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Parasites of amberjacks from the archipelago of Madeira, Eastern Atlantic

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ABSTRACT: Amberjacks, *Seriola* spp., are a group of carangid fishes of economic importance for fisheries and aquaculture worldwide. A survey of the parasites of greater amberjack *S. dumerili* and almaco jack or longfin yellowtail *S. rivoliana* from the Madeira archipelago (including the Madeira and Selvagens Islands) was carried out. This work is the first parasitological study of these 2 species in the Eastern Atlantic. A total of 14 parasite taxa were detected in the 47 fish analysed: *Allencotyla mcintoshi*, *Stephanostomum petimba*, *Rhadinorhynchus* sp. and *Caligus aesopus* (in both *Seriola* spp.); *Dionchus agassizi*, *Zeuxapta seriolae*, *Tormopsolus orientalis*, *Didymocystis* sp. and *Anisakis* sp. (in *S. rivoliana*); *Tetrochetus coryphaenae*, *Stephanostomum* sp., *S. ditrematis*, *Oncophora melanocephala* and *Hysterothylacium seriolae* (in *Seriola dumerili*). The monogenean *Dionchus agassizi* and the nematode *O. melanocephala* constitute new host records for the genus *Seriola*, and the species *Allencotyla mcintoshi*, *Z. seriolae*, *Tormopsolus orientalis*, *H. seriolae*, and *C. aesopus* are reported in the region of Madeira for the first time. Some of the parasites detected, in particular *Z. seriolae* and *C. aesopus*, could constitute a threat to amberjack aquaculture, and measures should be taken to prevent their introduction into sea cages.

KEY WORDS: Amberjack · *Seriola dumerili* · *Seriola rivoliana* · Madeira · Parasites · Atlantic · Portugal

INTRODUCTION

Amberjacks are a group of carnivorous, predatory fish that belong to the genus *Seriola,* family Carangidae. They are valuable commercial species (Mazzola et al. 2000, Fernandes et al. 2018), with high consumer acceptance due to their excellent flesh quality (Sicuro & Luzzana 2016). Four species of this genus occur in the Madeira archipelago: the Guinean amberjack *Seriola carpenteri*; greater amberjack *S. dumerili*; lesser amberjack *S. fasciata*; and almaco jack or longfin yellowtail *S. rivoliana* (Carpenter & De Angelis 2016). Amberjacks are mainly distributed in tropical to warm temperate waters (McEachran & Fechhelm 2010). In the Eastern Atlantic, they occur between the UK and West Africa, including mainland Portugal and the Madeira, Azores and Canaries archipelagos, and in the case of *S. dumerili*, also in the Mediterranean Sea (Valls et al. 2011). Both *S. dumerili* and *S. rivoliana* are common in Madeiran waters, with higher abundance in the Selvagens Islands, possibly due to the relatively unperturbed

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habitat of the Selvagens Marine Protected Area compared to Madeira Island, where they may have been somewhat overexploited by commercial fisheries (Hermida & Delgado 2016, Friedlander et al. 2017). These species are pelagic and epibenthic in oceanic waters and live at between 5 and 45 m depth, but are more common at depths of 30 to 35 m (Myers 1991).

Amberjacks are important not only for commercial fisheries, but especially for aquaculture production (Sicuro & Luzzana 2016). Greater amberjack is an important cultured species in Asia, with production exceeding 38 000 t annually in Japan alone, and it has also been produced in the Mediterranean since the 1980s (Sicuro & Luzzana 2016). Almaco jack is already produced commercially, albeit on a smaller scale, in the southern USA and Hawaii, with production reaching 500 t yr^{-1}, and shows a good potential for aquaculture diversification elsewhere (Sicuro & Luzzana 2016). This species has been recently introduced into aquaculture in Madeira, where the main production is gilthead seabream *Sparus aurata* (Berenguer 2017).

Due to the commercial importance of *Seriola* spp., some studies on their parasite communities in different geographical areas have been published. There are a few publications from Australia (Sharp et al. 2003, Hutson et al. 2007) and the Mediterranean Sea (Grau et al. 1999, Bartoli & Bray 2004); however, as far as we know, there are no studies about the metazoan parasite communities of *Seriola* spp. from the Eastern Atlantic. Several metazoan parasites from different taxonomic groups have already been identified in *Seriola* spp. and some of them can be potentially dangerous to aquaculture production, causing mortalities, e.g. the monogeneans *Zeuxapta seriolae* (Montero et al. 2004) and *Neobenedenia girellae* (Hirayama et al. 2009).

The main purpose of this study is to describe the metazoan parasite community of *Seriola* spp. from the Madeira archipelago and compare it with the parasite communities previously described in amberjacks. Furthermore, this study can contribute to the knowledge of parasite species which might constitute a risk to the aquaculture production of amberjacks.

MATERIALS AND METHODS

Fish sampling

A total of 47 specimens of *Seriola* spp. were obtained between August 2016 and October 2017. Of these, 30 fish came from the Selvagens Islands as a seizure from illegal fisheries; 29 of them were identified as *S. rivoliana* and 1 as *S. dumerili*. Since it was not possible to observe the fish immediately, they were frozen, which is the most acceptable method of conservation for evaluating parasite community taxonomic composition (Kvach et al. 2018). A further 15 specimens of larger size, 1 *S. rivoliana* and 14 *S. dumerili* from Madeira, obtained from recreational fisheries, were also sampled. In addition to this, 2 specimens of *S. dumerili* were obtained from a local aquaculture facility (see Table 1). Fishes were identified according to Carpenter (2002), McEachran & Fechhelm (2010) and Carpenter & De Angelis (2016).

Fish were measured and weighed: total weight, total length (TL), fork length (FL), girth and maximum body height of each fish were obtained. The sex of each specimen was determined through visual observation of the gonads. The gills and viscera were extracted and examined under a stereomicroscope with 100× magnification. Parasites found were collected, counted, washed in saline solution (10%) and stored in ethanol (70%) for morphological identification. When necessary, nematodes were cleared in a solution of 1:1 ethanol:glycerol and moved to 100% glycerol after 48 h.

In addition to the parasitology study, the stomach contents of *S. rivoliana* from the Selvagens Islands were examined, and prey items were quantified and individually identified with the aid of fish identification guides. The stomach vacuity index was calculated and percent abundance of each prey was quantified.

Parasite identification

Morphological identification of the different parasites proceeded to the lowest possible taxon. Monogeneans were identified according to the descriptions of Rao & Madhavi (1967), Rohde (1978), Hendrix (1994), Montero et al. (2003) and Jones et al. (2005). Identification of trematodes was based on Rao & Madhavi (1967), Bartoli & Bray (2004), Bartoli et al. (2004), Jones et al. (2005) and Repullés-Albelda (2013) for the Acanthocolpidae, and Bray & Gibson (1977) for the Accacoeliidae. Nematodes were identified according to Rodrigues et al. (1975), Deardorff & Overstreet (1980), Moravec et al. (1999), Li et al. (2007) and Costa et al. (2009a), and copepod identification followed Cressey (1991), Choe & Kim (2010) and Repullés-Albelda (2013).

Statistical analysis

Biological condition factors, including the gonadosomatic index, hepatosomatic index, girth/length ratio and Fulton's *K* condition factor were determined according to Lloret et al. (2014). Prevalence, mean intensity and mean abundance of each parasite species were calculated according to Bush et al. (1997).

For the sample of 29 almaco jacks from the Selvagens Islands, correlations between parasite abundance and host parameters were assessed using Spearman's rank correlation (r_S). Host parameters used were total length, weight, *K* and girth/length ratio. Fisher's test was used to assess differences in prevalence between the sexes. Spearman's rank correlations and Fisher's test were only carried out for the most prevalent species: *Allencotyla mcintoshi*, *Caligus aesopus, Tormopsolus orientalis*, *Anisakis* sp. and *Hysterothylacium seriolae*.

RESULTS

Of the 47 specimens of *Seriola* spp. from Madeira and the Selvagens Islands analysed in this study, 30 were identified as *S. rivoliana* and 17 as *S. dumerili*. Their provenance and biometric data are detailed in Table 1.

A total of 14 parasite taxa were detected in *S. dumerili* and *S. rivoliana* from the Madeira archipelago (Table 2), 2 of which constitute new host records for the genus *Seriola*: the monogenean *Dionchus agassizi* and the nematode *Oncophora melanocephala* (Fig. 1). Furthermore, 5 parasite species are new records for Madeira: *Allencotyla mcintoshi*, *Zeuxapta seriolae*, *Tormopsolus orientalis*, *Hysterothylacium seriolae*, and *Caligus aesopus* (Fig. 1).

Almaco jack

In the 29 *S. rivoliana* from the Selvagens Islands, which were considered the main sample, 8 species of metazoan parasites were found: *Allencotyla mcintoshi* Van Beneden & Hess, 1863, *Dionchus agassizi* Goto, 1899 and *Zeuxapta seriolae* (Meserve, 1938) (Monogenea); *Didymocystis* sp. Ariola, 1902 and *Tormopsolus orientalis* Yamaguti, 1934 (Trematoda); *Rhadinorhynchus* sp. Lühe, 1911 (Acanthocephala), *Anisakis* sp. Dujardin, 1845 (Nematoda) and *Caligus aesopus* Wilson, 1921 (Copepoda).

T. orientalis was the most prevalent species (P = 36.7 %) in almaco jack from the Selvagens Islands, followed by *A. mcintoshi* (P = 33.3 %) and *C. aesopus* (P = 30.0 %). The highest intensities were shown by *Z. seriolae* (mean intensity [mI] = 127.0) and *Dionchus agassizi* (mI = 17.0). *Z. seriolae* was also the most abundant species (mean abundance [mA] = 4.38), followed by *T. orientalis* (mA = 2.31).

A significant negative correlation between *T. orientalis* abundance and host *K* was detected through Spearman's rank correlation ($p = 0.043$; $r_S = -0.378$), while the abundance of the copepod *C. aesopus* showed a positive correlation with fish weight ($p = 0.024$; $r_S = 0.417$).

Table 1. *Seriola* spp. specimens from the Madeira archipelago (Madeira and Selvagens Islands) sampled in this study. TL: total length, FL: fork length. TL, FL and weight are given as mean ± SD (range)

Date	Location	Species	n	TL (cm)	FL (cm)	Weight (g)
Aug 2016	Selvagens	*S. rivoliana*	29	49.8 ± 2.3 (45.5–55.0)	44.3 ± 2.0 (41.0–49.5)	1644.4 ± 257.9 (1170.3–2100.8)
Aug 2016	Selvagens	*S. dumerili*	1	51.0	45.5	1564.5
Jan 2017	Madeira	*S. rivoliana*	1	123.4	108.0	22644.0
Jan 2017	Madeira[a]	*S. dumerili*	2	49.1 ± 2.3 (47.5–50.7)	43.1 ± 2.3 (41.7–44.5)	1520.0 ± 198.0 (1380.0–1660.0)
Mar 2017	Madeira	*S. dumerili*	1	85.5	83.4	9156.0
Apr 2017	Madeira	*S. dumerili*	1	122.4	107.1	20234.0
Jun 2017	Madeira	*S. dumerili*	2	124.0 ± 7.0 (119.0–129.0)	112.0 ± 5.7 (108.0–116.0)	22300.0 ± 5232.6 (26000.0–18600.0)
Aug 2017	Madeira	*S. dumerili*	5	129.4 ± 8.2 (122.3–143.2)	113.5 ± 6.8 (108.1–125.0)	20910.0 ± 4111.0 (16550.0–27600.0)
Oct 2017	Madeira	*S. dumerili*	5	136.5 ± 17.9	119.3 ± 13.2	24495.6 ± 5363.9

[a]from aquaculture facility

Table 2. Parasites detected in *Seriola* spp. from the Madeira archipelago and respective site of infection. P: prevalence, mI: mean intensity ± SD (range), mA: mean abundance ± SD

Host/parasite	Site	P (%)	mI	mA
***Seriola rivoliana* (Selvagens Islands) (n = 29)**				
Monogeans				
Allencotyla mcintoshi	Gills	33.3	1.7 ± 1.1 (1–4)	0.59 ± 1.02
Dionchus agassizi	Gills	3.3	17.0	0.59 ± 3.16
Zeuxapta seriolae	Gills	3.3	127.0	4.38 ± 23.58
Digeneans				
Didymocystis sp.	Intestine	3.3	5.0	0.17 ± 0.93
Tormopsolus orientalis	Stomach/intestine	36.7	6.1 ± 4.3 (1–12)	2.31 ± 3.96
Nematodes				
Anisakis sp.	Stomach/intestine	23.3	1.7 ± 1.5 (1–5)	0.41 ± 1.02
Acanthocephala				
Rhadinorhynchus sp.	Stomach	3.3	1.0	0.03 ± 0.19
Copepods				
Caligus aesopus	Gills	30.0	4.8 ± 4.3 (1–13)	1.48 ± 3.20
***Seriola dumerili* (Selvagens Islands) (n = 1)**				
Digeneans				
Stephanostomum ditrematis	Intestine	100.0	6.0	6.00
***Seriola rivoliana* (Madeira) (n = 1)**				
Digeneans				
Stephanostomum petimba	Intestine	100.0	1.0	1.00
Copepods				
Caligus aesopus	Gills	100.0	12.0	12.00
***Seriola dumerili* (Madeira) (n = 14)**				
Monogeans				
Allencotyla mcintoshi	Gills	11.8	1.0 ± 0.0	0.13 ± 0.35
Digeneans				
Stephanostomum petimba	Intestine	7.7	1.0	0.07 ± 0.26
Stephanostomum sp.	Intestine	15.4	11.0 ± 1.4 (10–12)	1.47 ± 3.89
Tetrochetus coryphaenae	Caeca	15.4	17.5 ± 20.5 (3–32)	2.33 ± 8.24
Nematodes				
Hysterothylacium seriolae	Stomach/caeca/intestine	69.2	40.2 ± 56.6 (1–142)	24.13 ± 47.39
Oncophora melanocephala	Caeca	15.4	1.0 ± 0.0	0.13 ± 0.35
Acanthocephala				
Rhadinorhynchus sp.	Stomach/intestine	38.5	13.2 ± 25.1 (1–58)	4.40 ± 14.87
Copepods				
Caligus aesopus	Gills	60.0	8.7 ± 6.4 (1–19)	3.47 ± 5.80

In addition to the parasitology study, the stomach contents of *S. rivoliana* from the Selvagens Islands were examined. They were composed exclusively of sardine *Sardina pilchardus* (Walbaum, 1792) (85.6 %) and blue jack mackerel *Trachurus picturatus* (Bowdich, 1825) (14.4 %).

Greater amberjack

In *S. dumerili* from Madeira Island, 8 parasite species were found: *Allencotyla mcintoshi* (Monogenea); *Stephanostomum* sp. Looss, 1899, *Stephanostomum petimba* Yamaguti, 1970 and *Tetrochetus coryphaenae* Yamaguti, 1934 (Trematoda); *Oncophora melanocephala* (Rudolphi, 1819) Baudin-Laurencin, 1971 and *Hysterothylacium seriolae* (Yamaguti, 1941) Deardorff & Overstreet, 1981 (Nematoda); *Rhadinorhynchus* sp. (Acanthocephala) and *C. aesopus* (Copepoda).

In greater amberjack, *H. seriolae* was the most prevalent species (P = 69.2 %), followed by *C. aesopus* (P = 60.0 %) and *Rhadinorhynchus* sp. (P = 38.5 %). The highest intensities were shown by *H. seriolae* (mI = 40.2), *T. coryphaenae* (mI = 17.5) and *Rhadinorhynchus* sp. (mI = 13.20). The nematode *H. seriolae* was also the most abundant species (mA = 24.13). The abundance of this species showed a significant positive correlation with host weight ($p = 0.017$; $r_S = 0.644$).

The only specimen of *S. dumerili* from the Selvagens Islands was infected by a single parasite species:

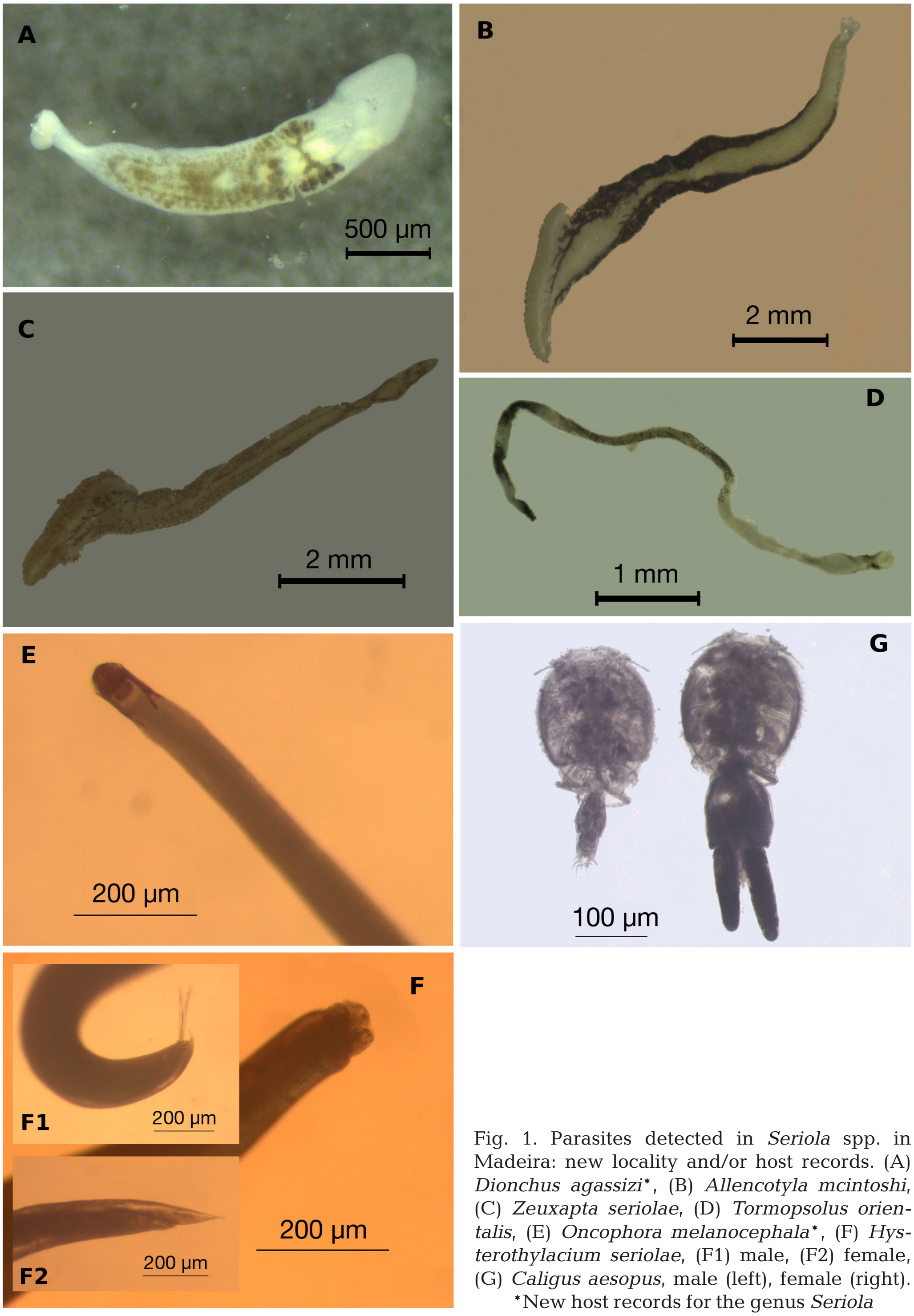

Fig. 1. Parasites detected in *Seriola* spp. in Madeira: new locality and/or host records. (A) *Dionchus agassizi**, (B) *Allencotyla mcintoshi*, (C) *Zeuxapta seriolae*, (D) *Tormopsolus orientalis*, (E) *Oncophora melanocephala**, (F) *Hysterothylacium seriolae*, (F1) male, (F2) female, (G) *Caligus aesopus*, male (left), female (right). *New host records for the genus *Seriola*

Stephanostomum ditrematis (Yamaguti, 1939) Manter, 1947 (Trematoda). The specimen of *S. rivoliana* from Madeira was parasitized by 2 species of metazoan parasites: *Stephanostomum petimba* and *C. aesopus*. In addition, 2 *S. dumerili* from a local aquaculture facility were examined and no parasites were found.

DISCUSSION

This study is the first parasitological survey of amberjacks from the Eastern Atlantic. Of 14 parasite taxa detected, 2 constitute new records for *Seriola* and 5 are new records for Madeira. Some of the species detected, in particular *Z. seriolae* and *C. aesopus*, might have a negative impact on *Seriola* spp. aquaculture.

It might be expected that the parasite community in *Seriola* spp. from the Selvagens Islands would be more diverse than that of fishes from Madeira, due to the higher biodiversity present in that area (Friedlander et al. 2017). However, this was not the case, with both communities presenting similar species richness.

Ectoparasites

Both *A. mcintoshi* and *Z. seriolae* have been detected in greater amberjack in the Mediterranean (Montero et al. 2003, 2004, Repullés-Albelda 2013). *Z. seriolae* is a very common parasite of *Seriola* spp. that occurs worldwide (Sharp et al. 2003, Montero et al. 2004, Hutson et al. 2007, Repullés-Albelda 2013), usually with very high infection levels. In this study it only occurred in 1 specimen of *S. rivoliana*, with very high intensity (127). The other polyopisthocotylean, *A. mcintoshi*, was more frequent, occurring in both *S. dumerili* and *S. rivoliana*, with moderate prevalences (11.8 to 33.3%), consistent with those detected in *S. dumerili* from the Mediterranean, but with lower intensity.

The monogenean *Dionchus agassizi* has not been previously detected in *Seriola* spp., but it has occasionally been reported from other carangids. It is typically a parasite of remoras or suckerfish (family Echineidae), and it can infect the fish to which a remora is attached (Bullard et al. 2000), which could explain why only 1 *S. rivoliana* was infected by this parasite.

Finally, the copepod *C. aesopus* was detected in both amberjack species and areas. The prevalence observed in *S. dumerili* from Madeira was similar to those detected in the same species in the Mediterranean (Repullés-Albelda 2013), while it was slightly lower (30%) in *S. rivoliana*. Intensity and abundance were also higher in large *S. dumerili* from Madeira, and indeed in the only large specimen of *S. rivoliana* observed. In the *S. rivoliana* sample from the Selvagens, *C. aesopus* abundance was positively correlated with fish weight, which could help illuminate the higher infection levels observed in larger amberjacks, since larger fish have more available gill habitat.

Endoparasites

Acanthocolpid digeneans are a family of parasites with spinous tegument that have prosobranch gastropods as first intermediate hosts and piscivorous fishes as definitive hosts, with a variety of teleost species as second intermediate hosts (Bray et al. 2005). They are often found in amberjacks (Grau et al. 1999, Bartoli & Bray 2004, Bartoli et al. 2004, Hutson et al. 2007), as well as in other piscivorous carangids (Bray & Cribb 2004, 2007). The acanthocolpid *T. orientalis* has been detected in several *Seriola* spp., including possibly in *S. rivoliana* from Bermuda (Bartoli et al. 2004). Interestingly, in the present study it was only detected in *S. rivoliana*, whereas it is a common parasite of *S. dumerili* in the Mediterranean (Bartoli et al. 2004, Repullés-Albelda 2013). This could be related to the size of the specimens. In our sample of almaco jack from the Selvagens Islands, fish measured 45.5 to 55 cm (TL), which is comparable to the size of the *S. dumerili* observed by Bartoli et al. (2004) and Repullés-Albelda (2013); in contrast, greater amberjack specimens from Madeira observed in this study were in the range of 118 to 143 cm (TL). It is possible that larger specimens of *Seriola* spp. are not parasitized by this particular species due to ontogenetic changes in feeding habits, since larger fish are more likely to feed on larger prey which might not be intermediate hosts of *T. orientalis*. Alternatively, it could be the case that larger fish have acquired immunity to this digenean parasite, which presented a significant negative correlation with fish condition in the almaco jack sample in this study, suggesting it could have a negative effect on fish condition. In order to assess these hypotheses, a sample of smaller *S. dumerili* from the Madeira archipelago would have to be analysed.

In this study, *S. dumerili* were found to be infected by another genus of acanthocolpid trematodes, *Stephanostomum* spp., including *S. ditrematis*, *S. petimba* (which also occurred in a large almaco jack from Madeira), and specimens which could belong to either *S. petimba* or *S. euzeti*, according to the descriptions of Bartoli & Bray (2004), but could not be identified to species level due to the impossibility of accurately counting the circum-oral spines. Both *S. euzeti* and *Tetrochetus coryphaenae*, a trematode which was also detected in *Seriola dumerili* from Madeira, are parasites of bogue *Boops boops* in the Mediterranean (Pérez-del Olmo et al. 2007), where this small sparid constitutes an important prey of greater amberjack (Andaloro & Pipitone 1997, Sley et al. 2016). It is likely that *S. dumerili* from Madeira could have become infected with *T. coryphaenae*, and possibly also *Stephanostonum euzeti*, by feeding on *B. boops*. Predation on bogue by *Seriola dumerili* and *S. rivoliana* has been observed by divers near Porto Santo Island (Neves et al. 2018).

The nematode *O. melanocephala* is a first record for *S. dumerili*, but it has previously been detected in other fishes from the Madeira region, for instance in Atlantic chub mackerel *Scomber colias* (Costa et al. 2009a) and bigeye tuna *Thunnus obesus* (M. Hermida unpubl. data). It is a common parasite of tunas in the Atlantic and Mediterranean (Bussiéras & Laurencin 1973, Mladineo et al. 2011). It is likely that *Seriola dumerili* would have acquired this parasite through feeding on *Scomber colias*. Amberjacks are piscivorous and while *Seriola dumerili* from the Mediterranean is reported to feed mainly on clupeids and small sparids (Andaloro & Pipitone 1997, Sley et al. 2016), Barreiros et al. (2003) report *Scomber colias* and *Trachurus picturatus* as the most important prey of almaco jack in the Azores, where they also feed on sardine *Sardina pilchardus*, longspine snipefish *Macroramphosus scolopax* and swallowtail seaperch *Anthias anthias*. However, the high interannual variation in prey composition detected in that study (Barreiros et al. 2003) suggests an opportunistic feeding pattern. In our study, *S. pilchardus* and *T. picturatus* were the only species detected in stomach contents of *Seriola rivoliana* from the Selvagens Islands.

A high prevalence of *H. seriolae* was detected in *S. dumerili* from Madeira, with the parasite occurring throughout the digestive tube, including the stomach, intestine and caeca. This species, originally described in Japanese amberjack *S. quinqueradiata* from Japan (Yamaguti 1941), can be clearly distinguished from other *Hysterothylacium* spp. through the size of the male spicules and the ratio between this and the body length (Li et al. 2007). It has previously been detected in *S. dumerili* from the Mediterranean (Repullés-Albelda 2013), albeit with lower prevalences than in the present study, and in alfonsino *Beryx decadactylus* from Mauritania, in the Eastern Atlantic (Rodrigues et al. 1975). While the intermediate hosts of *H. seriolae* are unknown, it is possible that small pelagic fishes such as sardines, Atlantic chub mackerel, and even the small sparid *Boops boops,* could function as intermediate or transport hosts of this parasite, since they are often parasitized by larval *Hysterothylacium* spp. (Oliva et al. 2008, Pérez-del Olmo et al. 2008, Rello et al. 2008). In the present study, *H. seriolae* occurred only in *S. dumerili* from Madeira, and not in *S. rivoliana* from the Selvagens Islands, which feed largely on sardines. Instead, these almaco jacks had a relatively low prevalence of *Anisakis* sp. L3 larvae, which were clearly morphologically distinct from *Hysterothylacium* larvae. Due to the differences between the sampled fish from the 2 locations, however, it is unclear whether this difference in ascaridoid nematode infection is due to the difference in species, size or location of the fishes, and/or whether it might reflect differences in feeding habits.

A significant positive correlation between *H. seriolae* abundance and host weight was found. We suggest that fish with higher weight have consumed more and larger prey, increasing the opportunities for infection with parasites that are trophically transmitted.

In the present study, *Rhadinorhynchus* sp. was detected in both amberjack species, with higher prevalence in *S. dumerili* from Madeira. Acanthocephalans of this genus seem to be quite common in the region, having been detected in a number of fish hosts, including middle and high trophic level species such as European conger *Conger conger* (Costa et al. 2009b), blackspot seabream *Pagellus bogaraveo* (Hermida et al. 2013) and skipjack tuna *Katsuwonus pelamis* (Hermida et al. 2018), but also low trophic level, small pelagic species such as *Scomber colias* (Costa et al. 2004) and *T. picturatus* (Costa et al. 2013, Vasconcelos et al. 2017), 2 species which are usual prey of amberjacks (Barreiros et al. 2003). The higher prevalence of *Rhadinorhynchus* sp. in *Seriola dumerili* from Madeira could be related to the higher consumption of fish prey on the part of these larger amberjacks.

Potential impact of parasites on *Seriola* spp. aquaculture

Monogenean parasites such as *Z. seriolae, Benedenia seriolae* and *Neobenedenia girellae* are frequently implicated as a cause of high mortalities in farmed *Seriola* spp. (Grau et al. 2003, Montero et al. 2004, Tubbs et al. 2005), and even in 1 case in wild amberjack (Lia et al. 2007). This study shows that the gill parasite *Z. seriolae* is present in the Madeira archipelago, although with a low prevalence in the wild, while the skin parasites *B. seriolae* and *N. girellae* were not detected. *Z. seriolae* is a highly deleterious parasite, with infected fish exhibiting gill dysfunction due to mechanical obstruction of water flow in the gill, destruction of gill tissue, hyperplasia, lamellar fusion, and hyperproduction of mucus, as well as anaemia, due to the blood-feeding activity of these monogeneans (Grau et al. 2003, Montero et al. 2004, Lia et al. 2007). The presence of *Z. seriolae* in Madeira, and the high intensity of infection observed, suggests that measures should be taken to prevent its introduction into aquaculture, for instance the purchase of juveniles only from certified producers, adherence to quarantines and application of other preventive measures, such as disinfection of nets, tank surfaces and pipes in aquaculture facilities (Montero et al. 2004, Lia et al. 2007).

The copepod *Caligus aesopus* was detected in 30% of the *S. rivoliana* and 60% of the *S. dumerili*, with moderate intensities. Caligids are very common parasites of fish, and marine fish farming creates ideal conditions for their proliferation (Kearn 2005). Although less damaging than the polyopisthocotyleans, they can cause injuries when present in high densities (Grau et al. 1999). Furthermore, both *Z. seriolae* and *Caligus* spp. can be potential vectors of pathogenic bacteria in *Seriola* aquaculture (Sepúlveda et al. 2017).

The infection of cultured amberjacks by trophically transmitted parasites is unlikely, since the fish are fed commercial feed; however, there are reported instances of transmission of *Hysterothylacium* spp. to farmed fish through the ingestion of small invertebrates that are naturally present in the environment, such as copepods. This transmission has been reported in farmed rainbow trout *Oncorhynchus mykiss* and arapaima *Arapaima gigas* (González 1998, Azevedo et al. 2017). *Hysterothylacium* spp. are rarely pathogenic and are not usually implicated in zoonotic events; however, the large size and number of *H. seriolae* in the gastrointestinal tract could conceivably have a negative effect on fish performance.

Amberjacks are important species for global aquaculture and there has been increasing interest in recent years in investing in the production of these species, particularly in Europe and Asia. In the Madeira archipelago, where this study was carried out, aquaculture is a small but expanding industry, and *S. dumerili* production was recently introduced in this region. We consider the results of this study to be especially relevant to decision makers involved in amberjack aquaculture production.

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