwait clearly belong to *O. persica* sp. nov., whereas the single specimen from the Strait of Hormuz likely belongs to another new species, *Owenia* sp. The characteristics of the local distribution of *O. persica* sp. nov. along the Iranian coast are analyzed on the basis of the available environmental data.

**Keywords:** *Owenia*; New species; Taxonomy; Biogeography; Ecology

### Introduction

Traditionally, *Owenia fusiformis* Delle Chiaje, 1841 (Polychaeta, Oweniidae) has been considered as a cosmopolitan species. The latest extensive review carried out by Dauvin and Thiébaud (1994) concluded that “*O. fusiformis* seems truly cosmopolitan which is absent only in Antarctic waters.” However, several observations (Caullery 1944; Nilsen and Holthe 1985; Imajima and Morita 1987) provided information indicating the heterogeneity of this taxon.

Recently, careful observations based on specimens corresponding to multiple worldwide reports of *Owenia fusiformis* have identified marked morphological differences between different populations (Koh 2002). Thus, there is a growing body of literature pointing out the existence of different species of *Owenia* in geogra-

phical areas as diverse as California (Blake 2000), the Yellow Sea (Koh and Bhaud 2001), the North Atlantic (Koh et al. 2003), the Australian waters (Ford and Hutchings 2005), and the Persian Gulf (present paper).

The genus *Owenia* was first mentioned from the Persian Gulf by Wesenberg-Lund (1949), from Henjam Island at the Strait of Hormuz, and later reported from intertidal areas in Kuwait (Mohammad 1971). Both authors identified the respective specimens as *O. fusiformis*. The present paper reports on a third occurrence of *Owenia* in the Persian Gulf, a population in the north of Nay Band Bay (Iran) which is situated between the two previously known areas. Based on the previously defined distinctive morphological characters (Koh 2002), the present paper revises the three populations of *Owe-*

*nia* known from the Persian Gulf. In addition, the local pattern of distribution of the new species along the Iranian coast is analyzed on the basis of the available environmental data.

## Material and methods

### Sampling and analytical methods

The area studied for the present paper is situated along the Iranian shoreline on the east coast of the Persian Gulf, near Assaluyeh in the north of Nay Band Bay, 250 km south of Bandar Bousher (27°30' S, 52°35' E) (Fig. 1).

Five transects, each 3 km in length, were positioned perpendicular to the Iranian coast from the North to the South. On each transect, three stations were distributed from the deepest margin of the coral reef belt to about 30m depth (Fig. 1), and were sampled both in August 1998 and November 2002.

Sediments were sampled using a Van Veen grab (35 x 42 x 90 cm, about 0.1 m<sup>2</sup> per grab). A one-litre volume of sediment was taken from one grab, transferred into polyethylene flasks, and stored in the dark prior to being used for physico-chemical analyses (granulometry, water content, organic matter, organic carbon).

Laser granulometry (% volume) was performed on dry sediment after sifting through a 0.8mm mesh sieve, using a Malvern Mastersizer S laser granulometer. Sediments were characterized by the respective percentages of silt plus clay (diameter < 63 µm) and sand (0.2 mm < diameter < 2 mm), and by the median grain diameter. Sediment water content (%) was measured according to the European experimental AFNOR standard X 31-102. Concentration of total organic matter (% dry weight) was calculated by steam-drying at 105 °C, according to the AFNOR standard NF U 44-160. Organic carbon content was measured according to the European experimental standard NF ISO 14235 (oxidation method, 0.1 % m/m).

The density of *Owenia* worms was estimated on the basis of a total sampling area of 0.3 m<sup>2</sup> (i.e. three grabs). The grab contents were gently mixed in a container, then sieved out on board by pouring the contents through a 1mm mesh sieve. The retained sediment was fixed with a 4% formaldehyde/seawater solution, stained with Rose Bengal, and stored until sorting. An initial sorting was done under a stereomicroscope to separate the tubes containing *Owenia* worms, which were then counted to express their densities as numbers of individuals per m<sup>2</sup>. All *Owenia* specimens were preserved in 70% ethanol.

Contour maps for all abiotic and biotic variables are based on a bidimensional interpolation (40 rows per 63 columns grid size) using Kriging as the gridding method. Land nodes have been blanked using digitized

series of coordinates representing the shoreline profile. The analyses were performed by means of the Surface Mapping System (SURFER) 6.01 (© Golden Software Inc.).

The relationships between sampling stations based on the environmental variables were assessed by a Principal Component Analysis (PCA), which was carried out on log-transformed, normalized data using the PRIMER 5.2.2 (© PRIMER-2000) routines (Clarke and Gorley 2001).

Two-way and one-way analyses of variance (ANOVA) were used to assess the size differences between *O. persica* sp. nov. and *O. fusiformis*, using species and populations (Iran August, Iran November and Kuwait, Mediterranean juveniles and adults, respectively) as factors. The differences between environmental variables and density of the Iranian population were assessed by one-way ANOVA, using year of sampling and the PCA-defined groups as factors. The responsible ones among all significant effects were assessed by Tused Honest Significant Difference test (Tukey HSD). The relationships between environmental parameters and the density of *O. persica* sp. nov. at each station in Iran were assessed by Pearson correlation analysis. When required, data were transformed (log-transformed for silt and organic matter content; rank-transformed for *Owenia* density as well as gravel- and organic carbon contents) in order to meet the assumptions of normality and homoscedasticity (Zar 1984), as tested by Kolmogorov-Smirnov and Bartlett tests, respectively. The analyses were performed by means of the SYSTAT 5.2.1. software (© SYSTAT Inc., 1990–92).

### Morphological observations

More than 100 Iranian worms were carefully extracted by cutting their tubes under a dissecting stereomicroscope. Body size was measured for 40 complete specimens (20 each from August 1998 and November 2002). Three complete specimens from Kuwait (ref. 1969-242, The Natural History Museum, London), one from the Strait of Hormuz (ref. 2586, Zoologisk Museum, Copenhagen), and 20 from the Bay of Banyuls (M. Bhaud, personal collection) were available for observation and measurements.

For light microscope observations (LM), the specimens were directly placed on slides, in a solution of glycerine and distilled water. LM drawings were made with a compound microscope equipped with a camera lucida. LM micrographs of uncini were made by dissecting a fragment from a parapodium and squashing it directly between the slides. LM micrographs of the C region (i.e. abdominal) parapodia were obtained after simple dissection. LM micrographs of tubes were made on empty fragments. LM micrographs were made with

a Leica-Wild MPS 32 through Diaplan Leitz LM or Wild M3Z compound microscopes.

Methyl green colour patterns were assessed by staining the specimens for 5 minutes with a solution of 0.05 g of methyl green powder in 10 ml of distilled water. Excess methyl green was removed by washing in 70% alcohol under visual control, prior to documenting appropriate examples by digital photography of dorsal and ventral sections of the thorax.

Observations of soft (body) and hard (hooks and capillary chaetae) structures were made with a Scanning Electron Microscope (SEM). First, all specimens were rinsed twice with distilled water (one hour each) in order to dissolve the numerous mineral concretions and to eliminate formaldehyde crystals. The different body sections were run through a series of increasing ethanol concentrations, and stored in 90% ethanol until observation. Immediately prior to viewing in a Hitachi S 4500 SEM (University of Perpignan, Center of Electron Microscopy) they were transferred to 100% alcohol, air-dried, mounted on a grid with double-sided sticky tape, attached to a stub, and coated with gold palladium. The terminology and measurements used for the descriptions of chaetae are based on Koh and Bhaud (2003).

For SEM observations of the thorax of Iranian specimens, the anterior region was first cut in two parts by a cross-section just behind the first abdominal segment. A second, lengthwise section gave two halves, left and right, which fit perfectly on the stub. For SEM observations of the dorsal capillary chaetae, part of the tegument around the base of the fascicle was removed with a scalpel. The uncinial torus was wholly removed from the dorsal to ventral sides in order to observe any possible variation in hook morphology between the upper and lower parts, or between anterior and posterior parts. The same procedure was performed on the Kuwait and Strait of Hormuz specimens, but only one half of each thorax was used. The chaetal measurements for each studied individual are based on five hooks from the middle region of the uncinial torus, as well as on five capillary chaetae from chaetiger B1.

## Systematics

Family Oweniidae Rioja, 1917

Genus *Owenia* Delle Chiaje, 1841

### *Owenia persica* sp. nov.

*Owenia fusiformis* Delle Chiaje, 1841 sensu Mohammad (1971: 298); misidentification

*Owenia* sp. A—Koh and Bhaud (2003: figs. 3K, 4K, 5K, 6K, 7K, 8K, 17(a)E)

## Etymology

The adjectival specific epithet refers to the type locality in the Persian Gulf.

## Material examined

*Type material.* Holotype (MNCN 16.01/10390) and 10 paratypes (MNCN 16.01/10391), deposited at Museo Nacional de Ciencias Naturales, Madrid, Spain. IRAN, east coast of Persian Gulf, north Nay Band Bay off Asaluyeh, 250 km S of Bandar Bousher, 52°33.2' N, 27°29.4' E; st. 18; 16m depth; sample composition 42.6% gravel, 3.9 % silt, 3.2 % organic matter, 19.7 % pore water; November 2002, leg. E. Dutrieux.

*Additional material.* (A) For the present study, a total of 140 specimens were collected by E. Dutrieux along the Iranian east coast of the Persian Gulf (Fig. 1); those specimens not listed as type material above are in the collection of the first author. (B) 7 specimens from Kuwait labelled as *O. fusiformis*, collected by M.-B.M. Mohammad (Mohammad 1971), preserved in 70% alcohol, ref. 1969-242, The Natural History Museum, London; 20 specimens of *O. fusiformis* from the Bay of Banyuls, collected on November 1999 at 8–9m depth on fine sand with *Spisula subtruncata* community, fixed in 10 % formaldehyde/sea water and preserved in 70% alcohol, ex coll. M. Bhaud.

## Description

General organisation of body as in all *Owenia* species. Body divided in three sections: branchiate area or feeding organ, thorax, and abdomen (Fig. 4A). First two sections separated by a collar (i.e. a circular belt consisting of a pronounced furrow, or even a fold). Thoracic region with three bundles of capillary chaetae (Fig. 4A). Abdominal region with 8 to 23 biramous segments with notopodial capillary chaetae and minute neuropodial hooks having two curved teeth at their apices. Hooks very numerous, arranged in dense patches forming dorso-ventral tori which cover most of the circumference of the body (Figs. 3A, B; 4A). By convention, the forward direction of the hooks corresponds to the anterior or ventral face, so that it is possible to define a right and a left tooth on an isolated uncinus.

Colour absent in preserved specimens, although a pair of reddish ocular spots may be observed by light microscopy (Fig. 3A, B) and some irregular patches of light brown pigment can be observed ventrally in freshly collected specimens (Fig. 6A).

Holotype: thorax length (l) 0.45 mm, total body length (L) 5.46 mm, body width (w) 0.31 mm, ratio l/w = 1.45, ratio L/w = 17.6.

Iranian specimens collected in August 1998: average thorax length (l) 0.8 mm, total body length (L)

average 7.17 mm (range 3.6–12.0 mm,  $n = 20$ ), body width ( $w$ ) average 0.27 mm (0.2–0.35 mm,  $n = 20$ ), ratio  $l/w = 2.57$ , ratio  $L/w$  average 26.6 (18.0–34.3,  $n = 20$ ). Abdominal segment number average 16 (8–23,  $n = 20$ ). Iranian specimens collected in November 2002:  $l = 0.85$  mm,  $L$  average 9.9 mm (7.1–15.3 mm,  $n = 20$ ),  $w$  average 0.38 mm (0.29–0.49 mm,  $n = 20$ );  $l/w = 2.24$ ,  $L/w$  average 25.97 (17.8–36.3 mm,  $n = 20$ ). Specimens from Kuwait:  $l = 2.5$  mm,  $L$  average 37.2 mm (28.7–46.2 mm,  $n = 3$ ),  $w$  average 1.17 mm (1–1.3 mm,  $n = 3$ ),  $l/w = 2.57$ ,  $L/w$  average 32.1 (28.8–35.5,  $n = 3$ ).

Tentacles arise from a basis with four trunks, the two dorsal ~~sz~~ be equal to the two ventral ones (length average 0.09 mm, range 0.08–0.12 mm; width average 0.08 mm, range 0.06–0.30 mm), with 3 (sometimes 4) tentacular rami mostly located near the distal tentacular ends (Figs. 3A, B; 4A). Tentacles measuring 0.06 mm (up to 0.4 mm long in Iranian, up to 1.2 mm in Kuwaiti specimens). Thorax / crown length ratio average 1.9 (1.8–2.5). Angular collar (150° angle) with an anterior margin having a dorso-ventral slit, with a vertical upper part and an inferior oblique part directed forwards; change of direction abrupt, occurring at level of slit, well marked longitudinally (Figs. 3A, B; 4A). Three thoracic chaetal bundles, the first two pointing vertically, the third in more dorsal position, relative to a line given by the positions of bundles 1 and 2 (Figs. 3A, B; 4A).

Hooks with relatively short teeth (parameter  $o$  in Fig. 2B, averaging 1.04  $\mu\text{m}$ ). Distance from teeth to hook's head (Fig. 2B:  $s$ ) relatively large (average 1.15  $\mu\text{m}$ ). Nuchal process (parameter  $np$  in Fig. 2B) also distinct (average 2.5  $\mu\text{m}$ ). Ratio  $o/d$  averaging 0.56. Angle of teeth reaching 70–75°. Dorsal offset in ventral view marked (Figs. 2D:  $do$ ; 4H; 5A). Ventral offset in apical view (parameter  $vo$  in Fig. 2C) absent (Figs. 4H, 5B). Discontinuity from teeth to nuchal curve (parameter  $nc$  in Fig. 2C), and then to shaft, absent (Figs. 4F, 5F), with a marked nuchal curve separating teeth from shaft (i.e. teeth do not arise directly from top of shaft) (Figs. 4F, 5C). Top of shaft not enlarged. Ventral edge of shaft slightly curved, instead of rectilinear as in many other *Owenia* species (Figs. 3F, 5C). Hooks without shoulders (i.e. dorso-lateral expansions of shaft), oblique and ventral borders of shaft divided by lower border of teeth (Figs. 4F, 5C). Teeth not flattened on upper part of shaft, leaving a free zone between their lower border and ventral edge of head (Fig. 4F). Dorsal offset of teeth in apical view (parameter  $do$  in Fig. 2C) ranging from 0.45 to 0.75  $\mu\text{m}$  (Figs. 4G, 5B).

Hooks of first abdominal segment with a 45° angle with respect to longitudinal axis (Fig. 4E), but with marked intra-specific variation: on the first torus (ab-

dominal segment 1), the angle on three different specimens was 45°, 90° and 0°, respectively. Orientation of hooks inside each torus always the same, but highly variable along body (Fig. 7); therefore in this species this criterion cannot be considered as taxonomically informative.

Scales on capillary chaetae oval all along scaled region, with a long, ill-defined transition between sections a and b (Figs. 4D; 5G, H). Total length of scales ( $a+b$ ) averaging 8.05  $\mu\text{m}$  (range 6.88–8.91  $\mu\text{m}$ ). Sharpness of scales ( $a/d$ ) averaging 2.60 (2.47–2.76). Length of free part ( $c$ ) averaging 3.97  $\mu\text{m}$  (2.57–5.02  $\mu\text{m}$ ).

Size of sand grains forming the tube very homogeneous (mean size of the largest grain 180 ~~+32~~  $\mu\text{m}$ ). Anterior part of each sand grain free, partly covering the adjacent grain; overall arrangement resembles a tiled roof (Fig. 4B). Sand grains usually flat, all sides of similar lengths. Width of tube walls slightly ~~smaller~~ than inner tube diameter (ratio 1.3:2; Fig. 4C).

Methyl green staining pattern characterized by branchiae unreceptive to staining; dorsal side of collar with a dark narrow bracket, mid-ventral side of collar with circular spots and median diffuse V (whole figure longer than wide), latero-ventral sides of collar with two dark bands (longer than wide, wider at tip); ventral side of abdominal region with two parallel longitudinal lines (Fig. 6B, C).

#### Taxonomical remarks

The main features distinguishing *Owenia persica* sp. nov. from *O. fusiformis* Delle Chiaje (Mediterranean Sea, Bay of Banyuls) come from two different sources: morphology and the methyl green staining pattern. Morphologically, *O. persica* sp. nov. has hooks without shoulders and with marked dorsal offset, short teeth and a longer distance from teeth to the hook's head than *O. fusiformis* (Table 1). The methyl green stainable areas are the same, but staining intensity and the form of the different elements significantly differ between species (Table 1).

In addition to the differences from the Mediterranean specimens of *Owenia fusiformis*, *O. persica* sp. nov. differs from all other known populations and species of the genus (for a review see Koh and Bhaud 2003) in the shape of hooks in lateral view. *Owenia persica* sp. nov. and specimens from the Gulf of California (population "J" in Koh and Bhaud 2003) do not show a disruption between teeth and shaft (Fig. 4F), due to the absence of shoulders. However, in *O. persica* sp. nov., the teeth are shorter, the thorax is longer, and the distance between the tips of two successive scales on capillary chaetae (parameter  $c$  in Fig. 4D) is longer than in other material studied (Koh and Bhaud 2003).

### Biological remarks

Comparison of body measurements on the Iranian *O. persica* sp. nov. populations from August 1998 and November 2002 with both juveniles and adults of Mediterranean *O. fusiformis* (Bay of Banyuls, France; B-S Kho, unpublished data) reveals that there always are significant interactions between the factors population and species (two-way ANOVA, L:  $F = 44.3$ ,  $p < 0.000001$ ; w:  $F = 241.0$ ,  $p < 0.000001$ ; L/w:  $F = 29.2$ ,  $p < 0.000001$ ). The Tukey HSD test reveals significant differences in length and width between the two *O. persica* sp. nov. populations, as well as between those and *O. fusiformis* ( $p < 0.0002$ ), whereas the L/w ratio does not vary within *O. persica* sp. nov. and was 1.6 times higher in adult than in juvenile *O. fusiformis* ( $p < 0.0002$ ) (Fig. 8). When comparing *O. persica* sp. nov. with juvenile *O. fusiformis*, the August 1998 population does not significantly differ in L and w, and the L/w ratio is 1.70 times higher in the former (Tukey HSD,  $p < 0.0002$ ); the November 2002 population is (2.18 times) longer and (1.23 times) wider and has a high L/w ratio (1.74) (Tukey HSD,  $p < 0.0002$ ) (Fig. 8). *Owenia persica* sp. nov. is more than two times shorter than adult *O. fusiformis* (i.e. relative length 0.29 in August 1998, 0.41 in November 2002) and about three times narrower (i.e. relative width 0.27 in August 1998, 0.38 in November 2002) (Tukey HSD,  $p < 0.0002$ ), whereas the L/w ratio does not differ significantly (Fig. 8).

Inclusion of the specimens of *O. persica* sp. nov. from Kuwait in the analysis allows comparison of large adults with both Iranian populations and with *O. fusiformis*. The former differ significantly in w, L and L/w ratio (one-way ANOVA;  $F = 220.6$ ,  $p < 0.000001$ ;  $F = 142.7$ ,  $p < 0.000001$ ;  $F = 41.6$ ,  $p < 0.000001$ ; respectively). However, the Tukey test indicates that members of the August 1998 Iranian population are always small (p < 0.001), whereas the L/w ratio does not differ significantly between the November 2002 population and the specimens from Kuwait (Fig. 8). The latter are significantly longer and wider than juvenile and adult *O. fusiformis* (one-way ANOVA;  $F = 45.1$ ,  $p < 0.000001$ ;  $F = 196.4$ ,  $p < 0.000001$ ). However, no significant differences occur in the L/w ratio (Fig. 8).

Therefore, *Owenia persica* sp. nov. from Iran is much smaller than the adults of *O. fusiformis* from Banyuls, with width and length ranges within those of *O. fusiformis* juveniles, while proportionally they are indistinguishable from *O. fusiformis* adults. Therefore, the August 1998 and November 2002 specimens were initially considered as small adults, with the later-collected ones slightly larger due to natural growth. The fact that the Iranian specimens were smaller than adult *O. fusiformis* from the Mediterranean and all other known populations (Koh and Bhaud 2001, 2003; Koh

et al. 2003), appeared at first to be referable to the extreme environmental conditions along the Iranian coast, resulting in a kind of dwarf condition. This hypothesis was rejected after examining the large Kuwaiti specimens of *O. persica* sp. nov., which are even wider and longer than adult *O. fusiformis*, but also indistinguishable as regards body proportions (Fig. 8). They are larger adults of *O. persica* sp. nov., inhabiting a region with similarly extreme environmental conditions, such as a summer sea water temperature of 33 °C or salinities ranging from 39 to 41 ‰ (Mohammad 1971). The major difference between the two known areas where *O. persica* sp. nov. has been found is the presence of two large rivers (Euphrates and Tigris) near the Kuwaiti collecting area, as well as the presence of many storm-water outfalls. These lead to high organic content in the water column (Heill et al. 2001) and sediments (Al Bakri and Kittaneh 1998). Although the *Owenia* material from Kuwait was collected around 1967–68, considerably before data were gathered for the two papers referred to, we may hypothesize that the larger size of the Kuwaiti specimens could be related to more trophic resources available to them.

On the other hand, we have no direct evidence of sexual maturity to confirm whether or not these specimens are adults. None of the collected specimens has intra-coelomic oocytes. Although the extent of the reproductive period and the phases of the cycle cannot be determined precisely due to seasonally incomplete sampling in Iran, the short reproductive period (i.e. less than two months) that usually characterizes the species of *Owenia* may explain the absence of oocytes. In turn, the low number of Kuwaiti specimens, as well as their long-term preservation, have prevented us to assess whether they were taken during a non-reproductive phase or are males. The imprecisely stated collection dates (i.e. between November 1967 and November 1968) did not help to clarify this point. Moreover, it is not known whether or not *O. persica* sp. nov. may reproduce asexually, but the specimens studied showed no signs of regeneration.

### *Owenia* sp.

*Owenia fusiformis* Delle Chiaje, 1841 sensu Wesenberg-Lund (1949: 345); misidentification

### Material examined

One specimen (ref. 2586, Zoologisk Museum, Copenhagen); IRAN, Strait of Hormuz, Henjam Island, St. 67; Petersen grab, 23m depth on mixed sand and shell sediments; 17 April 1937, G. Thorson (Wesenberg-Lund 1949).

## Description

General organisation of body (Fig. 3D) agrees with that of all *Owenia* species; body divided in three sections: branchiate area or feeding organ, thorax, and abdomen. First two sections separated by a collar. Thoracic region with three bundles of capillary chaetae, the first two arranged laterally, the third slightly more dorsally relative to a line given by the positions of bundles 1 and 2. First abdominal segment with notopodial capillary chaetae and minute neuropodial hooks having two curved teeth at their apices. Hooks very numerous, arranged in dense patches forming dorso-ventral tori which cover about 5/6 of body width in lateral view (Fig. 3C).

Colour absent in preserved specimens, ocular spots absent.

Thorax 1.76 mm long (l) and 1.37 mm wide at b1 (w). Ratio l/w = 1.28. Tentacles arise from a basis with four trunks, the dorsalmost two wider, the mid-dorsal one slightly longer, the ventralmost one shorter than the remaining ones, respectively; tentacular rami mostly located near distal tentacular ends, with 7–10 main and 4–6 small secondary ramifications (Fig. 3C). Tentacle length 0.58 (ventralmost) to 1.1 (mid-dorsal) mm. Angular collar (150° angle) with an anterior margin having a dorso-ventral slit, with a vertical upper part and an inferior oblique part directed forwards; change of direction abrupt, occurring at level of a horizontal slit, well marked longitudinally (Fig. 3C).

Hooks with relatively long teeth (parameter o in Fig. 2B; length 2.5 µm). Distance from teeth to hook's head (parameter s in Fig. 2B) relatively long (1.0 µm). Nuchal process (parameter np in Fig. 2B) also distinct (length 3.0 µm). Ratio o/d = 0.83. Angle of teeth higher than 80°. Dorsal offset in ventral view marked (Fig. 5E). Ventral offset in apical view (parameter vo in Fig. 2C) absent (Fig. 5E). Discontinuity from teeth to nuchal curve (parameter nc in Fig. 2C), and then to shaft, absent, with a marked nuchal curve (parameter nc in Fig. 2B) separating teeth from shaft, i.e. teeth not arising directly from top of shaft (Fig. 5F). Top of shaft slightly enlarged. Ventral edge of shaft markedly curved, instead of rectilinear as in many other *Owenia* species. Hooks without shoulders, oblique and ventral borders of shaft divided by lower border of teeth (Fig. 5D, F). Teeth not flattened on upper part of shaft, leaving a free zone between their lower border and ventral edge of head. Dorsal offset of teeth in apical view (parameter do in Fig. 2C) ranging from 0.25 to 0.35 µm (Fig. 5E).

Most scales on capillary chaetae rhomboidal (Fig. 5I), becoming oval near basis (Fig. 5J), with a marked, angular transition between sections a and b (Fig. 5I). Total length of scales (a+b) averaging 7.50 µm (range 7.88–7.91 µm). Sharpness of scales (a/d) averaging 2.0

(1.81–2.10). Length of free part (c) averaging 4.12 µm (3.43–4.83 µm).

Methyl green staining pattern characterized by branchiae unreceptive to staining, except at basis of trunks; dorsal side of collar with a dark wide belt, mid-ventral side of collar with circular spots and median V virtually fused, clearly stained (whole figure wider than long), latero-ventral sides of collar with two dark bands as long as wide; ventral side of abdominal region with longitudinal parallel lines (Fig. 6D).

## Taxonomical remarks

Only one anterior fragment was available for observation, including the branchiate area, the thorax, and one abdominal segment. Nevertheless, *Owenia* sp. can be distinguished from *O. persica* sp. nov. by the branchiae with trunks of different widths and lengths as well as with numerous primary and secondary rami, by a low l/w ratio, scales of capillary chaetae with rhomboidal shape and both angular and round transition between sections a and b, and by a different methyl green staining pattern (Table 1). The shape of the branchial crown, the methyl green staining pattern, the morphology of the tube, and the shape of scales on capillary chaetae, together with the angular collar and the absence of shoulders on the hooks, also allow distinction of this species from *O. fusiformis*. The absence of eyes in *Owenia* sp. is either a remarkable distinctive character of the species or a preservation effect resulting in fading of the eye pigment.

This specimen clearly represents a separate species, but without additional material confirming the distinctive features, formal description as a new taxon is not advisable.

## Ecology of the Iranian populations of *Owenia persica* sp. nov.

### Environmental characteristics —U3

Along the coast near Assaluyeh, the natural seawater temperature and salinity near the bottom ranged from 35.5 °C (1998) to 32.5 °C (2002), and from 39.4 ‰ (1998) to 37.3 ‰ (2002), respectively. The water column was very clean, usually with a slight increase in suspended solids near the bottom (e.g. from 2.5 mg/l at the surface to 6.5 mg/l at the bottom in summer), and is characterized by very low oxygen concentrations (Eric Dutrieux, personal observation).

The sediment characteristics in the two years of study (Table 2) differed only in the organic matter and organic carbon contents (Table 3), the latter being higher in 1998, the former in 2002 (Table 2). The results of the PCA (Fig. 9A) confirmed the relative relevance of these two variables, which mainly defined the variability (i.e. 13%) explained by the second axis. The samples from

1998 tend to show higher values than those from 2002 according to this axis. The first axis in the PCA explained 58% of the variability and was mainly described by the opposition between gravel content and median grain size, with positive values, and pore water content, silt content and depth, with negative values. Accordingly, gravel content and median grain size were positively correlated but showed significant negative correlations with all remaining variables (Table 4). Among all remaining environmental variables, the correlation was always positive when significant (Table 4).

The distribution of samples in the PCA showed comparable patterns independent of the year (Fig. 9B). This gave rise to four groups of stations (Fig. 9C), which always showed significant differences among them in the ANOVA based on environmental variables (Table 3). Therefore we analyzed the responsible part of each significant effect by means of the Tukey HSD test (Table 5). Depth was always significantly different in all groups, except between II and III, tending to increase from I to IV. Silt+clay and gravel contents did not differ between groups I and II, which showed lower and higher contents than the other groups, respectively; the highest silt+clay content and the lowest gravel content occurred in group IV. Consequently, median grain size did not differ between groups I and II (i.e. large size) and III and IV (i.e. small size). Pore water also tends to increase from group I to IV, but group II did not differ significantly from groups I and III. Organic matter and organic carbon showed less clear pattern within the PCA groups. Particularly organic carbon content did not show any significant difference, while only group IV had significantly higher organic matter content than groups I and III.

The sediments in the study area were mostly sandy. However, they were characterized by a tendency to have larger grains when shallower, and to be more silty with higher organic matter, organic carbon and pore water when deeper. Moreover, there was a second axis of variation, from North to South, with the stations near the harbour being less silty and having more gravel. This second axis was particularly relevant for the organic matter content, which was higher near the harbour, especially in 2002.

### Density distribution

The density of *O. persica* sp. nov. ranged from fewer than 3 ind./m<sup>2</sup> at station 5 (1998) to more than 360 ind./m<sup>2</sup> at station 8 (1998) and about 470 ind./m<sup>2</sup> at station 13 (2002) (Fig. 10). Differences in density between 1998 and 2002 were non-significant (Table 3). Thus, the relationships between population density and environmental variables were analyzed for the two years combined.

The population shows marked density variations, as revealed by the significant differences observed between the groups obtained in the PCA (Table 3). According to the Tukey test, group I was responsible for this effect (Table 5) by having significantly higher density than the remaining ones (Fig. 10). The other groups did not show significant differences among them.

On the other hand, the correspondence analysis demonstrated that the density of *Owenia persica* sp. nov. increased with an increase in gravel content as well as with decreases in depth and silt+clay and pore water contents (Table 4).

Although the *O. persica* sp. nov. is widely distributed in the study area, it tends to be absent from the southern, deepest stations. There is a clear preference for the northern, shallowest stations (8 in 1998, 13 in 2002) next to the limit of hard-bottom substrate and at medium depths (Fig. 10). The population was concentrated mainly to the stations forming PCA group I (Figs. 9C, 11) characterized by compact sediments having low pore water contents ( $22.7 \pm 2.9$  %) and intermediate values for silt, organic matter and organic carbon content ( $4.1 \pm 1.9$  %,  $4.0 \pm 1.7$  % and  $0.45 \pm 0.18$  %, respectively). However, the most distinguishing environmental feature of the stations in this group was the high gravel content ( $93.9 \pm 2.5$  %) and thus the large size of the sand grains ( $354 \pm 43$   $\mu$ m) (Fig. 12), which may likely be the most favourable for adult tube building.

### Discussion

The Persian Gulf is a concentration basin (Tchernia 1978) in which evaporation processes dominate the evaporation/rainfall ratio (Sheppard et al. 1992). Thus the water is salty and warm. In winter, temperature ranges from 21 to 22 °C in the Strait of Hormuz and from 15 to 17 °C in the NW waters. Salinity shows an inverse gradient, from 36.5 to 37.5 ‰ at the opening to 40 ‰ over a wide area inside the Gulf. In summer, Gulf waters warm quickly (to above 34 °C at the SE coast), reaching peak values higher than 36 °C (Sheppard et al. 1992). During this period, salinity rates than 50 ‰ can be found frequently in the shallows of the southern Gulf coast, but values higher than 70 ‰ have been reported locally (Sheppard 1993).

Environmental conditions along the Iranian coast near Assaluyeh (i.e. low oxygen concentrations, high salinity rates, and very high temperatures even near the bottom; Bhaud et al. 2003) do not differ from those elsewhere in the Gulf, thus may be considered as extreme for marine life. The only favourable condition seems to be the elevated concentration of suspended solids near the bottom (Bhaud et al. 2003), likely related to the presence of an outlet channel entering the bay between

stations 8 and 13 (where densities of *O. persica* sp. nov. are higher). *Owenia persica* sp. nov. probably switch between filter- and deposit-feeding, depending on the quantity and quality of food in the water column versus the sediment surface, a behaviour known from other *Owenia* species (Gambi 1989; Desroy et al. 1997; Koh 2002). This implies that in the Assaluyeh area enough food is available to the worms, irrespective of the nutritional quality of the particular sediment patch. Accordingly, the density of *O. persica* sp. nov. showed non-significant correlations with total organic matter and carbon contents of the surrounding sediments.

The fine fractions of the sediments seem to play an important role in structuring *Owenia fusiformis* populations (Dauvin and Gillet 1991; Dauvin 1992; Pinedo et al. 2000). The mitraria larvae of Oweniidae are essentially passive (i.e. highly dependent on advection of the water mass), and the young recruits are able (or even prefer) to settle on fine sediments for tube-building (Pinedo et al. 2000; Koh 2002). However, after successful recruitment food availability seems to play an important role in the distribution of the organisms, and adult populations do not seem to follow a clear relation with granulometry (Pinedo et al. 2000). The presence of *Owenia* individuals during the settlement period tends to occur over large areas with various environmental conditions. Soon after settling most juveniles disappear, with only those settling on appropriate locations being able to develop to adult age (Pinedo et al. 2000). As a consequence, the populations (mainly composed of adults) become concentrated to limited areas (Pinedo et al. 2000; Koh 2002). Then, the number of individuals decreases progressively, probably following the direction of the main local currents (which likely carry progressively less trophic resources to maintain the populations).

In Assaluyeh, density distribution during the two sampling periods also showed a patchy pattern, with the highest abundances concentrated at shallow depths and in front of the outlet channel, which agrees with the pattern reported for *O. fusiformis* in the Bay of Blanes (Pinedo et al. 2000). In contrast with those from Blanes, the preferred Iranian stations tended to show the largest grain sizes, which may likely be the most favourable for tube-building. However, large adults (with sizes comparable to those observed in Kuwait) were not found in Iran. This may mean either that we were observing part of the area successively occupied by waves of settlers, thus missing large adults at the study site, or that the number of large adults was very low and we were not able to collect them with our sampling strategy. In the second case, we suggest that they would have had to be located near the shallow northern stations 8 and 13 at which most individuals were concentrated both in 1998

and 2002. Moreover, assuming that Iranian *O. persica* sp. nov. behave in a way similar to *O. fusiformis* in the Mediterranean, their populations either were observed just after the settlement period (i.e. with young adults still remaining outside of areas with large adults, the relatively smaller size in summer 1998 versus autumn 2002 being due to the natural growth process), or they have a continuous reproduction period (i.e. with permanent and widespread arrival of settlers, which only persist successfully after recruitment near the adult population at the appropriate location). Testing these two hypotheses would require a temporal sampling strategy not considered when the present study was planned. However, irrespective of the two scenarios, the main concentration of *O. persica* sp. nov. individuals at the shallow northern stations probably can be explained by the combination of trophic resources, an adequate hydrographic regime, suitable sediments, and the protection given by the nearby hard bottoms and coral reefs.

On a larger geographic scale, the Persian Gulf tends to function as a concentration basin (Tchernia 1978). The circulation pattern includes a main current from the Strait of Hormuz and drift along the Iranian coastline towards the inner regions of the Gulf, turning then to run along the Persian coast prior to returning to the Strait (Sheppard et al. 1992). Certainly, this pattern contributes to keeping the populations of *O. persica* sp. nov. isolated from the outside of the gulf, including the Strait of Hormuz where the specimen of *Owenia* sp. was found. As pointed out recently (Bhaud 1998; Bhaud et al. 2003) for different polychaete species, the increasing number of descriptions of new species of *Owenia* from all around the world (e.g. from the North Atlantic, Yellow Sea, Persian Gulf) strongly argues against a direct link between the existence of long-living planktonic larvae and the specific area of distribution for the adults. In fact, the morphological differences between *O. persica* sp. nov. and the previously known species of the genus (including the Mediterranean populations of *O. fusiformis*) clearly support the erection of the new taxon.

The existence of different species of *Owenia* in geographical areas as diverse as California (Blake 2000), the Yellow Sea (Koh and Bhaud 2001), the North Atlantic (Koh et al. 2003) and the Persian Gulf (present paper) disproves a cosmopolitan distribution of *Owenia fusiformis*. Although several species of *Owenia* may cohabit (e.g. *O. assimilis*, *O. borealis* and *O. polaris*; Koh et al. 2003), the populations of *O. persica* sp. nov. and *Owenia* sp. (both previously reported as *O. fusiformis*) are neither juxtaposed with the populations of *O. fusiformis* sensu stricto, nor with those of any other species in the genus. From a biogeographical point of view, an immediate consequence is that the distribution



area of *O. fusiformis* is reduced. Careful studies should be carried out under different approaches (from classical but fine morphological observations to genetic analyses) before any given species is considered cosmopolitan in distribution.

In the present case, each time the identified differences justify the erection of a new species, the range of distribution of the so-called cosmopolitan *Owenia fusiformis* sensu lato is reduced, at the same time revealing it as a species complex with a still undefined number of members.

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**Table 1:** Main characters differentiating *Owenia persica* sp. nov., *O.* sp. (Straight of Hormuz), and *O. fusiformis* Delle Chiaje (Bay of Banyuls).

	<i>Owenia persica</i> sp. nov.	<i>Owenia</i> sp.	<i>Owenia fusiformis</i>
Collar shape	angular	angular	straight
THORAX	[n = 20 (Iran, Kuwait)]	[n = 1]	[n = 14]
width/length ratio	Iran: 2.29–4.00 Kuwait: 2.72–2.93	1.28	1.09–1.26
HOOKS	[n = 5 (Iran), 3 (Kuwait)]	[n = 1]	[n = 10]
shoulders between teeth and shaft	absent	absent	present
dorsal offset	marked	marked	absent
length of teeth	Iran: 1.00–1.19 μm (0.69–0.76); Kuwait: 2.30–2.54 μm (0.62–0.73)	2.5–2.83 μm (0.75–0.77)	2.05–2.41 μm (0.89–0.92)
(tooth length / shaft width)			
distance from teeth to head	Iran: 0.93–1.45 μm; Kuwait: 1.18–1.74 μm	1.0–1.14 μm	0.54–1.05 μm
METHYL GREEN STAINING PATTERN ON:			
branchiae	unreceptive to staining	unreceptive to staining, except at bases of trunks	uniformly light green
dorsal side of collar	dark, narrow bracket	intensely stained, wide belt	slightly stained, narrow belt
mid-ventral side of collar	circular spots and median V diffuse, whole figure longer than wide	circular spots and median V fused, whole figure wider than long	circular spots and median V well-defined, whole figure wider than long
latero-ventral sides of collar	two dark bands, longer than wide, wider at tip	two dark bands, as long as wide	two dark spots, as long as wide, wider at basis

**Table 2:** Summary of the environmental variables at the study site.

	1998			2002		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Depth (m)	14	30	21	14	30	21
Silt + clay (%)	3.75	44	14.2	1.96	24.4	9.3
Gravel (%)	45.6	95.2	80.4	50.7	96.77	84
Median grain size (μm)	164.6	411.5	289.9	141.5	377.6	249.4
Pore water (%)	19.7	39.3	27.9	19.5	37.7	27.8
Organic matter (%)	2.5	5.2	3.6	2.4	8.8	5.2
Organic carbon (%)	0.37	3.4	0.82	0.25	0.68	0.4
<i>Owenia</i> density (ind./m <sup>2</sup> )	3	367	73	10	469	145

**Table 3:** Results of the one-way ANOVAs using year of sampling and the PCA-defined groups as factors. Df = degrees of freedom; P = level of significance; NS = non-significant.

Year	Sum of Squares	Df	Mean Square	F-ratio	P
Density	20.833	1	20.833	0.264	NS
Depth	0.000	1	0.000	0.000	NS
Median grain size	12322.133	1	12322.133	1.973	NS
Silt + clay	0.996	1	0.996	1.684	NS
Gravel	58.800	1	58.800	0.752	NS
Organic matter	0.516	1	0.516	7.254	0.01
Organic carbon	653.333	1	653.333	11.500	0.002
Pore water	0.012	1	0.012	0.000	NS

Group	Sum of Squares	Df	Mean Square	F-ratio	P
Density	865.656	3	288.552	5.505	0.005
Depth	573.967	3	191.322	40.497	0.00001
Median grain size	139568.000	3	46522.648	25.401	0.00001
Silt + clay	13.275	3	4.425	26.853	0.00001
Gravel	1857.323	3	619.108	41.308	0.00001
Organic matter	1.022	3	0.341	5.964	0.003
Organic carbon	568.573	3	189.524	2.941	0.05
Pore water	697.351	3	232.450	21.290	0.00001

**Table 4:** Results of Pearson correlation analysis among environmental variables and between them and the density of *Owenia persica* sp. nov. r = correlation coefficient; (P) = probability; (NS) = non-significant.

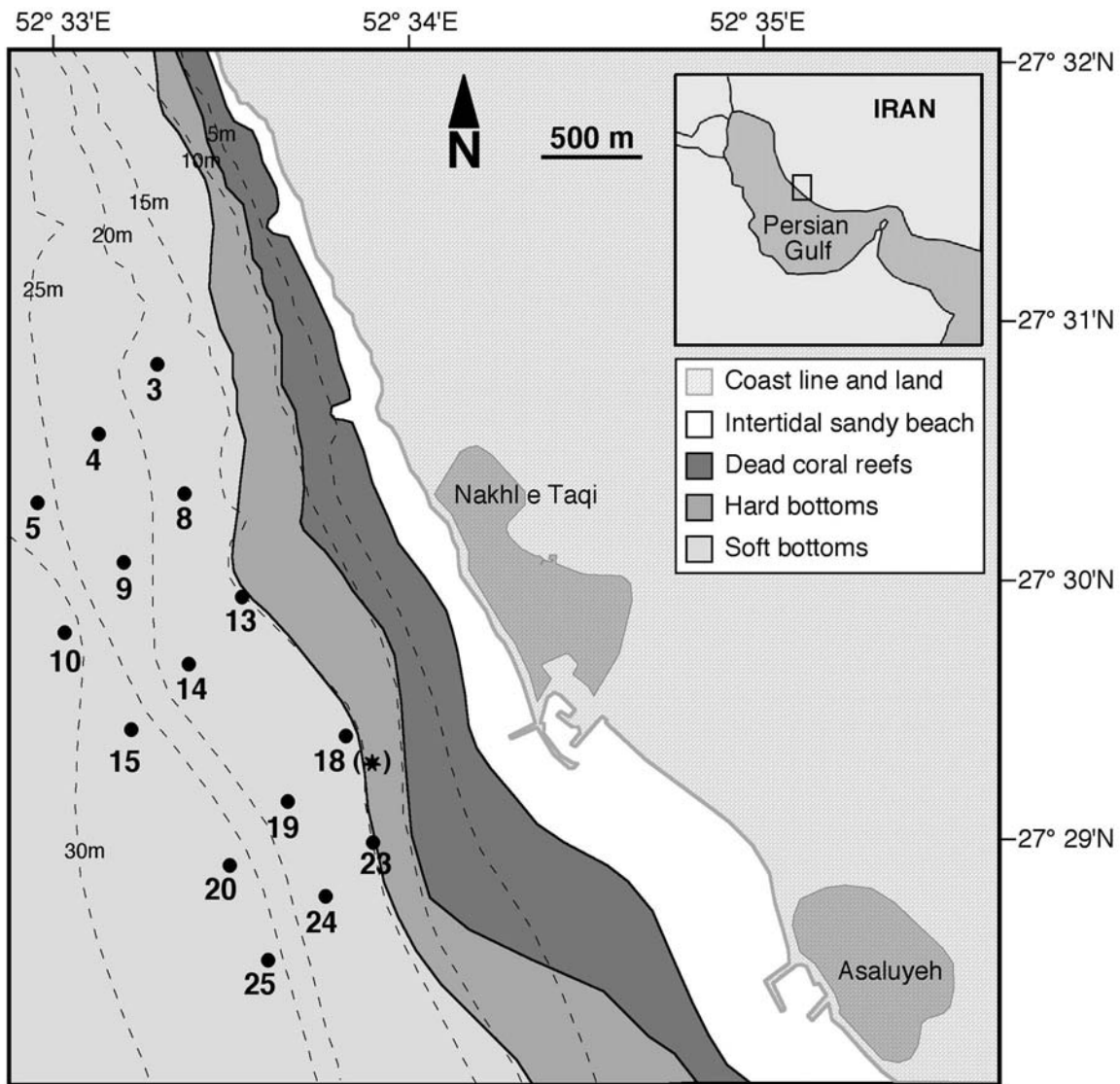
	Depth		Median grain size		Silt + clay		Gravel	
	r	(P)	r	(P)	r	(P)	r	(P)
Median grain size	-0.817	(0.0001)						
Silt + clay	0.832	(0.0001)	-0.8186	(0.0001)				
Gravel	-0.842	(0.0001)	0.87988	(0.0001)	-0.958	(0.0001)		
Organic matter	0.4269	(0.02)	-0.3317	(NS)	0.161	(NS)	-0.1677	(NS)
Organic carbon	0.3271	(NS)	-0.0807	(NS)	0.4333	(0.017)	-0.3658	(0.047)
Pore Water	0.7327	(0.0001)	-0.6413	(0.0001)	0.6847	(0.0001)	-0.6514	(0.0001)
<i>Owenia</i> density	-0.37	(0.044)	0.31904	(NS)	-0.369	(0.045)	0.4051	(0.026)

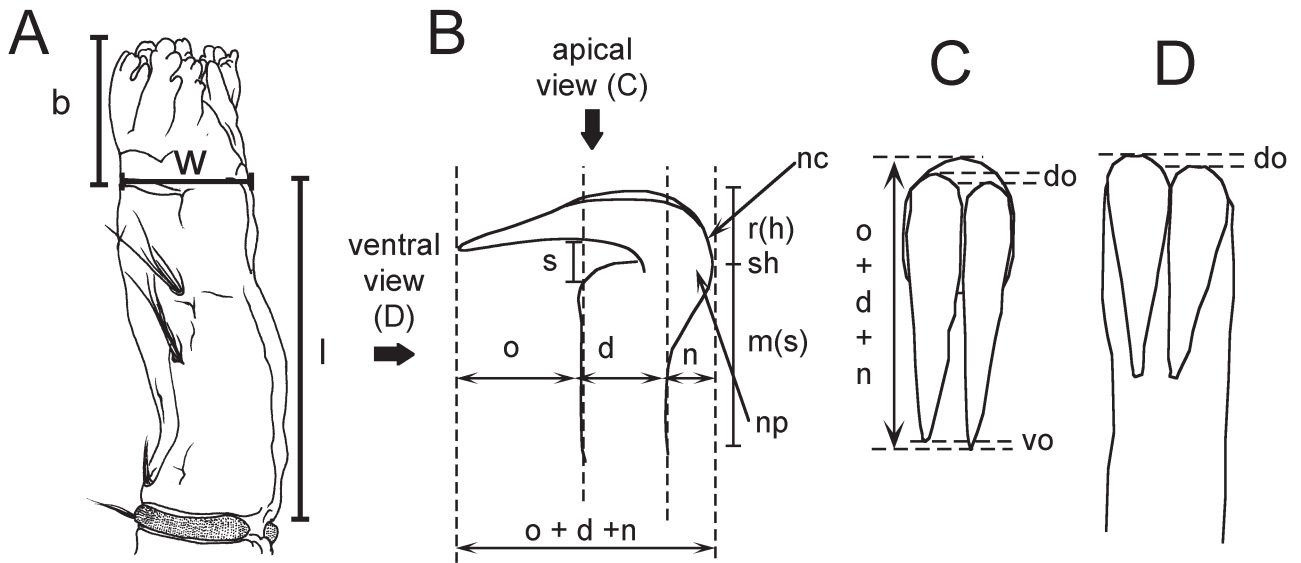
	Organic matter		Organic carbon		Pore water	
	r	(P)	r	(P)	r	(P)
Organic carbon	0.1709	(NS)				
Pore water	0.2887	(NS)	0.358	(NS)		
<i>Owenia</i> density	-0.124	(NS)	-0.342	(NS)	-0.459	(0.011)

**Table 5:** Results of the Tukey HSD post-hoc test to assess the PCA groups responsible for the significant effect detected in the one-way ANOVA. Values represent levels of significance; NS = non-significant

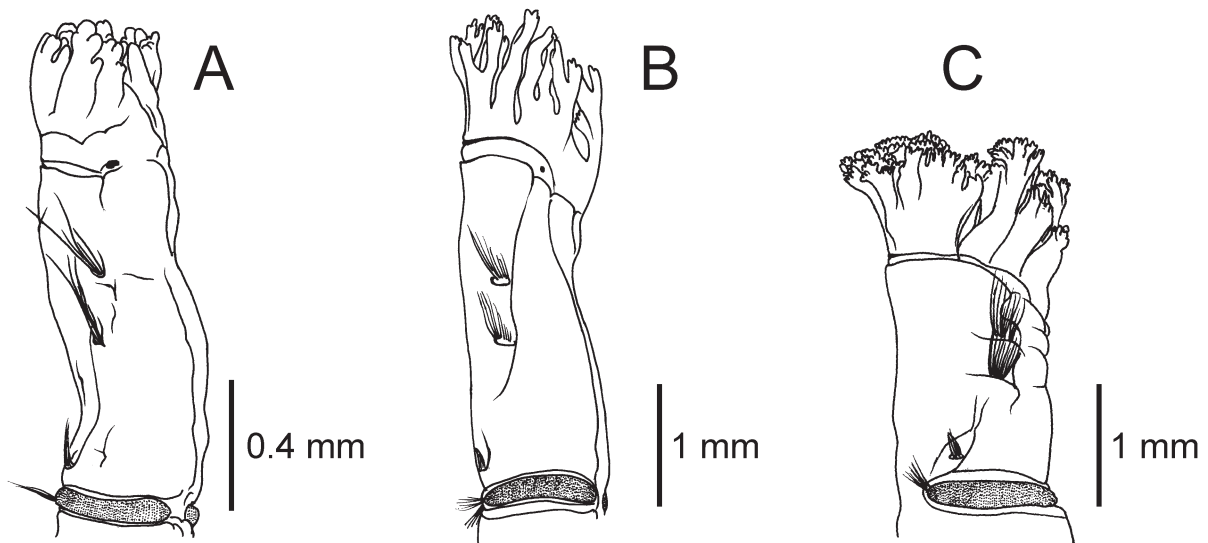
Density	I	II	III
II	0.05		
III	0.01	NS	
IV	0.008	NS	NS
Depth	I	II	III
II	0.02		
III	0.0007	NS	
IV	0.0002	0.0002	0.0002
Median grain size	I	II	III
II	NS		
III	0.0002	0.004	
IV	0.0002	0.0002	NS
Silt + clay	I	II	III
II	NS		
III	0.001	0.004	
IV	0.0002	0.0002	0.007
Gravel	I	II	III
II	NS		
III	0.0002	0.0003	
IV	0.0002	0.0002	0.02
Organic matter	I	II	III
II	NS		
III	NS	NS	
IV	0.05	NS	0.002
Organic carbon	I	II	III
II	NS	NS	NS
III	NS	NS	NS
IV	NS	NS	NS
Pore water	I	II	III
II	NS		
III	0.03	NS	
IV	0.0002	0.0002	0.0005



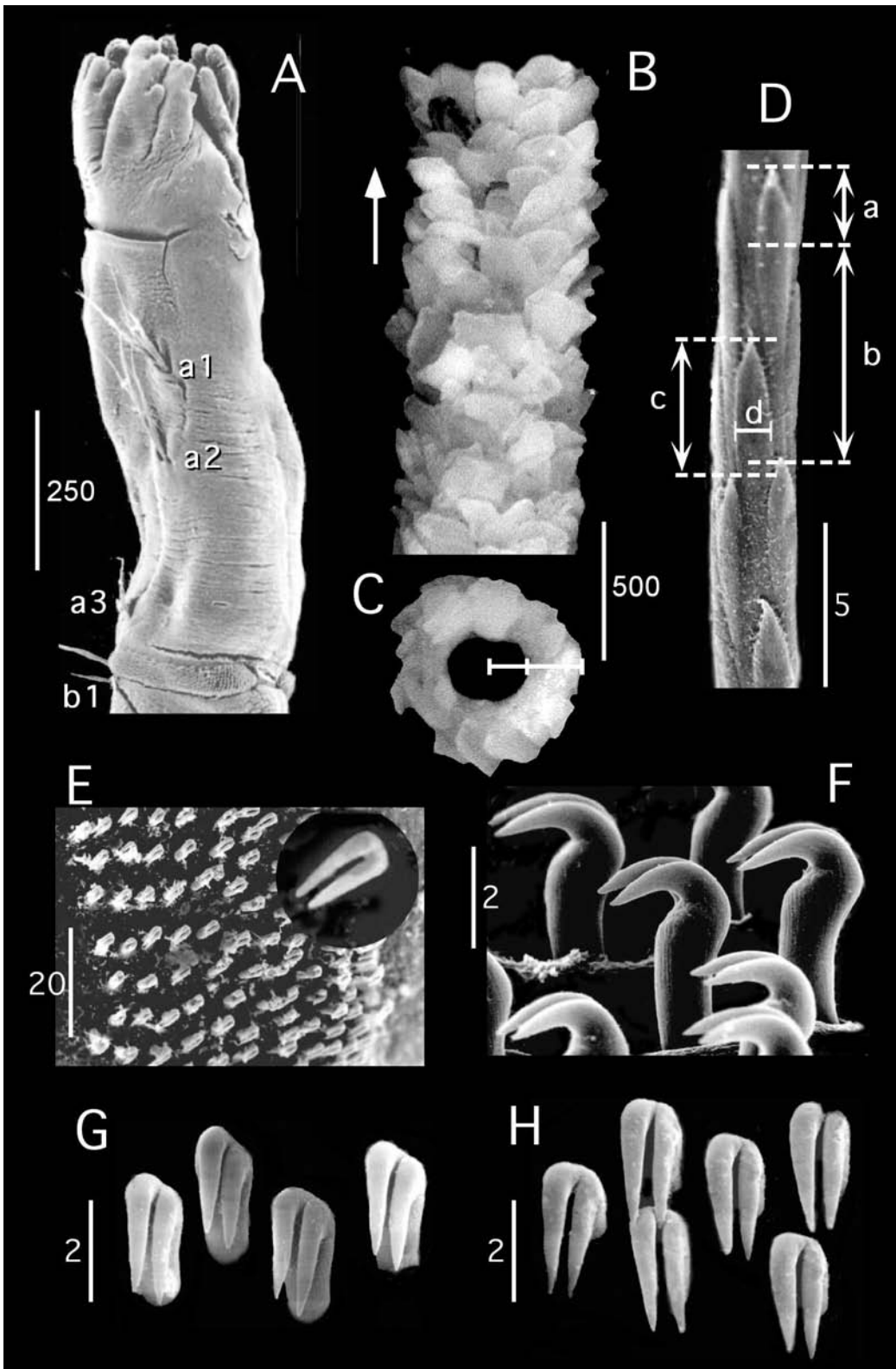
**Fig. 1:** Map of collecting area and sampling stations. Asterisk indicates type locality of *Owenia persica* sp. nov.



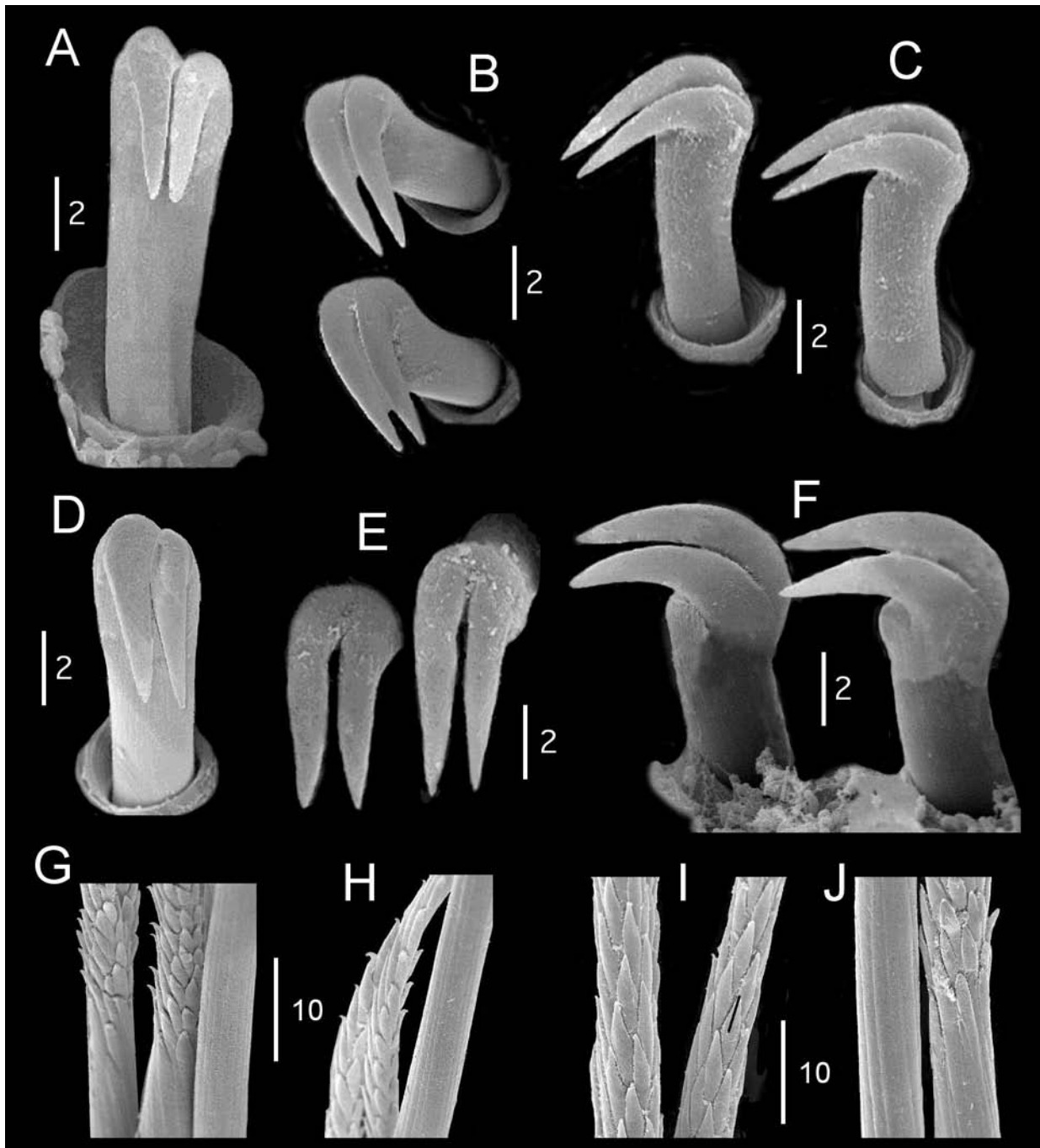
**Fig. 2:** Morphological parameter definitions. (A) Anterior body region. (B) Hook, lateral view. (C) Hook, apical view. (D) Hook, ventral view. b= branchial length; d = width of shaft; do = dorsal offset of teeth; l = thorax length; m(s) = manubrium (shaft) ; n = nuchal width; nc = nuchal curve; np = nuchal process; o = length of free part of teeth; r(h) = rostrum (head); s = distance between teeth and tip of shaft; sh = position of shoulder, if present; vo = ventral offset of teeth; w = body width.



**Fig. 3:** *Owenia* spp., anterior region in lateral view. (A) *O. persica* sp. nov. from Iran. (B) *O. persica* sp. nov. from Kuwait. (C) *O. sp.* from Strait of Hormuz.

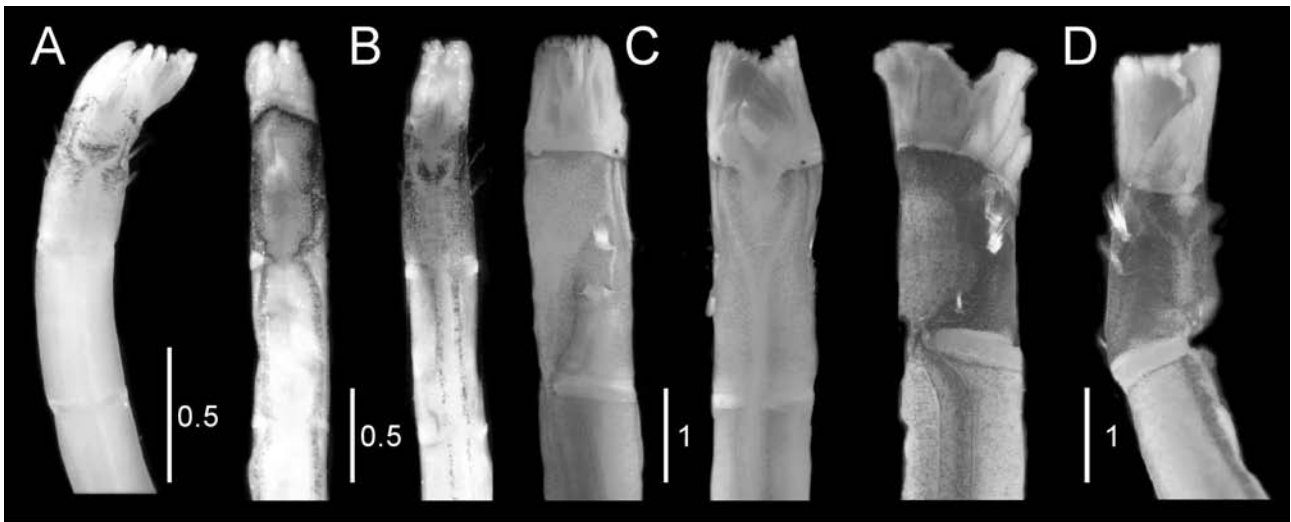


**Fig. 4:** *Owenia persica* sp. nov. from Iran. (A) SEM view of thorax, right side (a1–3: thoracic segments; b1: first abdominal segment). (B) Arrangement of sand particles in a tube section (arrow points in anterior direction). (C) Cross section of tube. (D) midsection of capillary seta from first abdominal segment, indicating parameters measured to characterize scale pattern. (E) SEM view of middle part of first abdominal torus from the right side, showing close view of hook with same general orientation. (F) Lateral view of hooks from first abdominal segment. (G) Ventral view of hooks from first abdominal segment. (H) Apical view of hooks from first abdominal segment. Scale bar lengths given in  $\mu\text{m}$ .

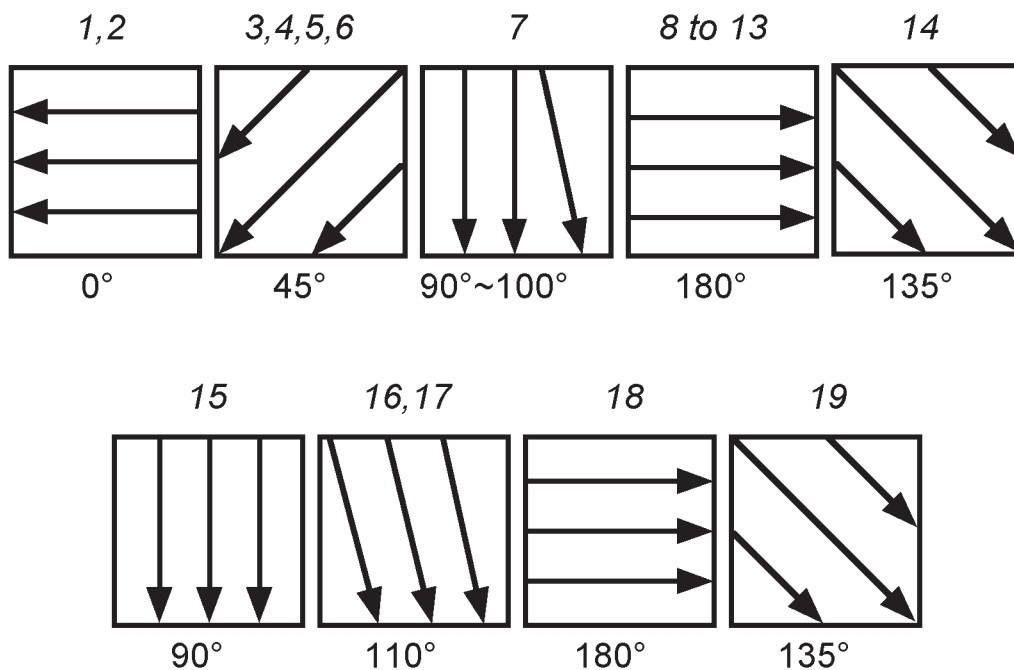


**Fig. 5:** SEM views of chaetae. (A–C, G, H) *Owenia persica* sp. nov. from Kuwait; (D–F, I, J) *Owenia* sp. from Strait of Hormuz. (A, D) Ventral view of hooks. (B, E) Apical view of hooks. (C, F) Lateral view of hooks. (G, J) Capillary chaetae showing basal smooth section and beginning of scaled section. (H) Capillary chaetae showing basal smooth section and end of scaled section. (I) Capillary chaetae showing middle part of scaled section. Scale bar lengths given in  $\mu\text{m}$ .





**Fig. 6:** Colour patterns. (A, B) *Owenia persica* sp. nov. from Iran; (C) *Owenia persica* sp. nov. from Kuwait; (D) *Owenia* sp. from Strait of Hormuz: (A) Brownish colouring in a recently collected specimen in ventral view. (B–D) Methyl green staining pattern of anterior end of body in dorsal (left) and ventral (right) views. Scale bar lengths given in mm.



**Fig. 7:** *Owenia persica* sp. nov.; variation in hook orientation in relation to longitudinal axis, along chaetigers of abdominal region of a given specimen. Italics: chaetiger numbers.

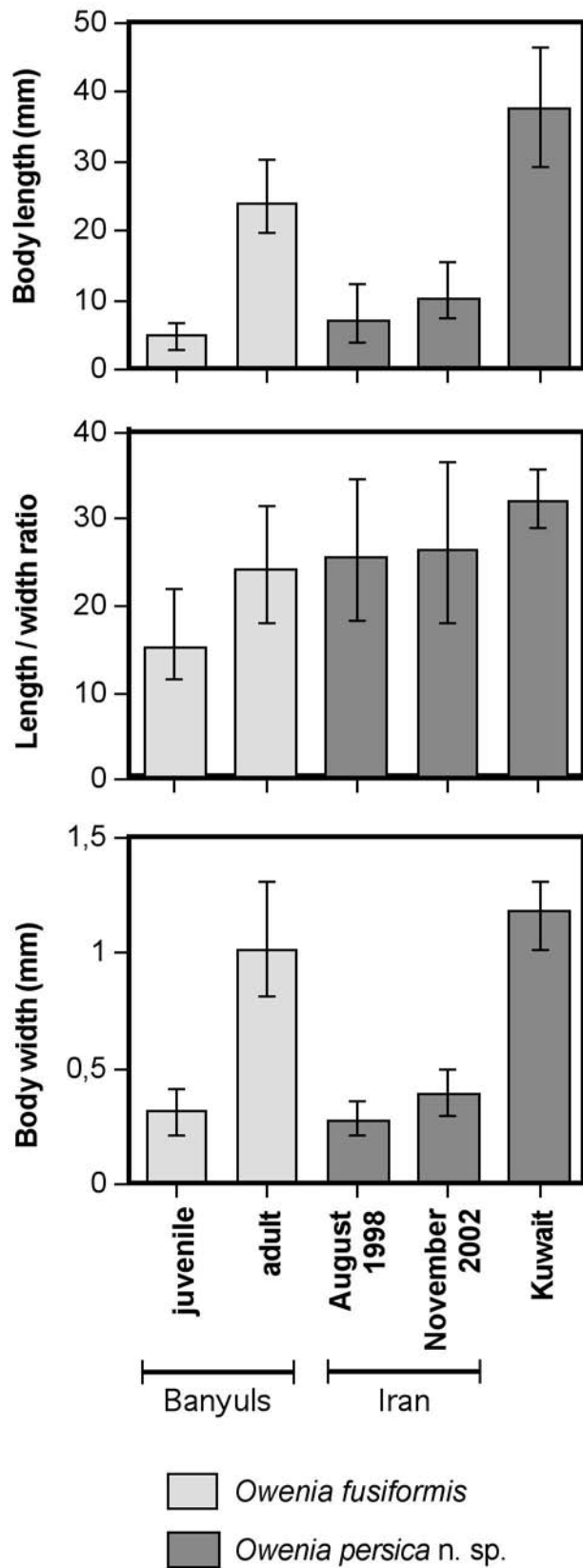
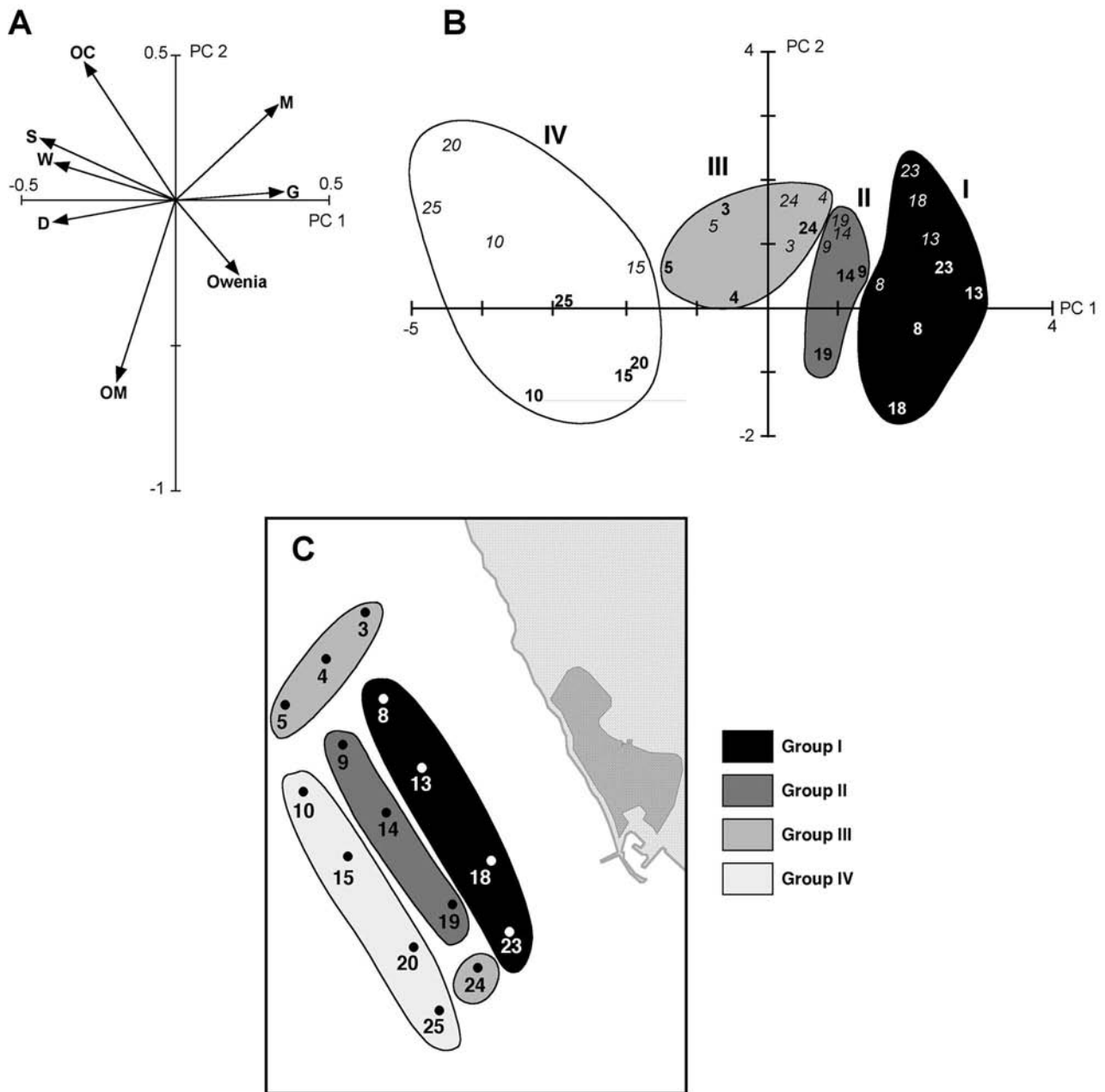
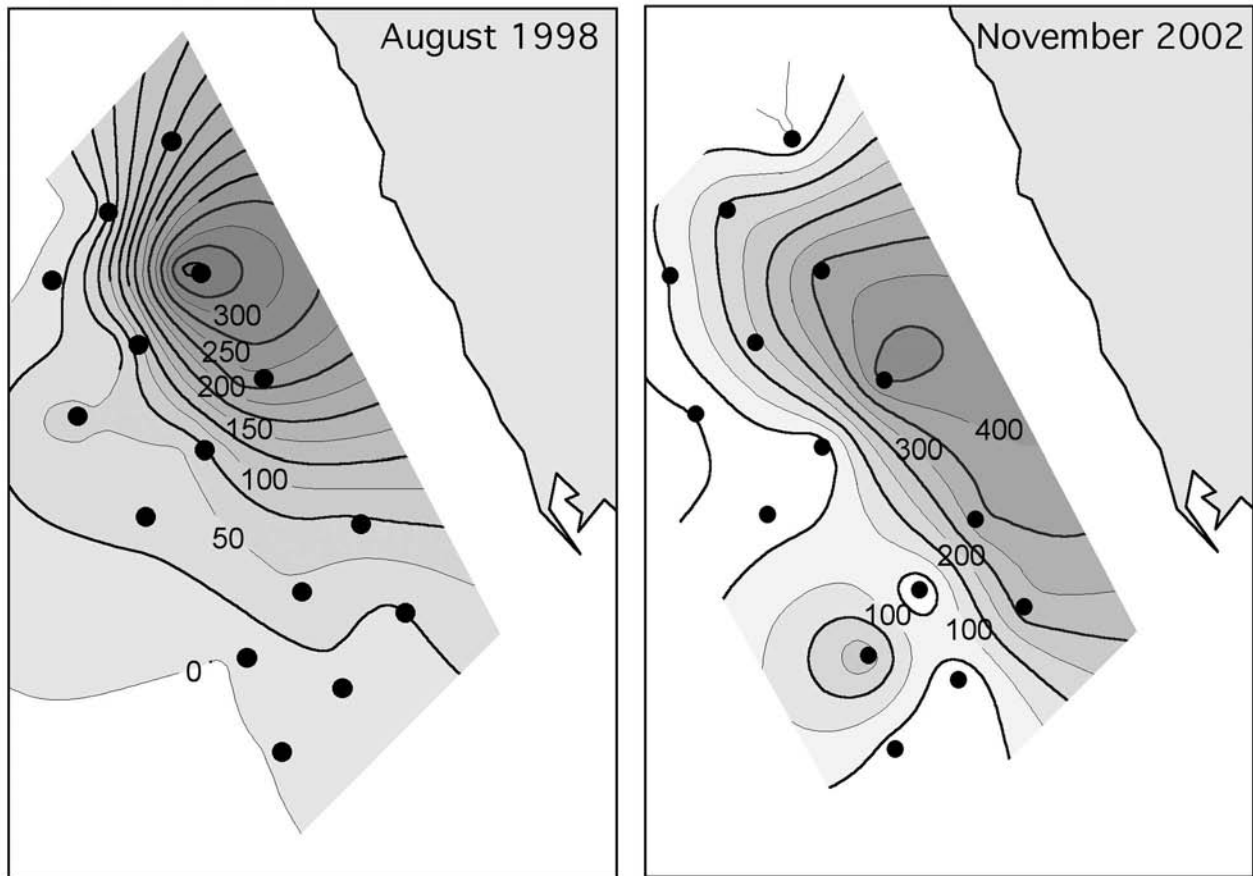


Fig. 8: *Owenia persica* sp. nov.; size comparisons between Iranian (August 1998, November 2002) and ~~Kuwait~~ populations, and between them and Mediterranean juveniles and adults of *O. fusiformis*.



**Fig. 9:** Results of principal component analysis. (A) Axis definition. (B) Distribution of stations along axis, and proposed grouping. (C) Grouping of sampling stations according to the PCA. Boldface: 2002 samples: D = depth; G = gravels; M = median grain size; OC = organic carbon; OM = organic matter; S = silt; W = pore water.



**Fig. 10:** *Owenia persica* sp. nov.; density distribution (ind. m<sup>-2</sup>) of the Iranian population.

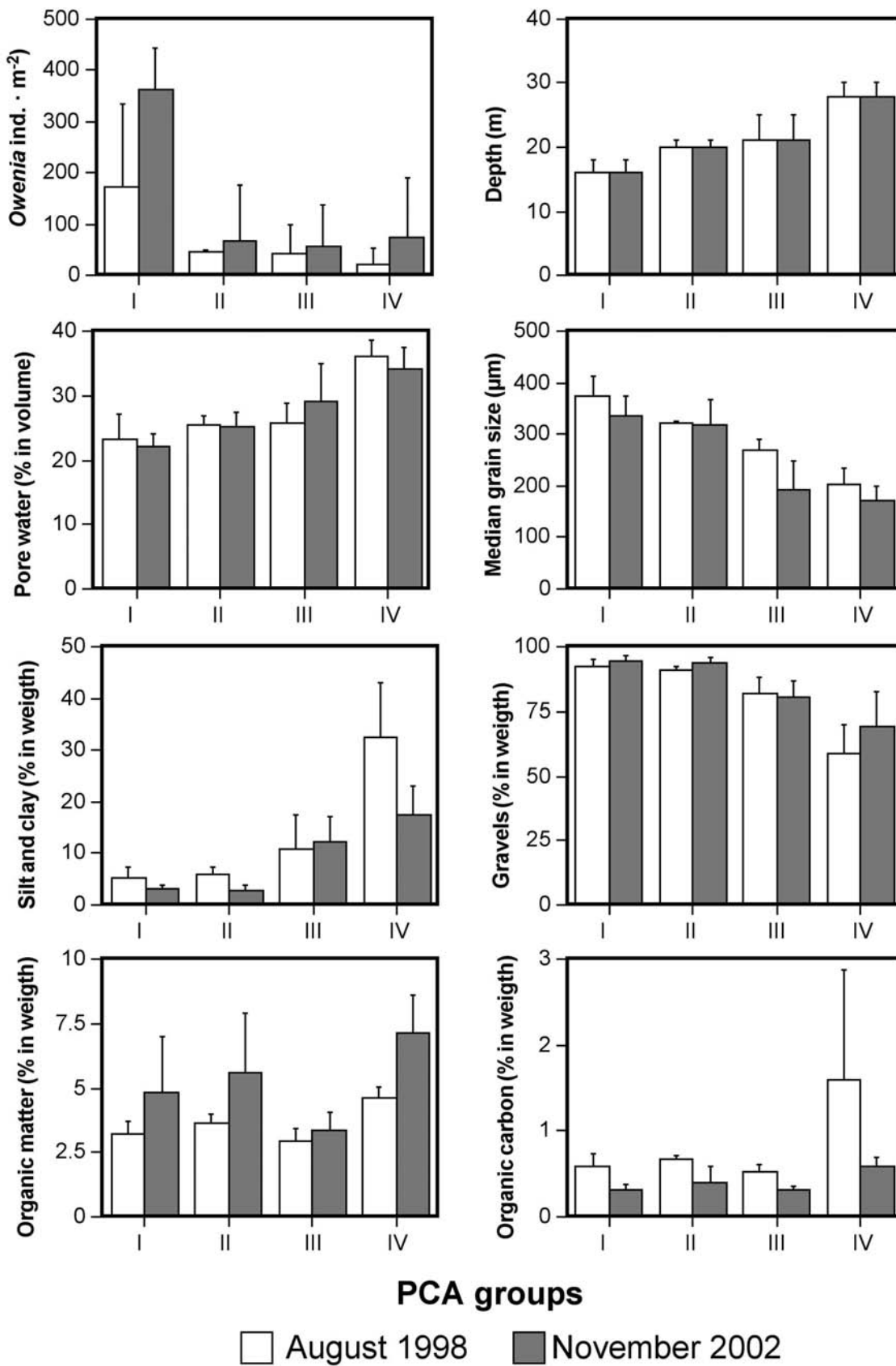


Fig. 11: *Owenia persica* sp. nov.; density and environmental variables off Assaluyeh, classified according to study year and PCA groups.