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Feeding Habits and Biological Features of Deep-Sea Species of the Northwest Atlantic: Large-eyed Rabbitfish (*Hydrolagus mirabilis*), Narrownose Chimaera (*Harriotta raleighana)* and Black Dogfish (*Centroscyllium fabricii*).

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Abstract

Feeding habits and biological features of three deep-water species -large-eyed rabbitfish (*Hydrolagus mirabilis*), narrownose chimaera (*Harriotta raleighana*) and black dogfish (*Centroscyllium fabricii*)- distributed in the Grand Bank and Flemish Cap (Northwest Atlantic) were analyzed. Both chimaeroid species fed on endo and epi-benthic organisms, but with different behavior. Narrownose chimaera showed a closer relationship with the sea bed in the feeding habits, denoted mainly by the high polychaete and sediment presence; while in large-eyed rabbitfish, the great importance of pelagic prey (*Coryphaenoides rupestris* and cephalopods) would indicate wider feeding habits, increased with the predator size. Black dogfish preyed mostly on pelagic and benhopelagic prey (crustaceans, scyphozoans and fish).

High infestation of *Gyrocotyle* affected the chimaeroid species, increasing with depth. The parasitation affected 67% of large-eyed rabbitfish, with higher percentage for smaller individuals; narrownose chimaera (84% with parasites) had a greater number of parasites per host, and bigger individuals were more affected. However, presence of *Gyrocotyle* did not seem to harm the well-being of the specimens. Length-weight relationship indicated bigger body weight for males in the small sizes of 108, 31.5 and 50 cm of large-eyed rabbitfish, narrownose chimaera and black dogfish respectively. However, the body-eviscerated weigh relationship did not show differences between sexes. The hepatosomatic index (HIS) was high in all species, mainly in narrownose chimaera (31.3%) and it reached in the other species a value around the fourth part of their eviscerated weight. Black dogfish showed a clear increase of HSI with the body weight, while chimaerids presented a bigger variation.

Introduction

The cartilaginous fishes, class Chondrichthyes, are the oldest surviving group of jawed vertebrates that includes approximately between 900 and 1100 living species. They diverged into two groups, the Holocephalii (chimaeras, ratfishes and elephantfishes) and the Elasmobranchii (sharks, skates and rays). Holocecephalii is a small group, primarily inhabiting deep water, containing between 31 and 50 species. Large-eyed rabbitfish, *Hydrolagus mirabilis*, (Family Chimaeridae) is distributed in Atlantic waters from Iceland to Namibia and in northwest Atlantic. Narrownose chimaera, *Harriotta raleighana,* (Family Rhinochimaeridae) is more widely distributed in Atlantic and Pacific waters; in the Atlantic waters is distributed from Iceland to South Africa and from Nova Scotia to southern Brazil. Chimaerid species are deep-water species and are part of the associations established in these ecosystems considered vulnerable. Black dogfish, *Centroscyllium fabricii* (Elasmobranchii, Dalatiidae) is also a deep-water species distributed in Northwest Atlantic: South Baffin Island and Greenland to Virginia, USA and possibly the Gulf of Mexico; and in the Eastern Atlantic: Iceland along Atlantic slope to Senegal; Guinea to Sierra Leone; Namibia to Quoin Point, South Africa.

Life history of deep-water species has proved they are vulnerable, and the potential risk increased due to the fishing effects, which have been extending towards deeper water in the last years (Stevens *et al*., 2000). Species, communities and trophic relationship in these ecosystems are not well-known, however, ecosystem model approach is needed for the study and management of the marine resources (Caddy and Cochrane, 2001; Browman and Stergiou, 2005). Ecological studies focused on fish communities, assemblages, and other aspects of fish ecology such as feeding habits and habitat requirements are necessary to provide advice in relation to ecosystem, biodiversity and nature conservation issues (Krebs, 1989; Rice, 2005).

Stomach is absent in chimaeroids. It has been postulated that there was a stomach in the ancestors of sharks and chimaeras and that food specialization (phyto and sclerophagy) was responsible for the loss of stomach in the evolution of the Holcephalii. However, in some sclerophage elasmobranchs, the adaptation to sclerophagy is observed in the change in the structure of the tooth apparatus but did not result in loss of stomach, and for some species, the stomach is highly active. The loss of stomach in the evolution process could be determined by the peculiarities of the stomach morphogenesis in ancestors of the stomachless fishes and the characteristic features of the diet during the stomach morphogenesis period, and it was not due to food specialization exclusively (Kobegenova, 1993).

There is relatively little available literature for chimaeroid fishes, however biological studies on feeding habits and /or parasites of chimaeroids in Atlantic waters have been reported (Mauchline and Gordon, 1983; Mauchline and Gordon, 1984a; Mauchline and Gordon, 1984b; Pascoe, 1987; Berland *et al*., 1990; Karlsbakk *et al*., 2002; Moura *et al*., 2005). We report information on the diet and biological traits such as length-weight, body-eviscerated weight relationships, and hepatosomatic index of large-eyed rabbitfish, narrownose chimaera and black dogfish distributed on the Flemish Cap and Grand Bank (Northwest Atlantic). Information of intestinal parasites for these chimaeroid species is also contributed.

Material and Methods

The chimaeroid individuals sampled were taken in the northwest Atlantic in the NAFO Regulation Area between 450 and 1450 m in three Spanish Bottom Trawl Research Surveys: *Platuxa* developed in Divisions 3NO (Grand Bank) in spring in 2006 and 2007 (González-Troncoso *et al*., 2007), EU Survey *Flemish Cap* developed in Division 3M (Flemish Cap) in summer of 2006 (Casas and González Troncoso, 2007) and *Fletán Negro-3L* in Division 3L (Flemish Pass) in summer of 2006 (*unpublished data, personal comment Esther Román*). All the holocephalan individuals in the catch were sampled (74 individuals). Data reported about black dogfish were collected in the first two surveys mentioned above in the year 2006 (Table 1).

Predator data collected were: total length (TL) to the nearest lower cm and length from the tip of the snout to the posterior end of the second dorsal fin (DL or pre-supracaudal fin length) to the nearest lower ½ cm for chimaerids with an ichthyometer; total and eviscerated weights (g) and liver weight (g); sex; volume of stomach content for sharks and digestive tract content for chimaerids quantified in c.c. using a trophometer (Olaso, 1990); percentage and digestion stage of each diet component. The food contents were analyzed on board.

The importance of each food component was evaluated using the weight percentage (W_p) of each prey item: $W_p = w_p / W_t * 100$, where w_p was the weight (g) of the prey item p and W_t was the total prey weight (g) (Hyslop, 1980; Amezaga, 1988). The relationship between pre-supracaudal fin length (in chimaerids) or total length (in sharks) and body weight was estimated by the allometric equation: $W = a.L^b$, where W is the body weight, L is the length, a is the intercept and b is the slope. Linear regression was used to establish the eviscerated and wet weight relationship. Hepatosomatic index (HSI) for each specimen was calculated as followed: $HIS = (LW / EW)*100$, where EW is eviscerated weight and LW is liver weight recorded in g. Eviscerated weight was used because it is a more adequate body mass indicator than total weigh since it is not affected by individual variation in the mass of the digestive tract, liver and reproductive organs (Perez and Vooren, 1991).

Results and Discussion

Diet. It was not possible to identify a high percentage (>85% in some divisions) of digestive tract contents of large-eyed rabbitfish (*H. mirabilis*) because they were greatly digested; this same problem had already been previously recorded (Mauchline and Gordon, 1983). Identified predominant prey were: echinoids (8%) and scyphozoans (3%) in the Grand Bank; caprellids (7%) and priapulids (5%) in Flemish Cap; and scyphozoans (41%), roundnose grenadier (*Coryphaenoides rupestris*) (26%) and tunicates (23%) were present in the Flemish Pass. Specimens sampled in this last area presented fewer digested food contents, which allowed a better identification of the prey (Table 2). The results correspond to the 17 individuals caught, which had a size range of 74 to 120.5 cm (LD) in a deep range of 1177 to 1449 m (Table 1). Narrownose chimaera (*H. raleighana*) was only captured in the Grand Bank between 460 and 1450 m; the sampled individuals were 57, ranged between 8.5 and 68.5 cm (LD) (Table 1). It was possible to identify better digestive tract contents and to record bigger prey spectrum. Polychaetes, which were very digested and blended with sediment, stood out (51%), and bivalves (3%) were also present (Table 2).

Both species are endo and epi-benthic feeders on small organisms, however they showed differences (Figure 1). Presence of sediment blended with polychaetes would be indicative of the association with the sea bed, mainly in narrownose chimaera (Mauchline and Gordon, 1984a). General feeding pattern was observed in other Atlantic areas, but our results would suggest that large-eyed rabbitfish would prey on more pelagic prey than narrownose chimaera, which is opposite to the observed behavior by Mauchline and Gordon (1983). Changes with the predator size were also observed, mainly in large-eyed rabbitfish. Echinoderms diminished and more pelagic prey increased in larger fish diet (Figure 1). Ontogenic variation in the diet composition for chimaerids was described such as *Chimaera mosnstrosa* (Moura *et al*., 2005), *Callorhinchus callorhynchus* (Di Giácono and Perier, 1996) and *H. mirabilis* (Mauchline and Gordon, 1983). A behavior variation in the same geographical area, season and period, it could be attributed primarily to the morphology and behavior of the predator.

Crustaceans were the main prey group (almost the 50% in weight) in black dogfish (*C. fabricii*) diet, which preyed mainly on *Acanthephyra* spp (16%) and *Pasiphaea tarda* (11%) in Grand Bank and *Acanthephyra* spp (29%) in Flemish Cap. Furthermore, scyphozoans and Pisces were prominent (Table 3), appearing in the diet of individuals ≥40 cm (Figure 2). Ontogenic changes were observed but with different geographical pattern. In Grand Bank, Pisces were preyed by individuals of intermediate sizes and scyphozoans increased with the predator size; both prey showed less changes in relation to predator size in Flemish Cap. Crustaceans were preyed by individuals <50 cm in the Grand Bank, which was opposite to the diet in Flemish Cap (Figure 2). Black dogfish behaves as a generalist and opportunist predator with high niche breadth, showing little geographical changes (Mauchline and Gordon, 1983; Punzón and Herrera, 1998; González *et al*., 2006). A bigger scyphozoan consumption is remarkable in relation to those results reported for Atlantic areas in previous years.

Parasites. Both chimaerid fishes were infested with *Gyrocotyle* (Platyhelminthes, Class Cestoda, Subclass Cercomeria, Order Gyrocotyloidea). Gyrocotyllid cestodes are primitive parasitic platyhelminths and they are found exclusively in the spiral intestine of Holocephalan species, which are an ancient group that has evolved a unique parasite fauna. *Gyrocotyle* species were noticed in other chimaerids and areas (Berland *et al*., 1990; Karlsbakk *et al*., 2002). The incidence of gyrocotyllid worms was high (67% in *H. mirabilis* and 84% in *H. raleighana*), very superior to the one reported for Mauchline and Gordon (1984b) for the Rockall Trough area (9% in *H. mirabilis* and 20% in *H. raleighana*). The infestation increased with the depth. Smaller individuals of *H. mirabilis* were more affected, aspect which has already been reported (Machline and Gordon, 1984b). *H. raleighana* presented higher number of parasites per host, with a similar percentage of infestation in both sexes, but superior in bigger individuals (Table 4). Mean eviscerated weight of *H. mirabilis* was not significantly different ($F_{(4,33)} = 0.39$, $p > 0.05$) when individuals without parasites, those with 1 or 2 parasites and individuals with 3 or more parasites were compared within each size class. On the other hand, *H. raleighana* turned out to be affected by the infestation rate, and this caused a significant variation in the mean eviscerated weight ($F_{(1,7)} = 13.07$, $p < 0.01$). However, we should point out that when visualizing the estimated marginal means of eviscerated weight (it gives estimates of predicted mean values) of these three established groups, the presence of parasites does not seem to harm the condition measured as eviscerated weight (Figure 3).

Biological features: length-weight, body-eviscerated weight and hepatosomatic index-body weight relationships.

Pre-supracaudal fin length (DL)-total weight (TW) relationship of large-eyed rabbitfish was described by the equation $TW = 0.0204{*}DL^{2.8298}$ for females and $TW = 0.0924{*}DL^{2.5073}$ for males. Males had bigger body weight than females in smaller sizes than 108 cm approximately. These parameters in narrownose chimaera was $TW = 0.0191{*}DL^{2.8546}$ and $TW = 0.0812{*}DL^{2.4351}$ for females and males respectively. Females had bigger wet weight than males for sizes >31.5 cm approximately. The relationship estimated between total length and weight in black dogfish was $TW = 0.0004{*}TL^{3.6409}$ and $TW = 0.0016{*}TL^{3.2855}$ for females and males respectively. Males present bigger body weight in sizes < 50 cm approximately (Figure 4).

Total weight-eviscerated weight (EW) showed linear relation. The equations obtained were: $EW = 0.7603{*}TW+167.71$ and $EW = 0.7418{*}TW+212.96$ for females and males respectively in large-eyed rabbitfish. The relationship in narrownose chimaera was $EW = 0.7228{*}TW+30.298$ for females and $EW = 0.7143{*}TW+22.336$ for males. The parameters calculated in black dogfish were $EW = 0.723{*}TW+16.219$ and $EW = 0.7309{*}TW+31.657$ for females and males respectively. Therefore, three species had minimum differences between sexes in the body-eviscerated weight relationship. Eviscerated weight is slightly superior in males for black dogfish and females for narrownose chimaera, as it happens with large-eyed rabbitfish when the specimens have a body weight higher than 2470 g approximately (Figure 5). Sexual dimorphism in other corporal dimensions for chimaerid species has been reported (Garrick and Inada, 1975).

The mean hepatosomatic index (HSI) of large-eyed rabbitfish and narrownose chimaera were 23.22±2.60 and 31.29±2.35 and it was 25.34±4.62 in black dogfish, which is virtually a quarter or even more of the eviscerated weight value. This index presents high values in holocephalian fish, although it varies specifically (Oguri, 1978). HSI of individuals of large-eyed rabbitfish seems to show three groups in relation to the total weight: individuals of between 3640 and 6950 g of body weight with average value of HSI of 21.89±3.23, individuals between 8300-10100 g with mean HSI of 24.52±1.03 and one individual of 14800 g with HSI of 23.54±2.60. Similarly, the specimens of narrownose chimaera could also be divided in three groups: a first group between 610 and 1770 g with mean HSI of 31.15±2.49, specimens between 2200-3130 g with mean HSI of 30.78±2.26 and those between 3350 to 3830 g with mean HSI of 33.30±1.34. However, black dogfish showed a progressive increment of HSI regarding body weight without clear differentiation in groups (Figure 6). Variation in the liver weight in elasmobranchs is strongly correlated with the reproduction. Liver weight diminishes in the viviparous species with the gestation (Ranzi, 1993); in oviparous species, the egg capsule production and its content may imply an enormous effort by females (Mellinger and Wrisez, 1989). In males an increase in the gonads weight accompanied or preceded by the storage of substances in the liver was linked to a maximum HSI (Oddone, 2003).

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Table 1. No. individuals sampled of *Hydrolagus mirabilis, Harriotta raleighana* and *Centroscyllium.*

Specie	Area (NAFO Regulation Area)	Size range (TL, cm)	Size range (LD, 1/2cm)	No. Individuals			Deep range (m)
				Males	Females	Total	
H. mirabilis	Grand Bank (Divs. 3NO)		74-101.5	5	3	8	1177-1345
	Flemish Cap (Div. 3M)		77-120.5	3	3	6	1184-1353
	Flemish Pass (Div. 3L)		89-99.5	3		3	1272-1449
H. raleighana	Grand Bank (Divs. 3NO)		8.5-68.5	15	42	57	460-1450
C. fabricii	Grand Bank (Divs. 3NO)	30-39			1	1	1052-1052
		40-49		17	29	46	712-1450
		50-59		44	71	115	815-1450
		60-69		56	44	100	815-1450
		70-79		1	26	27	930-1345
		Total		118	171	289	712-1480
	Flemish Cap (Div. 3M)	10-19		1		1	972-972
		40-49		11	19	30	639-1268
		50-59		60	68	128	671-1270
		60-69		55	66	121	669-1365
		≥ 70		1	59	60	831-1268
		Total		128	212	340	639-1365

Table 2. Prey (% weight) of the *H. hydrolagus* and *H. raleighana* (NAFO Area).

Prey Group	Prey	Weight (%)			
		H. mirabilis			*H. raleighana*
		Divs. 3NO	Div. 3M	Div. 3L	Divs. 3NO
Pisces		*0.16*		*26.71*	*0.21*
	Myctophidae				0.21
	Coryphaenoides rupestris			25.73	
	Unidentif. Pisces	0.16		0.98	
Crustacea		*0.14*	*7.36*	*4.40*	*0.51*
	Gammaridea		0.51		0.43
	Mysidacea				0.01
	Euphausiacea				0.01
	Cumacea				0.04
	Caprellidae		6.85		
	Unidentif. Natantia	0.05		4.40	
	Unidentif. Crustacea	0.08			0.01
Mollusca		*0.16*	*1.20*	*0.49*	*5.78*
	Scaphopoda				0.58
	Gastropoda				1.73
	Bivalvia	0.16	1.20		3.48
	Cephalopoda			0.49	
Echinodermata		*8.32*		*1.96*	*0.28*
	Asteroidea	0.65			
	Echinoidea	7.67		1.96	0.28
Other Invertebrate		*5.76*	*5.21*	*63.86*	*51.70*
	Polychaeta (*)	1.43	0.34		50.60
	Aphoditidae				0.61
	Porifera	0.97			0.24
	Scyphozoa	3.36		40.55	0.25
	Priapullida		4.87		
	Tunicata			23.30	
Others		*85.46*	*86.23*	*2.59*	*41.52*
	Unidentif./digested prey	84.11	86.23	2.59	39.53
	Sediment				1.86
	Scales	1.35			0.01
	Vitello				0.11

(*) Blended with sediment

Table 3. Prey (% weight) of the *C. fabricii* (NAFO Area).

Prey Group	Prey	% Weight	
		Divs. 3NO	Div. 3M
Pisces		22.99	17.73
	Aspidophoroides monopterygius	0.16	
	Ammodytes dubius		0.28
	Cyclothone sp	0.50	0.33
	Myctophidae	0.17	0.36
	Arctozenus risso		1.16
	Stomias boa		0.76
	Sebastes spp	9.00	2.29
	Unidentified/Digested Pisces	13.19	12.55
Crustacea		49.83	45.57
	Copepoda	*	
	Gammaridea	0.25	
	Hyperiidae	0.06	0.01
	Mysidacea	*	0.31
	Euphausiacea	4.91	2.51
	Acanthephyra pelagica	0.07	0.29
	Acanthephyra purpurea	0.51	
	Acanthephyra spp	16.42	28.87
	Pasiphaea tarda	10.85	3.73
	Sergestes arcticus	4.65	0.85
	Sergia robusta	3.93	3.57
	Pandalus borealis		1.11
	Unidentified/Digested Natantia	6.73	3.47
	Unidenf. Crustacea	1.43	0.85
Mollusca		1.78	1.68
	Cephalopoda	1.04	1.68
	Semirossia sp	0.75	
Echinodermata			1.46
	Echinoidea		0.31
	Holothurioidea		1.15
	Ophiuroidea		*
Other Invertebrate		23.10	32.79
	Anthozoa		0.01
	Chaetognata	0.05	0.06
	Cnidaria		10.48
	Ctenophora	0.05	
	Polychaeta	0.03	
	Scyphozoa	22.97	22.24
Others	Unidentified prey	2.30	0.76

* <0.01%

Table 4. Infested individuals (%) of the *H. hydrolagus* and *H. raleighana*.

Specie	**Sex**	**Infested individuals (%)**	**No. parasites per host**	**Infested individuals (%)**	**Size range (LD, 1/2cm)**	**Infested individuals (%)**	**Deep range (m)**	**Infested individuals (%)**
H. mirabilis	Males	82	1	40	70-89.5	30	1000-1199	10
	Females	25	2	40	90-100.5	50	>=1200	90
	Total	67	3	20	101-110.5	10		
			4		120-130.5	10		
			≥5					
H. raleighana	Males	70	1	12	30-39.5	2	400-599	2
	Females	88	2	57	40-49.5	12	1000-1199	17
	Total	84	3	12	50-59.5	26	>=1200	81
			4	12	60.69.5	60		
			≥5	7				

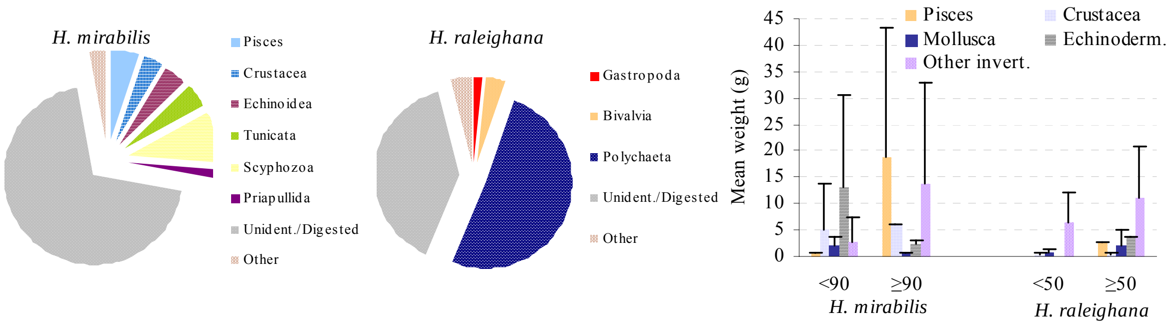

Figure 1. Main prey groups of *H. mirabilis* and *H. raleighana*: weight (%) (left) by species and mean weight±SD by size class (right).

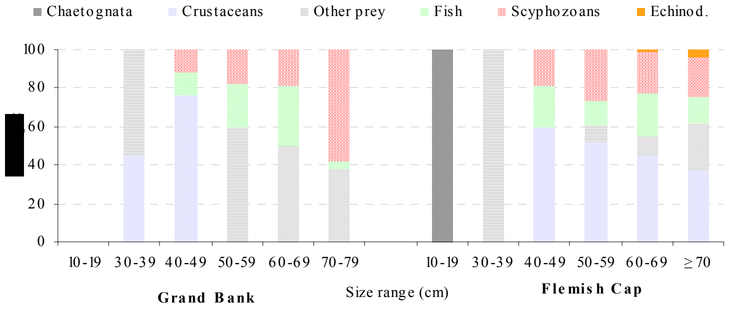

Figure 2. Weight (%) of main prey groups of *C. fabricii* in Divisions 3NO (left) and 3M (right) in NAFO Area.

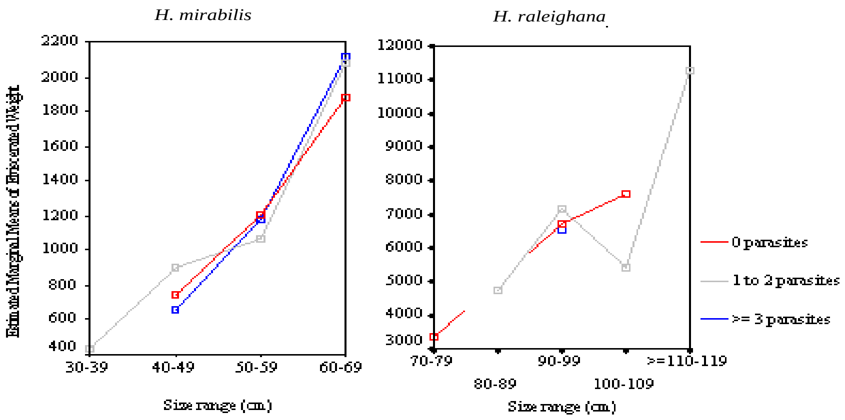

Figure 3 Estimated marginal means of eviscerated weight for *H. mirabilis* and *H. raleighana* with different infestation rate.

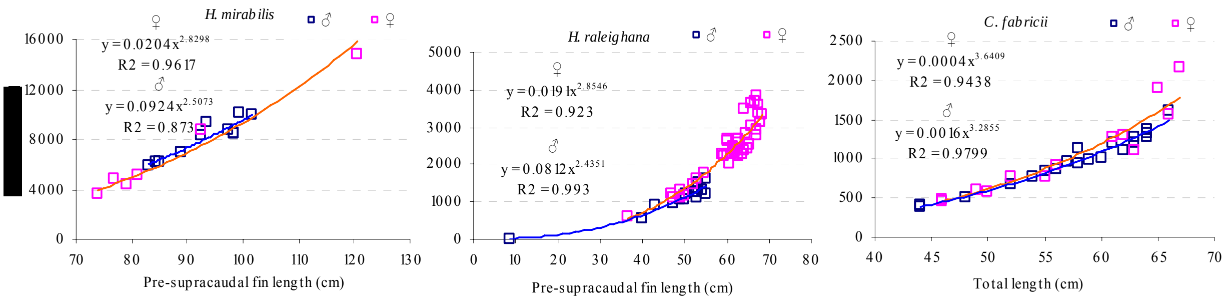

Figure 4. Length-weight relationship of *H. mirabilis*, *H. raleighana* and *C. fabricii* by sex.

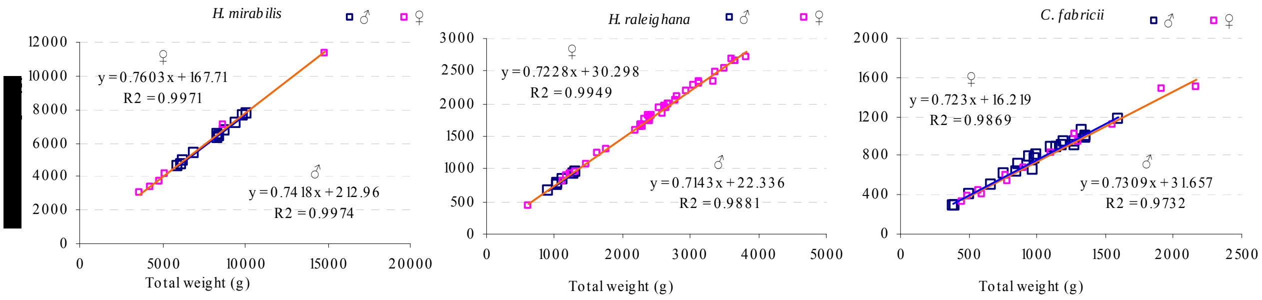

Figure 5. Total weight-eviscerated weight relationship of *H. mirabilis*, *H. raleighana* and *C. fabricii* by sex.

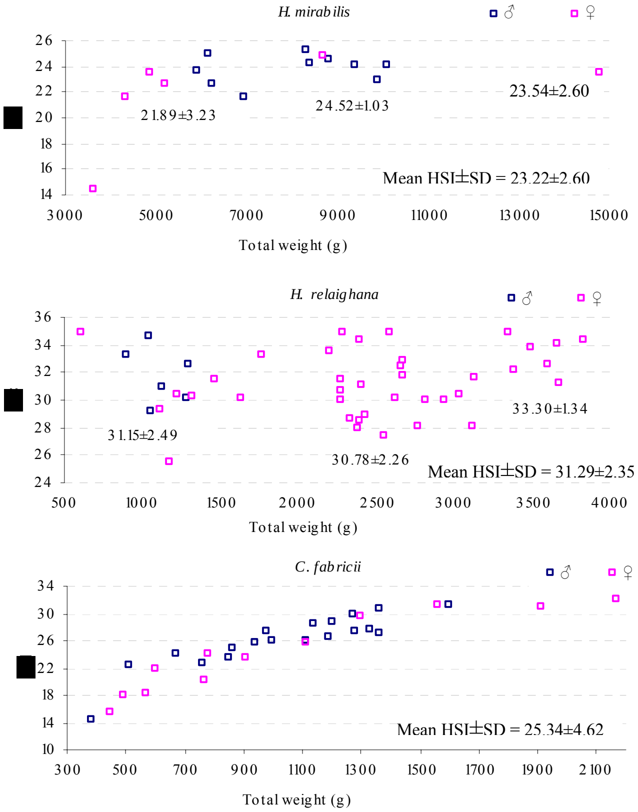

Figure 6 Total weight-hepatosomatic index (HIS) relationship of *H. mirabilis*, *H. raleighana* and *C. fabricii* by sex.