MINOUW

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# Science, Technology, and Society Initiative to Minimize Unwanted Catches in European Fisheries

## WP3. Impact assessment of minimizing unwanted catches and discarding.

## Deliverable 3.1 Effects of bycatch and discards ban on seabirds

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RESEARCH & INNOVATION

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# Effects of bycatch and discards ban on seabirds

## 1. Introduction

MINOUW is an EU H2020 project which main objective is to minimise unwanted catches by incentivising fishing technologies and practices that reduce pre-harvest mortality and post-harvest discards, while avoiding damage to sensitive marine species and habitats in European waters. It is developed by a consortium of 19 organisations including fisheries technologists, scientists, universities, a non-governmental organization and local fisheries managers.

Fisheries have an enormous economic importance; as a consequence, it is a challenge to reconcile economic and social issues involving fish and fisheries together with conservation and sustainability. Human fisheries harvest fish and other populations of marine organisms; as such, fisheries compete with marine top predators such as marine mammals, large predatory fish and seabirds. Competition is not the only type of interaction between fisheries and top predators: bycatch can be a source of additional mortality, whereas exploitation of discards or location of fish shoals can be beneficial for predators since it increases the availability and accessibility of foraging resources.

Fisheries and seabirds have always interacted, but since the industrialisation of fisheries their impact on seabird populations and other marine top predators has dramatically increased (e.g., Furness, 2003; Tasker et al., 2000; Wagner and Boersma, 2011). Trawling fisheries make available to seabirds a huge amount of extra food through discards (>7 million tonnes/year; Kelleher, 2005), predictable in time and space, affecting seabird species representing all taxonomic families. Discards provide an additional and predictable source of food and benefits have been recorded for several species (Garthe, Camphuysen & Furness 1996; Oro & Ruiz 1997; Oro, Pradel & Lebreton 1999; Oro *et al.* 2004b; Bugoni, McGill & Furness 2010). When discards are available, many demographic traits increase, affecting different life history stages of the species (Oro *et al.* 2013).

However, seabirds are also attracted to other fishing fleets (such as bottom and surface longliners, gillnet, purse-seine or sport trolling fishing) that generate bycatch mortality (Tull & Germain 1972; Davoren 2007; Croxall *et al.* 2012; Žydelis, Small & French 2013; Regular *et al.* 2013; Lewison *et al.* 2014) and counterbalance the positive effects of trawler discards. Bycatch is a problem for fishermen and it is also clearly among the most serious global threats for marine ecosystems, affecting not only seabirds but also a wide range of other top predators, from large fish to turtles and marine mammals (Furness 2003; Lewison *et al.* 2004, 2014). Thus a careful analysis of both positive and negative impacts of fisheries on seabirds is needed to assess the global effect and for the development of more careful, ecosystem-based approaches to sustainable fisheries (2010; Bicknell *et al.* 2013; Votier *et al.* 2013). This is especially timely due to the recent reform of the EU Common Fisheries Policy (CFP) (http://ec.europa.eu/fisheries/reform/ ). The plans to ban fishing discards (EU Commission 2013;Table 1), in particular, are expected to have a large impact on seabird ecology that needs to be quantified.

| Issue | Link |
|---|---|
| - Action Plan for reducing incidental catches of seabirds in fishing gears | http://ec.europa.eu/dgs/maritimeaffairs_fisheries/consultations/seabirds/consultation_document_en.pdf |
| - Common Fishing policy | http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:354:0022:0061:EN:PDF |
| - Discard banning plan | http://ec.europa.eu/fisheries/cfp/fishing_rules/discards/index_en.htm |

**Table 1.** European Union fisheries reports and plans that relate to seabirds and new policies affecting seabirds.

# 2. The effect of bycatch on higher trophic levels. The case of four endemic Mediterranean seabirds

We estimated and analysed the effect of bycatch in four seabird Mediterranean taxa, all of them included in the EU Birds Directive, and one of them classified as the most endangered vertebrate in Europe: the critically endangered Balearic shearwater *Puffinus mauretanicus*, the Cory's shearwater *Calonectris diomedea,* the European shag *Phalacrocorax aristotelis aristotelis*, and the Audouin's gull *Larus audouinii*. These four species appear to be primarily impacted by different types of fishing gear, which contrasting effects need to be estimated for each species separately.

## 2.1. Data and seabirds' bycatch rates according to species, gears and locations

### 2.1.1 Bycatch events of Balearic shearwaters

The Balearic shearwater is a high conservation interest species because has been predicted to go extinct in this century (Oro *et al.* 2004a). By catch events of the Balearic shearwater in the literature are frequent, even if their occurrence is difficult to quantify (Table 2). We then gathered data from Wildlife Recovery Centres in Valence, Catalonia and the Balearic Islands, almost covering the whole species foraging range during the breeding season. From 1985 to 2014, we found registered deaths of 78

Balearic shearwaters at Wildlife Recovery Centres. In 57.7% of the cases the cause of death could not be determined. From the remaining 33 individuals, in more than the half of the cases (67%), the cause of death was bycatch in fisheries gear, and longline bycatch represented 48.5% of the total known mortality. In Figure 1 we can observe the location of the individuals recovered dead and their cause of dead.


**Figure 1**: Map of the localization of all Balearic shearwaters found dead. Dot color show the cause of dead, being red by predation, blue by fisheries bycatch, red starved and green by unknown cause of dead.

a) **General information**

| **Date** | **Area** | **Gear** | ***Species*** | **Nb** | **Source** | **Observations** |
|---|---|---|---|---|---|---|
| 1970s | Fr Med. | Set nets (?) | *Pm/Py* | >40 | Besson 1973 | Inferred c. 800 per year drawning in set nets, from March to June (out of a few events of birds stranded with signs of entanglement) |
| 1998-2005 | Sp Med. | Demersal longline | *Pm* | 3 | Laneri et al., 2010 | Observers onboard data, CPUE/1000 hooks = 0.01266; CPUE/set = 0.01962 (n = 237 fishing operations) |
| 2000s | Sp Med. | Demersal longline | *Pm/Py* | | SEO/BirdLife 2013 | From questionnaires to fishermen, reported regular catches of several tens of birds (shearwaters spp), not so rare 100-300. Reported to be more frequent in the 1990s. This information could also involve Scopoli's shearwaters *Calonectris diomedea* in occasions, though some fishermen positively reported events mainly involving *Pm/Py* |
| 2004 | Sp Med. | Demersal longline | *Pm* | | Louzao & Oro 2004 | From questionnaires to fishermen, reported as second most caught species, after Cory's shearwater. Mainly February-March. About 10% of vessels reported captures, either demersal longliners or artisanal polyvalent vessels (presumably also using demersal longlines). |
| 2000-2009 | Sp Med. | Pelagic longline | *Pm/Py* | 6 | García-Barcelona et al. 2010a,b | Observers onboard data, CPUE/1000 hooks = 0.00111; CPUE/set = 0.00232 (n =2,587 fishing operations). Albacore fishery (small hooks) CPUE/1000 hooks = 0.005 (n = 391,244 hooks) |
| 2009-2012 | Sp Med. | Demersal longline | *Pm* | | Cortés in Boué et al. 2013 | Observers onboard data, CPUE/1000 hooks = 0.06 (n = 63 fishing operations) |
| 2009-2015 | Sp Med. | Pelagic longline | *Pm/Py* | >100 | Spanish Institute of Oceanography (IEO) (unpublished data) | From observers onboard, a unique case of massive catch, >100 birds |
| 2010-2012 | Portugal | Purse-seiners | *Pm* | 30 | Oliveira et al. 2014 | Three out of 353 fishing operations monitored by observers reported Balearic shearwaters, totaling 30 birds (20 + 5 + 5). |

| **Date** | **Area** | **Gear** | ***Species*** | **Nb** | **Source** | **Observations** |
|---|---|---|---|---|---|---|
| 2010-2012 | Portugal | | *Pm* | | Oliveira et al. 2014 | From questionnaires to fishermen, reported regular catches of Balearic shearwater by demersal longlines (29% of interviewed vessels) and purse-seiners (18%), plus polyvalent vessels using demersal longline (14%) |
| 2010-2013 | Portugal | Set nets | *Pm* | 1 | Oliveira et al. 2014 | 1 bird caught out of 237 fishing operations |

## b) **Specific events**

| Date | Area | Gear | Species | Nb | Observer/contact/source | Observations |
|---|---|---|---|---|---|---|
| 01/1993 | Sp Med | Demersal longline (presumed) | *Pm* | 5+ | J.M. Arcos | Found dead on the beach, injuries on neck (hook?) |
| Winter 1999-2000 | Sp Med | Trawler/purse-seiner? | *Pm* | c. 50 | SEO/BirdLife; Ruiz & Martí 2004 | During winter. 50 birds beached, apparently drowned, signs of net entanglement in the neck |
| 2000-2001 | Sp Med | Demersal longline | *Pm* | c. 35 | From Fishermen to E. Badosa; Louzao et al. 2011 | Birds caught in a single line |
| 05/2007 | Sp Med | Demersal longline | *Pm/Py* | c. 100 | From Fishermen to O. Macián; Louzao et al. 2011 | Birds caught in a single line |
| 05/2007 | Sp Med | Demersal longline (artisanal) | *Pm/Py* | 72 | CRAM & Generalitat de Catalunya; Alegre 2008 | Line found drifting with 72 shearwaters (about 75% *Pm* & 25% *Py*). Small longline, probably of artisanal type (polyvalent vessels) |
| 06/2008 | Sp Med | Demersal longline | *Pm* | 12+ | J. Torrent - SEO/BirdLife; Louzao et al. 2011 | 12 corpses with hooks reported offshore during a 4-mile boat-based transect |
| 05/2011 | Sp Med | Trawler (experimental) | *Pm* | 1 | Pere Abelló; Abelló & Esteban 2012 | 2 hauls with 1 bird each, one drowned and other injuried (unable to fly) |

| Date | Area | Gear | Species | Nb | Observer/contact/source | Observations |
|---|---|---|---|---|---|---|
| 01/2013 | Sp Med | Purse-seiner/trawler | *Pm* | c. 25 | Generalitat Valenciana | Found dead in a beach, drowned (some with signs of net entanglement and dislocated wings). Stomach contents full of small-pelagics |
| 05/2014 | Sp Med | Trawler (experimental) | *Pm* | 14 | Pere Abelló | 14 birds (4 dead) caught on 5 different hauls. Very unusual year. |
| 05/2014 | Sp Med | Trawler | *Pm* | 2+ | D. Albiol (skipper) | 2 birds caught alive in 2 different boats, one of them unable to flight. Reported by fishermen as a very unusual event. |
| 06/2014 | Sp Med | Trawler | *Pm* | 4+ | J. Fàbrega (skipper) | At least 4 birds in 3 hauls by 2 vessels. One involved 2 birds (alive + dead). Reported by fishermen as a very unusual event. |
| 06/2015 | Sp Med | Demersal longline | *Pm/Py* | 20-30 | From fisherment to A. Cama (SEO/BirdLife) | Reported dead |
| 06/2015 | Sp Med | Longliner (?) | *Pm/Py* | 7 | GEPEC | 7 Birds stranded in the beach (5 *Pm*, 2 *Py*), neck injuries suggest hooks |

**Table 2.** Bycatch events of Balearic shearwaters gathered from the Literature. (a) General information from published papers and reports (b) Specific events collected on an opportunistic basis from a wide variety of sources. The search was focused on Balearic shearwater (*Puffinus mauretanicus*, *Pm*), but captures often involved also Yelkouan shearwaters (*Puffinus yelkouan, Py*) along with *Pm*, and/or it was unable to identify the birds to the species level; we should notice that Balearic shearwater from Minorca can be easily confounded with Yelkouan shearwaters (Genovart et al. 2007). Data from the Mediterranean mainly come from Spanish waters (Sp Med), and occasionally from France (Fr Med). CPUE: Catches per unit effort.

### 2.1.2 Bycatch rate estimates

We gathered capture-recapture data and estimate for the first time the probability of dying by fisheries bycatch in these four endemic Mediterranean taxa: the Balearic shearwater, the Cory's shearwater, the European shag and the Audouin's gull.

To estimate demographic parameters such as survival, recruitment or the probability of dying in fishing gears in the four species, we used multi-event capture-recapture modelling (Pradel 2005). Models were built and implemented in program E-SURGE (Choquet, Rouan & Pradel 2009b). These models hold two levels in capture-recapture data: the field observations, called “events”, encoded in the capture histories, and the “states” defined to match the biological questions, that can only be inferred (see articles attached in sections 5.1 and 5.2 to know methods and results in more detail).

We found that adult survival in Balearic shearwater was much lower than expected (0.809, SE: 0.013), and largely influenced by bycatch, which accounted for a minimum of 0.455 (SE: 0.230) of total mortality (Table 3).

We further evaluated the impact of longline bycatch as an additional source of mortality, using the “potential biological removal”, hereafter PBR (Dillingham & Fletcher 2008). We first calculated the maximum potential annual growth rate ($\lambda$max) by means of the “demographic invariant method”, hereafter DIM (Niel & Lebreton 2005). Using the DIM approach, the maximum population growth rate $\lambda_{max}$ was 1.101 (range 1.087–1.112), i.e. that under ideal demographic conditions, the population cannot grow at a rate higher than 11.2% per year. A conservative estimate of population size $N_{min}$ was calculated at 19965 shearwaters, from which we estimated a PBR of 100 shearwaters dying in fishing gear each year (range 87–112).

For the other three species we concluded that longline bycatch was particularly severe for adults of Cory’s shearwaters and Audouin’s gulls (ca. 28% and 23% of total mortality, respectively) and immature gulls (ca. 90% of mortality) (Table 3). Gillnets had a lower impact, but were still responsible for ca. 9% of juvenile mortality on shags, whereas sport trolling only slightly influenced the total mortality in gulls. Perhaps our most general finding is a clear documentation that bycatch mortality varies enormously between types of gears, species, and across age classes. Longlines in particular were responsible for the highest mortality, whereas the effects of gillnets and sport fishing are estimated to be relatively low. However, the low effect of these other fishing gears should be taken with caution. First, more detailed research should be carried out to assess if the estimated lower bycatch rates of these gears are related to the fact that they are intrinsically less harmful gears, or to the fishing effort of each fleet using specific gears (e.g. number of boats, power, and number of setting operations). Second, some recoveries could have been erroneously assigned to death in longline, in particular deaths caused by sport fishing, since in both cases the animal is found with a fishing line on its body. Even within the same fishing gear, differences in setting and specific gear operation may cause differences in bycatch rates.

| | | Age | Balearic shearwater | Cory's shearwater | European shag | Audouin's gull |
|---|---|---|---|---|---|---|
| Bycatch rate depending on fishing gear | Longlines | Juveniles | - | 0.0165 (0.0008-0.2530) | - | 0.8996 (0.8697-0.9237) |
| | | Immatures | - | 0.0165 (0.0008-0.2530) | - | 0.8996 (0.8697-0.9237) |
| | | Adults | - | 0.2815 (0.0204-0.8806) | - | 0.2349 (0.0851-0.5038) |
| | | Mean | 0.455 (0.119–0.837) | 0.5001 (0.4387-0.5633) | - | - |
| | Sport trolling | Juveniles | - | - | - | 0.0005 (0.0001-0.0020) |
| | | Immatures | - | - | - | 0.0005 (0.0001-0.0020) |
| | | Adults | - | - | - | 0.0094 (0.0044-0.0201) |
| | Gillnets | Juveniles | - | - | 0.0963 (0.0407-0.1932) | - |
| | | Immatures | - | - | - | - |
| | | Adults | - | - | 0* | - |
| Percentage dying annually | Longlines | Juveniles | - | 1.2 % - 35 % | - | 34 % |
| | | Immatures | 25.6 % | - | - | 16 % |
| | | Adults | 8.7 % | 3.4 % - 6.1 % | - | 2.5 % |
| | Sport trolling | Juveniles | - | - | - | 0.02 % |
| | | Immatures | - | - | - | 0.01 % |
| | | Adults | - | - | - | 0.1 % |
| | Gillnets | Juveniles | - | - | 3.4 % | - |
| | | Immatures | - | - | - | - |
| | | Adults | - | - | - | - |

**Table 3.** Bycatch rate (and 95% confidence intervals) from animals that died, and percentage of animals dying annually for each species, by age and fishing gears. For the Cory's shearwater, the percentage of animals dying annually are calculated based both on the age-specific and mean bycatch probabilities.

*These values should be taken with caution because we have no recoveries from adult birds, and thus, they were not estimable.

### 2.1.3 Effects of trawling moratoria on bycatch rates

As a parallel approach to assess bycatch effect on seabirds, we analyzed how trawlers moratoria within the foraging areas of Cory's shearwaters can potentially affect the population under study at Pantaleu islet (Mallorca, Balearic Archipelago) by promoting a higher attendance to longliners that may eventually increase mortality by bycatch (Laneri *et al.* 2010). Soriano-Redondo et al., (2016) observed that the probability of shearwaters attending longliners increased exponentially with a decreasing density of trawlers. Their on-board observations and mortality events corroborated this hypothesis: the probability of birds attending longliners increased 4% per each trawler leaving the longliner proximity and bird mortality increased tenfold when trawlers were not operating (see below in section 3.3 for more details on moratoria periods and foraging areas).

We tested the potential effect of moratoria on survival by means of multievent capture-recapture models (Pradel 2005). We first performed GOF tests (Table 4) and accordingly we incorporate trap-dependence effects in all models (see Pradel and Sanz-Aguilar, 2012).

| Test | Chi | df | c_hat |
|---|---|---|---|
| 3.SR | 25.02 | 14 | |
| 3.SM | 26.17 | 16 | |
| 2.CT | 212.54 | 13 | |
| 2.CL | 23.56 | 18 | |
| global model | 287.29 | 61 | 4.71 |
| trap model | 74.75 | 48 | 1.56 |
| trap+transient model | 49.73 | 34 | 1.46 |

**Table 4**. GOF tests for the data base for testing the effect of trawling moratoria in Cory's shearwater survival.

All models included a single age class for survival (i.e. did not account for transients), an additive trap-dependence effect and a time-dependent variability of recapture probability (see Pradel and Sanz-Aguilar, 2012; Sanz-Aguilar et al., 2016). We tested the potential effects of moratoria by considering different model structures accounting for the presence or absence of a trawler moratoria, the number of months and the season (spring-summer vs. fall). Given that previous analyses (Genovart *et al.* 2013; Tavecchia *et al.* 2016) found that the temporal variation of shearwaters at Pantaleu was partially explained by the Southern Oscillation Index (SOI) we also tested the effects of moratoria in combination with the values of the SOI (Table 5).

| Effect on survival | np | Dev | QAICc | Δ | $R^2$ |
|---|---|---|---|---|---|
| SOI | 18 | 4997.51 | 3239.76 | 0.00 | 0.23 |
| SOI + No. months of moratoria | 19 | 4996.73 | 3241.28 | 1.53 | 0.24 |
| SOI + categorical moratoria (YES/NO) | 19 | 4997.30 | 3241.65 | 1.89 | 0.23 |
| SOI + categorical moratoria (Summer/Fall/NO) | 20 | 4996.57 | 3243.21 | 3.45 | 0.25 |
| SOI + categorical moratoria (No. months) | 20 | 4996.72 | 3243.30 | 3.55 | 0.24 |
| constant | 17 | 5006.42 | 3243.45 | 3.69 | |
| time | 30 | 4966.80 | 3244.46 | 4.71 | |
| SOI + categorical moratoria (No. months and season) | 21 | 4996.28 | 3245.05 | 5.29 | 0.26 |
| categorical moratoria (YES/NO) | 18 | 5005.91 | 3245.14 | 5.38 | 0.01 |
| No. months of moratoria | 18 | 5006.42 | 3245.47 | 5.71 | 0.00 |
| categorical moratoria (Summer/Fall/NO) | 19 | 5004.59 | 3246.32 | 6.56 | 0.05 |
| categorical moratoria (No. months) | 19 | 5005.46 | 3246.88 | 7.12 | 0.02 |
| categorical moratoria (No. months and season) | 20 | 5004.57 | 3248.34 | 8.58 | 0.05 |

**Table 5.** Model Selection for testing the effect of trawling moratoria in Cory's shearwater survival.

As previously found (Genovart *et al.* 2013; see also section 2.1.2 and article 5.2), the best models included a SOI effect. The models that included the effects of trawler moratoria on survival were not retained (Table 5). Note that a model in which the number of months of the moratoria has an additive effect is ranked second. However, this variable is playing the role of a pretending variable with little or none effects on model deviance.

## 2.2. The impact of bycatch mortality on seabirds' demography

To assess the impact of mortality on fishing gears in the four seabird species, we formulated stage-class matrix population models and estimate the predicted long-term population growth rate under current and possible future environmental conditions. Models followed a pre-breeding census format, and were based only on females, assuming equal survival between sexes, monogamy and equal sex-ratio at birth. We first carried out a deterministic analysis that included mean values of the previously estimated vital rates (section 2.1.2) and yielded the deterministic population growth rate or $\lambda$. We then used the estimated stable age distribution to initialize the stochastic models. While the deterministic growth rate describes the population trend for constant, invariant vital rates, we also constructed stochastic models and we account for parameter uncertainty and annual variability in those rates to assess the risk of population decline or extinction (see articles attached in sections 5.1 and 5.2 to see details).

For the Balearic shearwater, under the present scenario we predicted a time to extinction of 61 years (95% CI: 55–69), which confirms that the species is one of the most endangered bird in the western Palaearctic (BirdLife International 2015).

Despite the fact that there is not a reliable estimate of the number of birds caught per year, there is no doubt that this figure is well above our estimated PBR value, and the rough estimated bycatch rate of about half of the mortality observed in Balearic shearwaters confirms that current fishery impact is unsustainable. The only scenarios yielding positive population growth rates for the species were those assuming survival rates of other *Puffinus* species with little or no anthropogenic mortality (Table 6).

We demonstrate here that the actual bycatch rate is not compatible with the viability of the species. We thus recommend the implementation of urgent mitigation actions to reduce fisheries bycatch rates in this and other top-predator species severely affected by this anthropogenic impact. More data are required to determine which factors increase bycatch rates and which the critical areas with highest impact are. It is crucial to then apply measures such as time restrictions on fishing activity, bycatch mitigation technology and practices, as well as the education of stakeholders and consumers.

| Scenario | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Survival affected by bycatch | yes | yes | no | no | no | no |
| Discard banning | no | yes | yes | no | yes | no |
| $\lambda_s$ | 0.856 | 0.848 | 0.951 | 0.972 | 1.006 | 1.044 |
| $\lambda_s$ lower 95% CI | 0.841 | 0.838 | 0.938 | 0.955 | 0.993 | 1.002 |
| $\lambda_s$ upper 95% CI | 0.872 | 0.860 | 0.965 | 0.989 | 1.020 | 1. 079 |

**Table 6**. Estimates of mean stochastic population growth rate $\lambda_s$ and 95% confidence intervals for the Balearic shearwater under different scenarios. Scenario 1: current situation. Scenario 2: reduced breeding success under future ban of discards. Scenario 3: conditions under future ban of discards but bycatch reduced. Scenario 4: current situation and bycatch reduced. Scenario 5: hypothetical conditions with minimum survival probabilities described for closely related Procellariiformes in optimal environments, and with a ban of discards. Scenario 6: Same demographic parameters as scenario 5 but no ban of discards. Sex ratio was set to 0.5 in all models. Recruitment and sabbatical estimates were common for all scenarios; recruitment was 1 for individuals >6 years old.

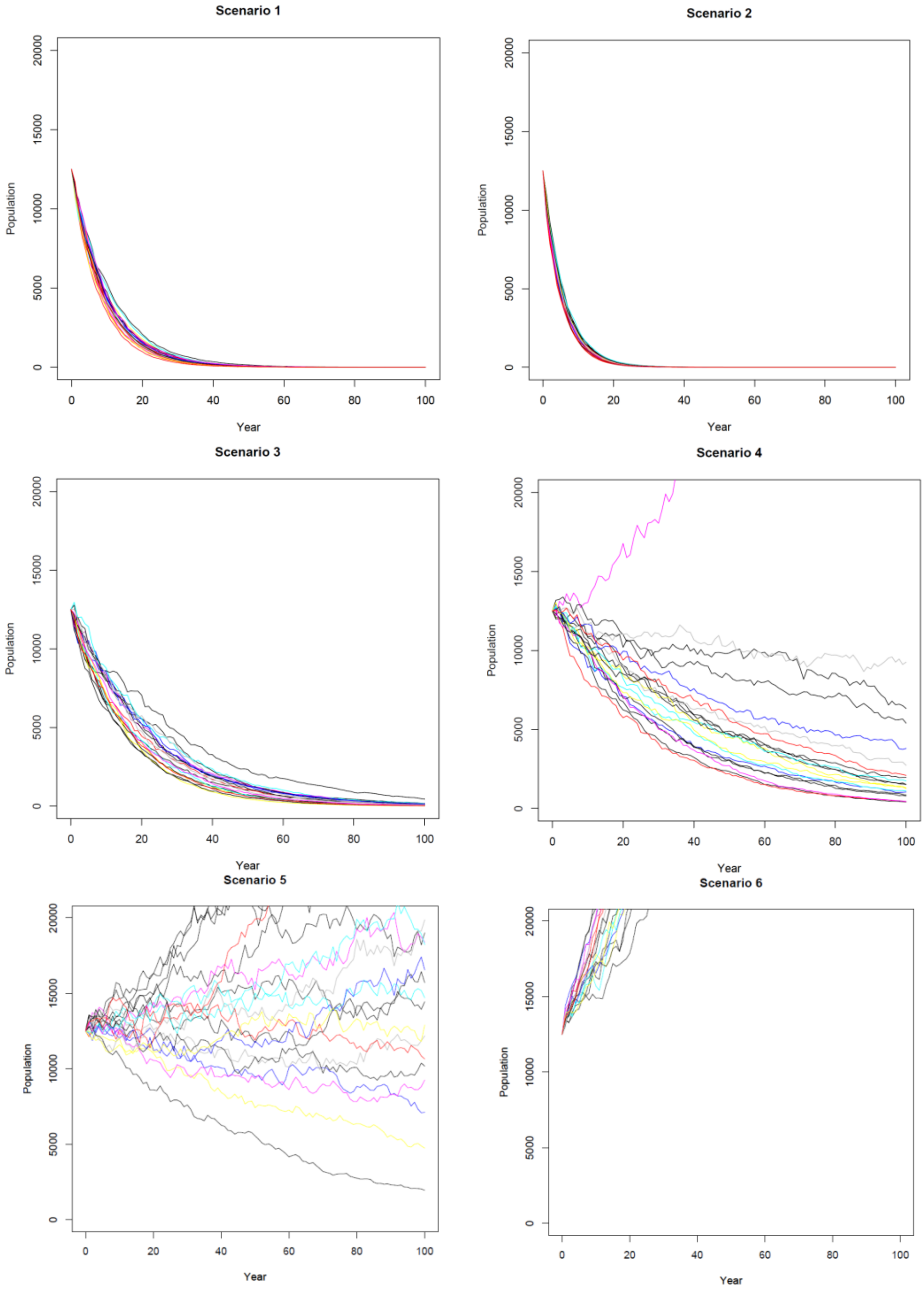



**Figure 2.** Stochastic projections of Balearic shearwater population over 100 years under different scenarios proposed: 1) current situation; 2) reduced breeding success under future ban of discards; 3) conditions under future ban of discards but bycatch reduced; 4) current situation and bycatch reduced; 5) hypothetical conditions with optimal survival probabilities and discard banning; 6) current conditions but with optimal survival probabilities. Each graph shows 20 randomly chosen trajectories from the 1000 population trajectories run in our Monte Carlo simulations.

When assessing the population growth rate of the other three seabird species under current and possible future environmental conditions, we demonstrate that the bycatch impact on four seabird species in the Mediterranean with very different life histories and foraging skills is significant, and it poses serious risks to the persistence of some populations under study (Table 7; Figures 3-5).

For Cory's shearwater, the estimated deterministic $\lambda$ under current conditions was 0.9280, reflecting an annual decline of about 7% in population size. We estimated a time to extinction of 81 years and a generation time for the species of 17.5 years. When adding environmental stochasticity under current conditions of bycatch impact, the mean growth rate for the population $\lambda s$ was 0.9287 (95% CI: 0.9151- 0.9417) (Table 7). The mean time to extinction was estimated at 81 years and the probability of extinction in 100 years was high (0.9798). Even in the absence of costs of reproduction, the population showed a strong decreasing trend (Figure 3). For the two scenarios assuming no bycatch occurrence, the probabilities of extinction in 100 years were almost null, although the only scenario with a stable or increasing trend was the one with no bycatch impact and assuming no differential bycatch probability between ages ("no bycatch 1", Table 7, Figure 3). In this species even the maximum value of fertility would not be able to compensate for adult survival values lower than 0.90.

For the European shag, deterministic $\lambda$ under current conditions was estimated as 1.025, reflecting an annual growth of about 2.5% in population size, and a generation time of 5.642 years When adding environmental stochasticity under current conditions, the mean growth rate for the population $\lambda s$ was 1.0337 (95% CI: 0.9492- 1.1134; Table 7, Figure 4) suggesting an equilibrium or a very slight population increase. As expected, when projecting a scenario with no bycatch impact on juveniles, $\lambda s$ was even higher (Table 7, Figure 4).

For the Audouin's gull, the estimated deterministic $\lambda$ under current conditions was 0.9944, reflecting almost equilibrium in population size, and a generation time of 12.43 years. When adding environmental stochasticity under current conditions, the mean growth rate for the population $\lambda s$ was 0.9724 (95% CI: 0.8914- 1.0640) (Table 7), showing that the population under current conditions will suffer an annual mean decrease of about 3%. The mean time to extinction was estimated at 99 years and the probability of extinction in 100 years was low (0.11). The scenario with increased survival resulting from an absence of longline bycatch predicted a stable population over time (Table 7, Figure 5).

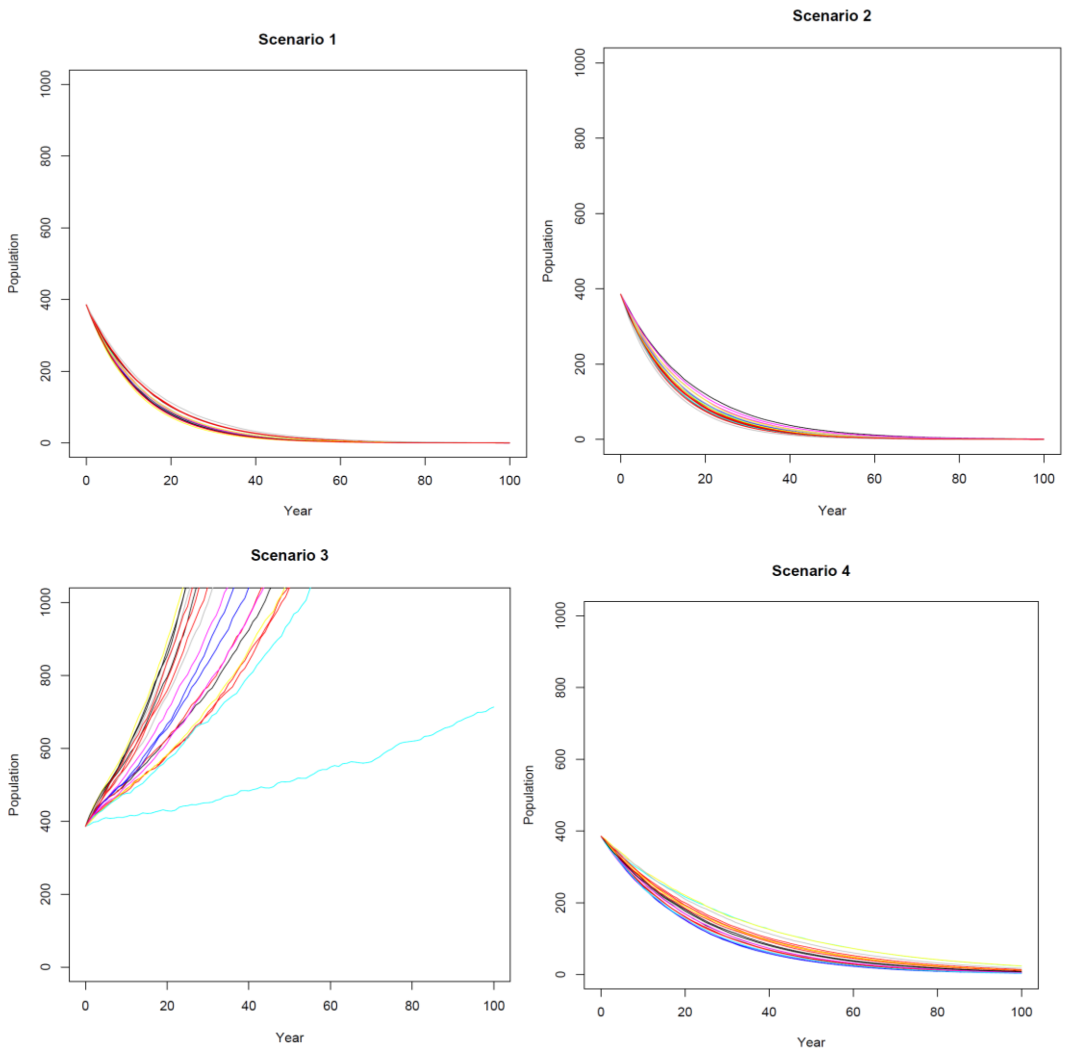



**Figure 3**. Stochastic projections of Cory's shearwaters from Pantaleu islet over 100 years depending on the scenario considered. Each graph shows 20 randomly chosen trajectories from the 1000 population trajectories run in our Monte Carlo simulations. Scenario 1: population under current conditions; scenario 2: current conditions but assuming no cost of first reproduction for 5 years old first time breeders; scenario 3: current conditions but without bycatch impact taking into account the mean bycatch probability; scenario 4 current conditions but without bycatch impact taking into account the age-specific bycatch probability.

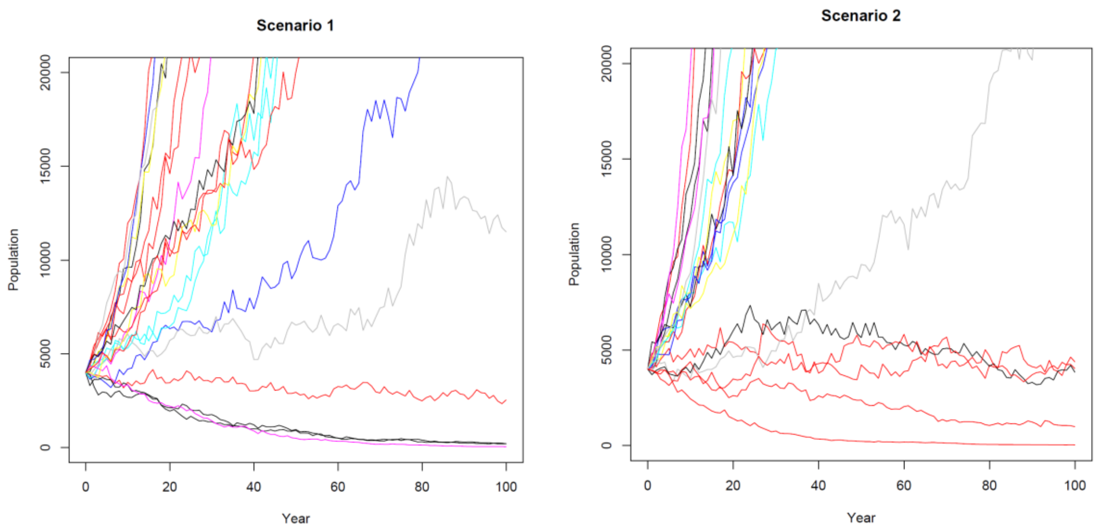



**Figure 4**. Stochastic projections of European shag population at Northern Adriatic Sea population over 100 years under different scenarios proposed. Each graph shows 20 randomly chosen trajectories from the 1000 population trajectories run in our Monte Carlo simulations. Scenario 1: current survival estimates and a very conservative estimate of sabbatical probability. Scenario 2: no bycatch impact on juveniles. Recruitment and sex ratios estimates were common for all scenarios and kept constant (see Methods and Table 4 for details).

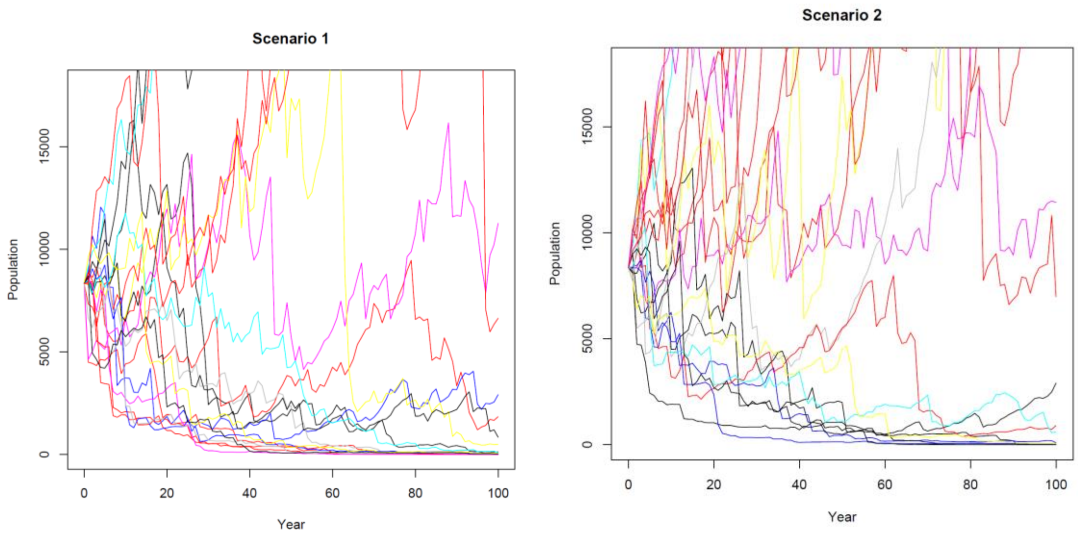



**Figure 5**. Stochastic projections of Audouin's gull population in the Ebro Delta over 100 years under current situation with longline bycatch (scenario 1), and without bycatch mortality (scenario 2). Each graph shows 20 randomly chosen trajectories from the 1000 population trajectories run in our Monte Carlo simulations.

Our study reinforces the idea that fisheries bycatch is probably the most serious global threat for long-lived marine taxa and we show that the demographic impact may strongly depend on the species and the fishing gear.

| | Cory's shearwater | | | | European shag | | Audouin's gull | |
|---|---|---|---|---|---|---|---|---|
| Scenario | current 1 | current 2 | no bycatch 1 | no bycatch 2 | current | no bycatch | current | no bycatch |
| $\lambda_s$ | 0.9287 | 0.9297 | 1.0285 | 0.9633 | 1.0337 | 1.0437 | 0.9724 | 1.0015 |
| $\lambda_s$ lower 95% CI | 0.9151 | 0.9159 | 1.0147 | 0.9508 | 0.9492 | 0.9607 | 0.8914 | 0.9134 |
| $\lambda_s$ upper 95% CI | 0.9417 | 0.9431 | 1.0414 | 0.9756 | 1.1134 | 1.1264 | 1.0640 | 1.0941 |
| Extinction probability | 0.9798 | 0.9598 | 0 | 0.0014 | 0.014 | 0.0104 | 0.1090 | 0.0316 |
| Mean time to extinction in years | 81 | 82 | 101 | 101 | - | - | 100 | 100 |

**Table 7.** Mean stochastic population growth rate $\lambda_s$ and 95% confidence intervals, probability of extinction, and mean time to extinction resulting from each scenario projected for Cory's shearwaters, European shag and Audouin's gull.

## 2.3. Comparing survival rates and bycatch risk at three western Mediterranean colonies of a long-lived seabird species.

We compared adult survival at three western Mediterranean colonies of Cory's shearwater. We then crossed this information with spatial data on foraging behavior during breeding at the three colonies, and with spatial distribution of fishing gears that may be causing bycatch in this species to explain the differences.

To estimate survival probability we used multi-event capture-recapture modeling and models were fitted in program E-SURGE (Pradel 2005; Choquet *et al.* 2009b). Individuals were classified in three groups based on their breeding colony and only adults were included in the analysis. We analyze 1561 individual histories from the three colonies; 231 from Illa de l'Aire, 876 from Pantaleu and 454 from Columbretes. We carried out a goodness-of-fit test using U-care (Choquet *et al.* 2009a). When analyzing the complete data set, the GOF for the Cormack-Jolly-Seber model was poor ($\hat{c}$ = 2.76) mainly due to the presence of transients and trap- heterogeneity. All our models included an age and a trap effect and we corrected for remaining overdispersion with a $\hat{c}$ = 1.42. To correct for trap heterogeneity (see results) we differentiate individuals depending on if they have been previously observed (Aware) or not (Unaware) (Pradel & Sanz-Aguilar 2012). Thus our models included three biological states: individual alive aware (AA); individual alive unaware (AU); and dead

(D), this last state being non-observable. The initial state in our models was always AA. Transitions between states were modelled in a two-step approach: survival and recapture probability (conditional on survival). In each capture-recapture occasion ('t') we considered two possible events: Individual not seen (noted 0); individual seen alive (noted 1). As we found a strong transient effect in adults, we included one different survival for the individuals captured for the first time. We tested for a time variant survival, and for an effect of the Southern Oscillation index (SOI) (http://www.cru.uea.ac.uk/cru/data/soi/soi.dat), in an additive and interaction manner with colony and age. As an exploratory model, we also run a model to estimate mean adult survival, including transients and residents. Given the different capture-recapture effort made annually in the three colonies, we kept the recapture probability time variant and colony dependent. Model selection relied on QAICc, i.e. the Akaike Information Criterion corrected for overdispersion and for small sample sizes (Burnham & Anderson 2002). Model selection clearly showed that adult survival probability varied between colonies (Table 8). The most parsimonious model indicated that adult survival differed between colonies and also depended on the annual SOI value (Model 1, Table 8).

| Model | Survival | np | Deviance | QAICc | ΔQAICc | $w_i$ |
|---|---|---|---|---|---|---|
| **1** | **(T/R) . colony + SOI** | **57** | **9452.72** | **2798.75** | **0** | **0.73** |
| 2 | (T/R) + colony + SOI | 55 | 9463.05 | 6870.65 | 3.28 | 0.14 |
| 3 | (T/R). colony | 56 | 9461.18 | 6871.36 | 3.99 | 0.10 |
| 4 | (T/R). colony. SOI | 62 | 9448.10 | 6874.33 | 6.96 | 0.02 |
| 5 | (T/R). colony + t | 72 | 9421.81 | 6876.13 | 8.77 | 0.01 |
| 6 | (T/R) + SOI | 53 | 9478.59 | 6877.65 | 10.29 | 0.00 |
| 7 | (T/R) + colony +t | 70 | 9430.26 | 6878.04 | 10.68 | 0.00 |
| 8 | (T/R) + t | 68 | 9447.18 | 6883.98 | 16.62 | 0,00 |
| *9* | *(T/R). colony* | *56* | *9481.09* | *6885.58* | *18.21* | *0.00* |
| 10 | colony + SOI | 54 | 9490.27 | 6888.04 | 20.68 | 0.00 |
| 11 | colony | 53 | 9495.24 | 6889.55 | 22.18 | 0.00 |
| 12 | colony + t | 69 | 9454.73 | 6893.46 | 26.10 | 0.00 |
| 13 | (T/R). t + colony | 84 | 9413,46 | 6894,99 | 27,63 | 0,00 |
| 14 | (T/R). t | 82 | 9429.57 | 6902.35 | 34.99 | 0,00 |
| 15 | colony . t | 96 | 9416.00 | 6921.75 | 54.39 | 0.00 |
| 16 | (T/R). colony . t | 141 | 9335.45 | 6958.95 | 91.59 | 0.00 |

**Table 8.** Model selection (see Methods) for estimating survival in Cory's shearwater in three western Mediterranean colonies. All models assumed a time variant and colony specific recapture probability. Best model is shown in bold and the model for estimating annual mean survival at each colony is shown in italics. T/R: two ages, transients and residents. "+" indicates additivity between factors and "." interaction.

Mean adult survival was higher at Illa de l'Aire than in the other two colonies (Model 1, Tables 8 and 9 and Figure 6). The mean adult survival probability, including those individuals found for the first time and also the residents, was 0.877 (0.846-0.902), 0.819 (0.802-0.834) and 0.860 (0.826-0.887) for individuals in Illa de l'Aire, Pantaleu and Columbretes respectively, showing again that individuals from Illa de l'Aire have a higher survival probability, and those from Pantaleu have the lowest one (Model 9, Table 8).

| | Illa de l'Aire | | Pantaleu | | Columbretes | |
|---|---|---|---|---|---|---|
| Parameter | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI |
| First encounter adult survival | 0.688 | 0.584-0.776 | 0.756 | 0.715-0.793 | 0.768 | 0.666-0.845 |
| Adult survival | 0.924 | 0.890-0.948 | 0.843 | 0.824-0.859 | 0.869 | 0.833-0.898 |
| Recapture probability | | | | | | |
| Unaware | 0.253 | 0.213-0.298 | 0.620 | 0.573-0.664 | 0.226 | 0.189-0.267 |
| Aware | 0.468 | 0.418-0.519 | 0.809 | 0.788-0.829 | 0.431 | 0.387-0.477 |

**Table 9**. Estimates of mean survival (and 95% Confidence Intervals) and recapture probabilities for Cory's shearwaters at Illa de l'Aire, Pantaleu and Columbretes (model 9, Table 8).

a) b)

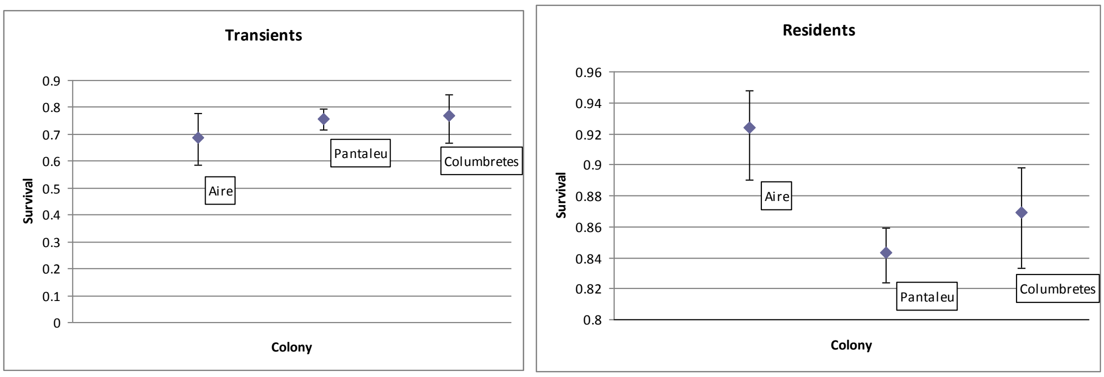



**Figure 6.** Mean survival estimates (and 95% Confidence Intervals) for residents (a) and transients b) of Cory's shearwaters at Illa de l'Aire, Pantaleu and Columbretes.

To assess wether these different survival probabilities from different colonies were due to different bycatch probabilities, we first analyzed the foraging areas for individuals from the three colonies. We gathered data from the Spanish Ornithological Society (SEO) of marked individuals with GPS at the three colonies. Data is very scarce thus we should be very cautious, but first results seem to show that individuals from the three colonies would use different foraging areas during breeding (Figure 7).

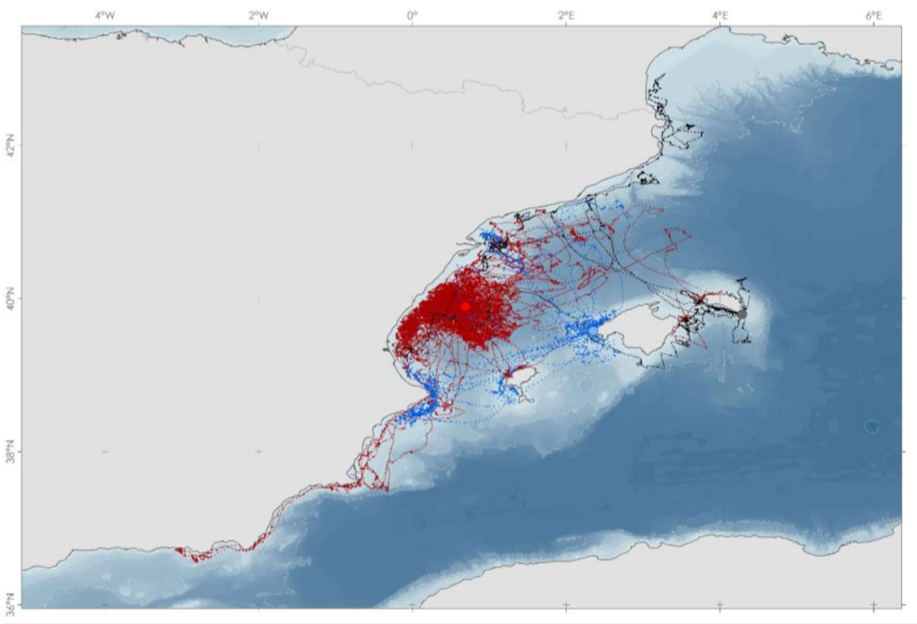
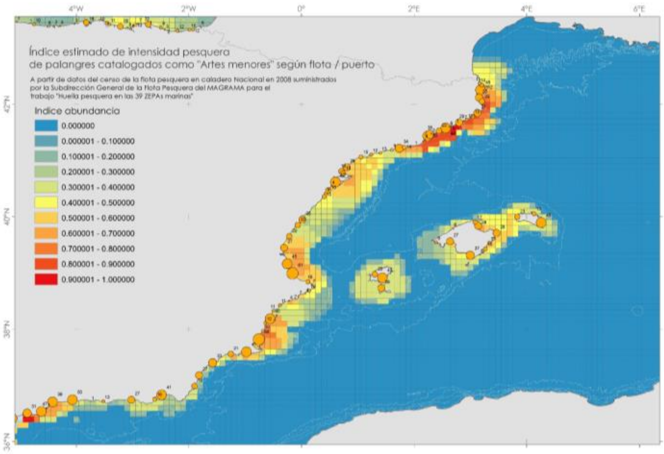


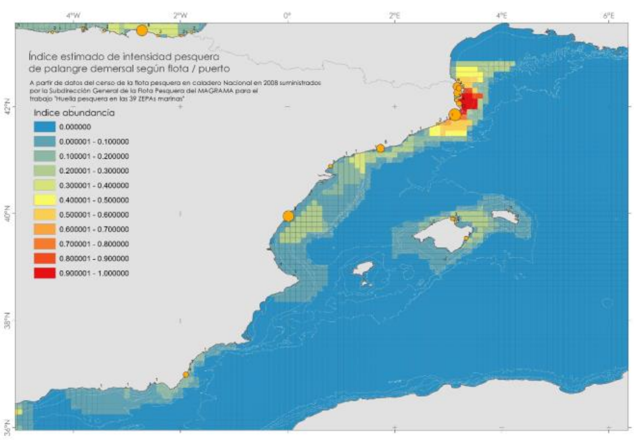

**Figure 7.** GPS data showing foraging trajectories during breeding of Cory's shearwaters breeding at Pantaleu (blue), I. de l'Aire (black) and Columbretes (red).

We the tried to summarize the distribution of the different fisheries gears that may cause bycatch in this specie (Bécares & Cama 2013) (Figure 8).

a)




b)



c)

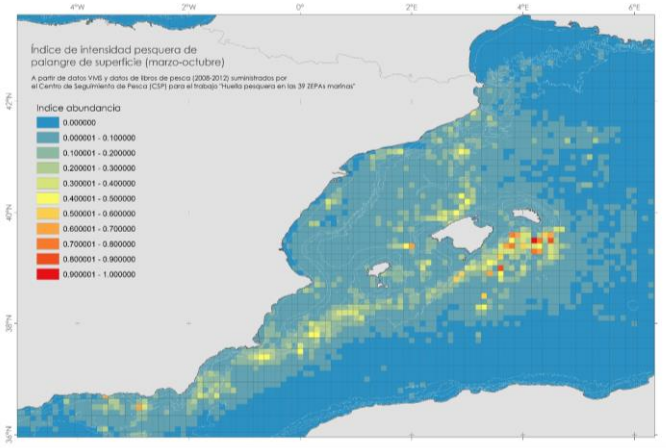



**Figure 8.** Abundance index of fisheries activity in the study area for different fisheries gears that may be causing bycatch in Cory's shearwater a) minor line b) bottom longliners and c) surface longliners. Activity index estimated for the months of March to October.

We then calculated an individual value that averaged the time spend under a bycatch risk.

Unexpectedly we did not find less bycatch risk for the individuals breeding at Illa de l'Aire showing higher survival probability than for individuals breeding at the other two colonies. On the contrary our results would show that individuals from Illa de l'Aire would be foraging in those areas with more bottom longline and minor line activity. These are preliminary results and should be taken with caution, also because they are based in a very small sample size, only 4 individuals from Illa de l'Aire, and 6 from Pantaleu islet (25 from Columbretes).

# 3. The importance of fishing discards in the ecology of seabirds

## 3.1. The Yellow-Legged gull *Larus michahellis*

Recent European policies on the ban of fishing discards but also on the closure of open-air landfills are expected to reduce predictable and abundant food resources for opportunistic seabirds. In order to forecast the consequences of this reduction on seabird breeding investment it is important to understand whether diverse anthropogenic foraging resources act synergically or not and whether their influence is mediated by density-dependent mechanisms. The yellow-legged gull *Larus michahellis*, is an opportunistic species widely distributed throughout the Mediterranean region that makes large use of fishing discards (Oro, Bosch & Ruiz 1995; Martínez-Abraín 2002; Cama *et al.* 2012) and open-air landfills (Duhem *et al.* 2003; Ramos *et al.* 2011; Jordi *et al.* 2014; Ramos *et al.*). These predictable and abundant food resources are thought to be responsible for the proliferation of yellow-legged gull populations. The relatively large population of yellow-legged gull during the last decades has raised conservation concerns to the point that several countries have undergone management actions to reduce its size (Bosch *et al.* 2000; Steigerwald *et al.* 2015). To assess these effects at large spatio-temporal scale, we measured mean egg volume as a proxy of breeding investment in ca. 5,000 three-egg clutches of the Yellow-legged gull from 20 colonies of the Western Mediterranean, located both along European and African coasts (Figure 9).

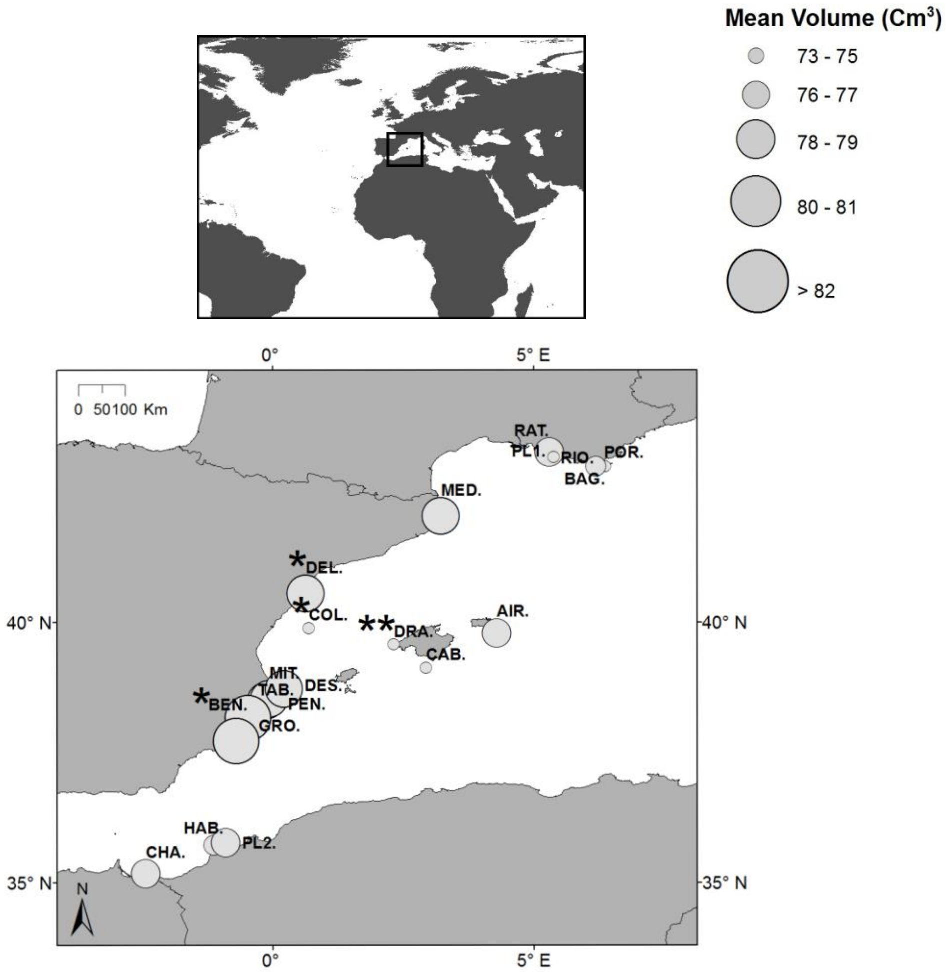



**Figure 9.** Study area with the distribution of the twenty Yellow-Legged Gull colonies throughout the Western Mediterranean where eggs were measured between 1992 and 2015. **AIR**: Aire, **BAG:** Bagaud, **BEN:** Benidorm, **CAB:** Cabrera, **CHA:** Chafarinas, **COL:** Columbretes, **DEL**: Delta, **DES:** Descubridor, **DRA:** Dragonera, **GRO:** Grossa, **HAB:** Habibas, **MED:** Medes, **MIT:** Mitjana, **PEN:** Penyal d'Ifach, **PL1:** Plane, **PL2:** Plana, **POR:** Porquerolles, **RAT:** Ratoneau-Pomegues, **RIO:** Riou, **TAB:** Tabarca. Circles represent the global mean egg volume per clutch for each colony. Colonies considered in the density-dependence analysis have been represented with an asterisk. Among these, those which were also subject to "no landfill" regime have been represented with double asterisk.

Egg volume varied among colonies with no relationship to latitude (r = -0.009; 95% CI: -0.036, 0.018; Figure 6). Moreover, egg volume was smaller in African colonies than in European ones ($F1/4962 = 23.75$; $P < 0.001$). We found that both horsepower and landfills had a positive effect on egg volume in European colonies (Figure 10).

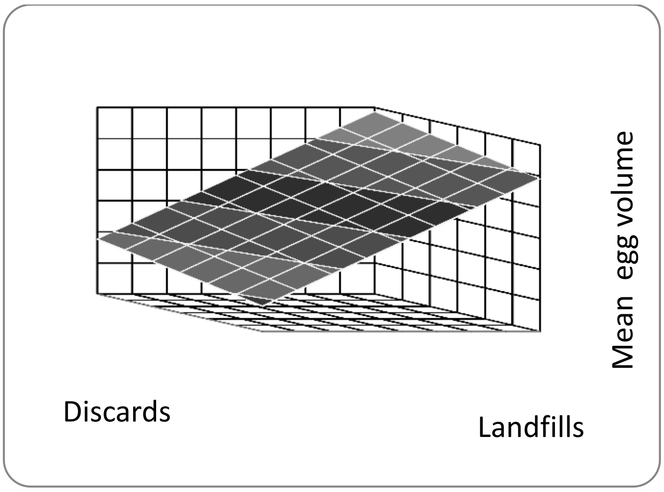



**Figure 10.** Mean egg volume as predicted by the retained model assuming an effect of trawl horsepower (as a proxy of trawling discards) and one of the number of landfills (as a proxy of refuse from open-air landfills) in 17 European colonies from the Western Mediterranean. Covariate values were scaled dividing by $1{\cdot}10^6$.

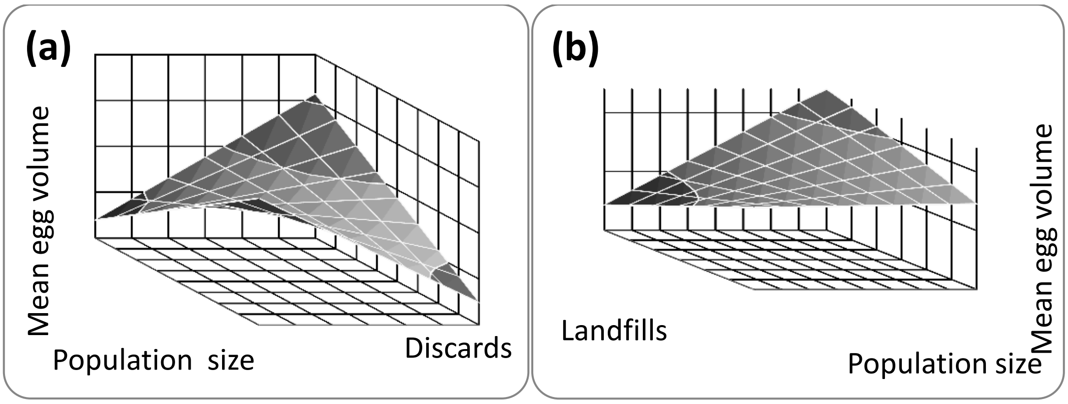



**Figure 11.** Regression surfaces of the influence of density-dependence on yellow-legged gull mean egg volume, where (a) represents the interaction between population size and horsepower (as a proxy of trawling discards) effects, and (b) represents the interaction between population size and landfill refuse effects. Data corresponds to four European colonies (Ebro Delta, Benidorm, Columbretes and Dragonera) from the Western Mediterranean (see methods).

However, the effect of waste from open-air landfills on Yellow-legged gull egg volume was much weaker than that from trawl fishing discards (Figures 10 and 11). We also show that trawling discards play a much more relevant role in European colonies than in African ones. On the other hand, the lack of effect of African landfills on egg volume could be explained by the fact that waste production per capita is much higher in the European countries considered in this study than in African ones.

## 3.2. The Balearic shearwater *Puffinus mauretanicus*

Sant Carles de la Ràpita harbour holds the bulk of the important trawling fleet operating off the Ebro Delta, where Balearic shearwaters often forage (Louzao *et al.* 2006). The species depended on trawling discards (Arcos & Oro 2002) and the amount of trawling discards and trawling landings are correlated (Oro & Ruiz 1997). We used the statistics of trawling landings at this harbour between March and June (i.e. encompassing most of the breeding cycle) as a proxy for inter-annual variability in food availability. Breeding success of monitored study nests was calculated between 1997–2004 and 2010–2013, as the number of fledglings by eggs laid, each season. We then used generalized linear models (GLM), with a logit link function and binomial error, to test for the potential association between our proxy of food availability and breeding success over the 12-year period. The intercept of this logistic regression function corresponded to the estimated breeding success in the absence of discards, and this value was used as the breeding success in the scenarios with discard banning.

Mean breeding success at Sa Cella colony (Mallorca island) was estimated at 0.665 (SE: 0.038), ranging from 0.400 to 0.920 fledglings per breeding pair. Breeding success for this species and colony was positively associated with trawling landings (z = 3.170, d.f. = 11, P = 0.001, Figure 12). The intercept of the logistic regression function corresponding to the estimated breeding success in the absence of discards was 0.433 fledglings per pair (SE = 0.137).

Also when assessing the population growth rate of this species under different scenarios in previous section we see that even if the most critical factor for the species to persist is bycatch rate, discards banning may aggravate the situation in the short term (Table 2 and Figure 2).

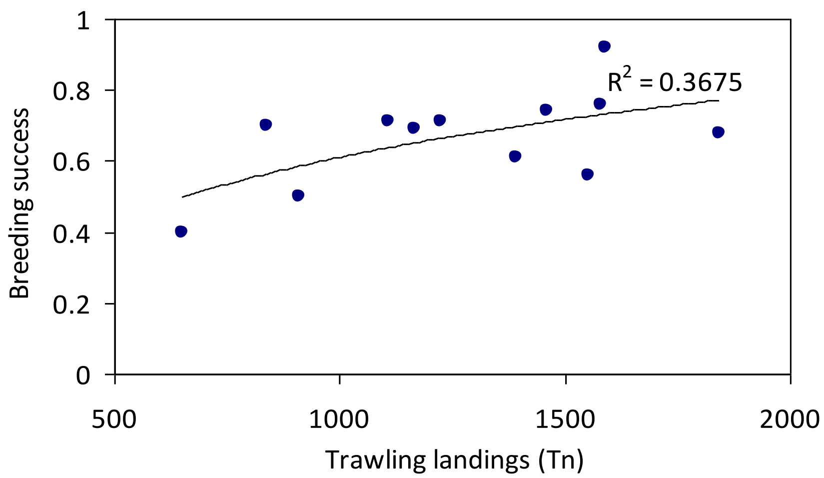



**Figure 12.** Relationship between Balearic shearwater breeding success (expressed as fledging per breeding pair) at the Sa Cella colony (Mallorca) and trawling landings in a fishing harbour working where the species is known to forage. Data correspond to a 12 year period (between 1997-2004 and 2010-2013), and modeling indicated that the association was statistically significant (see Results).

The imminent scenario arising from EU fishing policies poses both threats and opportunities for many seabirds, and especially for the critically endangered Balearic shearwater. The so-called "discard ban", if ultimately beneficial for the marine ecosystem, could bring negative effects for the Balearic shearwater in the short term (Bicknell *et al.* 2013). First, it could accelerate the decline of the species by reducing breeding success. Second, attendance and bycatch risk of shearwaters at longline vessels and other fleets may increase when trawlers do not operate (García-Barcelona *et al.* 2010; Laneri *et al.* 2010), so a discard ban might increase bycatch and thus extinction probabilities. In the long term, however, if the discard reduction is actually accompanied by efforts to increase selectivity and reduce fishing pressure, this should be regarded as a beneficial measure for the seabirds, as fish stocks (i.e. natural prey) are expected to recover.

## 3.3. The Cory's shearwater *Calonectris diomedea*

To assess the possible effects of discard availability in Cory's shearwaters in Pantaleu islet (an islet off the western coast of Mallorca Island in the Balearic archipelago), we analyzed annual breeding parameters in relation to Trawlers moratoria, when discards are not available. Trawlers moratoria within the foraging areas can potentially affect the species by decreasing available food resources and potentially affecting hatching success (if occurs during incubation) and/or fledgling success (if occurs during chick rearing).

The available information on the feeding areas of Cory's shearwaters breeding at Pantaleu Islet indicates that the main feeding areas are located in Nao cape between South Valencia and North of Alicante (Figure 13). Individuals also forage around the breeding colony in SW Mallorca and in the Ebro Delta area (Figure 13).

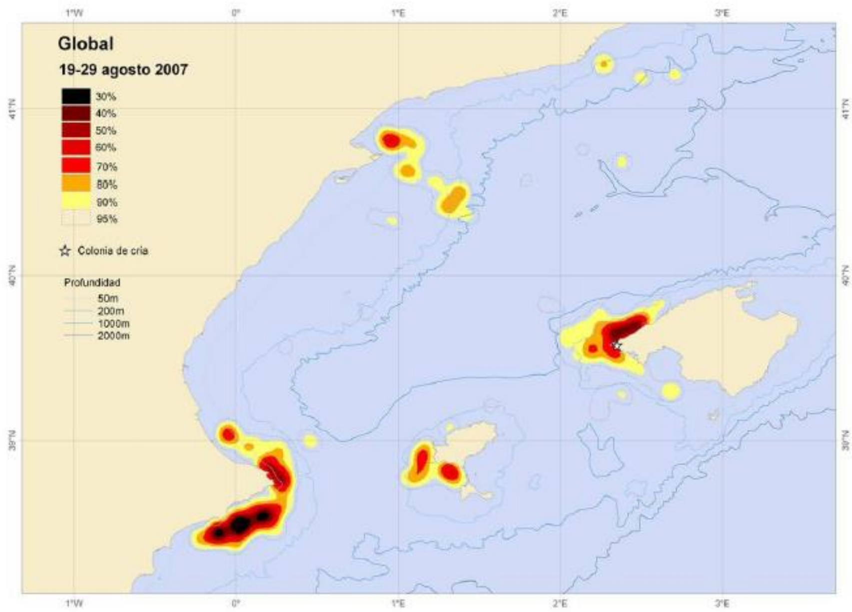



**Figure 13**. Foraging areas for Cory's shearwaters breeding at Pantaleu (August 2007).

Here we collected information on trawlers moratoria occurred in the Western Mediterranean since 2001 and tested their potential effects on hatching success, fledgling success and adult survival. No moratoria occurred in Balearic waters but see Tables 10 and 11 for details on Ebro Delta and Nao Cape.

| **Year** | **begining** | **end** | **period** | **months** |
|---|---|---|---|---|
| 2001 | 01/05/2001 | 30/06/2001 | laying/incubation | 2 |
| 2002 | 01/05/2002 | 30/06/2002 | laying/incubation | 2 |
| 2003 | 01/05/2003 | 30/06/2003 | laying/incubation | 2 |
| 2004 | 01/05/2004 | 30/06/2004 | laying/incubation | 2 |
| 2005 | 01/05/2005 | 30/06/2005 | laying/incubation | 2 |
| 2006 | 01/05/2006 | 30/06/2006 | laying/incubation | 2 |
| 2007 | 01/05/2007 | 30/06/2007 | laying/incubation | 2 |
| 2008 | 01/05/2008 | 30/06/2008 | laying/incubation | 2 |
| 2009 | 01/05/2009 | 30/06/2009 | laying/incubation | 2 |
| 2010 | 01/06/2010 | 30/06/2010 | incubation | 1 |
| 2011 | 01/05/2011 | 30/06/2011 | laying/incubation | 2 |
| 2012 | 01/05/2012 | 30/06/2012 | laying/incubation | 2 |
| 2013 | 01/05/2013 | 30/06/2013 | laying/incubation | 2 |
| 2014 | 01/05/2014 | 30/06/2014 | laying/incubation | 2 |
| 2015 | 01/05/2015 | 30/06/2015 | laying/incubation | 2 |

**Table 10**. Moratoria periods in Tarragona (not S of Ebro Delta).

| Year | Begining | end | period | Months |
|---|---|---|---|---|
| 2001 | 01/06/2001 | 01/07/2001 | incubation | 1 |
| 2002 | 01/06/2002 | 30/06/2002 | incubation | 1 |
| 2003 | 01/06/2003 | 30/06/2003 | incubation | 1 |
| 2004 | 01/09/2004 | 30/09/2004 | chick rearing | 1 |
| 2005 | 01/06/2005 | 30/06/2005 | incubation | 1 |
| 2006 | 01/09/2006 | 30/09/2006 | chick rearing | 1 |
| 2007 | 01/09/2007 | 30/09/2007 | chick rearing | 1 |
| 2008 | 15/09/2008 | 15/10/2008 | chick rearing | 1 |
| 2009 | 01/06/2009 | 30/06/2009 | incubation | 1 |
| 2010 | 01/09/2010 | 30/09/2010 | chick rearing | 1 |
| 2011 | 01/10/2011 | 31/10/2011 | chick rearing | 0.5* |

| | | | | |
|---|---|---|---|---|
| 2012 | 01/10/2012 | 31/10/2012 | chick rearing | 0.5* |
| 2013 | 01/10/2013 | 31/10/2013 | chick rearing | 0.5* |
| 2014 | no moratoria | no moratoria | | 0 |
| 2015 | no moratoria | no moratoria | | 0 |

**Table 11**. Moratoria periods in N Alicante and S Valencia (Nao cape).

*Assuming that shearwaters migrate out of Mediterranean in 15th October, moratoria from 15th October to 1st march were not considered.

As there was no temporal variability in moratoria period and duration in the Ebro Delta we only considered data on Nao cape moratoria. We tested the potential effect of spring moratoria on hatching success and of summer-fall moratoria on fledgling success by means of generalized linear models GLMs.

| Model | AIC | Dev | Np |
|---|---|---|---|
| Constant | 2733.5 | 2731.5 | 1 |
| Temporal | **2723.9** | 2693.9 | 2 |
| Trawling moratoria | 2733.8 | 2729.8 | 15 |

**Table 12. GLMs testing the effects of trawling moratoria on hatching success.**

| Model | AIC | Dev | Np |
|---|---|---|---|
| Constant | 957.3 | 955.3 | 1 |
| Temporal | **957** | 927 | 2 |
| Trawling moratoria | 958.9 | 954.9 | 15 |

**Table 13. GLMs testing the effects of trawling moratoria on fledgling success.**

We did not find any effect of the moratoria on breeding parameters (Tables 12-13).

# 4. The bycatch effect and the importance of fishing discards in the ecology of other marine top predators

As in the case of seabirds, competition for marine resources is not the only type of interaction between fisheries and other top predators (Gales, Hindell & Kirkwood 2003). Bycatch is also a source of additional mortality, with several species of sharks, rays, turtles and marine mammals getting entangled in the hauls and dying in fishing gears. This makes fisheries bycatch the most serious global threat to long-lived marine megafauna (Alverson 1994; Morizur *et al.* 1999; Gales *et al.* 2003; Read 2008; Wallace *et al.* 2013; Lewison *et al.* 2014; Oliver *et al.* 2015) (http://www.fao.org/docrep/003/T4890E/T4890E03.htm). Similar to seabirds, other top predators, such as marine mammals, may use discards as a predictable and easy food resource (Couperus 1994, Brotons 2012) but also the target and non-target fisheries species caught or trespassing the net, and this may constitute up to a 22% of their diet (Brotons 2012).

It is difficult to carry out the same detailed analysis that we carried on seabirds in other top-predators species. Seabirds offer us the opportunity to monitor them when breeding in land, while most mammals and all sharks in the Mediterranean do not breed in land, and in consequence: first it is almost impossible to access to their reproductive parameters and second is much more difficult their individual identification.

Even if most studies have been carried out outside the Mediterranean (Read, Drinker & Northridge 2006) the fisheries bycath of top-predators in the Mediterranean seems important (Reeves, McClellan & Werner 2013; Lewison *et al.* 2014) and evidences of this anthropogenic cause of mortality exist for all top predators groups: sharks (Carbonell *et al.* 2003; Abdulla 2004; Megalofonou 2005; Damalas & Vassilopoulou 2011), turtles (Margaritoulis *et al.* 2003; Alessandro & Antonello 2010; Casale 2011) and marine mammals (Bearzi *et al.* 2003; Tudela *et al.* 2005).

**Marine mammals**. Several studies show evidences of fisheries bycatch mortality for several species in the Mediterranean (Morizur *et al.* 1999; Tudela *et al.* 2005; Brotons *et al.* 2008; Cañadas & Hammond 2008; Fortuna *et al.* 2010). However most studies are local, focussing on limited area or fisheries. The species more affected are those more typical of the continental shelf as the bottlenose dolphin (*Tursiops truncatus*) and the short-beaked common dolphin (*Delphinus delphis*), whereas the most abundant marine mammal in the Mediterranean, the stripped dolphin *Stenella coeruleoalba* it is much less affected by bycatch, due to their pelagic distribution and its feeding habits, based largely on non-commercial prey species.

**Sea turtles**.

Incidental capture in fishing gears is probably one of the main threats to turtles in the Mediterranean. Most incidental catches occur in fisheries using longlines, towed nets and gillnets (ref). Most studies trying to estimate bycatch rates are local. A recent review of the impact of incidental catches in the Mediterranean estimate a minimum of 132000 incidental captures annually in the Mediterranean basin (Casale 2011), of these 57000 would occur in pelagic longlines, 39000 in fishing trawlers, 23000 in set nets and 13000 in demersal longlines. This would imply a minimum of 44000 deaths annually, the majority in small scale fisheries.

**Sharks, skates and rays**. Even if most species are not targeted by fisheries, they are frequently captured and either discarded or landed in land to be sold. Almost all species can be caught by both pelagic and bottom trawlers and at least 15 species of sharks and rays are reported to be caught by pelagic longlines (Bradai et al. 2012; Carbonell *et al.* 2003; Abdulla 2004; Megalofonou 2005; Damalas & Vassilopoulou 2011; Oliver *et al.* 2015; Gilman *et al.* 2016). Also gillnets may capture shark and ray species.

From a conservation point of view it seems clear that urgent mitigation measures should be taken to reduce the bycatch impact in marine top predators. Some previous studies on mitigation measures in the Mediterranean show that using circle instead of J-shaped hooks and fish instead of squid for bait, while benefitting sea turtles, odontocetes and possibly seabirds, but may exacerbate the catches of elasmobranches and injury, therefore warranting fishery-specific assessments to determine relative risks (Gilman *et al.* 2014). We also advise, even if sometimes highly demanding, setting up demographic long-term studies in marine top predators, to allow researchers to diagnose, with reliability, the status of the species and the effectiveness of management actions.

# 5. Resulting articles totally or partially funded by this project

## 5.1. Demography of the critically endangered Balearic shearwater: the impact of fisheries and time to extinction (published)

## 5.2. Varying demographic impacts of different fisheries on three Mediterranean seabird species (in press)

## 5.3. Consecutive cohort effects driven by density-dependence and climate influence early-life survival in a long-lived bird (published)

## 5.4. Colonization in social species: the importance of breeding experience for dispersal in overcoming information barriers (in press)

## 5.5. Predictable anthropogenic food subsidies, density-dependence and socio-economic factors influence breeding investment in an opportunistic seabird (under revision)

## 5.6. Non-lethal effects of density-independent perturbations may drive changes in age structure and reproductive value in populations: a seabird case study (under revision)

## 5.7. Different adult survival in three western Mediterranean colonies of a long lived species: are fisheries making the difference? (in preparation)

# 6. Aknowledgments

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