Sources of bycatch of loggerhead sea turtles in the western Mediterranean other than drifting longlines

Irene Álvarez de Quevedo, Luis Cardona, Andrea De Haro, Eva Pubill, and Alex Aguilar


A survey, including questionnaires to fishers and observers on board fishing vessels, was conducted to assess turtle bycatch in the waters off Catalonia (northeastern Spain), a region inhabited mainly by loggerhead sea turtles (Caretta caretta) from the highly endangered eastern Mediterranean rookeries. Observer reports confirmed that the data produced by the interviewees were reliable, so interview results were used to estimate turtle bycatch. The number of turtles caught monthly per vessel was estimated at 0.01 for bottom longlines, 0.02 for trammelnets, 0.07 for bottom trawling, and 1.2 for drifting longlines. From these values, 481 (95% CI: 472–491) turtles were estimated to be taken annually as bycatch by the whole fleet. Bottom trawling and trammelnets were the most widely used fishing gears (33 and 31% of the total 11 237 fishing months), but most turtles were caught either by bottom trawlers (249; 95% CI 83–415) or by drifting longlines (124; 95% CI: 40–199). Ivlev’s electivity index revealed that bottom trawler bycatch was higher than expected in areas with a wide continental shelf. Given the heavy turtle mortality associated with bottom trawling and the fact that, in southern Catalonia, the fleet mainly takes turtles from western Mediterranean rookeries, it is suggested that the fishery be regulated through winter fishing restrictions, reducing the number of bottom trawlers working in the area, reducing the time the net is in the water to prevent turtle suffocation, or being obliged to use turtle excluder devices.

Keywords: bottom trawling, drifting longlines, incidental bycatch, marine turtles, Mediterranean Sea.

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Introduction

The loggerhead turtle (Caretta caretta) is the most common sea turtle in the western Mediterranean Sea (Broderick et al., 2002), an area where individuals from rookeries located in both the eastern Mediterranean and the northwestern Atlantic coexist (Laurent et al., 1993, 1998; Casale et al., 1998; Carreras et al., 2006). Juveniles from the Atlantic stock mainly use the feeding grounds in the southwestern Mediterranean, whereas Mediterranean-origin turtles use the feeding grounds along the European shore of the western Mediterranean, north to Cape la Nao. This heterogeneous distribution results in a marked genetic structuring at the foraging grounds (Carreras et al., 2006).

The turtle stock nesting in the eastern Mediterranean is smaller than that nesting in the Atlantic (Ehrhart and Ogren, 2000; Margaritoulis et al., 2003), and it has declined dramatically as a consequence of incidental catch in fisheries, egg harvest, and tourism developments that encroach on the coastal environment (Margaritoulis et al., 2003). However, despite the threats to the breeding areas, demographic studies have shown that, in loggerhead turtles, the loss of adults and juveniles larger than 30 cm (straight carapace length) has a more dramatic impact on populations than the loss of younger turtles (eggs, hatchlings, and younger juveniles; Crouse et al., 1987; NRC, 1990). Boat collisions, ingestion of debris, and chemical pollution have been identified as threats for that segment of the population (Lutcavage et al., 1997; Margaritoulis et al., 2003), but interaction with fisheries is probably the main threat for the species in the Mediterranean, where several thousand immature turtles are caught incidentally every year (Aguilar et al., 1995; Carreras et al., 2004; Casale et al., 2007).

Driftnets (Godley et al., 1998; Silvani et al., 1999; Tudela et al., 2003), drifting longlines (Camiñas, 1988; Aguilar et al., 1995; Camiñas and Valeiras, 2001), bottom trawling (Bertolero, 2003; Casale et al., 2004), and trammelnets (Godley et al., 1998; Carreras et al., 2004) have been reported as catching sea turtles in the region, but reliable information on the relative contribution of each fishing gear to the total bycatch is unclear. Questionnaire-based surveys by Báez et al. (2006) revealed that most of the bycatch of sea turtles in southern Spain was attributable to drifting longlines, and longlines were involved in 28% of the turtle strandings in central-eastern mainland Spain during the past decade (Tomás et al., 2008). Trammelnets are a significant source of bycatch in southern Turkey, northern Cyprus, and the Balearic Archipelago (Godley et al., 1998; Carreras et al., 2004), and high levels of sea turtle bycatch by bottom trawlers have been reported for some regions in the eastern Mediterranean (Casale et al., 2004). Differences between areas are likely the result of dissimilarities in the composition of the local fishing fleets and their operations, for which any strategy for reducing
bycatch in the Mediterranean would require a multi-gear approach. The relevance of gillnets and other often-neglected fishing gear is probably higher in the eastern and northern Mediterranean than in the south because of the widespread use of such gear in the former areas, as well as the fact that the turtles inhabiting those regions originate mainly from the comparatively small eastern Mediterranean rookeries (Carreras et al., 2006) and make much use of the shelf waters (Cardona et al., 2009).

In this context, this study, conducted among fishers operating off northeastern Spain, sought to (i) assess the relevance of different fishing gear to loggerhead sea turtle bycatch, and (ii) estimate the total number of turtles that are caught and killed annually by each gear. From this information, management regulations are suggested.

Material and methods
We carried out our study along the coast of Catalonia (northeastern Spain), and given the difference in the behaviour of the fishing fleet between harbours and regions, we stratified the study area to provide more realistic estimates. We subdivided the study area into nine subareas (Figure 1) according to their depth profile, geographic orientation, and topography. We collected information from interviews with professional fishers, and to validate the reliability of their responses, we recorded the results of fishing sets directly by placing observers on board fishing vessels.

Interviews
We conducted the survey during July and August 2004 and June and July 2005, but the questions we asked referred to turtle bycatch and fishing sets in the period between June 2003 and July 2004. The survey was conducted at all Catalanian fishing harbours and was stratified in accordance with the information supplied by the Fisheries Office of Catalonia (Direcció General de Pesca i Afers Maritims de la Generalitat de Catalunya), which registers all professional fishing vessels based in the region and classifies them into five categories according to the main fishing gear they use: bottom trawlers, drifting longliners, bottom longliners, purse-seiners, and artisanal boats. The latter category includes boats using traps, whelk dredges, gillnets, pots, and trammel nets, and other gears. We interviewed fishers from at least 20% of the vessels in each port using each type of gear operational during 2003 and 2004 (Table 1). The study unit was the vessel, so just one fisher, generally the captain, was interviewed from each vessel. Only questionnaires fully responded to were considered for further analysis.

The questionnaire was designed by CIREM (Centre d’Iniciatives i Recerca Europees al Mediterrani) for the specific use of this study, and it included 41 questions (a combination of open and closed questions) concerning fishing sets carried out by the vessel during the period June 2003–July 2004, as well as any turtle bycatch. The main questions were:

(i) Which subareas from Figure 1 did you visit during the period June 2003–July 2004?
Table 1. Catalonian fishing fleet split by fishing gear, detailing survey coverage (as number of vessels per fishing gear).

<table>
<thead>
<tr>
<th>Fishing vessel</th>
<th>Fishers interviewed</th>
<th>Registered fishing vessels</th>
<th>Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom trawlers</td>
<td>76</td>
<td>336</td>
<td>22.6</td>
</tr>
<tr>
<td>Purse-seiners</td>
<td>20</td>
<td>115</td>
<td>17.4</td>
</tr>
<tr>
<td>Drifting longliners</td>
<td>9</td>
<td>18</td>
<td>50.9</td>
</tr>
<tr>
<td>Bottom longliners</td>
<td>30</td>
<td>55</td>
<td>54.5</td>
</tr>
<tr>
<td>Artisanal boats</td>
<td>100</td>
<td>483</td>
<td>20.7</td>
</tr>
<tr>
<td>All vessels</td>
<td>235</td>
<td>1 007</td>
<td>23.3</td>
</tr>
</tbody>
</table>

(ii) Monthly, which grounds did you use in this period?

(iii) Monthly, which gear did you use?

(iv) In your opinion, what is the status of the turtle population (declining, stable, or increasing)? If declining, what are the causes (open answer)?

(v) When do you think turtles are more often observed and caught, monthly?

(vi) How many turtles did you catch accidentally during the period June 2003–July 2004 (open answer)? In which months did this occur? What type of fishing gear was involved? Were the turtles released dead or alive?

A copy of the full questionnaire is available on request from the authors.

Based on the responses of the fishers, we estimated the total annual turtle bycatch of loggerhead sea turtles in the study area as well as the fishing effort of the fishing fleet. Fishers identified loggerhead as the most common turtle they caught, but they also knew leatherbacks. Other species of sea turtle are extremely rare in the area (Bertolero, 2003).

Fishing effort

A boat’s fishing effort was defined as the number of months during which it operated from June 2003 to July 2004. When the vessel visited more than one subarea (Figure 1) in the same month, the effort was assumed to be distributed evenly between subareas visited. When a vessel used several fishing gears in the same period, effort was divided by the number of subareas visited.

Total fishing effort with gear \( a \) in subarea \( z \) \( (E_{za}) \) was therefore

\[
E_{za} = \sum_{i=1}^{n_{zai}} E_{zai},
\]

where \( E_{zai} \) is the effort supported by subarea \( z \) from vessels in the \( i \)th harbour operating with gear \( a \). Consequently, \( E_{zai} \) was calculated as

\[
E_{zai} = E_{za} \frac{n_{zi}}{n_{zi}},
\]

where \( E_{za} \) is the effort reported by the fishers interviewed from harbour \( i \) operating in subarea \( z \) with gear \( a \), \( n_{zi} \) the number of registered vessels with a base in harbour \( i \) that used gear \( a \), and

\( C_{zai} \) the number of vessels from harbour \( i \) that used gear \( a \) and whose captain had been interviewed.

Turtle bycatch

Total turtle bycatch in subarea \( z \) with gear \( a \) \( (C_{zai}) \) was

\[
C_{zai} = C_{za} \frac{E_{za}}{E_{zai}}
\]

where \( C_{za} \) is the number of turtles that fishers reported to have caught in subarea \( z \) with gear \( a \), \( E_{za} \) the total fishing effort with gear \( a \) in subarea \( z \), and \( E_{zai} \) is the effort reported by fishers in subarea \( z \) with gear \( a \).

Finally, we calculated the catch per unit effort (cpue) as the number of turtles caught per vessel and fishing month, per fishing gear and subarea, from

\[
cpue = \frac{C_{zai}}{E_{zai}}.
\]

Observations on board

Loggerhead turtles are protected in the study area and it was feared that fishers might understate the frequency and the number of incidental catches. To validate the cpue calculated from the questionnaires, therefore, we placed scientific observers on board fishing vessels and compared the catch data recorded by the observers with those reported by fishers for the same subareas.

For each vessel, observers recorded the number of fishing sets and total fishing days surveyed, the geographic position of each fishing operation, and the number, if any, of turtles taken incidentally, along with their physical condition (healthy, injured, comatose, or dead).

Statistics

A Chi-squared test (Cuadras, 1983) was used to check whether the turtle bycatch was distributed similarly to fishing effort in the subareas. When differences were statistically significant, Ivlev’s (1961) electivity index \( (I) \) was calculated to identify the areas where turtle bycatch was higher or lower than expected:

\[
I = \left( \frac{p_t - p_e}{p_t + p_e} \right).
\]

where \( p_t \) is the percentage of turtles caught in a given area, and \( p_e \) the percentage of turtles expected to be caught according to the fishing effort displayed there.

Confidence intervals were calculated following Strauss (1979):

\[
E_e = \left[ \left( 2 - \frac{2p_e}{p_t + p_e} \right) + 1 \right] \pm 1.96 \times \frac{1}{\sqrt{2n_t p_t(1-p_t)(p_t + p_e)^2 + p_t(1-p_t)n_t p_e + \left( \frac{(1-p_t)}{n_t} \times \frac{(1-p_e)}{n_e} \right)^2}} - 1,
\]

where \( n_t \) is the number of turtles, and \( n_e \) the total number of subareas. The 95% confidence intervals of estimated turtle catch associated with each fishing gear for the whole region (\( \Sigma C_{zai} \))
were calculated using the procedure detailed by Greenwood (1996) for stratified sampling.

The average numbers of fishing sets per month and vessel were used to transform the cpue (turtles caught per fishing operation) reported by on-board observers to the unit used in the fisher questionnaires (turtles caught per month and vessel). Bootstrapping was used to calculate the 95% confidence interval of the cpue because the data were not normally distributed.

Results

We interviewed fishers from 235 vessels, representing 23.3% of the Catalonian fishing fleet (1007 vessels). When categorized by fishing gear, >20% of each gear type was covered (Table 1), except for the purse-seiners, which proved difficult to interview given that they operated at night and tended to be laid up by day. In all, 69% of fishers felt that the abundance of sea turtles was declining and, from these, 45% considered fishing at least partially responsible. Moreover, 22% recognized themselves as being responsible for turtle bycatch, although there was substantial variation in this response between fishing gears and subareas.

Fishing effort

Bottom trawling and trammelnets were the most used fishing gears according to survey respondents (33.67 and 31.58% of total effort, respectively; Table 2). However, effort was distributed unevenly between subareas (Table 3), with bottom longlines and purse-seines the only gear used in all subareas. Bottom trawling and trammelnets were used in all coastal subareas, excluding subarea 9 (Figure 1), which covers deeper water in the western Mediterranean.

Turtle bycatch

As a result of the data on fishing effort (Table 2) and the turtle bycatch reported by respondents, we were able to calculate that some 481 turtles (95% CI: 472–491) were caught annually by the whole fleet (Table 3). Seven fishing gears were responsible for this incidental catch, but the largest share was that of bottom trawlers (249 turtles; 51.5% of the total catch) and drifting longlines (124 turtles; 25.7% of the total catch; Table 3). However, the distribution of turtle bycatch between subareas differed significantly from what would be expected based on the distribution of the fishing effort of bottom trawling (χ² = 238.351; d.f. = 7; p < 0.001), drifting longlines (χ² = 108.516; d.f. = 1; p < 0.001), and trammelnets (χ² = 15.478; d.f. = 7; p = 0.009). Hence, Ivlev’s electivity index revealed that turtle vulnerability to bottom trawling and trammelnets was much higher in subareas 1 and 2 (Figure 1) and that vulnerability decreased northwards (Figure 2).

Furthermore, turtle bycatch differed significantly between seasons (χ² = 106.533; d.f. = 3; p < 0.001; Figure 3). Therefore, the estimated bycatch based on survey responses was much higher during summer (July–September; n = 87, nₑ = 156), when drifting longlines operated, than in any other season. Conversely, fishers on bottom trawlers declared a significantly greater bycatch in winter (n = 32) than in any other season (χ² = 53.833, d.f. = 3, p < 0.001). Seasonality could not be assessed for the other fishing gear, because the number of sea turtles taken was too small to allow statistical testing.

According to the responses of fishers, immediate mortality (i.e. the proportion of turtles found as a result of drowning or injury) was only caused by two types of fishing gear: bottom trawling and drifting longlines.
Table 3. Estimated number of turtles taken incidentally per vessel (cpue) during the period covered by the survey (June 2003–July 2004) according to fisher responses, and the estimated total catch of turtles taken (C_m) in the western Mediterranean by fishing vessels based in northeastern Spanish ports.

<table>
<thead>
<tr>
<th>Subarea*</th>
<th>Bottom trawling (0.066)</th>
<th>Purse-seines (0.003)</th>
<th>Drifting longlines (1.151)</th>
<th>Bottom longlines (0.014)</th>
<th>Traps (0.010)</th>
<th>Whelk drags (0.063)</th>
<th>Gillnets and trammelnets (0.019)</th>
<th>Total catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>0</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>193</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>14</td>
<td>10</td>
<td>228</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>–</td>
<td>0</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>18</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>–</td>
<td>0</td>
<td>120</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>120</td>
</tr>
<tr>
<td>Total catch</td>
<td>249 (83–415)</td>
<td>4 (3–5)</td>
<td>124 (49–199)</td>
<td>11 (1–21)</td>
<td>5 (0–16)</td>
<td>21 (0–66)</td>
<td>67 (33–101)</td>
<td>481 (472–490)</td>
</tr>
</tbody>
</table>

*See Figure 1.

However, unless many fishing sets are surveyed on board by observers, the surveys usually fail to detect catches made at low frequency. In such a situation, questionnaire-based surveys provide the most practical and reliable method to assess catches (Godley et al., 1998), although the resulting data may be poor or biased if the study is poorly designed or executed. As a result, such surveys are considered unreliable by some, but are used to gain a first insight into the problem or to identify potentially conflicting scenarios or gear (Lien et al., 1994). Fisher answers have to be reliable for questionnaire-based surveys to be valid, because fishers may either have a poor memory for bycatch size (Lien et al., 1994) or simply lie. Fortunately, fisher answers can be validated through data collected directly by observers aboard fishing vessels. Using this approach, in a study similar to the present one, Carreras et al. (2004) concluded that answers given by fishers operating off the Balearic Archipelago were credible. The same appears to be true for the answers obtained here from fishers off northeastern Spain. Therefore, we believe that the bycatch estimates derived from interviews are reliable and at least relatively accurate.

From these results, we found that drifting longlines and bottom trawling were the two most significant fishing gears causing loggerhead sea turtle bycatch in the study area. Drifting longlines had already been identified two decades ago as a threat to sea turtles in the western Mediterranean, and recent surveys estimate bycatch at 15 000 sea turtles (Camiñas, 1988; Mayol et al., 1988; Aguilar et al., 1995). Casale et al. (2004) reported high levels of sea turtle bycatch by bottom trawlers in the Adriatic Sea (eastern Mediterranean), but any evidence at all off northeastern Spain was scarce, and the potential bycatch there has never been quantified (Bertolero, 2003). Indeed, Carreras et al. (2004) and Baez et al. (2006) reported extremely low rates of sea turtle bycatch by bottom trawlers off the nearby Balearic Archipelago and southern Spain, respectively, and it was generally assumed that bottom trawls had a negligible impact on sea turtles. The difference between the results of our survey and those from other areas is likely attributable to dissimilarities in the fishing strategies of bottom trawlers or to variable rates of overlap between sea turtle distribution and bottom trawling.
Typically, off the Balearic Archipelago and most of northeastern Spain, bottom trawlers operate on the deeper side of the continental shelf and the upper slope (Bas et al., 2003; Massuti and Reñones, 2005). However, where the continental shelf is wide and the upper slope too far from the home port to be reached on a daily trip, trawlers are forced to restrict their activity to the shelf (Bas et al., 2003). This is the situation along the coast of central mainland Spain, where the width of the continental shelf is at its maximum, and it is precisely the area where the highest level of turtle bycatch was observed in the present study. Loggerhead sea turtles usually remain shallower than 200 m (Lutcavage and Lutz, 1997; Houghton et al., 2002), and are

Figure 2. Vulnerability of loggerhead turtles to being caught incidentally in different subareas off Catalonia (NE Spain), as revealed by Ivlev’s electivity index. The numbers along the x-axes refer to the subareas, as defined in Figure 1. Vertical lines show the 95% confidence intervals.
much more vulnerable to bottom trawlers operating on the continental shelf than to those operating on the upper slope. As a consequence, the average rate at which loggerhead sea turtles are taken incidentally increases dramatically in those areas where the trawler fleet operates mainly on the continental shelf, as off central mainland Spain (this study) and in the Adriatic Sea (Casale et al., 2004).

Conversely, average loggerhead sea turtle bycatch in trawls remains low where most of the fleet operate on the upper slope, as off northern mainland Spain (this study) and off the Balearic Archipelago (Carreras et al., 2004).

Identifying the fishing gear contributing to turtle bycatch is just a first step in understanding the extent of the problem. Current removals from the population can only be assessed effectively if post-release mortality is known. Fisher responses and on-board observations coincided in this respect in that most of the turtles entangled in bottom trawls were found alive but moribund, whereas those hooked in drifting longlines were generally released with the hook, but always still alive. Casale et al. (2004) reported comparable results for the Adriatic Sea: just 9.4% of the turtles taken incidentally by bottom trawlers were dead, but the rate of potential mortality was estimated to be as high as 43.8% if all comatose turtles died after release. The rate of post-release mortality for turtles hooked by drifting longlines has been suggested to be about half (Aguilar et al., 1995; NMFS–SEFSC, 2001), although the actual figure may be much lower (Chaloupka et al., 2004). Therefore, as a consequence of the high bycatch rate and the heavy mortality on capture, bottom trawling appears to be the most destructive means of marine turtle removals off northeastern Spain.

Our survey showed that bottom trawlers take turtles all year-round, but with a possible peak in winter. Aerial surveys covering the southern part of the study area have shown that turtles are there all year-round, with no apparent seasonality in abundance (Gómez de Segura et al., 2003, 2006), but satellite tracking has revealed that at least some turtles leave the area and move south in winter (Cardona et al., 2009). These data would indicate that the apparent peak in cpue during winter might be a sampling artefact or, if real, is not caused by a higher density of turtles in the area but because of a greater vulnerability of turtles to bottom trawlers then as a result of the lower temperature of the seawater (Casale et al., 2004; Braun-McNeill et al., 2008). This is because loggerhead turtles have a great capacity for long aerobic dives at low temperature, when they rest in a dormant state for most of their time on the seabed and keep energetic costs to a minimum, without truly hibernating (Hochscheid et al., 2007). Therefore, in such a state, it is more difficult for them to avoid the nets of bottom trawlers. Further research would be needed to confirm the seasonal pattern, however.

Although the Spanish drifting longliners operating in the western Mediterranean mainly fish on the feeding grounds off the Balearic Archipelago and southern Spain (Camínas and De la Serna, 1995) and are expected to take mainly loggerhead sea turtles originating in the comparatively large Atlantic rookeries...
(Carreras et al., 2006), the bottom trawlers surveyed here also took turtles from the highly endangered and comparatively scarce rookeries in the eastern Mediterranean (Carreras et al., 2006). This makes regulation of the fishery a matter of urgency if the Mediterranean loggerhead turtle population is to be conserved effectively. Possible mitigating techniques are (i) winter fishing restrictions, (ii) reducing the number of bottom trawlers working in the area, (iii) reducing the time the net is underwater to prevent turtle suffocation (Henwood and Stuntz, 1987; Robins-Troeger et al., 1995), and (iv) enforcing the use of turtle excluder devices (Epperly, 2003). A population viability analysis would be useful to assess the real impact of bottom trawling on the population nesting in the eastern Mediterranean and to identify the best management option for it (Crowder et al., 1994), but several of the required demographic parameters are unknown or have been estimated without discrimination between sea turtles from Atlantic and Mediterranean rookeries (Casale et al., 2007, 2009), which render them of limited utility in conducting a population viability study.

To summarize, our study aimed to assess the threat of different fishing gears to loggerhead sea turtles and to estimate the total number of turtles taken annually by each gear off northeastern Spain. Our conclusion is that most turtles were taken incidentally by bottom trawlers and drifting longlines, so indicating that any strategy for reducing bycatch in the Mediterranean would require a multi-gear approach.

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