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Diversity of shallow-water asteroids (Echinodermata) in the Azorean Archipelago

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A comprehensive review of the literature on shallow-water asteroids (Echinodermata) recorded in Azores was carried out to establish a definitive list for the Archipelago. A total of 49 echinoderm species was compiled, comprising members of all extant classes; Crinoidea (1), Asteroidea (12), Ophiuroidea (11), Echinoidea (10) and Holothuroidea (7). References of asteroids occurence in the Azores, including historical records and distribution of asteroids from the Azores are given. Seven asteroid species recorded found in the Azores are found also in the Mediterranean and adjoining Atlantic coastlines, three are recorded from the Mediterranean and both sides of the Atlantic, one is limited to the Eastern Atlantic and one is circumtropical. Differences between the littoral hydrological conditions found on the North American coast and those in Azores makes the colonization from American coasts particularly difficult and probably are related to chance events like the episodic anomalies found in the general pattern of oceanic circulation. Asteroids are important in determining habitat structure for other species and can represent a substantial portion of the ecosystem biomass.

Keywords: conservation, Echinodermata, North Atlantic, oceanic currents, Azores

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INTRODUCTION

The Azores Archipelago (latitude: 36°55′–39°43′N (530 km); longitude: 24°46′-31°16′W (320 km)) comprises nine strongly-isolated islands about 800 km from Madeira Island, 1500 km from Europe and 1900 km from America, in the junction of the North American, Euroasian and African lithospheric plates astride the Mid-Atlantic Ridge (Coutinho *et al.*, 2009), at the northern edge of the North Atlantic Subtropical Gyre—the rotor of the North Atlantic circulation (Bashmachnikov *et al.*, 2004). During the last two million years a series of ice ages, interglacial warming's and tectonic movements (especially in active areas such as plate junctions) have alternately lowered and raised sea levels and temperatures and produced changes in the positions and strengths of ocean currents (Morton & Britton, 2000). Today, the basic average ocean circulation pattern of the North Atlantic is an asymmetric, large-scale gyre, flowing to the north, on the western side, with the Gulf Stream transporting warm water of equatorial and tropical origin into the colder northern waters. The water flows to the south, on the centre/eastern side, through a multibranched current system (Santos *et al.*, 1995). Surveys by means of drifting buoys (Krauss & Meincke, 1982) have revealed more complicated patterns in the detail of the water curculation, with the current field dominated by mesoscale (100–150 km) eddies and meanders rather than a steady flow (Gofas, 1990). The ocean circulation patterns around the Azores are very complex (see e.g. Alves, 1990; Juliano, 1994) corresponding to a multibranching system that changes with the time of the year (Santos *et al.*, 1995). Although for almost all the year the current flow between Madeira and the Azores, is predominantly from west to east, there are also mean-events when the current flows mainly from east to west (from Madeira towards the Azores) (Santos *et al.*, 1995; Johnson & Stevens, 2000). Around Madeira and in the open ocean there is also a high variability current pattern with a series of eddies in the Azores Current and the Canary Current along the African coast (Johnson & Stevens, 2000) (Figure 1). Geographical location of the Azorean Islands is particularly important to the distribution of species as it corresponds to a climatic–ecological transition region, with the confluence of marine life of adjacent regions such as the subtropical north-eastern Atlantic, the north-eastern Atlantic cold temperate and the Mediterranean. The islands are composed mostly of volcanic rocks, predominantly basaltic lavas and trachytic pumice deposits (Morton *et al.*, 1998), and sandy beaches are scarce. On rocky shores, there are ledges projecting from the foot of the cliffs but, typically, the cliffs lunge straight into the sea, so that the intertidal zone is vertical and there is virtually no shore. The dominant subtidal environment comprises rocky outcrops, interrupted by unconsolidated sediments of gravel, sand, mud or a combination of these. Individual boulders also may lie upon or within these unconsolidated sediments (Morton *et al.*, 1998).

The phylum Echinodermata has a long Precambrian history, since echinoderms were fairly common in some habitats in the Early Cambrian, nearly 600 million years ago (Hendler *et al.*, 1995). Echinoderms comprise a major

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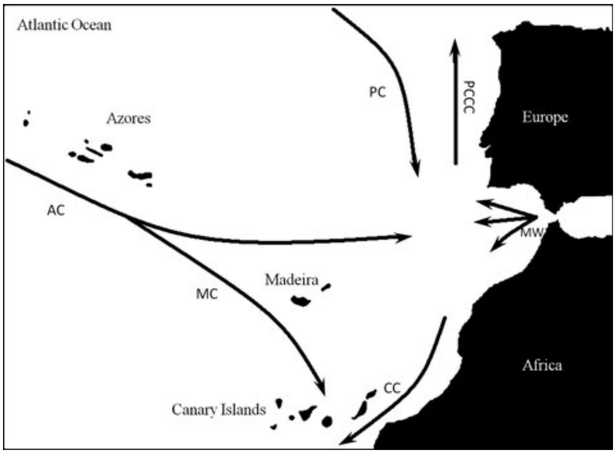

Fig. 1. Schematic diagram of the eastern North Atlantic Circulation between the Azores, the Canary Islands and the Strait of Gibraltar, AC Azores Current; CC Canary Current; MW Mediterranean Water outflow (deep currents); PC Portuguese Current—summer season; PCCC Portuguese Coastal Counter Current—winter season).

food resource for certain fish and crustacean species and some are eaten by humans. The ecological role of echinoderm species on marine communities is poorly documented, but it is known, for example, that some species can influence the species composition of their environment (see, e.g. Kempf, 1962; Verlaque, 1987; Sala & Zabala, 1996).

Historical overview of studies on Azorean echinoderms

The first published scientific observations of Azorean echinoderm diversity dates from the 19th Century (Drouët, 1861) and listed six species from two classes (four Echinoidea and two Asteroidea). Twenty-seven years later in the 'Liste des Échinodermes recueilis aux Açores' Barrois (1888) identified 18 species from the five extant classes (one Crinoidea, four Ophiuroidea, one Holothuroidea, seven Echinoidea and five Asteroidea) and included four more species of Ophiuroidea collected by Ljungman (1871); of the latter, only two are considered valid species. Also in the 19th Century, working on the asteroid specimens collected during the '*Campagnes Scientifiques du Monaco*', Perrier (1896) identified 1 more asteroid species from the shallow water of the Azores. On an extensive survey of echinoderms, mostly based on specimens collected during the campaigns of Prince Albert I of Monaco, Koehler (1924) identified 28 echinoderms new for shallow Azorean waters; at this time there were 47 echinoderm species recorded, from waters shallower than 50 m. Although not adding to the list Nobre (1938) compiled all existing data from echinoderms collected and deposited in Portugal, including the Azores. During the preparation of the *Echinodermata—Fauna d'Italia* book, Tortonese examined specimens of *Luidia sarsi* collected in the Azores, a species not mentioned previously. Marques (1983) did not add any new records but summarized the ecological information of the shallow-water echinoderm species in the Azores. An interesting taxonomic overview of the Asteroidea, including specimens from the Azores, is provided in *Starfishes of the Atlantic* by Clark & Donwey (1992) working on specimens deposited in European museums mention 2 asteroid species not previously registered in the Azorean shallow waters. Pereira (1997) compiled a species register of 41 echinoderms from the Azores, including representatives of each extant class; Crinoidea (1), Ophiroidea (10), Holothuroidea (7), Echinoidea (14) and Asteroidea (9), occurring at depths ranging from intertidal to 200 m. Pereira (1997) also provided a bibliography of the Azorean echinoderm taxonomic literature, but the works of Koehler (1924) and Nobre (1938) were not mentioned. García-Diez *et al.* (2005) produced a taxonomic review of selected invertebrate groups, including echinoderms, collected during the Campaigns of Prince Albert I of Monaco in Azorean waters, but new records for the shallow water echinoderms were not found.

The aim of this study was to establish a definitive list of echinoderm species for the Azorean Archipelago, developing a working document on diversity that can be used for future research and where it is discussed the observed diversity with a biogeography perspective. The importance of a defined protection status for this taxonomic group is highlighted.

RESULTS

In the present work, shallow-water (<50 m) echinoderm fauna of the Azores was compiled from historical literature. A total of 49 echinoderm species (Table 1), distributed in 5 classes and 38 genera (Crinoidea (1), Asteroidea (10), Ophiuroidea (10), Echinoidea (13) and Holothuroidea (4)) were identified. Echinoidea (18) was the most diverse class followed by Asteroidea (12), Ophiuroidea (11), Holothuroidea (7) and Crinoidea (1). The systematic arrangement and nomenclature follows that proposed by Clark & Donwey (1992) for the class Asteroidea, Tortonese (1965) and for the classes Echinoidea and Ophiuroidea and Moyse & Tyler (in Hayward & Ryland (1995)) for the classes Crinoidea and Holothuroidea. More recent updates of echinoderm nomenclature were consulted in the database initiatives (see Stöhr & O'Hara, 2007; Mah, 2009; Kroh & Mooi, 2010). The checklist is organized by class and all subsequent infra-phylum taxa to species were considered. In Table 1, depth distribution notes were based on the literature (Nobre, 1930; Tortonese, 1965; Clark & Donwey, 1992; Hayward & Ryland, 1995; Hansson, 2001; Stöhr & O'Hara, 2007; Mah, 2009; Kroh & Mooi, 2010). In the same Table, 'Habitat' notes were based in the previous literature and include authors' own observations.

Species list

Coscinasterias tenuispina (Lamarck, 1816)

Historical records in Azores
Asterias tenuispina Lamarck, 1816—Barrois (1888) p. 4.
Coscinasterias tenuispina (Lamarck, 1816)—Nobre (1924) p. 88; Nobre (1930) p. 68; Nobre (1931) p. 35; Nobre (1938) p. 36; Marques (1983) p. 2; Clark & Donwey (1992) p. 427.

Coscinasterias tenuispina is very abundant in the Mediterranean where it remains essentially coastal and does not occur deeper than a few metres (Koehler, 1924). Although this species is by far the most abundant invertebrate predator in the Canary Islands (Clemente *et al.*, 2007), in Azores, *C. tenuispina* is not found in abundance (Marques, 1983). It is a typical inhabitant of rocks. Even near shore, it

Table 1. Shallow-water Echinodermata species from the Azores.

Species	Distribution	Depth distribution (m)	Habitat
Class CRINOIDEA Miller, 1821			
Order COMATULIDA Clark, 1908			
Family ANTEDONIDAE Norman, 1865			
Antedon bifida (Pennant, 1777)	Amphi-Atlantic/Mediterranean	0–100	Clinging to rocks, strong currents
Class ASTEROIDEA de Blainville, 1830			
Order FORCIPULATIDA Perrier, 1884			
Family ASTERIIDAE Gray, 1840			
Coscinasterias tenuispina (Lamarck, 1816)	Amphi-Atlantic/Mediterranean	0–165	On rocks
Marthasterias glacialis (Linnaeus, 1758)	Eastern Atlantic/Mediterranean	0–180 (rarely < 50)	On rocks
Order PAXILLOSIDA Perrier, 1884			
Family ASTROPECTINIDAE Gray, 1840			
Astropecten bispinosus (Otto, 1823)	Eastern Atlantic/Mediterranean	0–50	Gravel/sand/mud
Astropecten hermatophilus Sladen, 1883	Eastern Atlantic	15–1500	Gravel/sand/mud
Family CTENODISCIDAE Sladen, 1889			
Ctenodiscus crispatus (Retzius, 1805)	Circumpolar Arctic/Atlantic/Pacific	10–1890	Mud/sand/clay to silty sand
Family LUIDIAE Sladen, 1889			
Luidia ciliaris (Philippi, 1837)	Eastern Atlantic/Mediterranean	1–400	Gravel/sand
Luidia sarsi sarsi Düben & Koren, in Düben, 1845	Amphi-Atlantic/Mediterranean	9–1300 (rarely < 45)	Muddy
Order SPINULOSIDA Perrier, 1884			
Family ECHINASTERIDAE Verrill, 1870			
Henricia oculata (Pennant, 1777)	Eastern Atlantic/Mediterranean	0–1557	Firm substrata/shell gravel
Order VALVATIDA Perrier, 1884			
Family ASTERINIDAE Gray, 1840			
Asterina gibbosa (Pennant, 1777)	Amphi-Atlantic/Mediterranean	0–125	Crevices/under stones
Family CHAETASTERIDAE Sladen, 1889			
Chaetaster longipes (Retzius, 1805)	Eastern Atlantic/Mediterranean	30–1140	On rocks
Family OPHIDIASTERIDAE Verrill, 1870			
Hacelia attenuata Gray, 1840	Eastern Atlantic/Mediterranean	0–150	On rocks
Ophidiaster ophidianus (Lamarck, 1816)	Eastern Atlantic/Mediterranean	0–105	On rocks
Class OPHIUROIDEA Gray, 1840			
Order OPHIURIDA Müller & Troschel, 1840			
Family AMPHIURIDAE Ljungman, 1867			
Amphiura chiajei Forbes, 1843	Eastern Atlantic/Mediterranean	9–1200	Sand/muddy sand
Family OPHIACANTHIDAE Ljungman, 1867			
Ophiacantha bidentata (Bruzelius, 1805)	Circumpolar Arctic/Atlantic/Pacific	5–4500	Soft bottoms /on corals
Family OPHIACTIDAE Matsumoto, 1915			
Ophiactis virens (M. Sars, 1857)	Eastern Atlantic/Mediterranean	0–90	On coarse sand/gravel
Family OPHIOCOMIDAE Ljungman, 1867			
Ophiocomina nigra (Abildgaard, in O.F. Müller, 1789)	Eastern Atlantic/Mediterranean	0–400	On coarse sand/gravel
Ophiopsila aranea Forbes, 1843	Eastern Atlantic/Mediterranean	25–185	On coarse sand/gravel
Ophioconis forbesi (Heller, 1862)	Eastern Atlantic/Mediterranean	20–200	On coarse sand/gravel
Ophioderma longicauda (Bruzelius, 1805)	Eastern Atlantic/Mediterranean	0–70	On rocks
Family OPHIOTRICHIDAE Ljungman, 1867			
Ophiothrix fragilis (Abildgaard, in O.F. Müller, 1789)	Eastern Atlantic/Mediterranean	0–475	Under stones/gravel
Ophiothrix luetkeni Wyville Thomson, 1873	Eastern Atlantic/Mediterranean	50–500	Gravel
Family OPHIURIDAE Müller & Troschel, 1840			
Ophiocten affinis (Lütken, 1858)	Eastern Atlantic/Mediterranean	8–550	Muddy sand
Ophiura albida Forbes, 1839	Eastern Atlantic/Mediterranean	2–850	Coarse-grained sediments
Class ECHINOIDEA Leske, 1778			
Order ARBACIOIDA Gregory, 1900			
Family ARBACIIDAE Gray, 1855			
Arbacia lixula (Linnaeus, 1758)	Amphi-Atlantic/Mediterranean	0–40	On rocks
Arbaciella elegans Mortensen, 1910	Eastern Atlantic/Mediterranean	0–70	Coarse-grained sediments
Order CIDAROIDA Claus, 1880			
Family CIDARIDAE Gray, 1825			
Eucidaris tribuloides (Lamarck, 1816)	Amphi-Atlantic	0–800 (rarely < 50)	On rocks/crevices
Order CLYPEASTEROIDA L. Agassiz, 1835			
Family FIBULARIIDAE Gray, 1855			
Echinocyamus pusillus (O.F. Müller, 1776)	Amphi-Atlantic/Mediterranean	0–1250	Coarse sand/fine gravel

Continued

Table 1. Continued

Species	Distribution	Depth distribution (m)	Habitat
Order ECHINIDEA Kroh & Smith, 2010			
Family ECHINIDAE Gray, 1825			
Gracilechinus acutus (Lamarck, 1816)	Eastern Atlantic/Mediterranean	20–1280	On rocks
Gracilechinus elegans (Düben & Koren, 1846)	Eastern Atlantic	45–2000	On rocks
Echinus melo Lamarck, 1816	Eastern Atlantic/Mediterranean	30–1100	On rocks
Paracentrotus lividus (Lamarck, 1816)	Eastern Atlantic/Mediterranean	0–30	On rocks
Psammechinus miliaris (P.L.S. Müller, 1771)	Eastern Atlantic	0–100	Rock/gravel
Psammechinus microtuberculatus (Blainville, 1825)	Eastern Atlantic/Mediterranean	0–100	Rock/gravel
Order ECHINOTHURIOIDA Claus, 1880			
Family DIADEMATIDAE Gray, 1855			
Centrostephanus longispinus (Philippi, 1845)	Pacific/Amphi-Atlantic/Mediterranean	10–2000	On rocks/crevices
Order SPATANGOIDA L. Agassiz, 1840			
Family BRISSIDAE Gray, 1855			
Brissopsis lyrifera (Forbes, 1841)	Eastern Atlantic/Mediterranean	5–365	Burrowing in mud or muddy sand
Brissus unicolor (Leske, 1778)	Amphi-Atlantic	0–250	Burrowing in mud or muddy sand
Family LOVENIIDAE Lambert, 1905			
Echinocardium cordatum (Pennant, 1777)	Amphi-Atlantic/Mediterranean	0–230	Burrowing in mud or muddy sand
Echinocardium flavescens (O.F. Müller, 1776)	Eastern Atlantic/Mediterranean	5–325	Burrowing in mud or muddy sand
Family SPATANGIDAE Gray, 1825			
Spatangus purpureus O.F. Müller, 1776	Eastern Atlantic/Mediterranean	0–900	Burrowing in coarse sand/gravel
Order TEMNOPLEURIDEA Kroh & Smith, 2010			
Family TEMNOPLEURIDAE A. Agassiz, 1872			
Genocidaris maculata A. Agassiz, 1869	Amphi-Atlantic/Mediterranean	12–500	On rocks
Family TOXOPNEUSTIDAE Troschel, 1872			
Sphaerechinus granularis (Lamarck, 1816)	Eastern Atlantic/Mediterranean	3–100	On rocks
Class HOLOTHUROIDEA de Blainville, 1834			
Order ASPIDOCHIROTIDA Grube, 1840			
Family HOLOTHURIIDAE Ludwig, 1894			
Holothuria (Halodeima) mexicana Ludwig, 1875	Western Atlantic/Azores	2–20	Sand
Holothuria (Holothuria) tubulosa Gmelin, 1790	Eastern Atlantic/Mediterranean	0–100	Sand/muddy rocks
Holothuria (Panningothuria) forskali Delle Chiaje, 1823	Eastern Atlantic/Mediterranean	1–100	On rocks/stones
Holothuria (Platyperona) sanctori Delle Chiaje, 1823	Eastern Atlantic/Mediterranean	2–30	Rock/gravel
Family SYNALLACTIDAE Ludwig, 1894			
Mesothuria intestinalis (Ascanius, 1805) Östergren, 1896	Amphi-Atlantic/Mediterranean	20–1450	On mud
Order DENDROCHIROTIDA Grube, 1840			
Family CUCUMARIIDAE Ludwig, 1894			
Pawsonia saxicola (Brady & Robertson, 1871)	Amphi-Atlantic/Mediterranean	0–130	Crevices/under stones
Havelockia inermis (Heller, 1868)	Amphi-Atlantic/Mediterranean	30–180	Crevices/under stones

is possible to find individuals in various stages of development (Tortonese, 1965). Characteristically, this species has six to nine long arms, polyhedral, unequal in length, one side usually larger than the other. This species can reproduce by fissipary causing arms asymmetry and the presence of a possible second madreporite (Nobre, 1938).

Geographical distribution
Coscinasterias tenuispina is present on north-western Atlantic coasts from the Bay of Biscay to Guinea; Macaronesia Region and Mediterranean Sea. According to Tortonese (1965) since its accidental importation to Bermuda, it became the most common asteroid in the archipelago.

Marthasterias glacialis (Linnaeus, 1758)

Historical records in Azores
Asterias glacialis Lamarck, 1758 in Drouët (1861) p. 211;
Asterias glacialis O.F.Müller, 1776—Barrois (1888) p. 4
Asterias glacialis Linnaeus, 1758—Simroth (1888) p. 231; Koehler (1909) p. 116
Stolasterias madeirensis Stimpson—Perrier (1896) p.37
Marthasterias glacialis (Linnaeus 1758) – Nobre (1924) p. 88; Nobre (1930) p. 68; Nobre (1931) p. 33; Nobre (1938) p. 34; Chapman (1955) p. 400; Tortonese (1965) p. 188; Marques (1983) p. 2; Clark and Donwey (1992) p. 443; García-Diez et al. (2005) p. 48.

Marthasterias glacialis is one of the most common echinoderms in the Mediterranean (Tortonese, 1965) and is also widespread in the Atlantic (Koehler, 1924). It is a common species throughout the Azorean archipelago, characteristically found in the photophilic algal biocoenosis (Marques, 1983). *M. glacialis* is mainly coastal (Koehler, 1924) and although it can descend down to 180 m (Madsen, 1950), is rarely deeper than 50 m (Clark & Donwey, 1992). Individuals can be found on rocks, biogenic reefs in shallow water, mud and detritus on the seafloor. Young individuals are also under stones of the shallow water (Tortonese, 1965). During the autumn and winter months *M. glacialis* occurs closer to the coast (Nobre, 1938). *Marthasterias glacialis* is a major shelf predator of marine animals including those of commercial importance such as *Paracentrotus lividus* and *Choromytilus meridionalis* (Verling *et al.*, 2003). It tolerates polluted waters (Tortonese, 1965).

Geographical distribution
Marthasterias glacialis is widely distributed in Europe, from Finnmark (the northernmost county of Norway) to the Mediterranean Sea (Savy 1987); Macaronesia Region (Nobre, 1938; Clark & Donwey, 1992). In the Gulf of Guinea it was observed only in the offshore island of Annobon (Nataf & Cherbonnier, 1975). Although not recorded from the mainland of west Africa between Cape Verde and the west coast of Cape Province, it has been found in South Africa (Clark & Donwey, 1992).

Astropecten bispinosus (Otto, 1823)

Historical records in Azores
Astropecten bispinosus—Koehler (1924) p. 191; Nobre (1931) p. 53; Nobre (1938) p. 51; Tortonese (1965) p. 140.
Astropecten bispinosus is common in the western Mediterranean and in the Adriatic. It is widespread on the coasts of France and Algeria (Koehler, 1924). It is found in shallow water, sandy bottoms or in mud, sometimes exposed at low tide (Cúmano, 1934; Nobre, 1938) and associated with bivalves and *Echinocardium* individuals (Tortonese, 1965).

Geographical distribution
In the Atlantic *Astropecten bispinosus* has been reported from Portugal (mainland) and Azores, and is also present in the Mediterranean Sea (Koehler, 1924; Nobre, 1930, 1938).

Astropecten hermatophilus Sladen, 1883

Historical records in Azores
Asterias pentacanthus Simroth 1888, p. 231
Astropecten hermatophilus (Sladen 1883)—'Challenger expedition' 1890; also specimens collected by Professor E. Tortonese (1958); Clark and Donwey (1992) p. 36.

This species is known only from the Azores, through the 'Challenger expeditions' and from few specimens collected by Professor E. Tortonese (1958) deposited at the Natural History Museum of London. The specimens in the United States National Museum of Natural History (Smithsonian Institution), collected by the University of Miami in the Gulf of Guinea, represent a considerable extension of the range: Azores and West Africa from 15 to 1500 m deep (Clark & Donwey, 1992).

Geographical distribution
Macaronesia Region and West Africa (Clark & Donwey, 1992)

Ctenodiscus crispatus (Retzius, 1805)

Historical records in Azores
Ctenodiscus crispatus (Retzius 1805)—García-Diez *et al.* (2005) p. 47

According to Perrier (1896), two specimens of *Asterias polaris* Sabine, 1824, accepted name *Ctenodiscus crispatus* (Retzius, 1805), were collected from the intertidal of Baia de Porto Pim, Faial, Azores, during the *Campagnes Scientifiques du Monaco in the Azorean waters—Hirondelle* campaign in 1887. This is the only record of the species in Azorean waters. This mud star is an infaunal deposit feeder (Shick *et al.*, 1981).

Geographical distribution
Ctenodiscus crispatus is found in the North Atlantic and Pacific Oceans (Imaoka *et al.*, 1990; Hasson, 2001).

Luidia ciliaris (Philippi, 1837)

Historical records in Azores
Luidia ciliaris (Philippi 1837)—Clark & Downey (1992) p. 11; Wirtz (2009) p. 46.

Luidia ciliaris is a temperate water species that is best known from the Mediterranean (Koehler 1924), in sand or gravel, often without mud (Clark & Downey, 1992). According to Clark & Downey (1992), *L. ciliaris* has been recorded from the Azores. Wirtz (2009) reported the presence of an individual belonging to this species in a large tidal pool at Varadouro, Faial. *Luidia ciliaris* is known to prey upon *Ophiothrix fragilis* and other echinoderms (Brun, 1972) and is usually found in moderately exposed or sheltered slightly tide-swept rock or mixed substrata with dense brittlestar beds (Hughes, 1998).

Geographical distribution
Luidia ciliaris has been found in north-eastern Atlantic including the Macaronesia Region and in Mediterranean sea (Clark & Downey, 1992).

Luidia sarsi sarsi Düben & Koren, 1845

Historical records in Azores
Luidia sarsi (Düben & Koren 1846)—Koehler (1909) p. 59; Tortonese (1965) p. 150; Clark & Downey (1992) p. 18; García-Diez *et al.* (2005) p. 47.

Luidia sarsi sarsi lives mostly in the Atlantic. In the Mediterranean it has been found in limited numbers at localities such as Naples, La Ciotat, Crete and Cap Maléa (Koehler, 1924). It seems to prefer muddy bottoms rather than clean sand, or clay. It is reported to be very voracious predator of brittle stars and other echinoderms, molluscs and crustaceans (Tortonese, 1965). Specimens were collected from 200 m, near Faial Island, during the *Campagnes Scientifiques du Monaco in the Azorean waters—Princesse-Alice* campaign in 1897 (Garcia-Diez *et al.*, 2005). As *Luidia ciliaris*, *L. sarsi* are voracious predators of ophiuroids and other echinoderms (Brun 1972).

Geographical distribution
Luidia sarsi sarsi is found from the Faeroe Bank south to Cap Blanc, in Mauritania, the Azores and Mediterranean (Clark & Donwey, 1992).

Henricia oculata (Pennant, 1777)

Historical records in Azores
Henricia sanguinolenta (O.F. Müller)—Nobre (1924) p. 88; Nobre (1931) p. 38; Nobre (1938) p. 39
Henricia oculata (Pennant, 1777)—García-Diez *et al.* (2005) p. 47.

According to Madsen (1987) *Henricia sanguinolenta* Nobre, 1930 is a synonym of *Henricia oculata* (Pennant, 1777). It is the most common species of *Henricia* around the British Isles, occurring on stones, shells, and gravel. Specimens were collected from between 1266 and 1557 m deep, during the *Campagnes Scientifiques du Monaco in the Azorean waters—Hirondelle* campaign in 1888 (Garcia-Diez *et al.*, 2005). *Henricia oculata* is found on rocky bottoms and in kelp fields below the tide level where they feed on sponges (Daly, 1998).

Geographical distribution
Henricia oculata is found across the north-eastern Atlantic (Hasson, 2001).

Asterina gibbosa (Pennant, 1777)

Historical records in Azores
Asterina gibbosa (Forbes 1841)—Barrois (1888) p.5; Koehler (1924) p. 131; Tortonese (1965) p. 169.

Asterina gibbosa is a widespread species in all temperate regions of the boreal Atlantic and the Mediterranean (Koehler, 1924). It is very common in Italian waters, although only in specific locations and there appears to be local seasonal fluctuations of their abundance. It adheres to the lower surface of the stones, either naked or covered with algae and concretions, with sand or *Caulerpa* algae, *Posidonia* and *Zostera* fronds, coral, mud, muddy sand (Tortonese, 1965).

Barrois (1888) stated that it was a quite common species under stones of the littoral zone of Faial and São Miguel Islands. Nevertheless, neither Nobre (1938) nor Marques (1983) have found this species in the Azores and the present authors have not found it themselves. It is possible that *A. gibbosa* occurred in the past but is now extinct from the Azores.

Geographical distribution
It is known from north-eastern Atlantic including the Macaronesia Region; also throughout the Mediterranean (Koehler, 1924; Clark & Donwey, 1992).

Chaetaster longipes (Retzius, 1805)

Historical records in Azores
Chaetaster longipes (Retzius 1805)—Koehler (1924) p. 143; Tortonese (1965) p. 154; Clark & Downey (1992) p. 145; Wirtz (2009) p. 47.

Chaetaster longipes is not a common species but it is found in different localities in the Mediterranean and Atlantic Ocean (Koehler, 1924). It occurs predominantly below 30 m deep (Nobre, 1938). According to Nobre (1938) the mention of this species from Bermuda by Koehler (1924) results from confusion with the species *C. nodosus* Perrier.

Geographical distribution
Chaetaster longipes is found throughout the Eastern Atlantic including the Macaronesia Region and also in the Mediterranean (Clark & Donwey, 1992).

Hacelia attenuata Gray, 1840

Historical records in Azores
Hacelia attenuata (Gray 1840)—Koehler (1909) p. 89; Koehler (1924) p. 165; Tortonese (1965) p. 164; Marques (1983), p. 2; Clark & Downey (1992) p. 272.
Hazelia attenuata Gray, 1840—García-Diez *et al.* (2005) p. 47

Hacelia attenuata is not a common species in the Mediterranean. It can be found on the cliffs, among the typical members of the coral reefs (Koehler, 1924). In the Azores it is abundant below 40 m among the coralligenous biocenose. On the island of Graciosa, it was collected in large numbers, about 60 m deep (Marques, 1983).

Geographical distribution
This species can be found in the north-eastern Atlantic including the Macaronesia Region and in the Mediterranean (Clark & Donwey, 1992).

Ophidiaster ophidianus (Lamarck, 1816)

Historical records in Azores
Asterias loevigata Lamarck 1816—Drouët 1861, p. 211
Ophidiaster sp.—Simroth 1888, p. 231
Ophidiaster ophidianus L. Agassiz 1835—Barrois, 1888, p. 6
Ophidiaster ophidianus (Lamarck 1816)—Perrier (1896) p. 44; Koehler (1909) p. 92; Koehler (1924) p. 163; Nobre (1924) p. 89; Nobre (1930) p. 68; Nobre (1931) p. 47; Nobre (1938) p. 46; Chapman (1955) p. 400; Tortonese (1965) p. 160; Marques (1983) p. 2; Clark & Downey (1992) p. 279; García-Diez *et al.* (2005) p. 47

Ophidiaster ophidianus is a temperate water (thermophilic) species found mainly in the Mediterranean, on the coasts of Algeria, Messina and Naples (Koehler, 1924). It is the most abundant starfish on the bedrock of the Azorean coastline (Marques, 1983). Its colour can vary from orange-red, with or without spots of brown, to bright red. It presents a wide variation in the number of arms (Marques, 1983).

Geographical distribution
Ophidiaster ophidianus is found in the Macaronesia Region, St Helena and from the Mediterranean to the Gulf of Guinea (Clark & Downey, 1992).

Notes:
Asteroidea (class); **Paxillosida** (order); **Astropectinidae** (family)
Astropecten platyacanthus (Philippi, 1837)

Barrois (1888) identified three specimens of this species, collected off the coast of Ponta Delgada that constituted the only record of this species outside the Mediterranean. Clark & Downey (1992) considered that the identification may be questionable or that may have been a mistake with the sampling location.

Geographical distribution
Mediterranean (Mah, 2009).

Asteroidea (class); **Forcipulatida** (order); **Asteriidae** (family)
Leptasterias (Hexasterias) polaris (Müller & Troschel, 1842)

Perrier (1896) identified two specimens of *Asterias polaris* Gray (a synonym of *Leptasterias (Hexasterias) polaris* (Müller & Troschel, 1842)) collected in Faial during the *Campagnes Scientifiques du Monaco in the Azorean waters—Hirondelle* campaign in 1887. Garcia-Diez *et al.* (2005), in the 'Taxonomic review of selected invertebrate groups collected during the Campaigns of the Prince Albert I of Monaco in the Azorean waters' identified the same specimens as *Ctenodiscus crispatus* (Retzius, 1805).

Geographical distribution
Labrador south to George's Bank, north-east of Cape Cod; also circumpolar Arctic and in northern North Pacific (Clark & Downey, 1992).

DISCUSSION

Shallow-water Asteroidea in the Azores

The overall eastward circulation in the North Atlantic should allow colonization of the Azores by littoral fauna from the West Atlantic (Gofas, 1990). However, this is contradicted by the Azorean fauna (e.g. polychaete—Chapman & Dales (1954); hydroids—Rees and White (1966); demosponges—Boury-Esnault & Lopes (1985); molluscs—Gofas (1990); amphipods—Lopes *et al.* (1993); barnacles—Southward (1998) and Young (1998)) which shows a clear relation to the European/North African mainland and the other Islands from the Macaronesia Region. Also, of the 12 species of shallow-water asteroids reported from the Azores, seven species are recorded common to the Mediterranean and adjoining Atlantic coastlines (Eastern Atlantic/Mediterranean—Table 1); only 3 species are recorded from the Mediterranean and both sides (W/E) of the Atlantic; one species is limited to the Eastern Atlantic side and one species has circumtropical distribution.

The westernmost islands of the Azores are about 2000 km from each Atlantic coast. However, species of temperate or subtropical affinity entering the Gulf Stream south of Cape Hatteras would travel some 4000 km to reach the Azores. The great distance separating the Azores from American coasts make colonization from that side particularly difficult, only species with teleplanic larvae would survive (Gofas, 1988), but probably a more relevant factor to the ability of asteroids to colonize Azores rests with the littoral hydrological conditions found on the North American coast being very different (the northern side of the Gulf Stream is mainly of Labrador/Sub-Arctic origin) from those found at the Azores (which is predominantly sub-tropical). Thus, even if colonizers did arrive, it would be very unlikely for them to survive (Santos *et al.*, 1995). As there are no documented deliberate (or unintentional) introductions by humans, the successful colonizations of asteroids in the Azores may be related to chance events like the episodic anomalies found in the general pattern of oceanic circulation, or by adults arriving with floating material (rafting).

Of the 12 asteroid species recorded in Azorean shallow waters (and accepted by the authors) only four are easily found. Of these, three (*Hacelia attenuata*, *Marthasterias glacialis* and *Ophidiaster ophidianus*) have an Eastern Atlantic and Mediterranean distribution, and one has an amphi-Atlantic and Mediterranean distribution. The latter (*Coscinasterias tenuispina*) is believed to have been accidentally introduced to the western zone of the Atlantic. This affinity with the Mediterranean fauna is common among other marine invertebrates (e.g. polychaete, demosponges, amphipodsand barnacles) from Azorean shallow waters and is probably related to the seasonal sporadic events that change the main direction of the Atlantic currents flow promoting sporadic colonizations from the European mainland (north-eastern Atlantic), Madeira and Canarias islands and also Africa mainland (north-western Atlantic coast and Mediterranean).

Conservation remarks

Of the recent emerging conservation policies, only the Habitats Directive (HD) (http://eur-lex.europa.eu/ – 2010.12.05) which aims to ensure biodiversity through the conservation of natural habitats and wild fauna and flora in the European territory of the Member States, mentions a protective 'status' to echinoderm species (and only to four species). Of the 12 Asteroidea species recorded in Azorean shallow water, only *Ophidiaster ophidianus* is given a 'strictly protected status' by the Barcelona Convention (92/43/CEE) and is also considered a vulnerable species in Spain (Catálogo Nacional de Especies Amenazadas 2007). *Ophidiaster ophidianus* is the most abundant asteroid in the Azorean shallow waters (Marques, 1983) and the 'strictly protected status' is only applicable in the Mediterranean Sea. Asteroid species have an important ecological role in marine communities (Micael *et al.*, 2009). Most asteroids are generalists, feeding on anything that is too slow to escape, whilst the others are specialized feeders preying exclusively on sponges, corals, bivalves, or algae. Nevertheless, also some crabs, fish, birds, and other echinoderms are known to prey on asteroids. Despite the ecological importance of asteroids, their disappearance from coastal marine ecosystems is not fully understood. Some asteroid species are important in determining habitat structure for other species and can represent a substantial portion of the ecosystem biomass (Paine, 1969; Menge, 1972; Birkeland, 1982; Ambrose, 1993; Freeman *et al.*, 2001; Tuya *et al.*, 2004).

In the Azores, humans have exploited littoral, nearshore and offshore living resources since the earliest colonization (Frutuoso 15th Century—printed as Frutuoso, 1983); Ramos, 1869; Serpa, 1886; Sampaio, 1904; Depledge *et al.*, 1992; Santos *et al.*, 1995). In recent years pressures on littoral and offshore resources have increased (see Martins *et al.* 1987; Silva *et al.*, 1994; Santos *et al.*, 1995) with the shift from essentially subsistence or artisanal exploitation to more commercial operations. Exploitation of marine fauna of the Azores for the aquarium trade is not documented; however, many marine invertebrates, including asteroids, are popular in the global aquarium trade. *Astropecten* species, for example, are exported from Puerto Rico (Sadovy, 1991). These species and *Luidia* species are in the aquarium trade of Sri Lanka (Bambaradeniya, 2006). Since *Ophidiaster ophidianus* is protected in the Mediterranean it has also a huge potential to be exploited in the Azores. Worlwide, there are growing restrictions on the collection of tropical marine ornamental species such that there is an increasing risk of subtropical echinoderm resources being harvested. Little is known of the true extent of the global use of sea-stars as souvenirs but, in Mexico, for example, an estimated 62 fisheries, each collecting an average of 12,000 sea-stars annually, collect sea-stars for the souvenir industry (Micael *et al.*, 2009). Lack of legislation on the capture and trade of ornamental species in European waters, associated with the high market prices that marine ornamental species can attain and the growing restrictions on tropical marine ornamental collection and trade (Wood, 2001) can be a major problem threatening the sustainable use of these marine resources. The threats to echinoderms survival are numerous, for example, it is often hypothesized that echinoderms (both larval and adult stages) will be strongly impacted by ocean acidification—a phenomenon that consists in the continued uptake of CO_2 by the oceans increasing the concentration of hydrogen ions, thereby reducing pH (Caldeira & Wickett 2003)—see Dupont *et al.* (2010) for review. As a future consequence, differences will be observed between taxa (e.g. highly calcified sea urchins being more affected than less calcified sea stars (Havenhand *et al.*, 2008)) and stages (e.g. non-calcifying larval stages being less affected than calcifying adults in sea stars (Clark *et al.*, 2008)). In a near-future ocean acidification will have negative impact on echinoderm phyla with clear consequences at the ecosystem level which reinforces the need to develop a global database of echinoderm species to summarize information on biology, ecology, threats, monitoring and conservation needs that permits to create legislation to support an echinoderm management strategy.

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