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REVIEW ARTICLE

A Review of the Parasites of Deep-Water Fishes from Macaronesian Islands, North-East Atlantic Ocean

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Abstract: The deep-water fish fauna of Macaronesian islands is currently estimated at a total of 1029 different fish species, but records of both ecto- and endoparasites are from only about 30 of those species. This fact presents an exciting field of research for scientists interested in fish parasitology, by exploring the structure of parasite communities and their connections with ecological and oceanographic variables. Research on the effect of climatic changes on the parasite faunas, on the occurrence of fish parasites in man and its impact on human health, has not been carried out to date. The present review aims to collate our present knowledge about the parasites of deep-water fishes of Macaronesia, and to suggest directions for future research on the parasites of fishes from the deepwater realm. A checklist of the parasites infecting the deep-water fishes from this region is included.

Keywords: Deep-water fishes, Parasites, Madeira, Azores, Canary Islands, Macaronesian region.

1. INTRODUCTION

The deep-sea habitat encompasses the ocean regions below 200m depth, with temperatures around 4C, subjected to high pressures, low nutrient concentrations and poor or no sunlight. Thus, deep-water fishes are living in low productivity environments in comparison with the epipelagic fishes [1, 2]. Two regions can be identified in this zone: the mesopelagic (200-1000m) and the bathypelagic (1000-4000m) [3]. Of the 33,200 fish species described, it is estimated that 10-15% are inhabitants of the deep-sea [4]. In the North Atlantic alone, 593 fish species are inhabitants of the deep-water habitat [5]. In the Macaronesian region, which includes the island archipelagos of Azores, Madeira, Canary and Cape Verde, the number of deep-water fish species, according to the FishBase database, amounts to 193 fish species in Azores archipelago, 288 in Canary archipelago, 254 in Cape Verde and 294 in Madeira archipelago [4]. Nevertheless, in spite of the richness of species inhabiting this region, only a few are commercially exploited and thus readily available for biodiversity studies. For example, the black scabbard fishes, *Aphanopus carbo* Lowe, 1839 and *A. intermedius* Parin, 1983, which have been commercially exploited for some years in Madeira, were subjected to several studies including parasites, growth performance and fisheries management [6 - 11]. The need to adapt fishing gear to the conditions of the deep-water habitat has been a limiting condition for the exploitation of this ocean region. Overexploitation of the epipelagic fish resources has accelerated interest in the deep-water resources in recent years

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[5, 12, 13]. Many of the biotic surveys conducted in the deep sea were based on fish captured in the North-west Atlantic, and the northern North-east Atlantic (latitudes above 43°N), which did not include the Macaronesian island archipelagos although a good number of papers did include parasite surveys in Madeira and Azores Archipelagos [8, 9, 14 - 18]. Madeira archipelago is the richest in species, with about 49.6% of the species registered for the North Atlantic, closely followed by the Canary Archipelago with 48.6% of species. This highlights the importance of the deep-water fishing resources for the fisheries economy of these archipelagos. Notwithstanding this high number of fish species, information on the occurrence of parasites and other biological aspects of deep-water fishes is currently restricted to only 31 fish species, the commercially exploited ones and some other species of no commercial value collected during scientific deep-water fish surveys [16, 19]. Some of the deep-water fish species currently been commercially exploited, in particular from the Azores, Madeira and Canary archipelagos, are: *A. carbo*, *Beryx splendens* Lowe, 1834, *Centrophorus squamosus* Bonnaterre, 1788, *Conger conger* Linnaeus, 1758, *Dalatias licha* Bonnaterre, 1788, *Epigonus telescopus* Risso, 1810, *Etmopterus spinax* Linnaeus, 1758, *Helicolenus dactylopterus* Delaroche, 1809, *Lepidopus caudatus* Euphrasen, 1788, *Mora moro* Risso, 1810, *Pagellus bogaraveo* Brünnich, 1768, *Polyprion americanus* Bloch & Schneider, 1801 [11, 20, 21]. Surveys of the parasites occurring in deep-water fishes from other regions of the North Atlantic have been published [15, 16, 19, 22 - 27], although due to the inherent difficulties of fishing in deep-waters, which limits the exploitation of fish resources, parasites of deep-water fishes are less known in comparison with parasites of epipelagic and demersal fishes [16]. More papers are being published on the parasites of deep-water fishes in recent years due to the improvement of technical gear for the exploration of deeper waters [25, 27 - 31], so that the number of parasites infecting deep-water fishes is now estimated at 671 named species or higher taxa, with digeneans being the dominant group of parasites, followed by cestodes, in particular from the orders Trypanorhyncha, Tetraphyllidea and Triaenophoridae [16, 29, 32]. The present work aims at producing an up-to-date review of the diversity of parasites found in the exploited deep-water fishes of Macaronesia, their geographic distribution, transmission and food-web dynamics, as well as their role as indicators of fish population structure and climatic change, and their zoonotic potential. In particular, due to the present climatic change, which facilitates invasion of species from tropical areas [33, 34], it is important to update checklists of parasites and hosts. The importance of parasites as potential human health threats is also discussed [35 - 37]. Due to the lack of knowledge of the parasites infecting deep-water fishes from Macaronesian islands, it is strongly recommended that researchers engage themselves in basic scientific projects, targeting the study of the parasite diversity in fish species from this realm. This would lead to the description of many parasite species new to science, as well as to better understanding the biology and the feeding habits of the fish, based on the occurrence of the parasites.

2. DIVERSITY OF PARASITES OF DEEP-WATER FISHES

Although the deep-sea is known as a nutrient poor habitat, with low or no light, which suggests that fishes in this habitat should have depauperate parasite faunas [24, 38 - 40], a number of parasites belonging to many phyla have been reported from deep-water fishes [16]. In the Macaronesian region, myxosporeans belonging to the genus *Ceratomyxa* (2 species) and *Parvicapsula* (1 species) were found in the gall bladders of *A. carbo* and *B. splendens* [6, 17, 41, 42]. Haematozoans, of the genus *Haemohormidium* (Apicomplexa) were found in erythrocytes of *Coryphaenoides armatus* Hector, 1875 caught at Cape Verde [19]. Although blood smears of 11 deep-water fish species - *Alepisaurus ferox* Lowe, 1833, *Bathypterois grallator* Goode & Bean, 1886, *Bathysaurus mollis* Günther, 1878, *Borostomias elucens* Brauer, 1906, *Chauliodus sloanei* Bloch & Schneider, 1801, *Conocara salmoneum* Gill & Townsend, 1897, *C. armatus*, *Coryphaenoides profundicolus* Nybelin, 1957, *Histiobranchus bathybius* Günther, 1877, and *Sigmops elongatus* Günther, 1878- were examined, no further haematozoans were found [19]. Monogeneans are represented by at least 5 species, mostly specific to their respective hosts (Table **1**). Among the digeneans, lepocreadioids include groups of worms which are common in deep-sea fishes, from the subfamily Lepidapedinae, although members of the subfamily Lepocreadiinae have been found in deep-water fish (*e.g. Prodistomum priedei* Bray & Merrett, 1998) [28, 31, 43 - 46]. Hemiuridae, in particular *Lecithochirium* species, are common in deep-water fish. A total of 18 different digenean taxa were found infecting deep-water fishes from Macaronesia (Table **1**).

Table 1. Protozoan and metazoan parasites infecting the deep-water fishes from Macaronesian region, North-east Atlantic.

Parasite Taxon	Host																														
	Aphanopus carbo	*Alepisaurus ferox*	*Beryx splendens*	*Cataetyx laticeps*	*Centrophorus squamosus*	*Centroscymnus coelolepis*	*Centroscyllium fabricii*	*Centroscymnus cryptacanthus*	*Ceratoscopelus maderensis*	*Coelorinchus karrerae*	*Conger conger*	*Coryphaenoides armatus*	*Coryphaenoides nasutus*	*Dalatias licha*	*Deania calcea*	*D. hystricosa*	*D. profundorum*	*Etmopterus princeps*	*E. pusillus*	*E. spinax*	*Halosauropsis macrochir*	*Helicolenus dactylopterus*	*Heptranchias prelo*	*Lepidopus caudatus*	*Maurolicus muelleri*	*Myctophum punctatum*	*Pagellus bogaraveo*	*Poromitra crassiceps*	*Polyprion americanus*	*Scopelogadus beanii*	References
Apicomplexa																															
Haemohormidium sp.												Y																			[19]
Microsporidia																															
Glugea capverdensis Lom, Gaevskaya & Dykova 1980																										Y					[103, 104]
Pleistophora duodecimae Lom, Gaevskaya & Dykova 1980													Y																		[103, 104]
Myxozoa																															
Ceratomyxa maxima Gaevskaya & Kovaljova, 1980			Y																												[41]
Ceratomyxa tenuispora Kabata, 1960	Y																														[6, 42]
Parvicapsula schulmani Kovaljova & Gaevskaya, 1981			Y																												[105]
Monogenea																															
Calicobenedenia polyprioni Kritsky & Fennessy, 1999																													Y		[106]
Lamellodiscus virgula Euzet & Oliver, 1967																											Y				[57]
Octoplectanocotyla aphanopi Pascoe, 1987	Y																														[17, 107]
Paradiplectanotrema lepidopi Gerasev, Gaevskaja & Kovaleva, 1987																								Y							[15]
Digenea																															
Accacladocoelium petasiporum Odhner, 1928																											Y				[52]
Adinosoma gaevskaye Zubchenko, 1978											Y																				[108]
Botulus microporus (Monticelli, 1889)		Y																													[109] personal obs.
Brachyphallus crenatus (Rudolphi, 1802)																								Y							[15]
Degeneria halosauri (Bell, 1887) Campbell, 1977																					Y										[25]
Derogenes varicus (Muller, 1784)																											Y				[52]
Diphterostomum vividum (Nicoll, 1912) Bray & Gibson, 1986																											Y				[52, 67]
Gaevskajatrema halosauropsi Bray & Campbell, 1996																					Y										[25]
Gonocerca phycidis Manter, 1925																															[15]
Lecithocladium excisum (Rudolphi, 1819) Lühe, 1901																								Y							[15]
Lecithochirium furcolabiatum (Jones, 1933) Dawes, 1947											Y																				[54]
Lecithochirium grandiporum (= *L. fusiforme* Lühe, 1901) (Rudolphi, 1819) Lühe, 1901											Y																				[52, 54]

(Table 1) contd.....

Parasite Taxon	**Host**																														
Lecithochirium musculus (Looss, 1907) Nasir & Diaz, 1971	Y										Y																				[17, 54]
Odhnerium sp. Yamaguti, 1934																						Y									[49]
Pachycreadium carnosum (Rudolphi, 1819) Cortini & Ferretti, 1959																											Y				[52]
Pycnadenoides senegalensis Fischthal & Thomas, 1972																											Y				[52]
Steringophorus sp. Odhner, 1905																					Y										[25]
Cestoda																															
Aporhynchus sp. Nybelin, 1918																	Y	Y													[40]
Aporhynchus menezesi Noever, Caira, Kuchta & Desjardins, 2010																				Y											[40, 110]
Aporhynchus norvegicus (Olsson, 1868)																				Y											[40]
Aporhynchus tasmaniensis Beveridge, 1990																				Y											[111]
Aporhynchus pickeringae Noever, Caira, Kuchta & Desjardins, 2010																			Y												[40, 110]
Bilocularia hyperapolytica Obersteiner, 1914														Y																	[40]
Campbelliella heteropoeciloacantha Palm, 2004	Y																														[17]
Clistobothrium carcharodoni Dailey & Vogelbein, 1990															Y																[40]
Clistobothrium montaukensis Ruhnke, 1993						Y		Y							Y																[40]
Crossobothrium dohrnii (Oerley, 1885) Ruhnke, 1996																							Y								[47]
Crossobothrium sp. Linton, 1889																Y															[47, 111]
Deanicola sp. Beveridge, 1990															Y		Y														[40]
Heteronybelinia yamagutii (Dollfus, 1960)	Y																														[8, 17]
Bathygrillotia kovalevae (Palm, 1995) Beveridge & Campbell, 2012 (=*Grillotia kovalevae* Palm, 1995)										Y																					[53]
Grillotia acanthoscolex Rees, 1944 (= *Grillotia microthrix* Dollfus, 1969)																							Y								[47]
Grillotia meteori Palm & Schröder, 2001																	Y														[47]
Grillotia sp. Guiart, 1927				Y																										Y	[40, 48]
Gilquinia sp. Guiart, 1927					Y		Y											Y													[18, 40]
Monorygma Diesing, 1863						Y																									[40]
Nybelinia lingualis Cuvier, 1817	Y																							Y							[6, 15, 17]

(Table 1) contd.....

Parasite Taxon	**Host**																														
Nybelinia thyrsites Korotaeva, 1971	Y																														[17]
Pelichnibothrium speciosum Monticelli, 1889		Y																													[112], personal obs.
Plesiorhynchus brayi Palm, 2004																		Y													[40]
Tentacularia coryphaenae Bosc, 1802	Y				Y																		Y								[6, 17, 18, 47]
Scolex pleuronectis Müller,1788	Y																				Y										[25, 40], personal obs.
Heterosphyriocephalus tergestinus (Pintner, 1913) Dallarés, Carrassón & Schaeffner, 2016 (= *Sphyriocephalus tergestinus* Pintner, 1913)	Y										Y													Y							[6, 15, 54]
Tetraphyllidea																									Y		Y			Y	[46, 52]
Triloculate Tetraphyllidea					Y																										[18]
Acanthocephala																															
Bolbosoma vasculosum (Rudolphi, 1819)	Y																							Y							[7, 15]
Echinorhynchus sp. Zoega in Müller, 1776																					Y										[25]
Rhadinorhynchus pristis (Rudolphi, 1802)											Y													Y			Y				[15, 52, 54]
Nematoda																															
A. brevispiculata Dollfus, 1966	Y																														[8]
A. nascettii Mattiucci, Paoletti & Webb, 2009	Y																														[14]
A. pegreffii Campana-Rouget & Biocca, 1955	Y																									Y	Y				[14, 46, 50, 51]
A. physeteris (Baylis, 1923)	Y																					Y					Y				[8, 49, 51].
A. simplex (Rudolphi, 1809)	Y				Y																	Y		Y	Y	Y	Y				[14, 15, 18, 46, 49, 51]
Anisakis sp. Dujardin, 1845															Y						Y		Y				Y	Y			[25, 46, 47]
A. typica (Diesing, 1860) Baylis, 1920																											Y				[51]
A. ziphidarum Paggi, Nascettii, Webb, Mattiucci, Cianchi & Bullini, 1988	Y																										Y				[14, 51]
Comephoronema macrochiri Moravec & Klimpel, 2007																					Y										[25]
Contracaecum Railliet & Henry, 1912																											Y				[51]
Cristitectus congeri Petter, 1970											Y																				[54]
Hysterothylacium aduncum (Rudolphi, 1802)																								Y							[15][
Hysterothylacium sp. Ward & Magath, 1917																					Y						Y				[25, 50, 51]
Pseudoterranova ceticola Deardorff & Overstreet, 1981					Y																										
Crustacea																															

(Table 1) contd.....

Parasite Taxon	Host																														
Aega antillensis (Schioedte & Meinert, 1879)																											Y				[56]
Aega deshaysiana Milne Edwards, 1840																											Y				[56]
Anelasma sp. Darwin, 1852																		Y													[113]
Argulus sp. Muller, 1785																											Y				[56]
Caligus elongatus von Nordmann, 1832																								Y							[15]
Gnathia sp. Leach, 1814																											Y				[56]
Hatschekia pagellibogueravei Hesse, 1878																											Y				[56]
Jusheyus shogunus Deets & Benz, 1987																													Y		[114]
Rocinela danmoniensis Leach, 1818																											Y				[56]
Tautochondria dolichoura Ho, 1987																												Y		Y	[46]

The majority of the cestodes infecting deep-water fishes appear to be larval stages belonging to the order Tetraphyllidea, and adults of the order Trypanorhyncha. Larval trypanorynchs were also found in some deep-water sharks [18, 40, 47, 48]. Acanthocephala are poorly represented in the deep-water habitat, with only 3 species found to date [7, 17, 49]. In contrast, nematodes of the genus *Anisakis* were found in many of the fish examined, sometimes reaching high prevalences (up to 100%) and intensities of infection [8, 17, 50 - 52]. Finally, 9 species of Crustacea were found, which, with the exception of one, were generalist parasites. Summarizing, to date 1 haematozoan, 2 microsporidians, 3 myxozoans, 5 monogeneans, 17 digenean, 28 cestodes, 3 acanthocephalans, 12 nematodes and 9 crustaceans, have been found in the 30 different deep-water fishes from the Macaronesian region. Although the parasite fauna of deep-water squaliform sharks appears to be depauperate in comparison to the parasite fauna of deep-water carcharhiniforms [18, 40, 53], it would be worthwhile to conduct more research, including surveys of more host species, to understand better the dynamics of parasite transmission in the deep sea.

3. TRANSMISSION, FOOD-WEB DYNAMICS AND GEOGRAPHIC DISTRIBUTION OF PARASITES

The study of the occurrence of parasites in a particular fish species can give clues about the feeding ecology of the fish, and consequently about the food-web transmission of the parasites. In this respect a survey of parasites of the conger eel, *C. conger*, from Madeira Archipelago, found that some parasites were more abundant in deeper waters. For example the postlarvae of the trypanorhynch *Sphyriocephalus tergestinus* Pintner, 1913 and the hemiurid digenean *Lecithochirium grandiporum* (*L. fusiforme* Lühe, 1901) (Rudolphi, 1819) Lühe, 1901, occurred in waters below 400m deep, whereas the digenean *L. musculus* (Looss, 1907) Nasir & Diaz, 1971, was present in conger eels only at depths of 200-300m [54]. In the mesobathyal region, fish and crustaceans are the preferential prey, thus explaining the presence of *S. tergestinus* in deeper waters. Another study, that examined the parasite diversity of seven different meso- and bathypelagic fish species, from the Mid-Atlantic Ridge (MAR), found significant differences in prevalence with helminth parasites, which were correlated with the feeding habits of the fish hosts [46]. High prevalence with anisakids, in myctophid fishes, was correlated with feeding predominantly on euphausiids and on copepods, common intermediate hosts in the complex life cycle of these parasites. High prevalence with anisakids was also observed in *A. carbo* from Madeira waters [8, 17] due to feeding on prey items, which act as intermediate and paratenic hosts in the life cycle of the nematodes. Likewise the diversity of parasites infecting the silver scabbard fish, *L. caudatus* agreed well with its diet on copepods and euphausiids transmitting anisakid nematodes, amphipods transmitting acanthocephalans, and chaetognaths acting as intermediate hosts for hemiurid digeneans [15]. Larval stages of cestodes, of the orders Trypanorhyncha and Tetraphyllidae, were transmitted to the black scabbard fish, by feeding on cephalopods and crustaceans, as well as on mesopelagic fishes [6, 17]. In the deep water realm trypanorhynchs of the families Aporhynchidae, Gilquinidae and larval tetraphyllideans are the most common cestodes infecting fishes and sharks [18, 40, 47, 48]. Nevertheless, trypanorhynchs of the families Tentaculariidae and Sphyriocephalidae, common parasites of epipelagic and mesopelagic fishes, were additionally found in the black-scabbard fish and the conger eel [9, 17, 54]. This reflects the feeding behaviour of the fish hosts, which undergo extensive vertical migrations [11, 54]. Ecological factors such as diet, depth range, temperature, and host behaviour are important as driving forces shaping the community structure of parasites. One other factor in the shaping of parasite communities is the life cycle of the parasite, which is inherently connected to diet. Trypanorhynchs and tetraphyllidean cestodes mature in sharks, many of them deep-water sharks [40, 47, 53]. This explains why these parasites are common in deep-water fishes (28 taxa, Table **1**). On the other hand acanthocephalans, many of which mature in whales, were rare in deep-waters. The majority of the digeneans, cestodes and acanthocephalans found in deep-water fishes from the Macaronesia were generalists, with complex life cycles. In contrast, monogeneans and crustaceans, which tend be host specific have less complex life cycles. The relatively few (5) monogenean species and crustacean parasites (10) found in deep-water fishes from Macaronesia may be explained by the fact that, been ectoparasites, they are more vulnerable to being lost or damaged due to fishing procedures, and does not necessarily reflect poor diversity of these parasite groups.

It is believed that mesopelagic and bathypelagic fishes have more impoverished parasite communities than benthic fishes [24, 55]. If we take the parasites of the bathypelagic fish *A. carbo* as an example, the total number of parasite species found to date is 14 [7 - 9, 14, 17], whereas the parasite richness of the benthopelagic *P. bogaraveo* is represented by 22 parasite species [51, 52, 56]. Only 2 parasites infecting *A. carbo* are specialists, the remaining being generalists infecting a wide range of fish species, not all of them typical of deep-waters only, occurring also in mesopelagic zones. Among the parasites of *P. bogaraveo*, 3 are specialists and the remaining 19 are generalists. In very dilute environments, as is the case of oceanic islands, the generalist parasite mode of life is preferred as a survival strategy in these nutrient poor environments [55, 57]. Some parasites have a wide geographical distribution, whereas others are restricted to particular zones. Hosts that undergo extensive migrations, vertical and horizontal ones, concur to spread the parasites in wider geographic patterns. The anisakids, *A. simplex* (s.s.) (Rudolphi, 1809) and *A. pegreffii* Campana-Rouget & Biocca, 1955, are common in the entire Atlantic Ocean and Mediterranean Sea, the first one also present in the Pacific Ocean, with mainly benthic, demersal and bathypelagic life cycle [14, 58, 59]. Their definitive hosts, whales of the families Physeteridae and Ziphiidae, are present in the Macaronesian deep-water realm [60, 61]. Likewise the geographic distribution of tapeworm parasites infecting deep-water sharks, are a product of the host wide distribution and their trophic levels [62, 63]. Nevertheless the infection rate of deep-water sharks was low in comparison with infection rates of epi-pelagic sharks. For example, 57% of sharks examined in the Condor Seamount, Azores Archipelago, were not infected with cestodes [40]. This finding agrees with results from other researchers elsewhere, advocating that the parasite fauna of deep-water organisms is impoverished [40, 53].

4. ROLE OF PARASITES AS INDICATORS OF ENVIRONMENTAL HEALTH, CLIMATE CHANGE AND FISH POPULATION STRUCTURE

Parasites are important key elements to assess the quality of the water environment, the effects of climate changes, and population structure of fish [64 - 66]. Santos *et al.* [17] highlighted the role parasites play in the differentiation of stocks of *A. carbo* from different regions in the North Atlantic. The hemiurid digenean, *L. musculus* was only present in the Azores fish samples, and postlarvae of the trypanorhynchs *Campbelliella heteropoeciloacantha* Palm, 2004, *Heteronybelinia* sp. Palm 1999, *Nybelinia thyrsites* Korotaeva, 1971, and *Tentacularia coryphaenae* Bosc, 1802, only present in Madeiran fish samples. The conclusions of this study suggested the existence of three different stocks of black-scabbard fish, one in mainland Portugal (at Sesimbra), one in Madeiran waters and the third one in the Azores waters. Sequeira *et al.* [49] used parasites, in particular anisakid nematodes, for discrimination of populations of the bluemouth, *H. dactylopterus*. Differences were found in the occurrence of anisakid parasite species, with *A. pegreffii* as main species in the fish samples from mainland Portugal, an unidentified *Anisakis* species in Madeiran samples, and *A. physeteris* (Baylis, 1923) in the Azores samples. Another study of the helminth parasites infecting the black-spot seabream, *P. bogaraveo* from Madeira, Azores and mainland Portugal suggested the presence of different populations in the study areas [52, 67]. The conclusions were mainly based on the presence of hemiurid digeneans in mainland Portuguese Atlantic waters, and their absence in samples collected in the Azores and Madeira archipelagos. The higher diversity of digeneans in mainland Portugal was correlated with high diversity of benthic invertebrates, intermediate hosts for the digeneans, whereas in the island ecosystems, nutrient poorer waters supported an impoverished benthic invertebrate fauna and consequently a poor digenean fauna. Additionally, anisakid nematodes played a fundamental role as indicators of fish population structure, with *A. physeteris* dominant in the Azores samples, an unidentified *Anisakis* sp. in Madeira, and *A. pegreffii* in mainland Portugal [51, 67]. The impact of climatic changes, particularly rising water temperatures, is expected to critically affect the distribution of meso and epi-pelagic fishes and consequently their parasite faunas [68, 69]. In addition, rising surface water temperatures will allow tropical fish species to extend their distribution range further north, carrying with them new parasites which will thus be introduced and may evolve and complete their life cycles [33, 34, 70]. Since many parasites are not host specific, and can use both pelagic and deep-water fishes as paratenic hosts, it is expected that new colonization events by parasite species will be experienced in the near future. What will be the impact of these parasites in their new hosts, in terms of their pathogenicity and their competitive fitness, is something to ponder [69, 71]. New fish species arriving from tropical waters, which have already been reported in Madeira, include the monacanthids *Aluterus scriptus* Osbeck, 1765 and *A. monoceros* Linnaeus, 1758 [72], the goldspot goby *Gnatholepis thompsoni* Jordan, 1904 [73] and the carangid *Caranx crysos* Mitchill, 1815 [74]. Wirtz *et al.* [74] suggested that rising water temperatures were the trigger for the occurrence or the increase in frequency of species typical of warmer waters. These new arrivals can facilitate the introduction and transmission of new parasites in this marine habitat. Many parasites are generalists and those coming with these new fish species will probably spread to local fish species, seeking to establish themselves and conquer new life cycle pathways [55]. Although the impact of climatic changes on the biodiversity of the deep sea, have not been addressed with much detail, a few studies done in other deep-water ocean regions, have indeed demonstrated that, the effect of climatic changes on the biodiversity of this sea realm can not be neglected [75 - 78]. Studies of the effect of climatic changes in parasite diversity of deep-water species in Macaronesia have not been done yet. However, there are well documented baseline studies of parasites in some deep-water fishes, such as *A. carbo* and *P. bogaraveo* [14, 17, 51, 52, 56, 79], so follow-up surveys can be done in order to detect new parasites or parasite extinctions with time.

5. IMPORTANCE OF PARASITES FOR HUMAN HEALTH AND THEIR IMPACT ON FISH QUALITY

Larval anisakid nematodes (L3 stages) are parasites of a wide range of fish species, both pelagic and deep-water, with worldwide distribution, and can lead to inflammation of the gastrointestinal tract of man, following consumption of raw or poorly cooked fish [35, 80 - 82]. Major clinic symptoms are vomiting and epigastric pain [36, 83 - 86]. Reports of human infections with anisakid nematodes have been increasing in the last 30 years, probably because of more awareness and cooperation between parasitologists and medical professionals, with quite a number of papers published, including case studies and state of the art reviews [37, 86 - 90]. Not all anisakid species have exactly the same ability to infect humans and therefore to be of zoonotic potential. From the 9 known species of *Anisakis* infecting fish and squids, the only *Anisakis* species cited as occurring in man are *A. simplex* (s.s.) and *A. pegreffii*, both belonging to the complex of species called *Anisakis simplex* (s.l.) [89]. However, a recent comparative study of the behaviour of both species showed that *A. simplex* (s.s.) supports better the gastric juices, and migrates faster to the fish muscle, when the fish died, than *A. pegreffii* [90]. This suggests that it is very important to know what anisakid species is infecting fish used for consumption, and see if the parasites belong to *A. simplex* (s.s.) species, the most dangerous group, or to other potentially less dangerous species. In Europe, several cases of human infections due to *A. pegreffii* have been reported [89, 91]. According to several authors, nematodes with zoonotic potential include not only the two species, *A. pegreffii* and *A. simplex* (s.s.), but in addition *A. physeteris* and *Pseudoterranova decipiens* (Krabbe, 1878) Gibson, 1983 [36, 91 - 97]. Anisakid nematodes are common parasites of several fish species in the Macaronesian region, including deep-water species (*e.g.A. carbo*, *B. splendens*, *P. bogaraveo*) (Table **1**) [6, 8, 14, 49 - 51]. In some fish species, *A. simplex* (s.s.) was the most frequent nematode species [8, 14, 51], whereas in others *A. pegreffii* was the most frequent. Many studies which dealt with the occurrence of anisakids in fishes did not include the identification of the species, a procedure that involves the use of molecular tools. Specific identification of species was done for some fish species from the Madeira Archipelago [8, 14, 50, 51], although only for a sub-sample of the anisakids found. The work of Hermida *et al.* [51, 52] was also an important study on the occurrence of anisakids in *P. bogaraveo* from mainland Portugal, the Azores and Madeira archipelagos. This fish is host to a number of anisakid species, including the two species of zoonotic potential. A study of the distribution of anisakids in the viscera and musculature of forty black-scabbard fish, *A. carbo*, concluded that larvae were mainly located in the viscera, but some were found in the belly flaps region, beginning the process of penetrating into the muscle [98]. This highlights the potential danger of keeping fish with viscera after capture. One good measure to prevent migration of larvae from the visceral cavity to the muscles is to proceed with evisceration of fish on board, immediately after capture, a procedure that is taken place in many fishing vessels, whenever conditions permit such procedure. This action however, increases the risk of enhancing prevalence and abundance of parasite larvae in small pelagic fishes, such as mackerels and sardines, due to “anthropogenic short-cut” as discussed by Mattiucci and co-authors [89]. Evisceration on board would provide easy food to dolphins and whales (which are abundant in Macaronesian islands) [60, 61], the definitive hosts of anisakids. In the intestines of these marine mammals, parasites attain maturity and new release of infective larvae to pelagic fishes, such as mackerels and sardines, will be the outcome. Heavily infected mackerels, as well as other small pelagic fishes, will in turn be food for man. Ingestion of infected fish by man, not only presents the danger of gastroenteritis due to attachment of larvae on the stomach mucosa, but in addition, ingestion of infected fish can lead to allergic reactions in man [85, 97, 99 - 101]. In contrast to fish, sharks were apparently less susceptible to infections with anisakids, or perhaps due to the physiologic conditions of their digestive tract as gastric digestion leads to a semi-liquid chime, as a result of complete breakdown of the ingested prey, parasites were not detected [102]. In a survey of 69 leafscale gulper shark, *C. squamosus*, only 9 nematodes were recovered, 7 of them were *A. simplex*, one was *Pseudoterranova ceticola* Deardorff & Overstreet, 1981, and another one an unidentified anisakid [18]. In the black-scabbard fish, *A. carbo*, prevalence of *Anisakis* spp. can reach 100% [8, 14, 17]. High prevalence was also found in the blackspot seabream, *P. bogaraveo* [51] in Madeira Archipelago. In contrast to the research and data on the zoonotic potential of anisakids in Continental European and Mediterranean countries, there are no data about human infections in the Macaronesian region. The absence of reported cases of anisakiasis in this region can be due to the fact that fish is mainly consumed well cooked. One other reason could be that human cases of anisakiasis have been overlooked by medical professionals.

CONCLUSION

We strongly recommend a better collaboration between fish parasitologists and medical professionals, in order to assess with greater accuracy, the causes of many allergic reactions in man. As the consumption of fish is very popular in this region, the potential for human infections due to *Anisakis* larvae thus exists.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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