



Universidad de La Laguna.



Facultad de Ciencias
Sección Biología.

**PLASTICIDAD MORFOLÓGICA Y
SOLAPAMIENTO DE NICHOS TRÓFICOS
EN DORADAS (*Sparus aurata*)
ESCAPADAS DE INSTALACIONES
ACUICOLAS EN LAS ISLAS
CANARIAS.**

**MORPHOLOGICAL PLASTICITY AND
TROPHIC NICHE OVERLAPPING OF
SEA BREAM (*Sparus aurata*)
ESCAPED FROM AQUACULTURE
FACILITIES IN THE CANARY ISLANDS.**

María José Valera Jiménez

Máster Biología Marina: Biodiversidad y Conservación.

Junio 2018

KILIAN TOLEDO GUEDES, Investigador colaborador sénior del Departamento de Ciencias del Mar y Biología Aplicada de la Universidad de Alicante y PABLO SÁNCHEZ JEREZ, Profesor titular de la Universidad de Alicante.

CERTIFICAN:

Que la memoria presentada por la graduada en Ciencias del Mar María Josefa Valera Jiménez, titulada “Morphological plasticity and trophic niche overlapping of sea bream (*Sparus aurata*) escaped from aquaculture facilities in the Canary Islands.”, ha sido realizada bajo nuestra dirección y consideramos que reúne todas las condiciones de calidad y rigor científico requeridas para optar a su presentación como Trabajo de Fin de Máster, en el Máster de Biología Marina: Biodiversidad y Conservación de la Universidad de La Laguna, curso 2016-2018.

Y para que así conste y surta los efectos oportunos, firmamos el presente certificado en

Alicante,

a 28 de mayo de 2018



Fdo. Kilian Toledo Guedes



Fdo. Pablo Sánchez Jerez

TABLE OF CONTENTS

ABSTRACT	4
INTRODUCTION	5
MATERIALS AND METHODS	8
RESULTS	11
DISCUSSION	16
CONCEPTUAL MODEL	21
CONCLUSIONS	21
REFERENCES	22

Resumen

Los escapes en acuicultura suponen uno de los principales problemas de esta actividad, suponiendo una amenaza para la biodiversidad en los ecosistemas, como en el caso de la dorada (*Sparus aurata*) en las islas centrales y occidentales de Canarias. Este impacto puede ser mayor si los escapes se adaptan al medio, sufriendo un proceso de asilvestramiento. Con el objetivo de determinar si las doradas escapadas de granjas acuícolas son capaces de adaptarse al medio en las Islas Canarias se capturaron 71 individuos escapados mediante pesca con fusil, mientras que otros 20 fueron recolectados directamente de jaulas. El contenido estomacal fue clasificado, identificado y comparado con dietas de diferentes espáridos obtenidas a través de la revisión de literatura centrada en el Atlántico y el Mediterráneo. También se estudiaron cambios fenotípicos en la morfología, comparando individuos escapados con cultivados. Los análisis del contenido estomacal demuestran que una vez en el medio, los individuos son capaces de alimentarse de presas naturales, principalmente moluscos, crustáceos y plantas, compartiendo nicho trófico con otras especies. Además, las diferencias morfométricas sugieren que los individuos escapados pueden adaptarse al medio adoptando una morfología similar a la de individuos salvajes. En conclusión, una vez en el medio, son capaces de alimentarse y adaptar su morfología externa a las nuevas condiciones, lo que puede plantear un problema de solapamiento de nicho trófico con consecuencias desconocidas para el ecosistema.

Palabras clave: Acuicultura, Dorada, Escapes, Morfometría, Solapamiento de nicho trófico.

Abstract

Escapes of farmed fish from net-pens are one of the main concerns related to aquaculture being considered a threat to natural biodiversity in ecosystems, just as in the case of gilthead sea bream (*Sparus aurata*) in central and western Canary Islands. The impact of escapees is expected to be higher if the species is able to adapt to the natural environment, through a feralization process. The main objective of this study was determining if sea bream escapes of aquaculture farms are able to adapt to the environment in the Canary Islands, for this, 71 escaped sea bream individuals were captured by spearfishing, while twenty of them were collected from aquaculture cages. Stomach contents were sorted, identified and compared with the diets of other sparids, which were obtained through a literature review focused on the Atlantic and the Mediterranean. Moreover, we studied phenotypic changes in the morphology of escapees once in the wild; comparing morphometry of escaped and cultured sea bream. The stomach content analyses showed that escaped sea bream feed on natural preys (mainly mollusks, crustaceans and plants), sharing trophic niche with other cohabiting species. What is more, morphometric differences suggested that escaped individuals are able to adapt to the environment, adopting more fusiform body morphology, similar to wild individuals. In conclusion, escaped sea bream, once in the wild, is able to forage over natural preys and adapt its external morphology to the new environmental conditions, which could pose a problem of trophic niche overlapping, with unforeseen consequences for the ecosystem.

Key words: Aquaculture, Escapees, Gilthead sea bream, Morphometry, Trophic niche overlapping.

Introduction

The gilthead sea bream, *Sparus aurata* (L.), hereinafter called *S. aurata*, is a subtropical Sparidae whose distribution covers 62°N-15°N, 17°W-43°E (Lloris, 2005). It occurs naturally in Eastern Atlantic, from the British Isles to Cape Verde and around the Eastern Canary Island (Lanzarote and Fuerteventura) (Brito *et al.*, 2002), also can be found in the Mediterranean and the Black Sea (Magoulas *et al.*, 1995). This species inhabits seagrass beds and sandy bottoms as well as the surf zone, commonly to depths of about 30m, but adults may occur at 150m depth. It may be found either solitary or in small aggregations. It is mainly carnivorous feeding for the most part shellfish, (e.g. mussels and oysters) and accessorially herbivorous (Bauchot and Hureau, 1990). The sea bream is a protandrous hermaphrodite: maturing first as male in the first two or three years of age and after that, maturing as female, normally at over 30cm in length (Bauchot *et al.*, 1981; Buxton and Garrat, 1990).

Sea bream is a highly appreciated target species in the Mediterranean and Atlantic countries, regularly present in fish markets where they come from both extractive fisheries and aquaculture. For this latter activity, it is estimated that 195,853t in Europe were produced in 2016; meanwhile, extractive fisheries in the Atlantic Ocean and Mediterranean Sea, captured a total of 8,438t in 2015 (APROMAR, 2017). At the present, sea bream is cultured in 20 different countries, and Spain is the fourth country producing sea bream with a 7% of the total production, far from Turkey, the main producer, with 67.612t, which represents a 34.5% of total production. Aquaculture began to grow exponentially both in production and diversity of cultured species the last 50 years (Duarte *et al.*, 2007; FAO, 2012), maybe due to the over-exploitation suffered by wild fish stocks, which has led the stagnation of world fisheries (Jackson *et al.*, 2001; Worm *et al.*, 2006). Actually, the world capture production of sea bream is quite constant throughout the years, fluctuating from 6000 to 8500 t y⁻¹. In Spain, fishery captures of sea bream kept constant and reached 826t in 2015 while cultured sea bream amounts to 13,740t, 95.1% of Spanish product in markets (APROMAR, 2017). Here, the Valencian Community is ahead in the Spanish production with 5619t (40.9%), followed by Murcia, with 3368t (24.5%), Canary Islands with 2492t (18.1%), Andalusia with 1605t (11.7%) and Catalonia with 730t (4.8%) (APROMAR, 2017).

When one or several fish in any point of their life-cycle lose their confinement it is considered an escape event (Dempster *et al.*, 2013). These events can be large-scale escapes, when a fish-cage suffer structural damages by storms or sabotage, and most of the fish escape, or daily

escapes, through small holes in the net (CIESM, 2007). The latter is quite problematic to quantify since it is difficult to estimate the number of fish escaped before the holes are found (Dempster *et al.*, 2007). Escape events from fish cages are a common problem around the world and both native and non-native species are regularly released into the wild (Naylor *et al.*, 2005). In the case of escape of non-native species, they are more concerning in aquatic systems (Ruiz *et al.*, 1997, 2000; Streftaris *et al.*, 2005; Casal, 2006) due to their potentiality to adapt to the new natural environment and interact with native species.

Escaped farmed fish from sea-cages are able to survive, they may entail a threat to natural biodiversity in marine waters, they are considered as one of the main environmental problems caused by aquaculture due to the potential for escaped fish to interact with natural populations (McGinnity *et al.*, 2003; Arechavala-Lopez *et al.*, 2017). For management reasons, after an escape it could be relevant to be able to distinguish the escapes from wild individuals and monitoring the level of escapees' feralization. Domesticated organisms tend to exhibit morphological and physiological variations because of artificial selection that can persist under favourable conditions, as the abundance of food and absence of predators in captivity (Trut *et al.*, 2009; Balon, 2004; Teletchea and Fontaine, 2012), that are never seen in the wild. As has been shown in other studies, could identify differences between wild and reared individuals (i.e. salmon) thanks to different patterns since the development in hatcheries is faster and more controlled than in the wild (Swaine *et al.*, 1991; Fleming *et al.*, 1994; Hard *et al.*, 2000; Fiske *et al.*, 2005). During its lifetime, the individuals develop a series of behavioural, physiological and morphological changes (Toledo-Guedes, 2013). These changes, as differential relative growth of body parts, is a common feature of fish development and help to overcome drastic environmental stress once away from favourable conditions that human control contribute (Osse, 1990; Osse and van den Boogaart, 1995, 1999; Gisbert, 1999; Loy *et al.*, 2001; Brown and Laland, 2001) and may facilitate feralization (Valiente *et al.*, 2010) in the same way that aids to succeed in the initial stages of domestication. Several studies reveal that sea bass escaping from fish farms tend to converge towards a more similar wild phenotype compared to farmed conspecifics. Toledo-Guedes (2013) found clear differences in body shape dividing farmed fish, with more rounded body shape and wild fish, with smaller body depths and more streamlined bodies.

Once in nature, escaped fish exploit natural resources as soon as they are able to survive in the wild (Arechavala-Lopez *et al.*, 2012c). They are able to swim away from farm facilities which is a major environmental concern because they can interact with other species with potential

negative ecological consequences such as: direct predator-prey interactions, interspecific competition for resources, trophic cascade effects or competition for habitat occupation (Soto *et al.*, 2006; Arismendi *et al.*, 2009; Edelist *et al.*, 2013) even more important if they are able to access to Marine Protected Areas (Arechavala-Lopez *et al.*, 2011; Izquierdo-Gomez *et al.*, 2014; Toledo-Guedes *et al.*, 2014). Sometimes interactions with other species imply protected species or highly appreciated in the market. Moreover, escapees become available for sport and professional fisheries, attracting fishing pressure over certain areas or promoting the over-exploitation of other non-targeted species (Lorenzen *et al.*, 2012). Because of the high availability of escaped fish, easily caught by non-professional fishermen, market prices can collapse locally and these fish could be sold as wild fish even if their origin is unknown, with subsequent detriment to the consumer (Toledo-Guedes, 2013; Arechavala-Lopez *et al.*, 2012a,b,c, 2013a). Other problems could be transmission of pathogens to wild populations (Arechavala-Lopez *et al.*, 2013b) or even affecting to genetic diversity of natural populations which is important to prevent due to natural populations with low genetic diversity means more limited capacity to respond to changes in the environment (Araki and Schmid, 2010).

In the Canary Islands, marine fish production is mainly limited to two locally-absent species, legally cultured around different islands (La Palma, Tenerife, Gran Canaria and Lanzarote): Gilthead sea bream, *Sparus aurata* and the European sea bass *Dicentrarchus labrax* (Toledo-Guedes, 2009). Before aquaculture activities, these species were present only in the eastern islands: Lanzarote and Fuerteventura (Brito *et al.*, 2002) possibly due to larval dispersion through upwelling filaments from African coastal populations (Rodriguez *et al.*, 1999; Becognée *et al.*, 2006). Moreover, sea bream was not captured or recorded by visual census in coastal areas of central and western islands before the aquaculture development (Brito, 1991; Brito *et al.*, 2002; Falcón *et al.*, 1996). Therefore, escaped sea bream can be clearly identified in central and western islands since there are no natural populations. Even when natural mortality is believed to be high, they are able to disperse rapidly from aquaculture facilities and may resemble their wild conspecifics thanks to different adaptations to the new environment through the production of an alternative phenotype known as phenotypic plasticity (Arechavala-Lopez *et al.*, 2011, 2012a, 2012b; Uglem *et al.*, 2008; West-Eberhard, 1989).

There are many studies dealing with the long range dispersion of escaped sea bream and sea bass (González-Lorenzo *et al.*, 2005; Toledo-Guedes *et al.*, 2009; Arechavala-Lopez *et al.*, 2011a,b) but predicting establishment success of fish escaping is not without difficulties

(Bekkevold *et al.*, 2006; DeVaney *et al.*, 2009; Consuegra *et al.*, 2011). Food regime and swimming activity can have strong effects on body shape (Pakkasmaa and Piironen, 2001; Marcil *et al.*, 2006). Sea bream feralization appears to involve a sudden and dramatic shift in food regime and a variable period of starvation (Arechavala-Lopez *et al.*, 2012c). Food deprivation would result in the mobilization of lipids and loss of weight, specially hepatic weight (Pérez-Jiménez *et al.*, 2007). Sea bream escapees from sea cages have been well recorded in the Mediterranean Sea (Dempster *et al.*, 2002, 2005; Boyra *et al.*, 2004; Tuya *et al.*, 2005, 2006; Valle *et al.*, 2007; Fernandez-Jover *et al.*, 2008; Arechavala-Lopez *et al.*, 2012), due to technical and operational failures, cage breakage because of extreme weather or holes caused by wear or gnawing from cultured fish on fouling (Dempster *et al.*, 2007). However, few corresponding studies have been carried out for escaped fish from fish farms in the Northeastern Central Atlantic and their capacity to adapt to a new environment.

The main objective of the present study was to investigate if sea bream escapees are able to adapt to the environment in the Canary Islands. For this we (1) identified main items of the diet of escaped sea bream, (2) investigated trophic niche overlapping with other sparid species and (3) assessed morphometric changes in escaped individuals when compared to cultured individuals.

Material and methods

Study site and sampling method

The study was carried out in the Canary Island (Figure 1), a subtropical archipelago situated in the North of the Eastern Central. A total of 71 sea bream were spear-caught between June 2007 and April 2009 in two of the islands where sea bream has escaped some other time: Tenerife and La Palma (Toledo-Guedes *et al.*, 2009). Also, 20 sea bream were caught from aquaculture facilities in Tenerife Island.

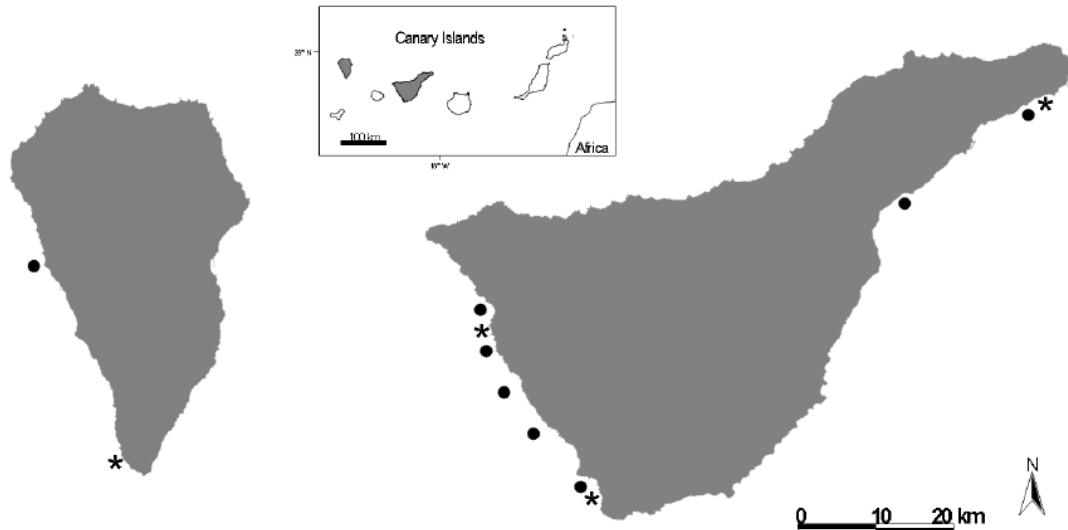


Figure 1. (Toledo-Guedes *et al.*, 2009). Location of sea bream farms (·) and sampling sites (*) in the coastal waters of the islands of Tenerife and La Palma (Canary Islands, Spain).

Stomach contents and diet analyses

The stomach-intestine was removed, and prey items were counted by number, fresh-weighed and identified to the lowest possible taxonomic level. Based on the study of Prokopchuk and Sentyabov, 2006, we use the following scale: 0-empty; 1-very little content; 2-some content; 3-full, but not bloated; 4-bloated; 5-everted; to determine the Stomach Fullness (SF). After that, percentage by number (%N), weight (%W), frequency of occurrence (O%) and alimentary coefficient (Q) as result of $N\% \times W\%$, were calculated for each prey (Hureau, 1970). Vacuity was calculated as percentage of empty stomach. The importance of prey groups was assessed using the categories used by Rosecchi and Nouaze, 1987, based on values of Q and O: main preferred prey, when $Q > 100$ and $\%O > 30\%$; main occasional prey, when $Q > 100$ and $\%O < 30\%$; secondary common prey, when $10 < Q < 100$ and $\%O > 10\%$; secondary additional prey, when $10 < Q < 100$ and $\%O < 10\%$ and finally, accidental prey, when $Q < 10$. Index of Relative Importance (IRI) was also estimated using next formula: $IRI = (N\% + W\%) \times O\%$ (Pinkas *et al.*, 1971).

A literature review was carried out for other species and fish diets were obtained from published studies based on stomach contents. An amount to 15 papers were reviewed but only to gather data from 8 different species. First, we tried to choose those papers where sparids diets were showed in the Atlantic Ocean but due to difficulties to find them, we also reviewed papers about sparids diets in the Mediterranean Sea. All of them were chosen because they showed a size range similar to wild sea bream individuals to be analyzed. We use data diet of

Epinephelus marginatus (fam. Serranidae) as reference. We obtained quantitative data in order to compare with those obtained for sea bream escapees. Moreover, we were able to compare our data with other three significant sparids diet data, one of them from *Pagellus acarne*, in the Atlantic Ocean in Azores (Morato *et al.*, 2001) and the other two from *Sparus aurata* in the Mediterranean Sea (Rosecchi and Nouazé, 1987; Arechavala-Lopez *et al.*, 2012) being the last one also data from escaped fish. To determine diet overlap we used the Schoener index (SI):

$$SI = 1 - 0.5(\sum_{i=1}^n |P_{iA} - P_{iB}|)$$

Where P_{iA} and P_{iB} are the numerical frequencies of item i in the diet of species A and B, respectively (Linton *et al.*, 1981). Values of this index vary from 0, where there isn't trophic overlap, to 1, where species make the same proportional use of food resources. Using this index we have to consider those values higher than 0.6 should be account as biologically significant (Wallace, 1981; Wallace and Ramsey, 1983) although there are no critical levels with which overlap values can be compared.

Variation in body morphology

We study feralization level using body shape divergence. For it, we took standardized photographs of 20 escapees and 19 cultured fish from Tenerife using a Nikon Coolpix 5400 digital camera. To ensure correct calibration in the following image processing, was necessary to use a ruler on each photograph. Morphological landmarks were selected to give a precise definition of the fish morphology (Figure2) (Humphries *et al.*, 1981; Straus and Bookstein, 1982). Altogether 16 morphological landmarks were digitized using the image processing programme ImageJ (Abramoff *et al.*, 2004). After that, distances between landmarks were calculated using the programme PAST v.2.17c (Hammer *et al.*, 2001).



Figure2. The 16 Landmarks which were used for the morphological analysis, scale 5cm. 1 tip of the premaxillary; 2 point of maximum curvature in the head profile curve; 3 anterior insertion of dorsal fin; 4 posterior insertion of dorsal fin; 5 dorsal point at least depth of caudal peduncle; 6 posterior extremity of the lateral line; 7 ventral point at least depth of caudal peduncle; 8 posterior insertion of anal fin; 9 anterior insertion of anal fin; 10 anterior insertion of pelvic fin; 11 insertion of the operculum on the profile; 12 dorsal insertion of pectoral fin; 13 most anterior point of the eye; 14 most dorsal point of the eye; 15 most posterior point of the eye; 16 most ventral point of the eye.

Statistical analyses

In order to have a visual representation of species with similar trophic niche, cluster diagram was performed. Previously, the data were standardized since sample size for each study reviewed was different. Finally, dissimilarity matrix was calculated, where higher values mean greater differences. These analyses were carried out with Statistical software R (R Development Core Team, 2011).

Prior to analysis, all morphometric measurements were size-adjusted using the ‘allometric vs. standard’ method proposed by Elliot et al., 1995. Discriminant analysis was used as a standard method for visually confirming or rejecting the hypothesis that cultured and escapees individuals are morphologically distinct. Equality of the two groups is tested by a multivariate analogue to the t-test, called Hostelling’s t-squared. For this purpose, we use the program PAST version 2.17c (Hammer *et al.*, 2001).

Results

Stomach content and diet analysis

An amount of 91 sea bream specimens were caught. Total lengths varied from 11.8 to 42.9 cm, with a mean value \pm standard deviation (sd) of 26.64 ± 4.53 cm. Diet indices are provided

in Table 1 obtained from the study of 33 stomach analyzed. Percentage of vacuity was 51.50% while Mean Stomach Fullness (MSF) was 0.87. Alimentary coefficient (Q), frequency of occurrence (O%) and IRI identifies Mollusca as main prey. Human origin items, Crustacea (Decapoda), Echinodermata and plants as secondary common preys and insecta and Polychaeta as accidental preys.

Table1. Diet composition of escaped *Sparus aurata*. Mean Stomach Fullness (MSF), Vacuity, numeric percentage (%N), weight percentage (%W), frequency of occurrence (%O), alimentary coefficient (Q), Index of Relative Importance (IRI) and Prey Preferences.

Prey	N%	W%	O%	Q	IRI	Prey Preferences
Polychaeta						Accidental preys
Unidentified	1,7	0,05	6,25	0,09	10,95	
Crustacea (Decapoda)						Secondary Common preys
<i>Xantho pilipes</i>	1,7	0,16	6,25	0,27	11,61	
<i>Ethusa sp.</i>	1,7	0,11	6,25	0,18	11,28	
Fam. Calappidae	3,4	0,11	12,5	0,36	43,82	
Unidentified	3,4	1,27	12,5	4,3	58,31	
Total	10,3	1,63	31,25	16,83	372,94	
Insecta						Accidental preys
Unidentified	3,4	0,16	12,5	0,54	44,48	
Equinodermata						Secondary Common preys
<i>Diadema africanum</i>	3,4	20,03	12,5	68,11	292,9	
Mollusca						Main prey
<i>Timoclea ovata</i>	8,7	50,61	6,25	440,27	370,66	
Fam. Cerithidae	50	2,53	12,5	126,52	656,63	
Total	58,7	53,14	18,75	2096,93	3119,1	
Plantas						Secondary Common preys
<i>Cymodocea nodosa</i>	3,4	0,74	12,5	2,51	51,73	
Unidentified	3,4	0,74	12,5	2,51	51,73	
Total	6,8	1,48	25	10,18	209,4	
Ítems de origen human	12,2	12,76	43,75	155,64	1091,9	
MSF	0,87					
Vacuity	51,50%					

The most important preys by number were mollusks of the family Cerithidae, followed by the bivalve *Timoclea ovata*. Those which contribute highly by weight to their diet were the mollusk *T. ovata* and the echinoderm *Diadema africanum*. Some food pellets were found in the stomach contents which are outlined as secondary common prey with the Index of Relative Importance.

Trophic Niche Overlapping

Table2. Reference, Specie and Number of individuals analyzed founded in literature and Location code (At for Atlantic Ocean, M for the Mediterranean Sea: here, codes 1and 2 are to distinguish the same specie studied by different authors).

Reference	Species	Number of individuals analyzed	Location Code
Arechavala <i>et al.</i> , 2012	<i>Sparus aurata</i>	38	M2
Killianotis <i>et al.</i> , 2005	<i>Lithognathus mormyrus</i>	120	M
Linde <i>et al.</i> , 2004	<i>Epinephelus marginatus</i>	157	M
Morato <i>et al.</i> , 2001	<i>Pagellus acarne</i>	235	At
Papaconstantinou <i>et al.</i> , 1989	<i>Pagrus pagrus</i>	122	M
Rosecchi and Nouazé, 1987	<i>Diplodus sargus, S. aurata</i>	471, 183	M, M1
Salas and Ballesteros, 1997	<i>Diplodus puntazzo</i>	16	M
Santic <i>et al.</i> , 1983	<i>Pagellus erythrinus</i>	798	M

According to the dendogram obtained from the cluster analysis performed on frequency percentage data (Figure 1), obtained about our data of *S. aurata* and the different species found in the literature (Table 2), three main cluster can be identified with a 50% of similarity. Could be verified in the first group that the most similar species trophically here are *E. marginatus*, used as reference, whose diet resembling to sparid diet *P. erythrinus* (l) (0.15). Following it, in this first group we can find diet similarity with *P. erythrinus* (m) (0.35) and *S. aurata* from Rosecchi and Nouazé, 1987 (0.40). The second group is composed only by specie *P. acarne* from Morato *et al.*, 2001 and this group has a 50% of similarity with the third group, where we can find our specie. Third, grouping different species gatherer in the same group with the results obtained for our *S. aurata* (*S. aurata* At), indicating that escapees are able to feed on in the same way that wild populations do. Most similar species in this third group are *D. sargus* and *L. mormyrus* with 75% of similarity approximately. Also could find association with *S. aurata* from Arechavala *et al.*, 2012 study, whose individuals are escapees too, in this case from fish farms in the Mediterranean Sea, this result corroborate that, once in the wild, escapees are able to feed on natural preys, adapting to the environment like wild individuals and with survival opportunities. Following specie in similarity is the sparid *D.*

puntazzo individually. Finally, this complete group is gathered in the same place that couple *S. aurata* At and *P. pagrus*.

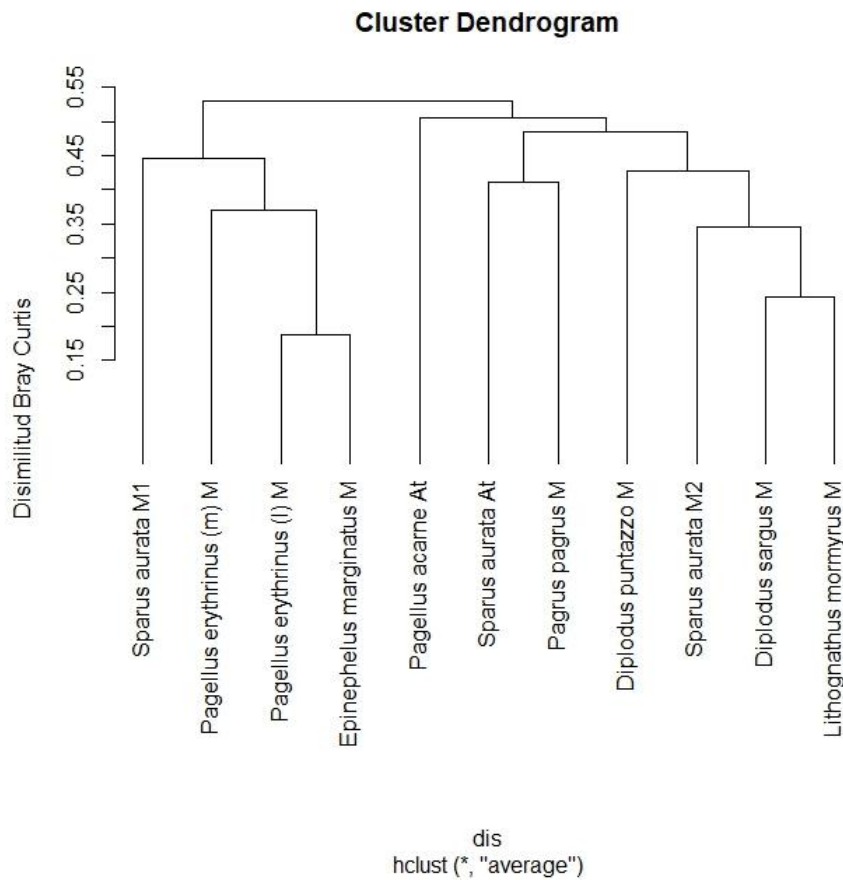


Figure 2. Dendrogram resulting from the cluster analysis performed on stomach contents data of the *Sparus aurata* studied in the present work (*Sparus aurata* At), being cultured and escapees from the aquaculture facilities of the Canary Island, compared with the different species founded in the literature.

Estimates of the degree of trophic overlap among species are given in Table3. Values under 0.6 founded between species indicate no significant overlap, according to the percentage of frequency values, diet overlap was higher than 0.6 between *S. aurata* At and the sparid *P. acarne* At and their conspecific of the Mediterranean Sea found in Arechavala et al., 2012.

Table3. Schoener Index (SI) values of trophic niche overlap between the different species. Code used for species was: S.a At for our data about *Sparus aurata*; P.p M for *Pagrus pagrus*; D.s for *Diplodus sargus*; D.p for *Diplodus puntazzo*; P.e (m) for *Pagellus erythrinus* (m); P.e (l) for *Pagellus erythrinus* (l); P.a for *Pagellus acarne*; L.m for *Lithognathu smormyrus*; S.a M2 for *Sparus aurata* of Arechavala et al., 2012; S.a M1 for *Sparus aurata* of Rosecchi and Nouazé, 1987 and E.m for *Epinephelus marginatus*. Those values coupled by (*) are higher than 0.6.

Sp	S. a At	P. p M	D. s	D. p	P. e(m)	P. e (l)	P. a	L. m	S. a M2	S. a M1	E. m
<i>S. a At</i>	1	0.59	0.55	0.46	0.45	0.44	0.61*	0.48	0.61*	0.34	0.54

Morphometry

The discriminant analysis carried out shows the difference of the individuals according to their origin, representing the individuals cultivated in blue and the escapees in red. Specimens were sharply separated along the discriminant axis (i.e. escapees in the positive portion, captive ones in the negative portion) (Figure3). Results of discriminant analysis are significant for all pairwise body-shape comparisons, and reveal a high discrimination in body shape between cultured and escapees. The relative classifications are very reliable (Percent correctly classified= 87.47%, Hotelling's $T^2= 53.144$, P-value= 0.04288). As is shown in Figure3, there are differences between cultured and escaped fish. In general, fish kept in fish farm develop deeper bodies, shorter heads and shorter caudal peduncles over time, whereas almost exactly the opposite occurs when they are released into the wild.

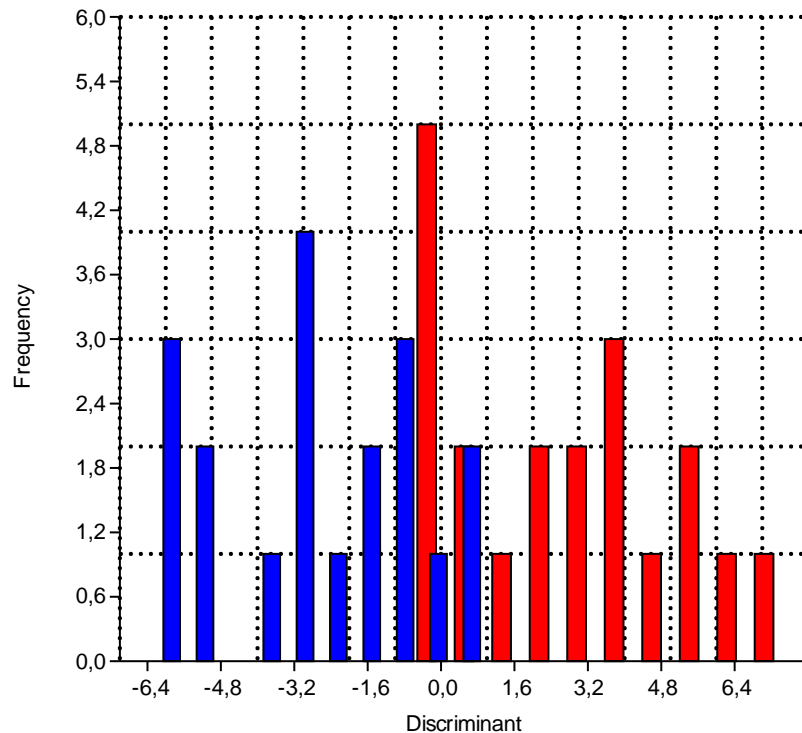


Figure3. Discriminant analysis for the grouping variable domestication status, here appears represented escapees in red and cultured fish in blue. In the middle of the figure could be observed that two both, cultured and escapees, overlap in morphometry.

In Table4, it can be observed that 17 of 20 cultured fish are well classified in their category, which represent 85%, while remaining part (15%) are classified as escapees. On the other hand, 17 out of 19 escapees are correctly classified, which represents 89.47%, while 10.53% are classified as cultured fish.

Table 4. Number of escapees and cultured fish classified per category in the discriminant analysis.

	Escapees	Cultured
Escapees	17	2
Cultured	3	17

Discussion

Throughout this work and as shown the results obtained in previous studies, it is plausible to say sea bream is able to adapt to the environment in the Canary Islands, being introduced in the central and western Canary Islands as a consequence of escape events from aquaculture activities. Furthermore, sea bream are able to feed in the natural environment, with a diet similar to their wild conspecifics from the Mediterranean Sea and their external morphology is more fusiform, adapting to new conditions in the wild, being more agile to both, avoid predators and access new preys, which could pose a problem of trophic niche overlapping, with unforeseen consequences for their preys and other competitor fish species.

When an escape occurs, the decisive survival factors are density and size of the escaped individuals (Pitcher, 1986; Kristiansen *et al.*, 2000). An unknown number of sea bream are able to survive in the environment, adapting to natural conditions and interacting with natural assemblages, and the activities taking place there (e.g. fisheries). Fisheries will play an important role in mortality of individuals and previous studies, such as Arechavala-Lopez *et al.*, 2010 reveal higher catches in seagrass, sandy or rocky bottoms, where wild individuals inhabit (Arechavala-Lopez *et al.*, 2012). In the Canary Islands, professional and recreational fishing are one of the main factors that control the densities of escaped fish (Toledo-Guedes, 2013), although it is not a determining factor in mortality of fish. On the other hand, the presence of predators around farms will be more important, especially when it comes to small escapes. It is known that pelagic fish are attracted to floating structures on the natural environment (Freon and Dagorn, 2000; Castro *et al.*, 2002) the same happens in FADs (Fish Aggregating Devices) and in aquaculture facilities (Dempster *et al.*, 2004). Some pelagic species are attracted to farms because they feed on unconsumed pellets, and this attracts piscivorous species due to greater abundance of small fish on which they prey (Sánchez-Jerez *et al.*, 2011). High densities of predators have been recorded in the vicinity of the facilities (Fernandez-Jover *et al.*, 2008, Arechavala-Lopez *et al.*, 2010, 2011a), these are the first steps

to avoid, the chance of survival increases when a massive escape occurs (Toledo-Guedes, 2013) since a greater number of individuals are able to escape and move to more remote areas.

Once in the wild, if individuals are not able to exploit natural resources, there are high mortality cases (Ramirez *et al.*, 2011). It has been registered that escapes, in general, have lower competitive capabilities than wild individuals, being unable to respond to environmental stimuli, which negatively affects their survival (Olla *et al.*, 1994; D'Anna *et al.*, 2004; Santos *et al.*, 2006; Basaran *et al.*, 2007). They also have a smoother and less aggressive mobility than their conspecifics, with a lower capacity to feed, which, added to the energy spent while moving around new sites, will result in a loss of energy during the first days (Sosiak *et al.*, 1979; Ersbak and Haase, 1983) and with it, changes in corporal morphology. Changes in behavior and environmental stimuli received over time, if favorable, will lead to the process of feralization (Daniels and Bekff, 1989). Therefore, many authors consider that both anti-predatory capabilities and ability to feed on natural preys are an important step in adaptation to the natural environment (Olla *et al.*, 1998; Brown and Laland 2001, 2003; Toledo-Guedes, 2013). Regarding to changes on trophic behavior, Wainwright and Richard (1995), based on the similarity of the serranid morphology and the interspecific relationships between their size and trophic composition, determined that the changes in the diet are associated more associated with the size of the individuals than with the differences in the capture mechanisms, extrapolating these results to those obtained in our study with the sea bream, may also imply that they compete with other species even of different families with which they share a range of size. In addition, the variation in the importance of preys will be related to the differences in the availability of it (Ferrari and Chierigato, 1981; Francescon *et al.*, 1987; Breber and Strada, 1995) and this availability will change depending on seasons (Zander, 1996). During the present study, the results obtained corroborate not only the trophic flexibility of the sea bream escape, but also their ability to find the most common prey in a medium in which they do not naturally occur. In the case of sea bream, it has been observed that it has a wide trophic range. Being an opportunistic animal, it is able to adapt its diet to the prey available at that time (Pita *et al.*, 2002, Tancioni *et al.*, 2003) and this period of starvation does not occur so frequently, being able to feed on their most common prey as of the fifth day after released (Arechavala-López *et al.*, 2012). This may entail a higher risk of invasion, displacing other native species of the islands or that frequent that area of the Atlantic, although many other factors are involved in the invasion process (Casal, 2006). They

naturally predate mainly on bivalve mollusks, followed by decapods, gastropods and crustaceans, although they can also feed on polychaetes, amphipods, seagrass, algae and, occasionally, fish (Arias, 1980; Rosecchi, 1985; Pita *et al.*, 2002; Tancioni *et al.*, 2003; Chaoui *et al.*, 2005). As soon as the escape occurs, sea bream adapt their feeding to macrophytes and pellets arising from farm; later they begin to feed on echinoderms and crustaceans associated to the facilities and finally feed on mollusks and crustaceans (Arechavala-Lopez *et al.*, 2012). Remarkably, escaped sea bream in the Canaries predate over *Xanthopilipes*, a highly appreciated bait species in recreational and professional fisheries of the parrotfish *Sparisoma cretense*. Moreover, predation over *Diadema africanum*, a species forming barren grounds due to the lack of predators (Clemente *et al.*, 2012) could lead to further changes at local level, mitigating the effect of this intensive grazer.

Analyzing the Schoener Index we find that there is some trophic overlap with *Pagellus acarne* from the paper by Morato *et al.*, 2001 studied in the Azores archipelago. Taking into account the distribution of *P. acarne*, which could be found from the Mediterranean to the east of the Atlantic Ocean, where the British Isles and the entire Macaronesia region are included (Barreiros *et al.*, 2002), and depths from 40 to 100m usually (Muus and Nielson, 1999), the introduction of sea bream in the Canary Islands, where *P. acarne* could be found naturally, could have negative consequences in case of becoming an active competitor. This trophic overlap could not be common due to *P. acarne* is a benthopelagic specie, however, this study demonstrate that there are evidences that *S. aurata* is able to compete with other species of a new environment, not only with species from the same family, but it could be extrapolated, as studied by Wainwright and Richard (1995) to any species with which it shares size range.

Due to scarcity of information available on trophic niche of fish species from the Canary Islands, we cannot assume, neither rule out, that escaped sea bream is able to displace other species cohabiting in the area. Many authors agree on the difficulty of assessing the effects caused by the introduction of a new species in marine ecosystems where it does not live (Underwood, 1997), especially if it involves shallow waters, where the introduced species are subject to the ecological relationships they develop naturally with the environment and other species (Toledo-Guedes, 2013). Generally, when clear cause-effect relationships occur, they are often accompanied by changes that in many cases are irreversible (Simberloff, 2003, 2007). Thus, the absence of evidence of negative effects does not indicate that such effects are not occurring or will not occur (Carlton, 1996; Altman and Bland, 1995). It would be

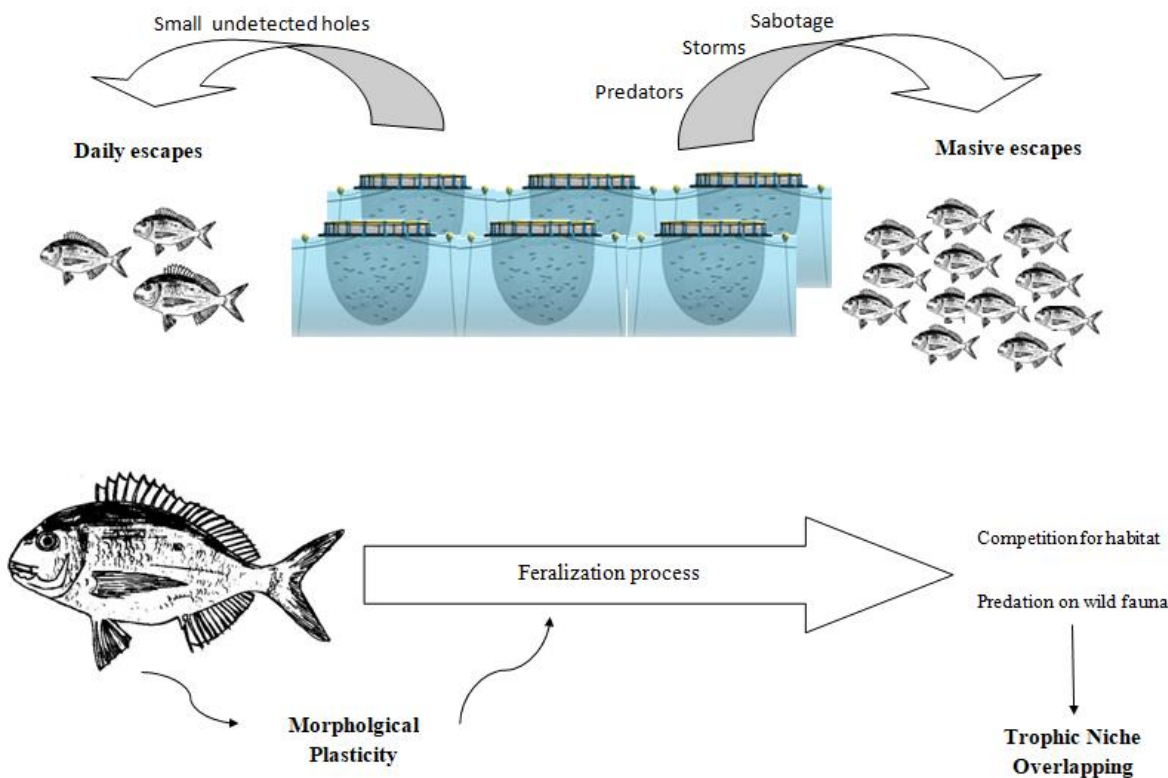
convenient to monitor escaped populations on the islands of La Palma and Tenerife in order to study if once adapted to live in the wild; they are capable of maintaining self-sustainable populations.

Once far from the facilities, the success of escapes will depend, to a larger extent, on their availability to survive during the first days after release into the wild. The ability of organisms to adapt to changes in a new environment, in which conditions are not controlled as occurs on fish farms (i.e. food and protection from predators) (Brown and Laland, 2001, 2003) is given by their phenotypic and genetic plasticity, acquired during rearing period, and will be very important to help individuals survive in the environment (Lorenzen *et al.*, 2012). This study allowed verifying that morphology between cultivated individuals and escapes were different. Cultured fish present rounded shape and small morphology while escapes tend to present more elongated and fusiform body, similar to wild individuals (Toledo-Guedes, 2013). These differences are not clearly strong, but could identify smooth transition between morphology, both cultured and escapes, which indicates that, depending on time they spend in the wild, morphological adaptations will be clearer. According to the results obtained by Kraljević and Dulčić (1997) estimating growth parameters of the von Bertalanffy equation, maximum time in the wild for our escaped individuals was 6 years; since the biggest size was 42.9cm. This could be other indicator pointing to the adaptation of escaped sea bream to natural environment in the studied area. Costa *et al.*, 2010 in their work proved that genetic plasticity of individuals facilitates their adaptation to the environment, in the same way that it helps when they are selected for culture to adapt to conditions of captivity. This allows the survival of the individuals not being compromised by the development in a new environment and the dietary changes, being verified in other species and indicating thus that the escapes undergo a feralization process (Lorenzen *et al.*, 2012; Vandamm *et al.*, 2012) that is given by the strong effects that the change in diet and swimming activity can have on the morphology of the body (Pakkasmaa and Piironene, 2001, Marcil *et al.*, 2006). As Toledo-Guedes, 2013 shown in his work with sea bass, other specie introduced by aquaculture in the Canary Islands, an elongation of the body occurs along with a reduction on the vertical axis, making them more fusiform in comparison with the cultured individuals. In this species, changes were also found in the size of the anal and dorsal fins, which were smaller and less variable in wild fish. On the other hand, in the sea bream the major morphological changes occur in head height (Arechavala-Lopez *et al.*, 2011), where it can be proven that in the case of cultivated individuals the head is more flattened and round, while that the elongation is clearer in

escapes or wild organisms. Thus, more elongated morphology of the fish can mean an advantage in fish movement, increasing therefore speed ranges (Benhaime *et al.*, 2012; Vandamm *et al.*, 2012) and helping the individuals to escape from predators more easily or access to preys that have greater mobility (Toledo-Guedes, 2013).

Arechavala-Lopez *et al.*, 2012 studied the post-escape behavior of sea bream escapes in the Mediterranean Sea, where they found a high dispersion capacity within the first 5 days of the escape, together with a high degree of mortality (> 60 %) but proved in his study that sea bream escapes are able to move to other aquaculture facilities and natural habitats where they live with both wild individuals and other escapes, reaching dispersions of more than 20km, while in studies such as Sánchez-Lamadrid, 2002 and Santos *et al.*, 2006, bigger distances were recorded, ranging from 18 to 40 km away from their farm origin. Many studies show an increased mortality occurring in different cultivated species once they escape from aquaculture facilities, as in the case of salmon (Soto *et al.*, 2001), sea bass in the Atlantic and Mediterranean (Toledo-Guedes, 2013; Arechavala-Lopez *et al.*, 2011; Grati *et al.*, 2011) and sea bream in the Mediterranean (Arechavala-Lopez *et al.*, 2012). Considering the contribution of each individual to the environment through escapes that occurred in the Canary Islands, we must consider how many of them are able to survive and adapt to new conditions, suffering a process of feralization (Toledo-Guedes, 2013). The wide dispersion range matches the behavior observed in the island of La Palma, where we find individuals of sea bream far from the aquaculture facilities. However, in Tenerife, samplings were carried out in nearby areas, so we can not estimate the level of dispersion on the island. Geomorphological features of the Canary Islands involve that aquaculture facilities are located near the coastal side, due to this islands not having a continental shelf around (Hoernle and Carracedo, 2009) this situation prevents escapes from expanding between islands or moving away from the coast (Acosta *et al.*, 2003) concentrating dispersion of fish around the farms or in coastal areas (Toledo-Guedes, 2013). These characteristics of the islands would facilitate the management plans in case of new escapes, being easier to face this problem.

Conceptual model



Conclusions

1. Escaped sea bream are able to survive and forage in the natural environment and their diet is similar to the diet of wild individuals, being able to have a wide range of prey, which facilitates adaptation to different environments.
2. This adaptability to new diet and the ecological interactions with the environment and other species, with which share trophic niche and are able to compete and overcome to it, makes the sea bream a dangerous specie to introduce in areas where is absent.
3. Morphometric traits differ between farmed and escaped individuals, being cultured individuals more rounded and escapees are more streamlined. That is thanks to their phenotypic plasticity that allowed them to adapt their body conditions to a new environment.

References

- Abràmoff, M.D., Magalhaes, P.J. and Ram, S.J., 2004. Image Processing with Image. J. Biophot. Int. 11(7):36-42.
- Acosta, J., Uchupi, E., Muñoz, A., Herranz, P., Palomo, C., Ballesteros, M. and ZEE Working Group, 2003. Geologic evolution of the Canarian Islands of Lanzarote, Fuerteventura, Gran Canaria and La Gomera and comparison of landslides at these islands with those at Tenerife, La Palma and El Hierro. Mar. Geophys. Res. 24: 1-40.
- Altman, D.G. and Bland, J.M., 1995. Absence of evidence is not evidence of absence. British Medical Journal. 311: 485.
- APROMAR, 2017. La acuicultura marina de peces en España. Asociación Empresarial de Productores de Cultivos Marinos, Cádiz, Spain.
- Araki, H. and Schmid, C., 2010. Is hatchery stocking a help or harm?: evidence, limitations and future directions in ecological and genetic surveys. Aquaculture, volume 308, supplement 1, pp s2-s11.
- Arechavala-Lopez, P., Uglem, I., Fernandez-Jover, D., Bayle-Sempere, J.T. and Sanchez-Jerez, P., 2011. Immediate post-escape behaviour of farmed seabass (*Dicentrarchus labrax*, L.) in the Mediterranean Sea. Journal of Applied Ichthyology. 27: 1375–1378.
- Arechavala-Lopez, P., Sanchez-Jerez, P., Bayle-Sempere, J.T., Sfakianakis, D.G. and Somarakis, S., 2012a. Morphological differences between wild and farmed Mediterranean fish. Hydrobiologia. 697:217-231.
- Arechavala-Lopez, P., Sanchez-Jerez, P., Bayle-Sempere, J.T., Sfakianakis, D.G. and Somarakis, S., 2012b. Discriminating farmed gilthead sea bream *Sparus aurata* and European sea bass *Dicentrarchus labrax* from wild stocks through scales and otoliths. Journal of Fish Biology 80(6):2159- 2175.
- Arechavala-Lopez, P., Uglem, I., Fernandez-Jover, D., Bayle-Sempere, J.T. and Sanchez-Jerez, P., 2012c. Post-escape dispersion of farmed seabream (*Sparus aurata* L.) and recaptures by local fisheries in the Western Mediterranean Sea. Fisheries Research. 121-122: 126-135.
- Arechavala-Lopez, P., Fernandez-Jover, D., Black, K.D., Ladoukakis, E., Bayle-Sempere, J.T., Sanchez-Jerez, P. and Dempster, T., 2013a. Differentiating the wild or farmed origin of Mediterranean fish: a review of tools for sea bream and sea bass. Rev. Aquaculture. 4: 1-21.
- Arechavala-Lopez, P., Sanchez-Jerez, P., Bayle-Sempere, J.T., Uglem, I. and Mladineo, I., 2013b. Reared fish, farmed escapees and wild fish stocks—a triangle of pathogen transmission of concern to Mediterranean aquaculture management. Aquaculture Environment Interactions. 3(2): 153-161.
- Arechavala-Lopez, P., Sanchez-Jerez, P., Izquierdo-Gomez, D., Toledo-Guedes, K. and Bayle-Sempere, J.T., 2013c. Does fin damage allow discrimination among wild, escaped and farmed *Sparus aurata* (L.) and *Dicentrarchus labrax* (L.)? Journal of Applied Ichthyology. 29: 352-357.
- Arechavala-Lopez, P., Uglem, I., Izquierdo-Gomez, D., Fernandez-Jover, D. and Sanchez-Jerez, P., 2016. Rapid dispersión of escaped meagre (*Argyrosomus regius*) from a coastal Mediterranean Fish Farm. Aquaculture Research, 2016, 1-11.
- Arias, A., 1980. Growth, food and reproductive habits of sea bream (*Sparus aurata* L.) and sea bass (*Dicentrarchus labrax* L.) in the esteros (fish ponds) of Cadiz. Investigación Pesquera. 44, 59–83.
- Arismendi, I., Soto, D., Penaluna, B., Jara, C., Leal, C. and León-Muñoz, J., 2009. Aquaculture, non-native salmonid invasions and associated declines of native fishes in Northern Patagonian lakes. Freshwater Biology. 54: 1135–1147.
- Balon, E.K., 2004. About the oldest domesticates among fishes. Journal of Fish Biology. 65 (Supplement A): 1–27.

- Basaran, F., Ozbilgin, H., Ozbilgin, Y.D., 2007. Comparison of the swimming performance of farmed and wild gilthead sea bream, *Sparus aurata*. *Aquaculture. Res.* 38, 452–456.
- Barreiros, J.P., Santos, R.S. and de Borba A.E., 2002. Food habits, schooling and predatory behaviour of the yellowmouth barracuda, *Sphyraena viridensis* (Perciformes: Sphyraenidae) in the Azores. *Cybiurn* 26(2):83-88.
- Bauchot, M.L., Hureau, J.C. and Miguel, J.C., 1981. Sparidae. In W. Fischer, G. Bianchi and W.B. Scott (eds.) *FAO species identification sheets for fishery purposes. Eastern Central Atlantic. (Fishing Areas 34, 47 (in part)).* volume 4. [var. pag.] FAO, Rome.
- Bauchot, M.L. and Hureau, J.C., 1990. Sparidae. p. 790-812. In J.C. Quero, J.C. Hureau, C. Karrer, A. Post and L. Saldanha (eds.) *Check-list of the fishes of the eastern tropical Atlantic (CLOFETA)*. JNICT, Lisbon; SEI, Paris; and UNESCO, Paris. Vol. 2.
- Becognée, P., Almeida, C., Barrera, A., Hernández-Guerra, A. and Hernandez-Leon, S., 2006. Annual cycle of clupeiform larvae around Gran Canaria Island, Canary Islands. *Fisheries Oceanography*. 15: 293-300.
- Bekkevold, D., Hansen, M. and Nielsen, E., 2006. Genetic impact of gadoid culture on wild fish populations: predictions, lessons from salmonids, and possibilities for minimizing adverse effects. *ICES Journal of Marine Science*. 63:198-208.
- Boyra, A., Sanchez-Jerez, P., Tuya, F., Espino, F., Haroun, R., 2004. Attraction of wild coastal fishes to Atlantic subtropical cage fish farms, Gran Canaria, Canary Islands. *Environmental Biology of Fishes*. 70, 393–401.
- Brito, A., 1991. *Catálogo de los peces de las Islas Canarias*. Francisco Lemus Editor, La Laguna (Santa Cruz de Tenerife). 230 pp.
- Brito, A., Pascual, P.J., Falcón, J.M., Sancho, A. and González, G., 2002. *Peces de las Islas Canarias. Catálogo comentado e ilustrado*. Francisco Lemus Editor, Arafo (Santa Cruz de Tenerife). 419 pp.
- Brito, A., Falcón, J.M. and Herrera, R., 2005. Sobre la tropicalización reciente de la ictiofauna litoral de las islas Canarias y su relación con cambios ambientales y actividades antrópicas. *Vieraea*. 33: 515-525.
- Brown, C. and Laland, K.N., 2001. Social learning and life skills training for hatchery reared fish. *Journal of Fish Biology*. 59: 471-493.
- Brown, C. and Laland, K.N., 2003. Social learning in fishes: a review. *Fish Fish*. 4: 280-288.
- Buxton, C.D. and Garratt, P.A., 1990. Alternative reproductive styles in sea breams (Pisces: Sparidae). *Environmental Biology of Fishes* 28(1-4):113-124.
- Carlton, J.T., 1996. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation*. 78: 97-106.
- Casal, C.M.V., 2006. Global documentation of fish introductions: the growing crisis and recommendations for action. *Biological Invasions*. 8: 3-11.
- Castro, J.J. and Martin, A.Y., 2000. First record of *Holocentrus ascensionis* (Osbeck, 1765) (Osteichthyes: Holocentridae) in the Canary Islands (Central-east Atlantic). *Scientia Marina* 64 (1): 115-116.
- Chaoui, L., Derbal, F., Kara, M.H. and Quignard, J.P., 2005. Alimentation et condition de la dorade *Sparus aurata* (Teleostei: Sparidae) dan la lagune du Mellah (Algérie Nord-Est). *Chiers de Biologie Marine* 46, 221-225.
- Clemente, S., Hernández, J.C., Rodríguez, A. and Brito, A., 2010. Identifying keystone predators and the importance of preserving functional diversity in sublittoral rocky-bottom areas. *Marine Ecology Progress Series*. Vol. 413: 55-67.
- Costa, C., Vandeputte, M., Antonucci, F., Boglione, C., Menesatti, P., Cenadelli, S., Parati, K., Chavanne, H. and Chatain, B., 2010. Genetic and environmental influences on shape variation in the European sea bass (*Dicentrarchus labrax*). *Biological Journal of the Linnean Society*. 101: 427-436.
- CIESM, 2007. *Impact of mariculture on coastal ecosystems. Workshop Monograph n° 32*. 120 pp.

- Consuegra, S., Phillips, N., Gajardo, G. and Garcia de Leaniz, C., 2011. Winning the invasion roulette: escapes from fish farms increase admixture and facilitate establishment of non-native rainbow trout. *Evolution. Appl.* 4: 660-671.
- Daniels, T.J. and Bekoff, M., 1989. Feralization: the making of wild domestic animals. *Behavioural Processes.* 19: 79-94.
- D'Anna, G., Giacalone, V.M., Badalamenti, F., Pipitone, C., 2004. Releasing of hatchery reared juveniles of the white seabream *Diplodus sargus* (L. 1758) in the Gulf of Castellammare artificial reef area (NW Sicily). *Aquaculture* 233, 251–268.
- Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J. and Kingsford, M., 2004. Extensive aggregations of wild fish at coastal sea-cage fish farms. *Hydrobiologia.* 525: 245-248.
- Dempster, T., Moe, H., Fredheim, A., Jensen, Ø. and Sanchez-Jerez, P., 2007. Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention. *CIESM Workshop Monographs n° 32.* pp. 55–60.
- Dempster, T., Jensen, Ø., Fredheim, A., Uglem, I., Thorstad, E., Somarakis, S. and Sanchez-Jerez, P., 2013. Escapes of fishes from European sea-cage aquaculture: environmental consequences and the need to better prevent escapes. In: *PREVENT ESCAPE Project Compendium. Chapter 1. Commission of the European Communities, 7th Research Framework Program.*
- DeVaney, S.C., McNyset, K.M., Williams, J.B., Peterson, A.T. and Wiley, E.O., 2009. A tale of four “carp”: invasion potential and ecological niche modeling. *PLoS One.* 4:e5451.
- Duarte, C.M., Marbá, N. and Holmer, M., 2007. Rapid Domestication of Marine Species. *Science.* 316: 382-383.
- Edelist, D., Rilov, G., Golani, D., Carlton, J.T. and Spanier, E., 2013. Restructuring the Sea: profound shifts in the world's most invaded marine ecosystem. *Diversity and Distributins.* 19(1): 69-77.
- Elliott, N.G., Haskard, K. and Koslow, J.A., 1995. Morphometric analysis of orange roughy (*Hoplostethus atlanticus*) off the continental slope of southern Australia. *Journal of Fish Biology.* 46:202-220.
- Ersbak, K. and Haase, B.L., 1983. Nutritional deprivation after stocking as a possible mechanism leading to mortality in stream-stocked Brook Trout. *North American Journal of Fisheries Management Impact Factor.* 3(2): 142- 151.
- Falcón, J.M., Bortone, S.A., Brito, A. and Bundrick, C.M., 1996. Structure of and relationships within and between the littoral, rock-substrate fish communities off four islands in the Canarian Archipelago. *Marine Biology.* 125: 215-231.
- FAO, 2012. *The state of world fisheries and aquaculture 2012.* Rome. 230 pp.
- Fernandez-Jover, D., Sanchez-Jerez, P., Bayle-Sempere, J.T., Valle, C., Dempster, T., 2008. Seasonal patterns and diets of wild fish assemblages associated to Mediterranean coastal fish farms. *ICES Journal of Marine Sciences.* 65, 1153–1160.
- Ferrari, I.; Chierigato, A. R., 1981: Feeding habits of juvenile stages of *Sparus auratus* L., *Dicentrarchus labrax* L. and mugilidae in a brackish embayment of the Po River delta. *Aquaculture* 25, 243–257.
- Fiske, P., Lund, R. A. and Hansen, L. P., 2005. Identifying fish farm escapees. *Stock Identification Methods,* 659–680.
- Fleming, I. A., Jonsson, B. and Gross, M. R., 1994. Phenotypic divergence of sea-ranched, farmed, and wild salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 808–2824.
- Francescon, A., Freddi A., Barbaro, A. and Giavenni, R., 1988. Daurade (*S. aurata* L.) reproduite artificiellement et daurade sauvage. Experiences paralleles en diverses conditions d'elevage. *Aquaculture* 72: 273–285.
- Freon, P. and Dagorn, L., 2000. Review of fish associative behavior: toward a generalization of the meeting point hypothesis. *Reviews in Fish Biology and Fisheries.* Volume 10, Iussue 2, pp 183-207.

- Gisbert, E., 1999. Early development and allometric growth patterns in Siberian sturgeon and their ecological significance. *Journal of Fish Biology* 54: 852–862.
- González-Lorenzo, G., Brito, A. and Barquín, J., 2005. Impactos provocados por los escapes de peces de las jaulas de cultivos marinos en Canarias. *Vieraea*. 33: 449-454.
- Grati, F., Scarcella, G., Bolognini, L. and Fabi, G., 2011. Releasing of the European sea bass *Dicentrarchus labrax* (Linnaeus) in the Adriatic Sea: Large-volume versus intensively cultured juveniles. *Journal of Experimental Marine Biology and Ecology*. 397: 144–152.
- Hammer, Ø., Harper, D.A.T. and Ryan, P.D., 2001. Past: Paleontological Statistics Software Package for Education and Data Analysis. *Paleontological Elect.* 4:1-9.
- Hard, J. J., B. A. Berejikian, E. P. Tezak, S. L. Schroder, C. M. Knudsen & L. T. Parker, 2000. Evidence for morphometric differentiation of wild and captive reared adult coho salmon: a geometric analysis. *Environmental Biology of Fishes* 58: 61–73.
- Hoernle, K. and Carracedo, J.C., 2009. Canary Islands, Geology. In: *Encyclopedia of Islands*. Gillespie RG and Clague DA (eds.). University of California Press. London. pp. 133-142.
- Humphries, J.M., Bookstein, F.L., Chernoff, B., Smith, G., Elder, R.L. and Poss, S.G., 1981. Multivariate discrimination by shape in relation to size. *Systematic Zoology* 30: 291–308.
- Hureau, J.C., 1970. Biologie comparée de quelques poissons antarctiques (Nototheniidae). *Bulletin de L'Institut National Scientifique et Technique*. (Monaco). 68: 1-250.
- Izquierdo-Gómez, D., Sánchez-Jerez, P., Fernández-Jover, D., Toledo-Guedes, K., Arechavala-Lopez, P., Forcada-Almarcha, A. and Valle-Pérez, C., 2014. Guía de buenas prácticas para la gestión de escapes en la acuicultura marina: Vol II, pp. 32. Mitigación. Proyecto ESCA-FEP, Fondo Europeo de Pesca. Ed. Oceanográfica.
- Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. and Warner, R.R., 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*. 293: 629-638.
- Kraljević, M., and Dulčić, J., 1997. Age and growth of gilt-head sea bream (*Sparus aurata* L.) in the Mirna estuary, northern Adriatic. *Fisheries Research*, 31(3), 249–255.
- Kristiansen, T.S., Otterå, H. and Svåsand, T., 2000. Size-dependent mortality of juvenile Atlantic cod, estimated from recaptures of released reared cod and tagged wild cod. *Journal of Fish Biology*. 56: 687-712.
- Linton, L.R., Ronald, W. and Wrona, F.J., 1981. Resource utilization Indices: an assessment. *Journal of Animal Ecology*, 50, 283-292.
- Lloris, D., 2005. A world overview of species of interest to fisheries. Chapter: *Sparus aurata*. Retrieved on 08 July 2005, from www.fao.org/figis/servlet/species?fid=2384. 3p. FIGIS Species Fact Sheets. Species Identification and Data Programme-SIDP, FAO-FIGIS
- Lorenzen, K., Beveridge, M.C.M. and Mangel, M., 2012. Cultured fish: integrative biology and management of domestication and interactions with wild fish. *Biological Reviews of the Cambridge Philosophical Society*. 87: 639-660.
- Loy, A., Boglione, C., Gagliardi, F., Ferrucci, L. and Cataudella, S., 2000. Geometric morphometrics and internal anatomy in sea bass shape analysis (*Dicentrarchus labrax* L., Moronidae). *Aquaculture*. 186: 33-44.
- Marcil, J., Swain, D.P. and Hutchings, J.A., 2006. Countergradient variation in body shape between two populations of Atlantic cod (*Gadus morhua*). *Proceedings of the Royal Society of London*. B. 273: 217-223.
- Magoulas, A., K. Sophronides, T. Patarnello, E. Hatzilaris and E. Zouros, 1995. Mitochondrial DNA variation in an experimental stock of gilthead sea bream (*Sparus aurata*). *Molecular Marine Biology and Biotechnology*. 4(2):110-116.

- McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N.Ó., Baker, N., Cotter, D., O’Hea, B., Cooke, D., Rogan, G., Taggart, J. and Cross, T., 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society B-Biological Sciences*. 270: 2443-2450.
- Morato, T., Solà, E., Grós, M. P., and Menezes, G., 2001. Feeding habits of two congener species of seabreams, *Pagellus bogaraveo* and *Pagellus acarne*, off the Azores (northeastern Atlantic) during spring of 1996 and 1997. *Bulletin of Marine Science*, 69(3), 1073–1087.
- Naylor, R.L., Hindar, K., Fleming, I.A., Goldberg, R., Williams, S., Volpe, J., Whoriskey, F., Eagle, J., Kelso, D. and Mangel, M., 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *Bioscience*. 55: 427-437.
- Olla, B.L., Davis, M.W. and Ryer, C.H., 1998. Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. *Marine Science*. 62(2): 531–550.
- Osse, J. W. M., 1990. Form changes in fish larvae in relation to changing demands of function. *Netherlands Journal of Zoology* 40: 362–385.
- Osse, J. W. M. and van den Boogaart, J. G. M., 1995. Fish larvae, development, allometric growth, and the aquatic environment. *ICES Marine Sciences Symposium* 201: 21–34.
- Osse, J. W. M. and van den Boogaart, J. G. M., 1999. Dynamic morphology of fish larvae, structural implications of friction forces in swimming, feeding and ventilation. *Journal of Fish Biology* 55(A): 156–174.
- Papaconstantinou, C. and Caragitsou, E., 1989. Feeding interaction between two sympatric species *Pagrus pagrus* and *Phycis phycis* around Kastellorizo Island (Dodecanese, Greece). *Fisheries Research*, 7(4), 329–342.
- Pérez-Jiménez, A., Guedes, M.J., Morales, A.E. and Oliva-Teles, A., 2007. Metabolic responses to short starvation and refeeding in *Dicentrarchus labrax*. Effect of dietary composition. *Aquaculture*. 265: 325-335.
- Pinkas, L., Oliphant, M.S. and Iverson, I.L.K., 1971. Food habits of albacore bluefin tuna and bonito in California waters. *California Department of Fish and Wildlife*. 152: 1-105.
- Pita, C., Gamito, S., Erzini, K., 2002. Feeding habits of the gilthead seabream (*Sparus aurata*) from the Ria Formosa (southern Portugal) as compared to the black seabream (*Spondyliosoma cantharus*) and the annular seabream (*Diplodus annularis*). *Journal of Applied Ichthyology*. 18, 81–86.
- Pitcher, T.J., 1986. Functions of shoaling behaviour in teleosts. In: Pitcher TJ, *Behaviour of Teleost Fishes*. 2nd edition. Chapman & Hall. London. pp. 363-439.
- Prokopchuk, I. and Sentyabov, E., 2006. Diets of herring, mackerel, and blue whiting in the Norwegian Sea in relation to *Calanus finmarchicus* distribution and temperature conditions. *ICES Journal of Marine Sciences*. 63: 117-127.
- Ramírez, B., Ortega, L., Cárdenes, Y. and Haroun, R., 2011. Evaluación de las interacciones de lubinas escapadas desde jaulas de acuicultura en la isla de La Palma en el año 2010. *Universidad de Las Palmas de Gran Canaria*. 44pp
- Rodríguez, J.M., Hernández-León, S. and Barton, E.D., 1999. Mesoscale distribution of fish larvae in relation to an upwelling filament off Northwest Africa. *Deep Sea Research Part I*. 46: 1969- 1984.
- Rosecchi, E., 1985. L'alimentation de *Diplodus annularis*, *Diplodus sargus*, *Diplodus vulgaris* et *Sparus aurata* (Pisces, Sparidae) dans le Golfe du Lion et les lagunes littorales. *Revue des Travaux de L’Institut Pêches Maritimes*. 49, 125–141.
- Rosecchi, E., and Nouaze, Y., 1985. Comparaison de cinq indices alimentaires utilisés dans l’analyse des contenus stomacaux. *Revue Des Travaux de l’Institut Des Pêches Maritimes*, 49, 111–123.
- Ruiz, G.M., Carlton, J.T., Grosholz, E.D. and Hines, A.H., 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent, and consequences. *American zoologist*. 37: 621-632

- Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M.J. and Hines, A.H., 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. *Annual Review of Ecology, Evolution and Systematics*. 31: 481-531.
- Sala, E., and Ballesteros, E., 1997. Partitioning of space and food resources by three fish of the genus *Diplodus* (Sparidae) in a Mediterranean rocky infralittoral ecosystem. *Marine Ecology Progress Series*, 152(1-3), 273-283.
- Sanchez-Lamadrid, A., 2002. Stock enhancement of gilthead sea bream (*Sparus aurata*, L.): assessment of season, fish size and place of release in SW Spanish coast. *Aquaculture* 210(1-4): 187-202.
- Sanchez-Jerez, P., Fernandez-Jover, D., Uglem, I., Arechavala-Lopez, P., Dempster, T., Bayle-Sempere, J.T., Valle-Perez, C., Izquierdo, D., Bjorn, P.A. and Nilsen, R., 2011. Coastal Fish Farms as Fish Aggregation Devices (FADs). In: Bortone SA, Pereira F, Fabi G and Otake S. *Artificial reefs in fisheries management*. CRC Press, USA. pp. 187-208.
- Santos, M.N., Lino, P.G., Pousão-Ferreira, P. and Monteiro, C.C., 2006. Preliminary results of hatchery-reared seabreams released at artificial reefs off the Algarve coast (southern Portugal): a pilot study. *Bulletin of Marine Sciences*. 78 (1), 177-184.
- Simberloff, D., 2003. Confronting introduced species: a form of xenophobia?. *Biological Invasions*. 5: 179-192.
- Simberloff, D., 2007. Given the stakes, our modus operandi in dealing with invasive species should be “guilty until proven innocent.” *Cons. Mag.* 8: 18-19.
- Sosiak, A.J., Randal, R.G. and McKenzie, J.A., 1979. Feeding by hatchery-reared and wild Atlantic Salmon (*Salmo salar*) parr in streams. *Journal of the Fisheries Research Board of Canada*. 36: 1408-1412.
- Soto, D., Jara, F. and Moreno, C., 2001. Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. *Ecological Applications*. 11(6), 1750-1762.
- Soto, D., Arismendi, I., González, J., Sanzana, J., Jara, F., Jara, C., Guzman, E. and Lara, A., 2006. Southern Chile, trout and salmon country: invasion patterns and threats for native species. *Revista Chilena de Historia Natural*. 79: 97-117.
- Strauss, R.E. and Bookstein, F.L., 1982. The truss: body form reconstruction in morphometrics. *Systematic Zoology* 31: 113-135.
- Streftaris, N., Zenetos, A. and Papathanassiou, E., 2005. Globalisation in marine ecosystems: The story of non-indigenous marine species across European seas. *Oceanography and Marine Biology* 43: 419-453.
- Swaine, D.P., Ridell, B.E. and Murray, C.B., 1991. Morphological differences between hatchery and wild populations of coho salmon (*Oncorhynchus kisutch*): environmental versus genetic origin. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1783-1791.
- Tancioni, L., Mariani, S., Maccaroni, A., Mariani, A., Massa, F., Scardi, M. and Cataudella, S., 2003. Locality-specific variation in the feeding of *Sparus aurata* L.: evidence from two Mediterranean lagoon systems. *Estuarine, Coastal and Shelf Science*. 57: 469-474.
- Teletchea, F. and Fontaine, P. 2012. Levels of domestication in fish: implications for the sustainable future of aquaculture. *Fish Fish*. doi:10.1111/faf.12006
- Toledo-Guedes, K., Brito, A. and Garcia de Leaniz, C., 2009. Phenotypic convergence in sea bass (*Dicentrarchus labrax*) escaping from fish farms: the onset of feralization?. *Aquaculture Environmental Interactions*.
- Toledo-Guedes, K., 2012. Asilvestramiento de los peces introducidos por la acuicultura y sus efectos ecológicos potenciales: el caso de la lubina, *Dicentrarchus labrax* (Linnaeus, 1758), escapada en las Islas Canarias. *Grado Doctor, Universidad de La Laguna, España*.
- Toledo-Guedes, K., Sanchez-Jerez, P. and Brito, A., 2014. Influence of a massive aquaculture escape event on artisanal fisheries. *Fisheries Management and Ecology*, 21(2), 113-121.

- Toledo-Guedes, K., Sanchez-Jerez, P., Benjumea, M. and Brito, A., 2014. Farming-up coastal fish assemblages through a massive aquaculture escape event. *Marine Environmental Research*. Volume 98, 86-95.
- Trut, L., Okina, I. and Kharlamova, A., 2009. Animal evolution during domestication: the domesticated fox as a model. *Bioessays*. 31(3): 349-360.
- Tuya, F., Boyra, A., Sanchez-Jerez, P. and Haroun, R.J., 2005. Multivariate analysis of the benthic-demersal ichthyofauna along soft bottoms of the Eastern Atlantic: comparison between unvegetated substrates, seagrass meadows and sandy bottoms beneath sea-cage fish farms. *Marine Biology*. 147: 1229-1237.
- Tuya, F., Sanchez-Jerez, P. and Haroun, R.J., 2006. Populations of inshore serranids across the Canarian Archipelago: Relationships with human pressure and implications for conservation. *Biological Conservation*. 128(1): 13-24.
- Uglen, I., Bjorn, P.A., Dale, T., Kerwath, S., Okland, F., Nilsen, R., Aas, K., Fleming, I. and McKinley, R.S., 2008. Movements and spatiotemporal distribution of escaped farmed and local wild Atlantic cod (*Gadus morhua* L.). *Aquaculture Research*. 39: 158-170.
- Underwood, A.J., 1997. *Experiments in ecology: their logical design and interpretation using analysis of variance*. Cambridge University Press, Cambridge, UK. 524 pp.
- Valiente, A.G., Ayllon, F., Nuñez, P., Juanes, F. and Garcia-Vazquez, E., 2010. No all lineages are equally invasive: genetic origin and life-history in Atlantic salmon and brown trout acclimated to the Southern Hemisphere. *Biol. Inv.* 12: 3485-3495.
- Valle, C., Bayle-Sempere, J.T., Dempster, T., Sanchez-Jerez, P. and Gimenez-Casualdero, F., 2007. Temporal variability of wild fish assemblages associated with a seacage fish farm in the southwestern Mediterranean Sea. *Estuarine, Coastal and Shelf Science*. 72, 299–307.
- Vandamm, J.P., Marras, S., Claireaux, G., Handelsman, C.A. and Nelson, J.A., 2012. Acceleration performance of individual European sea bass *Dicentrarchus labrax* measured with a sprint performance chamber: comparison with high-speed cinematography and correlates with ecological performance. *Physiological and Biochemical Zoology* 85(6): 704-717.
- Wallace, H., 1981. An assesment of diet overlap indexes. *Transactions of the American Fisheries Society*, 110:72-76.
- Wallace, H. and Ramsay, J.S., 1983. Reliability in measuring diet overlap. *Canadian Journal of Fisheries and Aquatic Sciences*., 40: 347-351.
- Wainwright, P.C. and Richard, B.A., 1995. Predicting patterns of prey use from morphology of fishes. *Environmental Biology of Fishers*., 44: 97-113.
- West-Eberhard, M.J., 1989. Phenotypic plasticity and the origins of diversity. *Annual Review of Ecology, Evolution and Systematics*. 20: 249-278.
- Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. and Watson, R., 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. *Science*. 314: 787-790.