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An interaction index to predict turtle bycatch in a Mediterranean bottom trawl fishery

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A B S T R A C T

Incidental catch is the major threat to the survival of loggerhead turtles (*Caretta caretta*) in the Mediterranean and the main reason for their decline. More than 100,000 turtles are estimated to be caught annually due to fishing practices; 10–50% die. Bottom trawls are among the fishing gears exerting the worst impact on sea turtle populations, especially in the coastal waters of Tunisia and Libya, northern Adriatic Sea, the Mediterranean coastal areas of Turkey and Egypt, where the continental shelf is large and turtles in the demersal stage are commonly found also in winter. Seven adult-sized loggerhead turtles captured incidentally by bottom trawls in the central-northern Adriatic Sea and treated in rescue centres were tagged with satellite transmitters before release. In this paper Italian bottom trawl track data obtained from vessel monitoring systems (VMSs) were analysed by VMSbase R suite to identify the areas of maximum fishing effort in the Adriatic. These data were combined with satellite information on turtle distribution to provide an interaction index enabling prediction of potential trawl–turtle interaction hotspots and periods. The present pilot study can be considered as a risk-analysis approach directed at identifying the areas and times of possible trawling–turtle interactions in a Mediterranean trawl fishery. By identifying the areas and seasons at highest risk of turtle bycatch, the index here developed has the potential to provide key information to design and implement mitigation strategies. Vessel monitoring system is actually in force in several countries, therefore the approach here studied might have a worldwide application.

1. Introduction

The Mediterranean populations of loggerhead turtle (*Caretta caretta*) have declined in recent decades, leading the International Union for the Conservation of Nature to list it as an endangered species (IUCN, 2015).

Incidental catches and other human activities are the main reasons for its decline. Degradation of their habitat (especially the nesting beaches), sea pollution (resulting in ingestion of plastic debris), ghost fishing, and direct harvesting for blood, meat and eggs are the main threats to its survival in the Mediterranean (Margaritoulis et al., 2003; Lucchetti and Sala, 2010). More than 100,000 sea turtles are estimated to be incidentally caught each year by a variety of fishing gears – 70,000 by longlines, 40,000 by bottom trawls, and 23,000 by bottom-set nets (Casale, 2008, 2011; Lucchetti and Sala, 2010) – with mortality ranging from 10% to 50% depending on gear. Actual bycatch figures may however be much higher, given that catch data are rarely reported by fishermen and information from North African countries is often poor.

The bottom trawl is one of the fishing gears exerting the most severe impact on sea turtles. The northern Adriatic Sea, the coastal waters of Tunisia and Libya, the areas south of Turkey and Egyptian waters, where the continental shelf is large and turtles in the demersal phase are commonly found also in winter, are the most affected areas (Casale et al., 2012). The northern Adriatic Sea (FAO geographical sub-area 17, GSA 17), with its shallow waters and rich benthic communities, is a major feeding habitat for turtles in the demersal stage, especially for the populations nesting in Greece (Lazar et al., 2004). Unfortunately, its shallow depth and flat seabed make it an ideal fishing ground for bottom-towed gears

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(Lucchetti and Sala, 2012); indeed GSA 17 is exploited by more than 1000 bottom trawlers, mainly from Italy and Croatia and to a lesser extent from Slovenia, Montenegro and Albania. The high density of bottom trawlers and sea turtles suggests that more than 10,000 annual capture events may take place in this area (Casale et al., 2004; Lazar et al., 2004; Lucchetti and Sala, 2010).

The broad distribution and occurrence of *C. caretta* in the Adriatic, which includes international waters and the national waters of several countries, complicate conservation and management efforts. Moreover, fishermen rarely report bycatch data, preventing reliable estimates. Identification of the areas and main periods of potential interaction between turtles and trawlers would facilitate conservation efforts. One way to achieve this goal is to compare the space/time distribution of the fishing effort with turtle distribution, developing models that can predict the areas and periods at highest risk of interaction.

Intensity of space use data were available for seven turtles that after being caught incidentally, and rehabilitated in special rescue centres, were implanted satellite transmitters before their release. These data were combined with trawling fleet track data obtained from vessel monitoring systems (VMSs) mounted aboard Italian industrial fishing vessels. The Italian fleet accounts for about 50% of trawlers exploiting the area, whereas VMSs are not in use in the other fleets. Therefore the main goal of the paper was to study the interaction between Italian trawl activity and turtle movements, rather than to investigate turtle behaviour. In fact two recent studies have provided a clear description of turtle migration routes and of the areas where young *C. Caretta* are found most commonly in the Adriatic (Casale et al., 2012; Luschi and Casale, 2014).

In the present study turtle distribution and trawling effort data in GSA 17 were combined to develop an interaction index (I.I.) to predict the areas and times of interactions, allowing quantification of the risk of turtle bycatch. Even though other fishing activities also take place in the area, they do not seem to involve a high risk of turtle bycatch (Lucchetti and Sala, 2012).

2. Materials and methods

2.1. Turtle movements

The loggerhead turtle dataset, provides the positions of seven individuals recorded from 2006 to 2012. These turtles were incidentally caught by bottom trawls in the central-northern Adriatic Sea. After rehabilitation they were tagged with satellite transmitters and released. Each record contains the individual's ID, the geographical coordinates of its position (latitude and longitude based on the World Geodetic System [WGS-84]), time coordinates (day and hour), and location classes (LCs), i.e. values grading signal accuracy (Royer and Lutcavage, 2008).

This dataset was combined with VMS bottom trawler track data. This information was available for the whole northern and central Adriatic (FAO GSA 17), but only data for the western (Italian) side were analysed, to prevent the lack of VMS data for the Croatian trawlers to affect I.I. reliability.

The dataset was cleaned by selecting one position per day based on the highest LC values. An exhaustive description of satellite data collection and processing is reported in Casale et al. (2012). Raw position data were used; no interpolation was applied to obtain an estimated position in case of missing daily data.

Although tracked days and total number of positions detected varied among the seven individuals (Table 1), the large amount of information made it possible to analyse them by season. The dataset was thus divided into years and quarters. Seasonal positions were translated into trajectories assuming that movement takes place along the direction that joins two consecutive points. A cell grid of GSA 17 was constructed. To increase space use information, either cells with evidence of turtle presence and those intersected by trajectories were considered as "exploited" cells. Space use intensity was then assessed by season (season 1: January–March; season 2: April–June; season 3: July–September; season 4: October–December) and stratified in space using 5 min × 5 min grid cells by counting the number of detections in each cell.

Table 1
General statistics of turtles tracked. Number of tracked days and number of positions detected per turtle.

Turtles	No. of tracked days	No. of positions detected
A	63	27
B	252	64
C	300	287
D	150	118
E	313	132
F	65	49
G	254	221
Mean	199.57 ± 106.36	128.3 ± 95.37

Further analysis were carried out to assess whether the seven monitored turtles were representative of the entire Adriatic population. To this aim the Adriatic basin was divided into six sub-areas (NW, NE, W, E, SW, SE) and a seasonal ranking of the turtle presence from one (low turtles presence) to 3 (high turtles presence) was assigned to each sector, based on the information available from literature. Similarly, the turtle's space use intensity obtained for each season by satellite tracking was classified based on a score from one to three, being 1 the sector with low turtle presence (ranging from zero to 33%), 2 with medium presence (from 33% to 66%) and 3 with high presence (from 66% to 100%).

Finally, sea surface temperature (SST) for the period of investigation (2006–2012) was analysed in order to characterise turtle movement, being temperature the main environmental variable affecting turtle distribution (Casale et al., 2012). Data were obtained from MyOcean web site (www.myocean.eu.org). SST data were cross-checked with sea turtle movements to investigate habitat preference in the different seasons.

2.2. Fishery data

The bottom trawl effort over the period spanned by the turtle dataset (2006–2012) was estimated from VMS track data obtained from the Italian Ministry for Agricultural, Food and Forestry Policies. The satellite-based VMS provides location, course and speed data of commercial fishing vessels at 2 h intervals. Each dataset point contains position (latitude and longitude in the WGS-84), time (day and hour), vessel speed (km h^{-1}), and prow heading (radian) information.

The number of vessels identified in each season is reported in Table 2.

Fishing data were analysed using R-platform VMSbase freeware (www.vmsbase.org; Russo et al., 2014), which implements

Table 2
Presence (in percentage) of the turtles monitored by satellite tags in each sub-area for each season. Presences are ranked as 1 if presence ranged between 0 and 0.33, 2 if varied between 0.33 and 0.66, 3 between 0.66 and 1.00.

	Winter	Spring	Summer	Autumn
NW	0.031	0.667	0.43	0.356
NE	0.143	0.321	0.448	0.086
W	0.076	0	0.047	0.148
E	0.75	0.012	0.052	0.365
SW	0	0	0	0.018
SE	0	0	0.023	0.027