RESEARCH NOTE

Parasites of the head of *Scomber colias* (Osteichthyes: Scombridae) from the western Mediterranean Sea

Salvatore Mele^{1*}, Maria Grazia Pennino², Maria Cristina Piras¹, José María Bellido²,
Giovanni Garippa¹ and Paolo Merella¹

¹Parassitologia e Malattie Parassitarie, Dipartimento di Medicina Veterinaria, Università di Sassari, via Vienna, 2, 07100, Sassari, Italy;

²Instituto Español de Oceanografía, Centro Oceanográfico de Murcia, C/ Varadero, 1, Apdo. 22, 30740, San Pedro del Pinatar, Spain

Abstract

The metazoan parasite assemblage of the head of 30 specimens of the Atlantic chub mackerel (*Scomber colias*) from the western Mediterranean Sea was analysed. Eight species of parasites were found, four mazocraeid monogeneans: *Grubea cochlear* (prevalence = 10%), *Kuhnia scombercolias* (59%), *K. scombri* (52%), *Pseudokuhnia minor* (86%); three didymozoid trematodes: *Nematobothrium* cf. *faciale* (21%), *N. filiforme* (41%), *N. scombri* (7%); and one laerneopodid copepod: *Clavelissa scombri* (7%). Results were compared with previously published data from 14 localities of the eastern Mediterranean Sea and the Atlantic Ocean, using non-parametric univariate and multivariate analyses, and the whole parasite fauna of *S. colias* was compared with that of the congeners (*S. australasicus*, *S. japonicus* and *S. scombrus*). Parasites showed to reflect the biogeographical and phylogenetic history of host. From a methodological point of view, the use of both non-parametric univariate and multivariate techniques proved to be effective tools to detect dissimilarities between parasite assemblages.

Keywords

Didymozoidae, Lernaepodidae, Mazocraeidae, *Scomber colias*, Mediterranean Sea, Sardinia

The mackerels (Osteichthyes: Scombridae: *Scomber* spp.) include four species widely distributed in the Atlantic (*Scomber colias* Gmelin, 1789; *Scomber scombrus* Linnaeus, 1758) and Indo-Pacific (*Scomber australasicus* Cuvier, 1832; *Scomber japonicus* Houttuyn, 1782) Oceans (Catanese *et al.* 2010). Among them, *S. colias* is an epipelagic fish inhabiting the warm and temperate transition areas of the Atlantic Ocean and the Mediterranean Sea (Velasco *et al.* 2011). The fishery of this species is one of the most important in both the Atlantic Ocean and the Mediterranean Sea, with 237 thousand tons landed in 2009 (FAO 2011).

The parasite fauna of the species of the genus *Scomber* is composed of adult stages of helminths and copepods (Cressey and Cressey 1980; Gibson *et al.* 2005; Costa *et al.* 2007) specific to *Scomber* spp., which are mainly located in the head

organs and tissues (Table I), and of larval stages of helminths (Oliva *et al.* 2008; Costa *et al.* 2011), infecting above all the viscera and body cavity.

The aim of this study is to describe the parasite fauna of the head of *S. colias* from the western Mediterranean Sea and to compare the results with data from the Atlantic Ocean and the Mediterranean Sea.

Parasites were collected from 30 *S. colias* caught in the Gulf of Asinara (Sardinia, western Mediterranean Sea) in June 2009 by commercial fishing. After landing the fish were measured (range of total length = 23.5–37.0 cm), weighed (range of total weight = 122–549 g), and the heads excised, stored individually in plastic bags and frozen at –20°C.

Subsequently, the heads (including gills and heart) were defrosted and examined under a stereomicroscope for meta-

*Corresponding author: smele@uniss.it

Fig. 1. Distribution of data published on the parasites of *Scomber colias*: A, North eastern Atlantic Ocean; B, North western Atlantic Ocean; C, Irving Bank; D, Great Meteor Bank; E, Madeira; F, North Morocco; G, Canaries; H, Western Sahara; I, Mauritania; J, central western Atlantic Ocean; K, South eastern Atlantic Ocean; L, Rio de Janeiro State; M, El Rincón; N, Mar de Plata; O, Aegean Sea (Area 1); P, Aegean Sea (Area 2); Q, Levantine Sea (Area 1); R, Levantine Sea (Area 2); S, central Mediterranean Sea; T, western Mediterranean Sea (present study)

zoan parasites. All parasites were counted and stored in 70% ethanol. Species identification was done by literature review and descriptive bibliography; for monogeneans: Rohde and Watson (1985) and Rohde (1989); for didymozoids: Baylis (1938) and Yamaguti (1970); for copepods: Cressey and Cressey (1980).

Prevalence, mean abundance and mean intensity of each parasite species were calculated according to Bush *et al.* (1997). The confidence interval of prevalence was calculated with the Sterne exact method, and the confidence intervals of

the mean abundance and mean intensity were obtained by the bias-corrected and accelerated Efron-Tibshirani bootstrap (Reiczigel and Rózsa 2005).

The results were compared with those of 10 localities of the Atlantic Ocean (Cremonte and Sardella 1997; Alves *et al.* 2003; Shukhgalter 2004; Oliva *et al.* 2008; Costa *et al.* 2011) (Fig. 1, Table II), using both univariate and multivariate analyses. Because prevalence was the index reported in all papers, it was chosen for assessing the differences between pairs of localities with the Fisher exact test, (Reiczigel and Rózsa

2005). Accidental species (i.e. only one specimen was collected) were not included in the analyses. Multivariate analyses were carried out only on parasite species with a significant difference in prevalence between at least one pair of localities. Two dimensional non-metric multidimensional scaling (NMDS, “Jaccard” distance, “monoMDS” engine, metaMDS” function, “vegan” library of the R-software, R Development Core Team 2012) and hierarchical cluster analysis (CA, “average” method, “hclust” function, “stats” library of the R-software, R Development Core Team 2012) were performed on a Ruzicka (Jaccard) similarity matrix to identify possible differences between the localities examined (Oksanen 2011). The vectors of each variable were included in NMDS graphs in order to determine the principal factors driving the separation of the areas. The significance of the values of the vectors was evaluated ($p\text{-value} \leq 0.05$, “envfit”

function, “vegan” library of the R-software, R Development Core Team 2012). To estimate the goodness of fit of the NMDS graphs and how the hierarchical structure of the CA represented the effective distance between the parasite assemblages, the Kruskal stress (Stress, “goodness” function, “vegan” library of the R-software, R Development Core Team 2012) and the coefficient of cophenetic correlation (Rc, “cophenetic” function, “stats” library of the R-software, R Development Core Team 2012) were computed.

The community dissimilarity of helminths was evaluated with the Marczewski-Steinhaus distance (MS, “cc” method, “betadiver” function, “vegan” library of the R-software, R Development Core Team 2012), and the Bray-Curtis index (BC, “-1” method, “betadiver” function, “vegan” library of the R-software, R Development Core Team 2012) functions.

Table I. Published data on the parasites of the head of the genus *Scomber* according to species: Sa, *S. australasicus*, Sc, *S. colias*, Sj, *S. japonicus*, Ss, *S. scombrus*. Data from: 1, Baylis (1938); 2, Ichihara *et al.* (1968); 3, Yamaguti (1970); 4, Kabata (1979); 5, Cressey and Cressey (1980); 7, Gibson *et al.* (1981); 8, Rohde (1989); 9, Somdal and Schram (1992); 10, Hayward *et al.* (1998); 11, Amirzha (2003); 12, Shukhgalter (2004); 13, Oliva *et al.* (2008)

	Sa	Sc	Sj	Ss
Monogenea Mazocraeidae				
<i>Grubea australis</i> Rohde, 1987	10			
<i>Grubea cochlear</i> Diesing, 1858		13		9
<i>Kuhnia scombercolias</i> Nasir <i>et</i> Fuentes Zambrano, 1983	10	13	8	
<i>Kuhnia scombri</i> (Kuhn, 1829)	10	13	8	9
<i>Kuhnia sprostonae</i> Price, 1961	10	8	16	9
<i>Pseudokuhnia minor</i> (Goto, 1984)	10	13	8	
Trematoda Didymozoidae				
<i>Didymozoon longicolle</i> Ishii, 1935			2	
<i>Halvorsenius exilis</i> Gibson, MacKenzie <i>et</i> Cottle (1981)		13		7
<i>Nematobothrium faciale</i> (Baylis, 1938)				1
<i>Nematobothrium filiforme</i> Yamaguti, 1934 §		12	2	
<i>Nematobothrium scombri</i> (Taschenberg, 1879) #		13	3	1
Crustacea Copepoda				
<i>Brachiella magna</i> Kabata, 1968	10			
<i>Caligus</i> sp.	10			
<i>Caligus diaphanus</i> von Nordmann, 1832				4
<i>Caligus pelamydis</i> Krøyer, 1863		7	4	9
<i>Clavellisa scombri</i> (Kurz, 1877)	5	13	5	9
<i>Clavellopsis saba</i> Yamaguti, 1939			2	
<i>Hatschekia</i> sp.		11		
<i>Kabatazus paradoxus</i> (Kabata, 1979)				9
<i>Laerneia</i> sp.		11		
<i>Pumiliopes jonesi</i> (Bennet, 1968)	5	5	5	
Crustacea Isopoda				
<i>Ceratothoa imbricata</i> (Fabricius, 1775)	10			

§, *Nemathobothrium filiforme* is considered as Didymozoidae gen. sp. *sensu* Shukhgalter (2004) and *Nemathobothrium* sp. *sensu* Costa *et al.* (2011)

#, *Nematobothrium scombri* is considered as *Nematobothrium* spp. *sensu* Cremona and Sardella (1997)

Eight species of parasites were found in the head of the 30 specimens of *S. colias* examined (Table II): *Grubea cochlear* Diesing, 1858, *Kuhnina scombercolias* Nasir et Fuentes Zambrano, 1983, *K. scombri* (Kuhn, 1829), *Pseudokuhnina minor* (Goto, 1894), *Nematobothrium* cf. *faciale* (Baylis, 1938), *N. filiforme* Yamaguti, 1934, *N. scombri* (Taschenberg, 1879), and *Clavellisa scombri* (Kurz, 1877).

Scomber colias is a new host record for *N. cf. faciale*, and the records of *K. scombercolias*, *N. cf. faciale*, *N. filiforme* and *P. minor* extend the geographical range of these species to the western Mediterranean Sea. The prevalence, mean abundance and mean intensity of infection of the parasites found in *S. colias* are shown in Table III. *Pseudokuhnina minor* had the highest prevalence (86%), mean abundance (5.4) and mean intensity (6.3), and it was the dominant species.

Comparing present and published data (Table IV), each parasite species showed significant differences of prevalence between at least one pair of localities, and some had higher prevalence in one locality than in all others, particularly: *K. scombri*, *P. minor*, *N. cf. faciale* and *N. filiforme* in the western Mediterranean Sea (T, present data); *Laernea* sp. *sensu* Akmirza, 2003 in the eastern Mediterranean Sea (O-P); *G. cochlear* and *N. scombri* in the Brazilian area (L); *C. scombri* and *P. minor* at Madeira (E).

The grouping of the areas in the NMDS plot of the Mazocraeidae (Fig. 2) is driven by significant prevalence values of the four species considered (p -value < 0.05). The analysis of this plot according to the 1 axis showed that, apart from the Great Meteor Bank (D) of the central eastern Atlantic Ocean, the prevalence of *P. minor* distinguishes the central eastern Atlantic areas (C, E-I) and the western Mediterranean Sea (T) from all the other localities; whereas according to the 2 axis the prevalences of *G. cochlear*, *K. scombercolias* and *K. scombri* separate the Brazilian area (L) from almost all of the other areas, except for the Aegean Sea area (O).

The CA dendrogram of the prevalence of Mazocraeidae (Fig. 2) showed three different groups: the Brazilian one

(L); the sub-group of the Argentine areas of the South western Atlantic Ocean (M-N) and the sub-group of three areas of the eastern Mediterranean Sea (P-R); and the Aegean area of the eastern Mediterranean Sea (D), the Great Meteor Bank of the central Atlantic Ocean (O), and the subgroup of all the other central Atlantic and the western Mediterranean areas (T).

The separation of the cluster of the western Mediterranean and the central eastern Atlantic samples, and the cluster of the eastern Mediterranean (apart from the Aegean Sea) and the Argentine assemblages (M-N) is related to the low prevalence of *K. scombri* and the absence of other mazocraeids in the eastern Mediterranean and Argentine Seas (Rohde 1989; Cremonte and Sardella 1997; Akmirza 2003), explaining why the most distant and oceanographically different areas of the entire range of *S. colias* cluster together. Apart from *K. scombri*, that was distributed throughout the geographical range of *S. colias*, the other monogeneans are limited to specific areas of the host distribution. For example, *K. sprostonae* has been reported from Madeira (Oliva *et al.* 2008), and *P. minor* from the South and central eastern Atlantic Ocean and the western Mediterranean Sea, meaning that (i) these parasites do not find suitable condition to live outside these areas, and that (ii) they can leave their host when it migrates outside of the endemic area of these parasites. This fact suggests that the distance between the opposite coasts of the Atlantic Ocean could be a barrier to the spread of these parasites of *S. colias*, as analogously indicated by Rohde and Hayward (2000) for the monogeneans of two scombrids with amphi-Pacific distribution (*Scomberomorus* spp. and *Grammatorcynus* spp.). Concerning the differences in the ectoparasite fauna of *S. colias* from the eastern and western Mediterranean Seas, they can be due to the different oceanographic conditions of the shallow water of these basins (Robinson *et al.* 2001) as it has also been reported for other fish (Marzoug *et al.* 2012; Culurgioni *et al.* 2014).

Table III. List of the parasites found in the head of *Scomber colias* from the western Mediterranean Sea, with indication of prevalence (P%), mean abundance (mA), and mean intensity of infection (mI). 95% confidence intervals in brackets

Parasites	P%	mA	mI
Monogenea Mazocraeidae			
<i>Grubea cochlear</i> Diesing, 1858	10 (3-27)	0.1 (0.0-0.2)	1.0 (-)
<i>Kuhnina scombercolias</i> Nasir et Fuentes Zambrano, 1983	59 (40-75)	1.3 (0.8-1.9)	2.2 (1.6-2.8)
<i>Kuhnina scombri</i> (Kuhn, 1829)	52 (34-69)	1.4 (0.9-2.1)	2.7 (2.1-3.7)
<i>Pseudokuhnina minor</i> (Goto, 1984)	86 (69-95)	5.4 (3.9-7.1)	6.3 (4.8-7.9)
Trematoda Didymozoidae			
<i>Nematobothrium</i> cf. <i>faciale</i> (Baylis, 1938)	41 (25-61)	1.5 (0.7-3.5)	3.6 (2.1-7.6)
<i>Nematobothrium filiforme</i> Yamaguti, 1934	21 (9-40)	0.5 (0.1-1.1)	2.2 (1.2-4.0)
<i>Nematobothrium scombri</i> (Taschenberg, 1879)	7 (1-22)	0.1 (0.0-0.2)	1.0 (-)
Crustacea Copepoda			
<i>Clavellisa scombri</i> (Kurz, 1877)	7 (1-22)	0.1 (0.0-0.2)	1.0 (-)

Table IV. Comparison of the prevalence of the helminths of the head of *Scomber colias* from the Atlantic Ocean and the Mediterranean Sea. *, significant difference ($p \leq 0.05$); -, no data. For localities see Fig. 1

	P%	C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T	<i>G. cochlear</i>
		0	0	3	1	0	3	5	18	0	0	0	0	0	0	10	
C	40	\	*		*	*				*			*	*	*		0
D	17		\						*							*	0
E	99	*	*	\					*								3
F	78	*	*		\				*							*	1
G	54	*	*	*	*	\			*							*	0
H	57	*	*		*		\		*								3
I	95	*	*	*	*	*	*	\	*	*						*	5
L	0	*	*	*	*	*	*	*	\	*		*	*	*	*		18
M	0	*	*	*	*	*	*	*		\						*	0
N	0	*	*	*	*	*	*	*			\						0
O	0	*	*	*	*	*	*	*				\					0
P	0	*	*	*	*	*	*	*					\			*	0
Q	0	*	*	*	*	*	*	*						\		*	0
R	0	*	*	*	*	*	*	*							\	*	0
T	86	*	*			*	*		*	*	*	*	*	*	*	\	10
<i>P. minor</i>		40	17	99	78	54	57	95	0	0	0	0	0	0	0	86	P%
		C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T	
	P%	7	0	39	0	2	0	0	46	0	0	0	0	0	0	59	<i>K. scombercolias</i>
C	0	\	*	*	*		*	*	*	*	*		*	*	*	*	7
D	15		\	*					*							*	0
E	44			\	*	*	*	*		*	*	*	*	*	*		39
F	19				\				*							*	0
G	2	*	*	*	*	\			*							*	2
H	4	*	*	*	*		\		*							*	0
I	11			*		*		\	*							*	0
L	11			*		*	*		\	*	*	*	*	*	*		46
M	1	*	*	*	*			*	*	\						*	0
N	1	*	*	*	*			*	*		\					*	0
O	32					*	*	*	*	*	*	\				*	0
P	3	*	*	*	*							*	\			*	0
Q	6	*		*	*							*		\		*	0
R	4	*	*	*	*							*			\	*	0
T	52		*	*	*	*	*	*	*	*	*		*	*	*	\	59
<i>K. scombri</i>		0	15	44	19	2	4	11	11	1	1	32	3	6	4	52	P%
		C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T	
	P%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	<i>N. cf. faciale</i>
C	0	\	*	*	*		*	*	*	*	*		*	*	*	*	0
D	7		\													*	0
E	0			\												*	0
F	7				\											*	0
G	7				*	\										*	0
H	13	*		*		*	\									*	0
I	17	*		*	*	*	*	\								*	0
L	0		*		*		*	*	\							*	0
M	0		*		*		*	*		\						*	0
N	0		*		*		*	*			\					*	0
O	0						*	*				\				*	0

	P	0				*			*	*						\		*	0	P
	Q	0							*	*						\		*	0	Q
	R	0		*		*			*	*						\		*	0	R
	T	41	*	*	*	*	*	*	*	*	*	*					\		21	T
<i>N. filiforme</i>			0	7	0	7	7	13	17	0	0	0	0	0	0	0	0	41	P%	
			C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T			
		P%	0	0	28	0	2	0	0	55	9	7	0	0	0	0	7	<i>N. scombri</i>		
	C	0	\		*					*				*				0	C	
	D	0		\	*					*	*			*				0	D	
	E	7			\	*	*	*	*	*	*	*		*	*	*	*	28	E	
	F	0			*	\	*			*	*	*		*		*	*	0	F	
	G	0			*		\	*	*	*				*				2	G	
	H	0			*			\		*	*	*	*	*		*	*	0	H	
	I	0			*				\	*	*	*	*					0	I	
	L	0			*					\	*	*	*	*	*	*	*	55	L	
	M	0			*						\			*				9	M	
	N	0			*							\		*				7	N	
	O	0											\	*	*	*		0	O	
	P	0			*									\				0	P	
	Q	0													\			0	Q	
	R	0			*											\		0	R	
	T	0															\	7	T	
<i>H. exilis</i>			0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	P%		
			C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T			
		P%	-	-	8	-	0	-	-	2	0	0	0	0	0	0	7	<i>C. scombri</i>		
	C	-	\	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N/D	C	
	D	-	-	\	-	-	-	-	-	-	-	-	-	-	-	-	-	N/D	D	
	E	0			\	-	*	-	-	*	*	*		*		*		8	E	
	F	-	-	-	-	\	-	-	-	-	-	-	-	-	-	-	-	N/D	F	
	G	0					\											0	G	
	H	-	-	-	-	-	-	\	-	-	-	-	-	-	-	-	-	N/D	H	
	I	-	-	-	-	-	-	-	\	-	-	-	-	-	-	-	-	N/D	I	
	L	0	-	-	-	-	-	-	-	\								2	L	
	M	0	-	-	-	-	-	-	-		\							0	M	
	N	0	-	-	-	-	-	-	-			\						0	N	
	O	9	-	-	-	*	-	-	-	*	*	*	\					0	O	
	P	18	-	-	*	-	-	-	-	*	*	*		\				0	P	
	Q	0	-	-	-	-	-	-	-				*	*	\			0	Q	
	R	0	-	-	-	-	-	-	-				*	*		\		0	R	
	T	0	-	-	-	-	-	-	-					*			\	7	T	
<i>Lernaea</i> sp.			-	-	0	-	0	-	-	0	0	0	9	18	0	0	0	P%		
			C	D	E	F	G	H	I	L	M	N	O	P	Q	R	T			

The multivariate analysis of didymozoids (Fig. 2) did not include the eastern Mediterranean Sea and the central eastern Atlantic Ocean areas (C) because this family has not been described in these areas. The grouping of the areas in the NMDS plot of Didymozoidae is driven by the significant prevalence values of three species (*N. cf. faciale*, *N. filiforme* and *N. scomбри*). The analysis of this plot according to the 1 axis showed that the higher prevalence of *N. cf. faciale* and *N. filiforme* in the western Mediterranean Sea (T) and of

N. scomбри in the Brazilian area (L) than in all the other localities, distinguish the didymozoid assemblages of these localities.

The CA of the prevalence of Didymozoidae (Fig. 2) identified four groups: the Brazilian and Madeira areas (L and E), the Argentine areas of the South western Atlantic Ocean (M and N), the western Mediterranean area (T), and the other areas of the central eastern Atlantic Ocean (D, F-I). Apart from *N. scomбри*, that has been found in all the geographical range

of *S. colias*, except in the eastern Mediterranean Sea, the other didymozoids are limited to specific areas of the host distribution. For example, *Halvorsenius exilis* has been reported from Madeira (Oliva *et al.* 2008), *N. cf. faciale* from the western Mediterranean Sea, and *N. filiforme* from the South and central eastern Atlantic Ocean and the western Mediterranean Sea, meaning that: (i) these parasites seem not to find suitable environmental conditions and/or intermediate hosts outside of these areas; (ii) their intermediate hosts could be associated to the specific oceanographic conditions of the western Mediterranean Sea and eastern Atlantic Ocean; and (iii) the specimens of *S. colias* infected by these didymozoids do not migrate to the eastern Mediterranean Sea and the South western Atlantic

Ocean. In fact, several didymozoids have been recorded outside their endemic areas (Lester *et al.* 1985; Mele *et al.* 2012), because they cannot leave their hosts, being encysted in the host tissues (Pascual *et al.* 2006). The distance could be a barrier to the spread of these didymozoids between the opposite coasts of the Atlantic Ocean, as also showed for several mazocraeids (*K. sprostonae*, *P. minor*); whereas the different oceanographic conditions between the eastern and western Mediterranean Seas (Robison *et al.* 2001; Manca *et al.* 2004), which can support a different macro fauna (Garibaldi 1998), can be an important factor that could explain the different trematode faunas of these basins (Gargouri Ben Abdalah *et al.* 2010; Culurgioni *et al.* 2014).

Fig. 2. Non-metric multidimensional scaling plots and cluster dendrograms based on the Ruzicka distance of the prevalence of the helminths of the head of *Scomber colias* that showed differences between at least one pairwise of localities, according to parasite family (Didymozoidae, Mazocraeidae). Stress values for the NMDS analyses were lower than 0.03 (0.00-0.01 for Didymozoidae and 0.01-0.03 for Mazocraeidae), indicating that this analysis has sufficient resolution for reliable interpretation. For localities see Fig. 1

Fig. 3. Cluster dendrograms (group-average linkage) of the parasites of the head of the four species of the genus *Scomber*, *S. australasicus* (Sa), *S. colias* (Sc), *S. japonicus* (Sj) and *S. scombrus* (Ss), using Marczewski-Steinhaus (M-S) and Bray-Curtis (B-C) dissimilarity measures based on the presence/absence of parasites (see Tables I-III)

On the bases of the published and present data on the parasites of the head of the four species of the genus *Scomber* worldwide, a datasheet of presence/absence of parasites by geographical region was created (Tables I-III), making it possible to evaluate the dissimilarity between the parasite faunas of the four mackerel species (Fig. 3). Only mazocraeids were included in the statistical analysis because didymozoids of *S. australasicus* have not been identified to species level (Perera 1994). The parasite assemblage of *S. colias* and *S. japonicus* cluster together and they are well separated from those of *S. australasicus* and *S. scombrus*. *Scomber colias* shares *K. scombrus* and *K. sprostonae* with all the other representatives of the genus *Scomber*, *P. minor* only with the Indo-Pacific *S. australasicus* and *S. japonicus*, and *G. cochlear* only with the Atlanto-Mediterranean *S. scombrus*. Among didymozoids, *S. colias* shares *N. scombrus* with the other members of the genus *Scomber*, except *S. australasicus*, in which no didymozoids have been identified (Perera 1994); *N. filiforme* with *S. japonicus*; and *H. exilis* and *N. cf. faciale* with *S. scombrus*. The occurrence of a parasite species in two host species could be due to host switching from one to another host species which share the habitat, or to inheritance from a com-

mon ancestor (Verneau *et al.* 2009). According to the cophylogenetic studies of Verneau *et al.* (2009), the current overlap of distributions of *S. colias* and *S. scombrus* in the Atlanto-Mediterranean area may allow the sharing of parasites between these hosts (i.e. *G. cochlear* and *N. cf. faciale*). On the other hand, the sharing of parasites among *S. colias* and the Indo-Pacific *S. australasicus* and *S. japonicus* cannot be explained by the current geographical distribution of the species, and it should have taken place in the past, before the segregation of hosts. For instance, *K. sprostonae* and *K. scombrus*, parasites that infect all the species of the genus *Scomber*, could have been parasites of an ancestral host distributed worldwide, whose populations diverged after the emergence of geographical barriers (Cheng *et al.* 2011); in accordance with the evolutionary history proposed by these authors, the speciation of *K. scombercolias*, *P. minor* and *N. filiforme* may have occurred after the segregation of *S. scombrus*, due to the closure of the Tethys Sea, but before the divergence of *S. colias* and *S. japonicus*. On the other hand, the speciation of *G. cochlear* in the Atlantic *Scomber* spp. and of *G. australis* in the Indo-Pacific *Scomber* spp. may have occurred after the complete separation of the host populations. The cluster analysis of the

mazocraeids of the four *Scomber* spp. seems to match with the phylogenetic relationships of the species of the genus *Scomber* (Cheng *et al.* 2011), suggesting that the speciation of parasites and hosts are closely related.

Acknowledgments. Research supported by the Spanish Government project PARATUN AGL2010-20892 and the Master and Back 2012-2013 project of the *Regione Autonoma della Sardegna*.

References

- Akmirza A. 2003. Distribution of parasite fauna of chub mackerel in Aegean and Mediterranean Sea. *Turkish Journal of Marine Sciences*, 9, 187–195.
- Alves D.R., Luque J.L., Abdallah V.D. 2003. Metazoan parasites of chub mackerel, *Scomber japonicus* (Osteichthyes: Scombridae), from the coastal zone of the State of Rio de Janeiro, Brazil. *Brazilian Journal of Veterinary Parasitology*, 12, 164–170.
- Baylis H.A. 1938. On two species of the trematode genus *Didymozoon* from the mackerel. *Journal of the Marine Biological Association of the United Kingdom*, 22, 485–492.
- Bush A.O., Lafferty K.D., Lotz J.M., Shostak A.W. 1997. Parasitology meets ecology on its own terms: Margolis *et al.* revisited. *Journal of Parasitology*, 83, 575–583. DOI: 10.2307/3284227.
- Catanese G., Manchado M., Infante C. 2010. Evolutionary relatedness of mackerels of the genus *Scomber* based on complete mitochondrial genomes: strong support to the recognition of Atlantic *Scomber colias* and Pacific *Scomber japonicus* as distinct species. *Gene*, 452, 35–43. DOI: 10.1016/j.gene.2009.12.004.
- Cheng J., Tianxiang G., Zhenqing M., Takashi Y. 2011. Molecular phylogeny and evolution of *Scomber* (Teleostei: Scombridae) based on mitochondrial and nuclear DNA sequences. *Chinese Journal of Oceanology and Limnology*, 29, 297–310. DOI: 10.1007/s00343-011-0033-7.
- Costa G., Freitas N., Dellinger T.H., MacKenzie K. 2007. Gill monogeneans of the chub mackerel, *Scomber japonicus* from Madeiran waters of the Atlantic Ocean, Portugal. *Journal of Helminthology*, 81, 33–38. DOI: 10.1017/S0022149X07207333.
- Costa G., Cavallero S., D'Amelio S., Paggi L., Garcia Santamaria M.T., Borges Perera C., João Santos M., Khadem M. 2011. Helminth parasites of the Atlantic chub mackerel, *Scomber colias* Gmelin, 1789 from Canary Islands, Central North Atlantic, with comments on their relations with other Atlantic regions. *Acta Parasitologica*, 56, 98–104. DOI: 10.2478/s11686-011-0006-1.
- Cremonte F., Sardella N.H. 1997. The parasite fauna of *Scomber japonicus* Houttuyn, 1782 (Pisces: Scombridae) in two zones of the Argentine Sea. *Fisheries Research*, 31, 1–9. DOI: 10.1016/S0165-7836(97)00024-6.
- Cressey R., Cressey H.B. 1980. Parasitic copepods of mackerel and tuna-like fishes (Scombridae) of the world. *Smithsonian Contributions to Zoology*, 311, 1–186.
- FAO 2011. FishStatJ: Universal software for fishery statistical time series. FAO Fisheries and Aquaculture Department, Statistics and Information Service.
- Culurgioni J., Mele S., Merella P., Addis P., Figus V., Cau A., Karakulak F.S., Garippa G. 2014. Metazoan gill parasites of the Atlantic bluefin tuna *Thunnus thynnus* (Linnaeus) (Osteichthyes: Scombridae) from the Mediterranean and their possible use as biological tags. *Folia parasitologica*, (in press). DOI: 10.14411/fp.2014.011.
- Gargouri Ben Abdallah L., Elbohli S., Maamouri F. 2010. Digenean diversity in labrid fish from the Bay of Bizerte in Tunisia. *Journal of Helminthology*, 84, 27–33. DOI: 10.1051/parasite/2012192129.
- Garibaldi L., Caddy J.F. 1998. Biogeographic characterization of Mediterranean and Black Seas faunal provinces using GIS procedures. *Ocean and Coastal Management*, 39, 211–227. DOI: 10.1016/S0964-5691(98)00008-8.
- Gibson D.I., MacKenzie K., Cottle J. 1981. *Halvorsenius exilis* gen. et. sp. nov., a new didymozoid trematode from the mackerel *Scomber scombrus* L. *Journal of Natural History*, 15, 917–929. DOI: 10.1080/00222938100770681.
- Gibson D.I., Bray R.A., Harris E.A. (Compilers) 2005. Host–Parasite Database of the Natural History Museum. London. World Wide Web electronic publication. Available from: <http://www.nhm.ac.uk/research-curation/research/projects/host-parasites/database/>.
- Hayward C.J., Perera K.M.L., Rohde K. 1998. Assemblages of ectoparasites of a pelagic fish, slimy mackerel (*Scomber australasicus*), from south-eastern Australia. *International Journal for Parasitology*, 28, 263–273. DOI: 10.1016/S0020-7519(97)00186-0.
- Ichihara A., Kamegai S., Machida M. 1968. Parasitic helminths of mackerel, *Pneumatophorus japonicus* (Houttuyn). *Research Bulletin of the Meguro Parasitological Museum*, 2, 45–60.
- Kabata Z. 1979. Parasitic copepoda of British fishes. Ray Society Pubs, 152: 1–468. The Ray Society, London.
- Lester R.J.G., Barnes A., Habib G. 1985. Parasites of skipjack tuna, *Katsuwonus pelamis*: fishery implications. *Fishery Bulletin*, 83, 343–356.
- Manca B., Burca M., Giorgetti A., Coatanoan C., Garcia M.J., Iona A. 2004. Physical and biochemical averaged vertical profiles in the Mediterranean regions: an important tool to trace the climatology of water masses and to validate incoming data from operational oceanography. *Journal of Marine Systems*, 48, 83–116. DOI: 10.1016/j.jmarsys.2003.11.025.
- Marzoug D., Boutiba Z., Gibson D.I., Pérez-del-Olmo A., Kostadinova A. 2012. Descriptions of digeneans from *Sardina pilchardus* (Walbaum) (Clupeidae) off the Algerian coast of the western Mediterranean, with a complete list of its helminth parasites. *Systematic Parasitology*, 81, 169–86. DOI: 10.1007/s11230-011-9335-6.
- Mele S., Macías D., Gómez M.J., Garippa G., Alemany F., Merella P. 2012. Metazoan parasites on the gills of the skipjack tuna *Katsuwonus pelamis* (Osteichthyes: Scombridae) from the Alboran Sea (western Mediterranean Sea). *Diseases of Aquatic Organisms*, 97, 219–225. DOI: 10.3354/dao02421.
- Nikolaeva V.M. 1980. On the Black Sea Didymozoidae, species composition, morphology and distribution. *Ekologiya Morya*, 2, 81–85.
- Oksanen J. 2011. Multivariate analysis of ecological communities in R: Vegan tutorial. World wide web electronic publication. Available from: <http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf>, accessed 23 January 2013.
- Öktener A., Trilles J.P. 2009. Four parasitic copepods on marine fish (Teleostei and Chondrichthyes) from Turkey. *Acta Adriatica*, 50, 121–128.
- Oliva M.E., Valdivia I.M., Costa G., Freitas N., Pinheiro De Carvalho M.A., Sanchez Z.L., Luque J.L. 2008. What can metazoan parasites reveal about the taxonomy of *Scomber japonicus* Houttuyn in the coast of South America and Madeira Islands. *Journal of Fish Biology*, 72, 545–554. DOI: 10.1111/j.1095-8649.2007.01725.x.

- Pascual S., Abollo E., Azevedo C. 2006. Host–parasite interaction of a muscle-infecting didymozoid in the Atlantic mackerel *Scomber scombrus* L. *ICES Journal of Marine Science*, 63, 169–175. DOI: 10.1016/j.icesjms.2005.08.010.
- Perera K.M.L. 1994. Light and electron microscopic study of the pathology of a species of didymozoid (Trematoda, Digenea) infecting the gill arches of *Scomber australasicus* (Teleostei, Scombridae). *Diseases of Aquatic Organisms*, 18, 119–127. DOI: 10.3354/dao02421.
- R Development Core Team 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.
- Reiczigel J., Rózsa L. 2005. Quantitative Parasitology 3.0. Budapest. Distributed by the authors.
- Robinson A.R., Wayne G.L., Theocharis A., Lascaratos A. 2001. Mediterranean Sea Circulation. *Encyclopedia of Ocean Sciences*, 3, 1689–1705. DOI: 10.1006/rwos.2001.0376.
- Rohde K. 1989. *Kuhnia sprostonae* Price, 1961 and *K. scombercolias* Nasir and Fuentes Zambrano, 1983 (Monogenea: Mazocraeidae) and their microhabitats on the gills of *Scomber* spp. (Teleostei: Scombridae), and geographical distribution of gill Monogenea of *Scomber* spp. *Systematic Parasitology*, 14, 93–100. DOI: 10.1007/BF00016903.
- Rohde K., Watson N. 1985. Morphology and geographical variation of *Pseudokuhnia minor* n. g., n. comb. (Monogenea: Polyopisthocotylea). *International Journal for Parasitology*, 15, 557–567. DOI: 10.1016/0020-7519(85)90053-0.
- Rohde K., Hayward C.J. 2000. Oceanic barriers as indicated by scombrid fishes and their parasites. *International Journal for Parasitology*, 30, 579–583. DOI: 10.1016/S0020-7519(00)00023-0.
- Romuk-Wodoracki D. 1988. Parasitic fauna of Atlantic mackerel (*Scomber scombrus* L.) from the fishing grounds of Cape Hatteras. *Acta Ichthyologica et Piscatoria*, 13, 49–60.
- Shukhgaltier O.A. 2004. Parasite fauna of the chub mackerel (Scombridae: *Scomber japonicus* Houttuyn, 1782) in the central eastern Atlantic Ocean (the Atlantic coast of the North Africa and the Azores banks). *Parazitologiya*, 38, 160–170 (in Russian).
- Solonchenko A. I., Bodyanitski V.A. 1968. Parasite fauna of *Scomber colias* from the Atlantic Ocean near the South western coast of Africa. “Naukova Dumka”, Biology of seas. No. 14. Parasites of marine animals. Kiev. pp. 90–95.
- Somdal O., Schram T.A. 1992. Ectoparasites on northeast Atlantic mackerel (*Scomber scombrus* L.) from western and North Sea stocks. *Sarsia*, 77, 20–31.
- Velasco E.V., Del Arbol J., Baro J., Sobrino I. 2011. Age and growth of the Spanish chub mackerel *Scomber colias* off southern Spain: a comparison between samples from the NE Atlantic and the SW Mediterranean. *Revista de Biología Marina y Oceanografía*, 46, 27–34.
- Verneau O., Du Preez L., Badets M. 2009. Lessons from parasitic flatworms about evolution and historical biogeography of their vertebrate hosts. *Comptes Rendus Biologies*, 332, 149–158. DOI: 10.1016/j.crvi.2008.08.019.
- Yamaguti S. 1970. Digenetic trematodes of Hawaiian fishes. Keigaku Publishing Co. Tokyo.

Received: May 27, 2013

Revised: August 3, 2013

Accepted for publication: December 11, 2013