Chapter 19. The Blackspot seabream fishery in the Strait of Gibraltar: lessons and future perspectives of shared marine resource

Juan Gil-Herrera (1), *Juan Carlos Gutiérrez-Estrada (2), Said Benchoucha (3), José Luis Pérez-Gil (4), Víctor Sanz-Fernández (2), Sana el Arraf (3), Candelaria Burgos (1), Mohamed Malouli (3), and Carlos Farias (1)

(1) Instituto Español de Oceanografía, Centro Oceanográfico de Cádiz, Spain.

(2) Dpto. Ciencias Agroforestales, Universidad de Huelva, Spain.
(3) National Institute of Fisheries Research (INRH), INRH-Tangier Center, Morocco.

(4) Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, Spain.

*****Corresponding author: juanc@uhu.es

Abstract

The Blackspot seabream (*Pagellus bogaraveo*) is one of the most important commercially-exploited fish species for the Spanish and Moroccan fleets which operate in the Strait of Gibraltar. In recent years, landings of Blackspot seabream in the main ports have decreased significantly respect previous periods of maximum catches, which makes it necessary to properly assess the abundance before establishing a management plan to make the fishery sustainable over time. In this chapter, we describe three different approaches to assess the abundance of this species in the Strait of Gibraltar. The results of three approaches tested (LCA/VPA, Gadget model and SimFish model) point out that from the 2010 the stock is kept at very low levels that oscillate between 900 and 1600 t, which supposes that the total biomass is between a 16% and 29% of the potential biomass. Additionally, the reference point values estimated by LCA/VPA and Gadget ($F_{0.1}$ = 0.12-0.17) imply a clear overexploitation of the resource what is reinforced by the SimFish model results indicating that at least the 64% of abundance variation is a consequence of the fishery component.

Keywords: *Pagellus bogaraveo*. Abundance. Biomass. Reference points. Simulations. Management plan. Spain. Morocco.

Introduction

Fish stocks commercially exploited are components of ocean ecosystems that are extremely complex to manage and plan. As a consequence of that, the abundance of the resources at a future time is related to a multitude of intrinsic and extra-compensatory and variable in time factors, frequently unknown and generally associated with a very high level of uncertainty, which greatly hinders the projections of abundance towards the near future. Among the intrinsic factors that influence the variation in abundance of a target species are every one of their biological characteristics such as growth capacity, type of reproduction, natural mortality and resilience to exploitation among others (Clark and Marr, 1955; Dragesund et al., 1980; Zhang et al., 2004). All these intrinsic factors are strongly influenced by a wide variety of external factors with different nature such as anthropogenic (type and level of exploitation), natural (environmental variability) (Kennedy, 1990; Bigelow et al., 1999; Lehodey et al., 2006; Jghab et al., 2019) and geopolitical, which strongly condition the stability and sustainability of fish communities.

The Blackspot seabream (*Pagellus bogaraveo*) fishery is a clear example of the influence of the aforementioned factors on the abundance variability (Báez et al., 2014; Gutiérrez-Estrada et al., 2017; Sanz-Fernández et al., 2019). This species, found from South of Norway to Canary Archipelagos in the Atlantic Ocean and in the

Mediterranean Sea basin (Desbrosses, 1938) is one of the main exploited resources in the Strait of Gibraltar. This protandric hermaphrodite species lives in a depth range that varies between the surface and 700 m, is the target species in this area of two artisanal fleets belonging to two countries with very different fishing policies developing their fishing activity in a small area characterised by a high environmental complexity (Gil, 2006; Czerwinski, 2008). In this context there is no an ideal methodology to manage and apply all available information and to provide an exact resource assessment and therefore, it is advisable the use of complementary procedures that allow to reduce the uncertainty associated to the obtained estimations. Thus, it would be possible to carry out an integrated management and ecosystem planning focused on the sustainability of the resource.

Therefore, this chapter describes different approaches to assess the abundance of the Blackspot seabream population in the Strait of Gibraltar. This way, using the joint data from Morocco and Spain, one classic method and two novel approaches were used to evaluate the current status of the stock were attempted. The first was based on Length Cohort Analysis (LCA) and Virtual Population Analysis (VPA): from the obtained results a Yield per Recruit (YpR) analyses was run to estimate *ad hoc* reference points (F_{MAX} and $F_{0.1}$); a second approach was carried out using the Globally applicable Area Disaggregate General Ecosystem Toolbox (Gadget) model developed by Begley and Howell (2004) and finally the third approach was obtained by means of the SimFish methodology proposed by Gutiérrez-Estrada et al. (2017).

Description of the fleets, stock identification and landings

The Blackspot seabream is one of the principal demersal species targeted in the Strait of Gibraltar for its highest commercial value compared to others demersal resources. The Spanish fishery targeting the Blackspot seabream has been developing along the Strait of Gibraltar area since the earliest 1980´s. This is an almost mono-specific fishery, with one clear target species which represents the 74% from the total landed species (Silva et al., 2002). The main harbours are located in Tarifa and Algeciras (Spain) and Tangier (Morocco). Less important landings are also carried out at Conil and Ceuta ports (Spain).

In Spain the main fishing hook gear used are known as "*voracera*" (Gil, 2006; Czerwinski, 2008), although occasionally this species is also caught by means of traditional longliners. The "*voracera*" is a local mechanized handline baited with sardine. Fishing is carried out taking advantage of the turnover of the tides in bottoms from 300 to 600 m depth. Every boat uses a maximum of 30 lines per day (each line attached a maximum of 100 hooks, usually ±70) with a maximum legal length of 120 m. The legal dimensions of the hooks are a minimum length of 3.95 ± 0.39 cm and a minimum width of 1.4 ± 0.14 cm. The maximum number of boats (more than 100) decreased till less than 60 in the last years and its mean technical characteristics are: Length= 9.80 meters, GRT= 6.36 and HP= 47.23.

The most important Moroccan fleets targeting the Blackspot seabream are the longliners based at the Tangier harbour and the artisanal fleet of the Strait of Gibraltar area. In the last years, the longliners fleet was more or less stable (78 to 101 vessels), but in 2016 the number of the longliners fleet was composed approximately 84 and 76 artisanal boats. The number of hooks (size of the hooks is between 8 and 11) by boat is between 200 and a maximum of 2000.

The operational area of the Spanish and Moroccan fleets is approximately a sector between 6º 25’W to 5º 15’W and 35º 45’N to 36º 15’N, which correspond with westernmost end of the Alboran Sea (Figure 1) (Burgos et al., 2013). Some studies have analysed the migration patterns using tagging surveys (Gil et al., 2001; Sobrino and Gil, 2001). These studies indicate that juveniles showed displacements from nursery areas towards the Strait of Gibraltar fishing grounds. However, recaptures from tagged adults did not reflect big displacements, which are limited to feeding movements among the different fishing grounds where the fleets work (Gil, 2006). There is not much information available on the stock structure of Blackspot seabream. FAO COPEMEDII TRANSBORAN (Transboundary population structure of Sardine, European hake and Blackspot seabream in the Alboran Sea and adjacent waters: a multidisciplinary approach) on-going project based on genetics, otolith shape and microchemistry analyses will be give some clues in the next future.

In the case of the Spanish fleet, the analysis of the data provides by Location and Track System for Andalusian Fishing Vessels (SLSEPA) between August-2007 and December-2009 (Figure 1) has allowed to identify the six main fishing areas (V-01 to V-06). On the other hand the operations area of the Moroccan fleet is limited by the Cap Spartel (at the west) to the east of Benyounech which approximately match with the areas V-02, V-03, V-04 and V-06 from the Spanish fishing grounds. However, until now there is a lack of precise information on the geographical distribution, pattern distribution and real stock boundaries of the Blackspot seabream population catched in the Strait of Gibraltar.

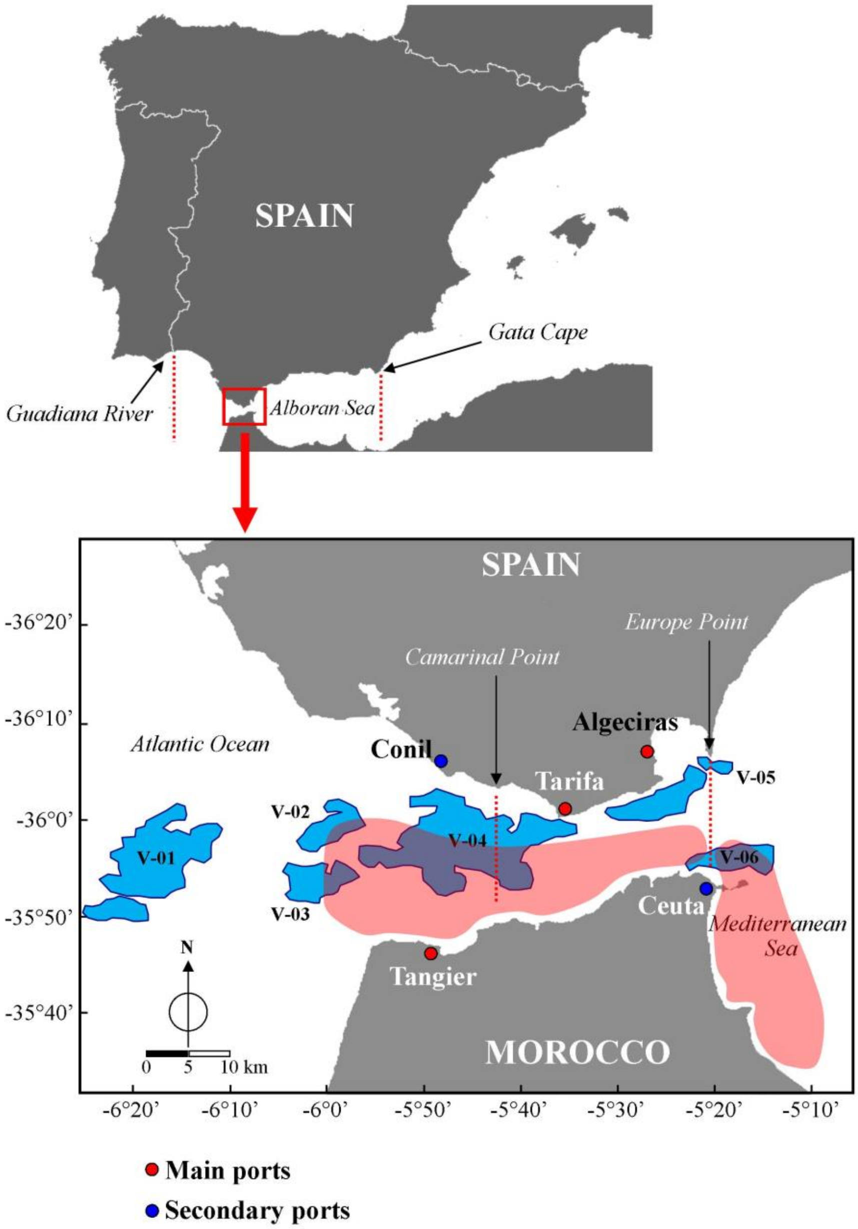


Figure 1. *Main fishing grounds of the Spanish (blue) and Moroccan (red) Blackspot seabream fishery. Information of the Spanish fleet (V-01 to V-06) has been obtained from the Location and Track System for Andalusian Fishing Vessels (SLSEPA) of the Junta de Andalucía. The area between the meridian of Gata Cape and the meridian of the mouth of the Guadiana River and between Camarinal Point and Europe Point (dotted red lines) established by the Order APA/3323/2002 are shown*

The compiled information from the Spanish fleet indicates that Blackspot seabream was significantly landed since 1983 (Figure 2). Considering only the main Spanish ports

(Tarifa and Algeciras), landings trend of the shows a big decline in the Spanish fishery from about 600 tons in 2009 to 104 t in 2016 (Table 1).

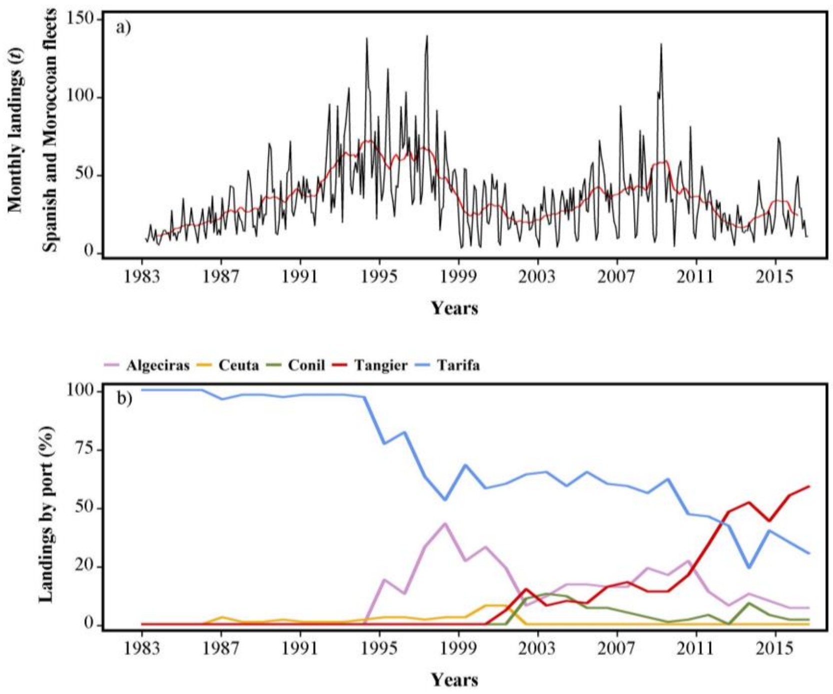


Figure 2. *a) Time series (1983-2016) of Blackspot seabream landings considering the ports of Tarifa, Algeciras, Ceuta, Conil and Tangier. Red line is the annual moving average; b) Percentage contribution by port and year to Blackspot seabream landings*

Catches from the Moroccan fisheries were low at the beginning to remain more or less stable until 2013 (Figure 2). From 2013 onwards it showed an increasing trend setting the highest value on 2015 with 219 tons and 159 t in 2016. The 2010-2016 mean production of this fishing resource is about 142 tons (Table 1).

From 2005 the fishing effort of Tarifa and Algeciras fleet was very high in comparison with the Moroccan one, but since 2009 declined and reached the same level of the Moroccan one. Moroccan fishing effort has increased and became highest in the last two years. However, the CPUE was more or less stable for both countries (Spain and Morocco) with an average of 51 and 36 kg/fishing trip, respectively (Table 1).

Table 1. *Annual landings and catches per unit effort (CPUE) in the Tarifa and Algeciras ports (Spain) and Tangier port (Morocco) from 2005 to 2016*

	Tarifa and Algeciras ports (Spain)		**Tangier port (Morocco)**	
Year	**Landings (t)**	**CPUE (kg/fishing day)**	**Landings (t)**	**CPUE (kg/fishing day)**
2005	330	69	39	40
2006	346	71	74	39
2007	362	52	89	35
2008	416	52	76	34
2009	579	66	99	40
2010	366	53	105	38
2011	240	43	136	34
2012	126	36	122	32
2013	66	32	92	33
2014	138	40	118	33
2015	168	51	219	44
2016	100	43	159	34

Management regulations

In Spain, the legislation applied to the management of the Blackspot seabream fishery has evolved from 1995 to 2016. In order to regulate the technical and biological aspects associated with the fishery.

The regulations relating to the technical characteristics of fishing gear began with the Order of June 17 1998, which establishes the maximum length of the "*voracera*" (120 m), the number of maximum hooks allowed (100 per "*voracera*") and the size of the hooks (length: 3.55±0.35 cm and width 1.3±0.13 cm). These aspects have been modified by different management plans until today (APA/3323/2002 Order of December 20; APA/8/2006 Order of January 12; APA/274/2007 Order of February 7; APA/445/2008 Order of February 18; ARM/521/2009 Order of February 24; ARM/3536/2009 Order of December 23). The AAA/1589/2012 Order of July 17 establishes that the number of maximum hooks allowed is 2400 and its dimension not less than large 3.95 cm and width 1.65 cm. Nowadays this management plan regulates the fishery.

As regards fishing effort (understood as days at sea), there has been an increase of 20 days from 1998-1999 (160 days) (Order of June17 1998; Order of November 2 1999) to 2016 (180 days) (AAA/55/2016 Order of January 26). The opposite case occurs with the census of vessels, which began with 148 (Order of June17 1998) and currently have 88 (AAA/1589/2012 Order of June 17).

With regard to the temporary closure of the fishery (understood as the prohibition of fishing in certain seasons), it is in 2002 when the obligation to stop the fishery from mid-January to March included is incorporated (APA/3323/2002 Order of December 20). After 2002 and until 2009, the months of temporary closure varied but were always from January to May, coinciding with the months in which the spawning takes place (APA/8/2006 Order of January 12 APA/274/2007 Order of February 7; APA/445/2008 Order of February 18; ARM/3536/2009 Order of December 23). In 2016, the obligation to carry out a temporary closure of the fishery acquires voluntary character (AAA/55/2016 Order of January 26).

Finally, the biological aspect of the fishery has been regulated by the minimum allowable catch length. The Blackspot seabream is a marine resource whose life cycle takes place under two different maritime domains (Atlantic and Mediterranean). Besides, it should be noted that the Strait of Gibraltar Blackspot seabream target fishery fishing grounds partially overlap areas from different Regional Fisheries Organizations / Advisory bodies, namely GFCM (General Fisheries Commission for the Mediterranean), CECAF (Fishery Committee for the Eastern Central Atlantic) and ICES (International Council for the Exploration of the Sea). This fact causes its minimum landing size to be modified according to the area of capture.

The historical evolution of the minimum landing size of the Blackspot seabream is shown in Table 2. Initially in 1995, the minimum landing size for the entire regulatory area was set at 25 cm. This size was maintained until the years 2002 and 2006, where depending on the area of capture, the size was 25 or 33 cm. From late 2006 to 2009, the minimum landing size was 33 cm for both the Atlantic and Mediterranean areas. Finally from 2012 to 2019, the Minimum landing size and the annual Total Allowable Catch (TAC) for Spain are determined by the European Union Regulation EU 2017/787 of 8 May 2017 which establishes that the minimum size for the Blackspot seabream is 33 cm (total length).

In Morocco, the main regulation is in force since 1992 and the interdiction of fishing beyond 80 m depth in the area between Tangier and Al Hoceima and below 3 miles in the area between Al Hoceima and Saidia. The minimal landing size is established on 25 cm (fork length; about 28 cm total length) with trawls codend mesh size ≥ 50 mm. The nets regulation establishes that the maximum size must be 1000 m with a codend mesh size of 70 mm. Also there is regulation about protection of marine areas and anti-trawling artificial reefs.

Table 2. *Minimum catch size of Blackspot seabream established for the Spanish fleet from 1995*

Minimum size (in cm)	Year	Reference
25	1995	Royal Decree 560/1995, of April 7
25(1)/33(2)	2002	Order APA/3323/2002
25(1)/33(2)	2006	Order APA/8/2006
33(2)	2007	Order APA/274/2007
33(2)	2008	OrderAPA/445/2008
33(2)	2009	Order ARM/521/2009
33(2)	2009	ARM/3536/2009
33(2,3)	2012	Order AAA/1589/2012

(1) Area between the meridian of Gata Cape (Mediterranean Sea) and the meridian of the mouth of the Guadiana River (Atlantic Ocean) (Figure 1).

(2) Area between Camarinal Point and Europe Point (Strait of Gibraltar) (Figure 1).

(3) Established respect the European Union regulations (currently EU Regulation 2017/787 of 8 May 2017).

Life history and biological parameters

The Blackspot seabream is a species belonging to the *Sparidae* family. It is a bentho-pelagic species with adults inhabiting depth ranges from 300 to 700 m throughout the eastern Atlantic and western Mediterranean. It is a sequential protandric hermaphrodite species, starting as males but changing into females at 30-35 cm, when got 4 to 6 years old (Alcaraz et al., 1987; Krug, 1990; Gil, 2006). They grow slowly to a maximum size of 70 cm, weight of 4 kg and an age of about 15 years (Coupé, 1954; Sánchez, 1983; Krug, 1994; Gil, 2006). These biological characteristics make this species very sensitive to disturbances introduced by fishing and confer a low level of resilience to exploitation.

As the same as the stock distribution information, there is relatively few information about the growth and reproduction of the Blackspot seabream in the Strait of Gibraltar. The parameters estimated on the growth model (von Bertalanffy growth function) were obtained by Gil (2006) and the parameters of the length-weight were reported by Gil (2006) and Czerwinski et al. (2008). Also, Gil (2006) analysed and determined the length-fecundity relationship and the most probable month and spawn percentage (*SP* vector). Later, from the original database generated by Gil (2006), Gutiérrez-Estrada et al. (2017) determined the length-size standard deviation relationship and the length-male and female proportion relationship (Table 3).

Environmental information

Nowadays there is a relatively wide knowledge about the environmental conditions in the Strait of Gibraltar which is available in different open databases. These databases record real and modelled data including on air and sea temperature, salinity, temperature flux, salt flux, current speed, chlorophyll a concentration, atmospheric pressure, rainfall, and freshwater discharge.

Table 3. *Biological parameters of the Pagellus bogaraveo live history experimentally obtained for the Strait of Gibraltar population*

Model, relationship	Parameters, values
Von Bertalanffy model*	L_∞, t_0, k
	58 cm, -1.1674 years, 0.169 year^{-1}* 62 cm, -0.3400 years, 0.162 year$^{-1\#}$
Length-weight relationship (cm-g)	a_{lw}, b_{wl}
	0.0140, 3.0140*
	0.0010, 3.2390§
Length-size standard deviation relationship (cm-cm)	a_σ, b_σ
	0.8591, 0.3663†
Length-fecundity relationship (cm-number of eggs)	a_{lf}, b_{lf}
	3·10-7, 4.26*
Month and spawn percentage (SP vector)	January(%), February(%)…
	(10n, 30n+1, 60n+2,…,0n+11)*
Length-male and female proportion relationship (cm)	f_0, f_1, f_2
	390.48, 15.4290, 0.1524†

*Gil (2006)
#Gil (2017) Combined data from the Spanish and Moroccan fleets
§Czerwinski et al., 2008
†Gutiérrez-Estrada et al., 2017

From an environmental point of view, the oceanographic conditions in which the biological parameters of the Blackspot seabream population were obtained (Table 3) are conditioned by an oceanic current scheme that links the Atlantic Ocean with the Mediterranean Sea. The Strait of Gibraltar is characterized by an interchange of water masses with different temperature and salinity properties between the Mediterranean Sea and the Atlantic Ocean with an inward flow from the Atlantic Ocean which moves at a faster velocity in relation to the outward flow from the Mediterranean Sea in the bottom (Parrilla et al., 1986; García-Lafuente et al., 2000, Vargas-Yáñez et al., this book).

These average conditions undergo medium and long term changes that are reflected as significant variations of anomalies of some important parameters like sea temperature and salinity along the depth gradient (Figure 3a and 3b).

Since the eighties, the variations of temperature and salinity anomalies have been particularly important in some periods. For example, the middle of 90's sea temperature anomalies significantly higher than two times the standard deviations were detected in the most shallow layers of the sea. Also, this increase of the sea surface temperature was very clear between the years 2010 and 2012. Also, anomalies significantly low were observed in several periods along all depth gradients. This was particularly evident for some years in depths lower than 130 m (years 2002, 2008 and 2010).

A similar anomalies pattern was detected for the salinity (Figure 3b). In this case is

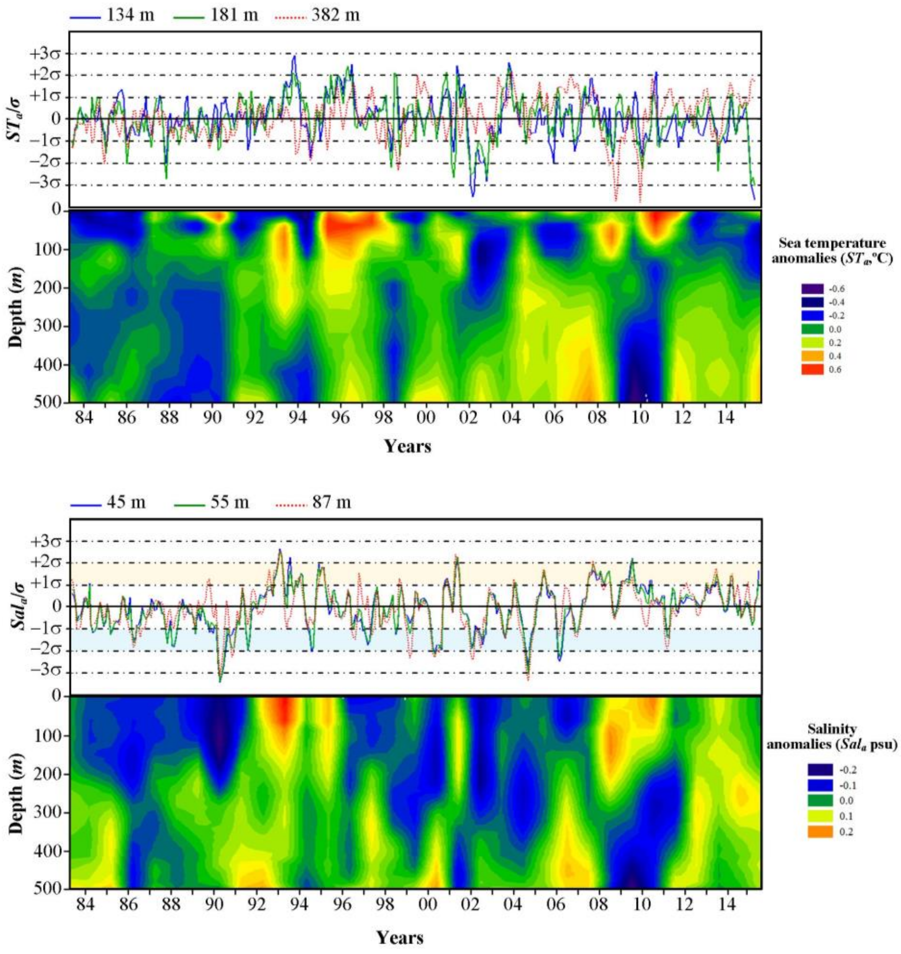


Figure 3. *Average sea temperature anomalies (a) and salinity anomalies (b) between 1983 and 2016 for a depth range between 0 and 500 m in the Strait of Gibraltar. For each variable, the average anomalies above and below one, two and three times the standard deviation (σ) recorded for different depth are shown. Raw data has been obtained from Simple Ocean Data Assimilation (SODA) v 3.3.1 reanalysis data set (http://www.atmos.umd.edu/~ocean)*

notable the variation of salinity in the surface layers in early 90s and between 2006 and 2010 where the anomalies oscillated between -3 and 3 times the standard deviation, and -2 and 2 times the standard deviation, respectively.

Population status (assessment approaches)

Length Cohort and Virtual Population Analyses (LCA and VPA)

Cohort Analysis or Virtual Population Analysis (VPA) (Gulland, 1965, Murphy, 1965) is a widely known analysis in which it is assumed that the stock is composed of several annual cohorts each of which is analysed and followed separately. Therefore, VPA is based on backward calculations through time and ages in function of all ages in the last year age group for all years and estimates the total abundance adding the number of individuals fished and lost by natural mortality during a year to the number of individuals at the end of the year.

Length Cohort Analysis (LCA) assessment was attempted using the VIT software (Lleonart and Salat, 1992). VIT program was designed to assess exploited marine populations caught by means of different gears and basically can obtain results based on catch data structured by ages or sizes. For this approach, the main assumption is that the population is in a steady state (equilibrium conditions) because the program works with pseudo-cohorts. Therefore it is not runs with historic series. In a first step, VIT rebuilds the mortality vectors and population from the catch data. After that, the user can obtain comprehensive VPA results, including yield per recruit analyses based on the fishing mortality vector, analyses of sensitivity and transitional analyses - outside the equilibrium - due to changes in the pattern of exploitation or recruitment. The stock size estimates, which include annual recruitment estimates, allow analyse the yield per recruit.

Spawning stock biomass per recruit (SSB/R) (Gabriel et al., 1989) and yield per recruit (Y/R) (Beverton and Holt, 1957) analysis are procedures commonly used to test different management strategies. Particularly, these approaches are very useful when historical information on recruitment is limited.

On the other hand, the combination of length/age data over years provides the estimation of reference points for management purposes which also can be extended to analyses the contribution of a fixed number of individuals to the spawning component of population. This way, from the VPA outputs, a spawning stock biomass per recruit analysis and the yield per recruit analyses were estimated the biological reference points (F_{MAX} and $F_{0.1}$).

Table 4. *Summary of the pseudo-cohort 2014-2016 of Blackspot seabream used in the Length Cohort Analysis (LCA). For this analysis, the parameters obtained from the combined data of Spanish and Moroccan fleets were used (see table 2)*

lengthclass (2 cm)	Spain-Morocco			Pseudocohort (2014-2016)
	2014	2015	2016	
20	0	0	1169	390
22	0	110	468	193
24	203	1248	1656	1036
26	21214	18397	22665	20758
28	63662	61850	44955	56822
30	78416	79288	54951	70885
32	82941	80593	60672	74736
34	55090	68976	52972	59013
36	32448	59470	44730	45549
38	23645	47187	30483	33772
40	15234	36132	22347	24571
42	11434	28508	16418	18787
44	8238	22430	12562	14410
46	6589	16343	9136	10689
48	5087	9458	5238	6595
50	3605	5413	2910	3976
52	2539	2195	1541	2092
54	892	464	476	611
56	311	142	42	165
58	242	61	65	122
60	363	0	32	132
tonnes	259	391	263	304

LCA/VPA input data and parameters

Before the analysis a smoothing process of the available data (harmonization) was carried out. Later, in order to check the stability of parameters LCA-VPA backwards test was applied for every two year separately. Finally, a 2014-2016 pseudocohort was generated for a last LCA run. Table 4 shows the length frequency distribution used in this assessment and the table 5 presents the 2014-2016 pseudocohort age distribution resulting from the slicing procedure.

Table 5. *Blackspot seabream of the Strait of Gibraltar area - Pseudocohort catch at age, mean weight at age (g), maturity ratio and natural mortality (M)*

Class	Catches (n)	MeanWeight (g)	Maturity ratio	M
0	938	167	0.0	0.2
1	79262	341	0.1	0.2
2	143575	561	0.5	0.2
3	81591	820	0.8	0.2
4	40925	1098	1.0	0.2
5	21778	1381	1.0	0.2
6	13178	1656	1.0	0.2
7	7189	1918	1.0	0.2
8	3788	2163	1.0	0.2
9	2110	2387	1.0	0.2
10	1170	2590	1.0	0.2
11	385	2774	1.0	0.2
12	247	2935	1.0	0.2
13	90	3078	1.0	0.2
14	48	3203	1.0	0.2
15	41	3311	1.0	0.2
16	29	3405	1.0	0.2
17	22	3486	1.0	0.2
18	19	3556	1.0	0.2
19	16	3617	1.0	0.2
20	14	3669	1.0	0.2
21	12	3713	1.0	0.2
22	10	3750	1.0	0.2
23+	1	3785	1.0	0.2

LCA/VPA results

The results of LCA/VPA are shown in Figure 4. The time series of recruitment and biomass obtained (Figure 4a) showed a clear decreasing trend and were close to the lower values of the whole series. The spawning stock biomass (SSB) levels were relatively stable over the last three years analysed (2014-2016) and their values were similar to the obtained in 2005 and 2006. On the other hand, fishing mortality ($F_{4\text{-}11}$) (Figure 4b), fluctuated between 0.1 and 0.8 and decreased after the last peaks reached in 2013 and 2015. From the VPA, the reference points indicated that fishing mortality was aproximately 0.3 ($F_{current}$=0.3) which was above the values estimated for the mortality level for the maximum sustainable yield (MSY) (F_{MSY} proxy: $F_{0.1}$=0.14) (Figure 5).

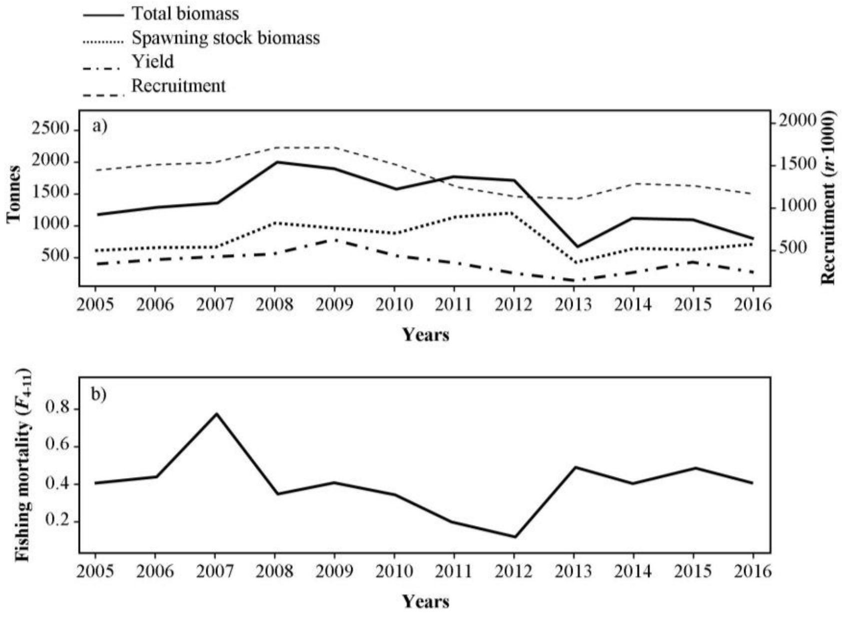


Figure 4. *a) Total biomass, spawning stock biomass, yield and recruitment; b) fishing mortality ($F_{4\text{-}11}$) estimated by means VPA for the Blackspot seabream in the Strait of Gibraltar area*

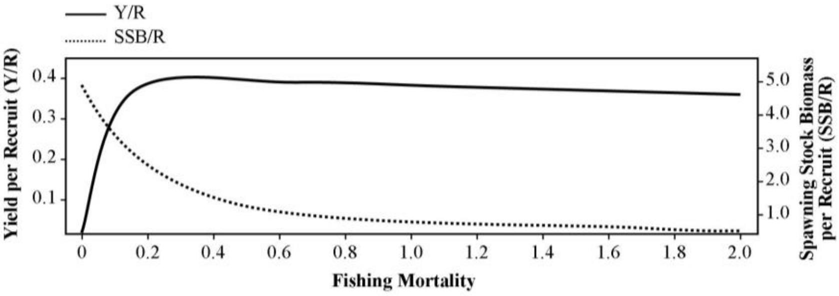


Figure 5. *Yield per recruit (Y/R) and Spawning Stock Biomass per recruit (SSB/R) analysis curves performed using NOAA Fisheries Toolbox ((NOAA fisheries Toolbox [NFT] webpage http://nft.nefsc.noaa.gov/)*

Globally Applicable Area Disaggregated General Ecosystem Toolbox (Gadget) model

Gadget is a model considered to show the greatest potential to contribute to practical fisheries management advice such as changes to total allowable catch (Plagányi, 2007). It contains a flexible and powerful software tool that has been developed to model marine ecosystems, including both the impact of the interactions between species and the impact of fisheries on the populations. Gadget works by running an internal forward projection model based on many parameters describing the ecosystem, and then comparing the output from this model to observed measurements to get a likelihood score (Begley, 2005; Taylor et al., 2007).

In this model the processes are usually length dependent. The framework allows the creation of multi-area or multi-fleets models in which it is possible to include predation and mixed fisheries. Gadget has essentially three components: a) an ecosystem simulator; b) a likelihood function that takes the output (from the ecosystem simulator) and compares the data and; c) a function minimizer (optimization routines to find the best set of the model parameters values). To work, Gadget needs initial estimates of recruitment (age 0) every year and initial abundances by age in the first year.

Gadget Input data and parameters

Particularly, to establish and project forward the population dynamic of the Blackspot seabream in the Strait of Gibraltar, Gadget follows this order: fish are caught by the *voracera* fleet with a five different selection patterns (1 for Morocco and 4 for Spain), afterwards it dies by natural mortality and eventually growths and ages.

As is stated above, model parameters are estimated minimizing differences among observations and estimated values provided for the program. Gadget´s probability process the result of the ecosystem simulation based on aggregate dimensions: thus within this module several datasets can be compared to the model output using a suite of different types of length distribution. Particularly, in the case of the Blackspot seabream fishery Gadget model take in account 4 different types of data to enter the probability function: length distribution from commercial fleets (Morocco and Spain), age-length distribution and sex ratio at length (from biological samplings) and finally fleets effort (in fishing days). Thus the likelihood or probability function included a total of 20 different components.

For a simulation with Gadget, it is necessary to assume that the Blackspot seabream is a long live species, so the maximum age is set at 17 (for males and females). While the model length range was from 0 to 62 cm, in 1 cm length intervals, with females population start at 20 cm. The period of simulation considered starts in 1983 and end in 2016. On the other hand, in Spain four catch categories (associated to market categories) are considered: small, medium, large and extra-large. For Morocco, a single pattern describes the suitability its fleet (Figure 6).

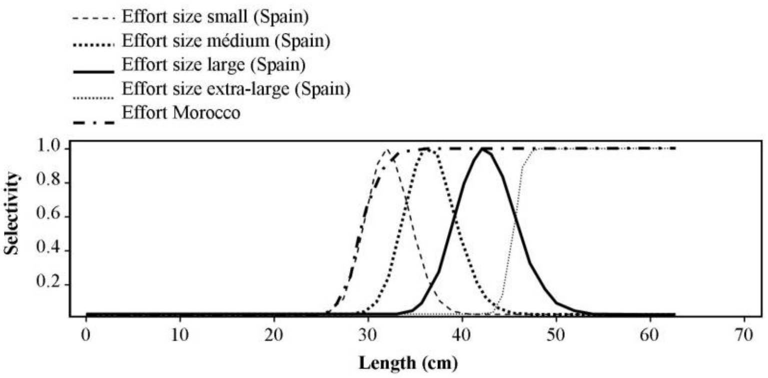


Figure 6. *Selectivity pattern for the voracera fleet of Spain and Morocco*

Gadget results

Considering the differences between fleets and market categories the results of the Gadget model for the Moroccan fleet showed a good fit to the observed data (Figure 7). A similar pattern was observed for the Spanish fleet (Figure 8a to 8d). This good fit also was observed when the proportions at age (from agreed otoliths readings) were compared with the model estimates for each market size (Figure 9 and 10).

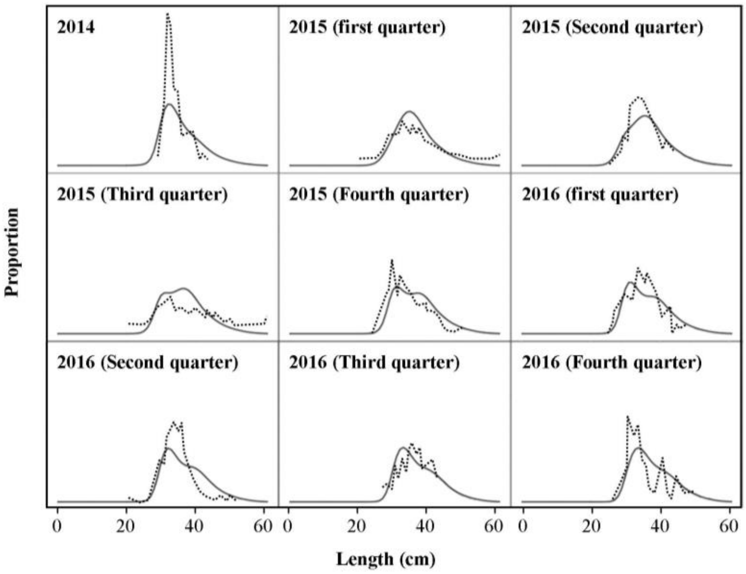


Figure 7. *Length distribution from Moroccan fleet from 2014 to 2016. Dotted lines denote the observed values while solid lines corresponds to the model predictions*

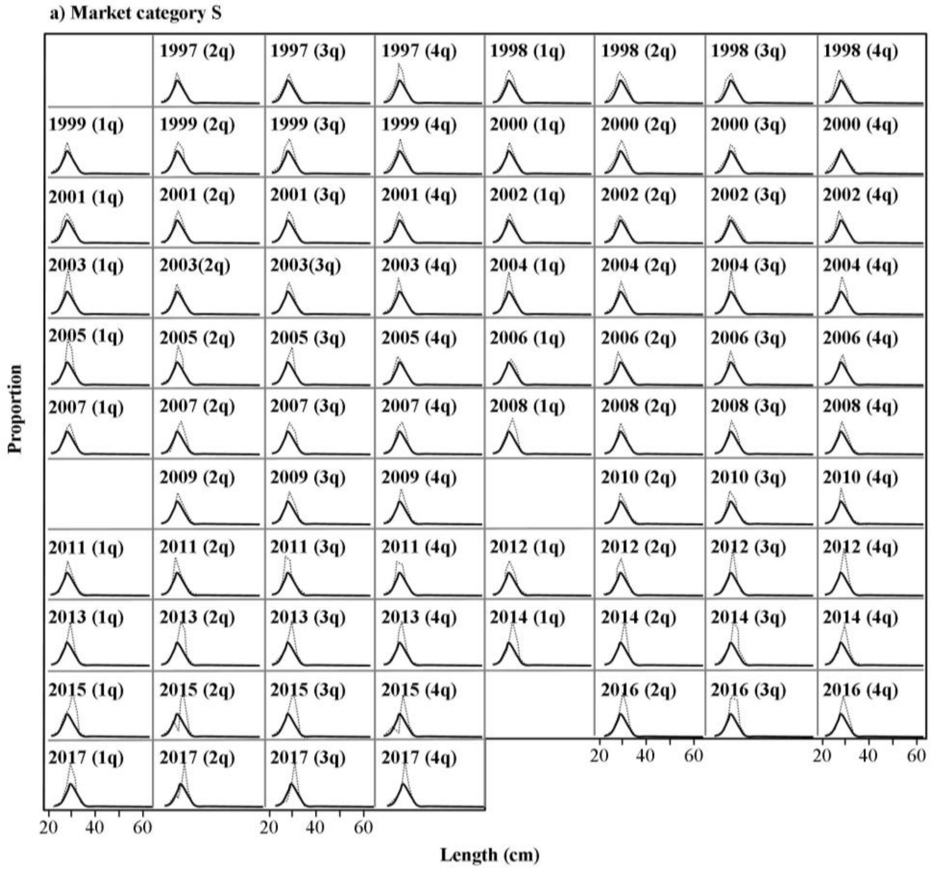
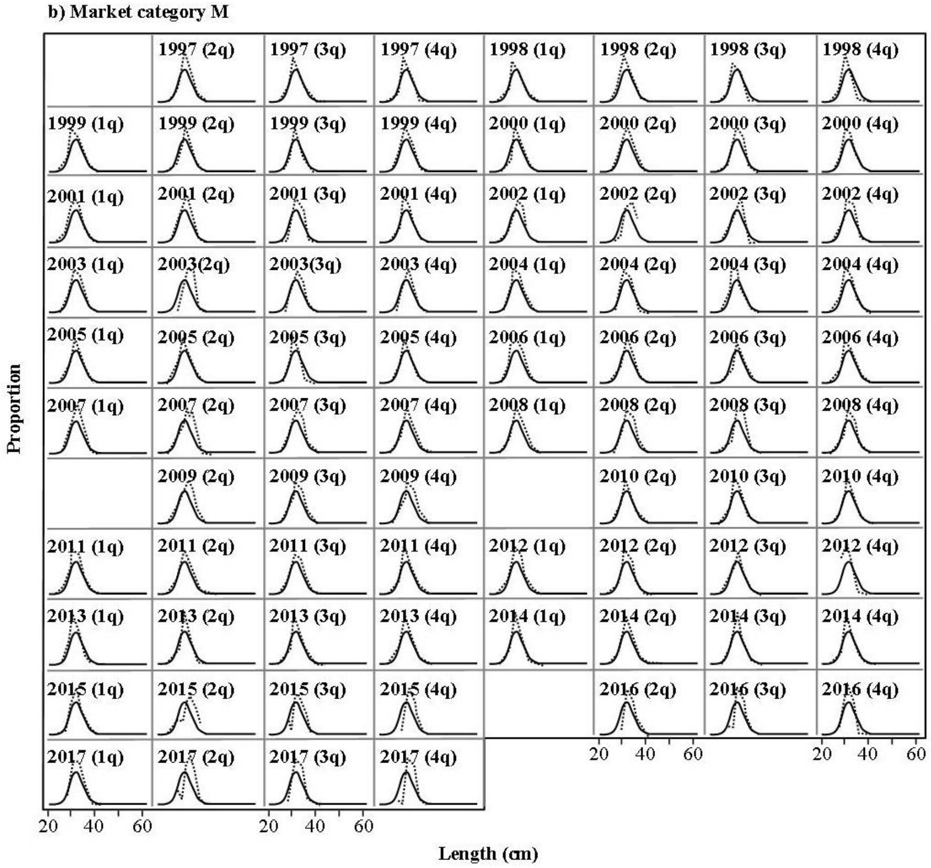
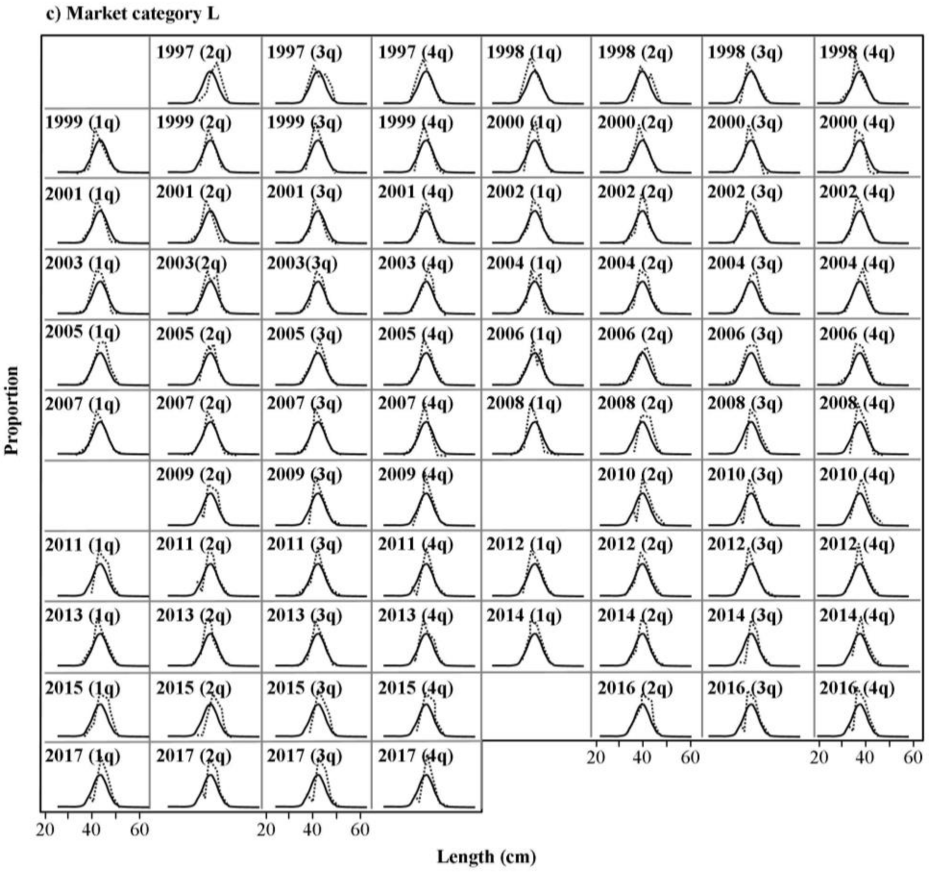


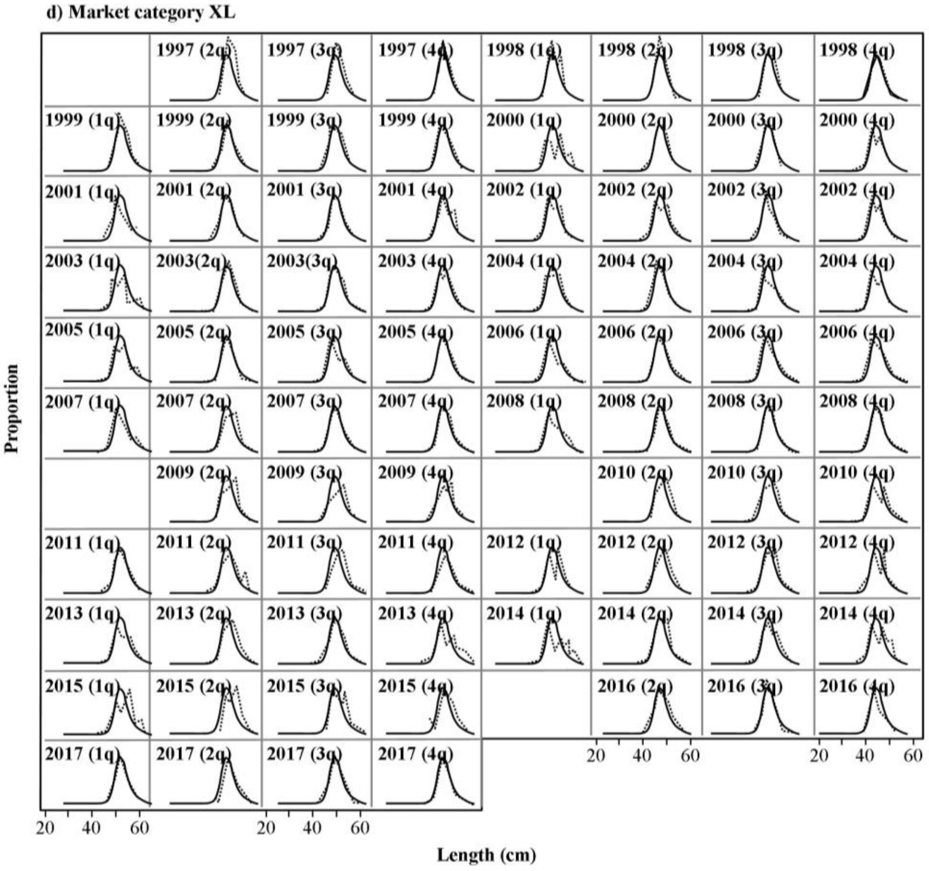
Figure 8a. *Length distribution from Spanish fleet (market category S). Dotted lines denote the observed values while solid lines corresponds to the model predictions*



Figures 8b. *Length distribution from Spanish fleet (market M). Dotted lines denote the observed values while solid lines corresponds to the model predictions*



Figures 8c. *Length distribution from Spanish fleet (market L). Dotted lines denote the observed values while solid lines corresponds to the model predictions*



Figures 8d. *Length distribution from Spanish fleet (market XL). Dotted lines denote the observed values while solid lines corresponds to the model predictions*

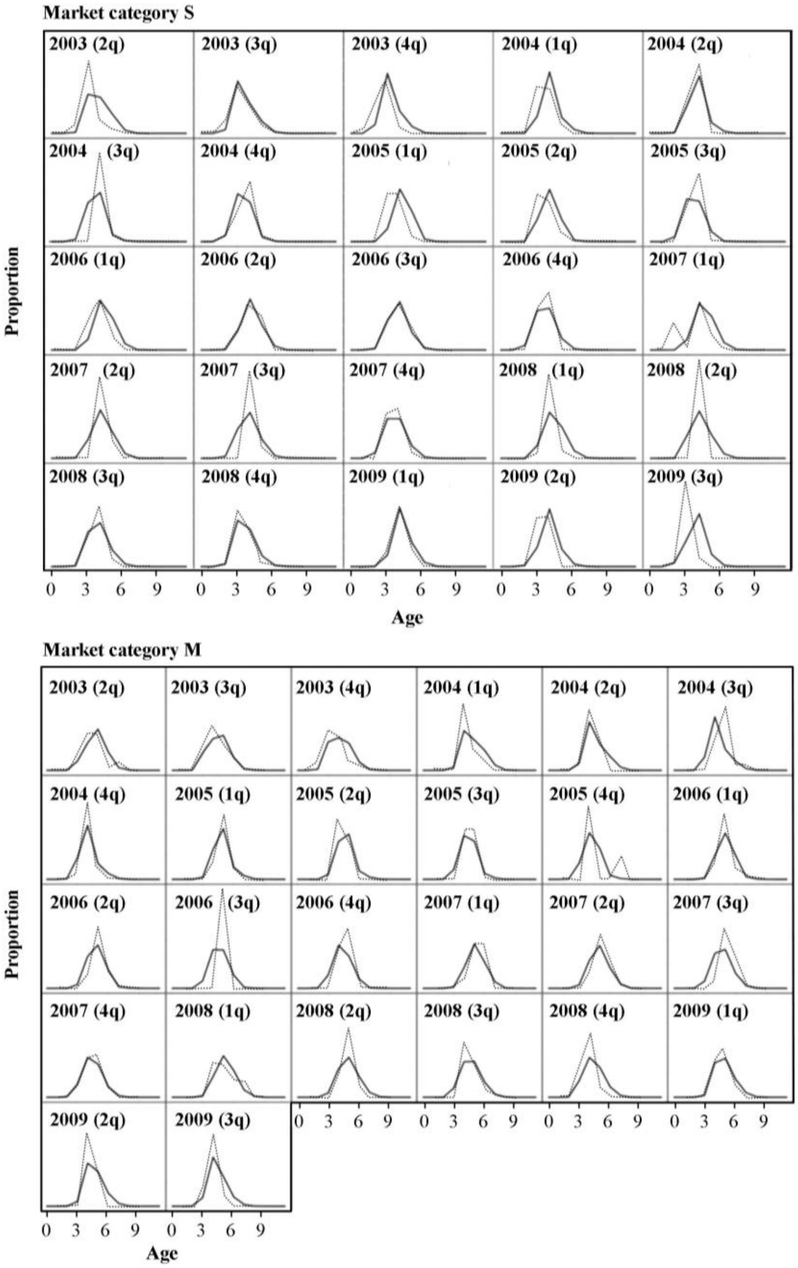
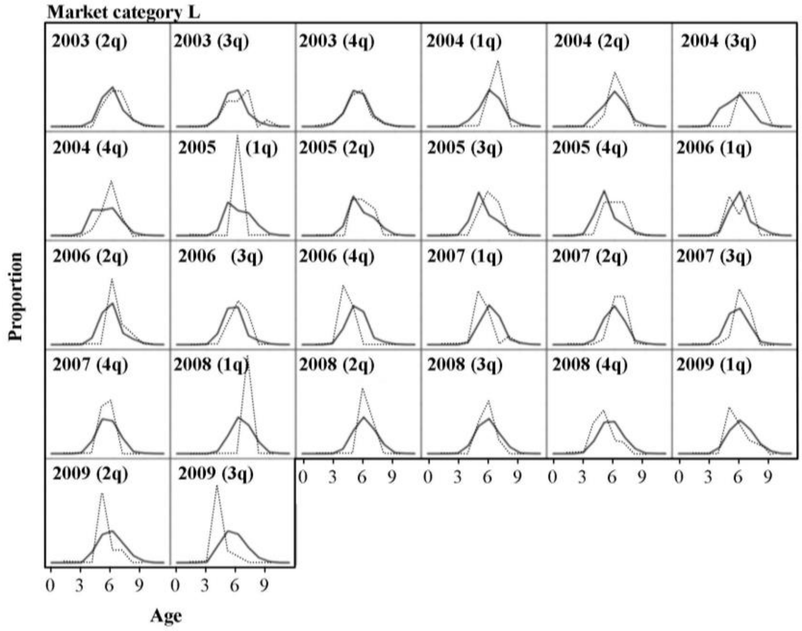


Figure 9. *Age distribution from Spanish fleet (market category S and M). Dotted lines denote the observed values while solid lines corresponds to the model predictions*

The model for the Blackspot seabream split the population in two components: males and females because the species hermaphroditism. Larger individuals are generally females and lower percentages in observed ratios were a consequence of the sampling level. Figure 11 shows the observed sex ratio and the estimated one by Gadget.

Market category L



Market category XL

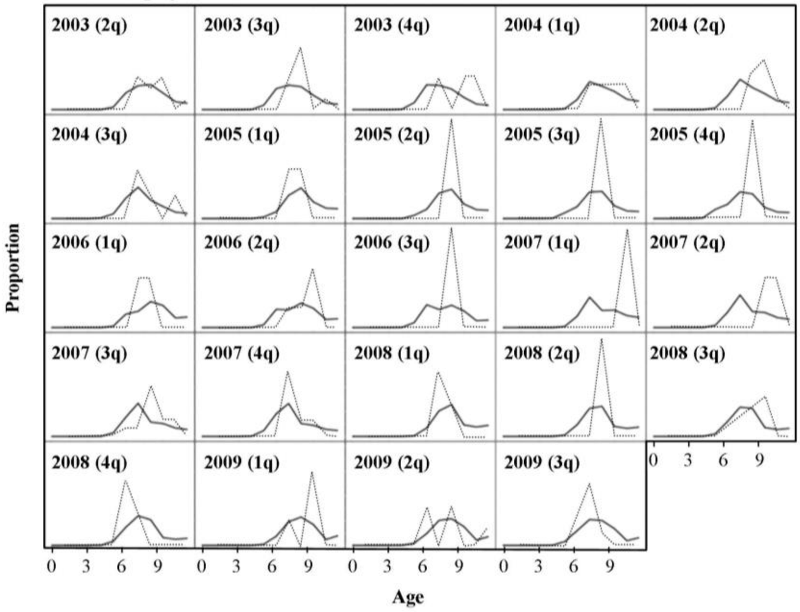


Figure 10. *Age distribution from Spanish fleet (market category L and XL). Dotted lines denote the observed values while solid lines corresponds to the model predictions*

Figure 12 represents the estimated disaggregated catches (males and females) included in the model. The Gadget model showed that the catches and total biomass for both sexes decreased after having peaked to its highest level in the mid-2000’s (Figure 13). On the other hand, the evolution of the fishing mortalities indicated two peaks over 0.6

centred around the mid-90s and 2010 associated to those period in which the catch levels were higher.

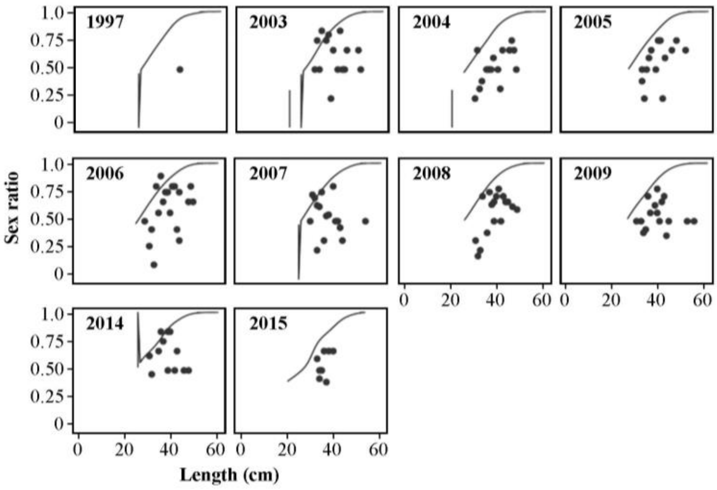


Figure 11. *Sex ratio at length distribution from biological samplings. Black points are the observed values while the continuous line represents the model estimates*

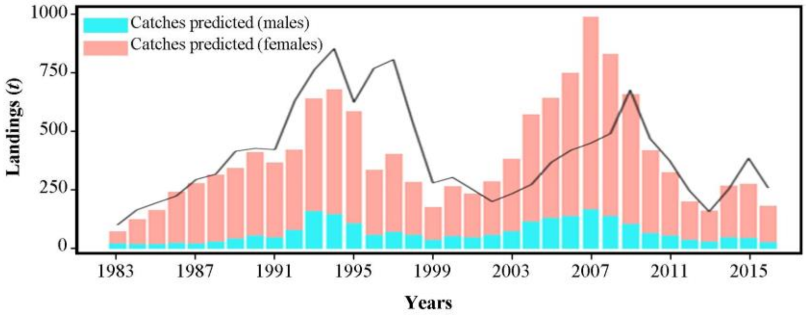


Figure 12. *Comparison between catches predicted from the Gadget model (blue and red bars) and the Strait of Gibraltar reported landings (Morocco and Spain) of Blackspot seabream (black line)*

Likewise, the recruitment estimates at age 0 provided by Gadget shows a strong seasonal profile with a recruitment peak in 1990 and the first years of 2000-s. The values of the most recent years are close to the bounds of the parameters file and looks unreliable, or at least with a lot of uncertainty (Figure 14).

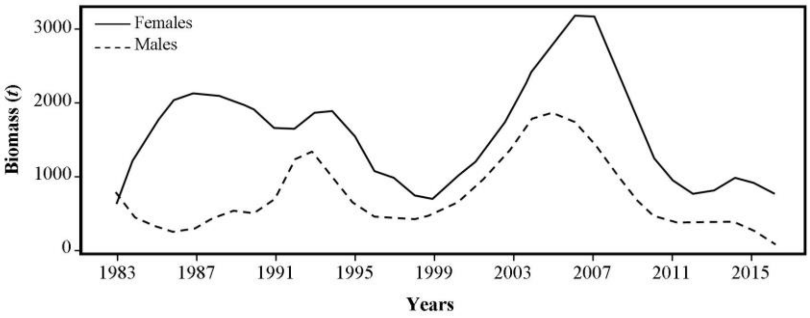


Figure 13.*Biomass estimates for the two components of the stock (males and females)*

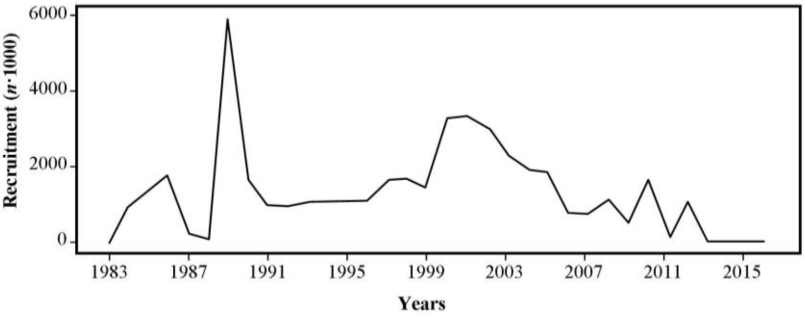


Figure 14. *Recruitment estimates at age 0*

In short, Gadget indicates that Blackspot seabream population of the Strait of Gibraltar shows a concerning biomass level and that the total biomass get the lowest value in the last year analysed 2016 (Figure 15).

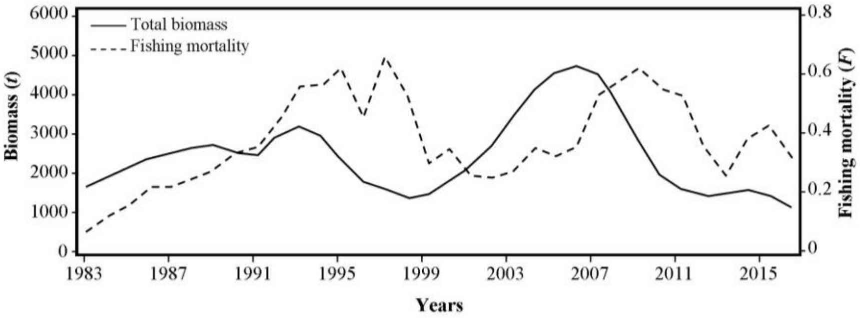


Figure 15. *Assessment summary provide for the Gadget model for the Blackspot seabream of the Strait of Gibraltar fishery*

Simulation of Fish populations (SimFish model)

The simulation of fish population dynamics (SimFish model) is based on the model proposed by Gutiérrez-Estrada et al. (2017) which was compiled in its first version in the SimFish 1.0 program. An improved version has been implemented in SFish Subclass 1.1. SFish works under three basic assumptions: (1) over a sufficiently long period of time, the biomass of a fish population tends to reach a dynamic equilibrium that oscillates around an average value (persistence principle); (2) the environmental conditions under which the parameters of the general growth model were calculated remain constant throughout the simulation and; (3) under the premise of environmental invariability, the variation in the abundance of a population is linearly dependent on the abundance of the resource in the past and the number of catches, so it can be modeled through an autoregressive process of non-seasonal order p and seasonal order P (Gutiérrez-Estrada et al., 2020). Likewise, all simulations are developed in a spatially implicit context.

Like others computer programs, SFish allows to assess the variation of abundance or biomass during the exploitation period. However SFish is specifically designed to disaggregate the environmental effects of the fishing component. If it is assumed that throughout the simulation the environmental conditions remain similar to those found in the period in which the growth model was obtained (i.e., if the model does not incorporate extra-compensatory effects), then the variation in biomass at time t+1 depends exclusively on the biomass and the catch made at time t, and therefore the biomass series over time can be adjusted to an autoregressive process. Under these assumptions, the lack of fit of the autoregressive model must be the consequence of exogenous factors to the fishery and biological parameters. In this way it is possible to find some type of correlation patterns (linear or nonlinear) between the autoregressive residual series and time series of environmental parameters.

SimFish data, parameters and simulations

Like Gadget, SimFish require several parameters about the Blackspot seabream biology like the population growth model or the population structure composition and different experimental relationships as the established between length and weight or length and fecundity. Additionally, it is necessary to take into account that the Blackspot seabream is a protandric hermaphrodite species but is functionally gonocoric (Alcaraz et al., 1987). That is, the young individuals are functional males that progressively develop their female gonads to become functional females, therefore it is necessary to know the relationship between length and the proportion of males and functional females.Also, a estimation of the natural mortality and the biomass of age class 0+ at the moment t=0 is required (a complete and detailed description of the parameters required and the algorithms can be found in Gutiérrez-Estrada et al., 2017 and Sanz-Fernández et al., 2019).

To simulate the abundance of Blackspot seabream SimFish requires the catches time series in a monthly scale. In this case, the catches of the Spanish and Morocco are considered jointly. If, in addition to evaluating the abundance or biomass of the population, we want to evaluate the effect of environmental variables, SimFish will require different environmental database composed of historical series of oceanographic and climate indices.

Initially, the simulations of the Blackspot seabream fishery in the Strait of Gibraltar were carried out under stability conditions, that is, in absence of catches and considering no effects of environmental conditions on the variation of biological parameters. This provided baseline simulations that allowed to obtain initial values of the biomass of the class 0+ at the moment *t*=0 and a mean natural mortality (*M*). Once established the parameters that provide a baseline simulation, the simulation process is repeated but subtracting the real catches.

Under this scenario of environmental stability, the variations in biomass at time *t*+1 depend exclusively on the biomass and the catch made at time *t*, so auto-regression behavior of the simulated biomass series is assumed. For that, ARIMA (Autoregressive Integrated Moving Average) Models are used. These models assume that a time series is a linear combination of its own past values and current and past values of an error term. Later, the program calculates the residual time series between the abundance simulated and ARIMA estimation and correlates it with the different time series of environmental variables if this time series are available.

SimFish results

4032 simulations corresponding with seven different bio-ecological scenarios were carried out. From these, the 81.4% provided extinct stocks. The remaining were selected and grouped seven biologic-environmental scenarios. These scenarios were classified in function of the age classes (ranged from 15 to 20), the biomass of class 0+ at time *t*=0 (between 20 y 45 t), the parameters of the Ricker stock-recruitment relationship and the percentages of spawn in the spawn period (from January to March).

All the simulations resulted in a similar behavior until early 2000s (Figure 16).The evolution of the total biomass started in the maximum biomass point around 5300 t. From this year the total biomass decreased to its minimum in 1999 (618 t). From this year, each biological scenario provided different estimations and with a maximum variance at the end of 2016. In this year SimFish estimated that total biomass of

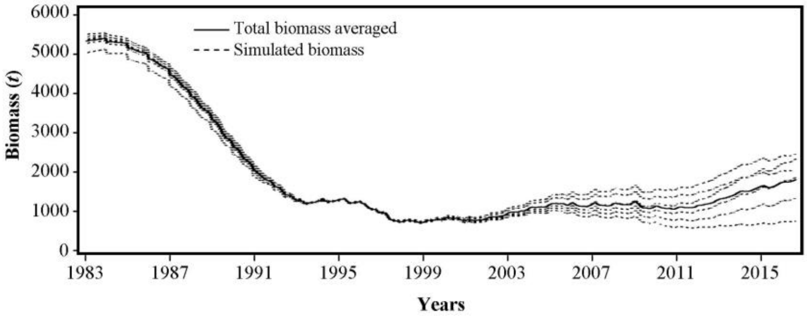


Figure 16. *Total biomass simulated obtained with SimFish. Continuous line is the total biomass averaged and dotted lines correspond to the total biomass calculated for simulations associated to different population structures (from 15 to 20 age classes)*

Blackspot seabream oscillated between a little more than 500 t and 2500 t, which supposed a 9.5% and 47% of the initial biomass respectively. When all simulations were averaged, SFish indicated that the biomass at the end of 2016 was 1900 t (35.8 of the initial biomass).

The annual forecasting of ARIMA models for these simulations provided good fits. In the case of the averaged simulations the average of annual explained variance was 64% and a root mean square error (RMSE) slightly higher than 80 t/year. Therefore, SFish indicates that a 36% of the biomass variation could be explained as a consequence of the effects of different environmental factors.

State of exploitation and scientific advice

The shift towards sustainable fisheries management strategies in a context of climate change involves making decisions with strong social and economic implications. How can managers make these decisions taking into account the uncertainty associated with existing information on fisheries and environment while assuming the principles of sustainable management and planning to short and longer term? It seems evident that the answer to this question involves the use of different types of models and this is evidenced in this work.

The results of this study support the idea that the main factor responsible of the changes on abundance of Blackspot seabream in the Strait of Gibraltar is the fishery component. The three approaches used to estimate the total biomass of this species indicate that from the 2010 the stock is kept at very low levels that oscillate between 900 and 1600 t (Figure 17). SimFish estimate that at least 64% of the biomass variation is consequence of fishery component. On the other hand, estimates of the reference point ($F_{0.1}$ = 0.12-0.17) from two of the models (LCA-VPA and Gadget) is far above from current fishing pressure (about 0.3) which reinforces the idea of a clear overexploitation of the resource.

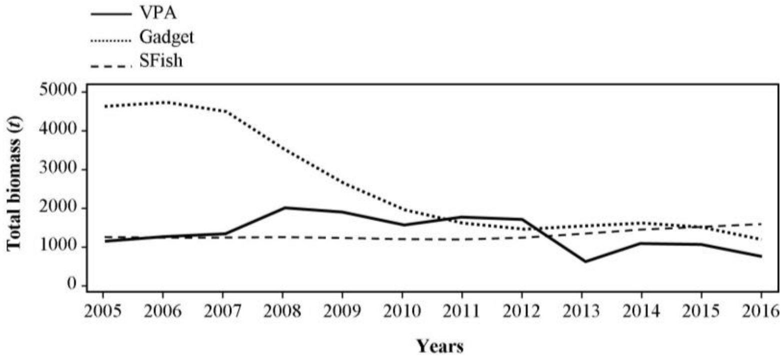


Figure 17. *Comparison of results from three different approaches (VPA, Gadget and SimFish) used for the assessment of the Blackspot seabream population of the Strait of Gibraltar*

On the basis of the above, the level of fishing effort should be reduced in order to set the level of fishing mortality at a more sustainable level. This could be gradually achieved by mean of multiannual management plans that foresee a reduction of fishing mortality through fishing limitations. However, nowadays there is not implemented a specific/joint management plan for the Blackspot seabream of the Strait of Gibraltar. Both countries have different management measures on the target fishery but there are not any common ones towards its sustainability. There only is a recent recommendation to establish an adaptive multiannual management plan for the sustainable exploitation of Blackspot seabream in the Alboran Sea (GFCM/43/2019/2). Its operational objective shall be to maintain fishing mortality for Blackspot seabream within agreed precautionary reference points in order to reach and maintain as soon as possible a fishing mortality level consistent with the MSY.

Therefore, the stock assessment of the Strait of Gibraltar Blackspot seabream target fishery is still subjected to a benchmark process within the GFCM. The objective of the benchmark is to perform a full analysis and review of the information and methods used to provide advice on the status of the stock, focusing on the consideration of old and new data sources as well as old and new (or improved) assessment models and assumptions. Once this process is closed the next tool/step might be the development of Management Strategy Evaluation (MSE) to simulate the fishery system and allow scientist, managers and stakeholders to test whether potential harvest strategies can achieve pre-agreed management targets. Only in this way, the Blackspot seabream fishery in the Strait of Gibraltar (as other fisheries around de World) will move toward management based on harvest strategies to increase its long-term sustainability, stability and profitability.

Acknowledgments

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