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# Significance of nocturnal purse seine fisheries for seabirds: a case study off the Ebro Delta (NW Mediterranean)

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**Abstract** Seabirds are known to make extensive use of fishery waste, a phenomenon that has been particularly well studied in relation to demersal fisheries, especially when operating during daylight hours. Contrarily, very little is known about the importance of predominantly nocturnal fisheries in providing feeding opportunities to seabirds. We considered the particular case of purse seining for small pelagic fish, which takes place basically at night, and assessed the significance of this fishing practice for seabirds off the Ebro Delta (NW Mediterranean). Fieldwork was conducted on board commercial purse seiners (nocturnal activity) in 1997–1998, and was complemented with observations performed on board both commercial bottom trawlers (diurnal activity; 1997–1998) and a research vessel (1999–2000). The purse seine fleet targets small clupeoids, which are attracted and concentrated by the light of a powerful lamp, and then captured using an encircling net. Purse seiners frequently changed fishing area, took very variable catches, and were strongly influenced by the weather. This made the fishery unattractive to most seabird species, which primarily attended purse seiners during the discarding process. This process took place on the way back to port after dawn (i.e. with daylight) during daylight and was quite irregular, thus attracting lower numbers of seabirds than did trawlers. The threatened Audouin's gull *Larus audouinii* was the only species attending purse seiners regularly at night, capturing live fish concentrated at the sea surface during the hauling process. This is in accordance with the specialisation of this gull in the capture of epipelagic fish at night, which seems facilitated by purse seiners. Indeed, the vessels would favour the direct capture of fish (illumination of the sea surface, concentration of the fish), as well as the location of the shoals (light signalling). The purse seining fishery was especially important for Audouin's gull during trawling moratoria (when trawling discards were not available) and in the non-breeding season. A simple bioenergetic model estimated that individual Audouin's gulls could obtain a mean of 669 kJ haul$^{-1}$, which would represent far more than half of the daily energy requirements of breeding birds. Provided that Audouin's gulls feeding in a given area could attend more than one haul in a short time, birds attending purse seiners at night could easily meet their energy requirements. However, there was strong variability in our estimate (from 0 to 1659 kJ bird$^{-1}$ haul$^{-1}$, 95% CI), and feeding at purse seiners would only sometimes be profitable for Audouin's gulls. Purse seine fisheries could be of importance for other nocturnal seabirds in other regions such as the SE Pacific, and this deserves further research. It is important to note that purse seiners could also be detrimental for many seabirds, through direct competition and eventual depletion of fish stocks.

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## Introduction

Seabirds interact in a variety of ways with human fisheries, as a consequence of exploiting the same or interconnected prey (e.g. Cairns 1992). These interactions can be either positive or negative for both seabirds and fisheries, depending on their nature (Duffy and Schneider 1994; Tasker et al. 2000). Among the interactions considered to be positive for seabirds, the consumption of fishery waste is

the most widely studied, and seems to play an important role in the feeding ecology of several seabird populations (e.g. Camphuysen and Garthe 1999; Oro 1999). This phenomenon has received special attention in relation with demersal fisheries (basically trawlers), which provide large amounts of discards and offal otherwise unavailable to the seabirds (e.g. Camphuysen et al. 1995). However, the role of other fisheries in providing feeding opportunities to seabirds has received less attention, as is the case for purse seiners (González-Solís et al. 1999). Furthermore, most studies on the consumption of fishery waste by seabirds have been performed under daylight conditions, with very few studies reporting on the association of seabirds with fishing vessels at night (Blaber and Wassenberg 1989; Garthe and Hüppop 1993, 1996), apart from studies of the incidental mortality of seabirds in long-line fisheries (cf. Tasker et al. 2000). In spite of the paucity of studies, many seabirds exhibit nocturnal activity to varying degrees (McNeil et al. 1993, and references therein), and several fisheries usually operate during the night. Hence, nocturnal fisheries could play an important role in the feeding ecology of some seabirds.

The present study examined the significance of pelagic purse seine fisheries (which usually target small shoaling fish at night) for seabirds, considering the particular case of the Ebro Delta region (NW Mediterranean). In this area recent research has shown the extensive use of trawling discards by many seabird species breeding nearby (Oro and Ruiz 1997; Arcos et al. 2001). Furthermore, the absence of discards caused by trawling moratoria strongly affected several biological parameters of species such as Audouin's gull *Larus audouinii*, the yellow-legged gull *Larus cachinnans*, and the lesser black-backed gull *Larus fuscus*, which demonstrates the importance of this extra food supply (see Oro 1999, and references therein). Contrarily, the purse seine fleet seems to play a minor role on the feeding ecology of seabirds breeding at the Ebro Delta, although the existing evidence is limited to indirect studies of daily activity and diet of breeding Audouin's gulls (Oro 1995 and Oro et al. 1997, respectively). These studies suggest that Audouin's gulls profit from purse seiners to a limited extent, and that this could be especially important during trawling moratoria. Indeed, Oro (1995) found a higher proportion of birds leaving their colony at sunset when trawlers did not operate, and this difference was slightly higher when purse seiners operated at night (vs. any fishing activity in the area). Similarly, the proportion of clupeoids in the diet of Audouin's gull was highest when purse seiners operated coinciding with trawling moratoria (73%), and this proportion decreased when no fisheries were operating (47%), thus suggesting that purse seiners facilitated the capture of clupeoids for this species (Oro et al. 1997). Nevertheless, there is no direct evidence of seabirds associating with purse seiners, either off the Ebro Delta or in other regions. Purse seiners are known to provide few discards (e.g. Oro 1995), and it is not clear how seabirds profit from these vessels. Here, we addressed this topic through fieldwork conducted on board a commercial purse seiner. The main goals of the study were:

1. To describe some features of the purse seine fishery relevant to understanding its significance for seabirds.
2. To ascertain how seabirds take advantage of purse seiners, as well as what seabird species are involved in our study area.
3. To assess the effect of some factors considered to potentially influence the association of seabirds with purse seiners, such as the fishing regime (trawling activity vs. trawling moratoria) and the season (breeding vs. non-breeding).
4. To assess the potential benefit that some seabirds obtain from purse seiners, through simple bioenergetic estimations.

Complementary observations were performed on board commercial bottom trawlers to compare the numbers of seabirds attracted by each fishery. Moreover, observations on the behaviour and efficiency of seabirds feeding at night in association with non-fishing vessels were used to make comparisons with those observed at purse seiners.

## Materials and methods

### Study area and commercial fisheries

The study was carried out at sea off the Ebro Delta (NW Mediterranean), between 39°55′N and 41°05′N latitude and 0°35′E and 1°30′E longitude (Fig. 1). The continental shelf off the Ebro Delta

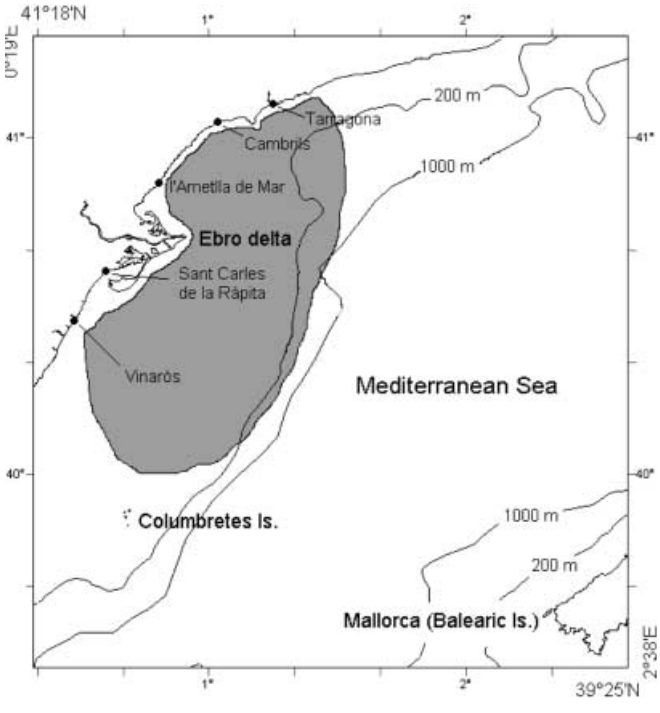


**Fig. 1.** Map of the study area (*in grey*), showing the most important fishing ports and geographical reference points. The 200 and 1000 m isobaths are also shown

is broad, extending up to 70 km offshore. This area is highly productive as a result of the Ebro River runoff and the influence of a shelf-slope front (Salat 1996). Given these features, the Ebro Delta region is considered one of the most important spawning areas for clupeoids in the western Mediterranean (Palomera 1992). It is therefore no coincidence that the area supports one of the most important seabird communities of the Mediterranean (Oro 1999), as well as very important fisheries within the context of this sea (Irzaola et al. 1996).

Two semi-industrial fishing fleets are of special importance in the study area: bottom trawlers and purse seiners (Irzaola et al. 1996; Pertierra and Lleonart 1996). The closest fishing ports to the area considered for study (Tarragona to Vinaròs; see Fig. 1) account for ca. 215 trawlers and 40 purse seiners. However, purse seiners may operate at long distances from their home ports; thus their number varies within the study area (from a few vessels when most of the local fleet is away from their ports of base, to up to 100 or more vessels when foreign vessels are present). The trawler fleet captures a wide variety of demersal and benthic fish and generates important amounts of discards; contrarily, the purse seine fleet is much more selective, targeting clupeoids and generating few discards (Pertierra and Lleonart 1996). Both fleets operate 5 days per week, with restricted timetables: trawlers by day and purse seiners by night (see Oro 1995). In addition, fishing moratoria are established for trawlers (in spring) and purse seiners (in winter) during 2 months each year.

## Collection and evaluation methods

Fieldwork was conducted during 29 one-day cruises on board a commercial purse seiner from l'Ametlla de Mar (see Fig. 1), from May 1997 to December 1998. We also considered data from 29 one-day cruises on board commercial bottom trawlers, carried out during the same period and in the same area (ports of l'Ametlla de Mar, Sant Carles de la Ràpita and Vinaròs; Fig. 1), to allow comparisons with the results obtained from purse seiners. Finally, we recorded observations of seabirds feeding at night attracted by the lights of a non-fishing vessel (R.V. "Cornide de Saavedra"), in spring 1999 and 2000.

During our cruises on board the purse seiner, we collected information concerning the fishing process and estimated the amount of fish discarded by counting the number of boxes of known average weight that were thrown overboard. In addition, fishermen allowed us to consult the vessel's notebook for the years 1997 and 1998, where we found valuable information concerning our vessel (captures, days of activity, etc.). This information was considered useful since it can reflect the performance of the whole fleet, given that environmental factors (weather, availability of fish) usually influence all vessels in the same way.

Seabirds were counted, and identified to the species level, at 15-min intervals during the fishing process of the purse seiner. These counts were classified with respect to different activities of the vessel: (1) attraction of fish to the sea surface, (2) encircling of the fish, (3) hauling of the seine and (4) discarding activity (separated from the haul, usually on the way back to port after sunrise). The maximum number of birds (i.e. the highest count) was recorded for each haul and activity, in order to make comparisons of the different uses of purse seiners by the different seabird species. For trawlers, only the maximum number of birds per haul is presented here.

Data on seabird numbers were treated regarding three different situations, with respect to the fishing regime (trawlers operating vs. trawling moratorium periods) and the season (breeding vs. non-breeding): (1) breeding season (March–July), trawlers operating; (2) breeding season, trawling moratorium; and (3) non-breeding season, trawlers operating. Trawling moratoria affecting all ports within the study area at the same time took place from 15 May to 30 June 1997 and from 1 60 30 June 1998. Other factors thought to potentially influence the attendance of seabirds at purse seiners were also considered for each haul: minimum distance to the coast and to the colony (Punta de la Banya, in the Ebro Delta), catches (kg), number of purse seiners in the same fishing aggregation and lunar phase (moonlight, including the three nights before and after the night of full moon, vs. other phases).

The efficiency of seabirds at capturing fish was assessed during the operation of hauling, when they picked up fish directly from the sea surface. Only Audouin's gull was considered here, since this was the only species regularly attending purse seiners at night. In order to do that, we recorded on tape the number of attempts to capture fish performed by Audouin's gulls at controlled intervals of time, relative to the number of individuals present at the vessel (attempts rate, $AR$, expressed as attempts per bird and minute). We also assessed the rate of success of these attempts ($SR$, percentage of successful vs. total attempts), which allowed obtaining the number of fish captured per individual and minute. Then, we estimated the total time that the gulls spent picking up fish from the sea surface ($T$, in min), and obtained the mean number of fish captured per seabird during each haul. A similar procedure was employed to assess the efficiency of Audouin's gulls capturing fish when attracted by the light of the research vessel, when no fishing activity was conducted. For purse seiners, we tried to estimate this efficiency in terms of energy, by building a simple model. We first estimated the mean representation of sardine and anchovy within the captures landed ($P_S$ and $P_A$, other prey were disregarded due to their scarcity), assuming that the fish landed by the vessels was representative of the fish available to (and captured by) the seabirds. These percentages were obtained in biomass, but were considered to be similar to those in number since anchovy and sardine presented very similar mean weights (see "Results"). After that, we estimated the mean weight of each of these fish species ($W_S$ and $W_A$), through analysing sub-samples of the captures landed by the vessel ($n = 10$ sub-samples, totalling 614 fish). We then transformed these data into an energetic value ($E_S$ and $E_A$, in kJ $g^{-1}$), considering data from lipid extractions conducted in the laboratory (Arcos 2001) and following Reynolds and Kunz (2001). Five samples were analysed for each fish species, each sample being the result of pooling and homogenising five fish of similar size. Considering an assimilation efficiency ($AE$) of 75% (Furness 1990), the energy obtained by each gull when attending a haul ($E_H$, in kJ $bird^{-1}$ $haul^{-1}$) was then calculated as:

$$E_H = T \times AR \times SR \times [(P_S \times W_S \times E_S) + (P_S \times W_S \times E_S)] \times AE$$

Given the variability of the parameters involved, we estimated a coefficient of variation (CV) of $E_H$ as a precision measure, using the Delta method (Stratoudakis 1999):

$$CV^2(E_H) = CV^2(T) + CV^2(AR) + CV^2(SR) + CV^2(P) + CV^2(W) + CV^2(E)$$

## Statistical analysis

Data were first tested for normality, using the Shapiro–Wilk test. When this assumption was violated, we either made the appropriate transformations (input data in the model) or used non-parametric statistics. Wilcoxon matched-pairs test (two samples) and Friedman two-way analysis of variance (three or more samples) were used to compare the numbers of seabirds associated to the vessel in different stages of the fishing process, given the interdependence of data. The effect of the different factors considered to potentially influence the attendance of seabirds at the vessel was assessed using either the Mann–Whitney $U$-test or the Spearman's rank correlation. The Bonferroni correction (Rice 1989) was considered when assessing the effect of these factors. Nevertheless, results were discussed without the restriction imposed by this correction, given that: (1) sample size was relatively small and (2) we employed the more restrictive two-tailed test in all cases, although for several factors we expected defined tendencies and the one-tailed test could have been employed. Other conventional tests were used when appropriate, following Zar (1996).

The significance level was held at 0.05, although marginal values were also discussed (see Stoehr 1999). Although consecutive

censuses of seabirds following fishing vessels may not accomplish independence of data, pseudoreplication was partially avoided by considering only one census (maximum number of seabirds) per haul and activity. Moreover, the vessel rarely performed more than one haul per night, and never more than two hauls when we were on board.

## Results

### Description of the purse seine fishery

Purse seiners targeted small shoaling fish, basically clupeoids, at night. The fishery operated over the whole continental shelf, except for depths $<30$ m and distances $<300$ m from the coast due to regulatory restrictions. The vessels tended to converge in areas where fishable aggregations occurred, with concentrations over 50 purse seiners often being observed. Fish were detected at first by means of acoustical methods (eco-sounder), although the concentration behaviour of the vessels also facilitated the detection of fishable shoals. The process of capture involved the main vessel and a small boat provided with a powerful lamp. Shoals were first attracted to the sea surface and concentrated around the boat by the light of the lamp. After that, the main vessel lowered the purse seine, encircling the fish gathered around the boat. The seine was then hauled, the whole process of capture lasting a median of 50 min (range 40–60 min, $n=23$ hauls). In most cases the vessel only performed one haul per night, this value ranging from 0 to 3 (mean $=0.81$, $n=340$ cruises). Since the process of locating, attracting and capturing fish took some time, most often hauls were performed shortly before dawn. The main prey types of the purse seine fishery were the sardine *Sardina pilchardus* (88.4% of the total catches by biomass, $n=340$ fishing days) and the anchovy *Engraulis encrasicholus* (10.8%). When the catches were completed, the vessel returned to port, usually after dawn (i.e. with daylight). At this stage, usually few discards (basically fish damaged during the hauling of the net) were thrown overboard (median $=15$ kg, interquartilic range 5–25 kg, $n=19$ operations). However, on a few occasions (15.8% of the observed cases, $n=19$), the vessel discarded large amounts of fish, up to an estimated 5600 kg. This was due to the capture of shoals of gilt sardine *Sardinella aurita*, a species with low economic value that was usually rejected.

A purse seining moratorium was established during 2 months each year in mid-winter (usually from mid-December to mid-February), coinciding with the recruitment period for the anchovy. During the rest of the year, catches of the purse seiner were found to be quite irregular (Fig. 2), and subject to weather conditions (Fig. 3). Indeed, the weather strongly influenced the capture of fish, since windy and rough-sea conditions made the process of encircling and hauling of the net difficult, if possible. Furthermore, fish probably stayed at greater depths during these conditions, making their capture even more difficult. Sometimes the cruise was aborted after a few hours of sailing, or directly remained at port, due to bad weather (Fig. 3). Under good weather conditions the vessels also returned without fish on some occasions (12%), probably due to several reasons (fish not concentrated enough, or not attracted by the lamp; capture of shoals of non-commercial species, such as gilt sardine; breakdown of either the vessel or the seine; etc.). Most often the whole fleet behaved in the same way, especially when it was affected by environmental factors (above all by the weather).

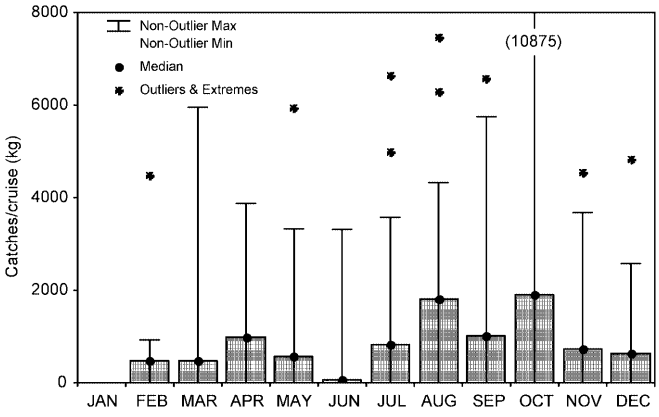


**Fig. 2.** Daily catches (median and range) by a single purse seiner off the Ebro Delta, in 1997 and 1998, separated by months. Only those days when the vessel operated were considered ($n=340$)

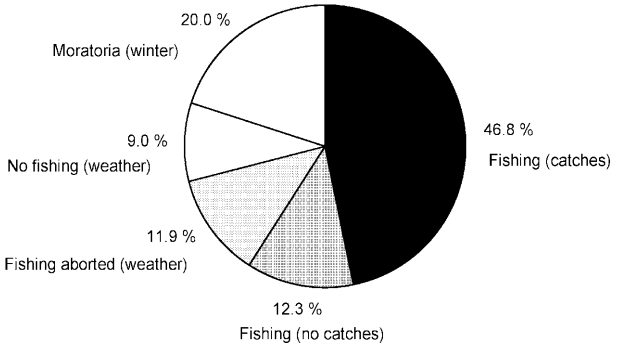


**Fig. 3.** Percentage of weekdays when the studied purse seiner: (1) operated with normality and landed some fish, (2) operated with normality and returned without fish, (3) operated but aborted the cruise due to bad weather, (4) did not operate due to bad weather and (5) did not operate due to a purse seine moratorium (mid-winter) during the study (information from 1997 and 1998; $n=479$ weekdays)

### Association between seabirds and purse seiners

Seabirds took advantage of purse seine vessels in two different ways: (1) direct capture of live fish concentrated near the surface by the light of the lamp and the encircling seine, during the night and (2) capture of discards, after dawn (i.e. with daylight). The first strategy was only important for Audouin's gull *Larus audouinii*, which was present in 91.3% of the hauls ($n=23$) and

accounted for 86.2% of the seabirds observed during this process. Contrarily, several species of seabirds regularly attended purse seiners during the discarding process, although in lower numbers than those observed at trawlers (Fig. 4).

The number of Audouin's gulls significantly varied in accordance with the activity of the vessel (Friedman test, $\chi^2_r = 33.2$, $P < 0.0001$; Fig. 5). The first gulls appeared when the lamp was turned on, thus starting to attract fish towards the sea surface. At this stage, which sometimes lasted $> 2$ h, prey density (usually juvenile fish and adults of a few pelagic species, mainly garpike, Belonidae) was usually very low near the surface, and Audouin's gulls only performed occasional captures (picking up fish by both surface seizing and surface plunging). In accordance with this situation, very few individuals attended the vessel during this period. The number of Audouin's gulls increased when the vessel started to encircle the boat with the purse seine, reaching their maximum during the operation of hauling. Only then, when the circle was completely closed and the fish were concentrated at a high density close to the sea surface, did Audouin's gulls start to pick up fish actively. This situation was observed in most, but not all, hauls (82.6% of the cases, $n = 23$), and lasted a median of 15 min (range 5–25 min) when it occurred. During the discarding process, usually separated in time from the last haul, the median number of Audouin's gulls was similar to that observed during the hauling of the net (Wilcoxon matched-pairs test, $T_{19} = 72$, $P = 0.56$).

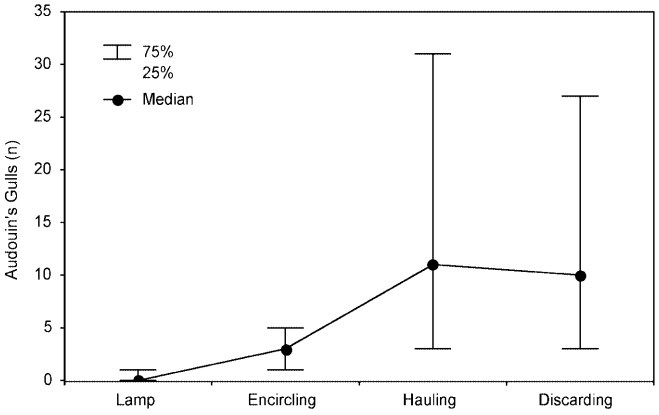


**Fig. 5.** *Larus audouinii*. Audouin's gull numbers (median and interquartilic range) in accordance with the activity of the purse seiner ($n = 18$ complete operations)

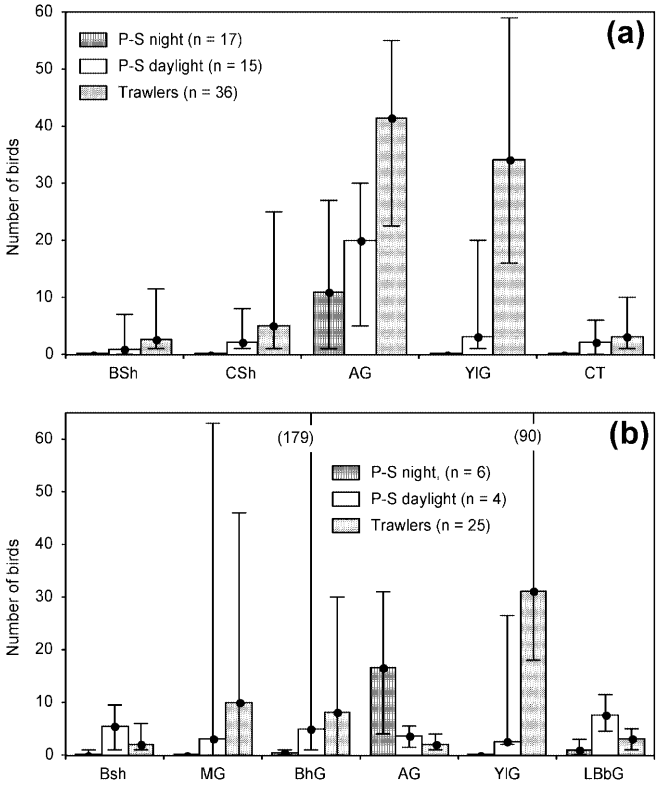


**Fig. 4a, b.** Numbers (median and interquartilic range) of the most common seabirds associated with fishing vessels: (1) purse seiners (*P-S*), hauling (nocturnal); (2) purse seiners, discarding (daylight); and (3) trawlers, discarding (daylight). Results are presented separately for the breeding (**a**) and the non-breeding seasons (**b**). Species considered: Balearic shearwater (*BSh*; *Puffinus mauretanicus*), Cory's shearwater (*CSh*; *Calonectris diomedea*), Audouin's gull (*AG*; *Larus audouinii*), the yellow-legged gull (*YlG*; *Larus cachinnans*), the black-headed gull (*BhG*; *Larus ridibundus*), the Mediterranean gull (*MG*; *Larus melanocephalus*), the lesser black-backed gull (*LBbG*; *Larus fuscus*), and the common tern (*CT*; *Sterna hirundo*)

## Factors influencing the attendance of seabirds at purse seiners

Of the factors considered to potentially influence the attendance of Audouin's gulls at purse seiners (Table 1), we found significant effects of the following: (1) fishing regime (higher numbers of gulls during trawling moratoria; Fig. 6), (2) season (higher numbers in the non-breeding season; Fig. 6), (3) number of vessels in the same area (more gulls as the number of vessels increases) and (4) distance to the coast (more gulls at longer distances). Neither the distance to the colony, the lunar phase, nor the amount of fish captured appeared to influence the number of Audouin's gulls attending purse seiners during the hauling process. If we apply the Bonferroni correction only the effect of the trawling moratorium is marginally significant ($P = 0.06$). However, sample size was relatively low ($n = 23$ hauls), and the effect of the season, the distance to the coast and the number of vessels in the area is probably important in determining the attendance of Audouin's gulls at purse seiners at night.

For the discarding period, we assessed the influence of the fishing regime (only considering the breeding season) on the number of the different seabird species attending the purse seiner. Audouin's gulls again were influenced by the trawling moratoria, being present in higher numbers at purse seiners when trawlers were not operating ($U_{8,7} = 4.0$, $P = 0.005$). The same tendency was true for Balearic shearwaters *Puffinus mauretanicus* ($U_{8,7} = 10.5$,

**Table 1.** *Larus audouinii*. Effect of the factors considered to potentially influence the attendance of Audouin's gulls at purse seiners during the hauling process ($n$ number of hauls; *n.s.* not significant; $U$ Mann–Whitney's $U$-test; $r_S$ Spearman's correlation coefficient)

| Factor | $n$ | Statistic | $P$ | Effect |
|---|---|---|---|---|
| Trawling moratorium[a] | 17 | $U_{9,8}=9.0$ | 0.009 | Higher numbers of Audouin's gull during trawling moratoria |
| Season[b] | 15 | $U_{9,6}=9.5$ | 0.039 | Higher numbers of Audouin's gull during the non-breeding season |
| Number of vessels | 23 | $r_S=0.51$ | 0.013 | Higher numbers of Audouin's gull with higher numbers of vessels |
| Distance to the coast | 23 | $r_S=0.51$ | 0.013 | Higher numbers of Audouin's gull at greater distances from the coast |
| Distance to the colony[a] | 17 | $r_S=0.40$ | 0.11 | n.s. |
| Catches | 23 | $r_S=0.17$ | 0.44 | n.s. |
| Lunar phase | 23 | $U_{15,8}=59.0$ | 0.94 | n.s. |

[a]Only those censuses performed during the breeding season were considered
[b]Only those censuses performed under comparable fishing regime (i.e. trawlers operating) were considered

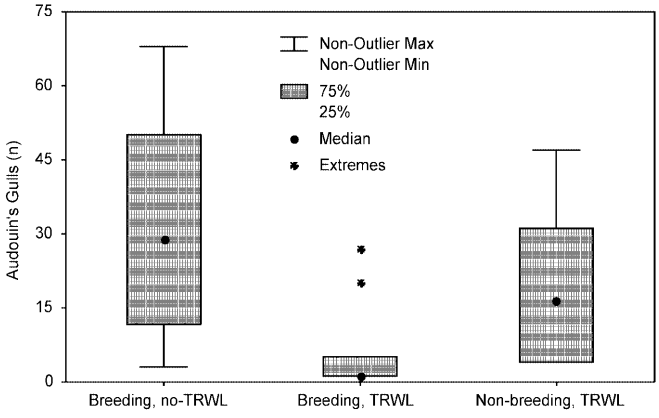


**Fig. 6.** *Larus audouinii*. Audouin's gull numbers associated with the purse seiner during the hauling activity, with respect to the season and the fishing regime: (1) breeding season, trawling moratorium ($n=8$); (2) breeding season, trawlers operating ($n=9$); and (3) non-breeding season, trawlers operating ($n=6$)

$P=0.04$), while Cory's shearwaters *Calonectris diomedea*, yellow-legged gulls *Larus cachinnans* and common terns *Sterna hirundo* did not show any significant differences in accordance with the fishing regime.

## Efficiency of Audouin's gull at capturing fish, and bioenergetic considerations

During the hauling of the seine, when most of the feeding activity of Audouin's gulls took place, we estimated that each gull captured a median of 0.18 fish min$^{-1}$ (Table 2). The type of fish captured at this stage did not apparently differ from that captured by the fishermen, which presented mean lengths ($\pm$SE) of 141.6 $\pm$ 9.8 mm in the case of the sardine ($n=515$) and 141.3 $\pm$ 11.9 mm in the case of the anchovy ($n=99$) (see weights in Table 3). In terms of energy, from the parameters shown in Table 3, we estimated that any single bird could obtain from 0 to 1658.6 kJ at each haul (95% confidence interval), with a mean value of 669.2 kJ.

The attendance of Audouin's gulls at non-fishing vessels, presumably attracted by illumination of the sea surface, was similar to that observed when the boat of the purse seiner turned on its lamp. In these cases, Audouin's gulls were observed to pick up mainly juvenile fish (roughly of 3–5 cm long in average), and sometimes adults of garpike and other pelagic species. On three occasions, during the spring, we observed significant numbers of Audouin's gulls, from 12 to 30 birds,

**Table 2.** *Larus audouinii*. Efficiency of Audouin's gulls at capturing fish in association with purse seiners (hauling process) and with non-fishing vessels (illumination of the sea surface). Number of hauls or observations ($n$) and total time spent observing the capture rate of gulls ($t$, in min) are also shown

| | $n$ | $t$ | Attempts bird$^{-1}$ min$^{-1}$ | | Success rate (%) | | Items min$^{-1}$ bird$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | | | Median | Range | Median | Range | Median | Range |
| Purse seiners | 19 | 86.8 | 0.38 | 0.06–1.69 | 66.7 | 31.3–100 | 0.18 | 0.03–1.60 |
| Non-fishing vessels | 3 | 19.4 | 0.17 | 0.04–1.33 | 62.5 | 0.0–63.0 | 0.10 | 0.00–0.84 |

**Table 3.** *Larus audouinii*. Specific input parameters used to estimate the energy obtained by individual Audouin's gulls at each haul of purse seiners (CV coefficient of variation, calculated from either absolute or transformed data; $n$ number of cases)

| | | $n$ | Mean | Transformation | CV (%) |
|---|---|---|---|---|---|
| Time of activity, $T$ (min) | | 23 | 12.07 | Logarithmic | 22.7 |
| Attempts rate, $AR$ (attempts bird$^{-1}$ min$^{-1}$) | | 18 | 49.1 | Square root | 22.5 |
| Success rate, $SR$ (%) | | 17 | 71.8 | Arcsine | 35.1 |
| Percentage, $P$ (%) | Sardine, $P_S$ | 232 | 92.7 | Arcsine | 37.0 |
| | Anchovy, $P_A$ | 232 | 7.3 | | |
| Weight, $W$ (g) | Sardine, $W_S$ | 515 | 21.59 | None | 23.4 |
| | Anchovy, $W_A$ | 99 | 18.67 | | |
| Energy, $E$ (kJ g$^{-1}$) | Sardine, $E_S$ | 5 | 10.03 | None | 22.9 |
| | Anchovy, $E_A$ | 5 | 6.67 | | |

when prey seemed to be in relatively high densities. In these situations Audouin's gulls approached the efficiency observed at purse seiners during the hauling process, with no significant differences when comparing the capture rate (items captured per bird and minute) in both situations ($U_{17,3} = 18.0$, $P = 0.43$; Table 2).

## Discussion

### Association between seabirds and purse seiners

Although seabird abundance and diversity are relatively high off the Ebro Delta at all times of the year (Oro 1999; Arcos 2001), few birds attended purse seiners during fish attraction and hauling (i.e. at night). This could partly be explained by the low adaptation to nocturnal foraging of most seabird species in the area. However, typically diurnal seabirds frequently attend nocturnal trawlers looking for discards in other regions, helped by the lights of these vessels (Blaber and Wassenberg 1989; Garthe and Hüppop 1993, 1996; though see García-Rodríguez 1972), thus suggesting that, in addition to their timetable, purse seiners present other disadvantages for most species. Firstly, the capture of fish when purse seiners are hauling requires certain flight skills and fishing specialisation, and this probably reduces the attraction of opportunist seabirds such as the yellow-legged gull *Larus cachinnans* (e.g. Arcos et al. 2001). Secondly, the purse seine fleet was quite mobile compared to the trawler fleet, and seabirds with restricted foraging ranges would have problems attending purse seiners when the fleet operated far away from the colony. Thirdly, fish captured by purse seiners (assumed to be the same available to the seabirds) do not present strong variation in size (as is the case for trawler discards), and could be too large to be suitable for small seabird species (cf. Oro and Ruiz 1997). Finally, purse seiners are strongly influenced by environmental conditions (mostly weather), and catches are consequently very irregular, the resource thus being relatively unpredictable for seabirds.

These disadvantages do not seem to apply to Audouin's gull *Larus audouinii*, which was the only species attending purse seiners during fish attraction and hauling. This agrees with the specialisation of this seabird in the capture of epipelagic and mesopelagic fish at night (Oro 1998), when these prey ascend to the sea surface following diel vertical migrations (Blaxter and Hunter 1982). The relatively large foraging range of Audouin's gull (Arcos and Oro 1996; Oro 1998) would facilitate the attendance at purse seiners at long distances from the colony, thus reducing the problem of the high mobility of the fleet. The size range of fish captured by purse seiners also seems suitable for Audouin's gulls (Arcos et al. 2001). Given these features, purse seiners could present some advantages to Audouin's gull. Firstly, the aggregation behaviour of the vessels and the use of powerful lamps would signal important concentrations of fish to the gulls. Secondly, the illumination of the sea surface seems to facilitate the detection of fish. Thirdly, the high concentration of fish near the surface, as a result of light attraction and net encircling, would facilitate capture of fish by gulls. Finally, the aggregation of vessels, usually hauling at different times, could also provide favourable feeding opportunities during substantial periods. The only other species in the study area with adaptations to nocturnal foraging is Cory's shearwater *Calonectris diomedea* (cf. Klomp and Furness 1992), which was frequently observed at night but rarely attended purse seiners during hauling. Differences in flight manoeuvrability and fishing strategies between Audouin's gull and Cory's shearwater could explain their different attendance at purse seiners at night. Nevertheless, purse seiners could still be advantageous to Cory's shearwaters in signalling concentrations of fish at long distances.

During the discarding process, conducted after dawn (i.e. with daylight), the number and diversity of seabirds attending purse seiners increased substantially. However, censuses at this stage showed lower numbers of birds than those attending trawlers. This was probably due to the unpredictability of the fishery, which was also reflected by the irregular and usually small amounts of discards. Off the Chafarinas Islands (western Mediterranean) purse seiners appear to be more predictable than trawlers, and the feeding ecology of the larids breeding in the archipelago (Audouin's and yellow-legged gulls) seems more influenced by the former (González-Solís et al. 1997, 1999). However, direct observations on board purse seiners are lacking, and it is not clear how seabirds profit from these vessels there.

### Factors influencing the attendance of seabirds at purse seiners

The fishing regime was the most important factor influencing the attendance of Audouin's gulls at purse seiners during hauling. Indeed, hauls conducted coinciding with trawling moratoria attracted significantly more gulls than those conducted when trawlers operated in the area. The same was true for the discarding process. This result suggests that most Audouin's gulls attended purse seiners as a buffering strategy to meet their energy requirements, especially when the most frequently used feeding resource (i.e. trawler discards) was not available in the study area (cf. Oro 1995; Oro et al. 1997; Arcos et al. 2001). The Balearic shearwater *Puffinus mauretanicus* could be in the same situation, since this species only occurred in meaningful numbers at purse seiners (discarding process) when trawlers were not operating. This suggests that the feeding ecology of this rare shearwater could be more influenced by discards than previously considered (see also Arcos and Oro 2002).

Audouin's gulls also associated with purse seiners in higher numbers at longer distances from the coast, in accordance with their more pelagic habits and relatively large foraging range (Arcos and Oro 1996; Oro 1998). The number of Audouin's gulls also increased in relation to the number of vessels aggregated. This might be because more vessels would increase the feeding opportunities for the gulls, and also would signal more important fish aggregations. Finally, seasonal differences were also clearly observed for Audouin's gull, with higher numbers at night during the non-breeding season (under the same conditions of the fishing regime). This result is of interest, especially considering that Audouin's gull is far scarcer in the study area during the non-breeding season (Oro 1998). Presumably, the low representation of Audouin's gulls compared to yellow-legged gulls could make it more difficult for the former to capture trawler discards, due to competition, making purse seiners comparatively more attractive at this time of year (cf. Arcos et al. 2001).

## Efficiency of Audouin's gull at capturing fish, and bioenergetic considerations

The field metabolic rate (FMR) of Audouin's gulls has been estimated at around 710 kJ $day^{-1}$, and this parameter would increase to slightly over 1000 kJ $day^{-1}$ for breeding adults (Ruiz et al. 2000). Therefore, our model estimate (mean of 669.2 kJ $bird^{-1}$ $haul^{-1}$) suggests that breeding Audouin's gulls attending a single haul of purse seiners would obtain, on average, more than half of their daily energy requirements. Considering that Audouin's gulls also picked up prey from time to time during the attraction of the fish, and presumably attended more than one vessel during the hauling process in a given fishing area, we suggest that individuals attending purse seiners could satisfy most of their daily energy requirements in this way. However, our estimate is subject to strong variability, which probably reflects the unpredictability of the fishery. Several data on the diet of focal breeding pairs suggest that some Audouin's gulls are more specialised than others in the capture of fish at night, thus attending purse seiners preferentially to trawlers (D. Oro, unpublished data). These birds could satisfy their energy requirements through fishing at night during most of the year (with the exception of adverse environmental conditions), which seems plausible according to our model.

Audouin's gulls were also observed to associate with non-fishing vessels at night, probably attracted by their lights. In these cases the vessels presumably only helped to detect fish, since they were sometimes steaming when the gulls turned up, thus precluding the attraction of fish to the surface. When fish density was high, Audouin's gulls associated with the non-fishing vessel approached the capture rate observed at purse seiners. However, the typical prey was juvenile fish of small size, thus making necessary the capture of a considerably higher number of fish in order to satisfy the daily energy requirements of the gulls. In situations of low prey density, and especially in the absence of any light to help, the situation would be even less suitable. Therefore, in spite of the presumed specialisation of Audouin's gull in the capture of epipelagic fish at night, the association with purse seiners seems to greatly improve its efficiency. Seabirds with better adaptations to foraging at night (basically better nocturnal vision), as may be the case with Cory's shearwater, could find it less advantageous to attend purse seiners, although the lights of these vessels could help them to locate important aggregations of fish at long distances.

## Nocturnal fisheries and seabirds: general considerations

Purse seine fisheries targeting small shoaling fish operate in several regions of the world, predominantly at night and using light attraction (e.g. Coello 1988; Camphuysen et al. 1995; Potier et al. 1997). Although the use of these fisheries by seabirds has been previously disregarded, it could be of special importance at least for some nocturnal species, as the present study demonstrates for Audouin's gull in the Mediterranean. For instance, the rare swallow-tailed gulls *Larus furcatus* and sooty gulls *Larus modestus* show strong nocturnal habits (McNeil et al. 1993) and could obtain a substantial profit by exploiting purse seiners, especially considering the important purse seine fisheries operating within their distributional range (central and SE Pacific; e.g. Coello 1988; Anonymous 1991; Hart 1995). However, purse seiners target the same prey as most seabirds do, the former being a much more important source of mortality for these prey (Furness and Tasker 2000; Furness 2002). Thus, purse seine fisheries could be favouring some seabird species at short term, by facilitating the capture of fish, but could exert a negative effect at long term through direct competition and the eventual depletion of the targeted fish stocks. Moreover, the powerful lights used to attract fish might cause direct mortality of seabirds by dazzling them and causing strikes, as has been recorded in connection with a lobster fishery off the Tristan da Cunha Islands (Ryan 1991), although this phenomenon was not observed during our study. Other fisheries that often operate at night are longliners, which are considered a threat to several seabird populations (see Tasker et al. 2000, and references therein). The mortality of seabirds entangled in longlines seems to be more important during daylight hours (e.g. Barnes et al. 1997; Belda and Sánchez 2001), but artificial lights also seem to increase the mortality of seabirds when these fisheries operate at night (Cherel et al. 1996). In the case of the western Mediterranean, the threatened Audouin's gull could be especially vulnerable to longline mortality at night, given the observed tendency of this gull to associate with vessels presenting artificial lights.

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