Feeding ecology and morphometric relationships of white seabream, *Diplodus sargus lineatus* (Sparidae), endemic species of Cape Verde

by

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ABSTRACT. - *Diplodus sargus lineatus* (white seabream) is an endemic coastal species in Cape Verde (CV). It is one of the most abundant seabream but has a low marketable value. In this work the feeding ecology of *D. sargus lineatus* and morphometric relationships were studied for the first time. Feeding indices and coefficients were determined and used along with multivariate analysis to characterise ontogenetic and sexual diet shifts. Diet was diversified and a total 53 food items were identified. Algae composed the majority of the items (36), namely Rhodophyta algae (26), followed by benthic macroinvertebrates (17). Feeding diversity is not related to sex or size classes. When compared with other species from the same genus, *D. sargus lineatus* showed a rich benthic fauna diet and the largest diet diversity in red algae consumption. This result reflects the rich benthic marine faunal environment and red algae flora availability of CV islands, even though red algae would be rather unusual considering the short coastal area associated with the Macaronesian Archipelagos. Diel diet analysis showed higher feeding activity during the day. Two alien algae species found in *D. sargus lineatus* diet were first described for CV. These results highlighted the importance of diet studies as ecosystem bioindicators tools. The estimated morphometric relationships showed negative allometries between body height (BH = 0.4163FL + 0.3711), head length (HL = 0.2649FL – 3.6456), ocular diameter (OD = 0.07FL + 0.61) and fork length (FL). Positive allometry and high correlation were found between weight and fork length (W = 0.0001787FL$^{-3.14}$).

RÉSUMÉ. - Écologie de l'alimentation et relations morphométriques du sar commun *Diplodus sargus lineatus* (Sparidae), espèce endémique du Cap Vert.

Le sar blanc, *Diplodus sargus lineatus*, est l'une des plus abondantes espèces de sars endémique au Cap Vert (CV) mais présente une faible valeur marchande. Dans ce travail, l'écologie de l'alimentation et les relations morphométriques de *D. sargus lineatus* ont été étudiées pour la première fois. Les indices et coefficients de l'alimentation ont été déterminés puis utilisés pour une analyse multivariée permettant de caractériser les variations liées à l'ontogénie et au sexe. Le régime alimentaire est diversifié et un total de 53 taxons a été identifié. Les algues sont majoritaires (36), en premier lieu les Rhodophyta (26), puis les macroinvertébrés benthiques (17). La diversité de l'alimentation ne varie pas en fonction du sexe ou de la taille. *D. sargus lineatus* présente une alimentation plus riche en faune benthique que les autres espèces du genre *Diplodus* et la plus grande diversité alimentaire avec la consommation d'algues rouges. Ces observations reflètent la richesse de l'environnement marin benthique des îles du CV, même si les algues rouges sont plutôt inhabituelles sur l'étroite zone côtière des archipels macaronésiens. La prise alimentaire est supérieure pendant la journée. Deux espèces d'algues invasives trouvées dans l'alimentation du *D. sargus lineatus* ont été décrites pour la première fois pour le CV. Ces résultats mettent en évidence l'importance des études sur l'alimentation qui peuvent être utilisées comme des outils bioindicateurs de l'écosystème. Les relations morphométriques estimées ont montré une allométrie négative entre la taille du corps (TC = 0,4163LF + 0,3711), la longueur de la tête (LT = 0,2649LF – 3,6456), le diamètre oculaire (DO = 0,07LF + 0,61) et la longueur à la fourche (LF). Il existe également une allométrie positive et une corrélation entre le poids (P) et la longueur à la fourche (P = 0,0001787LF$^{-3,14}$).

Key words. - Sparidae - *Diplodus sargus lineatus* - Cape Verde - Fish biology - Feeding ecology - Morphometric relationships.

In Cape Verde (CV), the sparid family assemblage is one of the most important due to its high abundance and biomass availability at coastal areas (Adams *et al*., 2004; Brashares *et al*., 2004). However, catches of this demersal sparid species along the West Africa coast are low and the sparids do not directly support a nearshore coastal artisanal fishery (Adams *et al*., 2004; Brashares *et al*., 2004). That is also the case in CV where sparids are considered to have a moderate market value and fishery (e.g. longline) does not directly target this family. However, sparids are landed in all Island ports composing an important additional economical income in nearshore artisanal fisheries, namely gill net, hook and line and/

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or purse and beach seine.

Diet ecological studies are nowadays an important source of information for coastal fisheries management. Pauly *et al.* (1998) demonstrated that fisheries, since 1950, have been increasingly relying on the smaller, short-lived fish and on the invertebrates from the lower parts of both marine and freshwater food webs, and that fish management have moved to an ecosystem based approach. This vision requires knowledge of trophic level of each fish (based on fish diet) and considers that trophic level is not an attribute of the fish whose feeding is being described, but of its interaction with other organisms.

The condition of a fish reflects food availability that affects fish physiology and biological condition indices. Thus, food resources and habitat quality can have major consequences on individual fish health and influence survival and population success affecting also morphology (Lloret and Planes, 2003). The estimation of morphometric relationships allows the comparison of life history and morphology between different species, or between populations of a single species from different habitats and/or regions. Moreover, variability in morphometric relationships (e.g. length-weight), as an indicator of condition in marine fishes, is a feature that can directly reflect environmental effects on a species condition, which may be taken as an indicator of the fitness of the populations (Pauly, 1984; Chu *et al.*, 1995; Pérez-Castañeda and Defeo, 2002). Knowing the fish size range that is vulnerable to capture is importance for management, since many fisheries harvest fish from a particular size range due to the size-selective characteristics of used fishing gears. In this concern, morphometric relationships, length-girth/body height, are important for gear technologists as they both influence the retention of fish by different fishing gears (Leite, 1991; Hart and Reynolds, 2002). Finally, morphometric relationships are important for monitoring biological sampling programs (onboard fishing vessels, on discarded points or market).

Sparids are coastal and amphiatlantic fishes with a wide range distribution in tropical, subtropical and temperate Atlantic and West-Oriental temperate coasts occurring from Norway to South Africa and also in Indian and Pacific oceans (Nielson, 1994; Froese and Pauly, 2011). Roberts *et al.* (2002) recognized CV (Central-East Atlantic) as one of the eleven hotspots for marine biodiversity and priority centre for tropical reefs conservation actions, because these islands are among the richest centres of endemism in the Atlantic waters. A total of 20 Sparid species were recorded at the CV Archipelago (Fischer *et al.*, 1981; Froese and Pauly, 2011). The White seabream *Diplodus sargus lineatus* (Valenciennes, 1830) is endemic to the CV Islands (Bauchot and Hureau, 1990). Adults are frequently found along the insular shelf of the CV islands, and juveniles in shallow waters associated with the coralline communities (Almeida

et al., 2007; González and Tariche, 2009). There are three other endemic sparid species: CV two-banded seabream – *Diplodus prayensis* Cadenat 1964, Banded seabream – *Diplodus fasciatus* (Valenciennes, 1830) and Bulldog dentex – *Virididentex acromegalus* (Osório, 1911) (monotypic). Floeter *et al.* (2007) stated that the high endemism at the CV Islands may be related to: (1) great geographic isolation (from the mainland and between islands), (2) high heterogeneity of habitats, and (3) maintenance of warm tropical waters in glacial periods.

Previous studies on *Diplodus* spp. biology and ecology showed that species can be found in a large range of habitats (Pike and Lindquist, 1994; Gonçalves and Erzini, 1998; Marian *et al.*, 2002; Matić-Skoko *et al.*, 2004; Figueiredo *et al.*, 2005; Leitão *et al.*, 2007). At CV, *Diplodus* spp. are mostly archipelagic, considered demersal and benthopelagic and present a wide range of distribution, from sandy to rocky bottoms and common in nearshore waters (Fischer *et al.*, 1981; Tenreiro de Almeida *et al.*, 2003). Mann and Buxton (1992) attribute the success of *Diplodus* to the capacity to feed on algae, sea-grasses and associated epibenthic organisms. Diet analysis studies suggested a strong feeding niche overlap, partitioning food resources among sparids (Sala and Ballesteros, 1997; Horta *et al.*, 2004). In coastal rocky areas *Diplodus* spp. are within the major predators of benthic invertebrates and algae communities, thus playing a major role in controlling their abundance and effects on benthic communities (Pike and Lindquist, 1994; Sala and Ballesteros, 1997; Gonçalves and Erzini, 1998; Figueiredo *et al.*, 2005). Seabreams may feed on algae to collect their epiphyte diatoms (Joubert and Hanekon, 1980), to extract nutrients directly from the algae (Mann and Buxton, 1992), or to optimise the digestion of animal preys (Lobel, 1981).

Up to date, excluding generalist information based on other sparid records (Bauchot and Hureau, 1990; Reiner, 1996), little is known about *D. sargus lineatus* biology and ecology. To our knowledge this is the first attempt to characterise *D. sargus lineatus* diet according to sex, age and diel feeding behaviour. In CV, *D. sargus lineatus* are commonly caught by polyvalent fleet (multi-gear) on a multi-species artisanal fishery, including gill net, the most used gear. A practical example from CV morphometric relationships application is the determination of the size of the fish, using ocular diameter – fork length relationships, remaining on hooks (longline fisheries) after coastal shark's attack. Despite several scientific surveys for fish data acquisition, including *D. sargus lineatus*, between 1985-95, little is known about morphometric relationships (Magnússon and Magnússon, 1987; Pálsson, 1989; Thorteinsson *et al.*, 1995). Therefore, morphometric studies are needed to be used by gear technologists in selectivity studies and stock assessment models.

MATERIALS AND METHODS

CV (central eastern Atlantic) is made up of ten islands and several islets of volcanic origin (Fig. 1) and is enclosed in the Macaronesian biogeographic region (Duarte and Romeiras, 2009), totalling a coastline with 965 km long and 5934 km^2 of island shelf (depths < 200 m) (Bravo de Laguna, 1985; DGMP, 1998). Sampling was conducted in ten locations of four islands: Santo Antão (N = 1 point), São Vicente (N = 6 points), São Nicolau (N = 2 points) and Boavista (N = 1 point) (Fig. 1). Specimens were collected between June and November 2007, with no fish capture in August. Two different types of methodologies were used for sampling. The first was based on recreational fishing activity, which is highly important as food source for fishermen's families' that uses bamboo fishing road and hand line hook. Recreational fishing always occurred in nearshore coastal areas at depth up to 40 m. The most used baits were: Carangidae (fish), Scombridae (fish), Patellidae (limpets), Cirripedia (barnacles) and Echinoidea (sea urchin). The time of specimens capture was recorded. Whenever allowed by fishermen, specimens were sexed and stomachs removed and brought to the laboratory. Biometric measurements of fishes were taken in the field, including weight (0.01 g) and total length (nearest mm). Secondly, specimens were collected by purse seine net in São Vicente (Praia da Laginha-Porto Grande Bay) and brought to laboratory for diet and biometric studies.

In the laboratory each specimen was sexed, measured and the stomach removed and fixed/stored in a solution known as KEW (40% salt water, 40% ethanol 70%, 10% glycerine, 10% formalin at 4%). Stomachs of White seabream were removed by cutting the oesophagus near the mouth cavity and the intestine in the area anterior to the pyloric caeca (Hyslop, 1980). Stomachs were opened and the contents removed for examination. The preys were separated to lower major taxonomic groups and baits discarded. Algae contents were preserved in KEW and invertebrates preserved in 70% alcohol. Prey items were identified (Hayward and Ryland, 1995; Saldanha, 1995; Afonso Carrillo and Sansón, 1999; dos Santos and Lindley, 2001; Debelius and Wirtz, 2004; Rolán, 2005), using a stereomicroscope, counted and weighed (0.01 g). Independently of the collection method, fork length (FL), body height (BH), head length (HL) and ocular diameter (OD) (calliper) were measured to the nearest mm. Each specimen total weight (W) was also recorded to the nearest 0.01 g.

Data analysis

Dietary composition was assessed through numerical percentage (%N_i), weight percentage (%W_i) and frequency of occurrence (%FO_i) of each prey taxa (i) following Hyslop (1980). The number of empty stomachs was recorded (V_i – vacuity index) (Hureau, 1970). The colonial taxa, hydrozoans, and both plants and other fragments were not counted and therefore the numerical value attributed to these prey items was 1. To evaluate the diet of *D. sargus lineatus* the feeding coefficient (Q) (Hureau, 1970) and the Index of Relative Importance (IRI_i) (Pinkas *et al*., 1971) were used. For IRI_i prey indexes were separated according to three categories: main preferred preys, $IRI_i > 200$; secondary preys, $20 < IRI_i < 200$; accidental preys, $IRI_i < 20$. Mean diel feeding activity was evaluated by the repletion index (R_i) that is the ratio between the aggregate weight of all food items in the stomach (bait discounted) and total weight of the fish, include empty stomachs (Hureau, 1970). As the time of specimens capture was recorded mean R_i was determined at hourly intervals, between 6 h 30 and 23 h 30. The R_i for each hour period was estimated considering average stomachs data.

Ecological indices were estimated individually for males and females and also for the overall sample (diverse routine procedure of Primer 6, Clarke and Warwick, 2001) and included: total number of species in diet (*S*); diet species/items richness that were estimated using Margalef index [d = (S−1)/logN]; and diversity of resources that was estimated using the Shannon index [*H*' = −$\Sigma P_i log P_i$]. In order to determine the minimum number of stomachs (size sampling) necessarily for evaluate *D. sargus lineatus* diet, the cumulative numbers of randomly sampled stomachs were plotted against the cumulative feeding items species numbers (species area plot routine of Primer 6 software). The t-Student test (Zar,
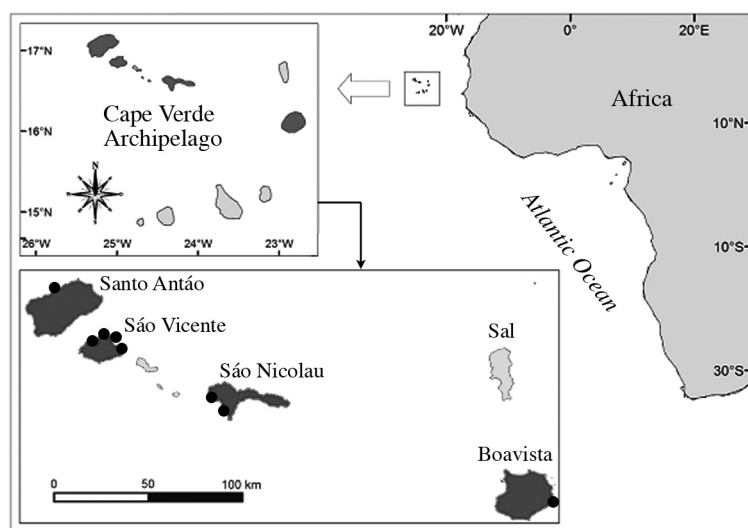

Figure 1. - Map of Cape Verde Islands. The islands of the archipelago where *D. sargus lineatus* specimens were collected are in dark grey. Dark dots (●): fishing grounds in the shoreline.

1996) was used for comparison between male and female ecological indices (S, d and H').

The estimation of pairwise Bray-Curtis similarity coefficients provides a measure of dietary overlap (Marshall and Elliott, 1997). Therefore, ontogenetic, sex and monthly diet changes were evaluated by hierarchical cluster analysis (dendrogram) based on Bray-Curtis index similarity matrix. Cluster analyses were based on the %N (numerical abundance) monthly data, i.e. stomach prey was grouped by month, and data were root transformed, as appropriate for percentage data (Platell and Potter, 2001). Cluster analysis was made with the Unweighted Pair Group Method (UPGMA). The mean size at first maturity for other *Diplodus* species (*D. sargus*, *D. vulgaris*, *D. bellottii*) that inhabit CV coastal waters is 150 ± 30 mm (Erzini *et al.*, 2002). Assuming proximity within the genus, and in absence of age studies for the species, three size class were selected to establish a size range (size classes of 40mm each) that allow for the separation of juveniles (93-159 mm), young recruits (160-240 mm) and adult fish (> 240 mm) in small, middle and large fishes. The importance of prey taxa in fish diet was assessed by SIMPER analysis, using PRIMER statistical package (Clarke and Warwick, 2001).

The estimation of W-FL relationship was made by adjust of an exponential curve ($W = a\,FL^b$) to the data (Ricker, 1973), where a is the intercept (initial growth coefficient or the condition factor) and *b* the slope (growth coefficient i.e. fish relative growth rate). The estimation of BH-FL, HL-FL and OD-FL relationships were made by linear regression (y = a + b FL) and the parameter a and b of linear regression were estimated using least-square regression (Zar, 1996). The degree of association among latter morphological variables was measured by the coefficients of determination (r^2). The p-value (statistical significance level of $\alpha = 0.05$) of the ANOVA regression was used to evaluate the fitness of the regression model to morphometric data.

Table I. - List of the prey species (N = 56) found in *D. sargus lineatus* stomach. Mean numeric percentage (%N), mean weight percentage (%W), frequency of occurrence (%FO), feeding coefficient (Q), index of relative importance (IRI$_i$). IRI$_i$ (%): overall percentage contribution of IRI$_i$ per taxa and item group. * principal prey, ** secondary prey, *** occasional prey (based on IRI$_i$), for species most contributed to sex diet shifts (see Tab. II).

Taxa / Species		%N	%W	%FO	Q	IRI$_i$	IRI$_i$ (%)
Rhodophyta							
1	*Hypnea spinella**	10.39	10.73	52.75	111.5	1 114.2	30.7
2	*Gelidiopsis intricata**	5.63	10.21	28.57	57.5	452.6	12.5
5	*Polysiphonia* sp.*	4.76	5.58	24.18	26.6	250.0	6.9
6	*Grateloupia filicina**	5.84	1.97	29.67	11.5	231.9	6.4
7	*Lomentaria articulata**	3.03	10.50	15.38	31.8	208.2	5.7
9	*Amphiroa rigida***	2.38	4.89	12.09	11.7	87.9	2.4
20	*Gelidium pusillum*	0.87	0.59	4.40	0.5	6.4	0.2
22	*Hypnea arbuscula*	0.65	1.25	3.30	0.8	6.3	0.2
23	*Palisada perforata*	0.43	2.62	2.20	1.1	6.7	0.2
24	*Corallina elongata*	0.87	0.15	4.40	0.1	4.5	0.1
25	*Grateloupia dichotoma*	0.87	0.09	4.40	0.1	4.2	0.1
28	*Caulachantus ustulatus*	0.43	1.29	2.20	0.6	3.8	0.1
29	*Spyridia hypnoides*	0.65	0.36	3.30	0.2	3.3	0.1
31	*Polysiphonia atlantica*	0.43	0.57	2.20	0.2	2.2	0.1
32	*Polysiphonia stricta*	0.43	0.22	2.20	0.1	1.4	–
33	*Osmundea truncata*	0.43	0.20	2.20	0.1	1.4	–
34	*Rhodymenia* sp.	0.43	0.16	2.20	0.1	1.3	–
36	*Rissoella* sp.	0.43	0.09	2.20	–	1.2	–
37	*Naccaria* sp.	0.43	0.05	2.20	–	1.1	–
45	*Lophocladia trichoclados*	0.22	0.05	1.10	–	0.3	–
48	*Chondriella isecmarus*	0.22	0.03	1.10	–	0.3	–
50	*Polysiphonia thuyoides*	0.22	0.03	1.10	–	0.3	–
53	*Gelidiopsis planicaulis*	0.22	–	1.10	–	0.2	–
54	*Jania adhaerens*	0.22	–	1.10	–	0.2	–
55	*Hypnea musciformis*	0.22	–	1.10	–	0.2	–
56	*Laurencia* sp.	0.22	–	1.10	–	0.2	–
Phaeophyta							
4	*Ectocarpus fasciculatus**	2.38	21.06	12.09	50.1	283.4	7.8
12	*Dictyopteris polypodioides***	2.81	0.58	14.29	1.6	48.4	1.3
27	*Ralfsia expansa*	0.65	0.41	3.30	0.3	3.5	0.1
38	*Colpomenia sinuosa*	0.43	0.01	2.20	–	1.0	–
44	*Chnoospora minima*	0.22	0.17	1.10	–	0.4	–
51	*Dictyota crenulata*	0.22	0.02	1.10	–	0.3	–
	Total	**6.71**	**22.25**				**9.3**
Chlorophyta							
13	*Ulva* sp.**	1.95	1.49	9.89	2.9	34.0	0.9
26	*Chaetomorpha nodosa*	0.43	1.70	2.20	0.7	4.7	0.1
41	*Caulerpa racemosa*	0.22	0.33	1.10	0.1	0.6	–
42	*Chaetomorpha* sp.	0.22	0.32	1.10	0.1	0.6	–
	Total	**2.82**	**3.84**				**1.1**
Mollusca							
14	*Fissurella* sp.**	4.11	1.17	5.49	4.8	29.0	0.8
15	*Brachidontes puniceus**	3.25	0.83	6.59	2.7	26.9	0.7
16	*Littorina punctata***	2.81	0.20	5.49	0.6	16.6	0.5

Table I. - Continued.

| Taxa / Species		%N	%W	%FO	Q	IRI$_i$	IRI$_i$ (%)
21	*Patella* sp.	1.95	0.70	2.20	1.4	5.8	0.2
35	*Aplysia* spp.	0.43	0.14	2.20	0.1	1.3	–
40	*Lamellaria* sp.	0.43	0.16	1.10	0.1	0.6	–
43	*Phenacolepas* sp.	0.43	0.01	1.10	–	0.5	–
46	*Fissurella fischeri*	0.22	0.05	1.10	–	0.3	–
47	*Columbella adansoni*	0.22	0.03	1.10	–	0.3	–
	Total	**13.85**	**3.29**				**2.2**
Crustacea							
3	*Plagusia depressa**	4.76	12.73	24.18	60.6	423.0	11.6
8	*Leucothoe* sp.	11.69	0.06	17.58	0.7	206.5	5.7
18	*Chthamalus stellatus****	9.09	0.38	1.10	3.4	10.4	0.3
19	*Candacia* sp.***	1.73	–	3.30	–	5.7	0.2
	Total	**27.27**	**13.17**				**17.8**
Polychaeta							
17	*Eulalia* sp.***	2.16	0.02	6.59	–	14.4	0.4
52	*Marphysa belli*	0.22	0.01	1.10	–	0.3	–
	Total	**2.38**	**0.03**				**0.4**
Hidrozoa							
30	*Synthecium evansi*	0.65	0.21	3.30	0.1	2.8	0.1
49	*Macrorhynchia philippina*	0.22	0.03	1.10	–	0.3	–
	Total	**0.87**	**0.24**				**0.1**
Miscellaneous							
39	Eggs	0.22	0.77	1.10	0.2	1.1	–
10	Debris	2.38	3.63	12.09	8.6	72.7	2.0
11	Unidentified Items	2.60	1.11	13.19	2.9	48.9	1.3
	Total	**5.19**	**5.51**				**3.4**
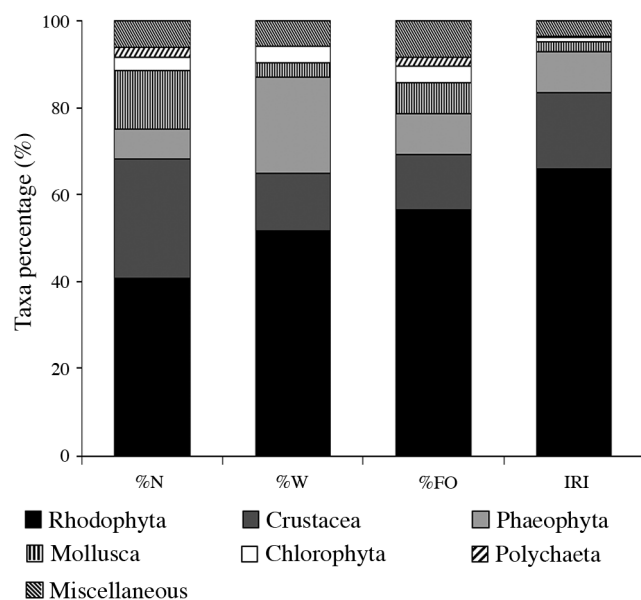
Figure 2. - Distribution of food *taxa* in the diet of *D. sargus lineatus* expressed by numerical percentage (%N), weight percentage (%W), frequency of occurrence (%FO) and index of relative importance (%IRI$_i$).

RESULTS

Diet

Of the 95 stomachs analysed only 4.2% (V$_i$) were empty. The majority of the fish were collected at São Vicente (50%) and at São Nicolau (10%). The number of female (56%, N = 53) stomachs analysed was approximately two times higher (23%, N = 22) than male stomachs. It was not possible to assign sex for the remaining individuals (21% undetermined, N = 20) because they were immature. The minimum, maximum and average fork lengths (mean ± SD – standard deviation) were 93, 293 and 221 ± 32 mm, respectively. Mean fork length (± S.D. FL) was not significantly different between females (219 ± 41mm) and males (229 ± 25 mm) (t-student: t = –1.03, F = 1.28, p > 0.05). The number of stomachs examined in this study appears sufficient, with cumulative numbers of randomly sampled stomachs curves reaching an asymptote at a number of 23 stomachs.

A total of 56 different taxa were found in *D. sargus lineatus* diet that consisted of a wide variety of items: algae (36) and benthic invertebrates (17) (Tab. I). Rhodophyta algae (red algae) were the most consumed item with the highest values of %N, %W and %O. Rhodophyta algae were represented by 26 taxa, almost a half of the total items found in *D. sargus lineatus* diet (Tab. I). This major group also contributed highly in terms of %N, %W, %O (Fig. 3) and both IRI$_i$ and Q (Tab. I). Particularly, *Hypnea spinella*, *Gelidiopsis intricata*, *Polysiphonia* sp., *Grateloupia filicina*, *Lomentaria articulata*, *Amphiroa rigida* played an important role in species feeding diet (principal prey items).

Crustaceans were also important in terms of %N, %W, %FO and IRI$_i$. In fact, crustaceans were second in terms of diet importance (Fig. 2). The most important representatives of this group were *Plagusia depressa*, *Leucothoe* sp. and *Chthamalus stellatus*. Phaeophyta algae with five species and Mollusca with nine species were the third and fourth most important prey groups in the diet of the White seabream of CV.

Molluscs included gastropod species of the genus *Fissurella* and also *Brachidontes puniceus*, *Littorina punctata* and *Patella* sp. Polychaeta and Hidrozoa were not frequently consumed (%FO) and were a prey group of low importance. The principal item species accordingly the relative IRI$_i$ (Tab. II) were: the algae *H. spinella* (%FO 52.75 and %IRI$_i$ 30.7) and *G. intricata* (%FO 28.57 and %IRI$_i$ 12.5);
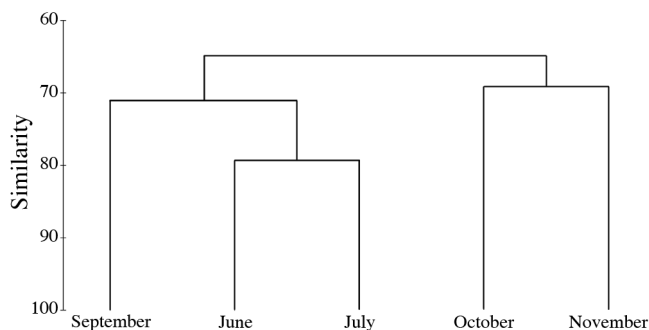
Figure 3. - Monthly variation of *D. sargus lineatus* diet based on numeric percentage of similarity (%N).

Table II. - List of the species items that most contributed to dissimilarity between males and females of *D. sargus lineatus*. Av.Diss.: average dissimilarity; Contrib. (%): percentage contribution to dissimilarity. + or – is used to express the relative abundance in females. * absence in males, ** absence in females.

Taxa	Av.Diss.	Contrib. (%)
Crustacea		
Leucothoe sp. (Amphipoda)	3.21	6.51
Plantae		
Gelidiopsis intricata +	2.34	4.75
Ralfsia expansa –	2.19	4.44
Gelidium pusillum –	2.19	4.44
Hypnea spinella +	2.10	4.06
Polysiphonia sp. +	1.85	3.75
Lomentaria articulata +	1.85	3.75
Amphiroa rigida +	1.85	3.75
Ectocarpus fasciculatus+*	1.36	2.76
Naccaria sp. –**	1.32	2.68
Caulerpa racemosa –**	1.32	2.68
Chaetomorpha sp. –**	1.32	2.68
Gastropoda		
Littorina punctata +*	1.81	3.68
Fissurella sp. +*	1.81	3.68
Bivalvia		
Brachidontes puniceus +*	2.27	4.6
Polychaeta		
Eulalia sp. –	1.74	3.52
Marphysa belli –**	1.32	2.68

the crab *Plagusia depressa* (%FO 24.18 and %IRI$_i$ 11.6), and the amphipod *Leucotoe* sp. (%FO 17.58 and %IRI$_i$ 5.7). The mean diversity, mean number of species per stomach and species richness of sampled *D. sargus lineatus* were (mean ± SD) 3.51 ± 0.5, 14 ± 5.3 and 3.76 ± 0.9, respectively.

Diet sexual shifts

Both female and male diet showed similar (H') diversity with 4.28 ± 0.55 and 4.49 ± 0.61 (t-student: $p > 0.05$). Females showed twice (46) the total number of species/items
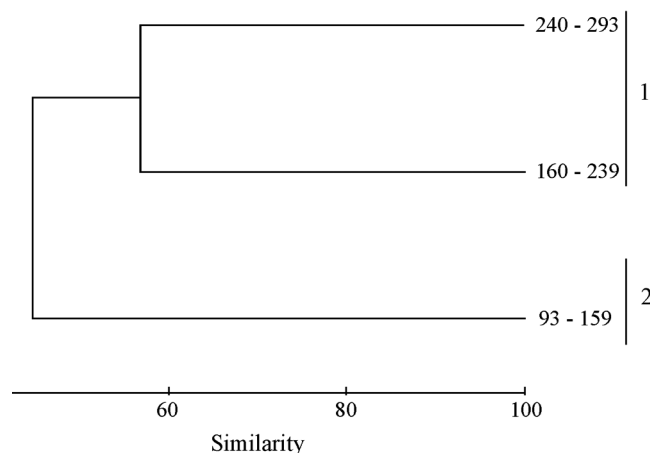

Figure 4. - Diet ontogenetic shifts dendrogram based on monthly average numeric percentage (%N) for *D. sargus lineatus*. Three fork-length size classes were considered: small (93-159 mm), middle (160-239 mm) and large (240-293 mm). Numbers 1 and 2 refer to the two clusters resulting from the size-class grouping analysis.

in diet than males (24). However, the mean number of items per stomachs (mean ± SD) between female (15.6 ± 5.98) and male (10.8 ± 4.19) was not statistical significant (t-student: $p > 0.05$). The diet species richness (mean ± SD) was also slightly higher in the case of females (7.97 ± 1.30) relatively to males (6.15 ± 0.75). However, species richness did not vary among sex (t-student: $p > 0.05$). There was no statistical difference between males and females diet based on monthly average %N (ANOSIM, $r = 0.078$; $p > 0.05$) and similarity was 63%. In fact, similarity differences between sex diets were not specifically marked by the contribution of any particular taxa (SIMPER analysis), but related with the low contribution of a high number of taxa (Tab. II). Monthly diet similarities (based on %N) were higher than 60% across all months meaning that diet composition in general was similar among the study period (Fig. 3).

Diet ontogenic shifts

Cluster analyses of ontogenetic variations in the diet composition separated two groups to a similarity level of 43% (Fig. 4). Cluster 1 grouped both 160-239 and 240-293 mm size classes, that is larger and middle size specimens. Cluster 2 referred to the small size class (93-159 mm). The species that most contributed to dissimilarity between size classes are listed in table III. Middle size classes consumed more *C. stellatus* (hardly incrusting benthic fauna) and hard shell fauna *Fissurella* sp. (Gastropoda) and *B. puniceus* (Bivalvia) than low size classes that feed preferentially on soft Polychaeta preys (*Eulalia* sp.) Moreover, differences among small and larger size classes were due to higher preferences of small sizes on red algae and Crustacea (*Candacia* sp.). ANOSIM analysis did not reveal a statistical difference in diet between size classes (ANOSIM, $r = -0.1$; $p > 0.05$).

Table III. - List of the food items species that contributed the most to dissimilarity among size classes. S, M and L refers to small, middle and large fork-length size-classes; + indicate higher abundance of a prey item in the diet of a given size class.

	Small size (93-159)		Middle size (160-239)	
Middle size (160-239)	Average dissimilarity = 58.58			
	Chthamalus stellatus +[M]	15.82		
	Fissurella sp. +[M]	6.03		
	Eulalia sp. +[S]	5.73		
	Candacia sp. +[S]	5.73		
	Brachidontes puniceus +[M]	5.65		
	Grateloupia filicina +[M]	5.00		
	Leucothoe sp. +[M]	4.77		
	Gelidiopsis intricata +[M]	4.62		
Large size (240-293)	Average dissimilarity = 59.21		Average dissimilarity = 45.59	
	Leucothoe sp. +[L]	21.12	*Chthamalus stellatus* +[M]	15.71
	Amphiroa rigida +[L]	7.31	*Leucothoe* sp. +[M]	15.17
	Candacia sp. +[S]	6.82	*Brachidontes puniceus* +[M]	5.61
	Gelidiopsis intricata +[L]	5.04	*Amphiroa rigida* +[L]	5.02
	Grateloupia filicina +[L]	5.04	*Littorina punctata* +[M]	4.49
	Dictyopteris polypodioides +[L]	4.96	*Ectocarpus fasciculatus* +[M]	4.11

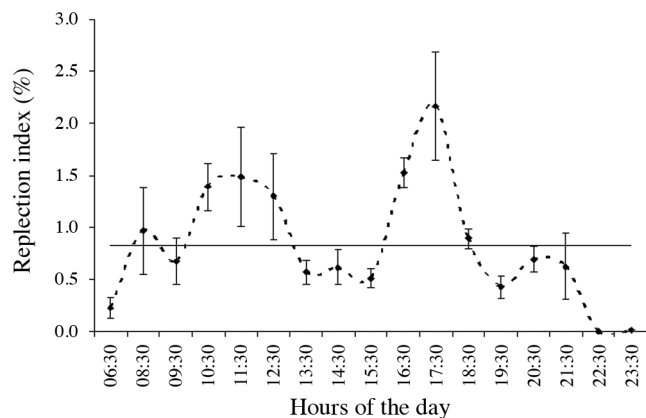
Figure 5. - Diel feeding activity of the *D. sargus lineatus* (N = 95) determined from changes in the mean (± SD) repletion index (R_i). Horizontal line represents the overall R_i mean.

However, the latter results must be interpreted with caution because of the high numbers of permutations.

Diel activity

Diel feeding activity of the *D. sargus lineatus* increased gradually after 6:30 am, until middle day (12:00 pm), followed by a period of feeding break (Fig. 5). From 3:30 pm feeding activity increased gradually reaching a maximum peak at 5:30 pm and then decreased again throughout the afternoon and evening, reaching the lowest activity at 9:30 pm. Followed this peaks feeding activity decreased to values below the overall R_i mean value (0.8 ± 0.52%; mean ± SD). The hour variability (based on SD) of R_i was high variable, namely until 12:30 am.

Biometrics relationships

A total of 248 individual were sampled. Females (24%) to male (10%) sex ratio was 2.56. The minimum, maximum and average fork length (± SD) was 40, 293 and 145 ± 57 mm.

The morphometric relationships established between BH, HL and OD and FL along with statistic results are given in figure 6. The coefficients of determination (r^2) were high for all relationships. Moreover, ANOVA tests ($\alpha = 0.05$) showed that the regression analysis model fitted statistically to the data ($p < 0.05$). The fish morphometric relationships indicated a clear prevalence of negative allometries between BH, HL and OD against FL. Positive allometric growth was observed between W and FL with correlation coefficient up to 98%.

DISCUSSION

The analysis of stomach contents has become the most widely used method for studying the diet of fish. *D. sargus lineatus* diet is generalist, opportunistic and omnivorous, as described for *Diplodus* spp. in coastal rocky areas (Pike and Lindquist, 1994; Gonçalves and Erzini, 1998; Figueiredo *et al.*, 2005), artificial habitats (Leitão *et al.*, 2007 and references therein), estuarine and lagoonal systems (Pita *et al.*, 2002), and interior seas (Marian *et al.*, 2002; Matić-Skoko *et al.*, 2004). The diet of *D. sargus lineatus* includes a large number of algae types (36 taxa), almost two thirds of the items consumed, and benthic invertebrates (17 taxa). The present work shows that *D. sargus lineatus* is predominantly herbivorous, consuming preferentially red algae that are mainly found in intertidal to infralittoral areas of the archipelago. The Rhodophyta group comprised 26 different types and contributed for approximately half of the total items. This algae group is also highly important in terms of %N, %W and %FO. The meaningful number of algae *taxa* (namely red algae) in the diet allows ranking the *D. sargus lineatus* as the highest consumer of algae within Sparid genus (for review see: Froese and Pauly, 2011). This includes works for which algae were as important as in our study (Coetzee, 1986; Sala and Ballesteros, 1997; Matić-Skoko *et al.*, 2004; Figueiredo *et al.*, 2005).

According to previous works (Francescon *et al.*, 1987; Pita *et al.*, 2002) the large number of consumed items and high diet diversity of *D. sargus lineatus* indicate that the species is far from being a specialized predator. Fish have the potential to integrate different aspects of their habitat(s) at spatial and/or temporal scales because of their mobility and longevity (Medina *et al.*, 2007). Thus, fish diet reflects the
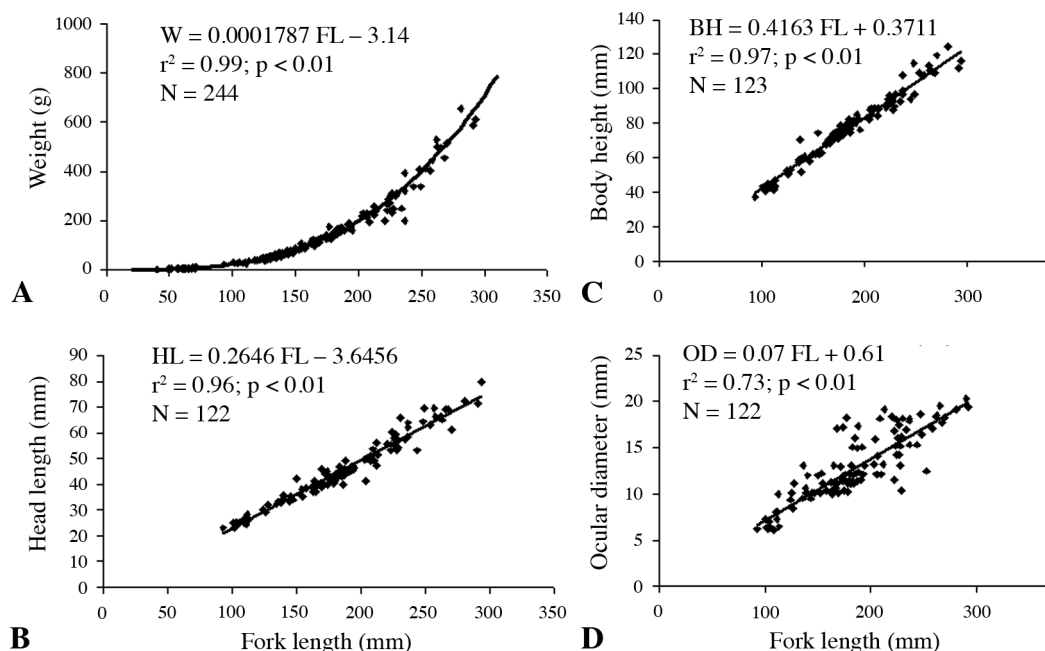
Figure 6. - Distribution of data points and adjusted exponential and linear regression to morphometric relationships. **A**: Weight (g) and fork length (mm); **B**: Body height and fork length (mm); **C**: Head length and fork length (mm); **D**: Ocular diameter and fork length (mm). The p-values ($\alpha = 0.05$) of the ANOVA regression are shown.

available preys, and fish stomach content can be considered as a tool representing prey availability in an aquatic environment (Wootton, 1990). Using *D. sargus lineatus* information from all islands we expect to provide a better characterization (true replication of CV archipelago) of the species feeding diet. This aggregative island analysis allows for having an overall view of the feeding habitats of this endemic species and can be used to describe feeding ecology of the species in CV.

High quantities of *Hypnea spinella* (C. Agardh) Kützing, 1847 were found in *D. sargus lineatus* diet (principal prey). *Hypnea spinella* is an intertidal/subtidal algae, native of Hawaii. Therefore, it can be considered as an alien species recorded for the first time in 2002 in CV coastal waters (John *et al.*, 2004; Prud'homme van Reine *et al.*, 2005). *H. spinella* was previously described in South Spain and Canary Islands (Gil-Rodríguez and Afonso-Carrillo, 1980), where it is also considered an alien species. The species of the genus *Naccaria* Endlicher, 1836 is also poorly studied worldwide and their concurrence in CV islands was unknown until the present study (Guiry and Guiry, 2010). Fishes move to exploit resources, mainly food and shelter, and as a general rule, they select the "best" preys to maximize food intake and to assure the most efficient somatic growth. Present results show that *D. sargus lineatus* have adapted its feeding to alien algae species, even though red algae would be rather unusual considering the short coastal area associated with the Macaronesian Archipelagos. Thus, the use of *D. sargus*

lineatus diet can be used as a valid indirect tool for bio-monitoring marine ecosystem species changes.

Fish species diet can change significantly along the year with more or less marked seasonal variations due to the type of food available, changes in water temperature and specialist or a generalist feeding habits (Macpherson, 1977; *cit. in* Rodríguez-Ruiz *et al.*, 2001; Matić-Skoko *et al.*, 2004). *D. sargus lineatus* monthly diet composition did not differ significantly in terms of the main prey items over the period of the study, indicating that the prey community is fairly stable in diversity and availability. This is a noteworthy result because the persistence of such seasonal pattern (monthly evolution) could indicate *D. sargus lineatus* selectivity preference rather than a generalist feeding behaviour generally attributed to *Diplodus* spp.

In this study ANOSIM tests did not reveal differences among small, middle and larger FL size classes diet. Nevertheless cluster analysis revealed differences with higher similarity between large and middle size classes than between large and small size classes. In fact, a consistent pattern was observed across size classes (SIMPER). There was a decrease in consumption of worms (*Eulalia* sp.) and *Candacia* sp. copepods (soft benthic items) and an increase in consumption of hardly incrusting benthic fauna, bivalves and gastropods with increasing fish size. These results agree with other studies for Sparids that describe ontogenetic dietary changes from soft towards harder prey items (Marian *et al.*, 2002; Pita *et al.*, 2002; Matić-Skoko *et al.*, 2004;

Figueiredo *et al.*, 2005). It is known that Sparids often shift their feeding habits from carnivorous to omnivorous and/or herbivorous with age (Marian *et al.*, 2002; Pita *et al.*, 2002; Matić-Skoko *et al.*, 2004; Figueiredo *et al.*, 2005; Dubiaski-Silva and Masurani, 2004; Castillo-Rivera *et al.*, 2007). This ontogenic diet changes are related to morphological changes in the feeding apparatus (molariform teeth) (Rodríguez-Ruiz *et al.*, 2001 and references therein). This was observed for species of other genus than *Diplodus*, like *Sarpa salpa* where diet changes from essentially omnivorous to almost completely herbivorous (Antolic *et al.*, 1994). Present results showed that algae (epiphyte flora) are ingested preferentially by the greater sizes classes of *D. sargus lineatus*. Therefore, results seem to demonstrate the ability of *D. sargus lineatus* to adapt its feeding behaviour according to prey availability. Different analyses have shown difference in diet ontogeny and thus it is difficult to draw a definitive conclusion. In fact, the ANOSIM numbers of interactions were too high and thus results should be interpreted with caution. Despite ANOSIM weakness, we believe that the general interpretation of our results (based on SIMPER analysis as well as cluster) can still provide opportunities to understand size-related *D. sargus lineatus* diet shifts. Otolith analyses should be performed in the future to increase the knowledge on the demographic structure of the *D. sargus lineatus* population (maximum age is currently unknown). Moreover, demographic studies would allow for more precise ontogenic diet shift analysis, presently only three sizes-classes, immature, young recruits and adults, were used.

A clear diel feeding pattern was observed for *D. sargus lineatus* in the present study. Following the diet intensity peak feeding activity decreases to near R_i overall mean value, except at 10:30 PM when it ceases. This suggests that the CV *D. sargus lineatus* forage during the day and that forage activity is influenced by light intensity. Therefore, the diel feeding rate of *D. sargus lineatus* matched the typical behaviour of size-selective predators that relies mostly on visual cues (Eggers, 1977). The decrease in the R_i in the beginning of the afternoon does not necessarily mean feeding cessation. In fact, there was minor stomach activity after dark, a pattern consistent with previous observations in other *Diplodus* species (Figueiredo *et al.*, 2005). The study was conducted in a period (Summer-early autumn) where nightfall schedule is at approximately 07:00 PM. After sunset feeding activity was always below the overall R_i mean. There are many processes, which can vary throughout the day and influence the R_i, namely digestion, gut passage rates and feeding activity. *D. sargus lineatus* do not forage at night, and gut contents after sunset represent the material in process of digestion (content diminishes accordingly of time) and gut turnover. Present results suggest a low evacuation rate as during the day preys were always observed in fish diet (R_i), a low evacuation rate between the stomach and the intestine, and lack of digestion

in the stomach (Lagardère, 1987). In opposition, Dubiaski-Silva and Masunari (2004) showed rapid digestive process for *Diplodus argenteus* (Valenciennes, 1830). Providing the vast literature on diel feeding pattern of herbivorous fishes and omnivores fish (Figueiredo *et al.*, 2005; Dubiaski-Silva and Masunari, 2004) caution must be taken when assuming that the diel pattern of R_i is similar to the diel feeding pattern. The R_i should be considered as a proxy of the feeding activity of *D. sargus lineatus*, that is a back indicator of the diel activity. Spatial variability affects fish assemblages and populations for species on scales of few kilometres (Munday, 2002). Since samples are from different islands it might be questioned if significant differences (feeding diet and morphometric relationships) would arise between samples/islands. Habitat connectivity is important in shallow areas because species can use rocky corridors to move (Fernández, 2008). In CV, *Diplodus* spp. are more commonly found in nearshore waters than open waters (Fischer *et al.*, 1981; Tenreiro de Almeida *et al.*, 2003). Considering the distances and depths that separate each island, as well as biological depth range distribution of the *Diplodus* species, some isolation might occurs among adult's populations from different islands. However, larvae pelagic stages could favour dispersion among islands. *D. sargus lineatus* is found in all archipelago islands but nothing is known regarding potential population isolation. Therefore, it would be interesting in the future to compare the diet and morphometrics relationships of fish from different islands to know how species can adapt their behaviour to the environment and ecosystem evolution.

Within all biometric measurement OD was the only one that does not present a relationship with FL. Weight, body length and body height showed a good correlation with FL (r > 0.96 for all relationships). Biometric variables are particularly important for gear technologists, since different shapes may influence the retention of fish by different fishing gears and thus can be used to estimate selectivity (Purbayanto *et al.*, 2000; Santos *et al.*, 2006). Due to the fishing gear size selectivity, most samples do not include juveniles or very small individuals and the use of the present relationships should be limited to the size range of studied fish. Additionally, since the individuals were collected over an extended period of time, these data are not representative of a particular season or time of the year and for comparative purposes should be considered as mean annual values.

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