PRELIMINARY ANALYSIS OF PARASITIC COPEPOD SPECIES RICHNESS OF CHONDRICHTHYAN FISH OFF TUNISIAN COASTS

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ملخص

دراسة أولية لثراء مجدافيات الأرجل عند الأسماك الغضروفية في السواحل التونسية : دراسة أولية في مختلف خلجان تونس (خليج بنزرت و خليج تونس و خليج الحمامات و خليج قابس) مكنتنا من أن نستنتج أهمية التنوع البيولوجي للأسماك الغضروفية. حيث أننا تمكنا من التعرف و دراسة خمسة عشر نوعا ينتمي إلى ثمانية عائلات من هاته الأسماك. من بين هاته العائلات ثلاث منها كانت محور دراسة معمقة بسبب أهميتها الاقتصادية. أهمية هدا التنوع حثنا على دراسة طفيليات هاته الأسماك خاصة أن بعضها مهددة بالانقراض جراء ضعف تكاثرها و الصيد العشوائي و التلوث. هدا العمل مكننا من اكتشاف تنوع بيولوجي هام لمجدافيات الأرجل وسجلنا وجود أربعة عشر نوع من هده الطفيليات موزعة على سبع عائلات كما لاحظنا أن حضوض الإصابة بالطفيليات مرتبط ببعض الصفات الاكوبيلوجية و الاتلوجية الخاصة بالأسماك المضيفة.

كلمات مفاتيح : الاسماك الغضروفية , الثراء الطفيلى, مجدافيات الارجل ,الخلجان التونسية.

RESUME

Analyse préliminaire de la richesse spécifique des copépodes parasites des poissons chondrichtyens des côtes tunisiennes: Un travail préliminaire de récolte et d'observation de différentes zones prospectées en Tunisie (baie de Bizerte, golfe de Tunis, golfe de Hammamet et golfe de Gabès) nous a permis de constater une grande diversité d'élasmobranches. En effet, 15 espèces appartenant à 8 familles différentes ont été identifiées et examinées. Parmi celles-ci, certaines familles, principalement les Triakidae, les Dasyatidae et les Torpedinidae, ont fait l'objet d'une étude approfondie en raison de leur importance économique. Cette importante biodiversité nous a incité à étudier les parasites des poissons Chondrichtyens, d'autant plus que la plupart de ces poissons sont en voie de disparition en raison de leur faible potentiel de reproduction, de la pêche illégale et de la pollution.

L'étude parasitologique effectuée sur ces espèces de poissons a révélé une grande diversité de copépodes parasites. En effet, nous avons signalé la présence de 14 espèces différentes appartenant à 7 familles. La diversité de ces espèces est liée à certaines caractéristiques éco-biologiques et éthologiques des poissons hôtes.

Mots clés: Poissons chondrichtyens, copépodes parasites, richesse parasitaire, côtes tunisiennes.

ABSTRACT

A preliminary work of harvest and observations from various prospected areas in Tunisia (Bay of Bizerte, Gulf of Tunis, Gulf of Hammamet and Gulf of Gabes) enabled us to note a great diversity of Elasmobranchs. In fact, 15 species belonging to 8 different families were identified and examined. Among these, some families, mainly Triakidae, Dasyatidae and Torpedinidae, have been the subject of an in-depth study because of their economic importance in the fisheries. The great importance of the biodiversity motivates us to study the parasites of Chondrichthyan fish, especially since most of these fish are in danger of extinction because of their low reproductive potential, catching by fisheries and pollution.

The parasitological study of these fish species revealed a great diversity of their parasitic copepods. In fact, we reported the presence of 14 different species belonging to 7 families. The diversity of these species is related to to some eco-biological and ethological characteristics of host fish.

Keywords: Chondrichthyan fish, parasitic copepods, parasite richness, Tunisian coasts.

INTRODUCTION

With more than 1300 km of coastline, Tunisia is largely open to the two basins of the Mediterranean Sea, the western basin by its north facade and the eastern basin by its east and south-east facades. The position of Tunisia as well as the topography of its coast, allows for the existence of a particularly interesting marine and coastal biodiversity. Indeed, according to Bradai *et al.* (2012), 61 species of Chondrichthyan fish are reported on the Tunisian coast.

However, little is known about these species (Capapé, 1989; Bradai *et al*., 2012) and only a few studies were carried out on them and on their parasites (Essafi, 1975; Neifar, 2001; Youssef *et al.*, 2016).

Elasmobranchs infested by parasites suffer a variety of health issues which may include retarded development of reproductive organs (Yano and Musick, 2000), reduced respiratory efficiency and anemia (Benz and Adamson, 1990; Heupel and Bennett, 1998).

In fact, Thresher shark gill filaments infected with the copepod *Nemesis robusta* exhibited a diseased state (Benz and Adamson, 1990). Tissue erosion seemingly associated with the rasping effects of various copepod appendages and feeding activity was evident (Benz and Adamson, 1990). Copepod attachment close to secondary lamellae was associated with the proliferation of both respiratory epithelium and epithelium between the secondary lamellae. Tissue proliferation partially or completely occluded inter-lamellar water channels and probably compromised respiratory efficiency by blocking water passage between secondary lamellae (Benz and Adamson, 1990). On the other hand, the degenerative process may extend beyond the epithelial layer resulting in responsive hyperplasia and necrosis of the gill epithelium exhibited in attachment sites (Kabata, 1970; 1984; Benz and Adamson, 1990).

Therefore, in this survey, we will analyze the parasite richness of the harvested copepods according to certain ecological and ethological characteristics of the host fishes and try to see which ones are more receptif to parasitic copepod infestation.

MATERIAL AND METHODS

Between 2013 and 2015, 2651 specimen belonging to 15 different species of Chondrichthyan fishes, including 8 families were examined for parasitic copepods (Tab. I).

Table I: Fish species collected in Tunisia

Family	Host species	Number of examined fish	Mean Lengh
Myliobatidae	*Aetomylaeus bovinus* (Geoffroy Saint-Hilaire, 1817)	11	80-230 cm
Dasyatidae	*Bathytoshia centroura* (Mitchill, 1815)	176	90-211 cm
	Dasyatis pastinaca (Linnaeus, 1758)	164	30-55 cm
	Pteroplatytrygon violacea (Bonaparte, 1832)	28	47-52 cm
Rajidae	*Dipturus oxyrinchus* (Linnaeus, 1758)	14	42-59 cm
	Raja clavata Linnaeus, 1758	480	51-82 cm
Gymnuridae	*Gymnura altavela* (Linnaeus, 1758)	22	57-61 cm
Triakidae	*Mustelus mustelus* (Linnaeus, 1758)	542	45-98 cm
	Mustelus punctulatus Risso, 1827	278	48-91 cm
	Galeorhinus galeus (Linnaeus, 1758)	64	110-154 cm
Scyliorhinidae	*Scyliorhinus canicula* (Linnaeus, 1758)	516	29-62 cm
Squalidae	*Squalus blainville* (Risso, 1827)	91	47-71 cm
Torpedinidae	*Torpedo marmorata* Risso, 1810	63	31-49 cm
	Tetronarce nobiliana (Bonaparte, 1835)	60	32-47 cm
	Torpedo torpedo (Linnaeus, 1758)	142	28-45 cm
Total		**2651**	

Fish were caught weekly (Tab. II) in the bay of Bizerte, the Gulf of Tunis, the Gulf of Hammamet and the Gulf of Gabes (Fig. 1).

A summary table of the different fish species examined in the different sampling sites during the different seasons is given in Table II.

The host species were identified using Whitehead *et al.* (1986), Fisher *et al.* (1987) and Séret (2006). Name, size and weight of the fish as well as the sampling sites were specified. Their body area, mouth cavity, gills chambers and cloacae areas were examined under a binocular microscope for parasitic copepods. The gill arches were removed after two incisions, ventral and dorsal, and were placed in Petri dishes containing sea water.

The parasites were removed from the fish, counted, and sorted to species. Subsequently, specimens were cleared in lactic acid for 2 hours prior to examination using stereo and light microscopy. Specimens were dissected on glass-slides and mounted temporarily preparations in lactophenol under a dissecting microscope. Measurements were made using an ocular micrometer. Parasite species identification was done at the Natural History Museum of London and based on morphological features according to Yamaguti (1963), Kabata (1964; 1979), Cressey (1967), Deets (1994), Ho and Kim (2004) and Boxshall and Halsey (2004).

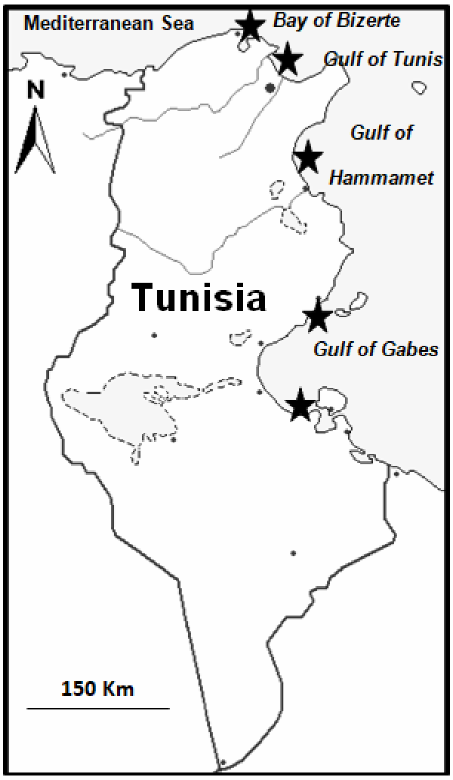

Figure 1: Sampling sites

To compare the results of the parasitic richness, the non-parametric statistical tests (Mann Whitney and Kruskal-Wallis) were used using the STATISTICA 10 software. The differences obtained were considered significant at the 5% level.

RESULTS

Ichthyological diversity

The 15 fish species examined are very diverse in their taxonomic status (Myliobatidae, Dasyatidae, Rajidae, Gymnuridae, Triakidae, Scyliorhinidae, Squalidae and Torpedinidae) (Tab. I), in their behavior (gregarious, solitary; migrant with the change of environment (Mi) or migrant without the change of environment (Mo) and their habitat (benthic, pelagic or demersal). In fact, among the fish species (Tab. I; III), eight are gregarious, five are solitary; two are benthic, four are pelagic, ten are demersal; six are migrant with change of environment and nine are migrant without change of environment (Tab. III).

Parasitological diversity

A parasitological study of these fish species revealed a great diversity of parasitic copepods. In fact, we found fourteen species belonging to seven different families (Eudactylinidae, Lernaeopodidae, Pandaridae, Caligidae, Trebiidae, Sphyriidae and Kroyeriidae) (Tab. III; IV). Five different species are recorded for the first time in Tunisia (Tab. III; IV) namely *Pseudocharopinus malleus*, *Perissopus dentatus*, *Nesippus orientalis*, *Caligus* sp. and *Kroyeria* sp.

Localization on the host: Our survey showed that six main body areas were infested by parasitic copepods in Tunisian fishes namely gills, oral cavity, spiracles, flank, cloacae cavity and dorsal fin (Tab. III).

Analysis of the copepod species richness: Among the fifteen species examined, seven were parasitized and eight appeared not to be parasitized by parasitic copepods. In other words, about 46 % of examined species were infected by parasitic copepods. The species richness varies remarkably as two fish species (*Torpedo marmorata* Risso, 1810 and *Scyliorhinus canicula* (Linnaeus, 1758)) are parasitized by a single copepod species, whereas only one fish species, *Mustelus mustelus* (Linnaeus, 1758), hosts seven

Table II: Number of individuals, season and sampling area of the host species

Host	Bay of Bizerte				Gulf of Tunis				Gulf of Hammamet				Gulf of Gabes				Total
	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	
Aetomylaeus bovinus	3	2	0	0	0	0	0	0	0	0	0	0	0	6	0	0	11
Bathytoshia centroura	5	2	5	4	8	9	12	5	2	4	7	3	26	24	30	30	176
Dasyatis pastinaca	4	0	5	9	10	6	6	7	9	7	15	12	15	20	18	21	164
Pteroplatytrygon violacea	0	0	0	0	0	0	0	0	0	0	0	0	5	3	12	8	28
Dipturus oxyrinchus	1	0	0	0	2	3	0	2	0	0	0	0	0	5	1	0	14
Raja clavata	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	480
Gymnura altavela	0	0	0	0	0	0	0	0	0	0	0	0	0	18	4	0	22
Mustelus mustelus	30	30	30	30	30	45	45	30	30	30	30	30	30	45	47	30	542
Mustelus punctulatus	10	4	11	11	36	35	10	16	7	1	6	6	30	30	35	30	278
Galeorhinus galeus	19	18	12	15	0	0	0	0	0	0	0	0	0	0	0	0	64
Scyliorhinus canicula	30	30	30	30	30	40	39	30	30	30	30	30	30	41	36	30	516
Squalus blainville	31	34	15	11	0	0	0	0	0	0	0	0	0	0	0	0	91
Torpedo marmorata	0	0	0	0	12	7	19	25	0	0	0	0	0	0	0	0	63
Tetronarce nobiliana	0	0	0	0	9	11	22	18	0	0	0	0	0	0	0	0	60
Torpedo torpedo	0	0	0	0	30	29	38	45	0	0	0	0	0	0	0	0	142

Caption: A: Autumn; W: Winter; Sp: Spring; Su: Summer

Table III: Host species, their characteristics and their parasitic copepods

Host species	Characteristics of host species	NEF	NIF	PR	Copepod species	Infested region	P (%)	IM	A
Aetomylaeus bovinus	G.B.P.Mo (Compagno *et al.*,1989 ; Brito, 1991)	11	0	**	******	******	***	***	***
Bathytoshia centroura	G.D.Mi (Bigelow and Schroeder 1953 ; Bernardes *et al.*, 2005)	176	4 1 6 6	6	*Eudactylinella alba* *Eudactylina insolens* *Pseudocharopinus bicaudatus* *Pseudocharopinus concavus*	Gills Gills Spiracles, gills and cloacae Gills Gills	2.27 0.56 3.40 3.40	1 1 1.5 1	0.022 0.005 0.051 0.034

			1 6		*Lernaeopoda galei* *Nemesis lamna vermi*	Gills	0.56 3.40	1 6.33	0.005 0.227
Dasyatis pastinaca	G.D.Mi (Brito, 1991)	164	6 8 2	3	*Eudactylinella alba* *Pseudocharopinus malleus* *Trebius caudatus*	Gills Gills Gills	3.65 4.87 1.21	1.5 1 1	0.054 0.048 0.012
Pteroplatytrygon violacea	G.P.Mo (Ebert, 2003; Mundy, 2005)	28	0	**	******	******	***	***	***
Dipturus oxyrinchus	D.Mo (Breder and Rosen, 1966; Stehmann, 1995)	14	0	**	*******	*******	***	***	***
Raja clavata	S.D.Mo (Holden, 1975; Hunter *et al*., 2005; Last *et al*., 2016)	480	1 4	2	*Caligus* sp. *Lernaeopoda galei*	Flanc Cloacae cavity	0.20 0.83	6 1	0.012 0.008
Gymnura altavela	D.Mi (Brito, 1991)	22	0	**	******	******	***	***	***
Mustelus mustelus	G.D.Mo (Mytilineou *et al*., 2005)	542	9 19 5 15 4 2 2	7	*Eudactylinella alba* *Kroyeria lineata* *Kroyeria* sp. *Lernaeopoda galei* *Perissopus dentatus* *Nesippus orientalis* *Tripaphylus musteli*	Gills Gills Gills Cloacae cavity Dorsal fin Buccal cavity Buccal cavity	1.66 3.50 0.92 2.76 0.73 0.36 0.36	1.5 1 1 1.2 1 1 1	0.016 0.035 0.009 0.027 0.007 0.003 0.003
Mustelus punctulatus	G.D.Mo (Compagno in prep)	278	7 1	2	*Lernaeopoda galei* *Eudactylina insolens*	Cloacae cavity Gills	2.51 0.35	1 1	0.025 0.003

Galeorhinus galeus	G.P.Mi (Compagno, 1984; Riede, 2004)	64	0	**	******	******	***	***	***
Scyliorhinus canicula	G.D.Mo (Sims, 2003 ; Mytilineou *et al.*, 2005)	516	1	1	*Eudactylina alba*	Gills	0.19	1	0.001
Squalus blainvillei	S.D.Mi (Mytilineou *et al.*, 2005)	91	0	**	******	******	***	***	***
Torpedo marmorata	S.B.Mi (Capapé and Desoutter, 1990)	63	1	1	*Pseudocharopinus malleus*	Cloacae cavity	1.58	1	0.015
Tetronarce nobiliana	S.P.Mo (Anonymous, 2000)	60	0	**	******	******	***	***	***
Torpedo torpedo	S.D.Mo (Capapé and Desoutter, 1990)	142	0	**	******	******	***	***	***

Caption: *: No parasitic copepods, NEF: Number of examined fish, NIF: Number of infested fish, PR: Parasitic richness; B.P: Benthopelagic, D: Demersal, P: Pelagic, G: Gregarious, S: Solitary, Mi: Migrant with change of environment, Mo: Migrant without change environment, P: Prevalence, MI: Mean Intensity, A: Abundance

Table IV: Presence of the parasitic copepod species on the different host species

Parasitic copepods	***Aetomylaeus bovinus***	***Bathytoshia centroura***	***Dasyatis pastinaca***	***Pteroplatytrygon violacea***	***Dipturus oxyrinchus***	***Raja clavata***	***Gymnura altavela***
Eudactylinella alba	-	+	+	-	-	-	-
Eudactylina insolens	-	+	-	-	-	-	-
Pseudocharopinus bicaudatus	-	+	-	-	-	-	-
Pseudocharopinus concavus	-	+	-	-	-	-	-

Pseudocharopinus malleus	-	-	+	-	-	-	-
Lernaeopoda galei	-	+	-	-	-	+	-
Nemesis lamna vermi	-	+	-	-	-	-	-
Trebius caudatus	-	-	+	-	-	-	-
***Caligus* sp.**	-	-	-	-	-	+	-
Perissopus dentatus	-	-	-	-	-	-	-
Nesippus orientalis	-	-	-	-	-	-	-
Tripaphylus musteli	-	-	-	-	-	-	-
Kroyeria lineata	-	-	-	-	-	-	-
***Kroyeria* sp.**	-	-	-	-	-	-	-

Parasitic copepods	***Mustelus mustelus***	***Mustelus punctulatus***	***Galeorhinus galeus***	***Scyliorhinus canicula***	***Squalus blainvillei***	***Torpedo marmorata***	***Tetronarce nobiliana***	***Torpedo torpedo***
Eudactylinella alba	+	-	-	+	-	-	-	-
Eudactylina insolens	-	+	-	-	-	-	-	-
Pseudocharopinus bicaudatus	-	-	-	-	-	-	-	-
Pseudocharopinus concavus	-	-	-	-	-	-	-	-
Pseudocharopinus malleus	-	-	-	-	-	+	-	-
Lernaeopoda galei	+	+	-	-	-	-	-	-
Nemesis lamna vermi	-	-	-	-	-	-	-	-
Trebius caudatus	-	-	-	-	-	-	-	-
***Caligus* sp.**	-	-	-	-	-	-	-	-
Perissopus dentatus	+	-	-	-	-	-	-	-
Nesippus orientalis	+	-	-	-	-	-	-	-
Tripaphylus musteli	+	-	-	-	-	-	-	-
Kroyeria lineata	+	-	-	-	-	-	-	-
***Kroyeria* sp.**	+	-	-	-	-	-	-	-

Caption: (-): absent; (+): present

parasites. *Bathytoshia centroura* (Mitchill, 1815) is parasitized by six copepod species (Tab. III).

On the other hand, many fish species are naturally infested with a high number of parasitic species, others by only one copepod species (Benmansour & Ben Hassine, 1998). This character of the diversity of infestation is referred to as "parasitic richness" (Combes, 1995). We analyzed some eco-ethological variables like habitat (benthic or pelagic); migration patterns (migratory with or without environment change) and behavior (solitary or gregarious) (Tab. III) to investigate correlations between these characteristics and parasite species richness. Furthermore, we analyzed the copepod species richness according to taxonomical variables (fish families and species).

a)Host species

In this study, *Mustelus mustelus* present the highest parasitic richness with seven copepod species (Tab. III). *Bathytoshia centroura* was infested by six parasite species and *Dasyatis pastinaca* (Linnaeus, 1758) with three parasitic copepods species. *Raja clavata* Linnaeus, 1758 and *Mustelus punctulatus* Risso, 1827 were infested by two species of parasites each and finally the lowest parasitic richness was registered on *Scyliorhinus canicula* and *Torpedo marmorata* Risso, 1810 (only one parasite species). However, *Aetomylaeus bovinus* (Geoffroy Saint-Hilaire, 1817), *Pteroplatytrygon violacea* (Bonaparte, 1832), *Dipturus oxyrinchus* (Linnaeus, 1758), *Gymnura altavela* (Linnaeus, 1758), *Galeorhinus galeus* (Linnaeus, 1758), *Squalus blainvillei* (Risso, 1827), *Tetronarce nobiliana* (Bonaparte, 1835) and *Torpedo torpedo* (Linnaeus, 1758) did not reveal the presence of any parasitic copepod species (Tab. III).

b)Host family

Among copepod species, eight infested the Dasyatidae and the Triakidae, two the Rajidae and one the Scyliorhinidae and the Torpedinidae (Fig. 2). However, the Myliobatidae, the Gymnuridae and the Squalidae did not reveal the presence of any parasitic copepod species.

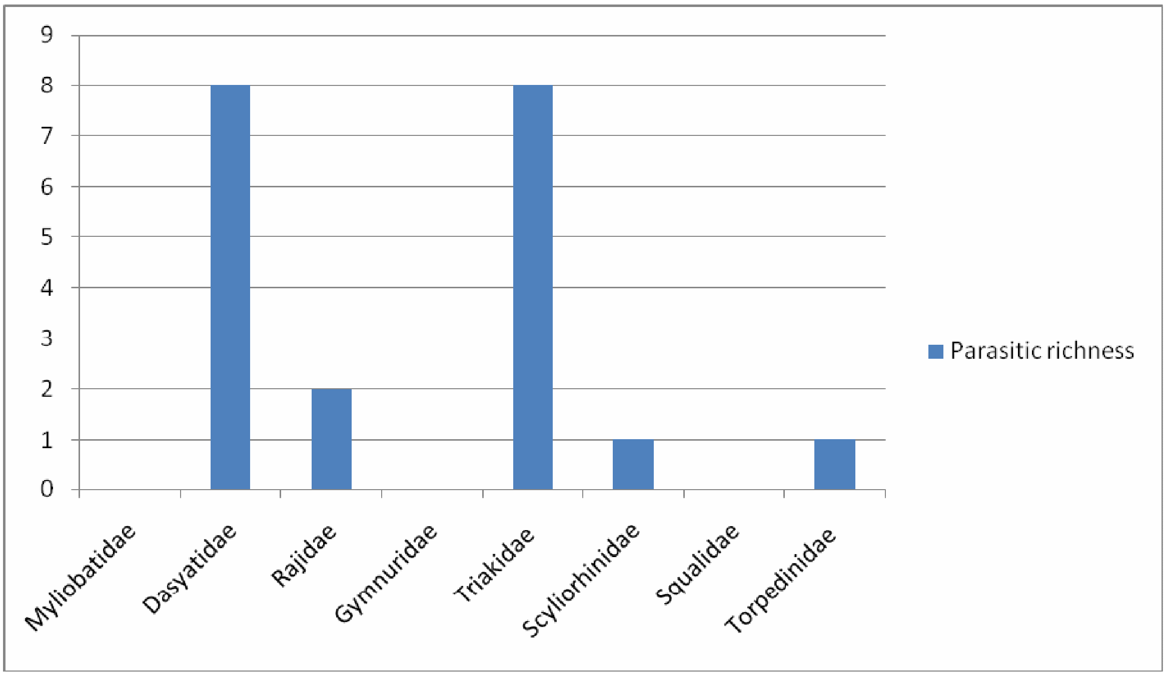

Figure 2: Parasitic richness per host family

c)Bio-ethological characteristics of the species hosts

Some eco-ethological characteristics were retained to analyze species richness of copepods parasitizing Tunisian elasmobranchs: behavior, habitat and migration (Tab. III). Other characteristics (weight, maximal size of the adult fish, color and diet) which analysis did not reveal any correlation with parasitic richness will not be presented in this study.

Behavior: The analysis of parasitic richness among gregarious and solitary fish demonstrates that gregarious fish have the highest parasitic richness (PR=14). The difference between the parasitic richness of those two fish categories is highly significant (Kruskal – Wallis test: p< 0.0001<0.05).

Habitat: A comparative analysis of the parasitic richness of the host species from a variety of habitats shows that demersal fish species clearly have the highest parasitic richness (PR=15) and benthic fishes have the lowest parasitic richness (PR=1) (Tab. III).

The differences of the parasite species richness from demersal and benthic fishes are highly significant (Kruskal – Wallis test: p< 0.0001< 0.05)

Migration: There are no sedentary fish in our sampling. The analysis of the parasite richness of the migratory fish (with or without change of environment) indicates that the migrant fish without change of environment present the highest parasitic richness (PR=10). Differences in parasite richness of migrating fish without environment change and those of migrating with environment change is significant (Kruskal-Wallis test: $p<0.0001< 0.05$).

Parasitic specificity

The study of parasitic specificity revealed that 10 of the species are oioxenous (strict copepod specificity: were restricted to a single host species in our samples) (*Caligus* sp infested only *Raja clavata* (Table V), *Pseudocharopinus bicaudatus* (Krøyer, 1837) infested only *Bathytoshia centroura*, *Pseudocharopinus concavus* (Wilson C.B., 1913) parasitized only *Bathytoshia centroura* and *Perissopus dentatus* Steenstrup and Lütken, 1861 infested only *Mustelus mustelus*) (Tables III, IV).

Table V: Parasitic specificity of copepod parasite

Families	Species of parasitic copepod	Specificity
Eudactylinidae	*Eudactylinella alba*	Euryxenous
	Eudactylina insolens	Euryxenous
	Nemesis lamna vermi	Oioxenous
Lernaeopodidae	*Pseudocharopinus bicaudatus*	Oioxenous
	Pseudocharopinus concavus	Oioxenous
	Pseudocharopinus malleus	Euryxenous
	Lernaeopoda galei	Euryxenous
Trebiidae	*Trebius caudatus*	Oioxenous
Caligidae	*Caligus* sp.	Oioxenous
Kroyeriidae	*Kroyeria lineata*	Oioxenous
	Kroyeria sp.	Oioxenous
Pandaridae	*Perissopus dentatus*	Oioxenous
	Nesippus orientalis	Oioxenous
Sphyriidae	*Tripaphylus musteli*	Oioxenous

On the other hand, only 4 species presented euryxenous specificity and have infested several species belonging to different families (Example: *Eudactylina insolens* Scott T. and Scott A., 1913 infested *Bathytoshia centroura* and *Mustelus punctulatus*; *Eudactylinella alba* Wilson C.B., 1932 parasitized *Bathytoshia centroura*, *Dasyatis pastinaca*, *Mustelus mustelus* and *Scyliorhinus canicula* and finally, *Lernaeopoda galei* Krøyer, 1837 infested *Bathytoshia centroura, Raja clavata* , *Mustelus punctulatus* and *Mustelus mustelus*) (Tab. IV; V).

DISCUSSION

About 46 % of examined species were infected by copepod parasites in Tunisia. Since this study is limited by many factors such as the number of examined fish, the locality and the period of investigation, it might not be representative and this pourcentage would probably have been underestimated. The majority of the collected copepods are gill parasites, indicating that the gill of most fish species represents a preferred biotope for many parasites (Benmansour, 2001).

For the two families (Myliobatidae and Gymnuridae), the absence of parasitic copepods is probably due to a sampling problem. Indeed, only eleven Myliobatidae specimens and 22 Gymnuridae specimens were examined. On the other hand, for Squalidae (91 examined specimens), the absence of parasitic copepods is probably due to other factors such as the area of prospection which would probably not coincide with the favorable site for infestation of the

host fish since we only found *Squalus blainville* in the bay of Bizerte.
The quantitative study (prevalence and intensity) revealed that the highest prevalence was noted by *Pseudocharopinus malleus* in *Dasyatis pastinaca* (4.87%) and the highest intensity was found by *Nemesis lamna vermi* in *Bathytoshia centroura* (6.33%). Those results showed that chondrichthyans of Tunisia are not very infested by parasitic copepods and these infestations would not appear to significantly affect the health of these animals. Our study demonstrates a positive correlation between parasite richness and certain eco-ethological characteristics and proves that the parasite richness is the highest for fishes which are demersal, migrating without environment change and gregarious. In fact, the demersal fishes belong to species living in diversified marine biotopes such as sandy silty bottoms, rocks or algal meadows which increase the chance of infestation by parasitic copepods. On the other hand, our observations indicate that the migration is a factor which increases the chance of becoming infested with parasitic copepod species. Furthermore, the species without change of environment stay in areas where ecological conditions are often quite similar and for this reason accumulated different species of copepods that can coexist on the same host specimen at the same time, which explain the high parasitic richness. In fact, some copepod species cannot tolerate the salinity variation and disappear (such as *Ergasilus lizae* parasitic copepod of Mullets) (Raibaut *et al.*, 1975). Gregariousness constitutes another ethological characteristic which increases parasitic richness. Indeed, nearly all the migrant fishes are also gregarious. This behavior would ease the transmission of parasites (Combes, 1995).

CONCLUSION

This analysis led us to think that the couple host-parasite is not fortuitous. In fact, some biological and ethological characteristics which are specific to host species increase or decrease the chance of infestation. However, some fish families are clearly more parasitized than others. This is probably due to biological characteristics but also some ecological characteristics that we are unable to explain in this study.
Otherwise, we have found a great variability of specificity of the copepods which ranged from the largest to the smallest.

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BIBLIOGRAPHY

Anonymous, 2000. - Fish collection database of the Intitut fur Seefischerei (ISH). Ed. Germany: BIOLAB Forschungsinstitut, Hohenwestedt.

Benmansour B., 2001. - Biodiversité et bioécologie des Copépodes parasites de poissons Téléostéens. Ph. D. thesis, University of Tunis II, Tunis El Manar.

Benmansour, B. and O. K. Ben Hassine, 1988. - Preliminary analysis of parasitic copepod species richness among coastal fishes of Tunisia. *Italian Journal of Zoololgy,* 65: 341-344.

Benz, G. W., and S. A. M. Adamson, 1999. - Disease caused by *Nemesis robusta* (van Beneden, 1851) (Eudactylinidae: Siphonostomatoida: Copepoda) infections on gill filaments of thresher sharks (Alopias vulpinus (Bonnaterre, 1758)), with notes on parasite ecology and life history. *Canadian Journal of Zoology,* 68 (1): 180- 1 187.

Bernardes R. A., De Figueiredo J. L., Rodrigues, A. R., Fischer L. G., Vooren C. M., Haimovici M. and C. L. Del Bianco Rossi-Wongtschowski, 2005. - Peixes de zona econômica exclusiva da região sudeste-sul do Brasil: Levantamento com armadilhas, pargueiras e rede de arrasto de fundo. ed. São Paulo: Editora da Universidade de São Paulo.

Bigelow H. B. and W. C. Schroeder, 1953. - Sawfishes, guitarfishes, skates and rays. In: *Fishes of the western North Atlantic Part two*, By J. Tee-Van et al., ed. New Haven: Sears Foundation, Marin Research, Yale University, pp. 1-514.

Boxshall G. A. and S.H. Halsey, 2004. - An introduction to copepod diversity. ed. London: The Ray Society.

Bradai, M. N., Saiidi, B. and S. Enajjar, 2012. - Elasmobranchs of the Mediterranean and Black sea: status, ecology and biology. Bibliographic analysis. 91st Studies and Reviews. General Fisheries Commission f or the Mediterranean . FAO, Rome. December 2012.

Breder, C. M., and D.E. Rosen, 1966. - Modes of reproduction in fishes. ed. New Jersey: Neptune City: T.F.H. Publications.

Brito, A., 1991. - Catalogo de los peces de las Islas Canarias. ed. La Laguna: Francisco Lemus.

Capapé, C., 1988. - Les Sélaciens des côtes méditerranéennes: aspects généraux de leur écologie et exemples de peuplements. *Océanis,* 15: 309-331.

Capapé, C. and M. Desoutter, 1990. - Torpedinidae. p. 55-58. In: Check-list of the fishes of the eastern tropical Atlantic**. (**Quero, J.C. Hureau, C. Karrer, A. P. and Saldanha, L.) ed. (CLOFETA). Lisbon : JNICT; Paris: SEI; Paris: UNESCO.

Combes, C., 1995. - Interaction durables: Ecologie et évolution du parasitisme. ed. Paris: Masson.

Compagno, L. J.V., 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. FAO Fish. Synop. 125(4/2):251-655. Rome: FAO.

Compagno L. J.V., Ebert, D. A., and M.J. Smale, 1989. - Guide to the Sharks and Rays of Southern Africa. ed. Cape Town: Struik Publishers.

Cressey, R., 1967. - Revision of the family Pandaridae (Copepoda, Caligoida). *Proceedings of the United States National Museum,* 121: 1–133.

Deets, G. B., 1994. - Copepod-Chondrichthyan coevolution: A cladistic consideration. Ph.D thesis, University of British Columbia. Canada.

Ebert, D. A., 2003. - Sharks, rays, and chimaeras of California. Ed. Berkeley, CA: University of California Press.

Essafi, K., 1975. - Contribution à l'étude des copépodes parasites des sélaciens de Tunisie.. Ph. D. thesis. Université Tunis El Manar. Tunis II. Tunisia.

Fischer, W. H., Bauchot, M. L. and M. Schneider, 1987. - Fiche F.A.O d'identification des espèces pour les besoins de la pêche Méditerranéenne et Mer Noire. *Zone De Pêche*, 37(I) : 761-1529.

Heupel, M. R., and M.B. Bennett, 2004. - Infection of the epaulette shark, Hemiscyllium ocellatum (Bonnaterre), by the nematode parasite *Proleptus australis* Bayliss (Spirurida : Physalopteridae). *Journal of Fish Diseases,* 21(6): 407–414.

Ho, J. S. and Kim, I. H., 2004. Lernanthropid copepods (Siphonostomatoida) parasitic on fishes of the Gulf of Thailand. *Systematic Parasitology*, 58: 17-21.

Holden, J. M., 1975. The fecundity of *Raja clavata* in British waters. *Journal du Conseil, Conseil Permanent International pour l'Exploration de la Mer,* 36 (2) : 110-118.

Hunter E., Buckley A. A., Stewart, C. and J.D. Metcalfe, 2005. Migratory behaviour of the thornback ray, *Raja clavata*, in the southern North Sea. *Journal of the Marine Biological Association of the United Kingdom,* 85: 1095-1105.

Kabata, Z., 1964. Revision of the genus *Charopinus* Kroyer 1863 (Copepoda : Lernaeopodidae). *Videnskabelige Meddelelser fra dansk Naturhistoriske Forening*, 127: 28-112.

Kabata, Z., 1970. - Crustacea as enemies of fishes. In "Diseases of fishes" (S.F. Sniedzko, and Axerod H. R.), book I. ed. New Jersy: Jersy City: TFH publications.

Kabata, Z., 1979. - Parasitic copepods of British fishes: i-xii, 1-468. (The Ray Society, London). 1981. Copepoda (Crustacea) parasitic on fishes: problems and perspectives. *Advances in Parasitology*, 19: 1-71.

Kabata, Z., 1984. - Diseases caused by metazoans: crustaceans. In "Diseases of marine animals" (Kinne, O.), volume 4. ed. Germany: Hamburg, Helgoland, Biologische Anstalt.

Last, P. R., White, W. T., De Carvalho, M. R., Séret, B., Stehmann M. F.W. and G.J.P. Naylor, 2016. -Rays of the world. ed. CSIRO Publishing: Comstock Publishing Associates.

Bruce C. M., 2005. Checklist of the fishes of the Hawaiian Archipelago. *Bishop Museum bulletin in zoology*, 6: 1-704.

Mytilineou, C., Politou, C. Y., Papaconstantinou, C., Kavadas, S., D'onghia, G. and L. Sion, 2005. - Deep-water fish fauna in the Eastern Ionian Sea. *The Belgian Journal of Zoology*, 135 (2): 229-233.

Neifar, L., 2001. - Biodiversité et évolution des plathélminthes parasites des Elasmobranches. Ph. D. thesis. F.S.T. Univ. Tunis II. Tunisie.

Raibaut, A., Ben Hassine, O. K., and G. Prunus, 1975. - Etude de l'infestation de *Mugil* (*Mugil*) *cephalus* Linné, 1758 (Poissons,Téléostéens, Mugilidés) par le Copépode *Ergasilus nanus* van Beneden, 1870 dans le lac Ischkeul, Tunisie. *Bulletin de la Société zoologique de France,* 100 (4): 427–437.

Riede, K., 2004. - Global register of migratory species from global to regional scales. Final Report of the R&D-Projekt 808 05 081. Federal Agency for Nature Conservation, Bonn, Germany.

Séret, B., 2006. - Guide d'identification des principales espèces de requins et de raies de l'Atlantique oriental tropical, à l'usage des enquêteurs et biologistes des pêches. Paris: IRD and MNHN.

Sims, D. W., 2003. - Tractable models for testing theories about natural strategies: Foraging behaviour and habitat selection of free-ranging sharks. *Journal of Fish Biology,* 63 (A): 53-73.

Stehmann, M. F.W., 1995. - First and new records of skates (Chondrichthyes, Rajiformes, Rajidae) from the West African continental slope (Morocco to South Africa), with descriptions of two new species. *Archive of Fishery and Marine Research,* 43 (1): 1-119.

Whitehead, P. J. P., Bauchot, M. L., Hureau, J. C., Nielsen J and E. Tortonese, 1986. - Fishes of North-eastern Atlantic and the Mediterranean. ed. Paris: UNESCO.

Yamaguti, S., 1963. - Parasitic copepoda and branchiura of fishes. ed. New York, London, Sydney: Publishers.

Yano, K. and J.A. Musick, 2000. - The Effect of the mesoparasitic barnacle *Anelasma* on the development of reproductive organs of deep-sea squaloid sharks, *Centroscyllium* and *Etmopterus*. *Environmental Biology of Fishes,* 59(3): 329–339.

Youssef F., Benmansour B., Ben Hassine O. K. and S. Zouari-Tlig, 2016. - Some parasitic copepods of selected Teleost and Chondrichthyan fishes from the Tunisian gulfs. *African Journal of Microbiology Research*, 10(35): 1467-1476.