Identifying light-induced grounding hotspots for Maltese seabirds

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Abstract

Light pollution is a well-documented threat to seabirds worldwide. Light pollution in the Maltese Islands has been attributed to the contraction of seabird breeding colonies and the direct cause of grounding events. Using a long-term database of reported light-induced grounding cases, we have identified the major locations, or 'hotspots' for light-induced seabird groundings in the Maltese Islands. Four main hotspots accounting for almost half of all grounding cases were identified. Close to 100% of all grounding cases involved fledglings. Identification of these areas will serve as a valuable tool in the conservation of Maltese seabirds through focusing rescue efforts and prioritising light pollution mitigation measures.

Introduction

Almost all life on Earth has evolved with a cycle of day and night. Important behavioural, biochemical and ecological processes depend on the natural rhythm of light and dark. Substantial ecological disruption can result where this cycle is disturbed by the alteration of natural light levels due to artificial light at night, or light pollution. Despite recent reports advancing our understanding of the potential impacts of light pollution, it remains an often overlooked cause of environmental disturbance, affecting the health and behavioural patterns of individual organisms that can have significant implications at a population level (Rich & Longcore 2006).

Seabirds are directly impacted by light pollution, primarily through their attraction or repulsion and subsequent displacement or disturbance (Rich & Longcore 2004, Montevecchi 2006, Guilford *et al.* 2019). Indirect impacts are also evident for example, in competition with nocturnal fisheries (Arcos & Oro 2002, Rich & Longcore 2004) and the increased risk of predation (Oro *et al.* 2005). Procellariiform seabirds are intensely sensitive to artificial light (Imber, 1975; Reed *et al.,* 1985). Species-specific and even age-specific sensitivities to artificial light are evident with the greatest negative consequences for young birds of nocturnally-active species (Montevecchi, 2006). Despite

these phenomena being well-documented, the mechanisms behind them are not yet fully understood (Rich & Longcore 2006, Hölker *et al.* 2010a, b).

Perhaps the most immediate and lethal effect of light pollution for seabirds is their disorientation by and attraction towards sources of artificial light (Telfer *et al.* 1987, Le Corre *et al.* 2002, Rodríguez & Rodríguez 2009, Merkel 2010, Troy et al. 2011, Day et al. 2015, Rodriguez et al. 2019). Where this phenomenon occurs close to breeding colonies of seabirds, fledglings often become stuck on land (Rodriguez *et al.* 2017a,b) after exhausting themselves or colliding with structures (Montevecchi 2006, Miles *et al.* 2010), a process known as light-induced grounding or "fallout" (Reed *et al.* 1985, Ainley *et al.* 2001).When grounded, birds are unlikely to become airborne again and are vulnerable to predation, illegal taking by humans, traffic collisions, exposure, dehydration and starvation (Telfer 1987; Montevecchi 2006, Raine *et al.* 2007, Rodriguez *et al.* 2017a). Worldwide, at least 56 species of procellariiform seabird have been recorded in light-induced grounding events due to light pollution (Rodriguez *et al.* 2017a). This process primarily affects young individuals: global records of light-induced groundings involving shearwater species show a disproportionate percentage of recently fledged birds recovered, ranging from 73.7 to 98.9% (Rodriguez *et al.* 2017a). For some populations of seabirds, light-induced groundings are a leading cause of juvenile mortality (Ainley *et al.* 1997; Le Corre *et al.* 2002).

Light pollution near nesting colonies is one of the prime recognised threats that Procellariiform seabirds face during their breeding season (Podolsky *et al.* 1998, Day *et al.* 2003, Fontaine 2011). Most Procellariiform species rely on the cover of darkness to visit their nesting areas in cliffs as a strategy to avoid predation and, therefore, darkness is a key habitat quality for these species (Montevecchi 2006). Parental attendance is reduced where colony sites are exposed to light pollution as the perceived risk of predation is increased (Oro *et al.* 2005). In extreme cases of persistent and permanent light pollution, breeding pairs are forced to abandon their nests which could lead to the abandonment of entire breeding colonies (Wolf *et al.* 1999, Sultana *et al.* 2011).

Figure 1. *Light pollution in the Central Mediterranean with the Maltese Islands in the foreground as seen from space. Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center, ISS025-E-10429, http://eol.jsc.nasa.gov*

The intensive and ongoing coastal development established in Malta since the early 1980s, mainly for the tourism industry, has turned the islands into a literal spotlight in the Mediterranean (Figure 1). Poorly designed outdoor lighting schemes utilising an excessive number of bright-white lights has recently resulted in Malta being ranked as the 17th worst light polluted country in the world (Falchi *et al.* 2016).Light pollution has long been identified as a problem for Maltese breeding seabirds, as documented by Sultana *et al.* (1975, 2011), leading to the contraction of breeding colonies or their eventual abandonment. Over the last four decades, BirdLife Malta has recorded a significant number of reports from the public regarding light-induced groundings of seabirds primarily in coastal locations around Malta, Gozo and Comino. The three species recorded include the Yelkouan Shearwater *Puffinus yelkouan*, the Scopoli's Shearwater *Calonectris diomedea* and the Mediterranean Storm-petrel *Hydrobates pelagicus melitensis.* The number of light-induced grounding cases varies between years and is likely dependent on numerous environmental factors

(Syposz *et al.* 2018) and public awareness, with more birds being reported as a result of successful media campaigns (Rodriguez *et al.* 2011)). Given the life histories of these three species, being philopatric, slow-breeding and long-lived seabirds with delayed maturity and low-fecundity (Sultana *et al.* 2011), juvenile mortality caused by light-induced groundings can have a significant impact on the resident population, especially when considering the low reproductive output due to other threats in Maltese colonies (Lago *et al.* 2019).

Here we provide an update on light-induced groundings of seabirds reported over a period of four decades with the aim to identify hotspots in the Maltese Islands which, as a consequence of light pollution, impose an increased risk of mortality. The results can serve as a suitable insight to the effects of light pollution on Maltese seabirds, shedding some light on the causes behind fallout and revealing the areas in highest need of urgent remedial action.

Methods

Light-induced groundings

Data on grounding cases of Yelkouan Shearwaters, Scopoli's Shearwaters and Mediterranean Storm-petrels were collected from two sources; (i) personal records from John J. Borg and (ii) a database of light-induced grounding reports given to BirdLife Malta, mainly by members of the public, during the period 1978 - 2018 (41 years). For the BirdLife Malta database, each documented case included information on location, date, species, age, ring number (if ringed) and identity of the reporter, among other details. When possible, birds were ringed by a licensed ringer prior to release.

The reported cases include only individuals encountered on land or close to shore without any signs of water-logged plumage (Rodriguez *et al.* 2017b), with no specific ailments relating to causes other than being grounded or collision. Cases related to illegal killing (evident from injuries related to lead-shot use or other injuries inflicted by humans, see Raine *et al.* (2016) for discussion on the impact of illegal hunting on Maltese birds including seabirds), birds found offshore or lacking essential information such as location have been excluded as such cases cannot be directly associated with light pollution.

For readability and identification purposes, locations were grouped by proximity and similarity of the characteristics of each grounding area - as an example, those cases reported from Buġibba, Qawra, or St. Paul's Bay were grouped together in one cluster point with its epicentre in the Qawra peninsula.

Public awareness

To account for the effect that media campaigns about light pollution may have on the number of light-induced grounding cases reported, public awareness was quantified for the years 2017 and 2018 when similar levels of media effort were undertaken. Public awareness was measured as the total number of engagements generated by social media posts issued by BirdLife Malta on the subject of light-induced groundings. Data were taken from the social media accounts of the LIFE Arċipelagu Garnija project; Facebook, Twitter and YouTube. These figures represent the number of times each post was viewed and are not representative of the total number of people reached.

Results

Trend in number of light-induced groundings and hotspot identification

Over the last 41 years a total of 269 cases of grounded seabirds (57 Yelkouan Shearwater, 193 Scopoli's Shearwater and 19 Mediterranean Storm-petrel) have been reported to BirdLife Malta. The number of grounded birds reported is on the rise, with a particularly dramatic increase since 2014 (Figure 2) with almost 20 to 40 times more grounded birds reported compared to four decades ago. The trend indicates a growth in the amount of cases close to an exponential fit ($R^2 = 0.56$, obtained by adding a constant (1) to the y-variable).

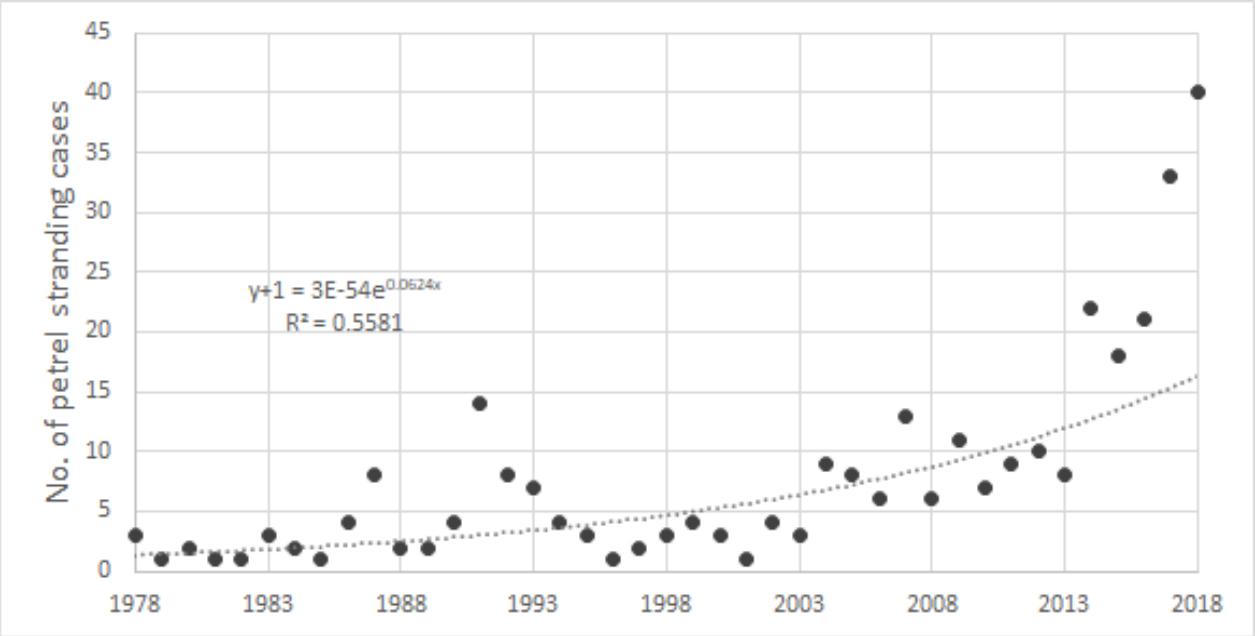

Figure 2. *Yearly light-induced grounding cases for Yelkouan Shearwater, Scopoli's Shearwater and Mediterranean Storm-petrel recorded in the Maltese Islands from 1978 to 2018 as reported to BirdLife Malta. A constant (1) was added to the number of cases each year (y) to create the exponential trendline.*

The exponential trend is stronger when considering the years covered by EU LIFE projects (R^2 = 0.70) (Figure 3).

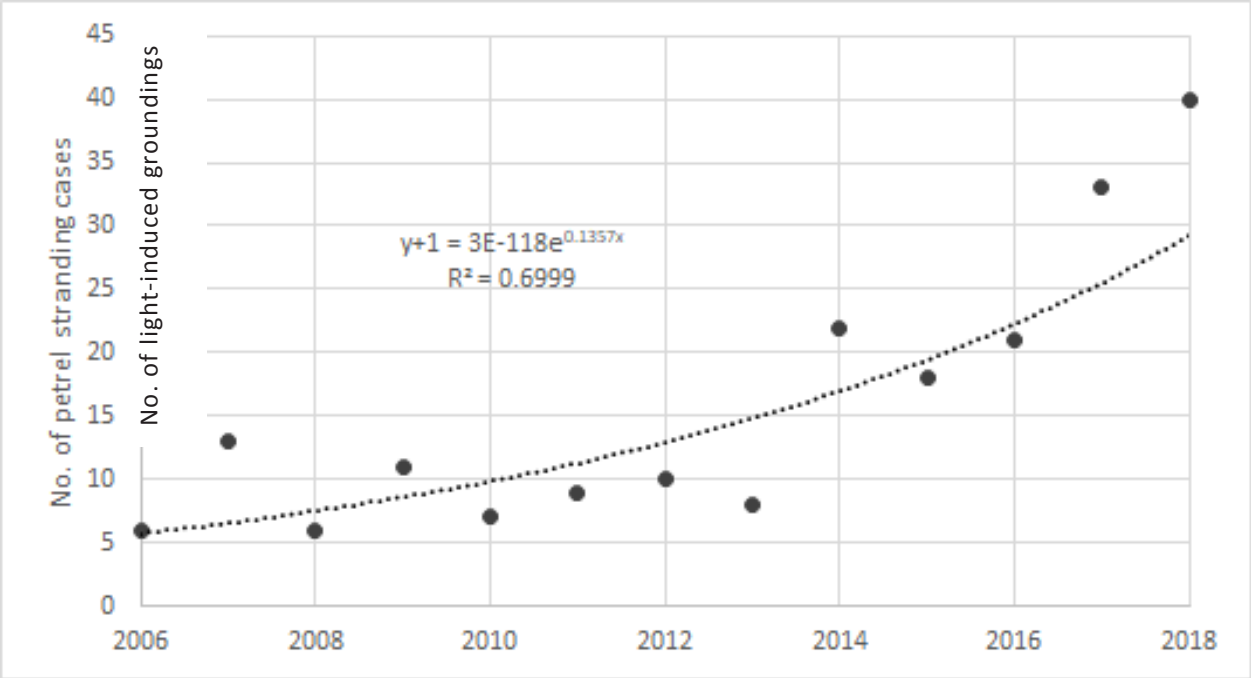

Figure 3. *Yearly light-induced grounding cases of Yelkouan Shearwater, Scopoli's Shearwater and Mediterranean Storm-petrel recorded in the Maltese Islands during successive EU LIFE projects managed by BirdLife Malta from 2006 to 2018. A constant (1) was added to the number of cases each year (y) to create the exponential trendline.*

After mapping and clustering the reports by location, we identified 29 different areas each with at least one documented case. The vast majority of light-induced groundings are located close to the sea with the exception of the localities of Victoria and Xewkija in Gozo as inland hotspots. Identified areas are widely scattered around the coast of Malta, Gozo and Comino, as shown in Table 1, but we highlight four areas as the main hotspots, responsible for nearly half (47.6%) of all cases. These areas include, Xlendi Bay in Gozo (50 cases, 18.6%), St Paul's Bay to Qawra (27 cases, 10.4%), Ħal Far industrial estate (26 cases, 9.7%), and Marsaxlokk to Freeport (24 cases, 8.9%).

Table 1. *Top ten areas reporting numbers of light-induced grounding incidents.*

Location	Mediterranean Storm-petrel	Scopoli's Shearwater	Yelkouan Shearwater	TOTAL	% TOTAL
Xlendi		50		50	18.6
St Paul's Bay to Qawra		8	20	28	10.4
Ħal Far		26		26	9.7
Marsaxlokk - Freeport	6	15	3	25	8.9
Għadira Bay/Mellieħa		5	9	14	5.2
Ċirkewwa	1	8	3	12	4.4
Ġnejna to Golden Bay/Manikata		8	3	11	4.1
Victoria		10		10	3.7
Żurrieq/Wied iż-Żurrieq	5	5		10	3.7
Marsalforn	1	6	1	8	3.0

Reports of grounded Yelkouan Shearwaters (57 cases, 21.2%) are mainly concentrated in the northeastern coast of Malta (Table 1). The peak number (20 cases) occurs in one of the four major hotspots, the area St. Paul's Bay to Qawra. Other locations include Għadira Bay/Mellieħa (nine cases) and scattered points in developed coastal areas and urban areas of Malta with a bias towards the northeastern to central coast: Salini (four cases), Ċirkewwa (three cases), Ġnejna to Golden Bay/Manikata (three cases), Marfa/Armier (three cases), Sliema/St Julian's (three cases), Marsaxlokk – Freeport (three cases), Grand Harbour area (two cases), Santa Venera/Msida/Qormi (one case), Naxxar (one case). The island of Comino records two cases, while Gozo has relatively few groundings of Yelkouan Shearwater with Qala/Nadur, Marsalforn and another unspecified location all with one case each (Figure 4).

Light-induced groundings involving Scopoli's Shearwaters represent the majority of documented cases (193 cases, 71.7%). Xlendi Bay and Ħal Far, both identified as two of the four major hotspots around the islands, exclusively involve incidents with Scopoli's Shearwaters and account for 39.4% (76 cases) of all recorded grounded Scopoli's Shearwater (Table 1). The other incidents of this species are spread around Gozo with many inland cases and various coastal locations of Malta (Figure 4).

Reports of grounded Mediterranean Storm-petrel account only for a small fraction of the total of incidents (19 cases, 7.2%), concentrating in the south sector of Malta (Figure 4).

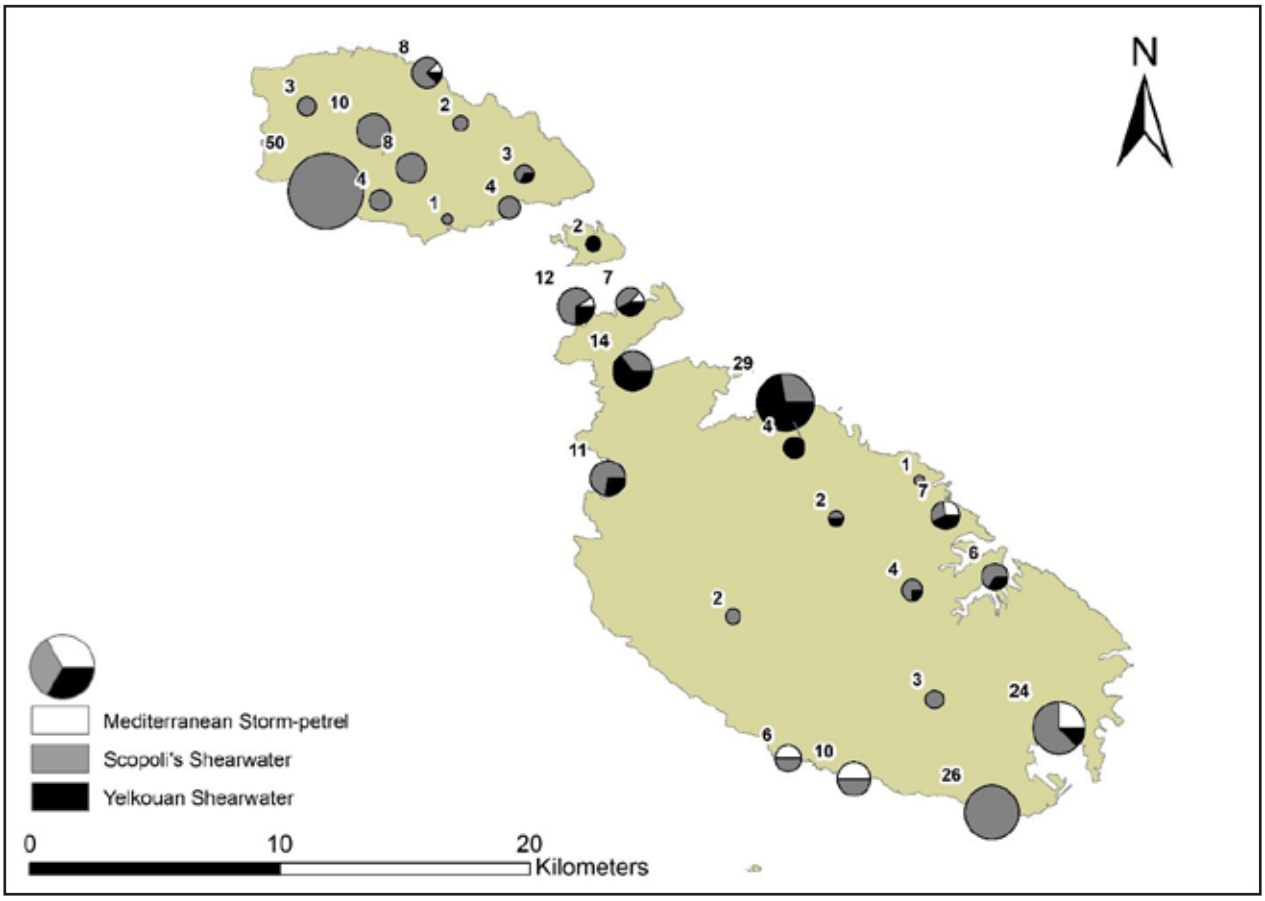

Figure 4. *Locations of recorded light-induced grounding cases per species. White = Mediterranean Storm-petrel; grey = Scopoli's Shearwater; black = Yelkouan Shearwater. Size of pie chart is relative to total number of grounded birds found at each location.*

Age of grounded birds

Grounded seabirds recovered by BirdLife Malta were processed and their age recorded. In some cases, age of the recovered bird could not be determined or was not recorded – these are represented as 'Unknown age' (Table 2).

Table 2. *Age of grounded seabirds recovered in the Maltese Islands 1978–2018.*

Species	Adult	Fledgling	Unknown age	TOTAL	% Fledgling
Yelkouan Shearwater	0	57	0	57	100
Scopoli's Shearwater	3	189	1	192	98.4
Mediterranean Storm-petrel	2	14	3	16	87.5
TOTAL	**5**	**260**	**4**	**269**	**97.7**

The percentage of grounded birds identified as fledglings was calculated from those recoveries where the age of the bird could be determined as either fledgling or adult. Individuals of unknown age were discounted from analysis.

All reported light-induced grounding cases involving Yelkouan Shearwater were fledglings with the earliest recorded grounding case in any year reported on 19 June and the latest on 29 July.

Light-induced grounding incidents involving Scopoli's Shearwater fledglings account for 98.4% of all grounding cases for this species with the earliest confirmed grounding of a fledgling in any given year on 22 September and the latest on 8 November. Three adult Scopoli's Shearwaters were recovered at times of year well outside of the fledgling season, July, August and early September. Of these birds, two were recovered from the localities of Ħal Far and Marsaxlokk – Freeport; areas directly adjacent to large colonies of Scopoli's Shearwaters. The third, positively identified as an adult by experienced BirdLife Malta staff, was recovered from Msida, an area with fewer than six reported groundings in total.

Mediterranean Storm-petrel grounding cases again mostly involve fledglings with 87.5% of all cases. The earliest fledgling Storm-petrel grounding in any given year was on 11 August and the latest on 11 November.

Overall, 97.7% of birds involved in light-induced groundings were fledglings.

Mortality of grounded fledglings

Rescued birds were recorded as dead or alive on recovery. Birds that could be identified as dead fledglings on recovery without obvious cause of death, were assumed to have died as a result of being grounded. The outcome of each grounding case involving fledglings recovered alive was recorded as released (successful) or died (unsuccessful) (Table 3) Mortality % of grounding cases was calculated as the percentage of fledglings of that were found dead or later died as a result of their being grounded.

Table 3. *Mortality of stranded seabird fledglings in the Maltese Islands 1978-2018*

Species	Died	Successfully released	Total	Mortality %
Yelkouan Shearwater	6	51	57	10.5
Scopoli's Shearwater	7	182	189	3.9
Mediterranean Storm-petrel	0	14	14	0

Grounded Yelkouan Shearwaters experience the highest mortality rate with 10.5% of recovered birds dying as a result of their grounding. No Yelkouan fledglings were found dead; however, those that died did so shortly after being recovered, apparently as a result of injuries sustained.

Of the 189 Scopoli's Shearwater fledglings recovered only one was found dead, the other six died as a result of injuries sustained – this represents a mortality of 3.7%.

No fledgling Storm-petrel was found dead or later died after recovery, a mortality of 0%.

There is little information on the type of injuries sustained by fledglings as no post-mortems are conducted. In those few cases where injuries could easily be detected, three had head injuries, four with wing injuries, one with a leg injury, one with a spinal injury, three were hit by traffic and one injured by cat or dog (Table 4). Internal injuries could not be assessed by BirdLife Malta but stress and dehydration are likely large factors in mortality associated with light-induced grounding.

So far, no grounded shearwater has ever been recaptured at a colony after their release. However, an adult Storm-petrel grounded in Sliema and released at Miġra l-Ferħa on 25 May 2017 was recaptured on 14 June 2017 during a ringing session on Filfla.

Table 4. *Summary of the injuries sustained by grounded fledglings*

Species	Head injury	Wing injury	Leg injury	Spinal injury	Hit by traffic	Injured by Cat or dog
Yelkouan Shearwater	1	0	0	1	2	0
Scopoli's Shearwater	2	4	1	0	1	1
Mediterranean Storm-petrel	0	0	0	0	0	0
TOTAL	3	4	1	1	3	1

Public awareness

Media posts made by the LIFE Arċipelagu Garnija Project 2017-2018 were analysed to calculate their reach which was used as an index for public awareness (Table 5). The total number of times each post was viewed was denoted as 'Reach'.

Table 5. *Reach of social media posts relating to the light-induced grounding of seabirds 2017-2018*

	2017				2018			
Social Media	**Total posts**	**Total reach**	**Max reach**	**Mean reach**	**Total posts**	**Total reach**	**Max reach**	**Mean reach**
Facebook	4	7007	3757	1752	8	14037	3444	1755
Twitter	3	1814	933	605	8	21222	5287	2653
YouTube	2	919	678	460	2	386	241	193
TOTAL	**9**	**9740**	**3757**	**1082**	**18**	**35645**	**5287**	**1980**

In the period 2017-2018, a total of 27 posts about grounded seabirds were made on social media being viewed 45,385 times. The total number of posts about grounded birds doubled between 2017 and 2018, reflected in twice as many views for Facebook posts during that period (2017: 7,007; 2018: 14,037). Reach of Twitter posts increased by nearly 12 times from 1,814 views in 2017 to

21,222 views in 2018. The reach of YouTube videos decreased by a factor of 2.4 (2017: 919; 2018: 386).

Discussion

This study has identified hotspots for the light-induced grounding of seabirds in the Maltese Islands, providing a valuable tool to help conserve these species and prioritise future light pollution mitigation measures.

Although not investigated by this paper, it is likely that risk of seabird fallout in the Maltese Islands is dependent on various factors as described for other procellariiform seabirds (Rodriguez & Rodriguez 2009, Syposz *et al.* 2018). Further analysis of the BirdLife Malta database will help to determine which factors are most influential in the context of the Maltese Islands and further increase understanding of light-induced groundings.

According to our results, areas of concern where most light-induced groundings of seabirds were reported accumulate in the coastal areas in the south and northeast of Malta, as well as in the west of Gozo. The main hotspots reveal a close connection between areas with a high concentration of settlements or industrial sites producing a large amount of light pollution, and the number of grounded birds. The four most prominent areas, Xlendi, St Paul's to Qawra, Marsaxlokk-Freeport and Ħal Far industrial estate, are examples of coastal locations that stay well-lit overnight, either because of the tourism oriented businesses or industrial activities. This strong correlation has been clearly documented before in the Maltese Islands (e.g. Raine *et al.,* 2007, Rodríguez *et al.* 2012, Mula-Laguna *et al.* 2014).

It is surprising not to find more grounded birds in the highly urbanised areas of the central east coast of Malta such as Valletta or St Julian's. We therefore believe that there are other important variables driving the number of incidences at certain areas. Not surprisingly, all main hotspots identified are in relatively close proximity to a sizeable seabird colony. Both Xlendi Bay and Ħal Far, which register a high number of incidents exclusively involving Scopoli's Shearwaters, have major breeding colonies of this species in their vicinities (Sultana *et al.* 2011). Some of the largest Scopoli's Shearwater colonies in Gozo are located in a range of less than four kilometres around Xlendi, namely in Wardija (ca 700 pairs) and Ta' Ċenċ (ca 1000 pairs). In the case of Ħal Far, a colony of around 800 pairs of Scopoli's Shearwater is found on the cliffs around one hundred

metres from well-illuminated factories. Similarly, the bias towards the northeast of Malta for light-induced grounding hotspots of Yelkouan Shearwater may be attributed to the presence of the largest colony of this species at L-Irdum tal-Madonna, ca 500 pairs (Sultana *et al.* 2011). Lastly, the Storm-petrel colonies are limited to the islet of Filfla and some locations along the west cliffs of Gozo. The locations with most light induced grounding cases of Storm-petrel, Għar Lapsi and Wied iż-Żurrieq, are situated directly opposite the islet of Filfla and show a similar trend to hotspots for the two shearwater species.

Results for all three species show a strong bias towards fledglings to become grounded as 97.7% of all reported grounding cases involved fledglings. This supports the findings of other studies as reported by Rodriguez *et al.* (2017a). Grounding cases involving adults were few, only three Scopoli's Shearwaters could be identified as adults and two of these were recovered from localities located in the immediate surrounds of their colonies. Disorientation of adult shearwaters by light sources in the immediate vicinity of their colonies has been recorded (Guilford *et al.* 2019) although, as adults make up a small percentage of grounded birds worldwide, data is understandably deficient. Our results do not attempt to describe the mechanism through which fledglings are more attracted to artificial lights at night - indeed the exact mechanisms through which light-induced groundings occur remain unknown. Leading hypothesis suggest that fledglings use natural light sources, like the moon and stars, to orientate themselves before leaving on their maiden flight (Telfer *et al.* 1987; Reed *et al.* 1985). Where these natural light sources are dominated by artificial light sources, fledglings may mistakenly orientate themselves towards the more intense artificial lights and fly towards them. This hypothesis is supported by the reduction in light-induced groundings during the full moon, when the moon is brightest (Rodriguez & Rodriguez 2009, Syposz *et al.* 2018).

The low number of groundings outside of immediate coastal areas may be in part due to the fact that breeding colonies of seabirds in the Maltese Islands do not occur far inland. It is likely that many fledglings leave directly out to sea when leaving their respective colony sites and are attracted to the lights of coastal developments (Rodriguez *et al.* 2015).

It is important to acknowledge that the origin of the data at our disposal, based on opportunistic reports, can introduce a certain degree of bias in the identification of the main grounding hotspots. Probabilities of encountering grounded birds in less urbanised or sparsely populated areas is likely

to be significantly lower compared to more active zones. This might produce a feedback effect in which grounding incidents occurring within less populated areas, where light pollution tends to be lower, are further under-reported. Numbers of grounded birds are further under-reported as already deceased birds, either hit by traffic or killed by domestic and feral cats and dogs, are less likely to be reported. This, together with the unknown level of illegal taking of grounded birds by humans leads to an underestimation of the true scale of light-induced groundings in Maltese seabirds. Although these factors must certainly lead to an under-representation of the total number of cases recorded, we do not expect it to significantly influence the correct identification of the main hotspots.

A similar mechanism of under-representation is expected to influence the overall low number of grounded Mediterranean Storm-petrel among the grand total. The proportion of grounded shearwaters seems to be related to population sizes of either species. Scopoli's Shearwater numbers are roughly three times higher when compared to Yelkouan Shearwaters, both in estimated population sizes (Sultana *et al.* 2011) and in grounding cases (Scopoli's ca 5000 pairs, 193 cases; Yelkouans 1190-1680 pairs, 57 cases). However, this rule does not seem to apply for the Storm-petrels, as their estimated population size is between 5000 and 8000 breeding pairs, but during the period of 41 years only 19 grounding cases were reported. It may be assumed that, given the small and inconspicuous nature of this species, the chances of encountering grounded Storm-petrels are much lower than for the larger shearwaters. Similarly, it is more likely that grounded Storm-petrels are predated more by cats, dogs, rats and gulls. This may go some way to explaining the apparently low number of Storm-petrel groundings recorded in the Maltese Islands.

The number of cases is increasing alarmingly in what seems to be an exponential trend while at the same time population sizes of the two shearwater species have been documented as decreasing (Sultana *et al.* 2011, Borg 2017). This trend is even more distinct when considering the years during EU LIFE projects managed by BirdLife Malta (2006 – present). This may be, in part, due to the rise of public awareness to grounded seabirds leading the public to report more incidents. Media campaigns appealing to the public for help in rescuing grounded birds started in the 1980s focusing on Scopoli's Shearwaters. These campaigns intensified during the successive EU LIFE projects run by BirdLife Malta: LIFE Yelkouan Shearwater Project (2006–2010); LIFE+ Malta Seabird Project (2011–2016) and the LIFE Arċipelagu Garnija Project (2016–2020). Since 2016,

local press releases appealing for the help of the public to rescue grounded birds have been issued twice per year, once prior to the Yelkouan Shearwater fledging period and again before the corresponding period for Scopoli's Shearwaters. Additionally, other press releases on the number of rescued birds after the season have been issued, together with online posts on social media. Unfortunately, data for social media post impact was not retrievable before 2017. Furthermore, no data could be obtained for media featured on television news channels. The public awareness data presented in this paper may serve as a baseline for future study. In recent years, BirdLife Malta have noted an increase in knowledge about the affected species and wider light pollution problem among those reporting grounded seabirds.

The extent and steepness of the increment of cases in the last decade highlights the fact that the sources of light pollution are not being properly addressed, and therefore the impacts on seabirds are still increasing. In fact, record numbers of grounded Yelkouan and Scopoli's Shearwaters were recorded successively in 2017 and 2018. As our results show, the mortality of grounded fledglings, Yelkouan Shearwaters in particular (10.5%), is worrying when considering the multiple other threats that this species faces leading to its classification as Vulnerable to extinction (BirdLife International 2018). The true figure for the mortality of grounded fledglings is expected to be higher as many are never found and are likely predated by feral cats or dogs or succumb to injury whilst on land (Rodriguez *et al.* 2017a). The fate of successfully released petrels remains unknown since the chance of recapture using conventional ringing methods is very small. Further investigation into their fate post-release is needed to ascertain whether recovery and rehabilitation of grounded fledglings is a viable conservation tool. In the absence of such knowledge, recovery and release campaigns of grounded fledglings must continue. Meanwhile, the intensification of long-term capture-mark-recapture effort within seabird colonies close to grounding hotspots will increase the recapture probability of returning birds. Tracking grounded birds post-release could be achieved using Platform Transmitter Terminals (PTTs); however, consideration should be given to the body condition of potential negative impacts such a device could have on an already rehabilitated bird.

We conclude that this problem, which should be acknowledged according to the important role of Malta in the conservation of these species on a global level, is in need of immediate action in order to reduce the existing levels of light pollution both through corrective and preventive measures.

The issue has been exposed and addressed with specific solutions in a comprehensive report produced by BirdLife Malta (Raine *et al.* 2007), with a recent data update by Mula-Laguna *et al.* (2014) and here including the latest data from 2014–2018. A recent report by Brincat & Pace (2018) includes suggested mitigation measures to reduce light pollution at and in the vicinity of colony sites affected by light pollution across the Maltese Islands. These mitigation measures are often simple and inexpensive; implementing them would not only reduce the impacts on Malta's avifauna, but also be beneficial for human health and reduce energy expenditure and improve the carbon footprint for both the private sector and the government (Pace 2002).

Our findings suggest that any action plan for light pollution reduction should focus on the major light-induced grounding hotspots identified here. Overall, a reduction of Malta's light pollution problem is believed to be a crucial conservation measure to safeguard the future of Malta's seabirds. Judicious planning and preventative policies that look at the problem holistically are much needed to avoid repeating the mistakes of the past. Environmental Impact Assessments for developments in coastal areas, protected sites or areas with good levels of natural darkness should feature seabirds prominently.

The ultimate responsibility for applying the principles of sensitive development and taking the appropriate measures falls on the shoulders of policy makers, planners and enforcement agents, as well as private initiatives, all of whom hold the power to prevent or rectify the negative consequences of light pollution. We expect that the work outlined here can serve as a tool for decision-makers in the process of taking focussed action, quickly and efficiently targeting the areas revealed as most problematic.

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