# Metazoan parasites of Skipjack tuna, *Katsuwonus pelamis* and Almaco jack, *Seriola rivoliana*, two important commercial species from Madeira archipelago, Portugal


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# Abstract

Parasite communities of skipjack tuna, *Katsuwonus pelamis* and almaco jack or longfin yellowtail, *Seriola rivoliana* from Madeira archipelago were described.

Thirty skipjack tuna from commercial fisheries were examined for the presence of parasites. Twenty-five species of metazoan parasites were detected: *Capsala katsuwoni, Allodidymocodium* sp*., Didymocylindrus filiformis, Didymocylindrus fusiformis, Didymocylindrus simplex, Didymocystis kamegaii, Didymocystis reniformis, Didymocystis* sp. 1*, Didymocystis* sp. 2*, Didymocystis* sp. 3*, Didymocystis* sp. 4*, Didymocystis* sp. 5*,* Didymozoidae gen. sp.*, Lobatozoum multisacculatum, Nematobothrium scombri, Neodiplotrema pelamydis, Oesophagocystis dissimilis, Oesophagocystis lydiae, Tentacularia coryphaenae,* Rhadinorhynchinae gen. sp. 1*,* Rhadinorhynchinae gen. sp. 2*,* Rhadinorhynchinae gen. sp. 3*,* Rhadinorhynchinae gen. sp. 4*,* Anisakidae gen. sp. and *Caligus bonito*. Parasites were located on the gills, stomach, intestine and abdominal cavity. *K. pelamis* is a new host of *N. scombri.*

Twenty-nine almaco jack from Selvagens islands, Madeira archipelago as a seizure from illegal fisheries, were observed and eight different species of parasites were found: *Allencotyla mcintoshi, Dionchus agassizi, Zeuxapta seriolae*. *Didymocystis* sp*., Tormopsolus orientalis*, *Rhadinorhynchus* sp*.,* Anisakidae gen. sp., *Caligus aesopus*. All parasites were located on the gills, stomach and intestine. *S. rivoliana* is described as a new host of: *A. mcintoshi*, *D. agassizi*, Z. seriolae, *Didymocystis* sp., *T. orientalis*, *Rhadinorhynchus* sp.. An extra specimen of large size of *S. rivoliana* was observed, one species of parasites was presents, *Stephanostomum petimba,* that's a first record in this host. It is the first time that *D. agassizi* was found parasitizing a species of de genus *Seriola*.

Correlations between parasite abundance and host parameters were assessed using Spearman rank correlation. Fisher's test was applied to find differences between parasites abundance in both sexes. The distribution of parasites on each gill arch was assessed using Friedman's test followed by the Conover test, whenever significant differences were detected to skipjack tuna.

# Resumo

Este trabalho pretende descrever as comunidades de parasitas metazoários de gaiado, *Katsuwonus pelamis* e charuteiro, *Seriola rivoliana* do arquipélago da Madeira.

Foram observados trinta espécimes de gaiado, nos quais se identificaram vinte e cinco espécies de parasitas metazoários: *Capsala katsuwoni, Allodidymocodium* sp*., Didymocylindrus filiformis, Didymocylindrus fusiformis, Didymocylindrus simplex, Didymocystis kamegaii, Didymocystis reniformis, Didymocystis* sp*.* 1*, Didymocystis* sp. 2*, Didymocystis* sp. 3*, Didymocystis* sp. 4*, Didymocystis* sp. 5*,* Didymozoidae gen. sp.*, Lobatozoum multisacculatum, Nematobothrium scombri, Neodiplotrema pelamydis, Oesophagocystis dissimilis, Oesophagocystis lydiae, Tentacularia coryphaenae,* Rhadinorhynchinae gen. sp. 1*,* Rhadinorhynchinae gen. sp. 2*,* Rhadinorhynchinae gen. sp. 3*,* Rhadinorhynchinae gen. sp. 4, Anisakidae gen. sp. e *Caligus bonito*. Estes parasitas encontravam-se alojados nas brânquias, no estômago, no intestino e na cavidade abdominal. *K. pelamis* é descrito como um novo hospedeiro de *N. scombri.*

Vinte e nove espécimes de charuteiro das ilhas Selvagens, Arquipélago da Madeira, provenientes de uma apreensão de pesca ilegal, foram observados para pesquisa de parasitas. Nesta amostra, foram encontradas oito espécies de parasitas alojadas nas brânquias, no estômago e no intestino: *Allencotyla mcintoshi, Dionchus agassizi, Zeuxapta seriolae*. *Didymocystis* sp*., Tormopsolus orientalis*, *Rhadinorhynchus* sp*.,* Anisakidae gen. sp., *Caligus aesopus*. Com isto, *S. rivoliana* foi identificada como novo hospedeiro de: *A. mcintoshi*, *D. agassizi*, Z. seriolae, *Didymocystis* sp., *T. orientalis*, *Rhadinorhynchus* sp.. Foi também observado um charuteiro de grande tamanho, no qual foi encontrado um parasita da espécie *Stephanostomum petimba,* que nunca tinha sido registado neste hospedeiro. Pela primeira vez, *D. agassizi* foi encontrado a parasitar peixes do género *Seriola*.

As correlações entre a abundância de parasitas e os parâmetros do hospedeiro foram avaliadas segundo o método de Spearman e o teste de Fisher foi utilizado para encontrar diferenças entre a abundância de parasitas em ambos os sexos. A distribuição de parasitas em cada arco branquial foi avaliada através do teste de Friedman. No gaiado, foram encontradas algumas diferenças significativas, tendo, posteriormente, sido aplicado o teste de Conover.

# Keywords

Skipjack tuna; *Katsuwonus pelamis*; Almaco jack; Longfin yellowtail; *Seriola rivoliana*; metazoan; parasites; Selvagens islands, Madeira archipelago; Atlantic Ocean; migrations; fisheries; aquaculture.

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# 1. General introduction

Madeira archipelago is in the North Hemisphere of Eastern Atlantic and his waters are part of the Portuguese EEZ (figure 1). This archipelago is constituted by seven islands: Madeira, Porto Santo, Desertas (Deserta Grande, Deserta Pequena e Bugio) e Selvagens (Selvagem Grande e Selvagem Pequena) and his EEZ has nearly 454,500 $km^2$. Only two islands are inhabited, Madeira and Porto Santo, being Madeira the largest and with more habitants (Shon et al., 2015).

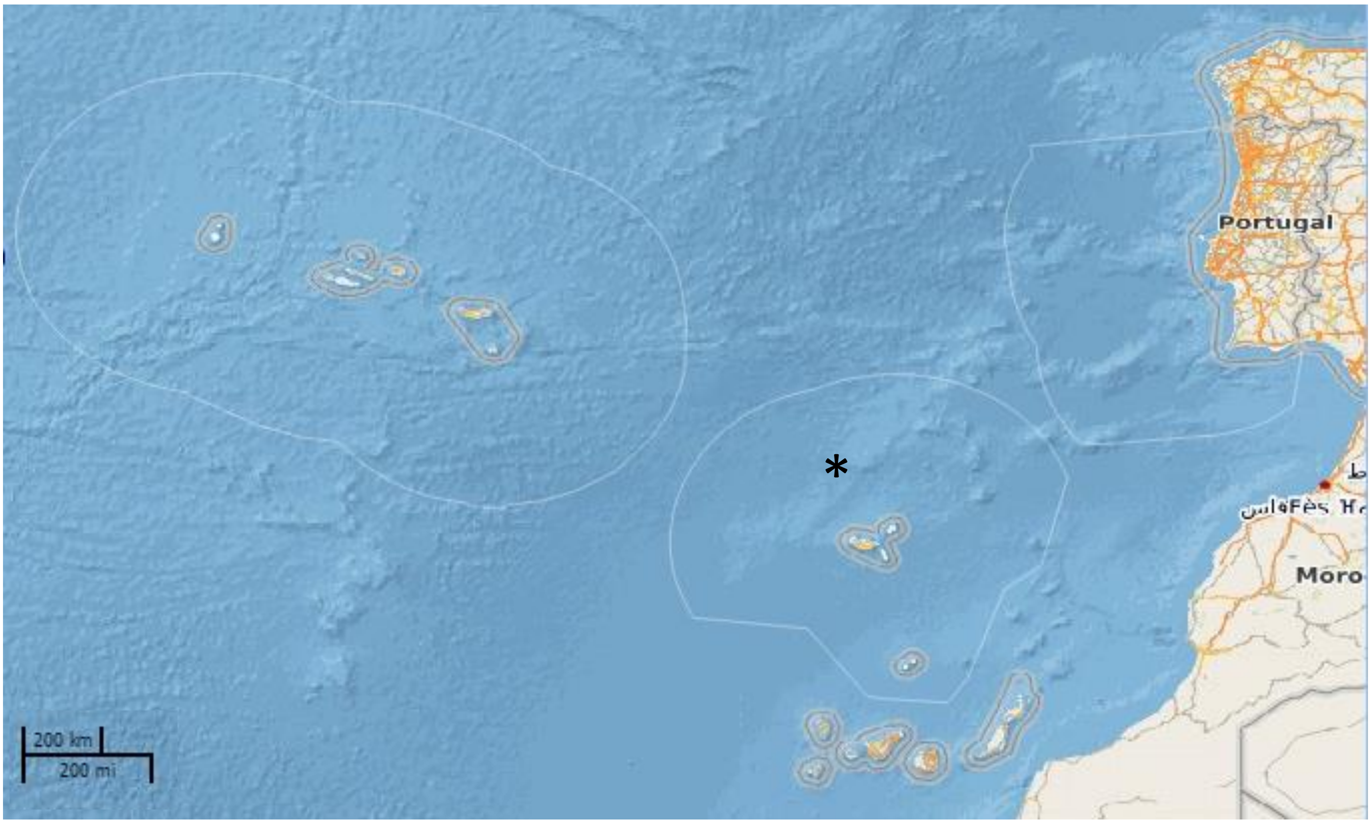


Figure 1 – Portuguese exclusive economic zone (EEZ) where it is possible to see that it is composed by tree regions; Continental, Madeira and Azores EEZ; * Madeira EEZ (OOM, 2017a).

Commercial fisheries have historically been very important in this region. Madeira archipelago has a fish community characterized by higher mean trophic level species (Hermida & Delgado, 2016), deep waters and very low productivity (Shon, et al., 2015). The most important species in this region are black scabbardfish, *Aphanopus carbo* and tunas – albacore (*Thunnus alalunga*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), atlantic bluefin tuna (*T. thynnus*) and skipjack tuna (*Katsuwonus pelamis*). *K. pelamis* and *Thunnus obesus* account for 95% of the total Madeira tuna landings (Morato, 2012).

Two small pelagic species are also important: chub mackerel, *Scomber colias* and blue jack mackerel, *Trachurus picturatus.* Other species of high commercial value, but less abundant, as sea breams, *Pagrus pagrus, Dentex gibbosus*, and others, blacktail comber, *Serranus atricauda*, wreckfish, *Polyprion americanus* and amberjacks, *Seriola* spp.. It is in this group of species very appreciated and with high commercial value, but relatively less abundant, that *Seriola rivoliana*, almaco jack or longfin yellowtail, is inserted (OOM, 2017d).

It was stated that there are no parasitological studies on several of these fish species in Madeira archipelago and very few in the Atlantic Ocean. On the other hand, it is known that the knowledge of metazoan community's is one of the tools that has been used and contributing to knowledge of the biology of several fish species, including their food habits, migrations or ecosystem preferences.

The aim of this work was to study the metazoan parasites communities of, two economically important fish species*, Katsuwonus pelamis* and *Seriola rivoliana* collected in Madeira archipelago.

# 2. Skipjack tuna, *Katsuwonus pelamis*

## 2.1. Introduction

### 2.1.1. Skipjack tuna biological characteristics

The skipjack tuna, *Katsuwonus pelamis* (Linnaeus, 1758), is a pelagic fish from the *Scombridae* family that inhabits oceanic waters from the surface to about 260 m depth (Collette & Nauen, 1983).

*K. pelamis* has a cosmopolitan distribution between 63°N - 47°S and 180°W - 180°E but is not found in the Black Sea (figure 2).

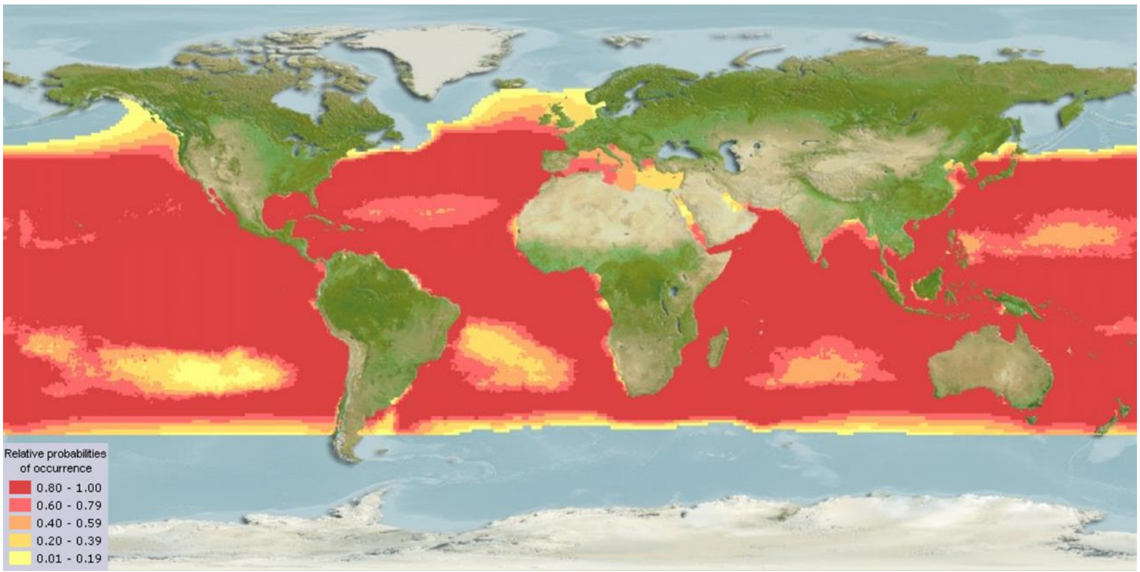


Figure 2 – Map of relative probabilities of occurrence of *Katsuwonus pelamis* (Aquamaps, 2017a).

It prefers tropical and warm-temperate water and its occurrence has been recorded in waters between 15-30°, therefore it's considered a tropical tuna species (Collette & Nauen, 1983).

*K. pelamis* (figure 3) is a medium size tuna with a fusiform, rounded and elongated body. It has two dorsal fins, the first with 14-15 spines and the second with 7-9 spines. The pectoral fins are short with 26-27 rays and the anal fin is followed by 7 or 8 finlets. Its caudal fin has a strong keel on the base of each side, between 2 small keels. Skipjack tuna only has scales in the corselet and lateral line. The typical body colour of this species is dark purplish blue on the back and silvery on the belly and lower sides, with 4-6 conspicuous longitudinal dark bands (Collette & Nauen, 1983).

This species lives up to 12 years old and its maximum fork length is about 108 cm and 32.5 to 34.5 kg of weight. The mean fork length and weight is 80 cm and 8 to 10 kg.

Fork length at first maturity is about 45 cm. *K. pelamis* fecundity increases with the size of the fish but is highly variable. A female of 41 to 87 cm fork length can spawn 80 000 to 2 000 000 eggs per season. Spawning occurs throughout the year in equatorial waters and from spring to early autumn in subtropical waters. Its eggs and larvae are pelagic and larvae prefer waters with a minimum of 25°C of surface temperature (Collette & Nauen, 1983).

The food habits of the skipjack tuna include several species of small fishes, the most common being *Macroramphosus scolopax*, *Scomber colias*, *Sardina pilchardus* and *Boops boops* (Olaso et al., 1992; Ramos, 1989; Ramos et al., 1995). Cannibalism is common in *K. pelamis* (Collette & Nauen, 1983).

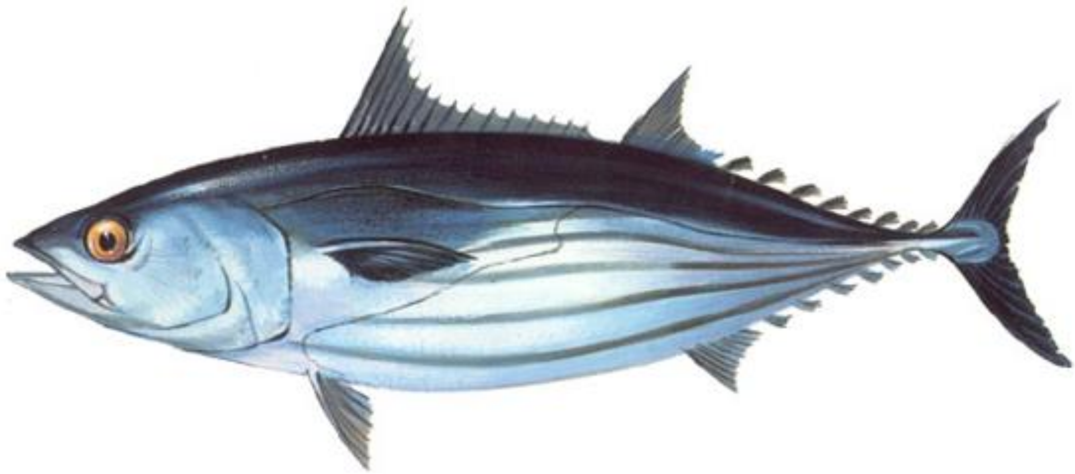

Figure 3 – Illustration of a specimen of *Katsuwonus pelamis* (Collette & Nauen, 1983).

## 2.1.2. Migrations of skipjack tuna in Atlantic Ocean

Most scombrids undertake seasonal migrations, traveling long distances for food and the best places for spawning. In tunas, migration depends on the water temperature of their habitat. Tunas from temperate water have a long migration route while tunas from tropical water, as skipjack tuna, travel shorter distances and don’t make transoceanic migrations. However, they have movements between feeding areas, in temperate waters, and spawning area which is usually located in tropical waters (Collette & Nauen, 1983).

The migration of *K. pelamis* depends not only from temperature but also from environmental conditions (salinity, nutrients, etc) (IEO, 2006) and in Eastern Atlantic starts on Gulf of Guinea, as described by Foucher (1996). This region has favourable temperature conditions for spawning and larval development. Then, as described for the skipjack tuna population from the Southwest Atlantic (Andrade, 2003), the route probably becomes related to the superficial ocean currents characterized by warmer waters, to the surrounding area of Dakar, Canary Islands and Madeira Archipelago (IEO, 2006), from where they probably continue toward the Bay of Biscay or the Mediterranean Sea (figure 4). Apparently, between April and July migration occurs on a South-North

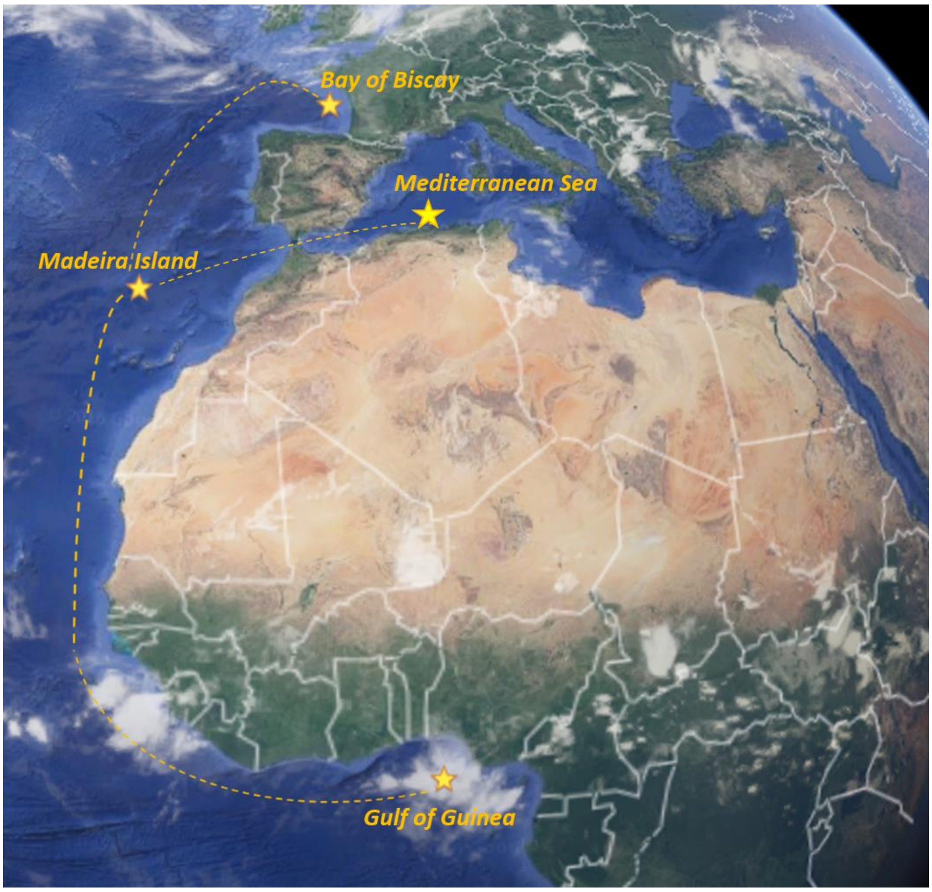


Figure 4 – Migrations route of skipjack tuna in Eastern Atlantic Ocean.

directions, changing to a predominantly North-South directions between August and October, which explains the occurrence of skipjack tuna in Madeira during the warmer months (OOM, 2017b). The average speed of migration of skipjack tuna is 4.5 km/day (IEO, 2006). In Eastern Atlantic, there is only one study about skipjack tuna population migration made by Foucher (1996), in southeast region near the Gulf of Guinea, and there are no scientific publications regarding the northeast region.

### 2.1.3. The fishery of skipjack tuna in Madeira archipelago, Portugal

Traditional fishing of Madeira archipelago targets several species of tuna, which constitute an important economical and food resource in this region. Tuna fisheries are variable from year to year depending on local abundance of tuna species. Between 1960-1999, *Thunnus obesus* and *K. pelamis* were the most important species in Madeira archipelago, representing 95% of total tuna captures (Gouveia et al., 2001). Since 2008 to 2014, tuna fisheries represent 45% of the total of fish catches which means 2500 t/year and €1 500 000 (figure 5). The fishery of *K. pelamis* represents 26% of the total of tuna fishery and it's de second most captured species. It's caught by the traditional fishery using pole and line gear with live bait. (Gouveia et al., 2001). Skipjack tuna occurs in Madeira archipelago between May and December but is more frequent between June

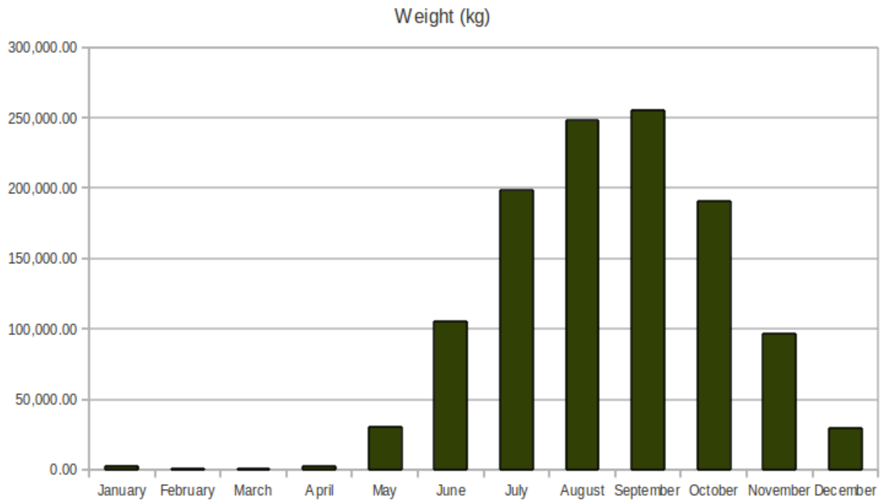


Figure 5 – Skipjack tuna average monthly landings between 2008 and 2014 (OOM, 2017b).

and October (figure 5) (OOM, 2017b), with maximum values between July and September (Gouveia & Mejuto, 2003). Although most of the catches of this species refer to Madeira archipelago, it can be fished along the entire Portuguese EEZ (Collette & Nauen, 1983).

### 2.1.4. Problems related to skipjack tuna consumption

The consumption of skipjack tuna and other fishes from Scombridae family can be related to intoxication by histamines. This problem is commonly named "scombroid poisoning". Fishes from Scombridae family contain large amounts of free histidine in their muscle tissue that can be decarboxylated by bacteria to produce histamine under certain conditions of conservation. There are many bacteria able to convert histidine to histamine

(Arnold et al., 1980) and in last 30 years, many genera of bacteria were identified as histidine-decarboxylase producers: *Escherichia* spp., *Klebsiella* spp., *Salmonella* spp., *Shigella* spp., *Clostridium* spp., *Vibrio* spp., *Proteus* spp. (Arnold et al., 1980).

Histamine formation occurs when scombrids are conserved at 0-10 ºC (32-50 ºF) and levels of histamine is related with temperature and bacteria load (Frank & Yoshinaga, 1987). Skipjack tuna, as a Scombridae, should be conveniently kept, preferably frozen, to avoid intoxication by histamines.

### 2.1.5. Previous records of skipjack tuna metazoan parasites

In recent years, some studies about metazoan parasites of skipjack tuna were made in different regions of the world. There are some publications made in Pacific (Lester et al., 1985), Indic (Murugesh, 1995), South-western Atlantic Ocean (Alves & Luque, 2006; Justo & Kohn, 2005) and Mediterranean Sea (Mele et al., 2012), however there are no scientific studies about metazoan parasites communities of skipjack tuna from Eastern Atlantic, more specifically in EEZ of Madeira archipelago. There's one study about skipjack tuna from Mediterranean Sea, that is an important reference, but only includes gills parasites (Mele et al., 2012).

Metazoan parasites from several different taxonomic groups have already been identified in *K. pelamis*. The most abundant group is Didymozoidae, a very important group of parasites of Scombridae, including tunas (Annex 1).

# 2.2. Materials and Methods

## 2.2.1. Sampling

Thirty skipjack tuna, were caught in Madeira archipelago in September 2016 by commercial fisheries. After capture, the fishes were frozen.

Firstly, in each fish several measures were collected: total-length, fork-length, curved-fork-length, girth and maximum body height. After this, total-weight was obtained.

Fish fat contents were measured using a *Distel Fish Fatmeter*. This equipment was specifically calibrated for skipjack tuna fat levels by the manufacturer.

After all measures, left and right gills were collected and separated arch by arch in individual petri dishes for observation. Left and right pseudobranchs were collected in the same way. Posteriorly, the abdominal cavity was open to extract internal organs. Viscera was separated organ by organ and kept in petri dishes for observation. The sex of each specimen was determined through gonad's observation. Lastly eviscerated weight was obtained.

The gills were examined under a stereomicroscope – *Leica MZ125* – with 100x magnification. All parasites found on the gills were collected, counted, washed in saline solution (10%) and stored in an alcohol solution (70%) for identification.

Identification guides, book and articles were used to identify parasites found in skipjack tuna:

- Monogenea: Murugesh (1995)
- Trematoda: Jones et al. (2005), Bray et al. (2008), Mele (2012)
- Cestoda: Palm (2004)
- Acanthocephala: Yamaguti (1963); Golvan (1969)
- Crustacea: Cressey (1991)

Parasites were photographed under a stereomicroscope – Zeiss Stemi 2000-C – with 6.5 to 50x magnification.

## 2.2.2. Statistical analysis

Some biological conditions factors as Gonadosomatic index, Hepatosomatic index, *K* condition factor and girth/length ratio were assessed to this sample, according to Lloret et al. (2014).

The gonadosomatic index (GSI) was calculated by the formula:

$$GSI = \left(\frac{GW}{EW}\right) x\ 100$$

were *GW* the gonad weight and *EW* the eviscerated weight of the individual.

The hepatosomatic index (HSI) was calculated as follow:

$$HSI = \left(\frac{LW}{EW}\right) x\ 100$$

were *LW* the liver weight and *EW* the eviscerated weight of the individual.

K (or Fulton's) condition factor was calculated by the formula:

$$K = \left(\frac{W}{L^3}\right) x\ 100$$

where *W* is the weight of the individual and *L* its total length.

The Girth/length ratio was assessed by dividing the girth of each fish by its total length:

$$G/L = \frac{girth}{length}$$

Prevalence, mean intensity and mean abundance of each parasite species were calculated according Bush et al. (1997).

Prevalence, P%, is the number of infected hosts (N inf) with a parasite species divided by the number of examined hosts (N) expressed as a percentage.

$$P\% = \frac{N\ inf}{N}$$

Mean intensity (mI) is the arithmetic mean of the number of parasites of each species divided by the number of infected hosts (N inf) with that parasite species.

$$mI = \frac{number\ of\ parasite\ specimens}{N\ inf}$$

Mean abundance (mA) is the arithmetic mean of the number of parasite specimens of each species per total number of examined hosts (N).

$$mA = \frac{number\ of\ parasite\ specimens}{N}$$

Correlations between parasite abundance and host parameters were assessed using Spearman rank correlation. The host parameters used were total length, weight, K condition factor, girth/length ratio and fat levels. Fisher's test was used to assess differences in prevalence between the sexes ($N_{males}$ = 10, $N_{females}$ = 20). Parasite abundance was compared between the left and right gills, in total and by arch, using Wilcoxon signed ranks test and the distribution of parasites on each gill arch was assessed using Friedman's test followed by the Conover test, whenever significant differences were detected. For gills statistical analysis, only the four most prevalent parasite species were considered: *Didymocylindrus filiformis, Didymocylindrus fusiformis*, *Didymocylindrus simplex* and *Lobatozoum multisacculatum*. For digestive tube statistical analyses, the following parasite species were analysed: *Allodydimocodium* sp., *Didymocystis* sp. 1, *Didymocystis* sp. 2, *Didymocystis* sp. 4, *Didymocystis* spp. (including *Didymocystis kamegaii, Didymocystis reniformis, Didymocystis* sp. 3 and *Didymocystis* sp. 5), total Didymozoidae gen. sp., *Oesophagocystis dissimilis, Tentacularia coryphaenae,* Anisakidae gen. sp. and Rhadinorhynchinae gen. sp. (including Rhadinorhynchinae gen. sp. 1, Rhadinorhynchinae gen. sp. 2, Rhadinorhynchinae gen. sp. 3, Rhadinorhynchinae gen. sp. 4.). The software used for statistics analysis was *R 3.3.0*. (R Core Team, 2016). The significance level used for all tests was p<0.05.

Some indexes of diversity, dominance and equitability were calculated. To estimate diversity, Shannon's index (H') and the inverse of Simpson's index (1/D) were calculated as follow:

$$H' = -\sum p_i \, ln p_i$$

$$\frac{1}{D} = \frac{1}{\sum_{i=l}^{s} p_i^2}$$

were $p_i$ is the relative abundance of each species, calculated by the proportion of the individuals belong to the same species and the total number of individual found in the community ($n_i$/*N*; $n_i$= number of individual of each species; *N* = total number of parasites).

The Berger-Parker index was used to calculate the dominance and express the proportional abundance of the most abundant species. This index was calculated as follow:

$$d = N_{max}/N$$

were $N_{max}$ is the number of individual of the most abundant species and *N* is the total number of parasites detected.

The equitability indexes used were the Shannon's index (J') and the inverse of Simpson's index (E)

$$J' = H'/\, lnS$$

$$E_{1/D} = \frac{(\frac{1}{D})}{S}$$

were *H'* is the value of diversity of Shannon's index and *(1/D)* is the value of the inverse of Simpson's index. *S* is the number of species found.

The species richness, that's the number of parasites species present, was assessed according to Magurran (2013).

# 2.3. Results

Thirty *K. pelamis* from Madeira archipelago were sampled to parasites research and their measures and biological condition factors are shown on table 1.

All specimens were infected by at least one parasite species. Twenty-five species of metazoan parasites from different taxonomic groups were detected in skipjack tuna (table 2, figures 6-24). Only one species of monogean was found: *Capsala katsuwoni.* Digeneans were represented by a huge diversity of didymozoids: *Allodidymocodium* sp., *Didymocylindrus filiformis, Didymocylindrus fusiformis, Didymocylindrus simplex, Didymocystis kamegaii, Didymocystis reniformis, Didymocystis* sp. 1, *Didymocystis* sp. 2, *Didymocystis* sp. 3, *Didymocystis* sp. 4, *Didymocystis* sp. 5, Didymozoidae, *Lobatozoum multisacculatum, Nematobothrium scombri, Neodiplotrema pelamydis, Oesophagocystis dissimilis, Oesophagocystis lydiae.* Only one species of cestode was found: the trypanhorhynch *Tentacularia coryphaenae.* Four species of rhadinorhynchid acanthocephalans were detected: Rhadinorhynchinae gen. sp. 1, Rhadinorhynchinae gen. sp. 2, Rhadinorhynchinae gen. sp. 3, Rhadinorhynchinae gen. sp. 4. Nematodes and copepods were only represented by Anisakidae gen. sp. and *Caligus bonito*, respectively. Parasites were located on the gills, stomach, intestine and abdominal cavity. The specific location of each parasite on the host is presented in table 2.

Table 1 – Mean value of measures and indexes of *Katsuwonus pelamis* sampled specimens.

| Parameter | Mean value |
|---|---|
| Weight (g) | 2792.22 (± 522.56) |
| Total lenght (cm) | 52.95 (± 2.66) |
| Fork lenght (cm) | 49.95 (± 2.48) |
| Girth (cm) | 36.42 (± 2.48) |
| Girth/lenght ratio | 0.69 (± 0.03) |
| *K* condittion factor | 1.86 (± 0.11) |
| Max. high body (cm) | 14.02 (± 0.89) |
| Gonad weight (g) | 10.51 (± 7.47) |
| Gonadosomatic Index (GSI) | 0.37 (± 0.22) |
| Liver weight (g) | 34.88 (± 10.70) |
| Hepatosomatic Index (HSI) | 1.24 (± 0.28) |
| Stomach weight (full) (g) | 145.15 (± 63.80) |
| Heart weight (g) | 1.39 (± 1.84) |

Table 2 – Metazoan parasites observed in *Katsuwonus pelamis* and their organ location in the host.

| | Parasite species | Host location |
|---|---|---|
| MONOGENEA | | |
| | *Capsala katsuwoni* | Gills |
| DIGENEA | | |
| | *Allodidymocodium* sp. | Intestine |
| | *Didymocylindrus filiformis* | Gills |
| | *Didymocylindrus fusiformis* | Gills |
| | *Didymocylindrus simplex* | Gills |
| | *Didymocystis kamegaii* | Intestine |
| | *Didymocystis reniformis* | Stomach |
| | *Didymocystis* sp. 1 | Stomach |
| | *Didymocystis* sp. 2 | Stomach |
| | *Didymocystis* sp. 3 | Stomach |
| | *Didymocystis* sp. 4 | Intestine |
| | *Didymocystis* sp. 5 | Stomach |
| | Didymozoidae gen. sp. | Stomach |
| | *Lobatozoum multisacculatum* | Gills |
| | *Nematobothrium. scombri* | Stomach |
| | *Neodiplotrema pelamydis* | Pseudobranch |
| | *Oesophagocystis dissimilis* | Stomach |
| | *Oesophagocystis lydiae* | Stomach |
| CESTODA | | |
| | *Tentacularia coryphaenae* | Abdominal Cavity |
| ACANTHOCEPHALA | | |
| | Rhadinorhynchinae gen. sp. 1 | Intestine |
| | Rhadinorhynchinae gen. sp. 2 | Intestine |
| | Rhadinorhynchinae gen. sp. 3 | Intestine |
| | Rhadinorhynchinae gen. sp. 4 | Intestine, Stomach |
| NEMATODA | | |
| | Anisakidae gen. sp. | Abdominal cavity, Intestine, Stomach (outside) |
| CRUSTACEA | | |
| | *Caligus bonito* | Gills |


Figure 6 – Specimens of *Capsala kasuwoni* from skipjack tuna gills.

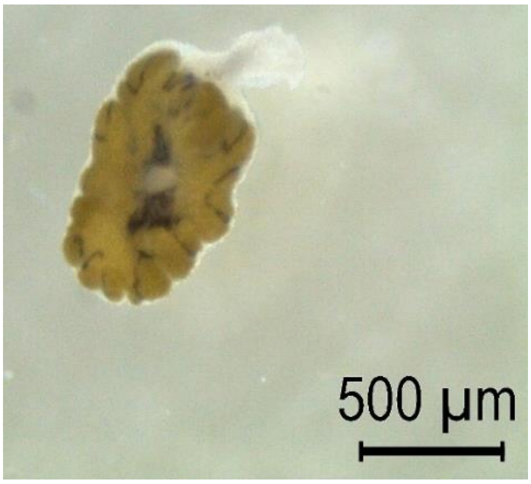


Figure 7 – Specimens of *Allodidymocodium* sp. from skipjack tuna intestine.

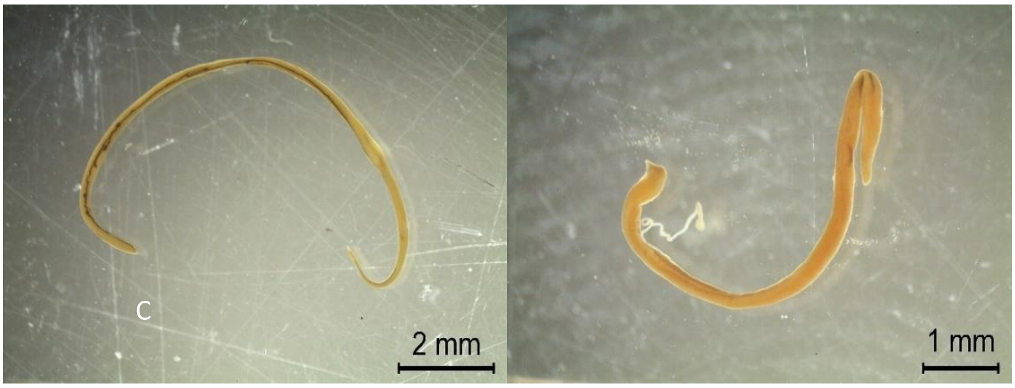


Figure 8 – Specimens of *Didymocylindrus filiformis* from skipjack tuna gills.


Figure 9 – Specimens of *Didymocylindrus fusiformis* from skipjack tuna gills.

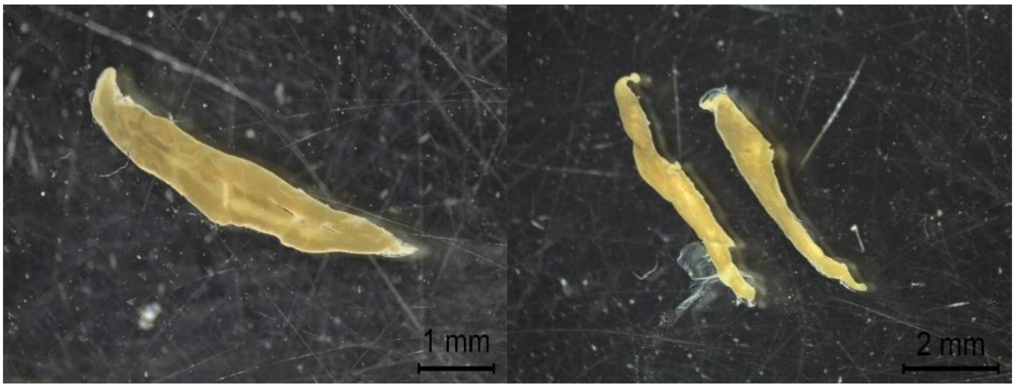


Figure 10 – Specimens of *Didymocylindrus simplex* from skipjack tuna gills.

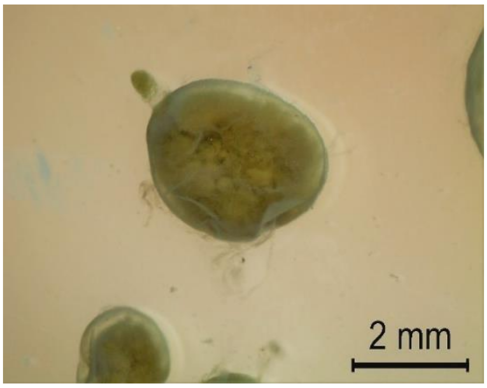


Figure 11 – Specimens of *Didymocystis kamegaii* from skipjack tuna intestine.

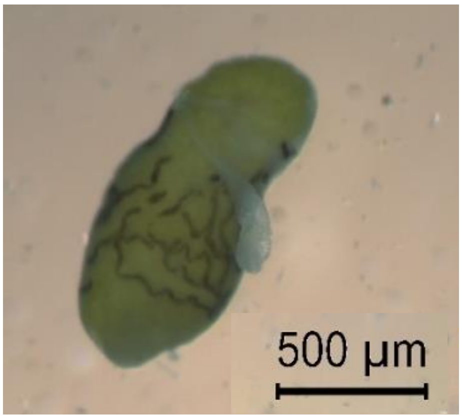


Figure 12 – Specimens of *Didymocystis reniformis* from skipjack tuna stomach.


Figure 13 – Specimens of *Didymocystis* sp. 1 from skipjack tuna stomach.

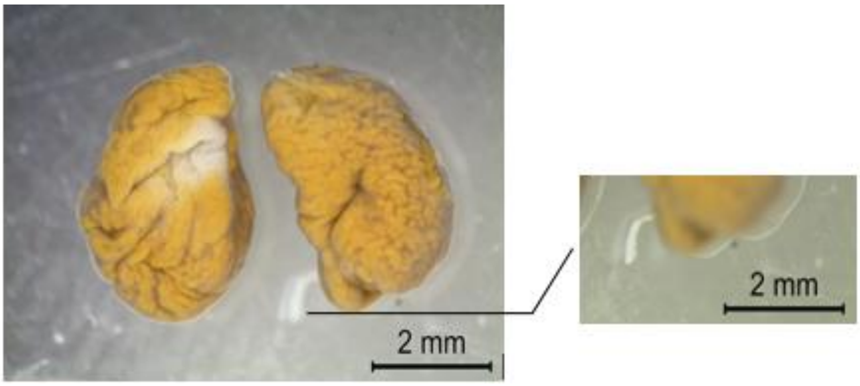


Figure 14 – Specimens of *Didymocystis* sp. 3 from skipjack tuna stomach.

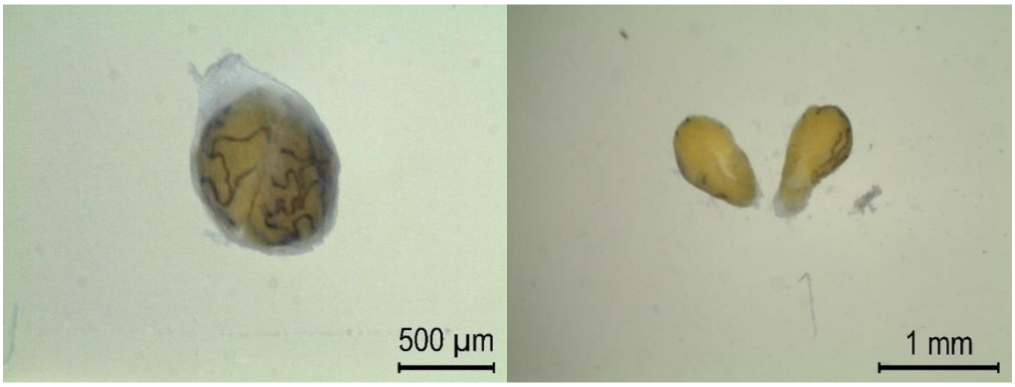


Figure 15 – Specimens of *Didymocystis* sp. 4 from skipjack tuna intestine.


Figure  16 - Gills of skipjack tuna parasitizes by *Lobatozoum multisacculatum.*

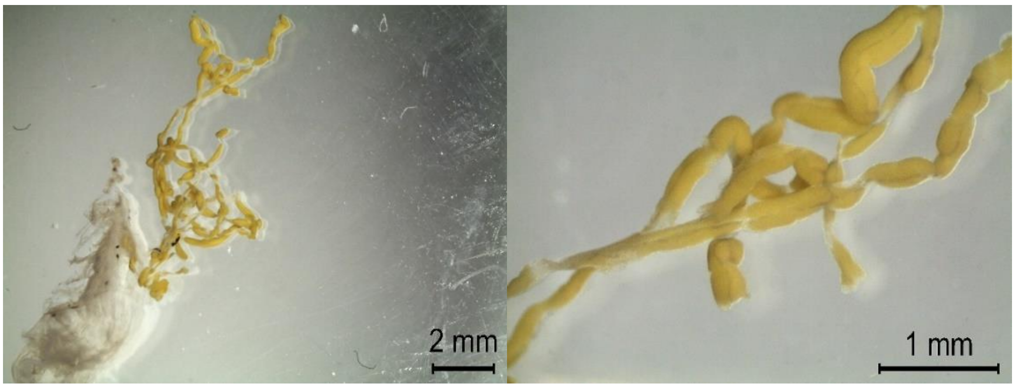


Figure 17 – Specimens of *Nematobothrium scombri* from skipjack tuna stomach.


Figure 18 – Specimens of *Neodiplotrema pelamydis* from skipjack tuna pseudobranchs.

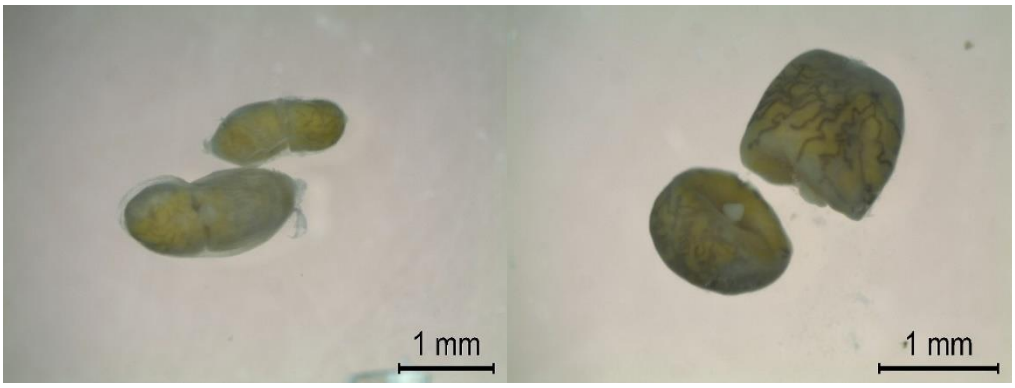


Figure 19 – Specimens of *Oesophagocystis dissimilis* from skipjack tuna stomach.


Figure 20 – Specimens of *Oesophagocystis lydiae* from skipjack tuna stomach.

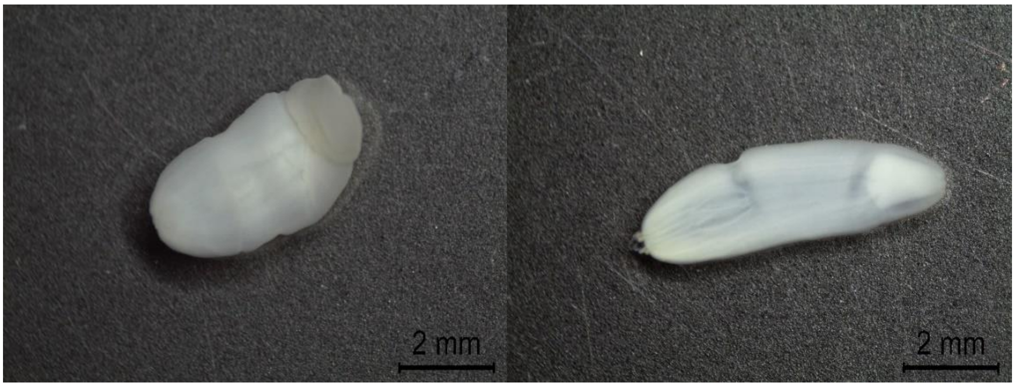


Figure 21 – Specimens of *Tentacularia coryphaenae* from skipjack tuna abdominal cavity.

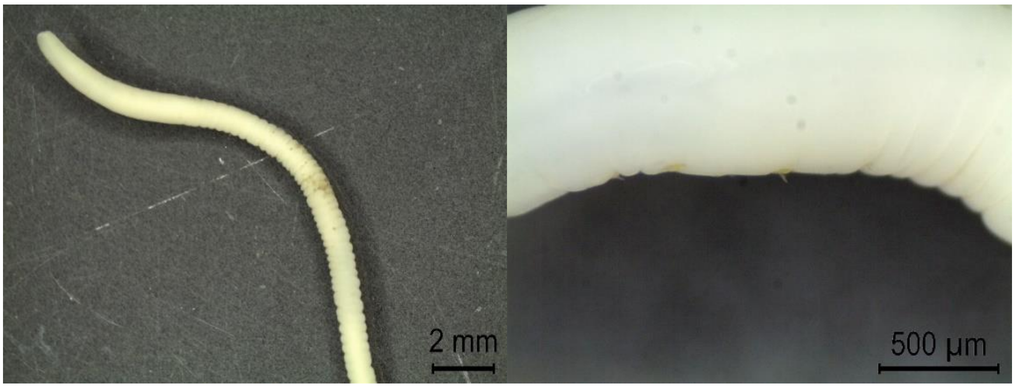


Figure 22 – Specimens of Rhadinorhynchinae gen. sp. 2 from skipjack tuna intestine.

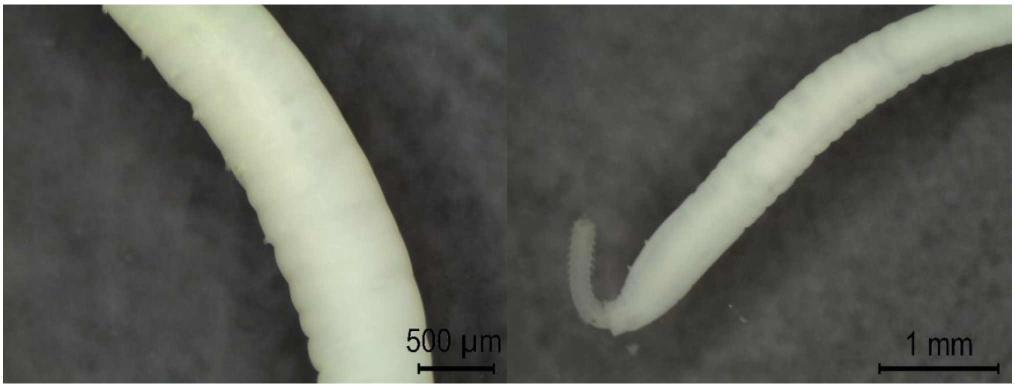


Figure 23 – Specimens of Rhadinorhynchinae gen. sp. 4 from skipjack tuna stomach and intestine.

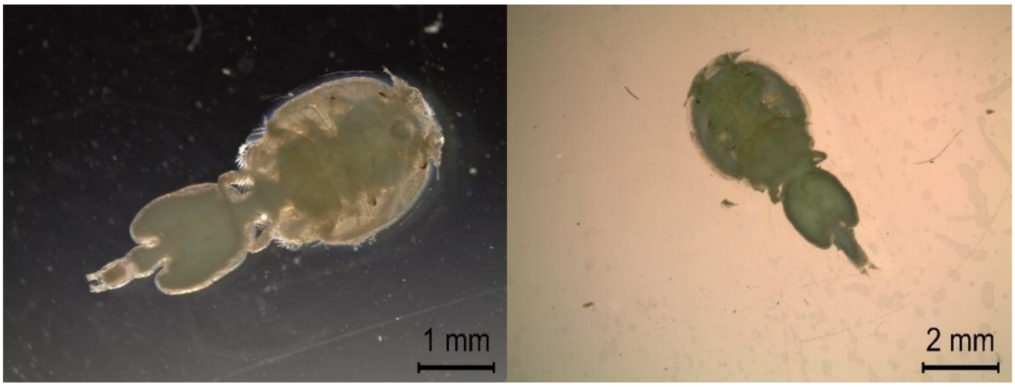


Figure 24 – Specimens of *Caligus bonito* from skipjack tuna gills.

Specimens from Anisakidae family were the most prevalent (P=93.33), followed by *Didymocystis* sp. 1 (P=86.67) and *T. coryphaenae* (P=80.00). The highest intensities were showed by *Didymocystis* sp. 4 (mI= 30.88), *Didymocylindrus. simplex* (mI=26.60) and Anisakidae gen. sp. (mI=20.25). Anisakidae gen. sp. were the most abundant specimens (mA=18.90), followed by *D. simplex* (mA = 17.73) and *Didymocystis* sp. 4 (mA = 16.47) (table 3).

Table 3 – Prevalence (P), mean intensity (mI) and mean abundance (mA) of the metazoan parasites of *Katsuwonus pelamis* from Madeira archipelago.

| Parasite | P (%) | mI | mA |
|---|---|---|---|
| MONOGENEA | | | |
| *Capsala katsuwoni* | 3.33 | 2.00 (± 0.00) | 0.07 (± 0.37) |
| DIGENEA | | | |
| *Allodidymocodium* sp. | 46.67 | 9.29 (± 10.57) | 4.33 (± 8.50) |
| *Didymocylindrus filiformis* | 66.67 | 10.85 (± 21.48) | 7.23 (± 18.14) |
| *Didymocylindrus fusiformis* | 46.67 | 9.79 (± 22.20) | 4.57 (± 15.67) |
| *Didymocylindrus simplex* | 66.67 | 26.60 (± 59.00) | 17.73 (± 49.43) |
| *Didymocystis kamegaii* | 16.67 | 8.20 (± 8.23) | 1.37 (± 4.36) |
| *Didymocystis reniformis* | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.18) |
| *Didymocystis* sp. 1 | 86.67 | 15.19 (± 15.02) | 13.17 (± 14.90) |
| *Didymocystis* sp. 2 | 46.67 | 6.14 (± 5.57) | 2.87 (± 4.86) |
| *Didymocystis* sp. 3 | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.18) |
| *Didymocystis* sp. 4 | 53.33 | 30.88 (± 41.63) | 16.47 (± 33.79) |
| *Didymocystis* sp. 5 | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.18) |
| Didymozoidae gen. sp. | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.18) |
| *Lobatozoum multisacculatum* | 20.00 | 1.33 (±0.52) | 0.27 (± 0.58) |
| *Nematobothrium scombri* | 6.67 | 1.00 (± 0.00) | 0.07 (± 0.25) |
| *Neodiplotrema pelamydis* | 10.00 | 1.00 (± 0.00) | 0.10 (± 0.31) |
| *Oesophagocystis dissimilis* | 66.67 | 13.80 (± 16.50) | 9.20 (± 14.91) |

| | | | |
|---|---|---|---|
| *Oesophagocystis lydiae* | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.18) |
| CESTODA | | | |
| *Tentacularia coryphaenae* | 80.00 | 6.25 (± 4.63) | 5.00 (± 5.23) |
| ACANTHOCEPHALA | | | |
| Rhadinorhynchinae gen. sp. 1 | 6.67 | 1.00 (± 0.00) | 0.07 (± 0.25) |
| Rhadinorhynchinae gen. sp. 2 | 6.67 | 2.5 (± 0.71) | 0.17 (± 0.65) |
| Rhadinorhynchinae gen. sp. 3 | 10.00 | 1.33 (± 0.58) | 0.13 (± 0.43) |
| Rhadinorhynchinae gen. sp. 4 | 40.00 | 1.33 (± 0.65) | 0.53 (± 0.78) |
| NEMATODA | | | |
| Anisakidae gen. sp. | 93.33 | 20.25 (± 31.70) | 18.90 (± 31.02) |
| CRUSTACEA | | | |
| *Caligus bonito* | 6.67 | 1.00 (± 0.00) | 0.07 (± 0.25) |

Spearman rank correlations were assessed in gill parasites and *D. simplex* showed a significant negative correlation with total length of the host (p = 0.018; R = -0.428) and *L. multisacculatum* a significant positive correlation with Girth/length ratio (p = 0.026; R = 0.407) (table 4).

Table 4 – Spearman rank correlations obtained between the abundance of gills parasites species and measures and parameters of *Katsuwonus pelamis*.

| Parasite | | Total length | Weight | *K* condition factor | Girth/length ratio | Fat levels |
|---|---|---|---|---|---|---|
| DIGENEA | | | | | | |
| *Didymocylindrus filiformis* | p | 0.854 | 0.589 | 0.356 | 0.152 | 0.723 |
| | R | 0.035 | 0.103 | 0.175 | 0.268 | 0.067 |
| *Didymocylindrus fusiformis* | p | 0.165 | 0.159 | 0.359 | 0.878 | 0.912 |
| | R | -0.260 | -0.264 | -0.174 | 0.029 | -0.021 |
| *Didymocylindrus simplex* | p | <u>0.018</u> | 0.144 | 0.217 | 0.174 | 0.521 |
| | R | <u>-0.428</u> | -0.273 | 0.232 | 0.255 | 0.122 |
| *Lobatozoum multisacculatum* | p | 0.645 | 0.508 | 0.118 | <u>0.026</u> | 0.394 |
| | R | 0.088 | 0.126 | 0.292 | <u>0.407</u> | 0.161 |

No significant differences in infection levels were detected between males and females, according to Fisher's test.

Wilcoxon test shows there were no significant differences in abundance between left and right gills.

The distribution of parasites on each gill arch was assessed using Friedman's test (table 5) followed by the Conover test, whenever significant differences were detected between parasites abundance. The didymozoids *D. simplex* and *D. filiformis* showed significant differences in distribution between gill arches. In both species, the first branchial arch was always the most parasitised, and the fourth was always the least parasitised. The two middle arches had more similar abundance. A summary of the significant differences detected in the microhabitat distribution of these two didymozoids is presented in table 6.

Table 5 – Significance of differences in abundance of skipjack tuna gill parasites among gill arches in left gill (L), right gill (R) and both gills (L+R) evaluated by Friedman's test.

| **Parasite** | **L** | **R** | **L + R** |
|---|---|---|---|
| DIGENEA | | | |
| *Didymocylindrus filiformis* | 0.031 | 0.188 | 0.002 |
| *Didymocylindrus fusiformis* | 0.615 | 0.071 | 0.177 |
| *Didymocylindrus simplex* | 0.044 | 0.001 | 0.0004 |
| *Lobatozoum multisacculatum* | 0.035 | 0.572 | 0.137 |

Table 6 – Microhabitat distribution of *Didymocylindrus simplex* and *Didymocylindrus filiformis* on the gills of skipjack tuna from Madeira archipelago. Significance of Friedman's test in parenthesis. For each branchial arch, mean abundance ± standard deviation. Different letters indicate statistically significant diferences.

| | | **1st BA** | **2nd BA** | **3rd BA** | **4th BA** |
|---|---|---|---|---|---|
| DIGENEA | | | | | |
| *Didymocylindrus simplex* | **Left Gill** (p=0.044) | 4.8 ± 16.0 c | 2.0 ± 5.6 b | 1.7 ± 3.6 b | 1.0 ± 2.3 a |
| | **Right Gill** (p=0.001) | 3.3 ± 10.9 d | 1.3 ± 4.6 b | 2.5 ± 5.8 c | 0.9 ± 2.5 a |
| | **Both** (p=0.0004) | 8.1 ± 26.9 d | 3.3 ± 10.0 b | 4.2 ± 9.1 c | 1.9 ± 4.5 a |
| *Didymocylindrus filiformis* | **Left Gill** (p=0.031) | 1.2 ± 2.3 c | 0.8 ± 5.6 bc | 0.9 ± 3.3 b | 0.3 ± 0.8 a |
| | **Both** (p=0.002) | 2.2 ± 5.12 d | 1.4 ± 2.5 c | 1.3 ± 3.5 b | 0.6 ± 1.2 a |

Spearman rank correlations for gastrointestinal parasites show there were no significant correlations with length (TL or FL) or weight of the fish (table 7).

*Didymocystis* sp.1 and Anisakidae gen. sp. have a significant positive correlation with the girth/length ratio (p = 0.040, R = 0.378; p = 0.001, R = 0.576). Anisakidae gen. sp. has a positive correlation with *K* condition factor (p = 0.004; R = 0.504) and *T. coryphaenae* a negative correlation with fat levels of the host.

Table 7 – Spearman rank correlations between the abundance of endoparasites and several parameters of *Katsuwonus pelamis* sampled speciemens (Didymozoidae TD = Total dydimozoids; Rhadinorhynchinae TR = Total Rhadinorhynchinae).

| Parasite | | Total length | Fork length | Weight | *K* condition factor | Girth/length ratio | Fat levels |
|---|---|---|---|---|---|---|---|
| DIGENEA | | | | | | | |
| *Allodidymocodium* sp. | p | 0.384 | 0.461 | 0.359 | 0.867 | 0.854 | 0.720 |
| | R | 0.165 | 0.138 | 0.173 | -0.032 | 0.035 | 0.068 |
| *Didymocystis* sp. 1 | p | 0.761 | 0.681 | 0.841 | 0.160 | <u>0.040</u> | 0.957 |
| | R | -0.058 | -0.078 | -0.038 | 0.263 | <u>0.378</u> | 0.010 |
| *Didymocystis* sp. 2 | p | 0.238 | 0.220 | 0.217 | 0.471 | 0.386 | 0.514 |
| | R | -0.222 | -0.231 | -0.232 | -0.137 | 0.164 | 0.124 |
| *Didymocystis* sp. 4 | p | 0.123 | 0.068 | 0.108 | 0.706 | 0.932 | 0.129 |
| | R | -0.288 | -0.337 | -0.300 | -0.072 | 0.016 | -0.284 |
| *Didymocystis* spp. | p | 0.119 | 0.159 | 0.160 | 0.480 | 0.159 | 0.452 |
| | R | -0.291 | -0.264 | -0.263 | 0.134 | 0.264 | -0.143 |
| Didymozoidae TD | p | 0.552 | 0.597 | 0.632 | 0.896 | 0.303 | 0.813 |
| | R | -0.113 | -0.101 | -0.091 | -0.025 | 0.195 | 0.045 |
| *Oesophagocystis* | p | 0.178 | 0.118 | 0.211 | 0.106 | 0.406 | 0.156 |
| *dissimilis* | R | 0.253 | 0.291 | 0.235 | -0.301 | -0.157 | 0.265 |
| CESTODA | | | | | | | |
| *Tentacularia* | p | 0.556 | 0.412 | 0.523 | 0.689 | 0.396 | <u>0.003</u> |
| *coriphaenae* | R | -0.112 | -0.155 | -0.121 | -0.076 | -0.161 | <u>-0.532</u> |
| ACANTHOCEPHALA | | | | | | | |
| Rhadinorhynchinae TR | p | 0.495 | 0.514 | 0.600 | 0.872 | 0.448 | 0.979 |
| | R | -0.129 | -0.124 | -0.100 | -0.031 | 0.144 | 0.005 |
| NEMATODA | | | | | | | |
| Anisakidae gen. sp. | p | 0.843 | 0.609 | 0.467 | <u>0.004</u> | <u>0.001</u> | 0.838 |
| | R | -0.038 | 0.097 | 0.138 | <u>0.504</u> | <u>0.576</u> | -0.039 |

Fisher's test was assessed to all parasite species present on digestive tube of *K. pelamis* and no significant differences were found between males and females.

The quantitative descriptors of the parasite community are shown on table 8. The specific richness of skipjack tuna metazoan parasites community (S) is 25.

Table 8 – Diversity, dominance and equitability indexes of metazoan parasites community of *Katsuwonus pelamis*.

| Index | Value |
|---|---|
| **Diversity** | |
| Shannon's Index | 2.255 |
| The inverse of Simpson's Index | 7.922 |
| **Dominance** | |
| Berger-Parker's Index | 0.185 |
| **Equitability** | |
| Shannon's Index | 0.700 |
| The inverse of Simpson's Index | 0.317 |

# 2.4. Discussion

The most prevalent and abundant parasites in *K. pelamis* from Madeira Archipelago were Anisakidae gen. sp.. Anisakidae are circumglobally distributed marine parasites. To complete their life cycle, Anisakidae need to infect intermediate and paratenic hosts of different trophic levels to achieve the final host, marine mammals. Anisakidae have been detected in skipjack tuna in Atlantic and Pacific Oceans (Alves & Luque, 2006; Lester et al., 1985). However, prevalence as high as those, found in Madeira archipelago, had never been reported to this host but, the high number of parasites present may be related to skipjack tuna's diet that includes small pelagic, probably, previously infected by Anisakidae. A few studies refer high prevalence levels of Anisakidae in *S. colias* from North-western Atlantic Ocean (Portugal and Morocco) (Abattouy et al., 2011; Santos et al., 2017) and according to Ramos et al. (1995), *S. colias* is an important species of skipjack tuna's dietary in Canary islands. Considering the proximity between Canary Islands and Madeira archipelago, it is possible to infer that the dietary is similar in both regions and, probably, *S. colias* is the main transmission way of Anisakidae to *K. pelamis.*

The highest intensities were showed by *Didymocystis* sp. 4 (a Didymozoidae from digestive tube). Didymozoidae are frequent in scombrids (Pozdnyakov & Gibson, 2008) and have been isolated from several organs of several species of tunas as *Thunnus thynnus* (Mladineo, 2006), *Thunnus alalunga* (Mele et al., 2010) and *K. pelamis* (Justo & Kohn, 2012; Kamegai & Araki, 1995) from different regions.

There are no studies about gill metazoan parasites communities of skipjack tuna in Northeast-Atlantic Ocean, however the parasites found in skipjack tuna gills in this study had been reported before in this host (Alves & Luque, 2006; Justo & Kohn, 2005; Lester et al., 1985; Mele et al., 2012). According to migration route described in ICCAT Manual of skipjack tuna, probably the specimens studied by Mele et al. (2012) in Mediterranean Sea belongs to the same population of the ones reported in the present work. Five of seven gill parasites found in skipjack tuna from Madeira Archipelago have also been found by these authors (*D. filiformis, D. fusiformis, D. simplex, L. multisacculatum* and *C. bonito*). The levels of infections were not very different, especially the ones reported in the Balearic Sea of the Mediterranean with the exception of the ones reported to *C. bonito* that were higher in Alboran Sea of the Mediterranean. It should be highlight that the two species not detected by Mele et al. (2012) in the Mediterranean Sea (*C. katsuwoni* and *N. pelamydis*) were detected with low levels of infection in the present study.

In short it was concluded that the most prevalent parasites in skipjack tuna gills from Madeira Archipelago are didymozoids. These parasites can lodge beneath a thin layer of cells in gills filaments. Tunas have a typical gill ventilation, the ram ventilation, that consists in a continuous water inflow in gill chamber that can hinder the fixation of ectoparasites as copepods and monogenean. Didymozoidae have more ability to remain fixed in gills of this type of host, especially in open habitats with oceanic currents as it happens in Atlantic Ocean. In calmer habitats, as in the Mediterranean Sea, tuna gills can also be colonised by other parasites as it seems to occur in *K. pelamis*. *D. simplex* showed a significant negative correlation with total length of the host, however Justo et al. (2013) and Mele et al. (2012), didn't find this correlation.

The didymozoids *D. simplex* and *D. filiformis* showed significant differences in distribution between gill arches. In both species, the first branchial arch was always the most and the fourth was always the least parasitised. The two middle arches had more similar abundance. This pattern was previously descripted for copepods parasitizing *K. pelamis* and other teleost fish (Hermida et al., 2012; Mele et al., 2012).

The metazoan parasites present in digestive tube of *K. pelamis* have been previously reported, in this species or in other scombrid fish. Some of them are the most prevalent and abundant parasites in skipjack tuna from Madeira archipelago. Didymozoidae are the most diversify group of parasites detected in the digestive tube (12 out of 18 parasite species in the digestive tract were didymozoids). Several authors had found diversified communities of digestive tube didimozoids parasites in *K. pelamis* (Lester et al., 1985) or other scombrids, as *Euthynnus affinis* from Bay of Bengal (Madhavi & Ram, 2000) and *Thunnus atlanticus* from Brazil (Justo & Kohn, 2014), however no study had found a community as diverse as the reported from Madeira archipelago to skipjack tuna.

The genus *Allodidymocodium* is a parasite of scombrids (Bray et al., 2008), however this is the first reference of the occurrence of this parasite in *K. pelamis*.

*D. reniformis* was reported by Mele et al. (2012) in skipjack tuna gills from Mediterranean Sea, but in skipjack tunas from Madeira archipelago it was found in stomach. It should be stressed that this is an usual observation as there are many references of the occurrence of didymizoids parasitizing the gills and the digestive tract of the host. In the case of *K. pelamis,* Silas (1962) referred the occurrence of *Koellikeria orientalis* in the gills, oesophagus, stomach and intestine. It is the first time that *N. scombri* is found in skipjack tuna from Atlantic Ocean, however, other authors had found these parasites in other species of scombrids. Eiras & Rego (1987) found *N. scombri* parasitizing *Scomber colias* in Brazil and Mele et al. (2014) in *S. colias* from

Mediterranean Sea. Oliva et al. (2008), refers *S. colias* from Madeira archipelago as host of *N. scombri*. As referred before, this small pelagic is an important species of skipjack tuna's dietary and may be the transmitted to *K. pelamis,* since this parasite was found inside the stomach of the host.

Spearman rank correlations were assessed for digestive tube parasites and show there were no significant correlations with length (TL or FL) or weight of the fish. *Didymocystis* sp.1 and Anisakidae gen. sp. have a significant positive correlation with the girth/length ratio ($p = 0.040$, $R = 0.378$; $p = 0.001$, $R = 0.576$). Anisakidae gen. sp. has a positive correlation with *K* condition factor ($p = 0.004$; $R = 0.504$) and *T. coryphaenae* a negative correlation with fat levels of the host.

All correlations found between parasites abundance and *K* condition factor or girth/length ratio, have a straight relationship with the host feeding. Fishes that ingest higher volumes of food are more predisposed to be infected with endoparasites acquired trophically, which can explain the positive significant correlations found in skipjack tuna.

*T. coryphaenae* is the only parasite that shows a negative significant correlation with a host parameter, fat levels. This correlation had never been found between this parasite and skipjack tuna, however, similar negative correlations were found by Lloret et al. (2014) for *Engraulis encrasicolus* parasitized by *Hysterothylacium aduncum*. These authors studied the influence of *H. aduncum* on the content of triacylglycerol (triglyceride) stores in muscles of fishes from Black Sea and showed that there are a huge influence of parasites decreasing the level of accumulated lipid reserves. Lloret et al. (2014) also suggest that low fat levels can negatively affects the immune system of fish and make them more susceptible to be infected. Probably, *T. coryphaenae* has one of this two effects in *K. pelamis*.

Two indexes of diversity were calculated in this study: Shannon's index and the inverse of Simpson index. Two indexes are in concordance and show that this metazoan parasites community has a median diversity. The parasite community observed in skipjack tuna collected in Madeira EEZ presented a high value of equitability. This indicates a balanced parasite community, with several important species, none of which particularly dominant what is confirmed by the low value obtained to the dominance index of Berger-Parker.

# 3. Almaco jack or Longfin yellowtail, *Seriola rivoliana*

## 3.1. Introduction

### 3.1.1. Almaco jack biological characteristics

The almaco jack or longfin yellowtail, *Seriola rivoliana* Valenciennes, 1833, it's an *Actinopterygii*, from Carangidae family.

It has a circumglobal distribution, appearing in tropical to warm temperate waters (McEachran & Fechhelm, 2010). In Eastern Atlantic, it occurs from Portugal to West Africa, including Madeira and Azores Archipelagos and Mediterranean Sea (figure 25) (Carpenter, 2002).

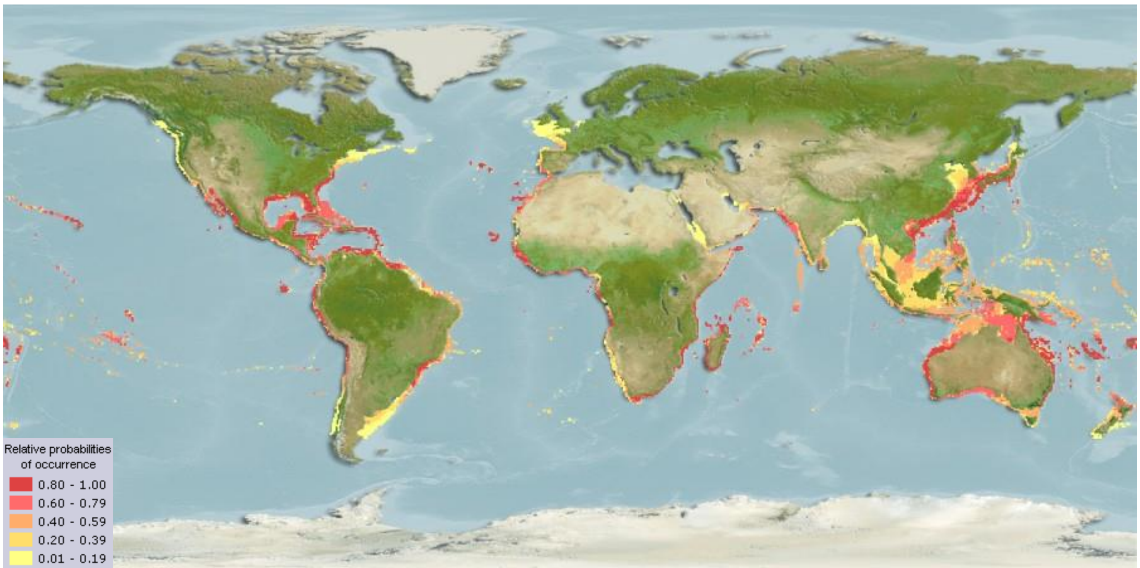


Figure 25 – Map of relative probabilities of occurrence of *Seriola rivoliana* (Aquamaps, 2017b)

This species is pelagic and epibenthic in oceanic waters and lives from 5m to 45m depth but is more common in 30-35m (Myers, 1991).

*S. rivoliana* has an elongated and slightly compressed body and the upper profile is slightly more convex than the lower (figure 26). The snout is moderately long and acutely pointed. Its pectoral fins are relatively short, acutely tipped and have 21 rays. First dorsal fin has 7 spines and second has 1 spine and 27 to 33 rays. Anal fin has two spines followed by one spine and 18 to 22 rays with anterior rays forming long, acute lobe. Almaco jack has small and cycloid scales and its lateral line is slightly arched anteriorly and consists of 122 to 143 scales.

The body colour of this species is brown, olivaceous or bluish green dorsally and silvery to whitish laterally and ventrally. A faint nuchal stripe may be present, from eye to nape. Caudal fin is shiny dark (McEachran & Fechhelm, 2010).

The common size of *S. rivoliana* is about 55 cm FL and 2.5 kg to 80 cm FL and 3.4 kg (Carpenter, 2002). Maximum FL known is 123 cm (McEachran & Fechhelm, 2010).

Figure 26 – Illustration of a specimen of *Seriola rivoliana* (Bray, 2017).

There are a few studies on almaco jack food habits. Manooch & Haimovici (1983) discovered that, in south Atlantic, almaco jack has a diversified dietary including fishes, cephalopods and crustaceans. In the North Atlantic (Azores), food habits of this species are mostly composed of *Trachurus picturatus* and *Scomber colias* (Barreiros et al., 2003). The proximity of Madeira to Azores suggests that food habits of *S. rivoliana* can be similar.

## 3.1.2. The fishery and aquaculture of *Seriola* spp. in Madeira archipelago, Portugal

Three different species of the genus *Seriola* occur in Madeira archipelago: the greater amberjack, *S. dumerili*, the lesser amberjack, *S. fasciata* and the almaco jack *S. rivoliana*. For fisheries statistics, there are no distinction between species and the three species are evaluated as *Seriola* spp.. At the end of the last century, these species were important for the commercial fisheries of this region. Nowadays, they represent a low percentage of landings. In the last 10 year, the volume of landings of *Seriola* spp. has been decreasing and currently it is about 2000 kg/year (figure 27) (OOM, 2017c).

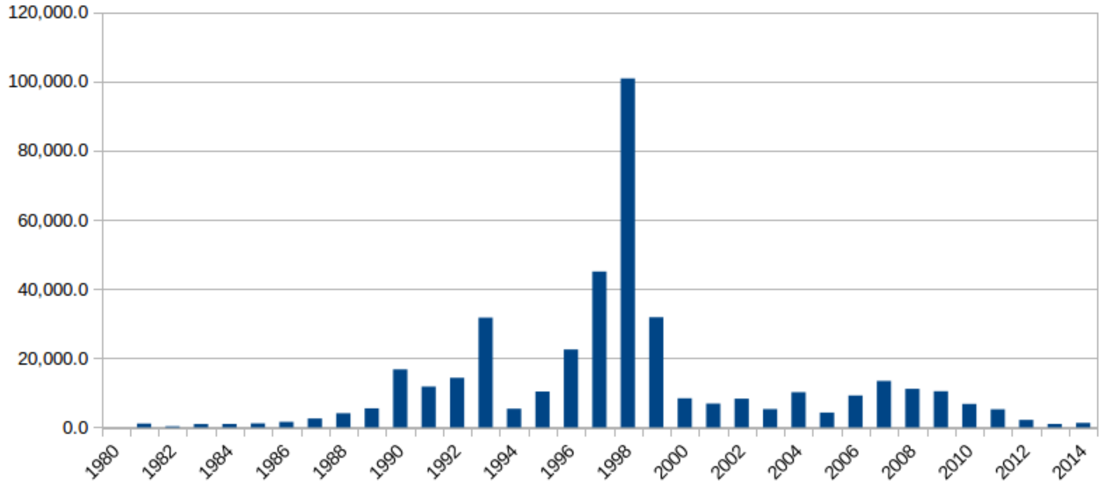


Figure 27 – *Seriola* spp. average weight annual landings (OOM, 2017c).

Seriola spp*.* is currently produced in aquaculture, starting in the 1960's in China with a production of *S. quinqueradiata.* This is the most produced species and the major producers are Japan and China. Nowadays, several species of the genus *Seriola* are produced in many countries, as described by Sicuro & Luzzana (2016) and the species differs from region to region:

- *S. dumeril* produced in Japan, Taiwan, Vietnam and Mediterranean Sea;
- *S. lalandi* produced in Japan, Australia, New Zealand, Chile and Netherlands (recirculation aquaculture system);
- *S. mazatlana* produced in North and Central America;
- *S. quinqueradiata* produced in Japan and China;
- *S. rivoliana* produced in United States of America and Hawaii;

In Mediterranean region, *S. dumerili* production started in the second half of the 1980's and the major producer has been Spain (Sicuro & Luzzana, 2016). In recent years, aquaculture has been developing in Madeira Archipelago been one of the most produced species (after gilthead seabream, *Sparus aurata*) is *S. dumerili*.

In recent years there has been a huge investment in greater amberjack aquaculture and the forecast is for continue the investment and increase the production.

Since three species coexist in Madeira archipelago waters and have similar biological characteristics, the study of *S. rivoliana* metazoan parasites can be a contribute to the beginning of *S. rivoliana* aquaculture.

## 3.1.3. Problems related to almaco jack consumption

Some species of fishes may cause poisoning when consumed. An example is Ciguatera Fish Poisoning (CFP), is a foodborne disease caused by the consumption of fishes that have accumulated lipid-soluble, polyether toxins known as ciguatoxins (CTXs). Ciguatoxins are assimilated and bioaccumulated through multiple trophic levels of the food web and in high levels they may produce an intoxication. They are present in fishes with economic value but it is produced by dinoflagellates, frequently of the genus *Gambierduscus* (Boada et al., 2010). CFP outbreaks usually occur with wild fishes from waters between 35º North and 35 South latitude (Caribean, Indo-Pacific and Indian Oceans). Sometimes it is reported in other regions such as Bahamas, Canada and Chile. More than 425 dinoflagellates species were reported as a cause of ciguatera poisoning in humans and *S. rivoliana* is one of than (Pérez-Arellano et al., 2005).

In north-eastern Atlantic, some outbreaks of ciguatera poisoning have been reported from Canary Islands (Boada et al., 2010; Nunez et al., 2012; Pérez-Arellano et al., 2005) and at least one case is reported from Madeira Archipelago (Gouveia et al., 2009), where the presence of CTXs were confirmed by Otero et al. (2010). In order to prevent Ciguatera Fish Poisoning in Madeira archipelago, the local government banned the capture of specimens from de genus *Seriola* spp. weighing more than 10 kg, due the probably of occurrence of high levels of ciguatoxins (Portaria no. 484/2016 de 14 de Novembro, 2016).

Ordinarily, poisoning occurs in 2-6 hours after consumption but it has an incubation period that can vary between minutes to more than 30 hours and the toxicity has different levels. The earliest symptoms are gastrointestinal disorders but there are cases where neurological manifestations occurs (Johnson & Jong, 1983).

## 3.1.4. Previous records of almaco jack metazoan parasites

*Seriola* spp. are important species for aquaculture and, for this reason, some studies about metazoan parasites were made in different regions of the world. There are publications from Australia (Hutson et al., 2007b; Sharp et al., 2003) and Mediterranean Sea (Bartoli & Bray, 2004; Grau et al., 1999), however, as far as we known, there are no scientific studies about metazoan parasites communities of *Seriola* ssp. from Eastern Atlantic, more specifically in EEZ of Madeira archipelago.

Metazoan parasites from several different taxonomic groups have already been identified in *Seriola* spp., including *S. rivoliana* (Annex 2).

# 3.2. Materials and Methods

## 3.2.1. Sampling

Thirty-four specimens of *Seriola* spp*.* were sampled between November 2016 and March 2017. Thirty fishes came from Selvagens Islands, Madeira Archipelago as a seizure from illegal fisheries. After capture, fishes were frozen. Twenty-nine of them were identified as *S. rivoliana* (Sr 01-29) and one as *S. dumerili* (Sd 01). Two specimens of larger size, one of *S. rivoliana* (Sr 20/01) and one of *S. dumerili* (Sd 29/03) from Madeira, were also sampled. In addition to this, two specimens of *S. dumerili* (SdA 01/02) were obtained from a local aquaculture facility. The specimens of *S. rivoliana* from Selvagens Islands were considered the main sample to statistical analysis and they had identical measures. All fishes were identified according to Carpenter (2002) and McEachran & Fechhelm (2010).

Firstly, in each fish several measures were collected: total length, fork length, girth and maximum body height. After this, total weight was obtained.

After all measures, left and right gills were collected and separated arch by arch in individual petri dishes for observation. Left and right pseudobranchs were collected in the same way. Posteriorly, the abdominal cavity was open to extract internal organs. Viscera was separated organ by organ and kept in petri dishes for observation. The sex of each specimen was determined through gonads' observation.

The gills were examined under a stereomicroscope – *Leica MZ125* – with 100x magnification. All parasites found on the gills were collected, counted, washed in saline solution (10%) and stored in an alcohol solution (70%) for identification.

Identification guides, book and articles were used to identify parasites found in *Seriola* spp*.*:

- Monogenea: Rohde (1978a); Rao & Madhavi (1967); Jones et al. (2005)
- Trematoda: Jones et al. (2005), Rao & Madhavi (1967), Bartoli & Bray (2004), Bartoli et al. (2004);
- Acanthocephala: Yamaguti (1963) and (Golvan, 1969);
- Crustacea: Cressey (1991) and Repullés-Albelda (2012);

Parasites were photographed under a stereomicroscope – Zeiss Stemi 2000-C – with 6.5 to 50x magnification.

### 3.2.2. Statistical analysis

Some biological condition factors as gonadosomatic index, hepatosomatic index, girth/length ratio and *K* condition factor were assessed to this sample, according to Lloret et al. (2014), as the same way as for *K. pelamis*

For statistical analysis, only the twenty-nine specimens of *S. rivoliana* from Selvagens Islands were considered. Prevalence, mean intensity and mean abundance of each parasite species were calculated according to Bush et al. (1997).

Correlations between parasite abundance and host parameters were assessed using Spearman rank correlation. The host parameters used were total length, weight, K condition factor and girth/length ratio. Fisher's test was used to assess differences in prevalence between the sexes ($N_{males} = 14$; $N_{females} = 15$). Spearman rank correlations and Fisher's test were assessed only for the most prevalent species: *Allencotyla mcintoshi*, *Caligus aesopus, Tormopsolus orientalis*, Anisakidae gen. sp..

The software used for statistics analysis was *R 3.3.0*. (R Core Team, 2016) and the significance level used for all tests was $p<0.05$.

Indexes of diversity (Shannon's index and the inverse of Simpson's index), dominance (Berguer-Parker index) and equitability (Shannon's index and the inverse of Simpson's index) were calculated for this sample in the same way as for *K. pelamis.*

# 3.3. Results

Twenty-Nine *Seriola* spp from Madeira archipelago were sampled to parasites research and their measures and biological condition factors are shown on table 9.

In all ten species of metazoan parasites from different taxonomic groups were detected in examined specimens of *Seriola* spp*.* (table 14, figures 28-35). Eight of them were found in *S. rivoliana* from Selvagens Islands (Sr 01-29), that were considered the main sample statistically evaluated. Monogeneans were represented by *Allencotyla mcintoshi, Dionchus agassizi* and *Zeuxapta seriolae*. Two species of digenean were found: *Didymocystis* sp*.* and *Tormopsolus orientalis*. Only one species of rhadinorhynchid acanthocephalan was detected: *Rhadinorhynchus* sp*..* Nematodes and copepods were only represented by Anisakidae gen. sp. specimens and *Caligus aesopus*, respectively. The only specimen of *S. dumerili* from Selvagens Islands (Sd 01), only had one parasite: *Stephanostomum ditrematis*. The specimen of large size of *S. rivoliana* (Sr 20/01) was parasitized by two species of metazoan parasites: *Caligus aesopus* and *Stephanostomum petimba*. In *S. dumerili* of large size (Sd 29/03) no parasites were found, as well as in farmed specimens (SdA 01/02). All parasites were located on the gills, stomach and intestine. The specific location of each parasite on the host is presented in table 10.

Table 9 – Mean values of measures and indexes of *Seriola rivoliana* (Sr 01-29).

| Parameter | Mean value |
|---|---|
| Weight (g) | 1644.42 (± 253.85) |
| Total lenght (cm) | 49.79 (± 2.30) |
| Fork length (cm) | 44.31 (± 2.00) |
| Girth (cm) | 33.00 (± 1.64) |
| Girth/length ratio | 0.67 (± 0.05) |
| K condition factor | 1.32 (± 0.10) |
| Max. high body (cm) | 14.29 (± 0.76) |
| Gonad weight (g) | 4.24 (± 2.25) |
| Gonadosomatic index (GSI) | 0.25 (± 0.11) |
| Liver weight (g) | 12.73 (± 3.97) |
| Hepatosomatic index (HSI) | 0.77 (± 0.20) |
| Stomach weight (full) (g) | 21.24 (± 4.32) |

Table 10 – Metazoan parasites observed in *Seriola* spp. and their organ location in the host.

| | Parasite | Host location |
|---|---|---|
| | *Seriola rivoliana* (Sr 01-29) | |
| MONOGENEA | | |
| | *Allencotyla mcintoshi* | Gills |
| | *Dionchus agassizi* | Gills |
| | *Zeuxapta seriolae* | Gills |
| DIGENEA | | |
| | *Didymocystis* sp. | Intestine |
| | *Tormopsolus orientalis* | Stomach and Intestine |
| ACANTHOCEPHALA | | |
| | *Rhadinorhynchus* sp. | Stomach |
| NEMATODA | | |
| | Anisakidae gen. sp. | Stomach and Intestine |
| CRUSTACEA | | |
| | *Caligus aesopus* | Gills |
| | *Seriola dumerili* (Sd 01) | |
| DIGENEA | | |
| | *Stephanostomum ditrematis* | Intestine |
| | *Seriola rivoliana* (Sr 20/01) | |
| DIGENEA | | |
| | *Stephanostomum petimba* | Intestine |
| CRUSTACEA | | |
| | *Caligus aesopus* | Gills |

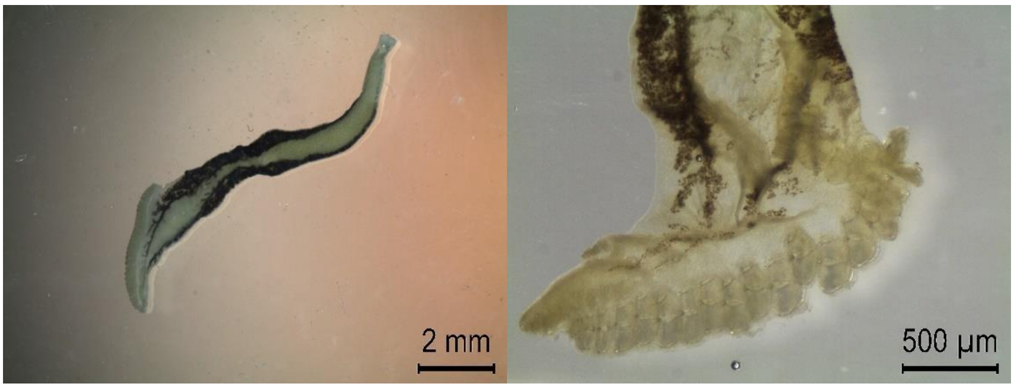


Figure 28 – Specimens of *Allencotyla mcintoshi* from almaco jack gills.

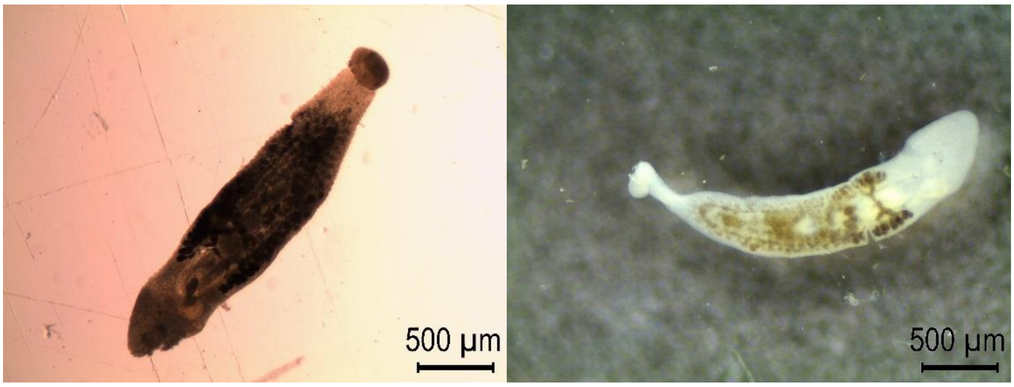


Figure 29 – Specimens of *Dionchus agassizi* from almaco jack gills.

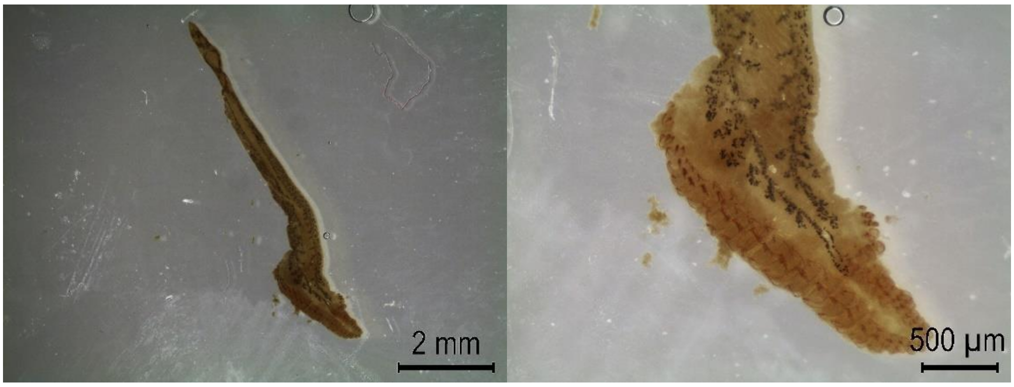


Figure 30 – Specimens of *Zeuxapta seriolae* from almaco jack gills.


Figure 31 – Specimens of *Stephanostomum ditrematis* from *Seriola dumerili* intestine.

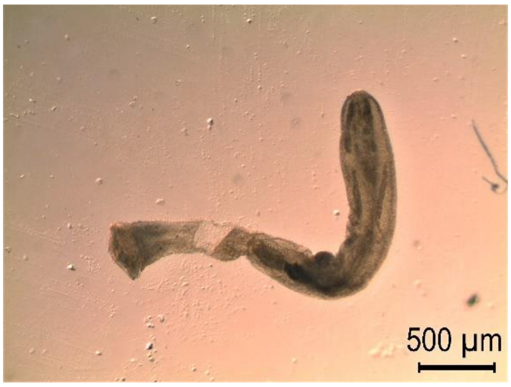


Figure 32 – Specimen of *Stephanostomum petimba* from almaco jack intestine.


Figure 33 – Specimen of *Tormopsolus orientalis* from almaco jack stomach and intestine.

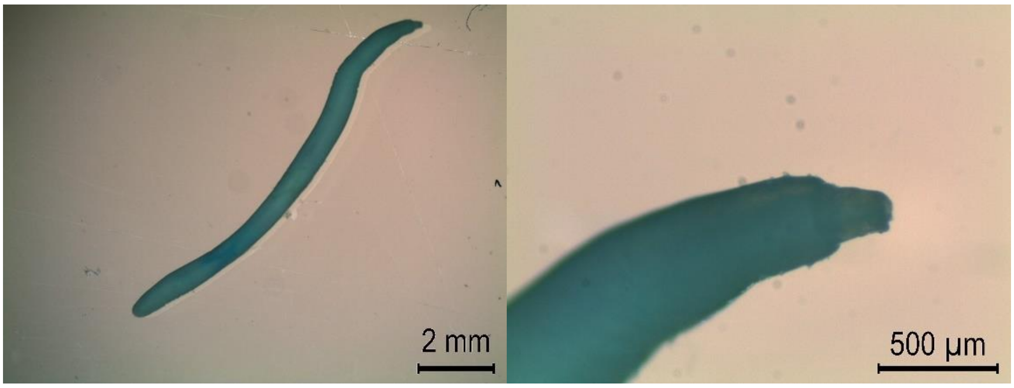


Figure 34 – Specimens of *Rhadinorhynchus* sp. from almaco jack stomach.

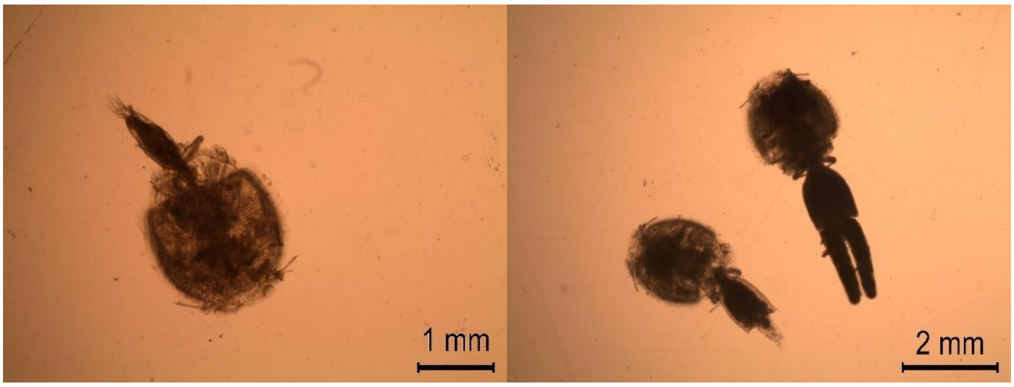


Figure 35 - Specimens of *Caligus aesopus* from almaco jack gills.

*T. orientalis* was the most prevalent (P = 36.67) species, followed by *A. mcintoshi* (P = 33.33) and *C. aesopus* (P= 30.00) in *S. rivoliana*. The highest intensities were shown by *Z. seriolae* (mI = 127.00) and *D. agassizi* (mI = 17.00). *Z. seriolae* was the most abundant species (mA = 18.90), followed by *T. orientalis* (mA = 2.31) (table 11).

Table 11 – Prevalence (P (%)), mean abundance (mA) and mean intensity (mI) of the metazoan parasites of *Seriola rivoliana* from Selvagens islands, Madeira Archipelago.

| Parasite | P (%) | mI | mA |
|---|---|---|---|
| MONOGENEA | | | |
| *Allencotyla mcintoshi* | 33.33 | 1.70 (± 1.06) | 0.59 (± 1.02) |
| *Dionchus agassizi* | 3.33 | 17.00 (± 0.00) | 0.59 (± 3.16) |
| *Zeuxapta seriolae* | 3.33 | 127.00 (± 0.00) | 4.38 (± 23.58) |
| DIGENEA | | | |
| *Didymocystis* sp. | 3.33 | 5.00 (± 0.00) | 0.17 (± 0.93) |
| *Tormopsolus orientalis* | 36.67 | 6.09 (± 4.30) | 2.31 (± 3.96) |
| ACANTHOCEPHALA | | | |
| *Rhadinorhynchus* sp. | 3.33 | 1.00 (± 0.00) | 0.03 (± 0.19) |
| NEMATODA | | | |
| Anisakidae gen. sp. | 23.33 | 1.71 (± 1.50) | 0.41 (± 1.02) |
| CRUSTACEA | | | |
| *Caligus aesopus* | 30.00 | 4.78 (± 4.27) | 1.48 (± 3.20) |

Spearman rank correlations were assessed for the most prevalent parasites of *S. rivoliana* (table 12). *T. orientalis* showed a significant negative correlation with *K* condition factor of the host (p = 0.043; R = -0.378) and *C. aesopus* a significant positive correlation with weigh (p = 0.024; R = 0.417) (table 12).

Table 12 – Spearman rank correlations obtained between the abundance of parasites and parameters of *Seriola rivoliana*.

| Parasite | | Total length | Weight | *K* condition factor | Girth/length ratio |
|---|---|---|---|---|---|
| MONOGENEA | | | | | |
| *Allencotyla mcintoshi* | p | 0.234 | 0.629 | 0.248 | 0.592 |
| | R | 0.228 | 0.094 | -0.222 | 0.104 |
| DIGENEA | | | | | |
| *Tormopsolus orientalis* | p | 0.760 | 0.693 | <u>0.043</u> | 0.149 |
| | R | 0.059 | -0.077 | <u>-0.378</u> | -0.275 |
| NEMATODA | | | | | |
| Anisakidae gen. sp. | p | 0.676 | 0.6549 | 0.694 | 0.849 |
| | R | -0.081 | -0.087 | -0.076 | -0.037 |
| CRUSTACEA | | | | | |
| *Caligus aesopus* | p | 0.057 | <u>0.024</u> | 0.371 | 0.449 |
| | R | 0.358 | <u>0.417</u> | 0.172 | -0.146 |

No significant differences in infection levels of these parasites were detected between males and females, according to Fisher's test.

The quantitative descriptors of the parasite community are shown on table 13. The specific richness of almaco jack metazoan parasites population (S) is 8.

Table 13 – Diversity, dominance and equitability indexes of metazoan parasites community of *Seriola rivoliana*

| Index | Value |
|---|---|
| **Diversity** | |
| Shannon's Index | 1.539 |
| The inverse of Simpson's Index | 3.630 |
| **Dominance** | |
| Berger-Parker's Index | 0.439 |
| **Equitability** | |
| Shannon's Index | 0.740 |
| The inverse of Simpson's Index | 0.055 |

# 3.4. Discussion

The three species of amberjacks, *S. rivoliana*, *S. dumerili* and *S. lalandi,* are very similar species and as it was expected, its parasite community are also similar. Nine of the ten species of metazoan parasites found in this sample of *Seriola* spp. have been reported before by other authors (Bartoli & Bray, 2004; Hutson et al., 2007b; Montero et al., 2003; Montero et al., 2004; Rohde, 1978b; Sharp et al., 2003). The only species not reported before was *Dionchus agassizi.*

Monogenean gills parasites were frequently reported as a cause of high mortalities in wild or farmed specimens of the genus *Seriola* (Montero et al., 2004; Sharp et al., 2003). There is an interest to invest in aquaculture of this fish species in Madeira archipelago and the existence of this parasites should not be overlook. *Benedenia seriolae* is a very usual parasite of fish from de genus *Seriola* (Hutson et al., 2007a), but was not yet found in this region and some measures should be taken to prevent it's introduction. The producers are advised to be very careful in choosing the place of purchase of juveniles or invest in their own hatchery.

The presence of *C. aesopus* in this region should be highlight too for the same reasons.

The parasites community observed in almaco jack from Selvagens islands present a low value of equitability. There is a dominant species, *Z. seriolae*, in the observed specimens of almaco jack. It should be referred that although this parasite species was the dominant one it only occurs in one host. Probably is for that reason that the values to diversity indexes, are not in accordance. Shannon index confers more importance to the most abundant species, while the inverse of Simpson index privileges de less abundant species. Since there is a dominant species.

# 4. General conclusion

*K. pelamis* and *S. rivoliana* are two predatory species from Madeira archipelago. Twenty–five species of metazoan parasites were found in this sample of skipjack tuna, while in almaco jack only eight were reported. This study reports, for the first time, *Allodidymocodium sp.* and *N. scombri* in *K. pelamis* and *A. mcintoshi*, *Z. seriolae, Didymocystis* sp*., S. petimba, T. orientalis* and *Rhadinorhynchus* sp*.* in *S. rivoliana.* The genus *Seriola* is described as a new host of *D. agassizi*.

Although these two fish species share the same ecosystem, at least in part of their life and have similar food habits, there have completely different parasite communities. There are two main explanations for it. In one hand, skipjack tuna is an oceanic and migratory species, occurring in Madeira archipelago during the warmer months. It has a more active lifestyle than almaco jack, being a voracious predator. On the other hand, almaco jack, occurs in this region during all year around.

As it was expected, the parasites community of *K. pelamis* is mostly constituted by digeneans, more concretely, didymozoids whereas in the parasites community found in *Seriola rivoliana* monogeneans are more frequent.

It will be very interesting to do an analysis of the stomach contents of these fish and this could great contribute to better understand the way these fish are infected by the detected endoparasites.

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# Annexes

## Checklist of metazoan parasites of *Katsuwonus pelamis*

| Parasite | Geographical region | References |
|---|---|---|
| **Monogenea** | | |
| **Family Capsalidae** | | |
| *Capsala katsuwoni* (syn. *Caballerocotyla katsuwoni, Caballerocotyla llewelyni*) | Atlantic Ocean (Brazil) | Kohn & Justo 2006 |
| | Indian & Pacific Oceans | Murugesh 1995 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| Capsalidae gen. sp. | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| *Tristomella interrupta* (syn. *Capsala interrupta*) | Mediterranean | Silas 1962, Williams & Bunkley-Williams 1996 |
| *Tristomella laevis* (syn. *Capsala laevis, Tristomum laeve*) | Atlantic Ocean (USA) | Silas 1962 |
| | Atlantic/ Mediterranean (Europe) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Linton 1901 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Tristomella nozawae* (syn. *Capsala nozawae)* | Pacific Ocean (Japan) | Silas 1962 |
| *Tristomella onchidiocotyle* (syn. *Capsala lintoni*) | Atlantic Ocean (USA) | Silas 1962 |
| **Family Gastrocotylidae** | | |
| *Allopseudaxine katsuwonis* (syn. *Pseudaxine katsuwonis*) | Atlantic Ocean (Puerto Rico) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean (Japan) | Silas 1962 |
| *Allopseudaxine macrova* | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| *Allopseudaxine* sp. | Pacific Ocean (New Caledonia) | Rohde et al. 1980 |
| *Allopseudaxinoides euthynni* | Atlantic Ocean (Brazil) | Justo & Kohn 2015 |
| *Allopseudaxinoides vagans* (syn. *Allopseudaxine vagans, Pseudaxine vagans*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Rohde et al. 1980, Williams & Bunkley-Williams 1996 |
| **Family Hexostomatidae** | | |
| *Hexostoma grossum* | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| **Family Thoracocotylidae** | | |

| Parasite | Geographical region | References |
|---|---|---|
| *Pricea minimae* | Indian Ocean? | Williams & Bunkley-Williams 1996 |
| **Trematoda: Digenea** | | |
| **Family Bucephalidae** | | |
| *Bucephalus* sp. | Atlantic Ocean (Brazil) | Fernandes et al. 2002 |
| *Rhipidocotyle pentagonum* | Atlantic Ocean (Brazil) | Fernandes et al. 2002, Alves & Luque 2006 |
| *Rhipidocotyle* sp. | Pacific Ocean | Lester et al. 1985 |
| **Family Didymozoidae** | | |
| *Adenodidymocystis intestinalis* | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Adenodidymocystis* sp. | Pacific Ocean | Pozdnyakov & Gibson 2008 |
| *Annulocystis katsuwoni* | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Annulocystis* sp. | Atlantic & Pacific Oceans | Pozdnyakov & Gibson 2008 |
| *Atalostrophion cf. biovarium* | Mediterranean | Mele et al. 2012 |
| *Didymocylindrus filiformis* | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Mediterranean | Mele et al. 2012 |
| | Indian Ocean | Nikolaeva & Dubina 1985, Mordvinova & Nikolaeva 1990 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| *Didymocylindrus fusiformis* (syn. *Didymoproblema fusiforme*) | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Mediterranean | Mele et al. 2012 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| *Didymocylindrus simplex* (syn. *Didymocystis simplex*) | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Atlantic Ocean (Brazil) | Justo et al. 2013 |
| | Mediterranean | Mele et al. 2012 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| *Didymocystis abdominalis* (syn. *Coeliodidymocystis abdominalis*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymocystis bilobate* | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymocystis coatesi* | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| *Didymocystis intestinomuscularis* (syn. *Didymocystoides intestinomuscularis*) | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Pacific Ocean | Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| *Didymocystis kamegaii* (syn. *Coeliodidymocystis kamegaii*) | Atlantic Ocean (Brazil) | Justo & Kohn 2005 |
| | Indian Ocean (Bay of Bengal) | Madhavi 1982 |
| | Indo-Pacific | Williams & Bunkley-Williams 1996 |
| *Didymocystis katsuwoni* (syn. *Lagenocystis katsuwoni*) | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Didymocystis lamotheargumedoi* | Atlantic Ocean (Brazil) | Kohn & Justo 2008 |
| *Didymocystis margolisi* | Pacific Ocean (Japan) | Kamegai & Araki 1995 |
| *Didymocystis ovata* | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymocystis philobranchia* | Indian Ocean | Nikolaeva & Dubina 1985, Mordvinova & Nikolaeva 1990, Williams & Bunkley-Williams 1996 |
| *Didymocystis pinnicola* (syn. *Didymocystoides pinnicola*) | Indian Ocean | Murugesh & Madhavi 1995 |
| | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Didymocystis reniformis* | Mediterranean | Mele et al. 2012 |
| | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Didymocystis rotunditestis* | Indian Ocean | Nikolaeva & Dubina 1985, Mordvinova & Nikolaeva 1990, Williams & Bunkley-Williams 1996 |
| *Didymocystis submentalis* (syn. *Didymocystoides submentalis*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymocystis thynni* | Atlantic / Mediterranean (Europe) | Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| *Didymocystis* sp. (syn. *Coeliodidymocystis* sp.) | Pacific Ocean | Lester et al. 1985 |
| *Didymosulcus soleiformis* taxon inquirendum (syn. *Didymocystis soleiformis*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymosulcus wedli* (syn. *Didymocystis wedli*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymosulcus* sp. | Pacific and Indian Oceans | Pozdnyakov & Gibson 2008 |
| *Didymozoon auxis* | Atlantic / Mediterranean (Europe) | Williams & Bunkley-Williams 1996, Yamaguti 1953 *in* Waldron 1963 |
| *Didymozoon filicolle* | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymozoon longicolle* | Mediterranean | Mele et al. 2012 |
| | Atlantic Ocean (Brazil) | Justo & Kohn 2012 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymozoon minus* (syn. *Didymozoon minor*?) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Didymozoon sp.* | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| *Koellikeria orientalis* | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Koellikeria* sp. | Mediterranean | Mele et al. 2012 |
| *Koellikerioides* sp. | | Pozdnyakov & Gibson 2008 |
| *Lobatozoum multisacculatum* | Mediterranean | Mele et al. 2012 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| *Nematobothrium scombri* | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Neodiplotrema pelamydis* | Atlantic Ocean (Brazil) | Justo & Kohn 2005 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Neodiplotrema* sp. | Pacific Ocean | Pozdnyakov & Gibson 2008 |
| *Oesophagocystis dissimilis* (syn. *Didymocystis dissimilis*) | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Indian Ocean | Murugesh & Madhavi 1995 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| *Phacelotrema claviforme* | Indian Ocean | Nikolaeva & Dubina 1985, Mordvinova & Nikolaeva 1990, Williams & Bunkley-Williams 1996 |
| *Phacelotrema* sp. | Atlantic & Pacific Oceans | Pozdnyakov & Gibson 2008 |
| *Pozdnyakovia gibsoni* | Atlantic Ocean (Brazil) | Justo & Kohn 2012; Justo et al. 2015 |
| *Wedlia globosa* (syn. *Koellikeria globosa*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Wedlia orientalis* | Pacific Ocean | Pozdnjakov 1992 |
| *Wedlia reniformis* (syn. *Koellikeria reniformis*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| **Family Fellodistomidae** | | |
| *Tergestia laticollis* | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Manter 1940 *in* Waldron 1963, Lester et al. 1985 |
| **Family Hemiuridae** | | |
| *Dinurus euthynni* (syn. *Dinurus thynni*) | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Lester et al. 1985, Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| *Lecithochirium microstomum* | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| **Family Hirudinellidae** | | |
| *Hirudinella ventricosa* (syn. *Hirudinella clavata, Hirudinella marina*). | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Manter 1940 *in* Waldron 1963, Nigrelli & Stunkard *in* Waldron 1963 |
| | - | Silas 1962 |
| *Hirudinella* sp. | Indian Ocean | Raju 1962 |
| | Pacific Ocean | Chen & Yang 1973 |
| **Family Syncoelidae** | | |
| *Copiatestes filiferus* (syn. *Syncoelium filiferum; Syncoelium katuwo*) | Atlantic Ocean (Brazil) | Fernandes et al. 2002 |
| | Pacific Ocean (Japan) | Silas 1962 |
| | Pacific Ocean | Yamaguti 1953 *in* Waldron 1963, Rohde et al. 1980, Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| **Cestoda** | | |
| **Family Phyllobothriidae** | | |
| *Pelichnibothrium* sp. | Pacific Ocean | Yamaguti 1934 *in* Waldron 1963 |
| **Family Tetraphyllidea** | | |
| *Scolex pleuronectis* (Tetraphyllidea *incertae sedis*) | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| **Order Trypanorhyncha** | | |
| Trypanorhyncha gen. sp. | Indian Ocean (Oman Sea) | Sattari et al. 2014 |
| **Family Lacistorhynchidae** | | |
| *Callitetrarhynchus gracilis* | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Callitetrarhynchus speciosus* | Pacific Ocean | Yamaguti 1952 *in* Waldron 1963 |
| *Hepatoxylon trichiurid* | Atlantic Ocean (Ivory Coast / Senegal) | Bussieras & Baudin-Laurencin 1973 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| **Family Philobothriidae** | | |
| *Pelichnibothrium sp.* | Pacific Ocean | Yamaguti 1934 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| **Family Tentaculariidae** | | |
| *Nybelinia lingualis* | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| *Tentacularia coryphaenae* (syn. *Tentacularia bicolor*) | Atlantic Ocean ? | Silas 1962 |
| | Atlantic Ocean (Ivory Coast / Senegal) | Bussieras & Baudin-Laurencin 1973 |
| | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Indian Ocean | Palm 2000 |
| | Pacific Ocean | Yamaguti 1934 *in* Waldron 1963; Lester et al. 1985 |
| *Tentacularia* sp. | Pacific Ocean | Chen & Yang 1973, Williams & Bunkley-Williams 1996 |
| **Nematoda** | | |
| **Family Anisakidae** | | |
| *Acanthocheilus* sp. (only one species in WoRMS: *A. rotundatus*) | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Anisakis simplex* | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| *Anisakis* spp. | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Pacific Ocean | Yamaguti 1941 *in* Waldron 1963, Chen & Yang 1973; Lester et al. 1985; Williams & Bunkley-Williams 1996 |
| *Contracaecum* sp. | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| *Terranova* sp. | Pacific Ocean | Lester et al. 1985, Williams & Bunkley-Williams 1996 |
| **Family Cystidicolidae** | | |
| *Ctenascarophis lesteri* | Atlantic Ocean (Puerto Rico) | Crites et al. 1993 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Crites et al. 1993 |
| *Prospinitectus exiguous* | Atlantic Ocean (Puerto Rico) | Crites et al. 1993 |

| **Parasite** | **Geographical region** | **References** |
|---|---|---|
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Crites et al. 1993 |
| **Family Philometridae** | | |
| *Philometra katsuwoni* | Atlantic Ocean (Gulf of Guinea) | Petter & Baudin-Laurencin 1986 |
| | Atlantic Ocean (Brazil) | Cárdenas et al. 2009 |
| *Philometra* sp. | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Lester et al. 1985 |
| *Philometroides* sp. | Pacific Ocean | Waldron 1963, Williams & Bunkley-Williams 1996 |
| **Acanthocephala** | | |
| **Family Rhadinorhynchidae** | | |
| *Raorhynchus mayeri* | Indian Ocean | Williams & Bunkley-Williams 1996 |
| *Raorhynchus terebra* | Indian Ocean | Williams & Bunkley-Williams 1996 |
| | ? | Golvan 1969 |
| *Rhadinorhynchus ganapatii* | Indo-Pacific (Philippines) | Briones et al. 2015 |
| *Rhadinorhynchus katsuwonis* | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| *Rhadinorhynchus ornatus* (syn. *Nipporhynchus ornatum, Nipporhynchus ornatus*) | Pacific Ocean | Van Cleave 1940 *in* Waldron 1963, Chen & Yang 1973; Amin et al. 2009 |
| *Rhadinorhynchus pristis* | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| *Rhadinorhynchus trachuri* (syn. *Nipporhynchus trachuri*) | Pacific Ocean | Williams & Bunkley-Williams 1996 |
| **Crustacea: Copepoda** | | |
| **Family Bomolochidae** | | |
| *Unicolax reductus* | Pacific Ocean | Cressey & Cressey 1980, Williams & Bunkley-Williams 1996 |
| **Family Caligidae** | | |
| *Caligus asymmetricus* | Indian Ocean (Madagascar) | Cressey & Cressey 1980 |
| | South Africa | Oldewage & van As 1989 *in* Dipenaar 2004 |
| | Pacific Ocean | Williams & Bunkley-Williams 1996 |

| **Parasite** | **Geographical region** | **References** |
|---|---|---|
| *Caligus bonito* | Atlantic Ocean (Angola) | Nunes-Ruivo 1956 *in* Dipenaar 2004 |
| | Mediterranean | Mele et al. 2012 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | South Africa | Oldewage & van As 1989 *in* Dipenaar 2004 |
| | Pacific Ocean | Wilson 1905 *in* Waldron 1963, Jones 1988 |
| *Caligus coryphaenae* (syn. *Caligus aliuncus, Caligus tessifer, Caligus thymni*) | Atlantic (Cape Verde, Gulf of Guinea; Brazil, Venezuela, USA, Puerto Rico); Indo-Pacific | Cressey & Cressey 1980 |
| | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| | Pacific Ocean | Wilson 1905 *in* Waldron 1963, Wilson 1937 *in* Waldron 1963, Shiino 1952 *in* Waldron 1963, Silas & Ummerkutty 1967, Jones 1988 |
| *Caligus mutabilis* | Atlantic Ocean (Western) | Williams & Bunkley-Williams 1996 |
| *Caligus pelamydis* | Atlantic Ocean (Ivory Coast) | Cissé et al. 2007 |
| | Pacific Ocean | Wilson 1905 *in* Waldron 1963 |
| *Caligus productus* (syn. *Caligus katuwo*) | Atlantic (Gulf of Guinea; Gulf of Mexico, USA, Dominican Republic, Venezuela, Brazil); Indo-Pacific | Cressey & Cressey 1980; |
| | Atlantic Ocean (Caribbean) | Lester et al. 1985 |
| | Atlantic Ocean (Puerto Rico, Venezuela, Brasil, USA) | Williams & Bunkley-Williams 1996 |
| | Atlantic Ocean (Brazil) | Alves & Luque 2006 |
| | Pacific Ocean | Wilson 1905 *in* Waldron 1963, Yamaguti 1936 *in* Waldron 1963 |
| *Caligus quadratus* | Indo-Pacific | Williams & Bunkley-Williams 1996 |
| *Lepeophtheirus curtus* (syn. *Homoiotes bermudensis, Lepeophtheirus bermudensis*) | Atlantic (Bermuda) | Heegaard 1943 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| *Lepeophtheirus dissimulatus* | Atlantic (Bermuda) | Heegaard 1943 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |

| Parasite | Geographical region | References |
|---|---|---|
| *Lepeophtheirus salmonis* | Pacific Ocean | Heegaard 1943 *in* Waldron 1963, Williams & Bunkley-Williams 1996 |
| **Family Siphonostomatoida** | | |
| *Pseudocycnus appendiculatus* | Mediterranean | Brian 1902 *in* Kabata 1970; Brian 1906 |
| | Atlantic (Angola) | Nunes-Ruivo 1954 *in* Kabata 1970 |
| | Atlantic (Western) | Williams & Bunkley-Williams 1996 |
| | Atlantic (Gulf of Guinea, Surinam); Indian Ocean | Cressey & Cressey 1980; |
| | Atlantic (Brazil) | Alves & Luque 2006 |

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## Checklist of metazoan parasites of *Seriola* spp.

| Parasite | Geographical region | References |
|---|---|---|
| **Myxozoa** | | |
| **Family Ceratomyxidae** | | |
| *Ceratomyxa buri* | Australia | Hutson et al. 2007 |
| *Ceratomyxa seriolae* | Australia | Hutson et al. 2007 |
| **Family Myxobolidae** | | |
| *Myxobolus* sp. | Mediterranean Sea | Grau 1999 |
| **Monogenea** | | |
| **Family Axinidae** | | |
| *Allencotyla mcintoshi* | Mediterranean Sea | Montero et al. 2003 |
| **Family Capsalidae** | | |
| *Benedenia seriolae* | Australia | Chambers & Ernst 2005 |
| | New Zealand | Sharp et al. 2003 |
| *Neobenedenia melleni* (syn. *Neobenedenia girellae)* | Japão | Hirayama et al. 2009 |
| | New Zealand | Sharp et al. 2003 |
| **Family Dionchidae** | | |
| *Dionchus sp.* | | Hendrix 1994 |
| **Family Heteraxinidae** | | |
| *Heteraxine heterocerca* | Mediterranean Sea | Grau 1999 |
| *Zeuxapta seriolae* | Mediterranean Sea | Montero et al. 2004 |
| | Australia | Rohde 1978 |
| | New Zealand | Sharp et al. 2003 |
| **Family Microcotylidae** | | |
| *Aspinatrium kahala* | Pacific Ocean | |
| *Paramicrocotyloides reticularis* | Australia | Rohde 1978 |
| | | Hutson et al. 2007 |
| **Digenea** | | |
| **Family Acanthocolpidae** | | |
| *Acanthocolpus Iiodorus* | Mediterranean Sea | Grau 1999 |
| *Stephanostomum cesticillum* | Mediterranean Sea | Bartoli & Bray 2001 |
| *Stephanostomum ditrematis* | Mediterranean Sea | Bartoli & Bray 2004 |

| Parasite | Geographical region | References |
|---|---|---|
| *Stephanostomum filiforme (*syn. *Stephanostomum ditrematis)* | Mediterranean Sea | Bartoli & Bray 2004 |
| *Stephanostomum euzeti* | Mediterranean Sea | Bartoli & Bray 2004 |
| *Stephanostomum petimba* | Mediterranean Sea | Bartoli & Bray 2004 |
| *Stephanostomum pristis* | Mediterranean Sea | Grau 1999 |
| *Tormopsolus attenuatus* | Australia | Bray & Cribb 2001 |
| *Tormopsolus orientalis* | Mediterranean Sea | Bartoli et al. 2004 |
| **Family Aporocotylidae** | | |
| *Paradeontacylix* sp. | Mediterranean Sea | Grau 1999 |
| *Paradeontacylix* spp. | Mediterranean Sea | Montero et a. 1999 |
| *Paradeontacylix balearicus* | Mediterranean Sea | Repullés-Albelda 2008 |
| *Paradeontacylix godfreyi* | Australia | Hutson et al. 2007 |
| *Paradeontacylix grandispinus* | Mediterranean Sea | Repullés-Albelda 2008 |
| *Paradeontacylix ibericus* | Mediterranean Sea | Repullés-Albelda 2008 |
| *Paradeontacylix kampachi* | Mediterranean Sea | Montero et al. 2003 |
| *Paradeontacylix sanguinicoloides* | Australia | Hutson et al. 2007 |
| **Family Bucephalidae** | | |
| *Bucephalopsis* sp. (syn. *Prosorhynchoides* sp.*)* | Mediterranean Sea | Grau 1999 |
| *Bucephalus gorgon* | Mediterranean Sea | Bartoli et al. 2005 |
| *Bucephalus introversus* (syn. *Bucephalus gorgon)* | Mediterranean Sea | Manter 1940 |
| *Bucephalus polymorphus* | Mediterranean Sea | Grau 1999 |
| *Prosorhynchus crucibulum* | Mediterranean Sea | Grau 1999 |
| *Rhipidocotyle longicirrus* | Mediterranean Sea | Bartoli & Bray 2005 |
| *Telorhynchus* sp. | Australia | Hutson et al. 2007 |
| **Family Didymozoidae** | | |
| *Nematobothrium scombri* | Mediterranean Sea | Grau 1999 |
| Didimozoidae gen. sp. | Australia | Hutson et al. 2007 |
| *Wedlia bipartita* | Mediterranean Sea | Grau 1999 |
| **Family Hemiuridae** | | |
| *Erilepturus hamati* | Australia | Hutson et al. 2007 |
| *Elytrophalloides oatesi* | Australia | Hutson et al. 2007 |
| *Elytrophallus* sp. | Australia | Hutson et al. 2007 |
| *Hemiurus communis* | Mediterranean Sea | Grau 1999 |
| *Hirudinella sp.* | Australia | Hutson et al. 2007 |
| *Lecithochirium jaffense* | Mediterranean Sea | Fischthal 1982 |
| *Lecithocladium sp.* | Australia | Hutson et al. 2007 |

| Parasite | Geographical region | References |
|---|---|---|
| *Parahemiurus merus* | Australia | Hutson et al. 2007 |
| *Pleururus digitatus* | Australia | Hutson et al. 2007 |
| **Family Lecithasteridae** | | |
| *Aponurus* sp. | Mediterranean Sea | Grau 1999 |
| *Aponurus laguncula* | Australia | Hutson et al. 2007 |
| *Bucephalopsis* sp. | Mediterranean Sea | Grau 1999 |
| **Family Lepocreadiidae** | | |
| *Opechona kahawai* | Australia | Hutson et al. 2007 |
| | | |
| **Cestoda** | | |
| **Family Lacistorhynchidae** | | |
| *Dasyrhynchus varioucinatus* | Miami | Ward 1954 |
| *Protogrillotia zerbiae* | Hawaii | Tamaru et al. 2016 |
| **Family Tentaculariidae** | | |
| *Nybelinia thyrsites* | Australia | Hutson et al. 2007 |
| **Family Tetraphylidae** | | |
| Tetraphylidae gen. sp. 1 | Australia | Hutson et al. 2007 |
| Tetraphylidae gen. sp. 2 | Australia | Hutson et al. 2007 |
| **Family Trilosporidae** | | |
| *Unicapsula seriolae* | Australia | Lester 1982 |
| | | |
| **Acanthocephala** | | |
| **Family Rhadinorhynchidae** | | |
| *Rhadinorhynchus* sp. 1 | Australia | Hutson et al. 2007 |
| *Rhadinorhynchus* sp. 2 | Australia | Hutson et al. 2007 |
| *Rhadinorhynchus* seriolae | | Golvan 1969 |
| | | |
| **Nematoda** | | |
| **Family Anisakidae** | | |
| Anisakidae gen. sp. | Japão | Yoshinaga et al. 2006 |
| *Anisakis* sp. | Australia | Hutson et al. 2007 |
| *Contracecum* sp. | Australia | Hutson et al. 2007 |
| *Pseudoterranova* sp. | Australia | Hutson et al. 2007 |
| **Family Raphidascarididae** | | |
| *Hysterothylacium* sp. | Australia | Hutson et al. 2007 |
| **Family Philometridae** | | |
| *Philometra globiceps* | Mediterranean Sea | Grau 1999 |

| Parasite | Geographical region | References |
|---|---|---|
| *Philometra globiceps* | Mediterranean Sea | Morvec et. al 2003 |
| **Family Rhabdochonidae** | | |
| *Rhabdochona sp.* | Australia | Hutson et al. 2007 |
| | | |
| **Crustacea** | | |
| **Family Bomolochidae** | | |
| *Naricolax chrysophryenus* | Australia | Hutson et al. 2007 |
| **Family Caligidae** | | |
| *Caligus* aesopus | New Zealand | Sharp et al. 2003 |
| | Mediterranean Sea | Repullés-Albelda 2012 |
| *Caligus amblygenitalis* | Australia | Hutson et al. 2007 |
| *Caligus curtus* | Mediterranean Sea | Grau 1999 |
| *Caligus diaphanus* | Mediterranean Sea | Repullés-Albelda 2012 |
| *Caligus lalandei* | Pacific Ocean | Ho et al. 2001 |
| | New Zealand | Sharp et al. 2003 |
| *Caligus seriolae* | Mediterranean Sea | Repullés-Albelda 2012 |
| *Caligus spinosus* | Japão | Cruz-Lacierda et al. 2011 |
| *Caligus tenax* | Mediterranean Sea | Repullés-Albelda 2012 |
| *Caligus* sp. | Australia | Hutson et al. 2007 |
| **Family Dissonidae** | | |
| *Dissonus hoi* | Australia | Hutson et al. 2007 |
| **Family Lernanthropidae** | | |
| *Lernanthropus paenulatus* | Australia | Hutson et al. 2007 |
| *Lernanthropus* spp. | New Zealand | Sharp et al. 2003 |
| **Family Lernaeopodidae** | | |
| *Parabrachiella seriolae* | Japão | Cruz-Lacierda et al. 2011 |
| *Parabrachiella sp.* | Australia | Hutson et al. 2007 |
| **Family Pennellidae** | | |
| *Pennella instructa* | Mediterranean Sea (Turkey) | Öktener 2009 |
| *Peniculus sp.* | Australia | Hutson et al. 2007 |
| | | |
| **Isopoda** | | |
| **Family Gnathiidae** | | |
| *Gnathia vorax* | Mediterranean Sea | Grau 1999 |

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