Distribution of parasites from red mullets (*Mullus surmuletus* L., Mullidae) in the North Sea and the Mediterranean Sea

Verbreitung der Parasiten von Streifenbarben (*Mullus surmuletus* L., Mullidae) in der Nordsee und im Mittelmeer

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Summary: A total of 167 red mullets (*Mullus surmuletus*) from four geographical locations (North Sea, Ligurian Sea, Tyrrhenian Sea, Adriatic Sea) were studied for metazoan parasites and food composition. Fourteen different parasite species were found and six new host records for red mullets could be established. The parasite richness among the different areas ranged from four up to ten species. The red mullets from the North Sea harboured the most species rich parasite fauna (10). This contrasts the Mediterranean locations (four to seven species) where endemic digeneans and nematode parasites were found. The nematodes *Anisakis simplex* s.l. and *Capillaria gracilis* as well as the acanthocephalan *Corynosoma strumosum* and the crustaceans *Caligus elongatus* and *Lernaeocera branchialis* were isolated from *Mullus surmuletus* from the North Sea sample, while the digeneans *Opecoeloides furcatus*, *Timonia mediterranea* and the nematode *Ascarophis valentina* occurred only in the Mediterranean fish. The stomach content analysis of *Mullus surmuletus* revealed 19 different prey items. This wide food range can explain the observed parasite richness. Our results support a restricted distribution of endemic digeneans and a nematode within the Mediterranean Sea, while several other metazoans occurred throughout the sampled locations. Historical reasons, especially the post-Messinian history, as well as host migrations are possible reasons for the observed red mullet parasitation.

Key words: Mediterranean Sea, North Sea, metazoan fish parasites, diet composition, biotic relationships, zoogeography, biodiversity

Zusammenfassung: Insgesamt wurden 167 Streifenbarben (*Mullus surmuletus*) aus vier geographisch unterschiedlichen Regionen (Nordsee, Ligurisches Meer, Tyrrhenisches Meer, Adriatisches Meer) auf ihre Parasitenfauna und die Nahrungszusammensetzung untersucht. Es konnten vierzehn verschiedene Parasitenarten identifiziert und sechs neue Wirtsnachweise erbracht werden. Die Parasitendiversität unterschied sich in den Untersuchungsgebieten und variierte zwischen vier und zehn Parasitenarten. Streifenbarben aus der Nordsee beherbergten mit zehn Arten die diverseste Parasitenfauna. Dieses Ergebnis steht im Gegensatz zu den Fischen aus dem Mittelmeer mit vier bis sieben Parasitenarten, bestehend aus endemischen Digeneen und Nematoden. Die Nematoden *Anisakis simples* s.l. und *Capillaria gracilis* sowie der Acanthocephale *Corynosoma strumosum* und die Crustaceen *Caligus elongatus* und *Lernaeocera branchialis* wurden ausschließlich bei Streifenbarben aus der Nordsee gefunden. Im Gegensatz dazu wurden die Digeneen *Opecoeloides furcatus*, *Timonia mediterranea* und der Nematode *Ascarophis valentina* nur bei den Fischen aus dem Mittelmeer nachgewiesen. Die Mageninhaltsanalysen erbrachten 19 unterschiedliche Nahrungsorganismen. Die Parasitierung der Streifenbarben lässt sich anhand eines unterschiedlichen Nahrungsspektrums in den Untersuchungsgebieten erklären. Im Mittelmeer waren insbesondere endemische Digenea- und Nematodaarten zu finden, wobei andere Parasitentaxa eine kosmopolite Verbreitung aufweisen. Erdgeschichtliche Ursachen, insbesondere die sog. messinische Salinitätskrise (post-Messinian), sowie Wirtswanderungsbewegungen sind vermutliche Gründe für die nachgewiesene Parasitenfauna.

Schlüsselwörter: Mittelmeer, Nordsee, metazoische Fischparasiten, Nahrungszusammensetzung, biotische Faktoren, Zoogeographie, Biodiversität

1. Introduction

One of the most interesting and dynamic boundaries in the world's oceans is the Strait of Gibraltar, separating the Atlantic Ocean from the Mediterranean Sea. The closure of the Rifian and Betic gateways between the Atlantic Ocean and the Mediterranean between 5.96 and 5.33 million years ago (Lourens et al. 1996, Krijgsman et al. 1999) led to the so-called Messinian salinity crisis (e.g. Hsü et al. 1977, Duggen et al. 2003), when the Mediterranean was reduced to a series of hypersaline lakes with thick evaporite deposition. The opening of the Strait of Gibraltar about 5.33 mya at the end of the Miocene (Lourens et al. 1996) was followed by colonization events with most of the present-day fauna. Afterwards, the interplay between glacial and interglacial periods during the Quaternary with associated marine regressions and transgressions has provided many opportunities for separation, diversification and speciation.

The dramatic palaeogeographical and palaeoclimatic events have played a crucial role in the evolutionary history of many marine taxa in the Mediterranean region (e.g. Taviani 2002, Duggen et al. 2003, Valsecchi et al. 2005). Isolation and restriction of gene flow through the Strait of Gibraltar has caused the existence of endemism for several taxa, such as molluscs (Gofas 1998) and ascidians (Naranjo et al. 1998). Studies analysing the genetic structure of Atlanto-Mediterranean marine species reported from none (*Nephrops norvegicus*, Stamatis et al. 2004) to moderate or strong genetic discontinuity between each side of the Gibraltar Strait (e.g. Quesada et al. 1995, Borsa et al. 1997, Pannacciulli et al. 1997). For littoral and epipelagic species, this boundary is not regarded as the main barrier between the Mediterranean and the Atlantic. Surface currents transport North Atlantic water as far as into the Alboran Sea (Tintore et al. 1998). The resulting front system (Almeria-Oran line) seems to mark the main barrier between Atlantic and Mediterranean populations (Maldonaldo & Uriz 1995, Quesada et al. 1995, Pannacciulli et al. 1997).

Endemism has been estimated to characterize about 28% of the marine fauna in the Mediterranean Sea (Fredj et al. 1992).

Fish parasites have been successfully used as biological indicators for host ecology and migration patterns (e.g. MacKenzie & Abaunza 1998, Klimpel et al. 2003, 2006, 2008). MacKenzie (1990) utilized fish parasites for stock separation of the Atlantic mackerel (*Scomber scombrus*) as well as McClelland & Melendy (2007) and Marcogliese et al. (2003) identified different stocks of the deepwater redfish (*Sebastes mentella*) and American plaice (*Hippoglossoides platessoides*). The distribution of parasitic organisms directly depends on the distribution of the final and intermediate hosts, and thus these organisms can overcome wide distances if they infect migratory species. Otherwise, the occurrence in endemic or local host species can restrict the parasite's distribution, resulting in endemic and often high host specific parasites. Natural boundaries such as currents, temperatures and straits can limit host and parasite distribution, and even artificial water ways not necessarily extend the potential range (Rückert et al. 2007). Studies on the occurrence of fish parasites within and outside the Mediterranean Sea are scarce. Marques et al. (2005) recorded plerocerci of the trypanorhynch cestode *Progrillotia dasyatidis* off the Portuguese coast, a species that was described from the Mediterranean off Tunisia (Beveridge et al. 2004). Klimpel et al. (2007) genetically identified a population of the nematode *Hysterothylacium aduncum*, which occurred inside the Mediterranean and also in the North Sea. MacKenzie et al. (2008) analysed the parasite fauna of Atlantic horse mackerel (*Trachurus trachurus*), identified three main fish stocks and suggested evidence for fish migration from the Atlantic populations into the extreme western part of the Mediterranean. The role of different fish species ecology and parasite life cycle strategies to enable transfer inside and outside the Mediterranean through the Gibraltar Strait has not yet been studied in detail.

Goatfishes of the family Mullidae consist of approximately six genera and over 60 species (Froese & Pauly 2008). The red mullet *Mullus*

surmuletus is one of the most abundant fish and widespread distributed in the sublitoral zone along the Eastern Atlantic, from the North Sea to the northern part of West Africa and the Mediterranean Sea. *Mullus surmuletus* mainly occurs on broken and rough grounds but also over sand and soft bottoms in less than 100 m water depth. It can be also found down to 400 m, where it feeds on benthic invertebrates and vertebrates, such as crustaceans (Decapoda, Amphipoda), polychaetes, molluscs and small fishes (FROESE & PAULY 2008). According to previous parasitological studies, *Mullus surmuletus* is highly infected with parasites in the Mediterranean Sea, hosting approximately 28 different species (e.g. HRISTOVSKI et al. 1989, BARTOLI & BRAY 1996, LE POMMELET et al. 1997, FERRER et al. 2005, FERRER-CASTELLÓ et al. 2007). Studies from the North Sea region, however, are lacking (e.g. PALM et al. 1999).

The purpose of the present study is an analysis of the parasite fauna of the red mullet *Mullus surmuletus*, covering its range of distribution in the North Sea and Mediterranean. An examination of the stomach content reveals information on the main prey items in the different regions. The comparison of the fish stomach content between the Mediterranean and the North Sea can indicate different feeding ecology and importance of *Mullus surmuletus* for the parasite´s life cycle in these habitats. Possible explanations for the observed patterns are given, discussing the role of the Strait of Gibraltar for the fish parasite distribution.

2. Materials and methods

2.1. Sample Collection

Fish samples were collected in 2005 between late August and November. A total of 167 *Mullus surmuletus* (red mullet), 52 specimens from the North Sea (N, 53°-55°N 003°-005°E, mean catch depth 26.6 m, range 10.2 to 40.1 m), 34 from the Ligurian Sea (L, 43°N 005°E, catch depth 2.0 m), 33 from the Tyrrhenian Sea (T, 38°N 14°E, catch depth 3.0 m) and 48 from the Adriatic Sea (A, 45°N 13°E, catch depth

2.5 m), were examined for parasites and stomach contents (fig. 1). All fishes were deep frozen immediately after catch for subsequent examination in the laboratory of the Heinrich-Heine-University. Prior examination, each fish specimen was defrosted at 0-1 °C. Morphometrical data including the standard length (SL) and total weight (TW) were recorded to the nearest 0.1 cm and 0.1 g.

2.2. Parasitological examination

The eyes, skin, fins, gills, nostrils and mouth cavity of each fish specimen were studied for ectoparasites. The body cavity was opened to examine microscopically the liver, stomach, pyloric caeca, intestine and gonads for endoparasites. Collected Acanthocephala were transferred to freshwater allowing evagination of the proboscis prior to fixation. All other isolated parasites were directly fixed in 4% borax-buffered formalin and preserved in 70% ethanol/5% glycerine. For identification purposes, Nematoda and Acanthocephala were dehydrated in a gradated ethanol series and transferred to 100% glycerine (RIEMANN 1988). Digenea and Cestoda were stained with acetic carmine, dehydrated, cleared with Eugenol or Creosote and mounted in Canada balsam. Crustacea were dehydrated and transferred into Canada balsam. Parasite identification literature included original descriptions. The parasitological terms follow BUSH et al. (1997): prevalence (P) is the number of infected fish with one or more individuals of a particular parasite species (or taxonomic group) divided by the number of hosts examined (expressed as a percentage); intensity (of infection, I) is the number of individuals of a particular parasite species in a single infected host (expressed as a numerical range); mean intensity (of infection, mI) is the average intensity, in other words, the total number of parasites of a particular species found in a sample divided by the number of infected hosts; and mean abundance (A) is the total number of individuals of a particular parasite species in a sample of a particular host species divided by the total number of hosts
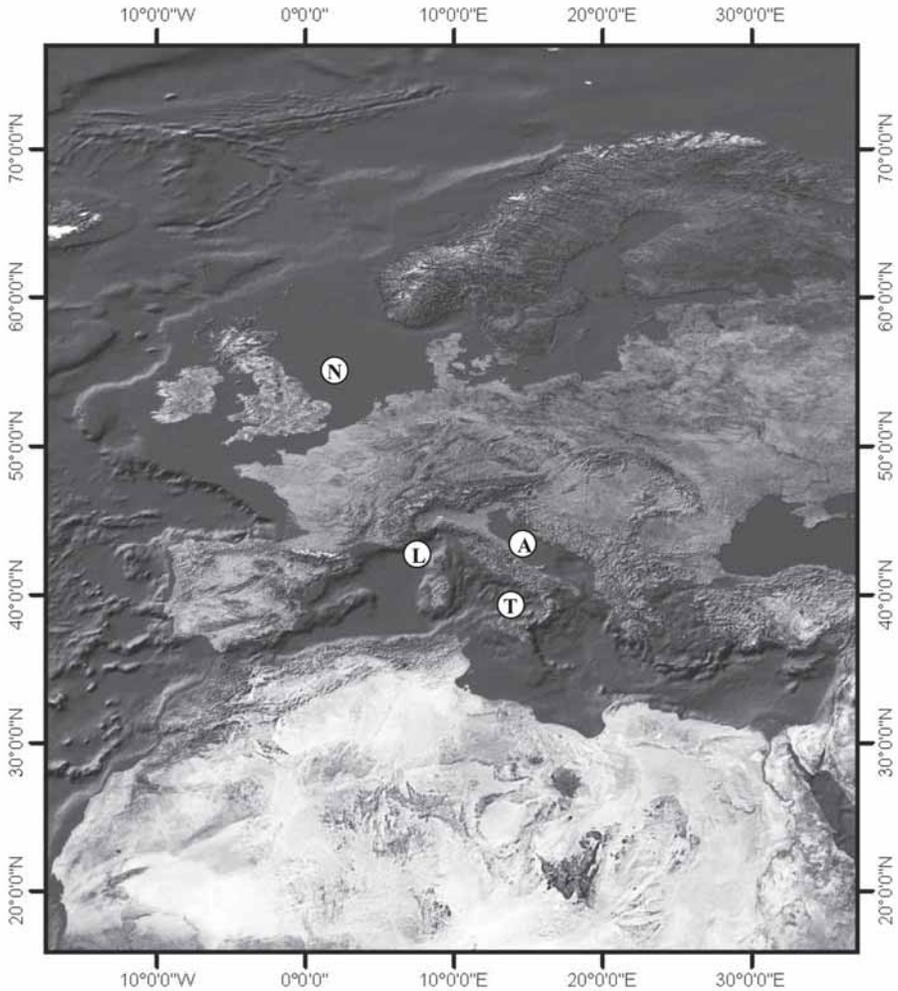
Fig. 1: Map of the areas of investigation: N = North Sea, L = Ligurian Sea, T = Tyrrhenian Sea, A = Adriatic Sea.

Abb. 1: Karte mit den Untersuchungsgebieten: N = Nordsee, L = Ligurisches Meer, T = Tyrrhenisches Meer, A = Adriatisches Meer.

of that species examined, including both infected and uninfected hosts.

2.3. Analysis of stomach contents

The stomach contents were sorted and food items were identified to the lowest possible taxon and grouped into taxonomic categories. In order to determine the relative importance of food items, the numerical percentage of prey (N %), the weight percentage of prey (W %), and the frequency of occurrence (F %) were determined (HYSLOP 1980). Using these three indices, an index of relative importance IRI (PINKAS et al. 1971) was calculated. The importance of a specific prey item increases with higher values for N, W, F and IRI.

3. Results

The analysis of 167 *Mullus surmuletus* from one representative location in the North Sea and

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from three different geographical regions in the Mediterranean Sea revealed a more species rich parasite fauna in the North Sea compared to the Mediterranean samples, where also endemic parasites occur. A total of 14 different parasite species were found. The prevalence, intensity, mean intensity and abundance for each parasite and sample station are given in table 1. Sixteen different prey items were identified from the stomach contents, belonging to the Bryozoa, Mollusca, Annelida, Crustacea, Echinodermata and Teleostei (tab. 2).

3.1. Parasite fauna and diversity

The parasite fauna of *Mullus surmuletus* from four investigated locations consisted of ten (North Sea), seven (Ligurian Sea), four (Tyrrhenian Sea) and six (Adriatic Sea) species, respectively (tab. 1). The digeneans, *Derogenes varicus, Holorchis legendrei, Opecoeloides furcatus* and *Timonia mediterranea*, occurred as adults in the digestive tract. Larval tetraphyllidean cestodes were isolated at a low infestation rate from the intestine. These tetraphyllideans are circumpolar distributed and have been found in various fish species. However, further identification is not possible without strobila characters or knowledge of the life cycle. Four nematode species, *Anisakis simplex* s.l., *Ascarophis valentina, Capillaria gracilis* and *Hysterothylacium aduncum*, were found. *Ascarophis valentina* and *C. gracilis* occurred as adults, *A. simplex* s.l. as third stage larvae (L3), while *H. aduncum* was isolated in the larval (L3-L4) and adult stage. The adult nematodes were isolated from the stomach lumen, pyloric caeca and intestine, while the larvae were found exclusively in or on the organs of the body cavity. The cystacanth of *Corynosoma strumosum* (Acanthocephala) was located in the body cavity of a single *M. surmuletus*. Two adult crustaceans (*Caligus elongatus, Hatschekia mulli*), larval stages of *Gnathia* sp. and juveniles of *Lernaeocera branchialis* were located on the gills.

3.2. Regional parasite distribution

There are some obvious differences in the parasite fauna of *Mullus surmuletus* from the North Sea and the samples from the Mediterranean (figs. 2, 3). More parasite species were found in/on *M. surmuletus* from the North Sea (ten) compared to the specimens from the Mediterranean (four to seven). The nematodes *Anisakis simplex* s.l. and *Capillaria gracilis* as well as the acanthocephalan *Corynosoma strumosum* and the crustaceans *Caligus elongatus* and *Lernaeocera branchialis* were isolated only from the North Sea sample (tab. 1). In contrast the digeneans *Holorchis legendrei, Opecoeloides furcatus* and *Timonia mediterranea* solely occurred in the Mediterranean Sea (tab. 1). While the digenean *Derogenes varicus* was isolated from fish sampled in the North Sea and Ligurian Sea (western part of the Mediterranean), both digeneans *H. legendrei* and *T. mediterranea* were found only in fish samples from the Adriatic Sea (eastern part of the Mediterranean) (tab. 1).

3.3. Feeding ecology

The diet composition analysis of specimens from the different locations showed that *M. surmuletus* was feeding mainly on crustaceans, such as different copepods (harpacticoid, calanoid, see tab. 2), euphausiids, decapods and amphipods. Benthic molluscs (gastropods, bivalves) and polychaets, however, also represented an important part of the diet. The food of *M. surmuletus* consisted of 13 (North Sea), 14 (Ligurian Sea), 11 (Tyrrhenian Sea) and 16 (Adriatic Sea) different prey items, respectively (tab. 2). The most diverse food composition was found for *Mullus surmuletus* from the Adriatic Sea compared with the other locations. The most important prey categories of *M. surmulteus* from the North Sea were polychaets, having an Index of Relative Importance (IRI) of 2185.51, followed by copepods (981.78) and euphausiids (318.04). The main important prey items in the Ligurian Sea were amphipods (IRI 4648.79), copepods (1317.64) and gastropods (206.21). The prey composition of *M. surmuletus* from the Tyrrhenian Sea was predominated by decapods (6735.85), amphipods (4451.11) and euphausiids (3314.08), while the food

Tab. 1: Metazoan parasites in/on Mullus surmuletus from four geographical locations. P = prevalence, mI = mean intensity, I = intensity, A = mean abundance.
Tab. 1: Metazoische Parasiten in/auf Mullus surmuletus von vier geographisch unterschiedlichen Gebieten. P = Prävalenz, mI = mittlere Intensität, I = Intensität, A = mittlere Abundanz.

parasite taxa / locality	North Sea P (%)	North Sea mI (I)	North Sea A	Ligurian Sea P (%)	Ligurian Sea mI (I)	Ligurian Sea A	Tyrrhenian Sea P (%)	Tyrrhenian Sea mI (I)	Tyrrhenian Sea A	Adriatic Sea P (%)	Adriatic Sea mI (I)	Adriatic Sea A
Digenea												
Derogenes varicus	1.9	3 (3)	0.06	2.9	1 (1)	0.09						
Holorchis legendrei										6.3	8.0 (1-22)	0.50
Opecoeloides furcatus				76.5	12.9 (1-82)	10.15	75.8	5.6 (1-24)	4.21	64.6	6.9 (1-45)	4.46
Timonia mediterranea										12.5	8.3 (1-21)	1.04
Cestoda												
Tetraphyllidea indet.	3.8	2.0 (2)	0.08	2.9	1.0 (1)	0.03						
Nematoda												
Anisakis simplex s.l.	3.8	3.0 (1-5)	0.12	2.9	4.0 (4)	0.12						
Ascarophis valentina												
Capillaria gracilis	7.7	3.0 (1-5)	0.12									
Hysterothylacium aduncum	51.9	6.4 (1-15)	3.04	8.8	8.0 (1-17)	0.71	45.5	1.5 (1-2)	0.67	4.2	2.5 (1-4)	0.10
Acanthocephala												
Corynosoma strumosum	1.9	1.0 (1)	0.02									
Crustacea												
Caligus elongatus	5.6	1.5 (1-2)	0.03									
Gnathia sp.	1.9	1.0 (1)	0.02	14.7	20.2 (1-48)	2.97	30.3	1.1 (1-2)	0.33	4.2	1.5 (1-2)	0.06
Hatschekia mulli	15.4	4.8 (1-16)	0.62	14.7	1.4 (1-2)	0.21	12.1	1.0 (1)	0.12	4.2	1.5 (1-2)	0.06
Lernaeocera branchialis	3.8	1.0 (1)	0.04									

Tab. 2: Frequency of occurrence (F), numerical percentage of prey (N), weight percentage of prey (W) and index of relative importance (IRI) of the food items identified from the stomach contents of *Mullus surmuletus* from four geographical locations. SL = fish standard length, TW = fish total weight.

Tab. 2: Prozentuales Vorkommen (F), prozentuale Anzahl (N), prozentuales Gewicht (W) und Index der relativen Bedeutung der jeweiligen Nahrungsorganimsen isoliert aus den Mägen von *Mullus surmuletus* von vier geographisch unterschiedlichen Gebieten. SL = Fischstandardlänge, TW = Fischgewicht.

locality	North Sea			
SL mean (range)	9.8 (5.6 - 22.1) cm			
TW mean (range)	31.8 (4.9 - 242.2) g			
prey items/groups	F [%]	N [%]	W [%]	IRI
Bryozoa	—	—	—	—
Mollusca				
Gastropoda	8.70	0.17	0.03	1.74
Bivalvia	4.35	0.13	0.01	0.61
Mollusca indet.	4.35	0.09	0.01	0.44
Annelida				
Polychaeta	73.91	18.61	10.96	2185.51
Crustacea				
Ostracoda	—	—	—	—
Copepoda (calanoid)	15.22	0.65	4.48	77.93
Copepoda (harpacticoid)	19.57	3.78	1.08	95.11
Copepoda indet.	43.48	19.35	3.23	981.78
Euphausiacea	26.09	1.61	10.58	318.04
Decapoda	8.70	0.74	10.68	99.35
Cumacea	—	—	—	—
Isopoda	—	—	—	—
Amphipoda	28.26	3.39	0.79	118.13
Gammaridae	—	—	—	—
Crustacea indet.	—	—	—	—
Echinodermata				
Ophiuroidea	21.74	1.74	4.05	125.87
Teleostei				
Ammodytes sp.	0.04	2.17	0.70	0.11
Teleostei indet.	0.04	2.17	3.43	0.22

locality	Ligurian Sea			
SL mean (range)	5.9 (4.2 - 13-6) cm			
TW mean (range)	7.5 (1.8 - 57.9) g			
prey items/groups	F [%]	N [%]	W [%]	IRI
Bryozoa	3.85	0.53	0.38	3.54
Mollusca				
Gastropoda	26.92	5.35	2.31	206.21
Bivalvia	—	—	—	—
Mollusca indet.	3.85	0.53	3.46	15.36
Annelida				
Polychaeta	7.69	1.07	1.15	17.07
Crustacea				
Ostracoda	3.85	0.53	0.38	3.50
Copepoda (calanoid)	23.08	6.42	22.31	663.09
Copepoda (harpacticoid)	42.31	13.37	4.62	761.16
Copepoda indet.	34.62	24.60	13.46	1317.64
Euphausiacea	3.85	0.53	4.23	18.33
Decapoda	—	—	—	—
Cumacea	3.85	1.60	0.38	7.62
Isopoda	11.54	1.60	1.15	31.74
Amphipoda	69.23	33.69	33.46	4648.79
Gammaridae	—	—	—	—
Crustacea indet.	15.38	9.63	5.00	225.01
Echinodermata				
Ophiuroidea	—	—	—	—
Teleostei				
Ammodytes sp.	—	—	—	—
Teleostei indet.	3.85	0.53	12.31	49.43

Tab. 2: continued.
Tab. 2: Fortsetzung

locality	Tyrrhenian Sea			
SL mean (range)	10.7 (6.7 - 13.3) cm			
TW mean (range)	29.1 (6.1 - 57.0) g			
prey items/groups	F [%]	N [%]	W [%]	IRI
Bryozoa	21.43	3.56	0.44	85.68
Mollusca				
Gastropoda	—	—	—	—
Bivalvia	—	—	—	—
Mollusca indet.	—	—	—	—
Annelida				
Polychaeta	14.29	1.78	1.07	40.73
Crustacea				
Ostracoda	7.14	8.89	0.47	66.83
Copepoda (calanoid)	—	—	—	—
Copepoda (harpacticoid)	7.14	0.89	0.06	6.78
Copepoda indet.	3.57	0.44	0.03	1.68
Euphausiacea	78.57	23.56	18.62	3314.08
Decapoda	71.43	27.56	66.74	6735.85
Cumacea	—	—	—	—
Isopoda	7.14	0.89	3.51	31.42
Amphipoda	89.29	44.89	4.96	4451.11
Gammaridae	—	—	—	—
Crustacea indet.	—	—	—	—
Echinodermata				
Ophiuroidea	3.57	0.44	0.38	2.93
Teleostei				
Ammodytes sp.	—	—	—	—
Teleostei indet.	3.57	0.44	2.66	11.07

| locality | Adriatic Sea | | | |
| SL mean (range) | 6.7 (4.2 - 10.1) cm | | | |
| TW mean (range) | 7.0 (2.3 - 25.6) g | | | |
prey items/groups	F [%]	N [%]	W [%]	IRI
Bryozoa	36.17	6.47	1.73	296.58
Mollusca				
Gastropoda	44.68	9.22	2.07	504.44
Bivalvia	44.68	12.75	1.59	640.71
Mollusca indet.	2.13	0.20	0.07	0.58
Annelida				
Polychaeta	57.45	19.22	13.69	1890.50
Crustacea				
Ostracoda	8.51	0.78	0.28	9.02
Copepoda (calanoid)	8.51	1.18	1.04	18.89
Copepoda (harpacticoid)	38.30	16.67	6.22	876.69
Copepoda indet.	12.77	2.75	2.28	64.23
Euphausiacea	36.17	6.86	18.53	918.36
Decapoda	6.38	2.55	12.03	93.02
Cumacea	4.26	0.78	0.21	4.22
Isopoda	8.51	0.78	0.83	13.70
Amphipoda	40.43	13.14	6.71	802.54
Gammaridae	6.38	4.51	1.87	40.70
Crustacea indet.	—	—	—	—
Echinodermata				
Ophiuroidea	—	—	—	—
Teleostei				
Ammodytes sp.	—	—	—	—
Teleostei indet.	2.13	0.20	0.14	0.72
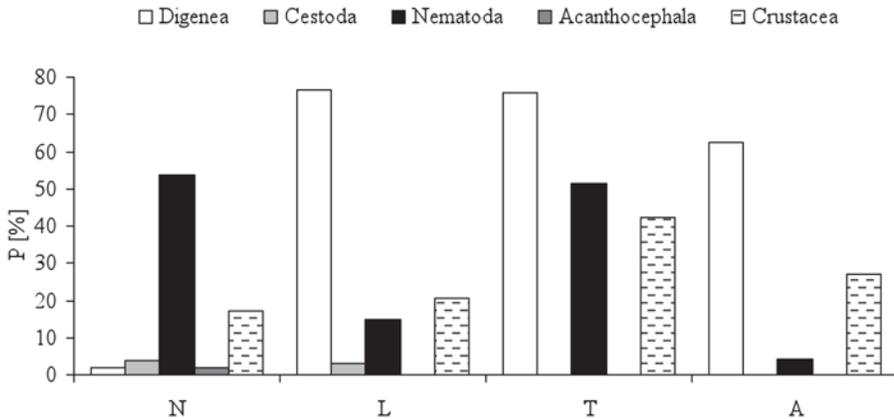
Fig. 2: Parasite composition of *Mullus surmuletus* from four geographical locations. N = North Sea, L = Ligurian Sea, T = Tyrrhenian Sea, A = Adriatic Sea, P = prevalence.
Abb. 2: Parasitenzusammensetzung von *Mullus surmuletus* von vier verschiedenen geographsichen Bereichen. N = Nordsee, L = Ligurisches Meer, T = Tyrrhenisches Meer, A = Adriatisches Meer, P = Prevalenz.
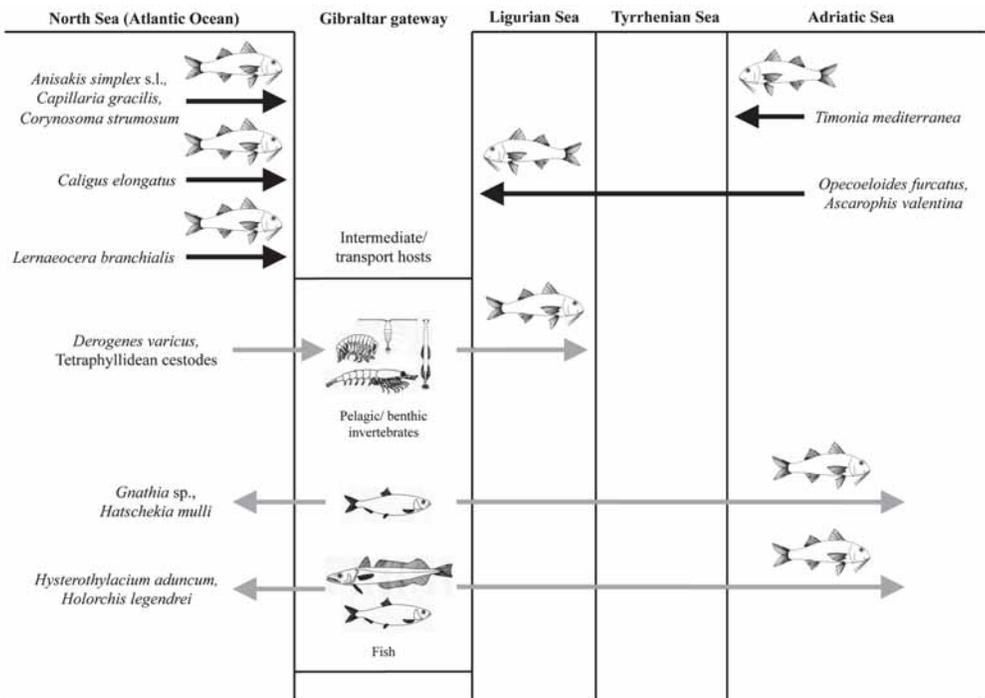

Fig. 3: Distribution of the recorded parasites in *Mullus surmuletus* of the North Sea (Atlantic Ocean) and the Mediterranean Sea (based on literature records and present study).
Abb. 3: Verbreitung der nachgewiesenen Parasitenarten von *Mullus surmuletus* aus der Nordsee (Atlantischer Ozean) und dem Mittelmeer (basierend auf Literaturdaten und auf Daten der vorliegenden Arbeit).

composition in the Adriatic Sea was dominated by polychaets (1890.50), molluscs (1145.15, including bivalves and gastropods), euphausiids (918.36), harpacticoid copepods (876.69) and amphipods (802.54) (tab. 2).

4. Discussion

The present study is the first large scale investigation of red mullet (*Mullus surmuletus*) fish parasites over its range of distribution from the mid-Mediterranean to the North Sea. The parasite richness and abundance was different between the studied regions (North Atlantic vs. Mediterranean Sea) and localities (e.g. Ligurian Sea), demonstrating peculiarities of habitats and parasite distribution. Having ten parasite species in the sampled North Sea location compared to four to seven species in the Mediterranean Sea, mullets in the North Sea (North Atlantic) appeared to be more parasite rich than their Mediterranean counterparts. A total of 14 parasite species were found over the whole range, including endoparasitic helminths and ectoparasitic crustaceans. Most common were the digenean *Opecoeloides furcatus* and the nematode *Hysterothylacium aduncum*, followed by both crustaceans *Gnathia* sp. and *Hatschekia mulli*. However, a rich red mullet parasite infra-community consisting of 17 different species from three different Mediterranean ports of Spain has been recently recorded by FERRER-CASTELLÓ et al. (2007). These authors also considered the above species being the most common parasites of *M. surmuletus* in the Mediterranean Sea (e.g. FERRER-CASTELLÓ et al. 2007). Thus, a total of ten different parasite species are known from the North Sea compared with 24 (including the new records) species in the Mediterranean.

Because of the benthic life and a wide range of prey items, red mullets are suitable hosts for a variety of helminth fish parasites transferred through the marine food web. The stomach content analysis of the studied *M. surmuletus* revealed a total of 16 different prey items, belonging to the Bryozoa, Mollusca, Annelida, Crustacea, Echinodermata and Teleostei.

Especially the crustaceans have been recorded as important intermediate hosts for fish helminths (MARCOGLIESE 2002), being important transmitters for cestodes, nematodes and also acanthocephalans. Consequently, these taxa are commonly found in red mullets, with FERRER-CASTELLÓ et al. (2007) recording 15 species from the western Mediterranean. The richest food range was observed for red mullets from the Adriatic Sea, feeding on polychaets, molluscs, amphipods, copepods and euphausiids (tab. 2).

The parasite diversity of red mullets in the North Atlantic is less studied, and only three different parasite species (*Lecithochirium musculus* (Digenea), *Nybelinia riseri* (Cestoda), *Breizacanthus chabaudi* (Acanthocephala)) with a wide host range and zoogeographical distribution are known (GOLVAN 1969, GIBSON & BRAY 1986, PALM & WALTER 2000). *Hysterothylacium aduncum* is the most prevalent nematode species in the North Atlantic (e.g. KLIMPEL & RÜCKERT 2005), infecting a various teleost intermediate and final hosts. *Derogenes varicus* is one of the most common and least host specific fish digenean in the Atlantic, and tetraphyllidean cestodes occur from the North Sea towards the Iberian Peninsula. These species were also collected during the present study, occurring in the fish from the North Sea and also the Mediterranean. *Derogenes varicus* and tetraphyllidean cestodes also infected mullets in the Mediterranean. Both species usually utilize pelagic crustaceans such as copepods as intermediate hosts (e.g. KØIE 1979, KLIMPEL et al. 2003, 2008). *Capillaria gracilis*, *Corynosoma strumosum* and *Lernaeocera branchialis* were collected only from red mullets in the North Sea, having few or no records from the Mediterranean Sea (e.g. HRISTOVSKI et al. 1989, LE POMMELET et al. 1997, FERRER-CASTELLO et al. 2007). These species are common in the North Atlantic, and might only accidentally occur in the Mediterranean through their migrating hosts.

The crustaceans *Gnathia* sp. and *Hatschekia mulli* and the nematode *H. aduncum* were recorded from the North Sea (Atlantic Ocean) throughout the Adriatic Sea. KLIMPEL et al. (2007) studied the genetic diversity of *H.*

aduncum from the Mediterranean to the North Sea and differentiated two genotypes. The Mediterranean type corresponded to specimens from the North Sea, demonstrating gene flow between both populations. This is not astonishing, considering low host specificity of *H. aduncum* in a wide range of also migrating host fish species. A similar result could be demonstrated by the infection of mullets from all studied locations with the less host specific larval isopod *Gnathia* sp. An interesting result is the occurrence of the parasitic copepode *H. mulli* in the Mediterranean Sea and the North Sea. Though it cannot be decided at present if the sampled specimens belong to the same or different populations, this red mullet specific parasite might also migrate between the Mediterranean and the North Sea (fig. 3).

The parasite fauna of red mullets in the Mediterranean is characterized by digeneans and nematodes, with the occurrence of species specific crustaceans. The predominant parasites in the Mediterranean within the present study were the digeneans *H. legendrei*, *Opecoeloides furcatus*, *Timonia mediterranea* (the both latter are endemic species) and the crustaceans *H. mulli* and *Gnathia* sp., while nematodes, cestodes and acanthocephalans were rare or missing. A similar result was presented by FERRER-CASTELLÓ et al. (2007), who identified these species at similar high prevalence and abundances. The stomach content analyses within the present study revealed similar rich prey items for Mediterranean mullets compared with the North Sea fish. Such wide range of invertebrates might explain the occurrence of two endemic digenean and one endemic nematode species (FERRER-CASTELLÓ et al. 2007 and present study). Species of the genus *Holorchis*, in our case *H. legendrei*, involve gastropods and bivalves as intermediate hosts in their life-cycle (JONES et al. 2005).

The parasite fauna of red mullets in the Mediterranean is the consequence of recent parasite speciation and adaptation together with host-parasite co-evolution, possibly influenced by palaeogeographical and palaeoclimatic events. It is well known that dramatic events took place in the Mediterranean region (e.g. TAVIANI 2002, DUGGEN et al. 2003), playing a crucial role in the evolutionary history of several marine taxa as well as shaping the present biogeography and biodiversity of the regional ichthyofauna (e.g. NIKULA & VÄINÖLÄ 2003, VALSECCHI et al. 2005). The combination of the opening and closing of the Strait of Gibraltar, advances and contractions of glaciation, and changes in current patters appears to have made the northeast Atlantic/Mediterranean area a notable generator of diversity (PANNACCIULLI et al. 1997). DANDO & SOUTHWARD (1981) hypothesized that the history of the Mediterranean combined with the present hydrographic pattern might have promoted and maintained divergence of the Mediterranean populations. Following the Messinian salinity crisis (HSÜ et al. 1977, MCCULLACH & DE-DECKKER 1989), communication between the Atlantic and Mediterranean was reestablished, and fully marine conditions were restored during the Pliocene (5.33 to 1.8 mya). During the Pleistocene (1.8 mya to 10.000 ya) and particularly during the Quaternary, a series of glacial and interglacial periods with associated marine regressions and transgressions affected the area (BLANC 1968). Atlantic and Mediterranean fish populations together with their parasites presumably became physically isolated during these cycles. This historical separation of mullet parasites can be seen as a reason that some of the recorded digeneans *O. furcatus*, *T. mediterranea* and the nematode *A. valentina* are endemic for the Mediterranean and do not occur in the North Sea (fig. 3). Indeed, *O. furcatus*, *T. mediterranea* and *A. valentina* have not been recorded outside the Mediterranean (e.g. LE POMMELET et al. 1997, BARTOLI & BRAY 1996, JOUSSON & BARTOLI 2000, FERRER et al. 2005).

5. Conclusion

According to the observed parasite fauna of red mullets from the North Sea (North Atlantic) compared with the Mediterranean, the record of several endemic species suggests the idea of Mediterranean parasite populations that do

not extend their range of distribution into the North Sea. We herewith suggest historical (post-Messinian history) and geographical reasons for the observed differences in mullet parasitation between the sampling sites (fig. 3). The historical separation of distinct water bodies and eco-systems through the Gibraltar gateway resulted in species speciation within the Mediterranean Sea and the presence of endemic parasite species. The present study also demonstrates that some parasites occur on both sides of the Gibraltar Gateway. Extensive fish parasite distri-bution is caused by a combination of final (KELLERMANNS et al. 2007) and intermediate/paratenic host migrations (PALM et al. 2007). Further studies with more dense sampling sites closer to the Strait of Gibraltar are needed to explore the actual role of this natural barrier to restrict metazoan parasite populations within and outside the Mediterranean Sea.

Acknowledgement

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