Taxonomic diversity hidden inside the mantle of *Octopus vulgaris*: valuable source of information

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Abstract

The common octopus, *Octopus vulgaris*, is a very important demersal fishery resource targeted, among other fleets, by freezer bottom-trawlers in the Mauritanian Economic Exclusive Zone (MEEZ). From August 2010 to September 2011, a total of 1696 octopuses caught in the MEEZ where analysed. Many organisms trapped into the octopuses' mantle were found and identified, which are jointly swept while the trawling catches the targeted species. A latitudinal (by ecoregion) and depth study was performed to determine differences in the taxonomic diversity of these hidden organisms. The findings showed that the diversity patterns were similar to already established in the area based on scientific surveys. Therefore, this ignored bycatch could provide complementary ecological information of the habitat of *O. vulgaris*.

Keywords*:* Octopus, Bottom trawl, Species richness, Spatial distribution, Mauritanian waters

Introduction

The common octopus *Octopus vulgaris* (Cuvier, 1797) inhabits a wide spectrum of benthic substrates (e.g., rocky bottoms, reefs, grass beds and soft sediments) from coastal to outer shelf worldwide (Jouffre 1998; Sauer et al. 2019). This species is a very important demersal fishing resource around the world, supporting artisanal and industrial fisheries (Roper et al. 1984; Xavier et al. 2015). Its ecological adaptability is also reflected in the diverse fishing gears used for its capture (e.g., lures, hooks and lines, pots and spears), although the bottom trawling is often the most relevant in landings (Roper et al. 1984; Sauer et al. 2019). One of the most important bottom trawl fisheries in the world targeting cephalopods occurs in the Northwest African waters, from the Saharan Bank to Senegal (e.g., Sobrino and García 1992; Balguerías et al. 2000; Sauer et al. 2019). This region is enriched by the Canary Current Upwelling System, one of the four main eastern boundary upwelling ecosystems in the world, where a variable year-round upwelling occurs (Demarcq and Faure, 2000; Arístegui et al. 2009; Klenz et al. 2018).

The Mauritanian Exclusive Economic Zone (MEEZ) has been exploited by a great variety of foreign fleets, being the most important fishing grounds for Spanish cephalopod-targeted freezer trawlers since the mid XX century. It has changed only in the first decade of the XXI century, when the sustainable fisheries partnership agreement (SFPA) between Mauritania and the European Union was modified (Council Decision, of 18 December 2012, Official Journal of the European Union, number 2012/827/EU). Due to its commercial and ecological importance, numerous studies have addressed the fisheries, biology and population dynamic of the common octopus (e.g., Balguerías et al. 2002; Murphy et al. 2002; Perales-Raya et al. 2010, 2014; Jurado-Ruzafa et al. 2014). But surprisingly, only one study has estimated the overall bycatch of this fishing activity in the MEEZ (Vázquez-Rowe et al. 2012) and another one, its impact on benthic ecosystems (Atkinson et al. 2011). The absence of reliable time series of catches of *O. vulgaris* in the region, its overfishing and the risk of irreversible stock depletion are worrisome (Sauer et al. 2019). In addition, although to

count discards is mandatory to achieve a reliable assessment of any fishing activity (Alverson et al. 1994), it is still a pending issue in the region. Due to scientific observers onboard were not allowed in the past, an intense sampling program was designed for the fishery in MEEZ by the Centro Oceanográfico de Canarias del Instituto Español de Oceanografía-Centro Superior de Investigaciones Científicas (COC of IEO-CSIC) between August 2010 to September 2011, in the framework of a collaborative project with ANACEF ("Asociación Nacional de Armadores de Buques Congeladores de Pesca de Cefalópodos"), whose associated cephalopod-targeted freezer trawlers operated in the Mauritanian waters. During this project, commercial landings were analyzed by researchers who highlighted the presence of numerous organisms swept jointly and 'trapped' into the octopuses' mantle (Supplementary Information Fig. SI1). In this context, in the absence of information on discards for commercial fleet activity, a question raised up: could these organisms trapped into the octopuses' mantles describe or give information about the taxonomic diversity in the region? Trawling samplings are considered an essential step for extrapolating information from benthic samples to the larger scale of habitats (de Juan et al. 2013). In fact, many specific scientific surveys have addressed the study of benthonic assemblages along the Mauritanian coast and shelf (Gascuel et al. 2010; Jouffre and Inejih 2005; Le Lœuff and von Cosel 1998), which finally have entailed an additional trawling impact on the bottom to the impact performed by commercial fisheries (Sauer et al. 2019).

Indirect approaches to describe the ecosystem taxonomical diversity using stomach content analyses have been used in the Atlantic Moroccan bottoms (Abdellaoui et al. 2017), according to literature (e.g., Cherel et al. 2004; Lansdell and Young 2007). Knowing that they do not represent the true diversity of ecosystems and that the information on the status of this fishing ground is scarce, their seasonal and geographical variation may serve as tool to detect disturbances in the region, supporting management recommendations where the collaboration of cephalopod-targeted freezer trawlers would play a role. The main goal of present study was (i) to determine the species found

within the octopuses' mantle, and (ii) to test if the taxonomic diversity found follow the same pattern of spatial pattern (latitude and depth) described in the MEEZ and driving by upwelling phenomena and the seasonal displacements of thermal fronts (Jager 1993; Le Lœuff and von Cosel 1998; Demarcq and Faure 2000; Arístegui et al. 2009).

Material and methods

The sample collection strategy (by vessel) designed for the mentioned collaborative project consisted of picking weekly one octopus of each commercial weight category, when possible, based on the commercial classification by Mitzubishi (see Jouffre et al. 2000). A total of 2622 *O. vulgaris* were analyzed from August 2010 to September 2011. Data used here correspond to the 1696 octopuses which contained some trapped organism/s in the mantle, varying from 129.2 g to 6961.2 g of total weight. The mid-point of the positions registered for the 212 hauls in which each of them were caught has been used as a georeference proxy (Supplementary Information Fig. SI2). The mantle-trapped organisms were extracted, photographed, labelled, and conserved frozen to be examined later. Every organism was identified to the lowest taxonomic level possible and crossed with data of the octopuses in whose mantles were found.

Depth information was assigned based on the provided coordinates by vessels and three strata were considered (Duineveld et al. 1993): shallow (<50 m), medium (50-100 m) and deep (>100 m). Besides, samples were also grouped in three latitudinal ecoregions (Gascuel et al. 2007; Kidé et al. 2015): northern (>19º15'N), central (19º15'N-17º40'N) and southern (<17º40'N). Matrix information on the presence/absence of species by zone (depth strata and ecoregions) is presented in Supplementary Information Table SI1.

The species richness was expressed as the total number of species found into the octopuses' mantle in each zone. Two taxonomic diversity measures were estimated based on distance between each pair of individuals as defined by a Linnaean classification tree (Warwick and Clarke 1995;

Clarke and Warwick 2001): average taxonomic distinctness (AvTD or Δ^+) and variation in taxonomic distinctness (VarTD or Λ^+). The average taxonomic distinctness defined the mean number of steps up the hierarchy that must be taken to reach a taxonomic rank common to two species, computed across all possible pairs of species:

$$\Delta^+ = \left[\sum\sum_{i<j} \omega_{ij}\right] \Big/ [S(S-2)/2]$$

where ω is the branch length between species pairs and S is the number of observed species in the sample. The variation in taxonomic distinctness reflects the degree to which certain taxonomic groups are over- or under- represented in one sample. This index can help distinguish between taxonomic trees that may have the same number of species but an unequal structure tree, considering taxonomic units:

$$\Lambda^+ = \left[\sum\sum_{i<j} (\omega_{ij} - \Delta^+)^2\right] \Big/ [S(S-2)/2]$$

where ω is the branch length between species pairs and S is the number of observed species in the sample and $\Delta+$ is the average taxonomic distinctness for the sample as defined above. The taxonomic hierarchies used in this study were species, genus, family, order, class and phylum.

In order to check if the taxonomic diversity follows a similar spatial distribution pattern as described in the literature, pairwise similarity matrices using Jaccard's index were computed and a dendrogram was obtained to visualize them (Warwick and Clarke 1995; Clarke and Warwick 2001). All statistical analyses were performed in R statistical and computing environment (R Development Core Team, 2020).

Results and discussion

A total of 66 species present into the mantles of octopuses were identified and classified into eight phyla (Fig.1, Supplementary Information Table SI1). The phylum Chordata (mainly Osteichthyes) and Arthropoda (mainly Decapoda) were the most common taxonomic groups in the three ecoregions and depth strata considered in the present study, although other phyla acquired a higher prevalence depending on ecoregion: Cnidaria in the northern, Annelida and Mollusca in the central and Annelida in the southern (Fig. 2). Five species of Osteichthyes were reiteratively found into mantles: *Arnoglossus imperialis* (Bothidae), *Microchirus boscanion* (Soleidae), *Helicolenus dactylopterus* (Sebastidae) and *Dentex macrophthalmus* (Sparidae) characterized by a benthic life-style, and *Capros aper* (Caproidae) with a benthopelagic behaviour (Supplementary Information Table SI1). In general, *H. dactylopterus* and *P. heterocarpus* only appeared in the northern ecoregion and *M. boscanion* was only sampled in the southern ecoregion. Including depth strata, fish species were mainly found in the medium strata (50-100 m) in the northern and in the deep strata in the central zone, whereas in the southern zone was similar observed in all strata (Supplementary Information Table SI1). Two Decapoda (*Munida* cf. *iris* and *Plesionika heterocarpus*) were commonly collected too.

The highest species richness (n= 34) was noted in the northern ecoregion between 50 and 100 m of depth, and the lowest ones (n= 3), in samples from the central ecoregion at depth >100 m (Table 1). Simulation test on Δ^+ using funnels showed that sites' values generally fell within the 95% confidence funnel, and only one case (southern ecoregion at >100 m of depth) was lower than the expected mean (Fig. 3). The highest values of Δ^+ were reached in the central ecoregion, while the highest values of Λ^+ were observed in the southern ecoregion (Table 1). These findings agreed with the idea that the diversity in the shallow Mauritanian waters follows a spatial gradient (latitudinal and bathymetric) promoted by the favourable environmental

conditions (Jager 1993; Demarcq and Faure 2000; Kidé et al. 2015). A permanent upwelling occurs in the northern ecoregion, while it is seasonal (from December to March) in the central ecoregion (Le Loeuff and von Cosel 1998; Arístegui et al. 2009). The presence of processes provides higher plankton productivity supporting a large variety of fish communities (Hagen, 2001; Zeeberg et al. 2006; Kidé et al. 2015). That is reflected in the cluster obtained, where a clear latitudinal separation was noted (Fig. 4). On another hand, the MEEZ is considered a transitional zone between temperate and tropical marine fauna (Le Loeuff and von Cosel 1998; García-Isarch et al. 2017), which may explain the high taxonomic diversity found in the three ecoregions. Finally, the type of bottom (soft *vs.* rocky) between shallow and medium strata also seemed to influence Δ^+, being higher in rocky bottoms, as occurs in other geographical regions (Tuya et al. 2019).

In conclusion, despite the limitations assumed in the present study (mainly in terms of quantitative-based results), our findings followed the expected diversity pattern in the study area. Cephalopod-targeted fisheries occurs worldwide (Sauer et al. 2019), but scientific observations onboard are still scarce, and discards are poorly studied or not reported at all. The analyzed hidden organisms are not even considered discards and at present this information is lost. Based on the present results, the consideration and sampling of these hidden specimens within the mantle of the commercially caught octopuses (and/or other cephalopods) may provide valuable indirect information about the ecosystems where octopuses inhabit. This indirect information-source may be considered complementary to the high-cost scientific surveys.

Authors' contributions AJR conceived the study, conducted the sampling and wrote the paper; VDN, MNC, MGP and JGJ carried out the sampling and the identification of marine organisms; VMT performed the statistical analysis and wrote the manuscript. All authors commented on previous versions of the manuscript and approved the final manuscript.

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Compliance with ethical standards

Conflicts of interest/Competing interests The authors declare that they have no conflict of interest.

Ethics approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

Consent to participate All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements, if applicable.

Consent for publication The datasets generated during and/or analysed during the current study are available in the Table SI1 of Electronic Supplementary Information.

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Figure Captions

Fig. 1 Megafaunal species trapped into octopuses' mantle analysed in the Mauritanian waters. **a** invertebrates; **b** fishes

Fig. 2 Phylum importance by ecoregion and depth of megafaunal trapped into octopuses' mantle analysed in the Mauritanian waters.

Fig. 3 Average taxonomic distinctness (Δ^+) against numbers of species trapped' into the octopuses' mantle in the Mauritania waters in relation to the "expected" value (and its upper and lower 95% probability limits) of this index. Color dot indicates the ecoregion: blue - northern; green - central; yellow - southern.

Fig. 4 Dendrogram of the cluster analysis of the species trapped' into the octopuses' mantle in the Mauritania waters (Jaccard similarity index). CD - central ecoregion and deep stratum; CM - central ecoregion and medium stratum; ND - northern ecoregion and deep stratum; NM - northern ecoregion and medium stratum; NS - northern ecoregion and shallow stratum; SD – southern ecoregion and deep stratum; NM - southern ecoregion and medium stratum; NS - southern ecoregion and shallow stratum.

Table 1 Taxonomic diversity trapped into the octopuses' mantle in the Mauritania waters. *S*, species richness; AvTD, average taxonomic distinctness (Δ+); VarTD, variation in taxonomic distinctness (Λ+)

Ecoregion	Depth	*S*	AvTD	VarTD
Northern	Shallow	21	78.00	4.14
	Medium	34	81.08	2.47
	Depth	19	77.20	3.83
Central	Shallow	3	100.00	17.16
	Medium	21	85.05	3.83
	Depth	21	84.28	3.83
Southern	Shallow	13	55.00	6.19
	Medium	22	80.18	3.68
	Depth	13	77.81	5.49

Figure