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ORIGINAL ARTICLE

Migration strategies of the Yelkouan Shearwater *Puffinus yelkouan*

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Abstract Although the Yelkouan Shearwater *Puffinus yelkouan* is listed as near threatened on the International Union for Conservation of Nature Red List, with many populations in serious decline, there is little detailed information on the location of its key foraging areas during the non-breeding season. To address this knowledge gap, adult Yelkouan Shearwaters at a breeding colony in Malta were fitted with geolocators in 2 consecutive years. Of the 13 birds tracked (two of which were tracked in both years), the majority ($n = 10$; 76.9 %) migrated in June–July to spend most of the non-breeding period in the Black Sea ($n = 5$), Aegean Sea ($n = 2$), Black and Aegean seas ($n = 2$), or Black and Adriatic seas ($n = 1$). The final three birds remained within the central Mediterranean area and did not move beyond 500 km of the breeding colony. There was considerable variation among individuals in terms of timing of the outward and return migrations, duration and location of periods of residency in different areas, and migration routes. However, migration patterns (including routes and areas visited) were very consistent in the two individuals tracked in consecutive years. All birds returned in November or December to waters closer to the breeding colony, concentrating between the North African coast and the southern Adriatic. This study has identified key areas during the non-breeding season for Yelkouan Shearwaters from Malta which are also likely to be important for other populations. Given the continuing decline of this species throughout its range, this information represents an essential step for improving international conservation efforts. At-sea threats in the wintering regions include by-catch in long-line and trawl fisheries, impacts of over-fishing, illegal hunting (particularly in Maltese waters), ingestion of plastics, pollution, and the potential impact of off-shore wind farms. These threats need to be addressed urgently in the areas identified by this study to prevent further declines.

Keywords Seabirds · Telemetry · Conservation · Migration · Malta · Yelkouan · Shearwater

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Zusammenfassung

Zugstrategien des Mittelmeersturmtauchers (*Puffinus yelkouan*)

Obwohl der Mittelmeersturmtaucher *Puffinus yelkouan* als „nahezu gefährdet"eingestuft wird und einige Populationen bereits stark zurückgehen, gibt es kaum detaillierte Informationen über die Hauptnahrungsgebiete außerhalb der Brutzeit. Um diese Wissenslücke zu schließen, wurden adulte Mittelmeersturmtaucher aus einer Brutkolonie in

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Malta zwei Jahre lang mit Geolokatoren ausgestattet. Von den 13 verfolgten Vögeln (zwei davon wurden während beider Jahre verfolgt) wanderte die Mehrheit ($n = 10$; 76.9 %) im Juni und Juli ab. Sie hielten sich außerhalb der Brutperiode im Schwarzen Meer ($n = 5$), im Ägäischen Meer ($n = 2$), im Schwarzen und Ägäischen Meer ($n = 2$) oder im Schwarzen und Adriatischen Meer ($n = 1$) auf. Die übrigen drei Vögel bleiben im zentralen Mittelmeerraum und entfernten sich nicht weiter als 500 km von der Brutkolonie. Es gab eine beträchtliche Variabilität zwischen den Individuen in Bezug auf zeitlichen Ablauf des Zuges, Dauer und Aufenthalt in den verschiedenen Gebieten sowie der Zugrouten. Dennoch stimmten die Zugmuster (inklusive der Routen und besuchter Gebiete) der beiden über zwei Jahre verfolgten Vögel überein. Alle Vögel kamen im November und Dezember wieder näher an die Brutkolonie heran mit Schwerpunkt in N-Afrika und in der südlichen Adria. Diese Studie identifizierte die Hauptnahrungsgebiete außerhalb der Brutzeit von Mittelmeersturmtauchern von Malta, doch dürften diese auch für andere Populationen wichtig sein. Angesichts des stetigen Rückgangs dieser Art in ihrem gesamten Verbreitungsgebiet ist dies ein wichtiger Schritt, internationale Artenschutzbemühungen zu verbessern. Die Bedrohungen auf See in den Überwinterungsgebieten beinhalten Beifang bei Langleinen- und Schleppnetzfischerei, Auswirkung der Überfischung, illegale Jagd (besonders in Maltesischen Gewässern), Aufnahme von Plastik, Verschmutzung und die potentiellen Auswirkung von Offshore Windkraftanlagen. Diese Bedrohungen müssen in den durch diese Studie identifizierten Gebieten dringend angegangen werden, um einen weiteren Rückgang zu verhindern.

Introduction

The Yelkouan Shearwater is a medium-sized *Puffinus* shearwater endemic to the Mediterranean region. It was previously considered to be part of the Manx Shearwater *Puffinus puffinus* species complex, but was elevated to species status (along with the Balearic Shearwater *Puffinus mauretanicus*) after taxonomic revision based on both genetic and morphological traits (Heidrich et al. 1998; Sangster et al. 2002). In recent years, populations of the Yelkouan Shearwater have declined, or disappeared entirely, throughout its range, with the result that it was up-listed in 2008 to the 'near threatened' status in the World Conservation Union (IUCN) Red List (IUCN 2010). There is now further discussion and gathering momentum to up-list this species to the 'vulnerable' status based on continuing declines throughout its range due to a wide range of threats. The current global population is estimated at between 10,815 and 53,574 breeding pairs, mainly concentrated in Malta, Italy, Greece, France, Croatia, and Turkey (Bourgeois and Vidal 2008).

Approximately 10 % of the global population is found in Malta, accounting for an estimated 1,660–1,980 pairs (Borg et al. 2010; Raine 2012). The Maltese population is found predominantly on the south and south-west coast of both Malta and Gozo, where it typically breeds on inaccessible cliffs and among boulder scree, with the largest concentration of breeding birds located at Rdum tal-Madonna on the north-east coast of Malta (Raine et al. 2009; Borg et al. 2010). Mating and courtship take place in January and February, with laying and incubation spanning March and April (Borg et al. 2010). The last chicks fledge by the end of July, after which colonies are deserted. Birds have been recorded returning to the colonies as early as mid-October to begin preparing nest sites for the following breeding season (Borg et al. 2002).

There are a number of major threats facing the Yelkouan Shearwater, including predation by introduced species (particularly rats *Rattus rattus* and feral cats *Felis catus*), fisheries by-catch, illegal hunting (shearwaters are shot by poachers in Malta for sport or trophies), human disturbance, light and noise pollution, and habitat destruction (Bourgeois and Vidal 2008; Raine et al. 2009; Borg et al. 2010; Oppel et al. 2011; Bonnaud et al. 2012). Threats within breeding colonies are relatively well-known and can be addressed (although this can be resource-intensive), whereas those at sea are less understood, in large part because of the limited information on the location and characteristics of key marine habitats. Nevertheless, recent research suggests that for birds from Malta, marine threats can be considered as some of the main factors contributing to population decline as long as on-going management actions at the colonies (such as controlling introduced predators and human impacts) remain in place (Oppel et al. 2011).

The purpose of this study was therefore to identify key marine areas for adult Maltese Yelkouan Shearwaters during the non-breeding period, when their movements and distribution are poorly known—which would then help guide international conservation efforts in these areas. With recent advances in microtechnology, deployment of tracking devices has become an increasingly important tool for identifying key areas used by seabirds both during and outside the breeding season (Burger and Shaffer 2008). In the case of this study, birds were tracked using geolocators, which are cheap, easy to attach, remain on the bird for months or years, provide locations with a mean error of approximately 185 km (Phillips et al. 2004), and have been used successfully on numerous species of seabirds ranging from terns (small) to albatrosses (large) (Phillips et al. 2005; Guilford et al. 2009; Egevang et al. 2010; Landers et al. 2011). These devices are also light in terms of weight and have had no discernible short-term impacts in previous studies of shearwaters (Igual et al. 2005; Catry et al. 2009).

Methods

Birds were selected from a colony at Rdum tal-Madonna, located on the north-east coast of Malta (35°59′N, 14°22′E). With between 398 and 602 pairs, it is the largest colony in the Maltese islands and holds approximately one-third of the Maltese population (Borg et al. 2010). The main colony is located along a 1-km stretch of limestone cliffs, and birds nest mainly in deep burrows (often with communal entrances) on the cliff face. As access to much of the colony is very difficult due to the terrain, only two areas (a narrow ledge and a small cave) were visited during the study period with sufficient regularity to allow geolocator deployment and recovery. At both sites, the vast majority of breeding birds had been ringed and recaptured on multiple occasions in monitoring programs that began in the mid-1970s and intensified as part of the EU LIFE Yelkouan Shearwater Project (http://www.lifeshearwaterproject.org.mt/) between 2007 and 2010. The locations of burrow entrances were therefore known, increasing the likelihood of recapturing of birds fitted with loggers.

A total of 26 geolocators (MK14; British Antarctic Survey, Cambridge, UK) were fitted to adult Yelkouan Shearwaters in June to early July in 2008 (13 loggers) and 2009 (13 loggers), during the last few weeks prior to departure from the colony at the end of the breeding season. Two individuals were tracked for 2 years, and the remainder for a single year. Geolocators were only fitted to known breeders, mainly those recorded as successful breeders in several previous seasons.

Geolocators were fitted to the metal identification ring using UV-resistant cable ties, after trials with a variety of attachment methods proved this to be the most effective and unobtrusive method available. All devices were calibrated for 1 week prior to deployment, and two additional loggers were left at a fixed, known location (which was outside, in an area with no nearby artificial lights and with an unobstructed view of the horizon) for calibration purposes over the entire study period. Each device weighed <2 g, equating to 0.5 % of the average weight of the birds that were tagged (mean Yelkouan Shearwater weight 396.4 g ± 41.5 g). All tagged birds were sexed based on a combination of morphological measurements, vocalization analysis and, in the majority of cases, physical evidence of either egg laying (such as a swollen cloaca) or a cloacal protuberance.

Loggers were recovered in the following breeding seasons and data downloaded and analyzed using TransEdit and BirdTracker software (British Antarctic Survey), according to established methods (Phillips et al. 2004). Briefly, the timing of sunrise and sunset was determined using a light threshold value of 10; longitude was then derived from the timing of local midday/midnight with respect to Greenwich Mean Time and day of the year, and latitude from the length of daylight/darkness using an angle of elevation of −4.7° based on calibration data from fixed locations. Locations derived from light curves with obvious interruptions around dawn or dusk were excluded from the analysis, as were those from periods close to the equinox (when latitude estimation is unreliable) and any others that were far inland and obviously erroneous.

Given the inherent error in the geolocation of approximately 185 km (Phillips et al. 2004) and the maximum foraging range of 280 km for Yelkouan Shearwaters from Malta fitted with GPS loggers during the breeding season (Raine, Borg, and Raine, unpublished data), a buffer of a 500-km radius was used to define the waters around the colony, following the approach used in several previous studies of seabirds (Guilford et al. 2009; Landers et al. 2011). For the purposes of this paper, this buffer area is described as the 'central Mediterranean.'

In order to identify key areas occupied during the non-breeding period, kernel density maps were generated for all valid locations in each 2-month period from the time of chick fledging to egg laying (July to February inclusive). Kernel analyses were performed using Hawth's Analysis Tools in a European Albers Equal Area Conic projection with a cell size of 50 km and a search radius of 200 km (Phillips et al. 2005). There was a high level of consistency in the timing of migration and distribution of the same individuals tracked in consecutive years (see below). Given the lack of evidence for an effect of year, data from birds tracked once were pooled in kernel analyses, along with data from the first season, only for the two birds tracked in consecutive years. Throughout the paper, means are provided ± standard deviation (SD).

Results

Geolocator retrieval

Of the 26 geolocators deployed in total in June–July in the two field seasons, 18 (69.2 %) were retrieved, 15 (83.3 %) of which provided data. Seven of these datasets were from the 2008/2009 winter and eight from the 2009/2010 winter and consisted of three males and ten females (with two of the females tracked in both years). With so few tagged males in the sample, we were unable to undertake a comparison of migration patterns between sexes. Visual inspections showed no adverse physical affects due to the attachment of the tags, and all birds went on to successfully raise young in the breeding season when the tags were recovered. There was no significant difference between the weights of the small sample of birds weighed when devices were recovered, and untagged controls (tagged ($n = 9$): 397.8 g ± 35.3 g, untagged ($n = 15$): 394.0 g ± 27.1 g; Mann–Whitney $U = 65.5$, $p = 0.46$).

The mean duration of deployment for the 15 loggers with useable data was 295.1 ± 51.0 (range 207–362) days. These provided a total of 6,525 locations during the non-breeding period (July to February), of which 1,272 (19.5 %), 411 (6.3 %), and 258 (4.0 %), respectively, were excluded because of proximity to the equinox or poor-quality light curves, or they were very far inland. After excluding these erroneous points, 4,584 validated locations (70.3 % of the total) were available for analysis.

Migration patterns

Of the 15 tracks (relating to 13 birds), 12 birds (80.0 %) left the central Mediterranean on 6 July ± 13.7 days (range 25 June to 9 August) and arrived in their main nonbreeding quarters on 12 July ± 14.7 days (range 26 June to 10 August). Birds returned to the central Mediterranean on 6 December ± 19.8 days (range 1 November to 31 December). Summary details of the timing of migration and location of the main non-breeding areas of each individual bird are presented in Table 1.

Several distinct phases were evident in the movements of the tracked birds, as illustrated by changes in the location of the kernel density contours (Fig. 1). Birds used several different regions during the immediate post-breeding period in July to August, with birds traveling to the Black Sea, and to a lesser extent, the Aegean Sea. One bird moved to the Adriatic Sea, and three remained within the central Mediterranean (Fig. 1). Distances from the colony to these areas were 320–340 km to the coast of Tunisia and Libya, 800 and 1,020 km, respectively, to the central and to the most distant location in the Adriatic Sea, 1,020 km to the central Aegean Sea, 2,000 and 2,400 km to the central and most distant location, respectively, in the Black Sea. Although the overall distribution was broadly similar in September–October, use of the Aegean and Adriatic seas had declined during this period. In November to December, most birds returned to the central Mediterranean, there was little use of the Aegean Sea, and only a minority were still present in the Black Sea. By January to February, all tracked birds had returned to central Mediterranean waters, ranging from the Tunisian and Libyan coasts to southern Italy, including the southern Adriatic Sea.

The ten individuals that left the central Mediterranean during the immediate post-breeding period spent an average of 148.6 ± 22.0 days in their main non-breeding grounds (Table 1). Eight spent several months in the Black Sea, including six that remained there for the full duration of the period away from the central Mediterranean. The average amount of time spent in the Black Sea was 129.1 ± 41.8 (range 36–209) days, during which time the majority of fixes came from the eastern portion of this enclosed sea. Four birds spent some of the non-breeding season in the Aegean Sea (as opposed to simply being in transit), of which two remained there for the duration of their time away from the central Mediterranean. The average residency time in the Aegean Sea was 92.7 ± 31.5 (range 53–106) days, excluding birds in transit.

Individual migration patterns were highly variable (Fig. 2). Five birds flew directly from the central Mediterranean to the Black Sea, passing through the Dardanelles and Bosphorus, and remained in the Black Sea until their return to Maltese waters in November or December (see Fig. 2a). Two flew directly to the Aegean Sea where they remained for the duration of the non-breeding season (see Fig. 2b). Three alternated between the Black and Aegean Seas, migrating to the Black Sea first, then heading back into the Aegean Sea (or in one case the Aegean Sea and the Sea of Marmara) for between 50 and 83 days, then returning to the Black Sea for several weeks before returning to the central Mediterranean (see Fig. 3c). A single bird migrated first to the Adriatic Sea, where it remained for 81 days, before continuing on to the Black Sea (Fig. 2d). Finally, three birds spent the entire non-breeding period within 500 km of Malta, utilizing waters between the North African coast (specifically Tunisia and Libya) and the southern Adriatic Sea (e.g. Fig. 2e).

Two individual females were tagged in consecutive years. Both followed the same migration pattern and utilized the same areas in the post- and pre-breeding periods in both years, indicating a high degree of regional site fidelity (Fig. 3). In addition, the timing of their movements was very consistent, with differences in dates of outward and return migration and arrival and departure from the Black Sea (and for one bird also the Aegean Sea) of 0–8 days in both non-breeding seasons, which was much less than the general variation among birds (Table 1).

Discussion

We report here the first tracking data to be obtained using geolocators for adult Yelkouan Shearwaters from Malta during the non-breeding period. Although less accurate than data obtained using satellite-transmitters, the accuracy of our data was more than sufficient for determining the timing of movements and for identifying key areas where non-breeding birds concentrated. Indeed, the

Table 1 Summary data for Yelkouan Shearwater (*Puffinus yelkouan*) from Malta tracked using geolocators during the non-breeding period in 2008 and 2009

Ring number	Year tagged	Sex	500-km radius		Duration (days)	Main non-breeding grounds	Main non-breeding grounds		Duration (days)
			Departure	Return			Date arrived	Date departed	
EE00735[a]	2008	F	5 July	1 December	149	Black Sea	7 July	29 November	145
EE00294[b]	2008	F	30 June	15 December	168	Black Sea and Aegean Sea (1 Aug–20 Sept)	4 July	10 December	159
EE00747	2008	F	9 August	25 November	108	Aegean Sea	10 August	24 November	106
EE00736	2008	M	27 June	8 December	164[c]	Black Sea	29 June	4 December	158
EE01312	2008	F	29 June	9 December	163	Black Sea	2 July	5 December	156
EE00729	2008	F	29 June	19 December	173	Black Sea	2 July	16 December	167
EE00745	2008	F	28 June	31 December	186	Adriatic Sea (28 Jun–17 Sept) and Black Sea (25 Sept–29 Dec)	28 June	29 December	184
EE00735[a]	2009	F	3 July	1 December	151	Black Sea	11 July	28 November	140
EE00746	2009	F	25 June	1 November	129	Aegean Sea	26 June	31 October	127
EE00294[b]	2009	F	30 June	22 December	175	Black Sea and Aegean Sea (30 July–21 Sept)	3 July	18 December	168
EE00726	2009	M	NA	NA	NA	Central Mediterranean and North African coast	NA	NA	NA
EE01145	2009	F	18 July	31 December	166	Black Sea	28 July	26 December	151
EE01151	2009	F	24 July	2 November	101	Black Sea and Aegean Sea/Sea of Marmara (8 Aug–1 Nov)	2 July	1 November	122
EE00734	2009	M	NA	NA	NA	Central Mediterranean and North African coast	NA	NA	NA
EE00742	2009	F	NA	NA	NA	Central Mediterranean and North African coast	NA	NA	NA

F female, *M* male, *NA* data not available

[a,b] Birds that were tracked in two consecutive years

[c] Returned to Black Sea again on 11–30 Dec

alternative approach of using satellite-transmitters is problematic, not only because deployment durations are relatively short if devices are taped to feathers (and harnesses can cause high mortality in seabirds; Phillips et al. 2003), but also because radio interference in the Mediterranean region results in fixes that are sporadic and of lower quality than elsewhere (Raine et al. 2011a). Deployment of geolocators did not appear to have adverse effects; instrumented birds had similar weights when recaptured to controls, there was no sign of injury to the leg, and all tracked birds successfully raised chicks in the breeding season following recovery. Although eight (29.6 %) of the original sample were not recaptured, not only do adults appear to have low over-winter survival in general (Oppel et al. 2011), but several were from a cave where recapture was more difficult because of the dispersed nature of the nests and swift disappearance of birds after landing into rocky scree.

The key results of this study include the substantial variation among individuals and the high level of consistency within individuals in terms of timing of movements and distribution. Of the 15 birds tracked, three (20 %) remained resident in the central Mediterranean between the Tunisian and Libyan coasts and the south coast of Italy, i.e. in waters within 500 km of the colony. In contrast, the vast majority of birds were long-distance migrants, moving eastwards after chick fledging in July to the Black Sea and/or the Aegean Sea, in some cases alternating between these two regions. A single bird spent the initial post-breeding period in the Adriatic Sea before moving to the Black Sea for the remainder of the winter. By early to late December, all birds had returned to the central Mediterranean, using the area from the North African coast (particularly of Tunisia and Libya) to the southern Adriatic, where they remained until the start of the breeding season in March. This relatively early return appeared to be related to the seasonal increase in marine productivity in waters near the colony, which presumably allows birds to feed successfully and provides opportunities for visits to land to maintain and defend the burrow and to renew the pair bond.

Of the 13 birds tracked from Malta, eight (61.5 %) used the Black Sea, in all cases for several months of the

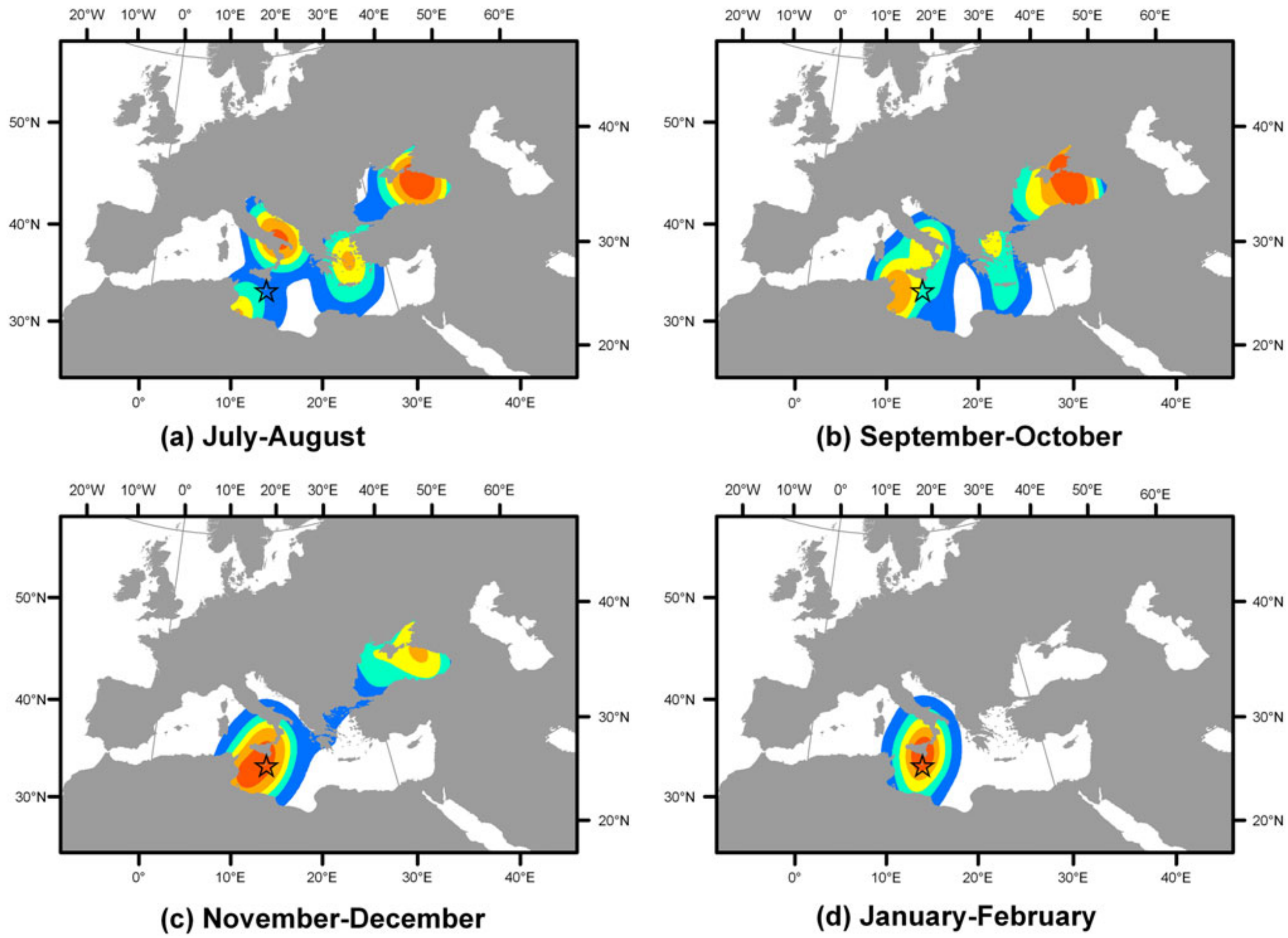

Fig. 1 Seasonal changes in distribution of Yelkouan Shearwaters (*Puffinus yelkouan*) (n = 15) from Malta tracked during the non-breeding season (July–February) in 2008 and 2009. *Star* Location of Malta. Kernels presented are 20, 40, 60, 80 and 95 %, respectively, with land masses (*shaded*) placed above kernel layers to allow better visualization of the migration patterns (color figure online)

non-breeding period. There are also three international ring recoveries of Yelkouan Shearwaters from Malta; (1) an adult ringed at Rdum tal-Madonna in May 1979 and recovered off Greece in June 1982; (2) a chick ringed at Rdum tal-Madonna in June 1972 and recovered 3 years later in August in the Black Sea; (3) a chick ringed at Rdum tal-Madonna in July 1977 and recovered in the Black Sea in June of the following year (Borg et al. 2002). Therefore, the tracking and ringing recoveries together confirm the importance of the Black Sea for the majority of Yelkouan Shearwaters from Maltese colonies during the non-breeding period.

Raine et al. (2011a) tracked juvenile Yelkouan Shearwaters using satellite-transmitters for several weeks after fledging. The data showed that these birds traveled to some of these areas highlighted in our study, but not to the Black Sea. However, the deployment durations in that study were relatively short, and there have been ring recoveries of sub-adults in the Black Sea, so there is no reason to suppose that young birds do not move there later in the autumn (Raine et al. 2011a). Indeed, in that study many of the juveniles headed in the direction of the Black Sea and were last tracked into the Aegean before the satellite tags stopped transmitting.

Although migration patterns were highly variable among individuals, of the two birds that were tracked in consecutive years, both followed the same routes, used the same areas, and were highly consistent in the timing of movements. Such results seem to be typical of most seabirds (Croxall et al. 2005; Phillips et al. 2005; Guilford et al. 2011), although there are exceptions (Dias et al. 2011). Variability in migration strategies among individuals does expose the population as a whole to a wider range of threats; however, under a scenario of natural or anthropogenic environmental variation (for example, in relation to climate or fishing effort), such diversity may offer an advantage in that a proportion of birds will be isolated from any deterioration in conditions that affects a specific region or operates for a limited time (Phillips et al. 2009).

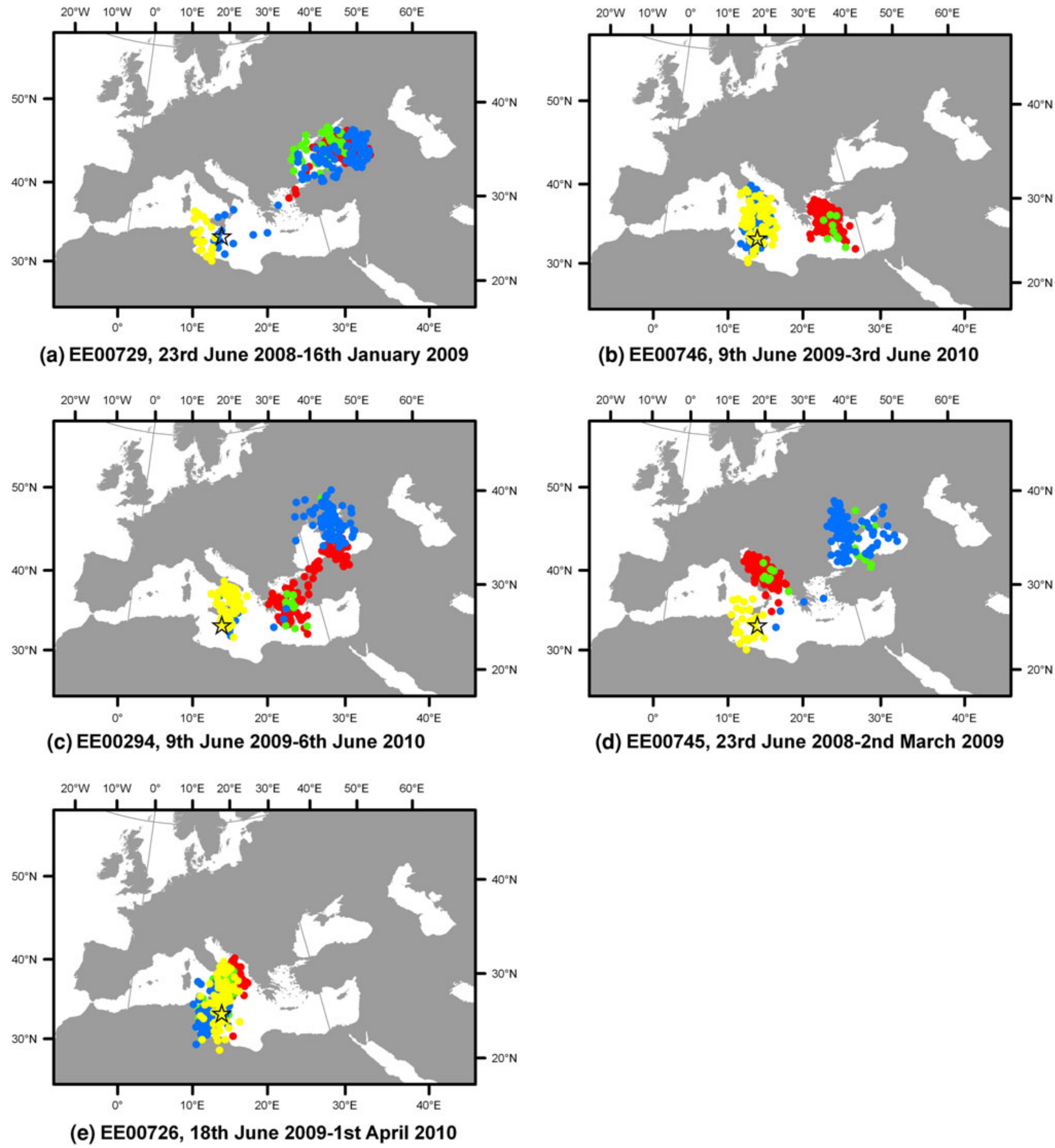

Fig. 2 Distribution of five representative Yelkouan Shearwaters from Malta tracked using geolocators during the non-breeding season in 2008 and 2009. Maps illustrate the main non-breeding migration strategies **a** Black Sea only, **b** Aegean Sea and central Mediterranean, **c** Black and Aegean Sea, **d** Adriatic and Black Sea, **e** central Mediterranean and Adriatic Sea. *Star* Location of Malta. *Different colors* represent different periods: July–August (*red*), September–October (*green*), November–December (*blue*), and January–February (*yellow*) (color figure online)

This eastwards migration of Maltese Yelkouan Shearwaters to the Aegean, Black, and Adriatic Seas is similar to that recorded for a small proportion of Yelkouan Shearwaters from French breeding populations (Militão et al. 2012). Of seven birds recovered with geolocators from the Hyeres Islands (Porquerolles and Port-Cros, France), three migrated to the Black or Aegean Seas, while the other four remained within the western Mediterranean. It is interesting that a much larger

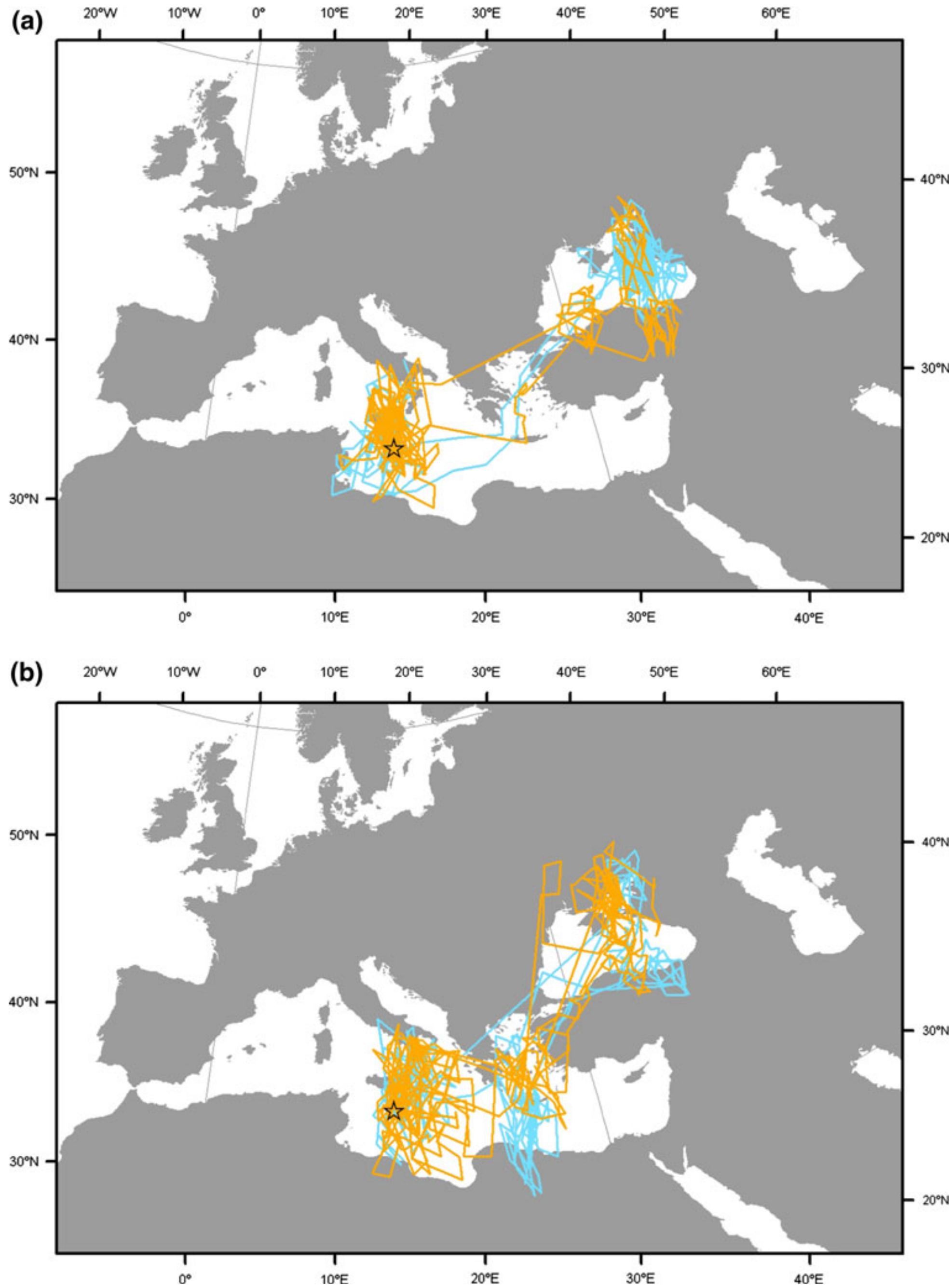

Fig. 3 Migration patterns of two Yelkouan Shearwaters (**a** EE00735, **b** EE00294) tracked in July 2008 to February 2009 (*blue tracks*) and July 2009 to February 2010 (*orange tracks*). *Star* Location of Malta (color figure online)

proportion of French than Maltese birds (57 vs. 20 %) remained in the vicinity of their breeding grounds, presumably reflecting a combination of differences in local resource abundance and the levels of intra- and inter-specific competition. The eastwards migration of many Yelkouan shearwaters is in stark contrast to the patterns shown for the two other shearwaters that breed in the Mediterranean, the Balearic *P. mauretanicus* and Cory's Shearwater *Calonectris diomedea*, both of which migrate westwards to spend the non-breeding season in the Atlantic Ocean (Ristow et al. 2000; Guilford et al. 2012; Militão et al. 2012). Initial tracking of newly fledged Cory's Shearwaters suggests that Maltese populations of this species show a similar pattern, migrating in a westerly direction into the Atlantic (Raine et al. 2011b).

The Aegean, Black, and Adriatic Seas are also considered to be important feeding areas for Yelkouan Shearwaters based on at-sea observations (Nankinov 2001; Bourgeois and Vidal 2008). However, the age, status (breeding or non-breeding), and proportion of birds in each area that originated from different colonies was unknown. Our study has shown that a proportion of the birds visiting these areas are in fact breeding adults from Maltese colonies. The Black Sea in particular is known to hold large numbers of Yelkouan Shearwaters, which are regularly counted transiting through the Bosphorus between the Black Sea and the Sea of Marmara (Elliot 1970; Nankinov 2001), apparently following the movement of their fish prey (Nankinov 2001).

The Maltese Yelkouan Shearwaters tracked during our study first pass through the Dardanelles and Bosphorus in late June and early July, which coincides with high counts of this species in the Bosphorus area (Nankinov 2001). That several of the tracked birds subsequently moved back and forth between the Aegean and Black Seas during the non-breeding season is also in line with the complex patterns of bird movements in both directions described for this area, possibly revolving around the migrations of prey populations (particularly anchovy) between the two seas (Nankinov 2001). Based on our data and the data reported by Militão et al. (2012), it is clear that the birds using the Aegean, Dardanelles, and Black Seas and Bosphorus include Yelkouan Shearwaters from a number of different breeding populations from throughout the Mediterranean region.

Of the 13 birds tracked, three (23.1 %) remained within a 500-km radius of Malta throughout the non-breeding season. This was an unexpected finding. Although some of these waters, including the northern Tyrrhenian Sea and marine areas west of Sicily and off the coast of Algeria, Tunisia, and Malta, are known to be used heavily by Yelkouan Shearwaters during the breeding season (Bourgeois and Vidal 2008; Borg et al. 2010; Raine, Borg, Raine unpublished data), their importance at other times of the year had not been recognized. However, our data confirm the suggestion by Borg et al. (2002) that a small number of Yelkouan remain within territorial waters during the non-breeding season. Furthermore, all of the tracked birds concentrated in this area in January and February in the lead-up to the breeding season, indicating that this is clearly a key region for Maltese birds.

In an effort to identify the environmental drivers underlying the observed movement patterns, we examined the within-season changes in bird distribution in relation to the oceanography of the region, including bathymetry, sea surface temperature, and chlorophyll *a* concentrations (Fig. 4). If oceanographic conditions during the initial post-breeding dispersal period in July–August 2008 are compared with Yelkouan Shearwater distribution during the same period (Figs. 1a, 4), the clearest habitat association is for birds that used waters off the coasts of Tunisia and western Libya, which are relatively shallow, warm, and highly productive. However, other tracked birds used: (1) the southeast Adriatic Sea and the Aegean Sea, which are also shallow but not particularly productive, and, in the case of the Aegean Sea, relatively cold, and (2) the Black Sea, where productivity is higher on average than most other waters of the central and eastern Mediterranean, but the water is relatively deep and of moderate temperature (Figs. 1, 4). Based on remotely sensed data, the seasonal trend in both study years was for a gradual decline in sea surface temperature and an increase in productivity (chlorophyll *a* concentration) in the Black Sea and in the central and eastern Mediterranean, including the Adriatic and Aegean Seas, from July to February (data not shown). With the exception of the Tunisian and Libyan coast, marine productivity is relatively low in much of the central Mediterranean from July to October, and it may be the increase in production from November onwards that encouraged the tracked birds to return to the vicinity of the colony by December, despite this being several months in advance of the breeding season.

Although there was little evidence of strong habitat association by the tracked birds in terms of a particular bathymetric, sea surface temperature or productivity regime, it can be assumed that such a mobile species would only migrate to the Black Sea if assured of a high density of prey. Yelkouan Shearwaters predominantly eat small fish, including European Anchovy *Engraulis encrasicolus*, Sardine *Sardina pilchardus*, and members of the Scombridae family (Nankinov 2001; Bourgeois et al. 2011), and the Aegean, Black and Adriatic Seas all have large stocks of these species (Cingolani et al. 1996; Somarakis et al. 2002; Tirelli et al. 2006; Ozturk 2009; Daskalov 2002). It is therefore intuitive that Maltese birds which leave the central Mediterranean during the non-breeding period do so either because their prey occur in higher densities or are more readily available elsewhere, or there is less intra- or inter-specific competition. In the Adriatic Sea, European Anchovy spawn from March to October, during which time they inhabit shallow waters of <30 m (Tirelli et al. 2006), which would make them easy prey for diving shearwaters. In contrast, anchovy move to deeper waters in the winter (Tirelli et al. 2006), which would tend to make them inaccessible. This seasonal vertical migration broadly coincides with the movements of at least one tagged bird, which spent the first 2.5 months of the non-breeding period in the Adriatic Sea, possibly to exploit spawning anchovy, before moving on to the Black Sea in mid-September.

The concentration of the tracked birds in the Black, Aegean, Adriatic, and central Mediterranean Seas should serve to focus attention on marine conservation in what are likely to be key areas not only for Yelkouan Shearwaters from Malta, but also for those from other colonies during the non-breeding season. Recent conservation work at the Rdum tal-Madonna colony, including the control of introduced predators (particularly rats), an education campaign to reduce human disturbance, and the cessation of ferreting and the deliberate killing of nesting birds, have resulted in a high breeding success rate (Borg et al. 2010; Raine et al. 2011c).

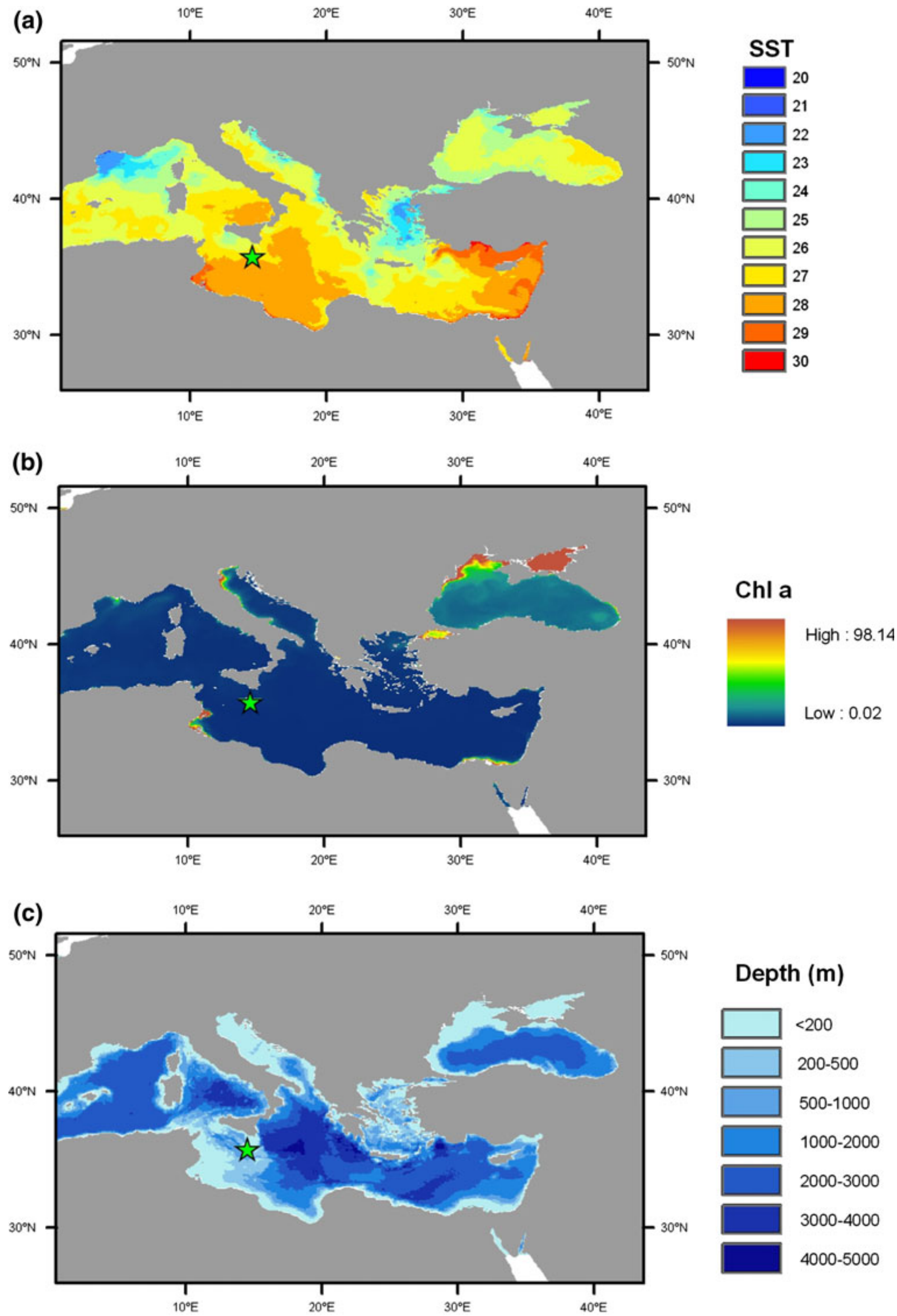

Fig. 4 Oceanography of the study region: **a** sea surface temperature (*SST*) in °C in July–August 2008, **b** chlorophyll *a* (*chl a*) concentration (mg m^{-3}) in July–August 2008, **c** bathymetry. Bathymetric grids (**c**) are at a 30 arc-second resolution (General Bathymetric Chart of the Oceans, GEBCO_08 Grid available at http://www.gebco.net). The 2-monthly composite of remotely sensed chlorophyll *a* concentrations (mg m^{-3}) is at a 4-km resolution (Aqua MODIS grids available from http://oceancolor.gsfc.nasa.gov). Sea surface temperature is given in °C (Aqua MODIS night-time data sets available from http://poet.jpl.nasa.gov). *Star* Location of Malta

However, unaddressed threats at sea can serve to negate the benefits of conservation efforts on land. One of the principal threats to shearwaters, and indeed to a wide range of seabirds, is by-catch in fisheries (Hall et al. 2000; Belda and Sanchez 2001; Cooper et al. 2003; Lewison et al. 2005; Gilman et al. 2006). By-catch of seabirds, including Yelkouan Shearwaters and other species (such as sea turtles and cetaceans) has been recorded in all of the main areas utilized in the non-breeding season by Maltese birds (Cooper et al. 2003; Casale et al. 2004; Darmanin et al. 2010). Furthermore, the central Mediterranean and Aegean Seas are known hotspots for pelagic longline fishing (Stergiou et al. 2002; Lewison et al. 2005); consequently, obtaining better data on by-catch rates, improvements to by-catch mitigation, and implementation of observer programs to assess compliance should be considered as top priorities for conservation.

A number of other at-sea threats to Yelkouan Shearwaters have also been identified, including the impact from bioaccumulation of the high level of contaminants in the Mediterranean basin (Bacci 1989; Roscales et al. 2010; Bourgeois et al. 2011) and the over-exploitation of fish stocks, leading to the collapse of populations of prey species (Furness 2003). The latter is a serious concern within the Black Sea (Kideys 1994; Prodanov et al. 1997; Zaitsev and Mamaev 1997; Kideys 2002; Daskalov 2002), as well as in the Aegean and wider Mediterranean region (Lleonart and Maynou 2003; Ozturk 2009). For birds that remain in Maltese waters outside the breeding season, illegal hunting at sea for trophies or sport is also a serious conservation issue (Raine and Temuge 2009, 2010). Ingestion of plastics and other marine debris (Ryan 1988; Derraik 2002; Aliani et al. 2003), the impact of invasive species on the food chain (Kideys 1994; Zaitsev and Mamaev 1997; Kideys 2002), direct pollution events (Zaitsev and Mamaev 1997; Ozturk 2009), and the potential threat from off-shore wind farms (Raine et al. 2010) may also have a detrimental impact on adult survival during the non-breeding season. Taking into account these risks, the development of appropriate management responses within the context of the areas identified in this study will be critical for the long-term survival of the Yelkouan Shearwater.

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