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The use of Depletion Methods to assess Mediterranean cephalopod stocks under the current EU Data Collection Framework

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Abstract

Fuelled by the increasing importance of cephalopod fisheries in Europe, scientists and stakeholders have demanded their assessment and management. However, little has been done to improve the data collection under the EU Data Collection Framework (DCF) in order to analyse cephalopod populations. While the DCF allows member states to design flexible national sampling programmes, it establishes the minimum data requirements (MDR) each state is obliged to fulfil. This study was performed to investigate whether such MDR currently set by the DCF allow the application of depletion models (DMs) to assess European cephalopod stocks. Squid and cuttlefish fisheries from the western Mediterranean were used as a case study. This study sheds doubt on the suitability of the MDR to properly assess and manage cephalopod stocks by means of DMs. Owing to the high plasticity of life-history traits in cephalopod populations, biological parameters should be estimated during the actual depletion period of the fished stocks, rather than performing triennial sampling as established by the DCF. In order to accurately track the depletion event, the rapid growth rates of cephalopods implies that their populations should be monitored at shorter time scales (ideally weekly or biweekly) instead of quarterly as specified by the DCF. These measures would not require additional resources of the ongoing DCF but a redistribution of sampling efforts during the depletion period. Such changes in the sampling scheme could be designed and undertaken by the member states or directly integrated as requirements.

Keywords: Assessment, management, cephalopod, depletion methods, Data Collection Framework, Mediterranean.

Introduction

Except for some Mediterranean artisanal fisheries, cephalopods have been traditionally considered as a minor resource for European countries (Pierce *et al.,* 2010). However, in accordance with their increased economic importance around the world during the last decades (Boyle & Rodhouse, 2005; FAO, 2012), some European cephalopod fisheries are now contributing substantially to the economic benefits from the fishing industry (Pierce *et al.,* 2010). Unlike the most important fin fish stocks, cephalopod stocks in Europe are not quota-regulated. Fuelled by the rising importance of their fisheries, scientists, stakeholders and policy-makers throughout Europe have requested for their assessment and management. This requires improving the knowledge of their exploitation status and of the specific tools and data that would be needed for achieving such a goal (Pierce *et al.,* 2010; ICES, 2010; STECF, 2012). Between the late 1990s and early 2000s, the European Commission's Directorate General for Fisheries initiated several studies to develop regular fishery and biological data collection protocols for commercially important cephalopod stocks (Young *et al.,* 2004). The EU Data Collection Framework (DCF) for national fishery data collection programmes (EU, 2000, 2008) includes some provision for the collection of biological data and fishery statistics of cephalopods in areas such as the North East Atlantic and the Mediterranean. However, in spite of these efforts, little has been done to assess European cephalopod stocks, and most existing studies have been focussing on the English Channel and Scottish waters (Young *et al.,* 2004; Challier *et al.,* 2005a; Royer *et al.,* 2006; Gras *et al.,* 2014).

Owing to their rapid growth rates and short life-span, little generation overlap and weak or no stock-recruitment relationships, cephalopods cannot be properly assessed by unmodified, standard assessment methods that were initially designed for fin fishes (Pauly, 1985; Pierce & Guerra, 1994). Depletion methods (DMs) have been traditionally used for cephalopod assessment (e.g. Dunn, 1999a; Royer *et al.,* 2002; Robert *et al.,* 2010). During the 1990s, the squid fishery around the Falkland Islands was assessed with this method, and for *Loligo* stocks it is still implemented (Beddington *et al.,* 1990; Agnew *et al.,* 1998, Andreas Winter pers. comm.). Recently, DMs have been used to analyse octopus populations from Moroccan waters (Robert *et al.,* 2010) and the western Indian Ocean (Sauer *et al.,* 2011). In European waters, DMs were applied for the assessment of cuttlefish and squid fisheries from the English Channel and northern Scottish waters (Dunn, 1999b; Royer *et al.,* 2002, 2006; Young *et al.,* 2004; Challier *et al.,* 2005b). The method consists of modelling the depletion of a stock during the main fishing season and analysing the influence of cumulative effort on an abundance index (Royer *et al.,* 2002). This allows interpolation of the total initial stock size during each fishing season (Leslie & Davis, 1939; DeLury, 1947).

Despite the high socio-economical importance of cephalopods in the Mediterranean, only few stocks have been assessed till date. Yield per recruit analysis has been used to assess horned octopus populations from the Ligurian Sea (Orsi-Relini *et al.,* 2006) and cuttlefish from Egyptian waters (Mehanna & Haggag, 2011). Surplus production models have been applied to assess several cephalopod stocks (common octopus, squid and cuttlefish) from the Balearic Sea using a time series spanning more than 40 years (Quetglas *et al.,* 2013).

In the Balearic Islands (western Mediterranean), squids (*Loligo vulgaris* and *L. forbesii*) and cuttlefish (*Sepia officinalis*) are important living resources for local fisheries, which exploit all the three species with both bottom trawl and artisanal fleets. In fact, these cephalopods species had the highest socio-economical impact in the study area (Cabanellas-Reboredo *et al.,* 2011). Squid constitute an important all-year-round by-catch of the bottom trawl fishery working on continental shelf grounds deeper than 50 m, whereas they are caught in relatively smaller numbers by the small-scale fishery (Quetglas *et al.,* 2000, 2014). The two squid species segregate in space and also show contrasting life histories with *L. vulgaris* living on the upper shelf and spawning in spring, whereas *L. forbesii* inhabits the deep shelf and spawns in summer (Šifner & Vrgoč, 2004; Uranga *et al.,* 2012). Contrastingly, cuttlefish supports an important seasonal small-scale fishery (Merino *et al.,* 2008). Artisanal fishers take advantage of the reproductive migration of cuttlefish to coastal waters to catch large, mature individuals using trammel nets during late winter and spring. On the other hand, the trawl fishery catches the recruits in deeper waters during late summer and early autumn (Keller *et al.,* 2014).

In this study, we tested the suitability of the minimum data requirements (MDR) established by the current sampling scheme under the European DCF to assess Mediterranean cephalopod stocks by means of depletion methods. The conclusions of this study will be used to discuss the possible improvements in data acquisition aimed at assessing cephalopod stocks under the current and future DCFs. Furthermore, the possible use of real time assessments in specific, socioeconomically important artisanal Mediterranean fisheries in order to ensure their sustainable management is discussed. To our knowledge, this is the first application of depletion methods to cephalopod stocks in the Mediterranean.

Material and Methods

Description of the fishery

Squid and cuttlefish are caught by the bottom trawl and small-scale fleets from Mallorca (Balearic Islands). However, whereas trawlers only catch them as a by-catch all year round, the squid *L. vulgaris* and the cuttlefish *Sepia officinalis* support important seasonal small-scale fisheries. The bottom trawl fleet consists of a rather small number of vessels that has been decreasing gradually over the years (from 41 vessels in 2000 to 32 in 2011; Fig. 1A). At the same time, the mean horse power per boat increased slowly from ca. 500 in the year 2000 to about 635 in 2011. The number of small-scale fishing boats decreased from 130 to 119 units while the mean fishing power (in HP) remained more or less constant, suggesting a decrease in the mean fishing effort during 2000–2011 (Fig. 1B). Most squid landings (Fig. 2A) came from trawlers, which showed a clear inter-annual increasing trend from nearly 10 tons (t) in 2000 to 73 t in 2011; landings from the small-scale fleet ranged between 4.7 t in 2008 and 30 t in 2009, with a mean of 11 t in 2000–2011. Trawl and small-scale squid landings show contrasting seasonal trends with maxima in November in the former and July in the latter (Fig. 2B). In contrast to squid landings, most cuttlefish landings came from the small-scale fleet and fluctuated between 25 and 56 t during the study period. At the same time, trawl landings of this species ranged from 3.6 to 10 t (Fig. 2C). Intra-annual landings of cuttlefish reflect the strong seasonality of its small-scale fishery, which takes place mainly between February and June. Trawl landings decrease progressively from a main peak in February to a minimum in July (Fig. 2D).

Daily landings per vessel of both the trawl and artisanal fleets of Mallorca were obtained from the fishing auction wharf for the years 2000 to 2011. Since all landings of the island are sold at the same auction wharf, the total landings of Mallorca were available. Furthermore, as discards of squids and cuttlefish are negligible in the area (Sartor *et al.,* 1998), landings represent total declared catches. While cuttlefish landings include a single species (*Sepia officinalis*), two squid species (*Loligo vulgaris* and *L. forbesii*) are commercialized in a pooled category. Therefore, a single combined assessment was conducted for both loliginids, as has been previously done either for the same squid species in Atlantic waters (Robin & Denis, 1999) and in other fish species that are also sold jointly (Sancho *et al.,* 2003). Biological data (individual size and weight) were obtained from monthly fish market samples analysed at the laboratory.

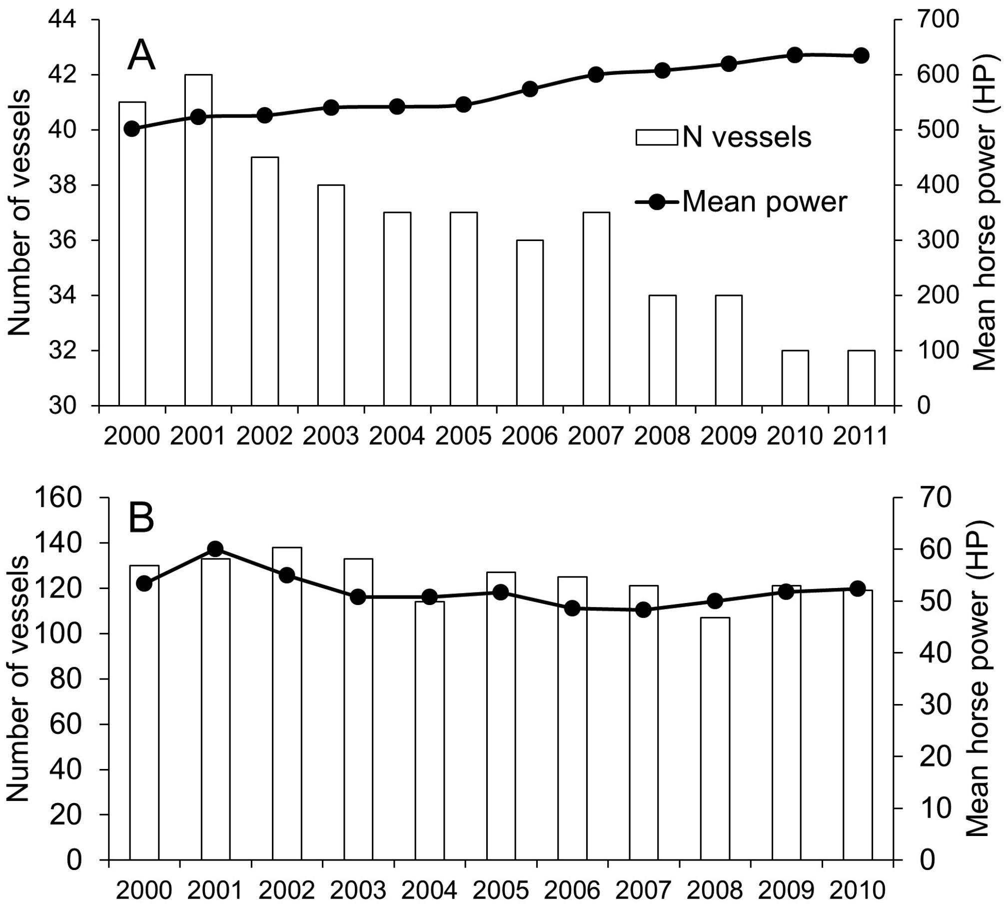

Fig. 1: Number of vessels and mean horse power (HP) of the bottom trawl (A) and small-scale (B) fleets from Mallorca (Balearic Islands, western Mediterranean).

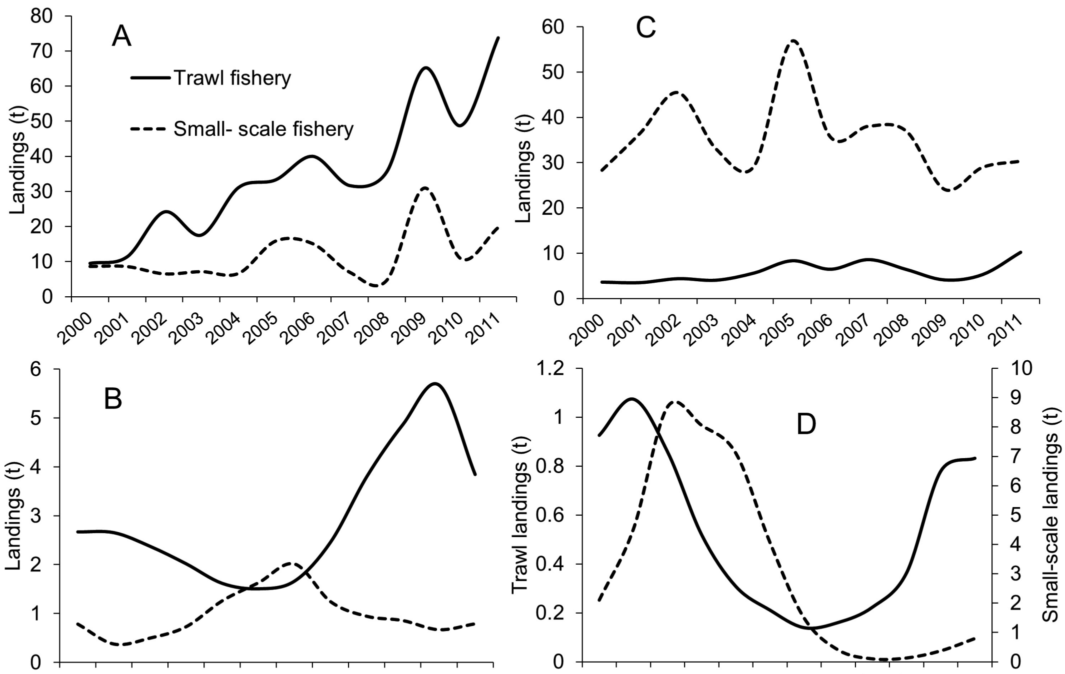

Fig. 2: Squid (A, B) and cuttlefish (C, D) total annual landings and monthly mean landings (t) of the bottom trawl and small-scale fleets from Mallorca during 2000–2011.

Squid samples were obtained on a monthly basis from the bottom trawl fleet between January and December 2009. A total of 1361 and 643 individuals of *L. vulgaris* and *L. forbesii* were analysed respectively. A total of 806 cuttlefish individuals from the small-scale fishery taken between January and July were analysed monthly for two consecutive years (2007, 2008).

Modelling and software

The assessments were conducted using the Leslie-DeLury DMs with the Catch and Effort Data Analysis (CEDA) software (Kirkwood *et al.,* 2003). The following indexed recruitment model was used:

$N_{t+1} = e^{-M} (qCPUE_t - C_t + \lambda R_t)$, where t is the time interval (fortnight), N is the population size in numbers at the start of the time interval t, M the natural mortality rate, q the catchability coefficient, C_t the total catch during the time interval t, λ the recruitment constant of proportionality, R_t the recruitment index and $CPUE_t$ the catch per unit effort during the time interval t.

As CEDA is based on the numbers of animals, the monthly mean weights from the biological sampling were used to convert catches and abundance indices into numbers. As a time interval of two weeks was used for the modelling, weights were interpolated. Although not optimal, this was the best compromise between using the high resolution of the catch data and the lower resolution of the biological data. Length-frequency data was used to calculate the recruitment indices (R_t). This index is the proportion of small individuals landed in time t to all small individuals landed during the depletion period, with "small" being below the modal landings modal size (≤10 cm for cuttlefish, ≤9 cm for squid) (Pierce *et al.,* 1994). The model estimates the following parameters: the initial population (N1) and the current stock size, the expected catches for each time step during the depletion event (all in numbers), the catchability coefficient (q), the number of recruits (λ) and a goodness of fit measure (R^2). Bootstrapped 95% confidence intervals for q, N1 and λ were also calculated.

CEDA allows specifying three different error models to achieve the best model fit. The least square model assumes independency of the residuals from the expected catch size, whereas in the gamma and the log-transform models, the sizes of the residuals are supposed to depend on the expected catches and are larger when the expected catches are bigger. This relationship between catches and residuals is stronger for the log-transform model than for the gamma one. A preliminary analysis was conducted to analyse the effect of each error model on the results and determine the most suitable one. The goodness of fit of the models was examined by analysing the distribution of the residuals with time. Furthermore, DMs require a constant value for the natural mortality (M) as an input parameter. Previous studies have used M = 0.05 for cuttlefish (Royer *et al.,* 2006) and M = 0.10 / M = 0.835 for squid (Royer *et al.,* 2002; Young *et al.,* 2004). The model's sensitivity to this parameter was checked by applying different homogeneous rates for M (cuttlefish = 0.03, 0.05, 0.07; squid = 0.05, 0.10, 0.12) and comparing the outcomes.

Input data and parameters

In each fishing season, only the depletion period was analysed, which is the period corresponding to the time where the CPUE or the catches are declining constantly due to fishing. The time steps chosen for both assessments were periods of two weeks. The biweekly time scale was a trade-off between better resolution of weekly data and monthly availability of the biological data. In both squid and cuttlefish assessments, in addition to the years with available biological data, the two subsequent years were analysed using the biological information from that year.

In cuttlefish, the biweekly landing data of the small scale trammel net fishery from 2007–2010 was analysed and as no biological sampling was performed in 2009–2010, the recruitment indices and mean weights from 2007 were used. For squid, the catches of the bottom trawl fishery from 2009–2011 were analysed. DMs were fitted using mean weights and recruitment indices derived from the biological sampling of commercial landings in 2010 and 2011 (both loliginid species combined). Comparisons with data from on-board sampling showed that the observer programme was not a suitable source of information because of the irregular timing of observations and insufficient sample sizes.

Hilborn & Walters (1992) suggested standardization of CPUE by using a Gaussian error GLM prior to employing them in stock assessment models in order to avoid biases related to spatial, temporal or fleet heterogeneity. Even if the method was successfully used to standardize various stock CPUEs including cephalopods (Royer *et al.,* 2006), it does not deal with zero inflated datasets. To standardize these datasets, the delta-GLM method (which combines a binomial error GLM dealing with presence/absence data and a Gaussian error GLM dealing with abundances) was developed and successfully used in recent years, including cephalopods (Stefansson, 1996; Fletcher *et al.,* 2005; Acou *et al.,* 2011; Gras, 2013). In our study, four variables were considered to standardize CPUE: 1) fortnight period; 2) fishing area; 3) fishing season; and 4) vessel engine power (HP).

Results

GLM-derived abundance indices (standardized CPUEs) showed that the depletion periods span from calendar weeks 15–28 (cuttlefish) and 9–27 (squid); therefore, these periods were used for modelling. The monthly mean weights of cuttlefish derived from the biological sampling of 2007 and 2008 followed a similar pattern in both years with a maximum in March–April (Fig. 3A). The calculat-

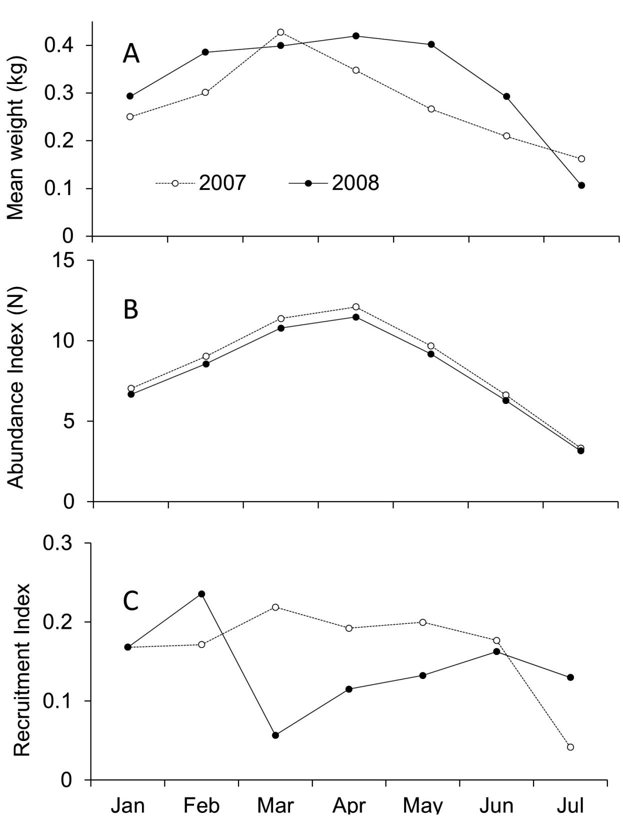

Fig. 3: Monthly mean weights (A), calculated abundance index (B) and recruitment index (C) of cuttlefish *Sepia officinalis* from the small-scale fleet off Mallorca during 2007 and 2008.

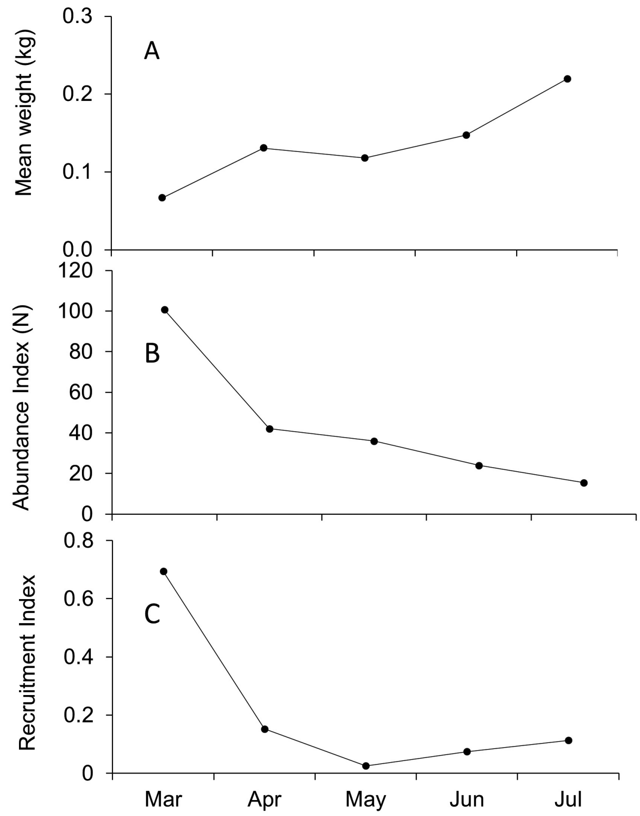

Fig. 4: Monthly mean weights (A), calculated abundance index (B) and recruitment index (C) of squid *Loligo vulgaris* and *L. forbesii* from the bottom trawl fleet off Mallorca in 2009.

ed abundance index (standardized CPUE) showed a very similar pattern in both years (Fig. 3B), whereas the monthly recruitment indices for 2007 and 2008 were very different (Fig. 3C). While the index dropped significantly in March 2008 and then increased again until June, in March 2007, it reached its maximum value and only dropped significantly in July of the same year. The estimated monthly mean weights of the squid from the biological sampling of 2009 showed a general upwards trend during the analysed period (Fig. 4A). The calculated abundance index (Fig. 4B) and the monthly recruitment index (Fig. 4C) showed a common decreasing trend with time.

Sensitivity analysis

For the *Loligo* data, a model fit was only obtained using a log-transform error model, wherefore it was applied to all depletion periods. Sensitivity analysis conducted using the *Sepia* data for 2007 revealed that all three error models produced very similar results regarding the estimates of original population numbers (N1), numbers of recruits (λ) and final population size (Fig. 5). Regarding the model's sensitivity to different mortality rates M, the cuttlefish model was not very sensitive (Fig. 6A), a result that is in accordance with former studies (Basson *et al.,* 1996; Royer *et al.,* 2006). In *Loligo*, employing an M of 0.12 led to about 1.5 times the initial population number and nearly double the final population, whereas changes between M = 0.08 and M = 0.10 were minimal (Fig. 6B). Based on these results, the median values also used in previous studies were used in all further analyses.

Model output

In both cuttlefish and squid assessments, fits for all periods were only obtained by using the log-transform model. Regarding cuttlefish, model fits were obtained for all years except 2008, and the parameter estimations differed widely between years, notably for recruits. The initial population (N1) varied between 26.000 and 103.000, and the final population was estimated between approximately 4.000 and 23.000 individuals. The number of recruits (λ) estimates varied between 400 and 59.000. Estimated and observed CPUE were very similar and ranged between 2.2 and 13.4 individuals per unit effort (days at sea), with notably higher total values in 2007–2008 than in 2009–2010 (Fig. 7A). Biweekly population numbers versus total catches are given in Figure 7B. Catches showed similar ranges in all three years with model fit (2007, 2009, 2010), but the pattern found in 2009 differed compared to the rest. Population numbers were much higher and declined more abruptly with time in 2009 than in 2008 and in 2010.

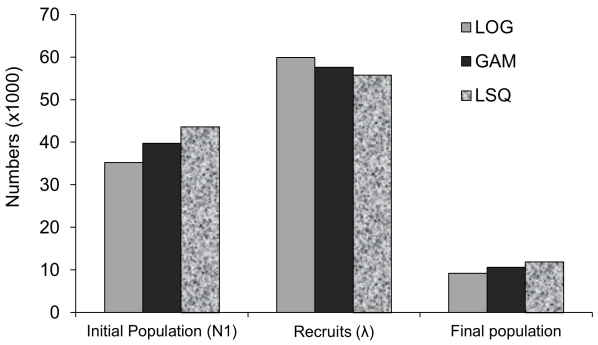

Fig. 5: Expected initial population (N1), number of recruits (λ) and final population (all in numbers) of cuttlefish from Mallorca using different error models (LOG: log-transformed; GAM: gamma; LSQ: least square).

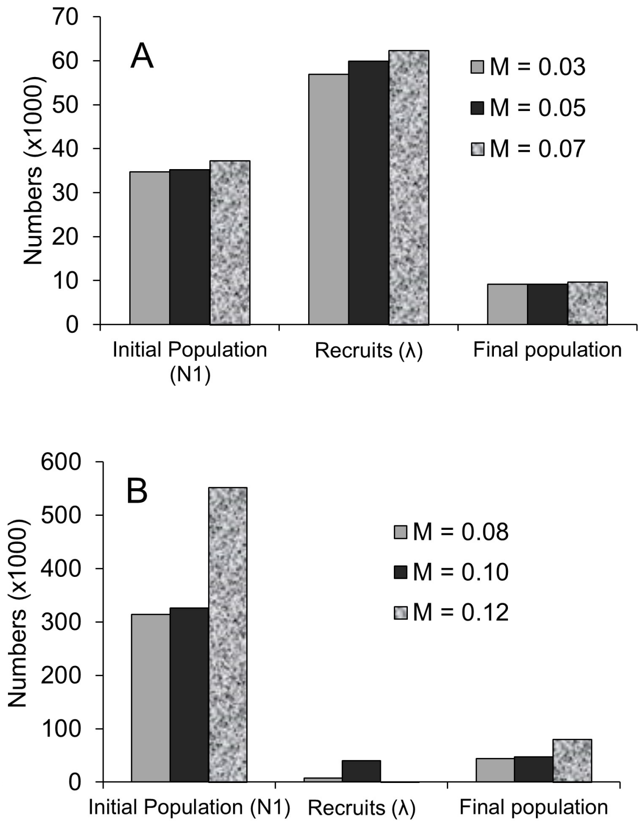

Fig. 6: Sensitivity analysis testing different natural mortality values (M) for cuttlefish (A) and squid (B) populations from Mallorca. The estimated initial population (N1), number of recruits (λ) and final population (all in numbers) obtained using the log-transformed error model are shown.

In the case of the loliginids, model fits were obtained for all the three years (2009–2011), and the model estimates differed less than for cuttlefish (Fig. 8). The initial population (N1) varied between 326.000 and 440.000 animals, and the final population between around 44.000 and 71.000 individuals. Apart from the first fortnight, estimated and observed CPUE were again very similar (Fig. 8A). Biweekly population numbers (estimated) start at approximately 30% higher in 2011 than in 2009 and 2010, and total biweekly catches (numbers) showed a different pattern every year (Fig. 8B).

Discussion

The assessment and management of cephalopod stocks is of great relevance owing to the socio-economically important fisheries they sustain worldwide and the pivotal role they play in marine food webs (Boyle & Rodhouse, 2005; ICES, 2010). Despite previous demands from both European scientists and fishing organisations to improve data collection for cephalopod assessment (Young *et al.,* 2004; ICES, 2010, 2011, 2012), little has been done under the EU Data Collection Framework (DCF) till date. While member states have been given the flexibility to design their own national sampling programmes in line with the community programme, the DCF establishes the minimum data that countries must acquire and report to the EU Commission.

Under the current DCF (EU, 2010), collection of biological information includes metier- and stock-related variables. In the first case, sampling must be performed to evaluate the quarterly length distribution of species in the catches and the volume of discards for each major fishing metier. In the second case, the sampling scheme requires individual information on length, weight, sex and maturity to be gathered every three years for each specified species. According to the current DCF, the sampling of stock-related variables of cephalopods in European waters is mandatory in only two main regions, the North East Atlantic and Western Channel (NEA-WC) and the Mediterranean and Black Seas (MS-BS). In all other European areas (North Sea and Eastern Channel, Baltic Sea, Skagerrak and Kattegat), the DCF does not include any cephalopod species. In the NEA-WC, three cephalopod species are to be sampled: the common squid (*Loligo vulgaris*), the common octopus (*Octopus vulgaris*) and the cuttlefish (*Sepia officinalis*). Because of the importance of cephalopods for Mediterranean fisheries, however, the following species were added to the three previous ones in this sea: the horned octopus (*Eledone cirrhosa*), the musky octopus (*Eledone moschata*), the southern shortfin squid (*Illex coindetii*) and the European flying squid (*Todarodes sagittatus*).

According to the current view, DMs may be considered the most suitable methods for cephalopod assessment (e.g. Royer *et al.,* 2002; Robert *et al.,* 2010; Rodhouse *et al.,* 2014). In this study, we investigated if the information currently demanded by the DCF allows the application of such methodology to properly assess the European cephalopod stocks. Owing to their rapid growth rates, cephalopods display high plasticity in life-history traits (Boyle & Rodhouse, 2005; Pierce *et al.,* 2008). Substantial changes in biological parameters in cephalopods are well-documented and reflected at different time scales encompass-

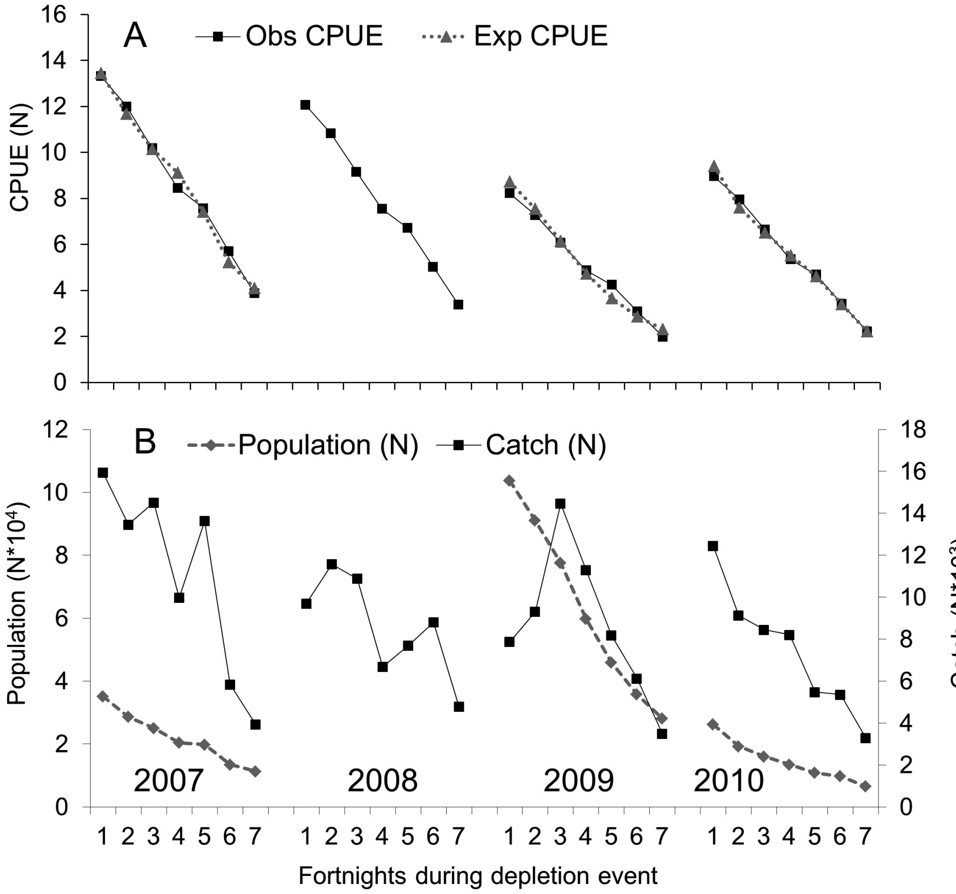

Fig. 7: Observed and expected biweekly CPUE (A) and stock size and catch (B) of cuttlefish *Sepia officinalis* from the small-scale fleet off Mallorca during 2007–2010 using M = 0.05. Fortnights 1–7 correspond to calendar weeks 15–28.

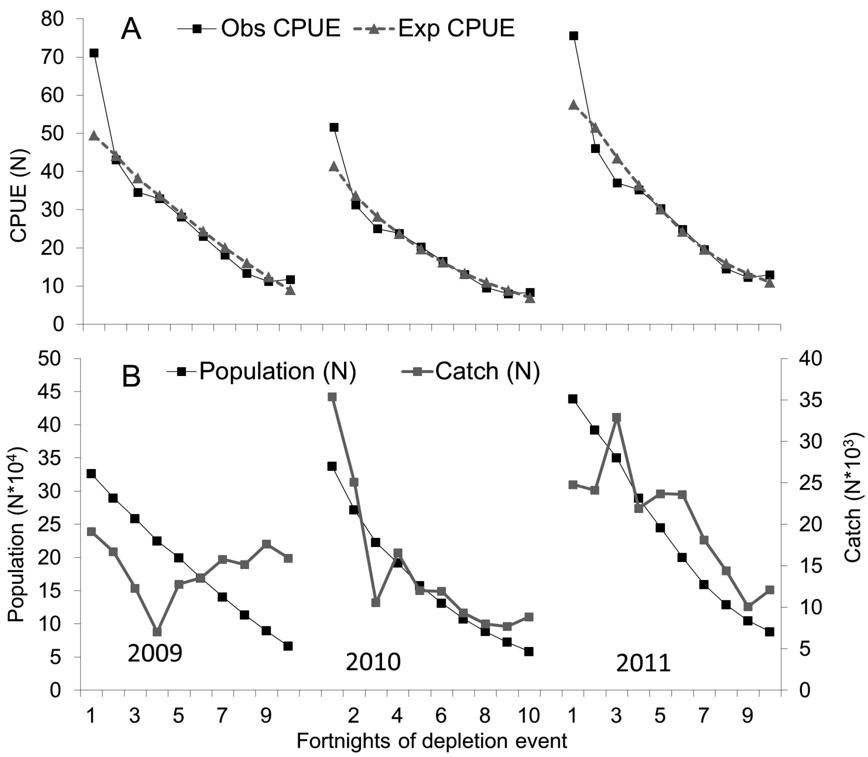

Fig. 8: Observed and expected biweekly CPUE (A) and stock size and catch (B) of squid *Loligo vulgaris* and *L. forbesii* from the bottom trawl fleet off Mallorca during 2009–2011 using M = 0.1. Fortnights correspond to calendar weeks 9–28.

ing years (Pecl *et al.,* 2004; Smith *et al.,* 2005), seasons (Jackson *et al.,* 1997; Pecl, 2001; Jackson & Moltschaniwskyj, 2001), weeks (Jackson & Pecl, 2003) and even days (Moltschaniwskyj *et al.,* 2002). All these studies indicate that biological parameters of cephalopods should be estimated at shorter time scales during the actual assessment period, invalidating the triennial sampling scheduled by the DCF, which is clearly not adapted to short-living species like cephalopods. Results of cephalopod stock assessments by means of DMs are, in fact, in agreement with this idea of more regular sampling. Indeed, strong and significant inter-annual differences in average monthly body weights in squid populations from Scottish waters were found (Young *et al.,* 2004).

Our results showed wide inter-annual variations in recruitment and population size, which seemingly are not linked to changing fishing activities owing to the short time period analysed (3–4 years). Such high variations seem to be inherent to cephalopod stock modelling using DMs, as they have been observed in most studies published till date (e.g. Agnew *et al.,* 1998; Royer *et al.,* 2002, 2006; Young *et al.,* 2004). In the English Channel, for example, the initial population size of squid ranged between 49.000 and 6.000.000 individuals (M = 0.2) and the recruitment numbers at the beginning of the depletion period ranged between about 1.000.000 and 2.100.000 individuals. For cuttlefish, annual recruitment varied between 44.000.000 and 79.000.000 (Royer *et al.,* 2006). Significant annual variability is also evident in the recruitment indices of Mediterranean cuttlefish, which were markedly different in 2007 and 2008 (Fig. 3B). Although these wide inter-annual variations might be reflecting the aforementioned plasticity of cephalopod populations, the fluctuations seem unrealistic in some cases and raise concerns of poor data quality or compromised model assumptions, as discussed below.

Regarding data quality, a distinction has to be made between fishery statistics (landings and effort) and biological (mean weights, reproductive index) data. In contrast to previous decades, most Mediterranean EU countries nowadays have reliable time series of catch-effort data gathered under the DCF. Having daily catch and effort data is a big improvement and could supply data of weekly mean weights if landings were sorted out by commercial categories, as proposed previously (Royer *et al.,* 2002) and already been used in some cephalopod stock assessments (Jouffre & Caverivière, 2005). The impediments noted by previous authors (Young *et al.,* 2004), such as no reporting of artisanal fishery or misreporting, was not a concern in our case. There is little missing data or hidden catches regarding cephalopod statistics, as there are no set total allowable catches (TACs). Problems arise only when a single commercial category includes several species, as is the case with our squid data that comprises of two species (*Loligo vulgaris* and *L. forbesii*) with different spawning and recruitment periods (Robin & Denis, 1999; Denis *et al.,* 2002). While some EU regulations specifically demand additional biological sampling for the purpose of getting species proportions in such cases, these are still missing in several statistics and national sampling programmes (ICES, 2010).

The model assumptions include a closed area, a constant catchability over stock size and time, and no target switching by fisherman within time. Both loliginid squid and cuttlefish undertake seasonal migrations, which lead to temporal, local accumulation or disappearance of the animals and therefore violate the model assumptions of a closed area and constant catchability (Arkhipkin *et al.,* 2013). In contrast to the Falkland Island fishery, where the animals are caught prior to their reproductive migration (McAllister, 2004), the Mediterranean small-scale fishery focuses on cuttlefish (Keller *et al.,* 2014) and squid (Cabanellas-Reboredo *et al.,* 2012) at their breeding grounds; which is the reason for excluding the period of initial arrival to the fishing grounds in our models. Furthermore, the emigration of big animals from the spawning area can lead to the sampling of different parts of the population at different times (Mangold-Wirz, 1963). When the mean weights drop for this reason, catches in numbers will increase and result in a seemingly slower depletion of the stock than actually happening. However, a depletion analysis of the English Channel loliginid squid stock gave similar outcomes regarding the total stock and recruitment size, and so did the virtual population analysis they conducted (Royer *et al.,* 2002). Therefore, the applied method seems to be valid. Another possible source of error arises from the parameter estimates, such as the natural mortality (M), which cannot always be determined with certainty (Wang & Liu, 2006; Jiao *et al.,* 2012). Furthermore, the semelparity of the species will lead to a change in the natural mortality rate after the spawning period, and some of this variability might already be reflected within our study period. Nevertheless, as revealed by our own results and also by previous studies (Royer *et al.,* 2002, 2006; Young *et al.,* 2004), DMs are quite robust to changes of M within the ranges tested.

Whereas the first EU framework (EU, 2000) was established at the stock level, by focusing on the most important commercial species, the current one (EU, 2010) is based on the so-called concurrent sampling, that is, sampling all or a predefined assemblage of species simultaneously in a vessel's catch or landings. Assessing cephalopod stocks by means of DMs requires intense sampling at low temporal scales (weekly or biweekly) to properly track the depletion event. To optimize the sampling of cephalopods for assessment purposes under the DCF, this should be concentrated during the relatively short period of the depletion event each year, which is the only relevant period for the required data of individual sizes and weights.

In conclusion, the trials conducted in this work shed doubt on the suitability of the minimum data requirements of the DCF to properly assess and manage Mediterranean cephalopod stocks with depletion methods. The suggested improvements in the sampling design would make the assessment of cephalopod populations in European waters more efficient and accurate. Considering the high importance of cephalopod fisheries in the Mediterranean, such improvements are especially relevant in these waters. In 1999, for instance, approximately 80% of the total world catch of cuttlefish came from this area, whereas the Mediterranean octopus landings ranked third, after the comparatively larger western and eastern central Atlantic FAO areas (Boyle & Rodhouse, 2005). In most cases, cephalopod fisheries are seasonal and the catches reach high prices. Besides the fisheries analysed in this study, it is worth mentioning the fishery for juvenile *Eledone cirrhosa* in some areas of Spain (Sánchez *et al.,* 2004) and Italy (Belcari & Sartor, 1999), where the prices of the smallest individuals can exceed 200 €/kg.

In such valuable fisheries, real-time assessments using depletion methods might be useful and have already been applied in the squid fishery from the Falkland Islands (Agnew *et al.,* 1998; Arkhipkin *et al.,* 2013). The assessment and management system used in this area makes it one of the best-managed squid fisheries in the world, with effective cooperation between scientists, managers and stakeholders to assure sustainable, long-term resource exploitation (Arkhipkin *et al.,* 2013). The Falkland Islands squid fishery is managed using a combination of effort control (a limited number of vessels are licensed to fish during each of two open seasons), a recruitment biomass survey before each commercial season and an in-season assessment of the state of the stock in relation to biological reference points, such as minimum levels of spawning stock biomass (Agnew *et al.,* 1998; Arkhipkin *et al.,* 2013). The stock size is then monitored in real time using DM assessments, and the fishery may be closed early to preserve a target escapement (Agnew *et al.,* 2002). Although the authors do not suggest the adoption of this complex, long-standing assessment scheme in Mediterranean waters, the issuing of licenses, together with in-season monitoring and post-season assessment, may be useful to ensure sustainable harvesting of the stocks. The high multi-specificity of most Mediterranean fisheries would likely preclude the effectiveness of this scheme, but it may be applied to the aforementioned high-valued artisanal fisheries, which are monospecific fisheries targeting a single cephalopod species. Post-season assessment in the remaining fisheries, however, might be useful to detect midterm trends and also to better understand the behaviour of fishing fleets in reaction to recruitment variations. As a result, Mediterranean fishers might reallocate the fishing effort towards alternative resources during periods of low recruitment using its flexibility to exploit different grounds even on a daily basis (Palmer *et al.,* 2009).

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