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Research Article

Exploitation status and stock assessment of the smooth clam *Callista chione* (Linnaeus, 1758) in the northern Alboran Sea (GSA01-W Mediterranean Sea)

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Abstract

The smooth clam, *Callista chione* (Linnaeus, 1758), is a venerid bivalve widely appreciated in southern Spain where it represents the top commercial bivalve species in terms of landings and economic value. In this area, a total of 223 artisanal boats (68% of the artisanal fleet) are involved in shellfishing targeting bivalve molluscs, including the smooth clam. The artisanal mechanised dredging that targets *C. chione* in the northern Alboran Sea is described and the current exploitation status of its populations is analysed. A surplus-production model was run using ASPIC and used to assess the temporal variation in the levels of fishing for this bivalve throughout the study period (2002-2015), as well as to suggest conservation reference points that could guarantee the sustainable exploitation of this resource. During the study period, the maximum *C. chione* catch was registered in 2003 (306 t) and the minimum in 2006 (93 t). The ASPIC model for *C. chione* stock suggests that a Maximum Sustainable Yield (MSY) of 216 t could be produced from a total stock biomass of 983 t (Bmsy) at a fishing mortality rate of total biomass of 0.22 (Fmsy), with B/Bmsy and F/Fmsy values of 1.34 and 0.82, respectively, indicating that the stock is approaching good status.

Keywords: Artisanal fishing mechanised dredges, Mediterranean Sea, *Callista chione*, stock status.

Introduction

The Alboran Sea represents a transitional ecoregion between the Atlantic Ocean and the Mediterranean Sea, connecting both oceanic domains through the Strait of Gibraltar (Spalding *et al*., 2007). It extends from the imaginary line between Cabo de Gata (Spain) and Cap Fegalo (Algeria) to the Strait of Gibraltar. Primary productivity in the Alboran basin is driven by the entrance of Atlantic surface waters into the Mediterranean and the development of anticyclonic gyres, stimulating upwelling and high phytoplankton productivity at the local scale (Parrilla & Kinder, 1987; Sarhan *et al*., 2000). The geographical location of the Alboran Sea, its complex oceanographic and hydrological processes caused by its special orographic features, and its high productivity, support a high biodiversity in comparison to other Mediterranean areas (García Raso *et al*., 2010; Templado, 2011; Sabelli & Taviani, 2014). These factors have also led to important fishing activity utilising a wide diversity of gears and targeting various species (Coppola, 2001). It is included in FAO area #37 as well as Geographical Subarea #1 (GSA01) of the General Fisheries Commission for the Mediterranean (FAO, 2009).

The artisanal fleet is the largest operating in the Alboran Sea (Alarcón, 2001; Robles *et al*., 2010), and is very important for the economy of many local communities. This type of fishing has a traditional character, involving small boats that make daily trips to fishing grounds located very close to the coast (Camiñas, 1990; Piniella *et al*., 2007). At the same time, it is characterised by the use of a high diversity of fishing gears that are alternated, both temporally and spatially, according to the seasonal abundance of resources or to the close season of target species (Farrugio *et al*., 1993). Traditional small-scale fishing methods are typified by their low environmental impact, where the product is high quality and attains a premium price in local markets.

Commercial fishing and the consumption of bivalves in Mediterranean coastal areas has been a common practice since ancient times (Voultsiadou *et al*., 2010). In the Alboran Sea, mechanised dredges for commercially collecting molluscs were already in use by the early twentieth century, although these were dragged by a hand-operated winch installed on the boat (Rodriguez Santamaría, 1923).The method was gradually replaced by the mechanised dredges currently used by the artisanal fleet until it disappeared in the 1980s (Baro *et al.,* 1992). Nowadays the fleet, known locally as "marisquera" (deriving from the Spanish word for shellfish), targets many different species. The most important economically are the smooth clam *Callista chione* (Linnaeus, 1758), the rough cockle *Acanthocardia tuberculata* (Linnaeus, 1758), the striped venus clam *Chamelea gallina* (Linnaeus, 1758), and the truncate donax *Donax trunculus* Linnaeus, 1758, and these are caught for by a high number of boats and fishermen.

Despite the importance of the Alboran Sea as a biodiversity hot-spot in Europe (Coll *et al.*, 2010; García Raso *et al.,* 2010), and the significant artisanal fisheries in this basin (Alarcón, 2001; Robles *et al*., 2010), there are only a few studies on the application of technical measures for the appropriate management of fisheries resources that contribute to the implementation of the Common Fisheries Policy (EC-Regulation No 1380/2013), which aims to ensure the conservation, management and exploitation of such resources (FAO, 2016). Indeed, the sustainable exploitation of marine resources requires the design of fisheries policies that guarantee their renewability without endangering the ecosystem (Kelleher, 2005; Bellido *et al.*, 2011). At present, mechanised dredging in the northern Alboran Sea is regulated by the Andalusian Regional Government, and the current management plan contains specific catch limits and fishing measures in order to maintain the biomass level of exploited populations within safe biological limits.

Several studies have focused on bivalves commercially exploited in the Alboran Sea, however, most of these projects have dealt with very specific aspects of their biology, such as growth and reproduction (Cano Pérez, 1981, 1983; Salas, 1987, Tirado & Salas, 1998; Tirado *et al.*, 2002a, b; Rodríguez de la Rúa *et al.*, 2003). In addition, a detailed description of the characteristics and evolution of the fleet involved in shellfish fisheries was carried out between 1986 and 1990 as part of the project "Local fisheries of the Spanish South Mediterranean Region between Punta Europa and Cabo de Gata". The main results obtained were related to the fishing gear used, catches of target species, catches per unit of effort, size frequency distributions of catches, size-weight relationships, and mapping of natural shellfish beds (Baro *et al.,* 1992). Since then, the only studies dealing with fisheries have focused on discard analysis and damage to discarded species (Urra *et al.*, 2017).

The venerid *C. chione* is distributed from Great Britain to Morocco, including the Canaries, Azores and Madeira, as well as the Mediterranean Sea, inhabiting clean sandy infralittoral and circalittoral bottoms (Salas, 2010). This bivalve is commercially exploited throughout the Mediterranean and widely appreciated in southern Spain, being the most important commercial bivalve in the northern Alboran Sea in terms of landings and economic value, followed by *D. trunculus* and *C. gallina*. Several aspects of its ecology and biology have been researched in detail in Spain (Baro *et al.*, 1992; Tirado *et al.*, 2002b; Baeta *et al.*, 2014), France (Charles *et al.*, 1999), Greece (Metaxatos, 2004; Leontarakis & Richardson, 2005; Damianidis *et al*., 2010), Croatia (Peharda *et al*., 2010; Ezgeta-Balic *et al.*, 2011), and Italy (Mattei & Pellizzato, 1997, Canestri-Trotti *et al*., 2000), as well as along the Portuguese Atlantic coast (Gaspar *et al*., 2001), but very few studies have analysed aspects relating to its exploitation (Baeta *et al*., 2014). The aims of this work are: (1) to describe the artisanal mechanised dredging used to target *C. chione* in the northern Alboran Sea; (2) to analyse the current exploitation status of its populations in this area; and (3) to suggest conservation reference points that could guarantee the sustainable exploitation of this resource.

Material and Methods

Fisheries data from 11 fishing ports in the northern Alboran Sea, located in the cities of Algeciras, La Línea de la Concepción (henceforth La Línea), Estepona, Marbella, Fuengirola, Málaga, Caleta de Vélez, Motril, Adra, Roquetas de Mar and Almería have been considered for this study (Fig. 1). Information regarding the number of boats and the technical characteristics of these ports has been obtained from the 2015 official fleet census. Fisheries data on *C. chione* from 2002-2015 was obtained from the fisheries statistics recorded by the Andalusian Government's Fisheries and Aquaculture Marketing and Transformation Service of the Regional Ministry of Agriculture, Fisheries and Rural Development, which collects information on daily catches per species and boat at landing sites. Moreover, a total of 33427 sale-notes reported between March 2013 and March 2014 were analysed in order to identify the metiers used by the fleet in the northern Alboran Sea fishing grounds.

Catch per unit effort (CPUE) is considered proportional to the average biomass of the resource if the effort is appropriately standardised (Gulland, 1964; Kimura, 1981), especially in those fisheries operated by boats with different technical characteristics or fishing gear. The use of CPUE as an index of relative abundance stems from the assumption of proportionality between the CPUE obtained by a boat or class of boats and the average annual resource abundance ($\overline{Ni}\overline{Ni}$). This proportionality relationship is expressed by the equation:

$$Cij = q * fij * \overline{N}i$$

where *Cij* represents the catch per boat *i* in year *j*; *fij* corresponds to the fishing effort, usually represented by fishing time; and *q* is the catchability coefficient.

The fleet targeting *C. chione* in the northern Alboran Sea is very homogeneous in size, gross register tonnage (GRT), and power (HP), however, and as a previous step to the assessment of the exploited stock of *C. chione* through a surplus production model, a standardisation of the abundance index was conducted by means of Gen-

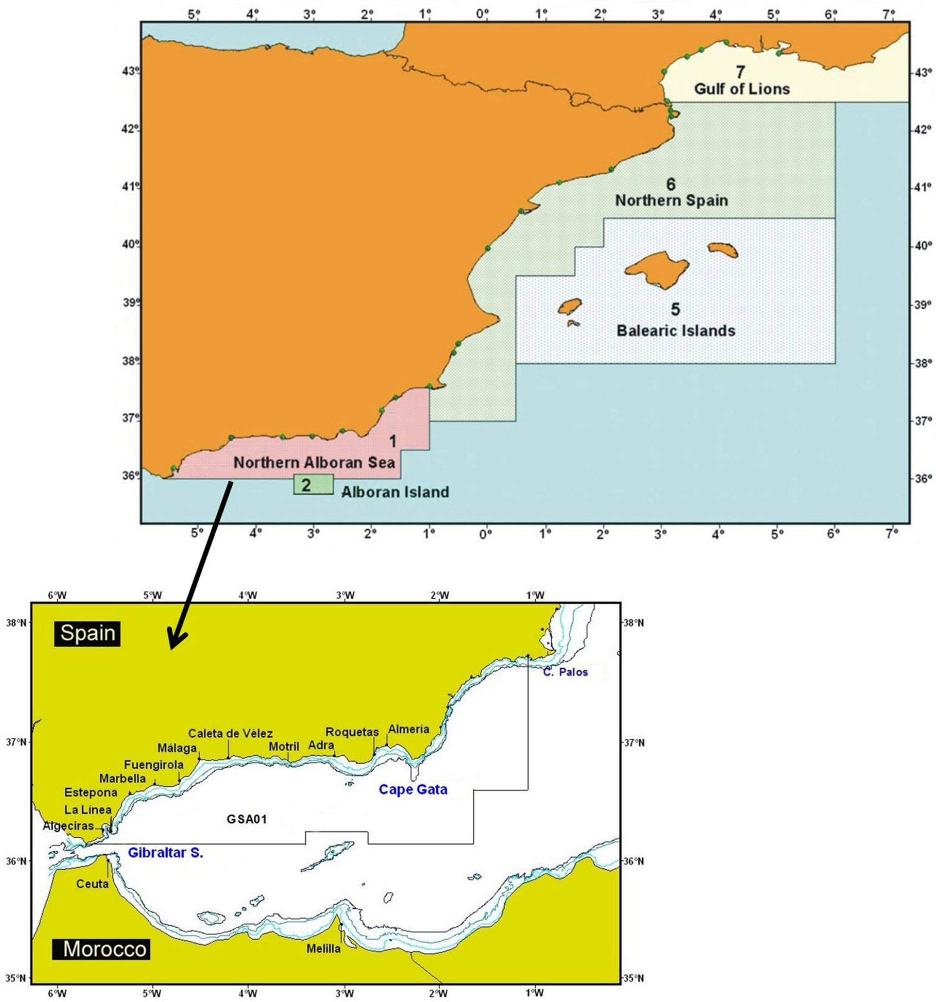

Fig. 1: Geographical subareas of the General Fisheries Commission for the Mediterranean (GFCM) and map of the study area in the northern Alboran Sea (W Mediterranean Sea), showing the locations of the fishing ports.

eralised Linear Models (GLMs, McCullagh & Nelder, 1989). Prior to this, the possible correlations between the technical characteristics of the boats (size, GRT, HP) were analysed using Spearman's rank correlation coefficient, in order to avoid the existence of co-linearity between these variables.

The monthly averaged daily CPUE values per boat targeting *C. chione* from 2002 to 2015 were used for the GLMs. A preliminary analysis of the CPUE data showed that this variable followed a log-normal distribution; hence, the link function used for the response variable was log with a Gaussian distribution function. CPUE data were modelled as a function of year, month, technical characteristics of the boat (GRT, HP, length), and boat. GLMs were performed on several models, including one technical factor at a time and the interaction term, with the aim of determining which factors best explained the observed variability in CPUE. The goodness of fit of the models was assessed by comparing their relative contribution to the total deviance explained and the Akaike Information Criterion (AIC, Akaike, 1974). All analyses were carried out using R routines and STATISTICA software.

A surplus production model was used to track temporal variation in the levels of fishing throughout the study period in order to assess the current stock situation. Assessments rely on the application of surplus production models because the size and age compositions of catches are not known. The analyses were performed using the ASPIC 7 Suite, a set of computer programs to fit non-equilibrium stock-production models to fisheries data and make projections (Prager, 1994, 2015). Production models can estimate some parameters precisely, including several stock status indicators such as maximum sustainable yield (MSY), as well as the relative levels of stock biomass (B/Bmsy) and fishing mortality (F/Fmsy). In this context, a fish stock is considered to be overfished when its biomass (B) is below Bmsy, a situation that occurs when the fishing mortality rate (F) is above Fmsy. In this case, the stock is unable to produce the MSY. As a general consensus, a stock is in good status and remains so if B > 2*Bmsy and F < Fmsy; a stock is approaching good status if B > Bmsy and F ≤ Fmsy; and a stock is outside safe biological/ecological limits if B < Bmsy or F > Fmsy.

ASPIC requires starting guesses for its estimated parameters. The leading parameters are MSY (maximum sustainable yield), Fmsy (fishing mortality rate under which MSY can be attained), B1/K (ratio of stock biomass at the beginning of the analysis to K, the unfished biomass), and the catchability coefficient *q*. Starting guess values of MSY and K were based on historical information on the size of commercial catches and the level of fishing pressure exerted, which were interactively adjusted in new trials depending on the program outputs. Prager (2015) suggested testing the sensitivity of the model, thus the starting guess of the relative biomass (B1/K) was fixed at a range of values (0.5 - 0.9). This is common practice when fitting surplus production models (Panhwar *et al*., 2012; Quetglas *et al*., 2013). The production model was conditioned on catch, given that landing data are assumed to be more precisely measured than effort. For each estimated parameter, 80% bias-corrected confidence intervals were calculated using bootstrapping with 1000 interactions. Estimates were used to project the population forward in time for a period of 20 years to evaluate changes in biomass and F.

Results

Artisanal fisheries in the northern Alboran Sea

There are currently 328 artisanal boats registered in the main landing ports of the northern Alboran Sea, with La Línea, Estepona, Caleta de Vélez and Almería, being the most important with regard to the number of boats, and clustering 56% of the artisanal fleet. Average boat length is 8.4 m, with 3.4t of GRT, and mean engine power of 37.6 HP. The longest boats with the biggest GRT and power are generally found in the ports of Algeciras and Roquetas de Mar (Fig. 2).

An analysis of reported daily catches shows that the artisanal fleet uses trapping gears (e.g., traps and clay pots) exclusively for the common octopus (*Octopus vulgaris*), bottom-set stationary gear (e.g., gillnets, trammelnets, longlines) for fish and cephalopods, and mechanised dredges for bivalves. From March 2013 to March 2014, 49% of the fishing trips were operated using gillnets, trammelnets or small bottom longlines, 29% with traps and clay-pots, and the remaining 22% with mechanised dredges. The importance of the different metiers used by the fleet varies between ports (Fig. 3), with widely diversified fishing activity from La Linea to Caleta de Vélez, whereas in the eastern sector, between Motril and Almería, fishing gears for fish and cephalopods are the most commonly used.

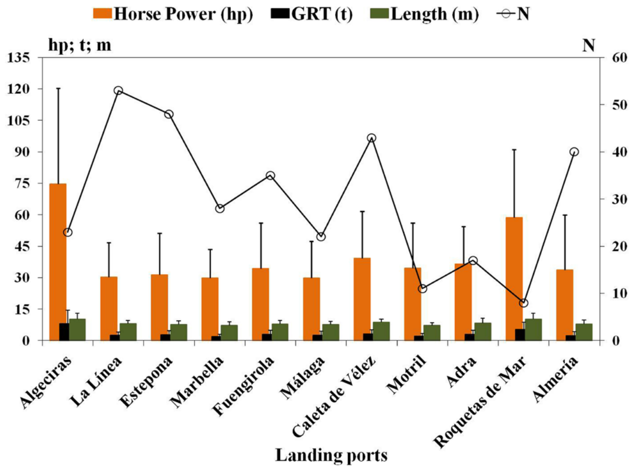

Fig. 2: Number and average technical characteristics (gross tonnes, length, and engine power) of artisanal vessels per landing port along the Alboran Sea.

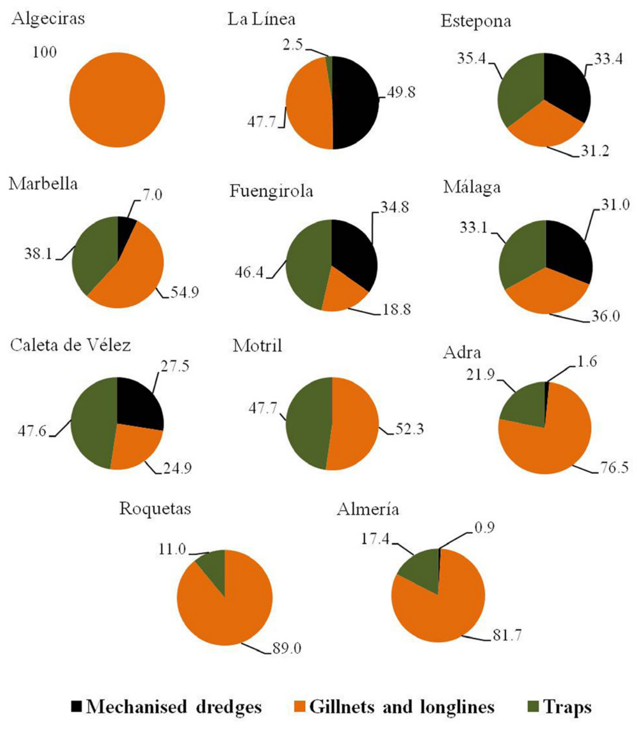

Fig. 3: Distribution of artisanal fisheries by fishing gear and landing port from March 2013 to March 2014. Values are given as percentage contribution of each fishery in tonnes.

Mechanised dredging targeting Callista chione

A total of 223 artisanal boats (68% of the fleet) are involved in shellfish fisheries, mainly targeting bivalves using mechanised dredges. The shellfish fleet is not equally distributed between the studied fishing ports, with La Línea

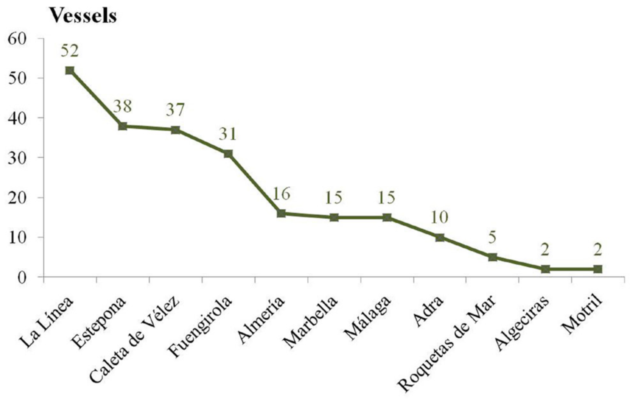

Fig. 4: Number of vessels by landing port targeting bivalves with mechanised dredges, in the northern Alboran Sea.

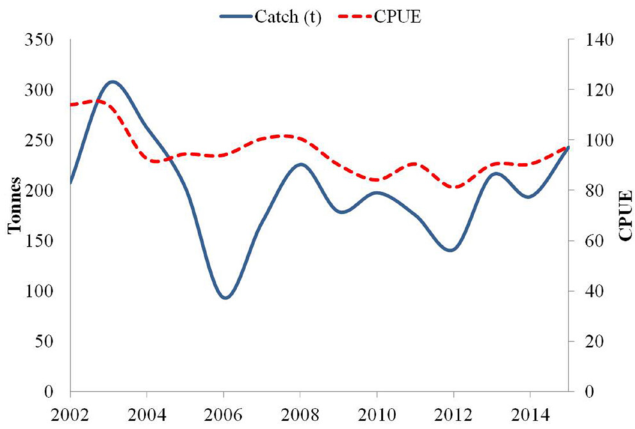

Fig. 5: Evolution of catches and CPUE for *Callista chione* in the northern Alboran Sea between 2001 and 2015.

being the port with the largest number of boats involved in these fisheries (52 boats), followed by Estepona (38), Caleta de Vélez and Fuengirola (37 each) (Fig. 4). Maximum annual catches of *C. chione* were made in 2003 (306 t) and minimum catches in 2006 (93 t). There was a stable period from 2008 onwards with ca. 200 t·y^{-1}, which dipped in 2012 to150 t (Fig. 5). The evolution of the CPUE shows a negative trend until 2009 when it seemed to stabilise until 2012, after which it progressively increased up to 2015 when it reached ca. 100 k·day^{-1}.

The GLM analysis showed that the technical characteristics of boats and the month was of very low importance in the model, explaining between only 0.003% and 0.02% of the deviance. Moreover, month and HP were not significant and therefore were not considered in the interaction models. Boat, a qualitative variable which explained more than 33% of the deviance, was the variable with the highest level of importance. The inclusion of an interaction term slightly improved the percentage of deviance explained, identifying the Boat+Year model with the lowest AIC statistic and a very good *p*-value the best model (Table 1).

The comparison of observed and predicted CPUE (using ASPIC) is a good diagnostic check of the model goodness-of-fit (Nelson, 1999). In this context, the model predicted CPUE very well (Fig. 6), with the best fit observed with an initial biomass value of B1/K = 0.9 (R^2 = 0.8). On the other hand, estimates of biomass were higher than the expected biomass at the B/Bmsy ratio, indicating that the stock had not been overfished. In relation to the stock time trajectory, estimates of F were below Fmsy indicating that the real fishing effort was lower than the fishing effort that should be exerted to attain the maximum sustainable yield (F/Fmsy < 1), once again suggest-

Table 1. Goodness of fit statistics for the GLM fitted to *Callista chione* CPUE from 2002 to 2015. AIC: Akaike Information Criterion; d.f.: degree of freedom; GRT: gross register tonnage; HP: power.

Model.	**d.f.**	**Residual deviance**	**Percentage of deviance explained**	**AIC**	**Wald Statistic**	***p-value***
Vessel+Year	4551	6532423	34.41	48369.2	38.77	<0.0001
Vessel+Year+Length	4550	6531897	34.41	48370.8	0.45	0.5
Vessel+GRT	4551	6581572	33.92	48404.9	3.01	0.083
Vessel	4552	6585436	33.88	48405.7	1800.4	<0.0001
Vessel+Length	4551	6585427	33.88	48407.7	0.008	0.93
Year	4763	9877668	0.82	49915.5	39.9	<0.0001
Length	4763	9935634	0.24	49943.4	11.4	<0.0001
GRT	4763	9950474	0.09	49950.5	4.21	0.04
HP	4763	9958244	0.01	49954.2	0.54	0.46
Month	4763	9959059	0.00	49954.6	0.14	0.71
NULL	4764	9959351			377974	<0.0001

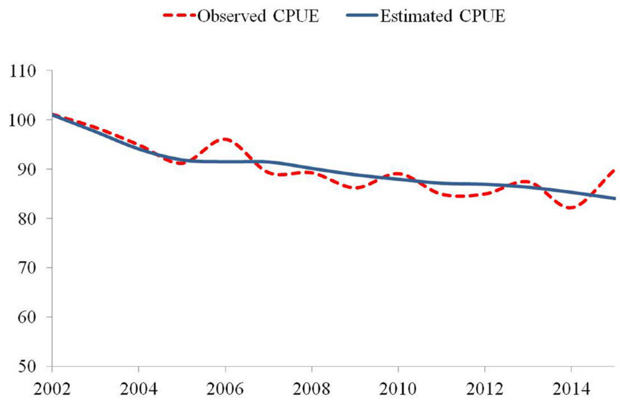

Fig. 6: Trajectories from 2002 to 2015 of observed CPUE and-CPUE estimated using the ASPIC model.

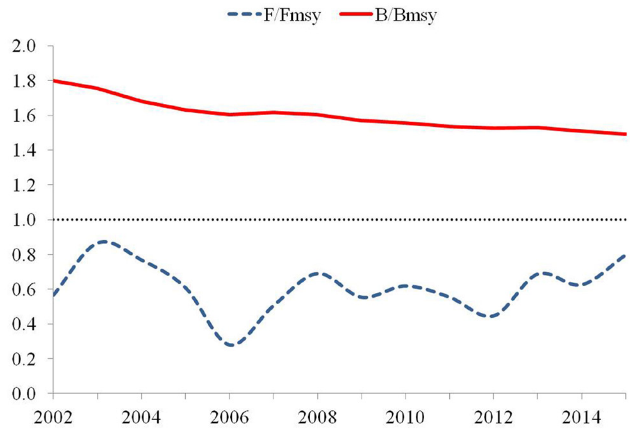

Fig. 7: Trajectories from 2002 to 2015 of relative fishing mortality and biomass for *Callista chione* in the northern Alboran Sea.

ing that the stock has not been subjected to overfishing (Fig. 7).

The current situation is summarised in Table 2, which contains the main stock status indicators. The ASPIC run for the *C. chione* stock suggested that a MSY of 216 t could be produced from a total stock biomass of 983 t (Bmsy) at a fishing mortality rate of total biomass of 0.22 (Fmsy), and B/Bmsy and F/Fmsy values of 1.34 and 0.82, respectively, indicating that the stock is approaching good status.

The projection carried out in the scenario where current exploitation levels are maintained over the next 20 years indicates that relative biomass decreases slightly throughout the period but not enough for it to drop below the level of B/Bmsy = 1. Relative fishing mortality increases slightly over the period, although in no year of the prediction do values rise above F/Fmsy = 1. In addition, this parameter shows more stability than biomass over time (Fig. 8).

Discussion

The smooth clam *C. chione* is a very much appreciated resource in the local markets of the northern Alboran Sea, and it is the most important bivalve species in terms of its catch-price ratio. The mechanised dredging fleet operating in the area has been exploiting this species for decades and the stock abundance has undergone strong oscillations. Although these oscillations may be associated with various processes affecting natural bivalve populations, such as disturbance, habitat destruction, diseases, predation, food availability, or pollution (Rothschild *et al.*, 1994; Charles *et al.*, 1999; Canestri-Trotti *et al.*, 2000; Walton *et al.*, 2002; Quijón *et al.*, 2007; Romanelli *et al.*, 2009; Baeta *et al.*, 2014), overfishing is probably one of the main factors contributing to the decline in abundance of commercial bivalves in natural beds (Rothschild et al., 1994; Dang *et al.*, 2010; Baeta *et al.*, 2014). Therefore, the assessment of marine resources should necessarily be based on continuous monitoring programmes, in order to

Table 2. Main stock status indicators for *Callista chione* in the northern Alboran Sea. MSY: maximum sustainable yield; Fmsy: fishing mortality at MSY; Bmsy: biomass giving MSY; Y(Fmsy): yield at Fmsy; fmsy: effort (in fishing days) that should lead to MSY; B/Bmsy: relative level of stock biomass; F/Fmsy: relative level of fishing mortality. CL: Confidence limits.

Parameter	Estimate	80% lower CL	80% upper CL
MSY	2.16E+05	2.00E+05	2.91E+05
Fmsy	2.20E-01	1.26E-01	3.06E-01
Bmsy	9.83E+05	7.27E+05	1.94E+06
Y(Fmsy)	2.34E+05	2.32E+05	2.38E+05
fmsy	3.40E+03	3.02E+03	4.65E+03
B/Bmsy	1.34E+00	1.23E+00	1.54E+00
F/Fmsy	8.21E-01	5.75E-01	9.41E-01

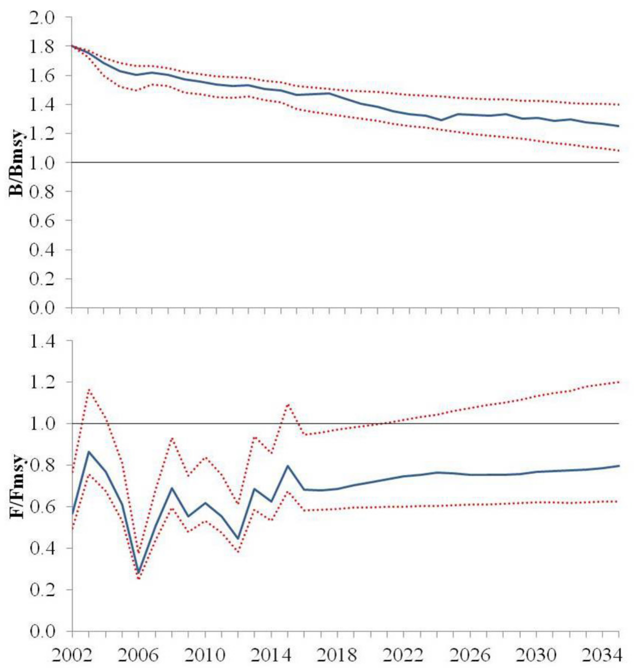

Fig. 8: Time trajectories from 2002 to 2015 and forecasting for the next 20 years (2016-2036) of the relative fishing mortality rate (F/Fmsy) and relative population biomass (B/Bmsy) estimated using a non-equilibrium surplus production model, setting maximum sustainable yield (MSY) at a level corresponding to the value of the latest year. The dotted lines represent the upper and lower 80% confidence limits.

guarantee bivalve preservation and keep exploitation levels within safe limits. In this context, management plans have recently been established that include, among other measures, biological benchmarks to achieve the sustainable exploitation of resources (Andalucía, 2017).

The main technical characteristics of the artisanal fleet operating mechanised dredges in the northern Alboran Sea is quite homogeneous, i.e., GTR, HP, length, with strong correlation between these parameters: Spearman's correlation coefficient GTR - HP = 0.60; GTR - length= 0.72; HP - length = 0.61; $p < 0.05$. In contrast, CPUE shows a weak correlation with GRT, HP, and length (Spearman's correlation coefficient< 0.05), and as a consequence these three technical characteristics were of very low importance in the GLM model. Finally, the boat variable was relevant in the model, as it explained more than 33% of the deviance. There are, therefore, factors intrinsic to the vessel variable, but not strictly related to the analysed technical characteristics that affect CPUE values and which should be considered in future modelling programmes on this type of fisheries (Sánchez *et al.*, 2004).

According to the analysed data, there is no clear seasonality in the fishing activity. Moreover, the month variable was neither very explanatory nor significant in the GLM model. The seasonality of catches, in this case of *C. chione*, can be directly influenced by various factors including the use of other fishing gears targeting non-bivalve species, discontinuity of fishing activity due to weather conditions, close seasons for reproductive purposes or red tide events, or indirectly by market fluctuations, among other issues. In fact, Sardá *et al.* (2000) reported a marked seasonality in *C. chione*, *Donax variegatus*, *D. trunculus,* and *Acanthocardia aculeata* catches in the Bay of Blanes (NW Mediterranean Sea), with higher monthly catches recorded during spring and summer related to the more favourable sea conditions required by the fleet. On the other hand, these authors also observed that total catch for commercial species was drastically affected by anthropogenic disturbances that had acute effects on the dynamics of soft-bottom assemblages, with marked declines in *A. aculeata*, *C. chione,* and *C. gallina* after dredging for beach nourishment. Despite these sporadic observations, there is an overall lack of information on the seasonality of fisheries operating along both the Mediterranean (Ezgeta-Balic *et al.*, 2011; Baeta *et al.*, 2014) and Atlantic European coasts (Gaspar *et al.*, 2001; Vasconcelos *et al.*, 2011). Therefore, further research on the seasonality of commercial stocks considering anthropogenic activities, biological issues such as periods of toxic algal blooms resulting in high toxin levels in commercial molluscs (very frequent in certain seasons), or different climate change scenarios would be desirable in order to model and predict temporal trends in important resources like shellfish.

The ASPIC results showed that the smooth clam resource in the northern Alboran Sea is currently in good condition, indicating that the stock has not been overfished, and has not experienced overfishing as well unlike in other Mediterranean areas (Baeta *et al.*, 2014). Moreover, the modelled projection suggests that the stock will remain in good condition in the future if the catch is maintained at the same level as that recorded for previous years. It therefore seems feasible to maintain the current catch level without jeopardising the resource biomass or increasing the F values. The non-equilibrium surplus-production model using ASPIC has shown to be a useful tool for assessing different fisheries and stocks (Link *et al.*, 2011), having been widely used for both demersal species (Nishimura & Yatsu, 2008; Abella *et al.*, 2010; Panhwar *et al.*, 2012; Quetglas *et al.*, 2013), large pelagic fish (Goodyear & Prager, 2001; de Bruyn *et al.*, 2012), and small pelagic fish (Baset *et al.*, 2017), although only in some cases for commercial invertebrates (Hunter *et al.*, 2007; Afzaal *et al.*, 2016; Moshin *et al.*, 2017). In the case presented here, surplus production models have proven useful for monitoring these exploited populations.

An important parameter to take into account in fisheries management is size/age. This study did not include continuous sampling of the size composition of the harvested biomass, although some samples were obtained between May 2013 and June 2015 (unpublished data). In those samples, the size of landings ranged from 39 mm to 95 mm (anteroposterior axis). In this region, *C. chione* is estimated to reach maturity at 38 mm (Tirado pers. com.), consequently there are no immature individuals in landings. Furthermore, the mean size of harvested smooth clams was 65.7 mm, considerably above the minimum conservation reference size of 60 mm. These data reinforces the good status of the stock, since catches are not based on smaller individuals. Nevertheless, it is necessary to periodically update the assessments and adopt appropriate management measures to avoid a decline in the smooth clam fishery in the Alboran Sea leading to a collapse of the fishery, as observed in other bivalve fisheries (Rothschild *et al*., 1994; Romanelli *et al*., 2009; Dang *et al*., 2010; Baeta *et al*., 2014).

Commercial bivalve populations have been assessed for management purposes using dynamic population methods (Rothschild *et al*., 1994; Munch-Petersen & Kristensen, 2001) and surveys at sea (Beukers-Stewart *et al*., 2003; Sánchez *et al*., 2014). To our knowledge, to date a surplus-production model using ASPIC has never been run for these purposes, this study being the first to test it. To this end, ASPIC has shown to be an effective tool for assessing the *C. chione* dredging fishery in the northern Alboran Sea, in this case using catch and effort data from official statistics rather than more expensive and time-consuming methods such as those mentioned above.

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References

Abella, A., Ria, M., Mancusi, C., 2010. Assessment of the status of the coastal groundfish assemblage exploited by the Viareggio fleet (Southern Ligurian Sea). *Scientia Marina*, 74 (4), 793-805.

Afzaal, Z., Kalhoro, M.A., Buzdar, M.A., Nadeem, A., Saeed, F. *et al.*, 2016. Stock Assessment of Blue Swimming Crab *Portunus pelagicus* (Linnaeus, 1758) from Pakistani Waters (Northern, Arabian Sea). *Pakistan Journal of Zoology*, 48 (5), 1531-1541.

Alarcón Urbistondo, J.A., 2001. *Inventario de la Pesca Artesanal en España Mediterránea (2000-2001)*. FAO-COPEMED Project, 45 pp. Available online at http://webco.faocopemed.org/old_copemed/vldocs/0000562/artfi_sp.pdf.

Akaike, H., 1974. A new look at the statistical model identification. *IEEE transactions on automatic control*, 19 (6), 716-723.

Andalucía, 2017. Orden de 1 de marzo de 2017 de la Consejería de Agricultura, Pesca y Desarrollo Rural por la que se modifica la de 24 de marzo 2014, por la que se establece un plan de gestión para la pesquería de rastros o dragas mecanizadas en el litoral mediterráneo de Andalucía. *Boletín Oficial de la Junta de Andalucía*, 44, 127-130.

Baeta, M., Ramón, M., Galimany, E., 2014. Decline of a *Callista chione* (Bivalvia: Veneridae) bed in the Maresme coast (northwestern Mediterranean Sea). *Ocean and Coastal Management*, 93, 15-25.

Baro, J., Ramos, F., Camiñas, J.A., Núñez, J.C., 1992. *Las pesquerías de bivalvos de la región surmediterránea española.* Informe Técnico del Instituto Español de Oceanografía, No 129, 108pp.

Baset, A., Liu, Q., Hanif, M.T., Liao, B., Memon, A.M. *et al.*, 2017**.** Estimation of Maximum Sustainable Yield Using Production Modeling: A Stock Appraisal of Indian Oil Sardine (*Sardinella longiceps*) from Pakistani Waters. *Pakistan Journal of Zoology,* 49 (2), 521-528.

Bellido, J.M., Santos, M.B., Grazia, M., Valeiras, X., Pierce, J.G., 2011. Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? *Hydrobiologia,* 670, 317-333.

Beukers-Stewart, B.D., Mosley, M.W.J., Brand, A.R., 2003. Population dynamics and predictions in the Isle of Man fishery for the great scallop, *Pecten maximus* L. *ICES Journal of Marine Science: Journal du Conseil*, 60 (2), 224-242.

Camiñas, J.A., 1990. Pesquerías artesanales mediterráneas. El caso andaluz. *Revista de Estudios Agrosociales,* 151, 83-117.

Canestri-Trotti, G., Baccarani, E. M., Paesanti, F., Turolla, E., 2000. Monitoring of infections by protozoa of the genera *Nematopsis*, *Perkinsus* and *Porospora* in the smooth venus clam Callista chione from the North-Western Adriatic Sea (Italy). *Diseases of aquatic organisms*, *42* (2), 157-161.

Cano Perez, J., 1981. Biología y crecimiento de *Callista chione* (L., 1758). *Iberus*, 1, 67-78.

Cano Perez, J., 1983. Índices de condición, humedad y cenizas en *Callista chione* (L., 1758), *Venerupis rhomboides* (Pennant, 1777) y *Cerastoderma tuberculatum* (L., 1758). *Iberus*, 3, 29-39.

Charles F., Amouroux J. M., Grémare, A.,1999. Comparative study of the utilization of bacteria and microalgae by the suspension-feeding bivalve: *Callista chione. Journal of the Marine Biological Association of the United Kingdom*, 79, 577-584.

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F. *et al*., 2010. The Biodiversity of the Mediterranean Sea: Estimates, Patterns and Threats. *PloS ONE* 5(8): e11842. doi:10.1371/journal.pone.0011842.

Coppola, S.R., 2001. *Inventory of Artisanal Fishery Communities in the Western-Central Mediterranean.* Fishery Resources Division FAO, 75 pp.

Damianidis, P., Karachle, P.K., Chintiroglou, C.C., 2010. Biology of *Callista chione* (L., 1758) in Thermaikos Gulf (N Aegean Sea). p 486. In: *Rapports Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, Venice, 10 - 14 May 2010*. CIESM, Monaco.

Dang, C., Montaudouin, X., Gam, M., Paroissin, C., Bru N. *et al*., 2010. The Manila clam population in Arcachon Bay (SW France): Can it be kept sustainable? *Journal of Sea Research*, 63, 108-118.

de Bruyn, P., Arrizabalaga, H., Kell, L., 2012. A preliminary investigation of the albacore tuna (Thunnus alalunga) stock in the southern Atlantic Ocean using a non-equilibrium production model, including comparison with an age-struc-

tured production model. *Collective Volume of Scientific Papers ICCAT*, 68 (2), 558-568.
Ezgeta-Balic, D., Peharda, M., Richardson, C.A., Kuzmanic, M., Vrgoc, N., 2011. Age, growth, and population structure of the smooth clam *Callista chione* in the eastern Adriatic Sea. *Helgoland Marine Research*, 65, 457-465.
FAO, 2009. General Fisheries Commission for the Mediterranean. *Report of the thirty-third session, Tunis, 23-27 March 2009*. FAO, GFCM Report, No 33, 126 pp.
FAO, 2016. General Fisheries Commission for the Mediterranean. *Report of the eighteenth session of the Scientific Advisory Committee on Fisheries, Nicosia, Cyprus, 21-23 March 2016*. FAO, Fisheries and Aquaculture Report, No R1154, 299 pp.
Farrugio, H., Oliver, P., Biagi, F., 1993. An overview of the history, knowledge, recent and future research trends in Mediterranean fisheries. *Scientia Marina* 57 (2-3), 105-119.
Gaspar, M.B., Dias, M.D., Campos, A., Monteiro, C.C., Santos, M.N. *et al*., 2001. The influence of dredge design on the catch of *Callista chione* (Linnaeus, 1758). *Hydrobiologia*, 465, 153-167.
García Raso, J.E., Gofas, S., Salas, C., Manjón-Cabeza, E., Urra, J. *et al*., 2010. *El mar más rico de Europa: Biodiversidad del litoral occidental de Málaga entre Calaburras y Calahonda.* Consejería de Medio Ambiente, Junta de Andalucía, Sevilla, 138 pp.
Goodyear, C.P., Prager, M.H., 2001. Fitting surplus-production models with missing catch data using ASPIC: evaluation with simulated data on Atlantic blue marlin. *Collective Volume of Scientific Papers ICCAT*, 53, 146-163.
Gulland, J.A., 1964. Catch per unit effort as a measure of abundance. *Rapports et procès-verbaux des réunions. Conseil permanent international pour l'exploration de la mer*. 155, 8-14.
Hunter, M., Glenn, R., Whitmore, K., McBane, C., Idoine, J. *et al*., 2007. *Assessment report for Gulf of Maine Northern Shrimp*. Atlantic States Marine Fisheries Commission, Northern Shrimp Technical Committee, 86 pp. Available online at http://www. asmfc. org/.
Kelleher, K., 2005. *Discards in the world's marine fisheries. An update*. FAO Fisheries Technical Paper, No 470, 131 pp.
Kimura, D.K., 1981. Standardized measures of relative abundance based on modelling log(c.p.u.e), and their application to Pacific ocean perch (*Sebastes alutus*). *Journal du Conseil Conseil Permanent International pour l'Exploration de la Mer*, 39, 211-218.
Leontarakis, P.K., Richardson, C.A., 2005. Growth of the smooth clam, *Callista chione* (Linnaeus, 1758) (Bivalvia: Veneridae) from the Thracian Sea, northeastern Mediterranean. *Journal of molluscan studies*, 71 (2), 189-192.
Link, J. S., Bundy, A., Overholtz, W. J., Shackell, N., Manderson, J. *et al.,* 2011. Ecosystem-based fisheries management in the Northwest Atlantic. *Fish and Fisheries*, 12 (2), 152-170.
McCullagh, P., Nelder, J. A., 1989. *Generalized linear models*. Chapman and Hall, New York, 511 pp.
Mattei, N., Pellizzato, M., 1997. Mollusk fisheries and aquaculture in Italy. p. 201-216. In: *The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Volume 3, Europe*. MacKenzie, Jr., C.L., Burrell, Jr., V.G., Rosenfield, A., Hobart, W.L. (Eds). U.S. Deparment of Commerce, NOAA Technical Reports 129, Seattle.
Metaxatos, A., 2004. Population dynamics of the venerid bivalve C*allista chione* (L.) in a coastal area of the eastern Mediterranean. *Journal Sea Research*, 52, 293-305.
Mohsin, M., Mu, Y., Zhu, Y., Memon, A.M., Akhter, N. *et al*., 2017. Stock assessment of molluscan fisheries in Pakistani marine waters by using CEDA and ASPIC computer packages. *Indian Journal of Geo Marine Sciences,* 46 (04), 692-697.
Munch-Petersen, S., Kristensen, P.S., 2001. On the dynamics of the stock of blue mussels (*Mytilus edulis* L.) in the Danish Wadden Sea. *Hydrobiologia*, 465, 31-43.
Nishimura, A., Yatsu, A., 2008. Application of surplus-production models to splendid alfonsino stock in the Southern Emperor and Northern Hawaiian Ridge (SE-NHR). p. 1-11. In: *Fifth Intergovernmental Meeting on Establishment of New Mechanism for Management of High Seas Bottom Trawl Fisheries in the North Western Pacific Ocean (NWPBT/SWG-05), Tokyo, 17-18 October 2008*. Fisheries Agency of Japan, Japan. Available at http://www.jfa.maff.go.jp/j/study/pdf/appendix_c.pdf.
Nelson, G.A., 1999. *Alternative Stock Assessment Methods Applied to Greater Amberjack, Seriola dumerili, in Florida*. Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute. Available at: http://myfwc.com/research/saltwater/stock-assessments/finfish/1999-greater-amberjack/
Panhwar, S.K., Liu, Q., Khan, F., Siddiqui, P.J., 2012. Maximum sustainable yield estimates of Ladypees, *Sillago sihama* (Forsskål), fishery in Pakistan using the ASPIC and CEDA packages. *Journal of Ocean University of China (English Edition)*, 11 (1), 93-98.
Parrilla, G., Kinder, T.H., 1987. Oceanografía física del mar de Alborán. *Boletín del Instituto Español de Oceanografía*, 4 (1), 133-165.
Peharda, M., Ezgeta-Balić, D., Vrgoč, N., Isajlović, I., Bogner, D., 2010. Description of bivalve community structure in the Croatian part of the Adriatic Sea - hydraulic dredge survey. *Acta Adriatica*, 51 (2), 141-158.
Piniella, F., Soriguer, M.C., Fernández-Engo, M.A., 2007. Artisanal fishing in Andalusia: A statistical study of the fleet. *Marine Policy*, 31, 573-581.
Prager, M.H., 1994. A suite of extensions to a non equilibrium surplus–production model. *Fishery Bulletin*, 92, 374-389.
Prager, M., 2015. *Users Guide for ASPIC Suite, version 7: A Stock-Production Model Incorporating Covariates and auxiliary programs.* Prager Consulting Portland, Oregon USA, 33 pp.
Quetglas, A., Ordines, F., Hidalgo, M., Monserrat, S., Ruiz, S. *et al*., 2013. Synchronous combined effects of fishing and climate within a demersal community. *ICES Journal of Marine Science: Journal du Conseil*, 70 (2), 319-328.
Quijón, P.A., Grassle, J.P., Rosario, J.M., 2007. Naticid snail predation on early post-settlement surfclams (*Spisula solidissima*) on the inner continental shelf of New Jersey, USA. *Marine Biology*, 150, 873-882.
Robles, R., Rodrıguez, J., Nachite, D., Berraho, A., Najih, M. *et al*., 2010. Conservación y desarrollo sostenible del mar de Alborán/Conservation et développment durable de la mer d'Alboran. IUCN, Gland, Suiza, 112 pp. ISBN: 978-2-8317-1254-3.
Rodríguez de la Rúa, A., Prado, M.A., Bruzón, M.A., 2003. Estudio del ciclo reproductor de *Chamelea gallina* (L., 1758) (Mollusca: Bivalvia) en tres poblaciones del litoral andaluz. *Boletín del Instituto Español de Oceanografía*, 19 (1-4), 57-63.
Rodriguez Santamaria, B., 1923. *Diccionario de artes de pesca de España y sus posesiones*. Sucesores de Rivadeneyra, Madrid, 332 pp.
Romanelli, M., Cordisco, C.A., Giovanardi, O., 2009. The long-term decline of the *Chamelea gallina* L. (Bivalvia:

Veneridae) clam fishery in the Adriatic Sea: is a synthesis possible? *Acta Adriatica*, 50, 171-205.

Rothschild, B.J., Ault, J.S., Goulletquer, I., Heral, M., 1994. Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. *Marine Ecology Progress Series*, 111, 29-39.

Sabelli, B., Taviani, M., 2014. The making of the Mediterranean molluscan biodiversity. p. 285-306. In: *The Mediterranean sea. Its history and present challenges*. Goffredo S., Dubinsky Z., (Eds). Springer Science & Business Media, Dordrecht.

Salas, C., 1987. Ecología de los Donacidae (Mollusca, Bivalvia) de la bahía de Málaga (SE de España). *Investigación Pesquera*, 51 (1), 67-77.

Salas C. 2010. Familia Veneridae, P. 677-690. In: *Moluscos marinos de Andalucía*. Gofas S., Moreno D., Salas C. (Eds). Consejería de Medio Ambiente, Junta de Andalucía, Sevilla.

Sánchez, P., Maynou, F., Demestre, M., 2004. Modelling catch, effort and price in a juvenile *Eledone cirrhosa* fishery over a 10-year period. *Fisheries research*, 68 (1), 319-327.

Sanchez, F., Caill-Milly, N., Lissardy, M., Bru, N., 2014. *Campagne d'évaluation de stock de palourdes du bassin d'Arcachon - Année 2014*. IFREMER, 47 pp. Available at http://archimer.ifremer.fr/doc/00233/34383/

Sardá, R., Pinedo, S., Gremare, A., Taboada, S., 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. *ICES Journal of Marine Science*, 57, 1446-1453.

Sarhan, T., García-Lafuente, J., Vargas-Yáñez, M., Vargas, J.M., Plaza, F., 2000. Upwelling mechanisms in the northwestern Alboran Sea. *Journal of Marine Systems*, 23, 317-331.

Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience*, 57 (7), 573-583.

Templado, J., 2011. La diversidad marina en España., p. 343-362. In: *Biodiversidad Aproximación a la diversidad botánica y zoológica de España. Memorias de la Real Sociedad Española de Historia Natural. Vol 9.* Viejo Montesinos J.L. (Ed). Real Sociedad Española de Historia Natural, Madrid.

Tirado, C., Salas, C., 1998. Reproduction and fecundity of *Donax trunculus* L., 1758 (Bivalvia: Donacidae) in the littoral of Málaga (Southern Spain). *Journal of Shellfish Research*, 17 (1), 169-176.

Tirado, C., Rodríguez de la Rúa, A., Bruzón, M.A., López, J.I., Salas, C. *et al*., 2002a. *La reproducción de bivalvos y gasterópodos de interés pesquero en Andalucía*. Junta de Andalucía, Consejería de Agricultura y Pesca, Huelva, 129 pp.

Tirado, C., Salas, C., López, J.I., 2002b. Reproduction of *Callista chione* L., 1758 (Bivalvia: Veneridae) in the Littoral of Málaga (southern Spain). *Journal of Shellfish Research*, 21 (2), 643-648.

Urra, J., García, T., Gallardo-Roldán, H., León, E., Lozano, M. *et al*., 2017. Discard analysis and damage assessment in the wedge clam mechanized dredging fisheries of the northern Alboran Sea (W Mediterranean Sea). *Fisheries Research*, 187, 58-67.

Vasconcelos, P., Morgado-André, A., Morgado-André, C., Gaspar, M.B., 2011. Shell strength and fishing damage to the smooth clam (*Callista chione*): simulating impacts caused by bivalve dredging. *ICES Journal of Marine Science*, 68 (1), 32-42.

Voultsiadou, E., Koutsoubas, D., Achparaki, M., 2010. Bivalve mollusc exploitation in Mediterranean coastal communities: An historical approach. *Journal of Biological Research-Thessaloniki*, 13, 35-45.

Walton, W.C., Mackinnon, C.J. , Rodriguez, L.F., Proctor, C., Ruiz, G.M., 2002. Effect of an invasive crab upon a marine fishery: green crab, *Carcinus maenas*, predation upon a venerid clam, *Katelysia scalarina*, in Tasmania (Australia). *Journal of Experimental Marine Biology and Ecology*, 272 (2), 171-189.