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Parasitism of dolphinfishes, *Coryphaena hippurus* and *Coryphaena equiselis*, in the western Mediterranean (Balearic Islands) and central-eastern Atlantic (Canary Islands)*

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SUMMARY: A total of 648 dolphinfishes were examined for internal and external parasites in western Mediterranean (Balearic Islands) and central-eastern Atlantic (Canary Islands) waters in order to make a comparative study between the two areas. The specimens studied from the Mediterranean Sea was *Coryphaena hippurus*, with 62 large individuals captured from May to September and 497 juveniles captured from August to December. The specimens studied from the central-eastern Atlantic were 39 adult *C. hippurus* and 49 adult *Coryphaena equiselis*. Parasites were found in 70% of the fish examined, and represented a total of nine endoparasitic taxa: six digeneans (Class Trematoda, Subclass Digenea: *Dinurus tornatus, Dinurus breviductus, Dinurus longisinus, Lecithocladium excisum, Bathycotyle branchialis* and *Hirudinella* sp.), two nematodes (Class Nematoda, Order Spirurida: *Philometroides* sp. and *Metabronema magna*) and one acanthocephalan (Phyllum Acanthocephala; *Rhadinorhynchus pristis*). Seven crustacean copepod ectoparasites were identified: *Caligus quadratus, Caligus productus, Caligus bonito, Caligus coryphaenae* (Family Caligidae) and *Euryphorus nymphae* (Family Euriphoridae) were found in gill mucus masses or on the inner surface of the operculum, the lernaeopodid *Neobrachiella coryphaenae* (Family Lernaeopodidae) was attached to gill filaments and the pennellid *Pennella filosa* (Family Pennellidae) was anchored to fins and rays or, deeply, to muscular tissue and abdominal cavity. The relationships between feeding habits, parasite recruitment and parasite transmission were analysed, some ecological aspects of all the parasitic species are discussed, and some comments are made on parasite-host relationships.

Key words: *Coryphaena hippurus, Coryphaena equiselis*, parasitism, western Mediterranean, central-eastern Atlantic.

INTRODUCTION

The dolphinfishes (Pisces: Coryphaenidae), common dolphinfish (*Coryphaena hippurus* L.) and pompano dolphin (*Coryphaena equiselis* L.), are epipelagic species distributed world-wide in tropical and subtropical waters where surface

water temperatures exceed 20°C (Gibbs and Collette, 1959). In the Atlantic, they are natural inhabitants and their spawning is probably year round, although it is most intense during the months with higher water surface temperatures (Shcherbachev, 1973). In the Mediterranean Sea, *C. hippurus* appear seasonally and undergo a reproductive cycle during the summer months, following the appearance of adult specimens every year in May-

June, when the water surface temperature reaches >18°C (Massutí and Morales-Nin, 1995). Juveniles are captured from late August to early December and then, when water temperatures fall to 18°C, they possibly migrate to the warmer waters of the Atlantic Ocean.

Dolphinfishes are top-level predators, but they are not very selective and feed on a wide range of pelagic organisms. In addition, they are very agile and capable of taking fast-moving prey (Palko et al., 1982). C. hippurus grows rapidly throughout its life and has a maximum life span of about 4 years, reaching lengths and weights in excess of one metre and 10 kg respectively (Beardsley, 1967; Rose and Hassler, 1968). C. equiselis is a relatively little known species which does not reach such a large size as C. hippurus, and its maximum known length is 74 cm (Herald, 1961). C. equiselis is more pelagic and oceanic, and consequently is rarely caught in coastal waters. Its distribution range is more tropical and according to Mather and Day (1954) it is not generally found in waters with surface water temperatures lower than 24°C. C. equiselis does not extend as far beyond the tropics as C. hippurus. There are few reports of C. equiselis in the Mediterranean Sea, and hence its presence in these waters is not well known.

Although several authors have reported parasites of dolphinfishes in every ocean, and an exhaustive list can be found in Palko et al. (1982), only a few focus on the study of the parasite community of these species by considering the ecology of the parasites. Burnett-Herkes (1974) analysed the ectoparasites on the gills and in the buccal cavity of C. hippurus, whereas Manooch et al. (1984) studied its

gastrointestinal parasites. Both studies were carried out along the South-Eastern and Gulf coasts of the United States in the Western Atlantic.

Therefore the objective of this study was to carry out, for the first time, a complete analysis of the parasitic community of dolphinfishes in the eastern Atlantic and the Mediterranean, and to study the relationships between diet and parasite recruitment in order to identify possible pathways of parasitic infection and life cycle. Special reference is made to the parasites which C. hippurus probably brings from the Atlantic to the Mediterranean Sea and those which this species acquires in the Mediterranean and carries to Atlantic waters. Our aim is to provide basic information that will allow parasites to be used as potential biological tags for C. hippurus in the study of its migratory routes between these two areas.

MATERIALS AND METHODS

The fishes were collected from two areas, the Balearic Islands (western Mediterranean) and the Canary Islands (central-eastern Atlantic). In the laboratory, the fish were measured to the nearest centimetre fork length (FL), weighed and sexed. Integument, fins, natural openings and gills of every fish were examined. The gills were dissected in order to survey all the gill arches for parasites. In all cases, the parasites were collected and, in addition to their number, size, shape and location, any pathological alterations were also recorded. Once any parasites were found, they were fixed in buffered gluteraldehyde (10%) for later identification, directly or after being cleared with lactophenol.

TABLE 1. – Number of specimens of C. hippurus and C. equiselis captured in Mediterranean and Atlantic waters, by fork length intervals. Year and month of capture and the surface water temperature are also given.

Fork length. cm.	BALEARIC ISLANDS Coryphaena hippurus					
	60-124	<20	20-29	30-39	40-49	50-59
1990	20	7	57	35	35	13
1991	18	4	27	33	28	17
1995	24	—	12	44	140	35
Month of capture	May-June	August	August	Sep-Oct	Oct-Nov	Nov-Dec
Temperature °C	16-18	27-28	27-28	25-26	24-22	20-16

Fork length. cm	CANARY ISLANDS Coryphaena hippurus		Coryphaena equiselis
	69-102	38-53	32-52
1994-95	25	14	49
Month of capture	June	October	June
Temperature °C	21	23	21

From the Mediterranean area, a total of 62 adult C. hippurus, ranging from 60 to 124 cm FL, were sampled during May-September in 1990, 1991 and 1995. In the same years, 497 juveniles (14-58 cm FL) were obtained from August to early December. From the Atlantic area, 25 adult (69-102 cm FL) and 24 juvenile (38-53 cm FL) specimens of C. hippurus were sampled during June and October in 1994 and 1995 respectively. In this area, 49 C. equiselis between 36 and 52 cm FL were also sampled during June in 1995.

To establish differences in parasitism as a function of size, the fish examined were differentiated into six size intervals in order to obtain a sufficient number of specimens per group. Size intervals, number of fish analysed per size group, year and month of capture and the surface water temperature range are summarised in Table 1. For each parasite, the infection level by size group was analysed according to standard methods (Margolis et al., 1982).

RESULTS

Endoparasites

Endoparasites were found in 390 of the specimens examined (70%). A total of eleven parasitic taxa could be identified (seven digeneans, one ces-

tode, two nematodes and one acanthocephalan), of which nine were to species level. The change in prevalence, intensity and abundance of the main species in relation to the size of the hosts is presented in Table 2 and 3.

Class TREMATODA
Subclass Digenea
Family Hemiuridae
Dinurus spp.

The most frequent and most numerous endoparasites were four species of the genus *Dinurus* Looss, 1907. These were D. tornatus (Rud, 1819) Looss, 1917, D. barbatus (Cohn, 1902) Looss, 1907, D. breviductus Looss, 1907 and D. longisinus Looss, 1907. D. tornatus was the dominant species. These parasites were found in the stomach of specimens of C. hippurus and C. equiselis captured in both areas. For the prevalence and other ecological parameters there were marked differences depending on the annual cycles, but in general adult fish were the most infected in both areas.

Lecithocladium excisum (Rudolphi, 1819) Looss, 1907

This other gastric hemiurid was only found in the Mediterranean, from juvenile fish <50 cm FL in the

TABLE 2. – Infection parameters of the helminth species (*Dinurus* spp., *Lecithocladium excisum*, *Floriceps saccatus*, *Rhadinorhynchus pristis* and *Metabronema magna*) of *Coryphaena hippurus* captured in Mediterranean waters. (FL: fork length in cm; first row: prevalence; second row: mean intensity ± SD; third row: mean abundance ± SD; fourth row: range).

FL	*Dinurus* spp. 1990	*Dinurus* spp. 1991	*Dinurus* spp. 1995	*L. excisum* 1991	*F. saccatus* 1990	*F. saccatus* 1991	*F. saccatus* 1995	*R. pristis* 1995	*M. magna* 1995
>60	10	100	56.5		60	33.3	21.7	25	60.8
	12±11.3	25.6±7.9	16.5±8.5		3±1.5	1.5±0.5	3.2±3.3	2.3±1.2	2.1±0.8
	1.2±4.5	25.6±7.9	9.3±10.4		1.8±1.9	0.5±0.8	0.7±1.9	0.6±1.2	1.3±1.2
	4-20	6-30	5-30		1-5	1-2	1-9	1-4	1-3
20-29				7.4					16.6
				6±1.4					1
				0.4±1.6					0.2±0.4
				5-7					0-1
30-39				10.3					40.9
				10.2±5.7					1.9±0.8
				1.1±3.5					0.8±1.1
				2-15					1-2
40-49		17.8		3.6	2.8	3.6			64.3
		8.2±5.5		3	2	1			1.3±0.6
		1.5±3.8		0.1±0.6	0.06±0.3	0.03±0.2			0.8±1
		1-16		0-3	0-2	0-1			1-3
50-59	5.5	47			27.7				47.3
	2	18.7±11.3			1.6±0.9				1.3±0.6
	0.1±0.5	7.2±11			0.4±0.8				0.6±0.8
	0-2	3-40			1-2				1-3

| FL | Coryphaena hippurus | | Coryphaena equiselis | |
	Dinurus spp. 1994	R. pristis 1994	Dinurus spp. 1995	R. pristis 1995
>60	24	12		
	18.8±14.2	3±1		
	4.5±10.4	0.35±1		
	1-30	1-5		
30-39				10
				2.3±0.6
				0.15±0.6
				1-4
40-49			4	
			7.5±2.1	
			0.3±1.5	
			6-9	

1991 cycle. Its prevalence, intensity and abundance were low.

Family Bathycotylidae
Bathycotyle branchialis Darr. 1902

Collected from gills of three large specimens of C. hippurus captured in Mediterranean waters.

Family Hirudinellidae
Hirudinella sp.

Collected from the stomach of two large specimens of C. hippurus captured in the Mediterranean

Class CESTODA
Order Trypanorhyncha
Family Lacystorhynchidae
Floriceps saccatus Cuvier, 1817

Plerocerci were found in specimens of C. hippurus larger than 30 cm FL captured in both areas. A total of 91 cysts containing a single plerocercoid were collected from the abdominal cavity and the surface serosa of the viscera. Cyst size was variable and ranged from 20 to 50 mm. The shape of the cysts also showed a great variety of forms, but they always had a terminal globular region, where the larva occurred, and a tail-like structure. The smallest cysts (4-7 mm in length) showed an enlarged or hood-like scolex with two rounded extensions. The medium sized larvae measured 10-12 mm and had tentacles and two leaflike bothridia. The largest plerocercoids (15-25 mm in length) showed two deeply indented bothridia, which superficially looked like four bothridia. Most cysts were attached to the parietal peritoneum and mesenteries (80%), whereas 10% were fixed to the gonadal parenchyma, 7% to the hepatic serosa and 3% to the pancreas surface.

The parasitism of this cestode from both areas has been studied in detail by Carbonell et al. (1998).

CLASS NEMATODA
Order Spirurida
Family Cystidicolidae
Metabronema (Cystidicoloides) magna
(Taylor, 1925)

Some cysts were collected from the walls of the pyloric caeca and in the pancreatic tissue of C. hippurus specimens captured in the Mediterranean. They contained several adult nematodes belonging to this species. The cysts measured 30-50 mm in length and 20-30 mm in width, and they were poorly defined, solid, opaque and included in the tissues. Most of the cysts were calcified. The infection appeared in small fish, and the prevalence increased rapidly, remaining high at all fish sizes, although it was only possible to follow the changes of the infection during the 1995 cycle. In the youngest fish, the cysts constituted a solid mass of conjunctive tissue which contained a male and various females encrusted irregularly in the mass. In the larger fish, the calcification was constant and complete, with most of the nematodes being broken and fragmented.

Family Dracunculidae
Philometroides sp.

Three large females (between 15 and 20 cm in length) were collected in the abdominal cavity of two medium-sized C. hippurus captured in the Mediterranean.

Phylum ACANTHOCEPHALA
Polymorphida
Family Rhadinorhynchidae
Rhadinorhynchus pristis (Rudolphi, 1802)
Lühe, 1911

This was collected in adult C. hippurus captured both in Mediterranean and Atlantic waters but its prevalence was low. Most specimens were found free in the stomach and some others were introduced into the pyloric caecal wall, with the spiny proboscis

Table 4. – Infection parameters of the copepod species (*Caligus* spp., *Pennella filosa* and *Neobrachiella coryphaenidae*) of *Coryphaena hippurus* captured in Mediterranean waters (FL: fork length in cm; first row: prevalence; second row: mean intensity ± SD; third row: mean abundance ± SD; fourth row: range).

FL	*Caligus* spp. 1990	1991	1995	*P. filosa* 1990	1991	1995	*N. coryphaenidae* 1995
>60	10	50	37.5	80	44.5	31.3	12.5
	3±1.4	11.4±11	6.7±11.5	7.2±8.3 ′	5±4.7	3.6±4.7	5.5±2.1
	0.3±0.9	5.7±9.6	2.5±7.4	5.7±8 ₍	2.2±4	1.1±3	0.7±2
	2-4	1-32	1-30	1-33 !	1-12	1-12	4-7
20-29	24.5	59.2	83.3				16.7
	2.6±2.1	2.4±2	2.5±3.5				3.5±0.7
	0.6±1.5	1.4±1.9	2.1±3.3				0.6±1.4
	1-3	1-8	1-12				3-4
30-39	71.4	57.9	77.3				18.2
	4.1±3.2	4±3.7	2.4±1.8				2.4±1.2
	2.9±3.2	2.3±3.4	1.9±1.9				0.4±1
	1-15	1-16	1-6				1-5
40-49	82.8	92.8	45				35.7
	7.3±7.6	5.7±5.4	4.1±3				3.3±4.3
	6±7.4	5.7±5.4	1.8±2.9				1.1±3
	1-30	1-20	1-18				1-6
50-59	83.3	76.5	34.3				45.7
	6.4±4.3	5.1±3.9	6.7±4.1				2.5±1.3
	5.3±4.6	3.9±4	2.3±4				1.3±1.6
	1-15	2-16	2-14				1-6

encapsulated in the caecal walls or deeply in pancreatic tissue. This species was also found in *C. equiselis* specimens smaller than 40 cm FL.

Ectoparasites

Seven species were found, all of which were crustacean copepods. Their infection parameters are given in Table 4 and 5.

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Class COPEPODA
Order Shiponostomatoida.
Family Caligidae
Caligus spp.

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Collected in the gills of *C. hippurus* captured in the Mediterranean and throughout all the size intervals considered. *Caligus quadratus* Shiino, 1957 was the dominant species. Other species of this genus, such as *C. coryphaenae* Steenstrup and Lütken, 1861, *C. bonito* Wilson, 1905 and *C. productus* Müller, 1785 were also found. They were located in large masses of mucus surrounding the gills (60%) and on the inner surface of the operculum (40%). *C. hippurus* and *C. equiselis* from the Atlantic area were not infected by these copepods. The prevalence in juvenile fish was higher than in adults. It was also higher during the months with

Table 5. – Infestation parameters of the copepod species*uryphorus nymph* of *Coryphaena hippurus* and *Coryphaena equiselis* captured in Atlantic waters (FL: fork length in cm; first row: prevalence; second row: mean intensity ± SD; third row: mean abundance ± SD; fourth row: range).

FL	*Coryphaena hippurus* 1994	*Coryphaena equiselis* 1995
>60	80	
	13.5±11.4	
	10.8±11.5	
	2-30	
40-49	78.6	18.4
	11.4±8.7	7.9±2
	8.9±9	1.4±3.2
	2-30	6-11

higher water surface temperature. Parasite females were more abundant than males, with the sex-ratio being 7:1.

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Family Euryphoridae
Euryphorus nymphae Steenstrup and Lütken, 1861

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Collected from both species in specimens bigger than 40 cm FL captured in Atlantic waters. The proportion between parasite females and males was 2:1. This species, as well as *Caligus* spp., produced an abundant mucus hypersecretion in the gills, and the parasites were found in this mucus mass. They were

also present on the inner surface of the operculum. Though the examined fish were dead, the parasites were still highly active and they could be found in the oral cavity, skin on the head and other skin locations.

Family Lernaeopodidae
Neobrachiella coryphaenidae Pearse, 1952

Collected from *C. hippurus* juvenile and adult specimens captured in the Mediterranean. The infection took place in juvenile fish during the months with high water temperatures, and in every case parasites were attached to the gill filaments by their appendages. Only a few parasites carried dwarf males. Mucus hypersecretion or any other anatomical alteration were not observed.

Family Pennellidae
Pennella filosa Linnaeus, 1758

Collected only from large specimens of *C. hippurus* captured in Mediterranean waters during May-September in 1990, 1991 and 1995. Young fish caught in this sea, and the ones from the Canary Islands, were not infected by this parasite. Although the ecological parameters were different during the three years studied, in every case they showed an increasing tendency as the fish became older. The parasites were mainly attached to the dorsal and anal fins (50%), to dorsolateral muscular tissue (25%) and to the abdominal cavity (22%). Mixed parasite locations were frequent in fish larger than 100 cm FL (40%). The depth at which the cephalothorax or radicular apparatus was anchored varied according to parasite location. Thus, it was deeper in the abdominal cavity and musculature than in fin rays or subcutaneous tissue. Some parasites were hyperparasitized by the cirriped *Conchoderma auritum*. Skin and muscular necrosis were always present, and the head and horns of the parasite were immersed in a bloody and inflammatory exudate mass. The cephalothorax was surrounded by a fibrous conjunctive tissue capsule and the adjacent tissues showed different rates of inflammatory alterations with fistulizations.

30% of the material found corresponded to premetamorphic forms that lacked cephalic horns and showed simple branchial filaments, without ramifications or at most with primary branches that always arose from the main branch. They were premetamorphic females with a fragile, whitish body of small size (45±14 mm in length; range 22-64 mm). The rest were composed of pregravid and gravid females with three well-developed horns, an intensely keratinized body and a dark brown colour. The size was 41-135 mm (59±19 mm). The gills consisted of the main filament from which primary, secondary and even tertiary branches arose, but they were always without anastomosis.

DISCUSSION

The results obtained allowed the little existing information concerning the parasite fauna of dolphinfishes in the Mediterranean and Central-Eastern Atlantic to be extended. None of the species found in the Mediterranean had been reported in this area until now. The Mediterranean records were limited to Dollfus (1927), who reported a metacercaria of the hemiurid trematode *Dinurus notatus*, Lozano-Cabo (1961) who found the isopod *Anilocra physodes*, and Delamare-Deboutteville and Nunes-Ruivo (1958) who reported the two parasitic gill copepods *Brachiella coryphaenae* and *Caligus belone*. By contrast, all the species found in the Canary Islands had been reported in Atlantic waters, although most of these records correspond to the western coast (e.g. Cable and Linderoth, 1963; Ho, 1963). The only available information from the central-western Atlantic were studies on trematodes from fishes off Ghana and Senegal (Fischthal, 1972; Fischthal and Thomas, 1972b).

Endoparasitism

The presence of gastric hemiurid digenean parasites in juvenile and adult specimens of *C. hippurus* suggests that infection takes place in Mediterranean as well as in Atlantic waters. The life cycle of these endoparasites is relatively complex, typical of many helminth parasites, with several intermediate hosts. It may follow the typical model described by Koie (1979, 1990b, 1990c), who reported benthic gastropods as first intermediate hosts where the cercariae develop, whereas metacercariae occur in the haemocoel of copepods and chaetognaths. This author also showed that some decapod larvae may be infected by eating the cercariae and that the definitive hosts were clupeids, scombrids and other plankton-feeding fishes. As all these organisms are present in the Mediterranean and Atlantic waters, it appears that *C. hippurus* could acquire the parasites

either through the ingestion of copepods and other crustaceans with metacercariae or through eating small infected fish, which act as second intermediate hosts (Gibson and Bray, 1986). These authors seem to conclude that non clupeid fish could acquire the hemiurids by feeding upon clupeids or other plankton-feeders. The infection of metacercariae hemiurid digeneans from clupeid fish and crustaceans has been recorded in *C. hippurus* by several authors (Dollfuss, 1927; Yamaguti, 1971; Manooch *et al.*, 1984).

Similarly to other areas of the Pacific and Atlantic, fish, crustaceans and cephalopods have been reported as main components of the diet of *C. hippurus* in the Mediterranean (Massutí *et al.*, 1998). Nevertheless, an important change takes place during the ontogenic development of the species. Whereas amphipod and crustacean larvae make up more than 50% of the diet of juvenile specimens smaller than 30 cm, cephalopods and mainly fish are the most important preys for bigger fish. Taking into account that the *Dinurus* species appeared in juveniles (>40 cm FL) and adult specimens (>60 cm FL), the transmission mechanism from invertebrates does not seem probable and their infection is likely to be produced from ingestion of clupeid or other plankton-feeder fishes such as carangids, which are an important component of the *C. hippurus* diet.

The only data that we possess on the biological cycle of the species of *Dinurus* are due to Dollfus (1927) and Szidat (1950). The first author suggests that certain metacercariae found in the body cavity of the crustacean decapod *Cerataspis monstrosa* belong to *Dinurus notatus*, a stomach parasite of *C. hippurus*, for which two forms of transmission are quoted as being possible: through invertebrates (copepods, decapods and chaetognaths) or through vertical migratory fish (clupeids, carangids and scombrids). Szidat (1950), on the other hand, considers that the clupeids are intermediate hosts for *Dinurus breviductus*, whose metacercariae encyst or encapsulate in the skin of *Sardina pilchardus* and *Sardinella aurita*, where the parasite produces a type of "black spot disease".

On the other hand, the other gastric hemiurid *Lecithocladium excisum* was only found in juveniles. This species is reported for the first time in *C. hippurus*. Its cycle is known through the experimental studies of Koie (1991). As in *Dinurus*, its first intermediate hosts are gastropod molluscs and the cercariae are found in the haemocoel of calanoid

copepod crustaceans. Metacercariae have also been described in jellyfish, in the ctenophores *Pleurobrachia*, in diverse species of *Sagitta* and in the coelom of the polychaete *Tomopteris*. These non-crustacean invertebrates are certainly infected when eating copepods with metacercariae, and should therefore be considered as paratenic hosts. In our case the infection by this trematode is early, which suggests that it took place when *C. hippurus* juveniles preyed on pelagic crustaceans, although the possible infection route by paratenic hosts such as *Sagitta* and other invertebrate components of the pelagic system cannot be ruled out.

The other two digeneans *Bathycotyle branchialis* and *Hirudinella* sp. only appeared in a few cases in Mediterranean waters, and can be considered rare as secondary parasitic species. *B. branchialis* had been previously reported in the gills of large *C. hippurus* specimens from the Straits of Florida (Burnett-Herkes, 1974), although it is not proved whether this parasite infects the gills or is vomited from the stomach, as we have found in *Dinurus* spp. Two species of *Bathycotyle* have been described, *B. branchialis* in scombrids and *B. coryphaenae* in *C. hippurus*. The only data to differentiate them is the presence of an external opening of the Laurer's canal in the first species (Gibson and Bray, 1979). Although it is not clear whether the Laurer's canal has an external opening or not, we have seen a dorsal opening in our specimens and in consequence we have considered them as *B. branchialis*. The life history of this species is not known. The genus *Hirudinella* is a typical stomach parasite of marine teleosts (mainly scombrids and tunas), although coryphaenids are habitual hosts (Yamaguti, 1971). Due to their great morphological variability, many studies have described up to fourteen different species of this genus, although Yamaguti (1971) stated that a wide-ranging revision is required. The life cycle of this endoparasite is also unknown.

Floriceps saccatus plerocerci have been recorded in teleosts, whereas adult cestodes are gut parasites of several elasmobranchs from the Atlantic and Pacific Oceans (Campbell and Beveridge, 1994). The only reference for these plerocercoids in coryphaenids was reported by Dollfus (1946) from specimens caught in French Atlantic waters. Its presence in *C. hippurus* coming from the Atlantic Ocean as well as in the juvenile fish born in the Mediterranean Sea indicated that the recruitment of this parasite is possible in both areas. The absence of parasitism in *C. equiselis* may be due to the small

size of these specimens in the sample, which included individuals in the 30-52 cm fork length range. In the same way, the diet composition may possibly play a role in the recruitment of the parasites. The high prevalence observed in adult fish (Carbonell et al., 1998) could suggest that the development of the cysts in *C. hippurus* is slow or that they get the infection late. Unfortunately, the time needed by the ingested procercoid larvae to develop into plerocercoid larvae, and the time needed for the defence mechanisms of *C. hippurus* to produce the large cysts of conjunctive tissue are both unknown. In any case, the above mentioned authors have postulated a four host cycle for this species, with crustaceans and plankton-feeder fishes as intermediate hosts for procercoid larvae, *C. hippurus* as a paratenic host for plerocercoid larvae and sharks as final hosts where the stage matures. This agrees with the experimental observations of Nakajima and Egusa (1972g), who demonstrated that copepod and teleost fish are necessary for procercoid maturation and other teleosts for plerocercoid development.

Metabronema magna is a nematode common in the stomachs of salmonids (Anderson, 1992). In marine fish, it had only been described in *Caranx* sp. and *Sparus* sp. (Skrjabin, 1991). This spirurid requires the participation of an intermediate host such as the crustacean amphipods, decapods and mysidacean larvae (Black and Lankester, 1980), in which the third larval stage can develop. Although they have been found in fish of all sizes and ages, it must be supposed that early infection takes place when *C. hippurus* feed on amphipods and decapods. The fact that the cysts generated by these nematodes are made of conjunctive tissue in fish with sizes smaller than 50-60 cm FL and are completely calcified in larger sized fish seems to suggest that the infection has been early. Given the rapid growth of *C. hippurus* (Beardsley, 1967; Rose and Hassler, 1968) however, it is not unexpected that conjunctive cysts have been observed in fish from 20 to 60 cm FL.

The other spirurid nematode *Philometroides* sp. is also reported for the first time in *C. hippurus*. However, in contrast, it only appeared in a few specimens from Mediterranean waters. The only species of this genus known to date is *Philometroides seriolae*, which was detected in marine fishes from Japanese waters (Skrjabin, 1991). Our specimens have the typical cuticular plates of this species, but we are not sure if they belong to it.

The acanthocephalan *Rhadinorhynchus pristis* appeared in fish from both areas, but with low

prevalence. This species was reported for the first time in dolphinfishes from Caribbean waters (Cable and Linderoth, 1963), although it is widely distributed in a great number of epipelagic fishes (Yamaguti, 1963; Petrochenko, 1971). The fact that this endoparasite has been found in *C. equiselis* specimens between 30 and 40 cm FL, and that in *C. hippurus* it only appeared in adult fish, suggests that the infection of this species could occur in Atlantic waters, before the seasonal migration of these specimens to the Mediterranean. It is known that the paratenic hosts have great importance in the biological cycles of the acanthocephalans. Thus, infection could occur when both species eat paratenic teleosts.

Ectoparasitism

Caligus quadratus and the other *Caligus* species have been recorded in all oceans as ectoparasites of coryphaenids. They have been found in the skin as well as in the oral cavity, operculum, gill cavity and gill filaments (Palko et al., 1982). They are monoxenous copepods whose copepodite infective forms have flat bodies with a circular dorsal carapace, and they swim freely in the water within the pelagic ecosystem. As the entire life cycle of *C. hippurus* takes place in the same habitat, it is not unusual that this species can be strongly parasitised during juvenile as well as adult stages. The infection starts in the early growth period, reaches its maximum in intermediate aged fish and decreases in adults. This could suggest an immunogenic condition in large specimens, which acquire resistance as they become older due to the repeated contacts between parasites and host. Nevertheless, it is difficult to reach any definitive conclusions about the infection data since the caligids have the ability to leave their host and infect other hosts (Kabata, 1979). Also, we must take into account the relationship between coryphaenids and floating objects, which have been postulated as cleaning stations where pelagic fishes go to have their parasites removed by other fish (Gooding and Magnuson, 1967).

Euryphorus nymphae is also a world-wide species that has been recorded as an ectoparasite of coryphaenids. This copepod parasitizes the same habitat as *Caligus* spp. and it seems that although it was a prevalent species in central-western Atlantic waters, it was not found in specimens captured in the Mediterranean, where *Caligus* spp. were predominant. These differences could be related to water

surface temperatures, since they ranged between 16 and 27°C in the Mediterranean Sea, whereas in the Atlantic the temperatures were less variable, ranging from 20 to 23°C. We cannot either explain the fact that the other ectoparasite copepod *Neobrachiella coryphaenae* was only found during 1995 in the Mediterranean and was absent in 1990 and 1991 and in Atlantic waters. The life history of this species is direct and the postembryonic stages belong to the planktonic community, which rises every night to surface waters (Kabata, 1981).

Pennella filosa is a mesoparasitic copepod which has been reported in *Xiphias gladius*, *Mola mola*, in some tuna species and in marine mammals (Kabata, 1992). Recently, *P. filosa* has been found embedded in the flesh of *Lepidocybium flavobrunneum* captured in the northwestern Atlantic (Benz and Hogans, 1993). Only *Pennella pustulosa* and *Pennella varians* had been reported in *C. hippurus* from Australian and Atlantic waters respectively (Yamaguti, 1963). Nevertheless, it is probable that both species could be synonymous with *P. filosa*, due to the great morphological variability of this pennellid copepod (Kabata, 1979; Hogans, 1987; Raibaut, 1991). This anatomic plasticity has also been observed by us, and although it is related to parasite age, it is mainly related to its location. In effect, there are important morphological differences if the parasite is attached to hard surfaces (fin rays) or if it is deeply anchored in muscular tissue or in the abdominal cavity.

P. filosa has an incompletely known life cycle, due to the lack of data on its chalimus larval phases and the metamorphosis of the infective preadults. However, it is probably similar to other pennellid species, which are the only copepod parasites that show a two-host life cycle. Some teleost fish (sometimes the same final host) and cephalopods have been reported as intermediate hosts of pennellids (Kabata, 1981). Rose and Hamon (1953) have also reported chalimus stages and free males of *P. filosa* in the gills of the cephalopods *Sepia* and *Loligo*. This parasite is characteristic of large specimens, which have a diet composed of almost 20% cephalopods and 60% teleost fish (Massutí *et al.*, 1998). Thus, its infection as the fish became older could be related to a higher catch and predation activity on squids (*Illex coindetii* and *Todarodes sagittatus*) and other cephalopods (*Histioteuthis* spp.). The predatory contacts might allow the invasion of infective forms from the gills and mantle of squids to the skin of *C. hippurus*.

P. filosa has not been found parasitising *C. hippurus* in any sea or ocean of the world. The only references to this parasite refer to the previously mentioned fish where the presence of *P. filosa* has always been occasional, with the collection of only a few parasites which very often appear to be incomplete due to the lack of the head. In our case, we obtained a total of 160 parasites, all them exclusively parasitising the large breeding fish that every year visit the Mediterranean Sea. The presence of 30% premetamorphic parasites, as well as young females, makes us suspect that infection takes place in the Mediterranean Sea after the breeding fish cross the Strait of Gibraltar and subsequently disperse through the whole sea. On the other hand, Pascual (pers. com.), studying cephalopods captured in the Alborán Sea and other areas of the southwestern Mediterranean, has proved that all the cuttlefishes and squids captured in these areas were parasitised (100%) in the mantle and gills by larval chalimus phases, possibly belonging to copepod pennellids. Consequently, it is very probable that *C. hippurus* is infected when predating on these cephalopods during its passage through the southwestern Mediterranean.

CONCLUSIONS

The study of the relationships between diet and parasite recruitment allows some comments to be made on the life cycles of some of the parasites found. Regarding the endoparasites (Fig. 1), a cycle of three hosts can be proposed for *Dinurus* spp., in which the benthic gastropod molluscs and planktophage fish, mainly clupeids, would take part as intermediate hosts, with *Coryphaena hippurus* and *C. equiselis* being the definitive or final hosts. A similar cycle could be applied to the other gastric hemiurid *Lecithocladium excisum* but in this case the secondary hosts would be larvae of copepods and pelagic decapods. The nematode *Metabronema magna* and the acanthocephalan *Rhadinorhynchus pristis* would have a cycle of two hosts, the first being pelagic amphipods and the second being larvae of diverse crustaceans in whose haemocoel the stage III infective larvae and the cystacanths would develop respectively. Finally, a cycle of four hosts is suggested for the cestode *Floriceps saccatus*, with crustacean larvae as primary hosts, planktophage fish as secondary hosts, *C. hippurus* as the tertiary host and various sharks as final hosts.
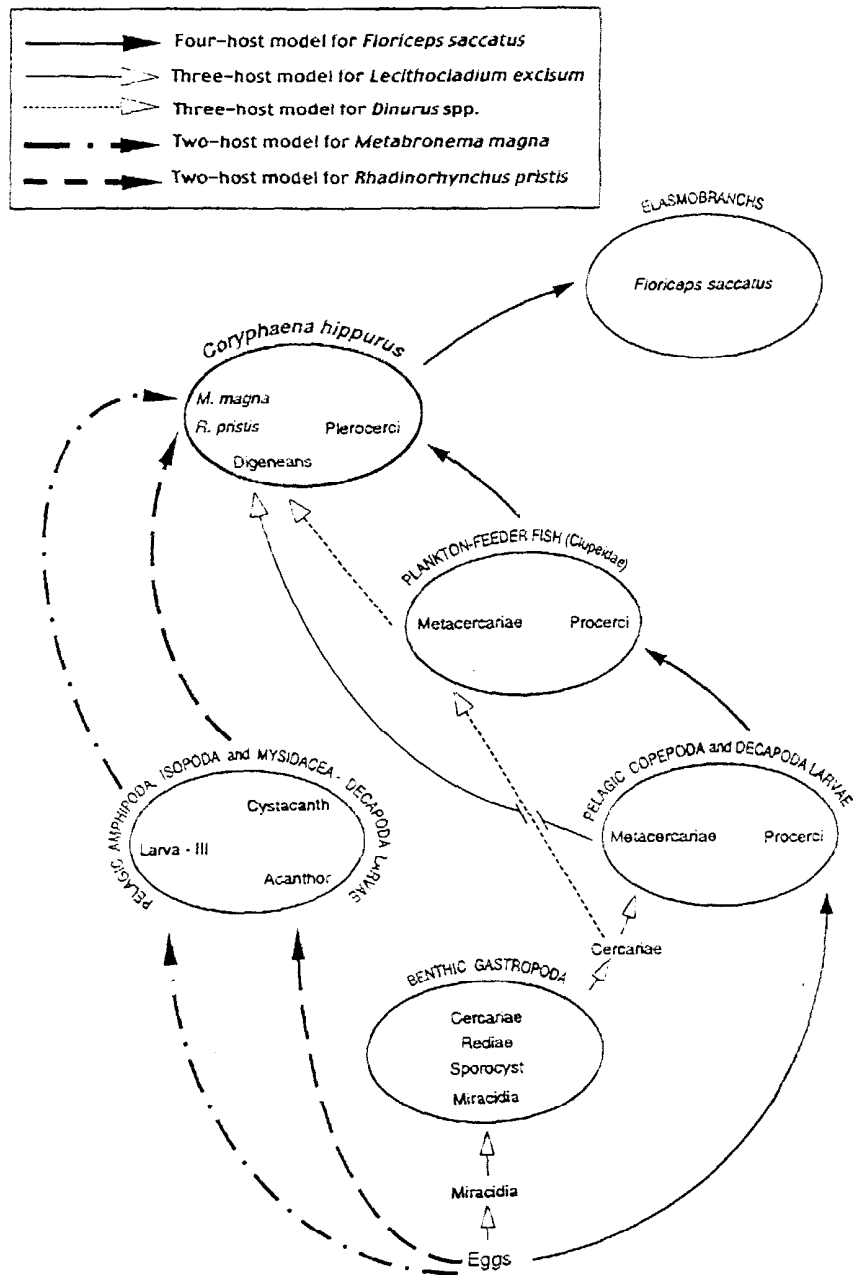
FIG. 1. - Proposed life cycles for the endoparasites *Floriceps saccatus*, *Lecithocladium excisum*, *Dinurus* spp., *Metabronema magna* and *Rhadinorhynchus pristis*.

Regarding the ectoparasites (Fig. 2), *Pennella filosa* is a copepod that needs two hosts, a fish or a cetacean as a definitive host and cephalopod molluscs as intermediate hosts. These last ones are infected by copepodite larvae that develop four chalimus stages in the mollusc, the last of which are differentiated sexually and are fertilised. The males then disappear and the fertilised females infect *C. hippurus* where they undergo extensive metamorphosis. This explains the great importance of the physical contacts between definitive and intermedi-

ate hosts. The remaining copepod parasites have copepodite and pelagic chalimus phases which form part of the planktonic community, where the fourth chalimus stage differentiates into preadult males and females that are the infective forms for the gills of the coryphaenids.

The present study shows that the life cycle and behaviour of *C. hippurus* and *C. equiselis* are of great importance in the recruitment, development, and transmission of parasites in the Atlantic Ocean and in the Mediterranean Sea. In both species, the
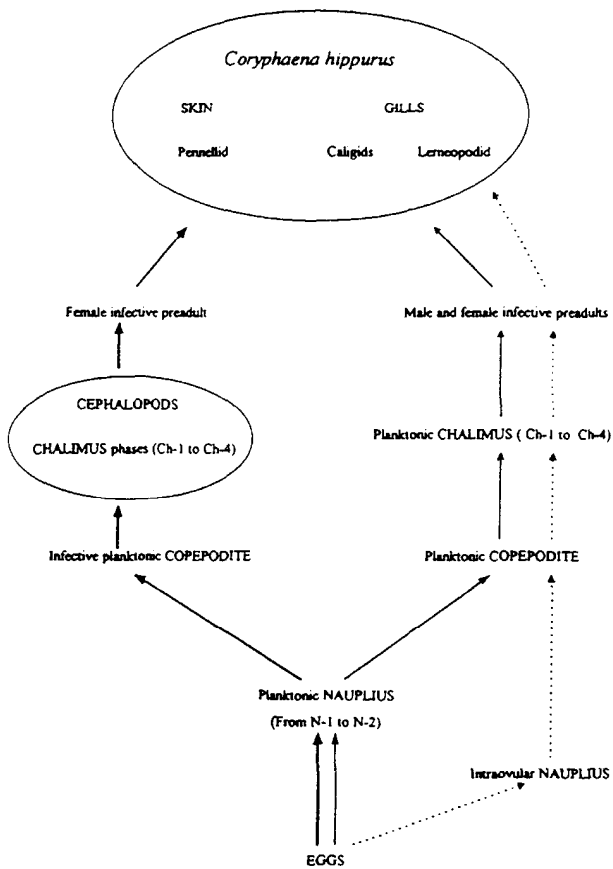
FIG. 2. – Proposed life cycles for the ectoparasites. Left: Cycle for *Pennella filosa*. Right: Caligid cycle for *Caligus* spp and *Euryphorus nymphae*. Lemeopodid cycle for *Neobrachiella coryphaenae*.

recruitment of parasites is qualitatively similar to that of the large fish whose diet is based almost exclusively on teleost fish. Therefore, the feeding habits, surface water temperature, and length and body weight of fishes are related to parasite recruitments (Fig. 3).

This study shows that there are several parasites of *C. hippurus* that are potentially useful as biological tags for studying its migratory movements and stock differentiation within the Mediterranean, and between this area and adjacent Atlantic waters. Within the endoparasites, the trypanorhynch species *F. saccatus*, widely recognised as a long-lived parasite, and the acanthocephalan *R. pristis*, despite its low prevalence, probably have the greatest potential as biological tags. These species have a sufficient life span and remain in an identifiable form in *C. hippurus* long enough to cover the time scale of the investigation. For the same reason, the usually short life spans (<1 year) of adult digeneans in the alimentary tract of fish, tends to limit the use of these species as biological tags. Of the ectoparasite copepods found, *P. filosa* has a particular advantage as a tag because it is a large, very easily seen ectoparasite that leaves a prominent scar after its death, thereby extending its usefulness as a tag beyond its actual life span.
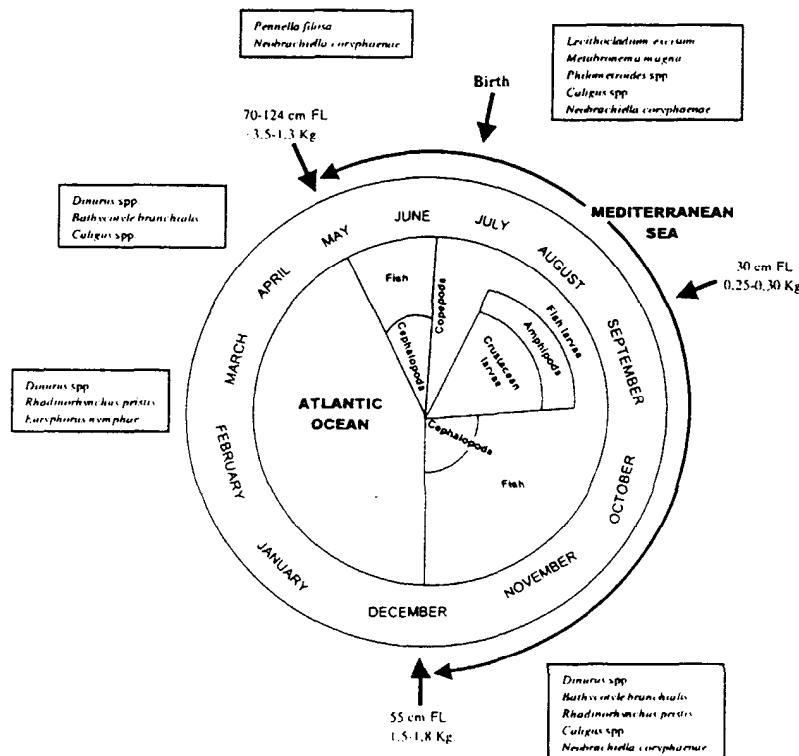
FIG. 3. – Reproductive cycle of *Coryphaena hippurus* from the Atlantic Ocean to the Mediterranean Sea. Length and weight of captured fishes, diet and parasite recruitments. FL: fork length (cm).

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