OPISTHOBRANCHIATE MOLLUSCA FROM GHANA: ONCHIDORIDIDAE AND AEGIRIDAE, WITH A CHECKLIST AND A REVIEW OF THE ECOLOGY AND DIVERSITY OF THE DORIDOIDEA

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Abstract *Descriptions are given of* Onchidoris depressa *(Alder & Hancock 1842) and* Aegires punctilucens *(d'Orbigny 1837) from Ghana belonging to the families Onchidoriddidae and Aegiridae respectively, both of which are widespread in temperate waters of the North-east Atlantic, together with brief descriptions of six further species of doridoid nudibranchs which are insufficiently documented to justify their being formally described and named. Fifty-three species of doriddoid nudibranchs have been recorded from Ghana, the most biodiverse site being the shallow 10 m deep offshore reef. It is estimated that a more intensive study might have yielded more than 70 species, but this is far fewer than can be found in the tropical Indo-Pacific region, probably because West Africa experiences a cold water current and lacks coral reefs. Thirty-one of the 53 species are currently only known from Ghana, probably because west African nudibranchs are so poorly known. Others also occur elsewhere in the Gulf of Guinea, Angola, the Azores, Canaries, Madeira, the Mediterranean and even northern Europe. There are 7 amphiatlantic species and 4 recorded from the Indo-Pacific, these latter probably being transported by boats.*

Key words *Doridoidea,* Onchidoris, Aegires, *ecology, biodiversity*

INTRODUCTION

Until recently the opisthobranchiate molluscan fauna of West Africa has been known from just a few records (notably e.g. Pruvot-Fol, 1953; Marcus, 1968; Edmunds, 1968a, b), but a large collection of doridoid nudibranchs from Ghana has now been described (Edmunds, 1981, 2007, 2009, 2010, 2011, 2012). The purpose of this paper is to describe the remaining species of doridoid nudibranchs belonging to the families Onchidoriddidae and Aegiridae together with a few poorly known doridids and discodoridids collected in Ghana between 1963 and 1973, and to document the biodiversity of doridoid nudibranchs from Ghana.

MATERIAL AND METHODS

All of the material described here was collected near to Accra and Tema in Ghana, close to longitude 0 latitude 5.7 by the author and by Mr Walter Pople. The method of collection, processing and preservation of specimens is described by Edmunds (2007, 2011). Body measurements and drawings of entire animals are from life unless otherwise stated.

The material collected and described in this paper (including microscope slides of radulae but excluding severely damaged specimens) is deposited in the Natural History Museum, London.

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SYSTEMATIC DESCRIPTIONS

Family Onchidoriddidae Alder & Hancock 1845

Genus *Onchidoris* Blainville 1816

Type species *Onchidorus leachi* Blainville 1816 by monotypy.

Renamed *Onchidoris leachii* Blainville: Blainville, 1824: 280.

The genus *Onchidoris* was originally spelt *Onchidorus* (1816) but a few years later Blainville himself spelt it *Onchidoris* (1824). This spelling was repeated by Gray (1840), and spelt with *-is* it conforms to the other genera derived from the original *Doris* Linnaeus 1758. It is possible that the original *-us* was a misprint. Justification for the genus and its spelling is given by Iredale & O'Donoghue (1923) quoted in full by Russell (1971).

Onchidoris depressa (Alder & Hancock 1842)
Figs 1A–B, 2

Doris depressa Alder & Hancock 1842: 32.
Onchidoris depressa – Adams & Adams, 1858: 58.

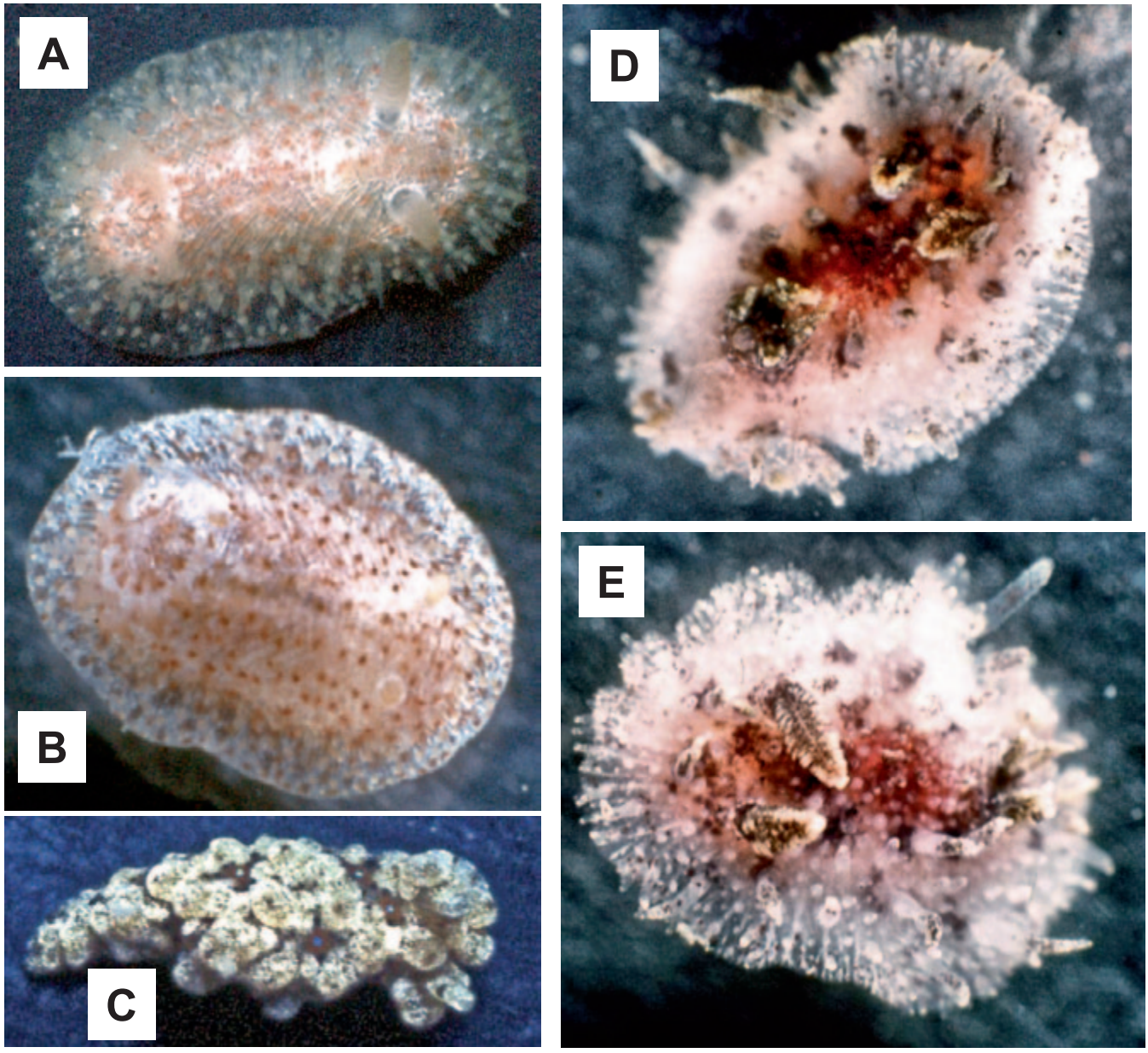

Figure 1 A *Onchidoris depressa* (Alder & Hancock 1842) 3 mm long, October 1969; B *Onchidoris depressa* (Alder & Hancock 1842) 4 mm long, November 1967; C *Aegires punctilucens* (d'Orbigny 1837) 3 mm long, December 1969; D & E Onchidorid species A 7 mm long, December 1967.

Onchidoris tridactila Ortea & Ballesteros 1982: 241–244, figs 2, 3, 8.

Material examined NHMUK reg. nos 20130440 & 20130445 (radula): 9–12 m reef Kpone Bay 1 spec. 4 mm long 19 November 1967, 1 spec. 5.5 mm long 15 December 1967, 1 spec. 3.5 mm long 19 October 1969, 1 spec. 6 mm long 2 November 1969, 2 spec. 5 mm long 22 February 1971, 1 spec. 4 mm long 11 March 1971, 2 spec. 2 mm long 10 April 1971.

External features (Figs 1A, B, 2A–F) Body oval with foot hidden beneath notum; dorsal surface with numerous slender papillae (Fig. 2E), shorter towards edge, spicules clearly visible in dorsal view arranged horizontally in centre of notum, diagonally in lines between rhinophores and gills, at right angles to mantle edge, but irregularly inside gill circlet (Fig. 2F); rhinophores slender up to 1 mm long with 8–11 lamellae sloping back to a posterior ridge (Fig. 2D); 13–16 unipinnate gills with up to 7 pinnae on each side of rhachis, forming a circle ending posteriorly in a spiral close to anus where new minute gills form as the animal grows, usually an even number of gills, broad

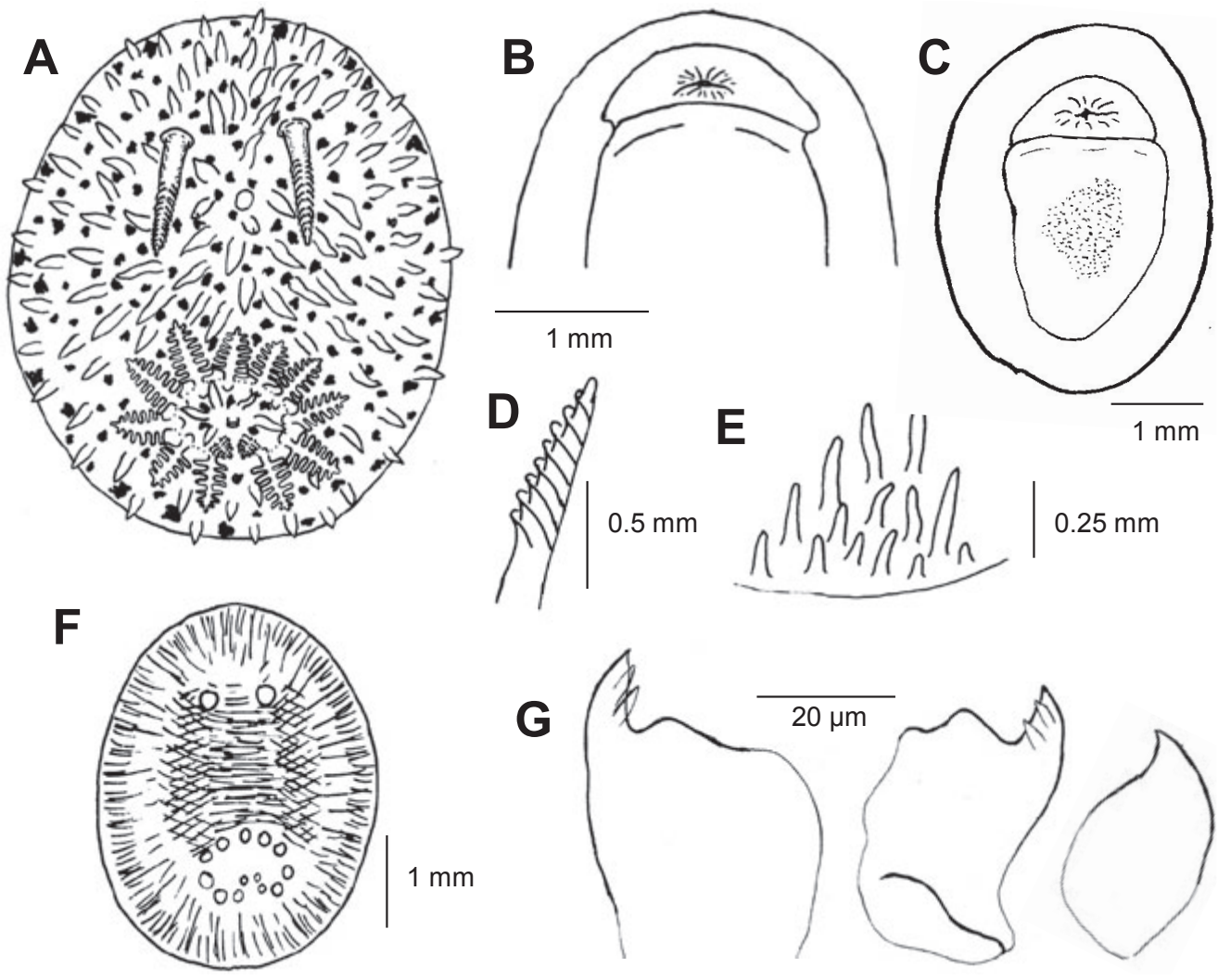

Figure 2 *Onchidoris depressa* (Alder & Hancock 1842), 4 mm long (except for B and G), November 1970: A dorsal view; B ventral view of 5.5 mm specimen; C ventral view; D rhinophore; E dorsal papillae; F dorsal view to show arrangement of dermal spicules; G radular teeth from 5 mm specimen. Black spots in A are orange in life.

space between anus and gills with some short papillae similar to those on notum (Fig. 2A); head ventrally forming a semicircle with no oral tentacles, foot broad, rounded, lacking a notch (Fig. 2 B, C). This description applies to specimens 4–6 mm long: smaller animals have fewer gills and fewer lamellae on rhinophores. Body transparent greyish white with yellowish orange to reddish orange spots all over (Fig. 1A, B), some specimens also with brown spots over entire notum or just near edge, or with brown centres to larger orange spots; papillae colourless or pale orange; rhinophores and gills pale orange or yellow; ventrally head, foot and mantle pale orange with blackish viscera showing through foot.

Internal morphology The radula of a 5 mm animal has the formula 16×1.1.0.1.1. The lateral teeth are broad with a thickened basal region and a curved cusp bearing two denticles, a few with three or four denticles and several with no denticles (Fig. 2G). The marginal teeth are oval with a small pointed tip.

Behaviour One 5 mm animal was observed feeding on the bryozoan *Stylopoma duboisii* (Audouin) after first removing the frontal membrane, but it did not eat a species of *Reptadeonella* (bryozoans identified by P.L.Cook). The skin secretion of this species is not acidic (tested with BDH wide-range indicator paper).

Geographical range *Onchidoris depressa* was first described from the British Isles where it is widely distributed though rarely common (Thompson & Brown, 1984). It also occurs on the Atlantic

coasts of France, Spain and Portugal (Bouchet & Tardy, 1976; Cervera, Calado, Gavaia *et al*., 2006). The records from Banyuls and Naples in the Mediterranean (Pruvot-Fol, 1954; Schmekel, 1968) are probably misidentifications (Schmekel & Portmann, 1982; and see below). The present records from Ghana are thus a considerable extension of the range of this species in the Atlantic Ocean. There have also been recent reports of *O. depressa* from India, Korea, New Caledonia and Tasmania (Sea Slug Forum, 2003–2009) which are further discussed below.

Remarks *Onchidoris depressa* is well illustrated by Alder & Hancock (1845–55) and more recently by Thompson & Brown (1984) and by Dr Henning Lemche of a specimen from Ireland (Just & Edmunds, 1985). It can be easily recognised by the yellow, orange or red spots on the notum, elongated slender papillae, wide gill circlet, and spicules clearly visible through the body wall. The radular teeth of the present specimen are very similar to those drawn by Thompson & Brown (1984) but with fewer though variable number of denticles on the lateral teeth. Although it has been reported from the Mediterranean (Pruvot-Fol, 1954; Schmekel, 1968) these latter specimens were probably *Onchidoris bouvieri* (Vayssière 1919) (Schmekel & Portmann, 1982) while the former may have been *O. neapolitana* (Delle Chiaje 1844) which has a similar radula (Thompson & Brown, 1984). Since *O. depressa* occurs on the Atlantic coast of Spain and Portugal but not in the Mediterranean while the other two species are confined to the Mediterranean, the question arises as to whether either *O. bouvieri* or *O. neapolitana* may be conspecific with *O. depressa*. *O. bouvieri* differs from *O. depressa* in colour, spicular papillae on the notum, three tubercles on the rhinophore rim and more slender lateral radular teeth. *O. neapolitana* can be distinguished by its bright or dark red colour (Schmekel & Portmann, 1982; Sánchez-Santos, 2005; Rudman, 2006), but since it feeds on red bryozoans its colour could be derived from its food. Its long papillae, wide gill circlet and radular teeth are similar to those of *O. depressa*. However, it differs from *O. depressa* in having large brown spots towards the edge of the notum and no indication of small orange spots over the entire surface, so pending a more detailed examination of both species I regard them as being closely related but distinct.

Another very similar species, *Onchidoris tridactila* Ortea & Ballesteros 1982, has been described from northern Spain alongside *O. depressa*. Ortea and Ballesteros (1982) distinguish the two on the basis of yellow or pink rhinophores and yellow gills in *O. tridactila* compared with salmon rhinophores and white gills in *O. depressa*; three papillae on the rhinophore rim and a wide gill circlet of 9–12 gills in *O. tridactila* compared with no papillae on the rhinophore rim and a narrow gill circlet of 5 gills in *O. depressa*; and partitions separating eggs which are in a single row in the egg ribbon of *O. tridactila* whereas in *O. depressa* the eggs are not separated and their placement is less regular. However, Thompson & Brown (1984) report some individuals of *O. depressa* having papillae on the rhinophore rim and up to 12 gills while Lemche's meticulous illustration of *O. depressa* from Ireland shows a wide circlet of 10 gills with some papillae inside it, just like the present material (Just & Edmunds, 1985). The photographs of radular teeth given by Ortea & Ballesteros (1982) are at an unusual angle and so cannot easily be compared with those of *O. depressa*, but they could be similar. The egg ribbon of *O. depressa* from the British Isles does not appear to have been described but ribbons from Tasmania, New Caledonia and India have eggs in a single row (Rudman, 2003a, 2003c; Bhave, 2009). *O. tridactila* was found on the bryozoan *Schizomavella linearis* (Hassall) which is the food of *O. depressa* in the British Isles (Thompson & Brown, 1984), but *O. depressa* feeds on other bryozoans elsewhere (Ortea & Ballesteros, 1982; this paper). On the basis of the evidence presented here I conclude that *O. tridactila* Ortea & Ballesteros 1982 is conspecific with and a junior synonym of *O. depressa* Alder & Hancock 1842.

A new species of *Onchidoris* has recently been described from Brazil, *Onchidoris brasiliensis* Alvim, Padula & Pimenta 2011, which is very similar in external features and colouration to *O. depressa*. According to Alvim *et al*. (2011) it differs from *O. depressa* in having tubercles inside the gill circlet, a small tubercle (a 'concretion') close to the thickened base of the lateral radular tooth, and a slender pointed cusp to the marginal tooth. However, *O. depressa* can have tubercles inside the gill circlet (Just & Edmunds, 1985), so this leaves just the two differences in the radular teeth as diagnostic for *Onchidoris brasiliensis*. The specimen described here from Ghana has neither

a tubercle on the inner radular tooth nor a slender cusp on the marginal tooth, so I consider it to be more similar to European *O. depressa* and distinct from *O. brasiliensis*. However, it is clearly necessary to study more material from both sides of the Atlantic including DNA profiling in order to confirm whether *O. brasiliensis* really is distinct from *O. depressa*.

Other species of *Onchidoris* from Europe differ from *O. depressa* in colouration, in details of the dorsal papillae, rhinophores and gills, and in the radular teeth (Thompson & Brown, 1984; Just & Edmunds, 1985; Ortea, 1978, 1979; Ortea & Urgorri, 1979; Cervera *et al*., 2006).

Recently there have been reports of *O. depressa* from several sites in the Indo-Pacific region: Tasmania, New Caledonia (Rudman, 2003a), India (Bhave, 2009; Rudman, 2009b) and Korea (Koh, 2009; Rudman, 2009a). Picton (2010) has questioned whether the Indian specimen is indeed *O. depressa* because of somewhat different papillae, and pending a more careful examination including DNA profiling of specimens from the Indo-Pacific, there must remain some uncertainty as to whether they are all conspecific. However, the photographs of living animals from all sites show that they are very similar in external morphology and colouration, and the radula of the Tasmanian specimen is very similar to that of specimens from Europe (Rudman, 2003b). I therefore consider it probable that *O. depressa* is now widespread throughout warm and temperate waters of the Indo-Pacific as well as the Atlantic coasts of Europe and Africa. The fact that the Indo-Pacific records are all recent in spite of some of these areas (notably Australia) having been studied intensively for more than 50 years suggests that this species may be a recent immigrant to this region. Since it feeds on bryozoans it can probably be transported on boats in the same way as are several other bryozoan-feeding doridaceans (Edmunds, 2010).

Onchidorid sp. A
Figs 1 D–E, 3A–B

Material examined NHMUK reg. no. 20130441: 10 m reef, Kpone Bay 1 spec. 7 mm long 13 December 1967.

External features Body oblong with foot hidden beneath notum (Fig. 3A); dorsal surface with numerous low rounded tubercles and fewer long tapering papillae, some smooth but most rugose, the largest almost 2 mm long (Fig. 3A inset); rhinophores 3 mm long but almost completely retractile, slender with 20 sloping lamellae arising from a frontal groove (Fig. 3A), rhinophore socket with many small rounded tubercles; 4 irregularly unipinnate gills not retractile; ventrally in the mantle there is a radial arrangement of spicules, head forms an almost complete circle with no trace of oral tentacles, foot narrow, not bilabiate, and lacking a notch. Notum semi-transparent grey with a few dark maroon spots (Fig. 3A) and numerous minute orange-red dots between the papillae (Fig. 3A inset), orange and purple-brown viscera showing through centrally; papillae with spicules visible in base and small brown spots distally (Fig. 3A inset); rhinophores yellow-brown with many brown blotches on club and cream dots especially at tip and edges of lamellae; gills brown with dark brown markings and white dots; ventrally head and foot orange.

Internal morphology Not examined.

Geographical range Known only from Ghana.

Remarks Superficially this species resembles *Thordisa poplei* Edmunds 2011 in colouration and long papillae on the notum, but its morphology is quite different: it has no oral tentacles and non-retractile gills. It probably belongs to the Onchidorididae, but in view of the unique nature of the specimen I am reluctant to damage it by removing the buccal mass.

Family Aegiridae Fischer 1883

Genus *Aegires* Lovén 1844

Type species *Polycera punctilucens* d'Orbigny 1837, by monotypy.

Aegires punctilucens (d'Orbigny 1837)
Figs 1C, 3C–D

Polycera punctilucens d'Orbigny 1837: 7–9, pl. 106.
Aegires punctilucens – Lovén, 1844: 49.
Aegires hispidus Hesse 1872: 346.

Material examined 10 m reef Kpone Bay 1 small spec. 22 January 1965 (dried up), 1 spec. 3 mm long 14 December 1969 NHMUK reg. no. 20130442.

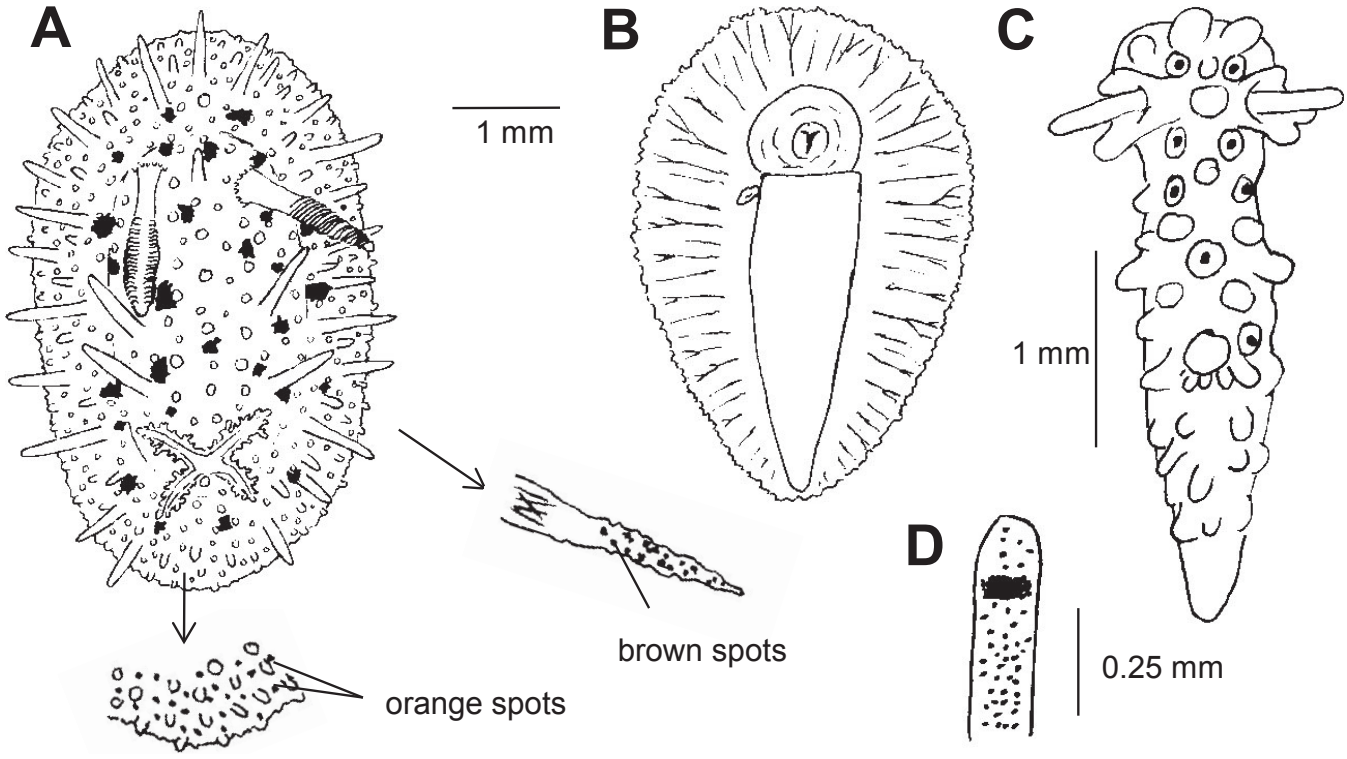

Figure 3 Onchidorid sp. A, 7 mm long: A dorsal view with detail of dorsal papilla and tubercular edge of mantle; B ventral view. *Aegires punctilucens* (d'Orbigny 1837) 3 mm long: C dorsal view; D rhinophore. Black spots in A are dark maroon in life; spots in D are cream and black band is brown in life.

External features (Figs 1C, 3C) Body elongate with blunt, shortly tapering tail; dorsal and lateral surfaces with about 30 short thick tubercles of variable size; gill scarcely visible below tubercles; rhinophores smooth arising from cylindrical sockets with three tubercles on outer rim. Body greyish brown with cream mottling and scattered darker brown dots, conspicuous turquoise spots in patches of brown (Fig. 1C); tubercles mostly cream; rhinophores with cream dots on shaft and tip and brown band just below tip (Fig. 3D).

Internal morphology The species can be recognised from its external characteristics and was not dissected so as to preserve the single remaining specimen intact.

Geographical range Mediterranean, western Europe from Norway to Spain, West Africa to Ghana (Schmekel & Portmann, 1982; Thompson & Brown, 1984; Fahey & Gosliner, 2004; this paper).

Remarks *Aegires punctilucens* has been beautifully illustrated by d'Orbigny (1837) and by Alder & Hancock (1845–55), the former recently displayed by Rudman (2005a) in Sea Slug Forum which also has several recent photos of European specimens. A closely related Mediterranean species of the genus is *A. leuckartii* Verany 1853, which may be conspecific with *A. punctilucens*. Fahey & Gosliner (2004) give a thorough review of the available information and conclude that pending careful morphological examination of additional material the two species should be considered distinct. *A. leuckartii* lacks the turquoise-green or blue spots on the dorsum which occur in *A. punctilucens* and in the present material. Rudman (2005b) argues that the Indo-Pacific *Aegires* allocated to *A. execches* is conspecific with European *A. punctilucens* and the widespread geographical occurrence is probably a consequence of travelling on boat hulls, but Fahey & Gosliner (2005) present detailed evidence to affirm their view that the two species are distinct. While there is strong evidence that several species of the Polyceridae travel on boat hulls (Edmunds, 2010) there is no evidence to my knowledge that this occurs with sponge-eating dorids (Edmunds, 2011, 2013). This may be because while the bryozoan food of polycerids often thrive on boat hulls, most sponges are unlikely to be able to withstand the strong water currents experienced on a moving

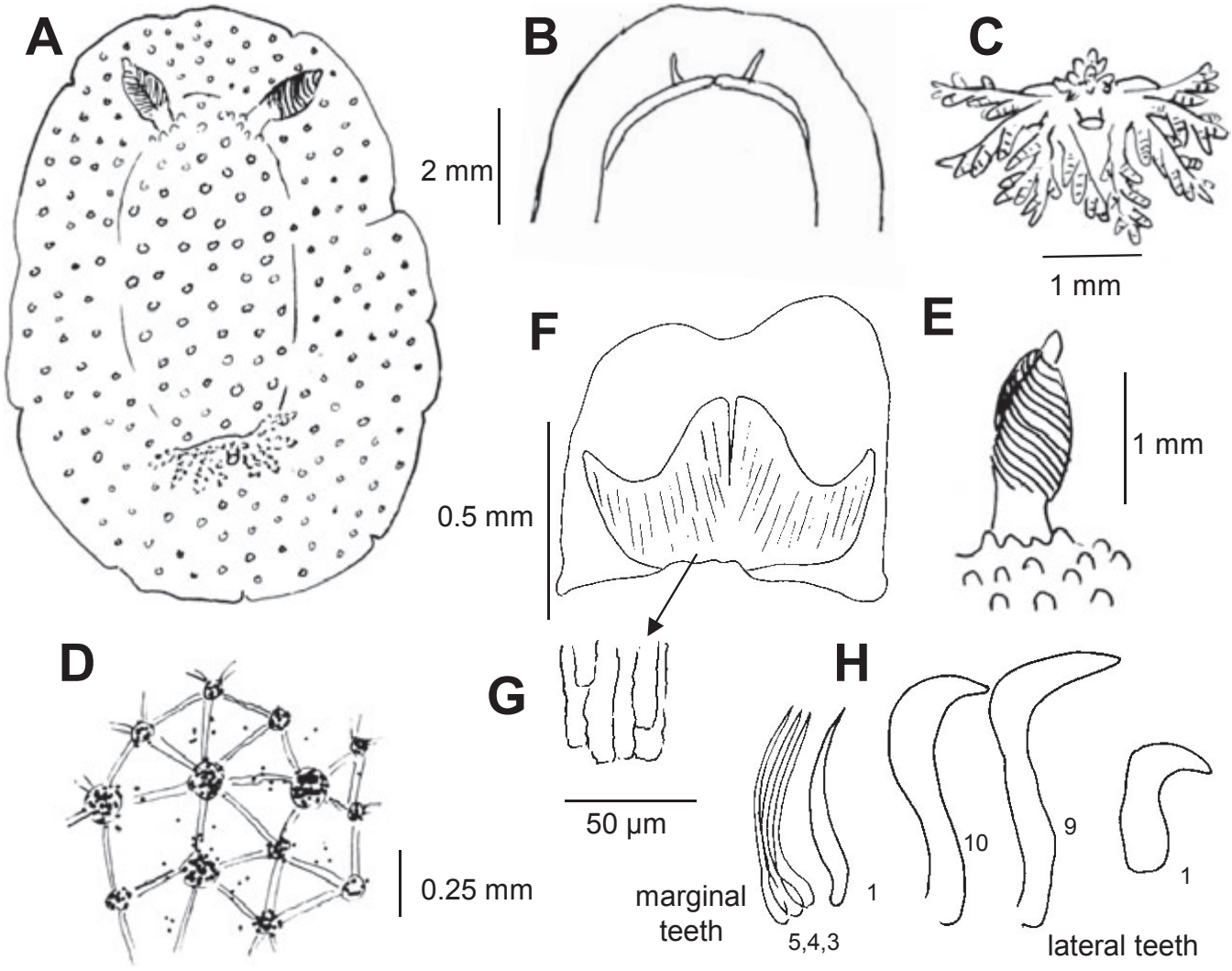

Figure 4 Discodorid sp. A: A dorsal view; B ventral view of head; C gills; D tubercles on notum; E rhinophore from left side; F jaw with area of rodlets hatched; G rodlets from jaw; H lateral and marginal teeth from radula with numbers indicating position of teeth in row. Black dots in D represent the brown dots concentrated in tubercles which are joined by spicules.

boat. With just a single immature specimen from Ghana I cannot contribute to this debate but simply record an extension to the geographical range of *A. punctilucens* round the coast of West Africa to Ghana.

The family name used for *Aegires* and the related genus *Notodoris* has for many years been either the Aegiretidae or the Notodorididae, but the first of these names is nomenclaturally incorrect: it should be the Aegiridae (Willan, 2000). Fahey & Gosliner (2004, 2005) use Aegiridae and justify this in their 2005 note while Rudman (2005b) prefers to retain Aegiretidae and cites 12 uses of this name in the literature to which can be added two further references cited in this paper: Schmekel & Portmann (1982) and Valdés *et al.* (2006). The critical point from the Official ICZN rules is Article 29.5 which states that old names can still be retained if they have been used 25 times in the past 50 years. Only 9 of the references cited above are within this time period, and while a thorough search of the literature would, I am sure, reveal several more, I believe they are unlikely to reach 25 because this is not a commonly researched family. Pending a ruling from the International Commission I am here using the nomenclaturally correct name: Aegiridae. The thorough phylogenetic analysis by Fahey & Gosliner (2004) supports the view that *Notodoris* Bergh 1875 and *Triopella* Sars 1878 should be regarded as junior synonyms of *Aegires* which is therefore the sole genus in the family.

Other Doridacea

In addition to the species of Doridacea described by Edmunds above and in previous papers single specimens of several further species were collected. Some were in poor condition and not preserved in the expectation that they would be found again later, others were very immature or have subsequently been lost so that they cannot be named. Nevertheless in order to describe the biodiversity of the doridacean fauna of Ghana and to assist malacologists who may find them in the future they are described briefly here.

Discodorid sp. A

Fig. 4A–H

Material examined 10 m reef Kpone Bay 1 spec. 10 mm long 22 January 1965. Radula preparation NHMUK reg. no. 20130447.

External features Body ovate, slightly longer than broad, tail not projecting beyond mantle (Fig. 4A); dorsal surface covered with sparse, low rounded tubercles without projecting spicules (Fig. 4D), smaller towards margin, but tubercles joined by spicules in dermis; rhinophore arising from socket with low tubercles, with 14 lamellae sloping back from frontal groove to posterior groove (Fig. 4E); 9 unipinnate gills with a few secondary pinnae (bipinnate) arising from socket that is transverse anteriorly (Fig. 4C); oral tentacles slender (Fig. 4B), foot notched with transverse anterior groove. Notum yellow, paler near margin, with minute brown dots concentrated especially on tubercles; rhinophores yellow with distal 10 lamellae dark brown, tip and upper lamellae with much white; gill socket and anus edged white, anterior four gills brown and white, posterior gills yellow with a few brown flecks; ventral surface of mantle and foot pale yellow.

Internal morphology The buccal mass was removed for examination. The labial cuticle has a W-shaped area composed of parallel rodlets (Fig. 4F–G). The radula was somewhat distorted but has the approximate formula 18 X 10.10.0.10.10. The lateral teeth are simply hamate, the marginal teeth are curved and needle-like (Fig. 4H).

Remarks The specimen unfortunately dried up so it is not appropriate to name it. It clearly belongs to the Discodorididae rather than the Doridiidae because of its slender oral tentacles (Valdés, 2002). The labial cuticle with rodlets, the shape of the radular teeth and the spicular tubercles separated from one another suggest it may be a *Hoplodoris* (again following Valdés, 2002). However, the subsequent meticulous *magnum opus* of Dayrat (2010) concludes that the key diagnostic character of the genus *Discodoris* is elongated and not sharply curved radular teeth, characters clearly exhibited in Fig. 4H. I therefore conclude that this is likely to be a species of *Discodoris*, but without further anatomical details I prefer to leave it as a species of discodorid. None of the species illustrated in the references cited below or in Edmunds (2011) correspond to this species.

Discodorid sp. B

Fig. 5A–D

Material examined NHMUK reg. nos 20130451/1 & 20130451/2 (radula): Teshie under stone at low tide 1 spec. 11 mm long 14 April 1965.

External features Body oblong with foot just projecting when crawling (Fig. 5A), covered with small, slender papillae, low and pyramidal when preserved (they do not appear to be typical caryophyllidia but my notes on the living animal are inadequate to be certain); rhinophores with 10 lamellae sloping back to posterior groove; 7 bipinnate gills; oral tentacles slender, foot bilabiate with median notch (Fig. 5B). Notum lemon yellow with scattered minute grey-brown dots, rhinophores grey with much dark brown especially on rhachis, tip white; gills brown and yellow.

Internal morphology The buccal mass was removed to examine the radula. There is no labial armature but the radular formula is 24×2.31.0.31.2. The innermost 10–12 teeth are simply hamate with zero or, very occasionally, one to three lateral denticles. Further along the row the teeth are larger with usually 6–9 lateral denticles and the outermost two teeth (the marginals) are small with fine pectinate bristles (Fig. 5C, D), only visible at high magnification.

Geographical range Known only from Ghana.

Remarks This appears to be an undescribed species of discodorid which was never found again in the next eight years of collecting. It is very similar to a specimen from Senegal in its granular

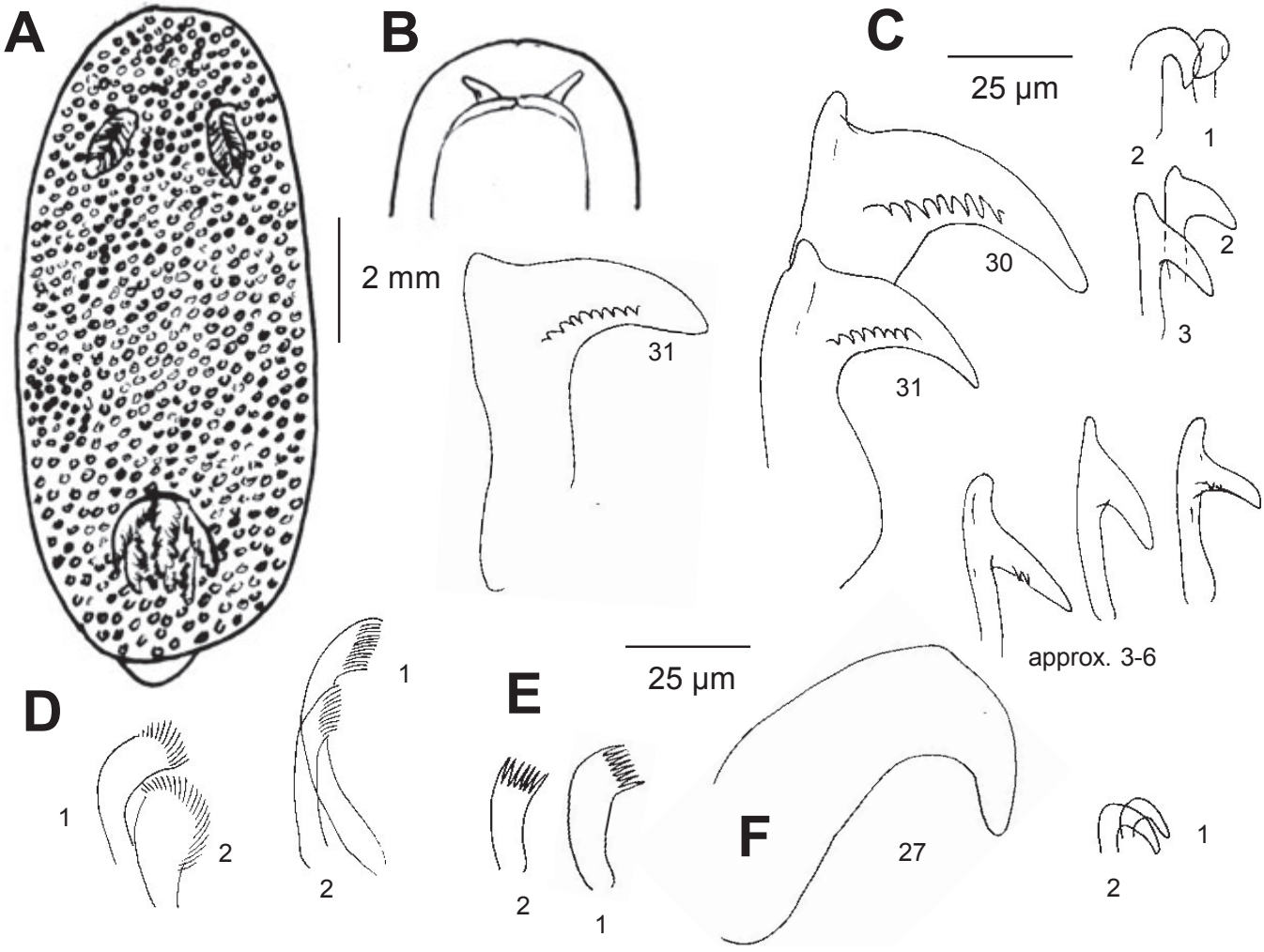

Figure 5 Discodorid sp. B: A dorsal view; B ventral view of head; C lateral teeth of radula with numbers indicating position of teeth in row; D four marginal radular teeth (to same scale as C). *Doris* sp. A: E two marginal radular teeth; F lateral teeth.

notum, shape of innermost radular teeth and lateral denticles on outer lateral teeth described by Pruvot-Fol (1953) and tentatively identified as *Alloiodoris* sp., but she gives no information on the colouration alive. However, following Valdés (2002) and Dayrat (2010) it could belong to *Peltodoris* because of its absence of a labial cuticle and having the innermost 6–8 lateral teeth noticeably smaller than the outer ones, although in this specimen the transition is gradual.

Doridoidea sp. A

Material examined East Tema rocks below low tide 1 spec. 29 mm long 2 November 1966.

External features The specimen was already dying when found. Body oblong of typical dorid shape. Notum orange with brown mottling; rhinophores orange; gills tipped with grey.

Internal morphology Not examined.

Geographical range Known only from Ghana.

Remarks This species could belong to either the Dorididae or the Discodorididae but the specimen was in such poor condition that it was not preserved. Its colouration, however, is different from that of any other doridacean found in Ghana.

Doridoidea sp. B

Material examined NHMUK reg. no. 20130443: Tema Bay dredged from 38–55 m 1 spec. 4 mm long 10 February 1968.

External features The specimen was in poor condition and dying. Body oblong; rhinophores with 9 sloping lamellae; gills retracted; oral tentacles short, blunt, foot lacking notch. Notum

and rhinophores brilliant vermilion-orange with scattered minute black dots on rhinophores.

Internal morphology Not examined.

Geographical range Known only from Ghana.

Remarks Compared with other red dorids this specimen differs from *Rostanga rubra* (Risso 1818) in shape of rhinophore lamellae, from *Doris* species A (Edmunds, 2012) in having short oral tentacles, and from *Aldisa smaragdina* Ortea, Perez & Llera 1982 in colour pattern and much smaller retractile gills.

***Doris* sp. A** Edmunds 2012
Fig. 5E, F

Doris sp. A Edmunds 2012: 348–9, Fig. 3.

Remarks When this species was described (Edmunds, 2012) the radula preparation made in 1965 was missing. It has now been found so I can add here a full description and illustration of the radular teeth. My notes from 1965 indicate that the teeth were all simply hamate, but I did not examine the preparation with an oil immersion objective. I have now examined them under a magnification of×100 and in addition to the 27 hamate lateral teeth there are also two small thin marginal teeth on each side, each with 7–9 slender bristles (Fig. 5E,F).

These specimens were deposited in the Natural History Museum with registration number NHMUK 20120316 (Edmunds, 2012 page 348), but the following page states that: "the specimens were all accidentally destroyed…". This statement is wrong for which I apologise. The registration number of the radula preparation is NHMUK 20130446.

The presence of oral lobes rather than digitiform tentacles indicate that this species belongs to the Doridiidae, most probably to the genus *Doris*, but the pectinate marginal teeth are not present in any of the *Doris* species described by Valdés (2002), so placement in this genus must be regarded as provisional.

Discussion

The two species which have been identified in this paper, *Onchidoris depressa* and *Aegires punctilucens*, are well known species from temperate waters of the north-east Atlantic extending south to Portugal and (for *A. punctilucens*) to the Mediterranean. The records here thus represent a considerable range extension for these species, and there is some evidence (see above) to suggest that *O. depressa* may even have spread *via* boat hulls to the Indo-Pacific. The second species of Onchidoriddidae appears to be an undescribed species which should be recognisable from its external features should it be found again. The next four species are too poorly known to name them but have been included in order to explore the biodiversity of the dorid fauna of Ghana. Two probably belong to the Discodoriddidae and are additional to the discodorids described in Edmunds, 2011, while the other two could belong to either the Doriddidae or the Discodoriddidae. Finally the missing radula of *Doris* sp. A (Edmunds, 2012) has been found and is described here. However, I consider there is still insufficient information to name this species, but its provisional placement in the genus *Doris* is confirmed.

Ecology and Diversity Of Dorid Nudibranchs in Ghana

This paper completes the description of dorid nudibranchs from Ghana collected by the author and colleagues between 1963 and 1973 (Edmunds, 1981, 2007, 2009, 2010, 2011, 2012). The three main collecting sites were the 10 m offshore reef at Kpone Bay (ranging from 9 to 12 m deep), the 30 m reef off Tema (ranging from 25 to 40 m deep) and the intertidal zone extending to about one metre depth of water below low water mark. The 30 m 'reef' actually comprises both solid and fine grain substrata, the latter extending into deeper waters. While the solid substrate contains many sponges and bryozoans similar to those on the shallower 10 m reef, the sandy deposits often have scattered or occasionally dense assemblages of arenaceous foraminiferans (Buchanan, 1960). In the 27 to 40 m deep samples reported here these foraminiferans are *Jullienella foetida* Schlumberger 1890 and *Schizammina arborescens* Buchanan 1960. Samples from all three habitats are probably too small to draw any definite conclusions, particularly the intertidal sites which were dominated by a single collection of 84 individuals of one species (*Okenia ghanensis*) on one day. Nevertheless Table 1 shows that the greatest diversity is found on the shallow offshore 10 m deep reef and the least diverse of the three sites is the intertidal area. The low

Table 1 Species diversity of dorid nudibranchs in Ghana 1963–1973.

Sites	10 m reef	30 m reef	Intertidal	All three sites
Number of individuals	124	55	158	343
Number of species	33	19	14	53
Shannon Index (H)	−3.203	−2.204	−1.513	−2.642
Shannon Evenness Value (E)	0.916	0.749	0.559	0.666
Simpson index (1-D)	0.949	0.811	0.642	0.937

diversity in the intertidal zone probably reflects the damaging action of waves, extreme changes in water temperature and occasional exposure to air for animals living there.

For comparison, a Mediterranean site that was intensively sampled over 8 years yielded 242 individuals of possibly 27 species (some unidentified 'species' may have been juveniles of one of the already recorded species) (Domenech, Avila & Ballesteros, 2002). However, sampling here only extended to 3 m depth compared with more than 40 m for the Ghana site.

Ignoring species where less than four individuals were found, more species were confined to the 10 m reef than to either of the other two sites (Table 2), but *Polycerella emertoni* was most abundant on the rich growth of its food *Zoobotryon* growing on buoys (77 specimens) compared with 23 in the intertidal site and just one on the 10 m reef.

The species diversity plot (Fig. 6) shows that the dorids from the intertidal zone and the two reefs (i.e. excluding those on boats and buoys) fit a logarithmic curve. The species diversity curve for a smaller number of dorids from Tanzania (70 individuals of 22 species) is very similar ($y = -1.0204\ln(x) + 3.0105$, $R^2 = 0.9853$) (data from Edmunds, 1971). This relationship is quite different from the species diversity plot of Ghanaian praying mantids where the relationship is linear (Edmunds, 1986). This may be a real difference reflecting different ecologies, or it may relate to different sampling methods: the mantids were repeatedly sampled in precisely the same way, but the collections of dorids by personal search (at low tide), by SCUBA diving or by dredging were irregular and did not involve equal sampling of each habitat throughout the year.

How many species of dorid are there in the Ghanaian fauna had I collected for another 10 years? Fig. 7 plots the cumulative number of individuals against the cumulative number of species. The weakness of this procedure is that

Table 2 Species of dorid nudibranchs found at only one collecting site where $N \geq 4$

10 m reef	30 m reef	Intertidal
Chromodoris luteorosea	*Doris minuta*	*Geitodoris tema*
Cadlina rumia		*Okenia ghanensis*
Hypselodoris bilineata		
Tyrinna evelinae		
Paliolla templadoi		
Doris species A		
Aldisa smaragdina		
Onchidoris depressa		

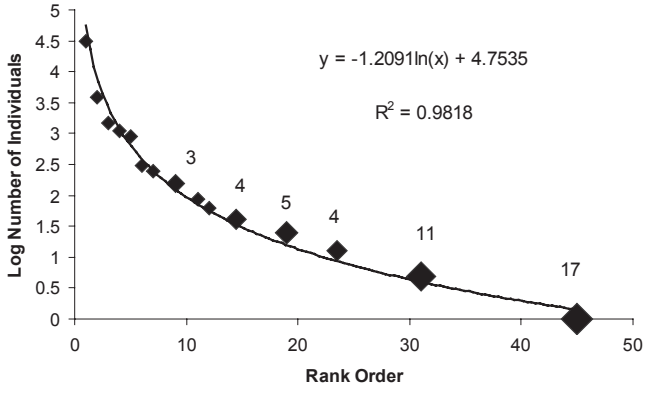

Figure 6 Species Diversity Curve for Ghanaian dorids. Small numbers beside points are numbers of species with the same rank.

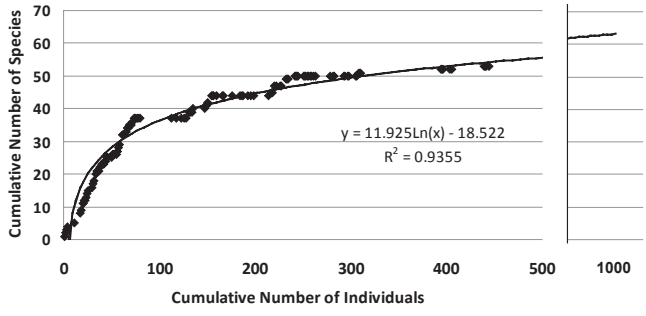

Figure 7 Cumulative plot of individuals and species of Ghanaian dorids showing numbers of species expected if trend is continued to 1,000 individuals.

Table 3 Checklist and faunal affinities of Ghanaian Doridoidea

Species	Endemic	Mediterranean	East Atlantic Isles[1]	Gulf of Guinea, Angola	West Atlantic	North Atlantic	Indo-Pacific	Cosmopolitan
Dendrodorididae – Edmunds, 2007								
Dendrodoris guineana Valdés & Ortea 1996				P				
Dendrodoris species – Edmunds, 2007	P							
Doriopsilla areolata Bergh 1880 ssp *albolineata* Edmunds 1968b				P				
Corambidae – Edmunds, 2007								
Corambe testudinaria Fischer 1889					P	P		
Goniodorididae – Edmunds, 2009								
Okenia impexa Marcus 1957			P		P			
Okenia ghanensis Edmunds 2009	P							
Okenia species A – Edmunds, 2009	P							
Okenia species B – Edmunds, 2009	P							
Okenia africana Edmunds 2009	P							
Okenia digitata (Edmunds 1966)				P				
Trapania africana Edmunds 2009	P							
Trapania luquei Ortea 1989			P					
Chromodorididae – Edmunds, 1981								
Hypselodoris picta (Schultz 1836) ssp *tema* Edmunds 1981[2]	P							
Chromodoris luteorosea (Rapp 1827)		P	P			P		
Mexichromis cf. tricolor Edmunds, 1981[3]	P							
Hypselodoris bilineata (Pruvot-Fol 1953)		P	P					
Glossodoris ghanensis Edmunds 1968b[4]	P		P					
Chromodoris kpone Edmunds 1981	P							
Tyrinna evelinae (Marcus 1958)[5]					P		P	
Polyceridae – Edmunds, 2010								
Paliolla templadoi (Ortea 1989)			P	P				
Limacia annulata Vallès, Valdés & Ortea 2000				P				
Thecacera pennigera (Montagu 1815)		P	P		P	P	P	P
Polycera species – Edmunds, 2010	P							
Polycerella emertoni Verrill 1880		P	P		P	P		
Kaloplocamus ramosus (Cantraine 1835)		P	P				P	
Discodorididae – Edmunds, 2011								
Peltodoris temarensis Edmunds 2011	P							
Discodoris ghanensis Edmunds 2011	P							
Paradoris indecora (Bergh 1881)		P	P					
Thordisa poplei Edmunds 2011	P							
Geitodoris tema (Edmunds 1968b)	P							
Platydoris species – Edmunds, 2011	P							
Baptodoris perezi Llera & Ortea 1982		P	P					
Jorunna glandulosa Edmunds 2011	P							
Jorunna ghanensis Edmunds 2011[6]	P							
Rostanga rubra (Risso 1818)		P	P			P		
Rostanga crocea Edmunds 2011	P							
Discodorid species A – this paper	P							
Discodorid species B – this paper	P							

Species	Endemic	Mediterranean	East Atlantic Isles[1]	Gulf of Guinea, Angola	West Atlantic	North Atlantic	Indo-Pacific	Cosmopolitan
Doridiidae – Edmunds, 2012								
Doris verrucosa Linnaeus 1758		P	P		P	P		
Doris kpone Edmunds 2012	P							
Doris species A – Edmunds, 2012	P							
Doris minuta Edmunds 2012	P							
Doris species B – Edmunds, 2012	P							
Doris species C – Edmunds, 2012	P							
Doris morenoi Ortea 1989	P							
Cadlinidae – Edmunds, 1981, 2012								
Cadlina dubia Edmunds 1981	P							
Cadlina rumia Marcus 1955			P		P			
Aldisa smaragdina Ortea, Perez & Llera 1982		P	P					
Onchidoriddidae – this paper								
Onchidoris depressa (Alder & Hancock 1842)						P	P	
Onchidorid species A – this paper	P							
Doridiidae/Discodoriddidae								
Doridoidea species A -this paper	P							
Doridoidea species B – this paper	P							
Aegiridae – this paper								
Aegires punctilucens (d'Orbigny 1837)		P				P		
Totals	31	11	15	5	7	8	4	1

Notes:
[1]Atlantic Isles comprises the Canaries, Madeira and the Azores.
[2]*Hypselodoris tema* Edmunds 1981 is now regarded as a subspecies of *Hypselodoris picta* (Schultz 1836) (Ortea *et al*., 1996). Other subspecies are known from Florida, the Canaries, the Mediterranean, São Tomé and Angola.
[3]The *Mexichromis tricolor* of Edmunds (1981) is distinct from specimens identified as *Hypselodoris tricolor* (Cantraine 1841) by Ortea *et al*. (1996). It is very similar in external features to *Hypselodoris xicoi* Ortea, Valdes & García-Gómez 1996 from São Tomé and Angola, but the inner radular teeth are different. The radula is similar to that of *Mexichromis francoisae* (Bouchet 1980) from Senegal and Cape Verde, but the external colour pattern is different (Ortea *et al*., 1996). Ortea *et al*. (1996) have renamed my Ghanaian *M. tricolor* as *Mexichromis garciagomezi* Ortea & Valdés 1996, but they have not designated a holotype, so I have not used this name in Table 3.
[4]*Glosssodoris edmundsi* Cervera, García-Gómez & Ortea 1989 is clearly conspecific with *G. ghanensis* Edmunds 1968b, but while Edmunds (1981) transferred it to *Chromodoris*, Ortea *et al*. (1996) have moved it back to *Glossodoris*.
[5]Although species of *Cadlina* are now considered to belong to the family Cadlinidae, Johnson (2011) has transferred *Cadlina evelinae* to the chromodorid genus *Tyrinna*.
[6]The immature specimen described under the name *Jorunna* sp. in Edmunds (2011) came from a different habitat to *Jorunna ghanensis* so was described separately, but it has been included in *J. ghanensis* in this table and in the species diversity calculations (above).

it assumes more or less equal sampling of the various habitats with time which is not true. Nevertheless the data points are a reasonable fit to a logarithmic curve which, by extrapolation, would give 64 species for a sample of 1,000 individuals or 73 species for a sample of 2,000. By comparison with the dorid fauna of the Mediterranean this is a very small number:

there are over 120 species in the Mediterranean (Gosliner, Cervera & Ghiselin, 2008), but this sea has been intensively studied for over 100 years, with a wider variety of different habitats than those studied in Ghana, so the difference is not surprising. The tropical Indo-Pacific has an even richer dorid fauna and is one of the richest and most species diverse marine ecosystems, probably because it includes many coral reefs which do not occur off the West African coast.

Zoogeography and Check list of Ghanaian Dorids

Table 3 lists the 53 species of Doridoidea collected by the author and colleagues in Ghana. The large number of apparently endemic species is due to the paucity of records of nudibranchs from West Africa: with more collecting most of these species will probably be found to occur from Senegal to Angola including the islands in the Gulf of Guinea. Table 3 shows that 15 of the Ghanaian species occur also in the Atlantic Isles (Canaries, Madeira and Azores) while 11 occur also in the Mediterranean: this affinity is to be expected given that west African coastal waters experience a cold current and so are not significantly warmer than Mediterranean waters from a much higher latitude. What is more surprising is that 8 species occur also in the North Atlantic from Portugal northwards. Seven species occur on both sides of the Atlantic, and there are a small number of species which also occur in the Indo-Pacific. Some of these (including the cosmopolitan *Thecacera pennigera*) are probably transported regularly on boat hulls, but others, including *Doris verrucosa*, *Cadlina rumia* and *Tyrinna evelinae*, may have long-lived (teleplanic) larvae which can drift across the Atlantic and then metamorphose successfully. Alternatively, DNA profiling of east and west Atlantic forms may show that these are distinct but closely related species, as has been shown for the aeolidiid *Spurilla neapolitana* (delle Chiaje 1841) (Carmona *et al.*, 2012). Similar species pairs on east and west sides of the ocean may indicate that very occasionally either larvae or adults have succeeded in crossing the Atlantic but have then adapted to local ecosystems so that they are now different species with no (or almost no) exchange of genetic material.

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