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Short communication

Eagle effects on seabird productivity: Effects of a natural experiment

J. Hentati-Sundberg [a,*], S. Melchiori [b], P.-A. Berglund [c], O. Olsson [d]

[a] Department of Aquatic Resources, Swedish University of Agricultural Sciences, Uppsala, Sweden
[b] University of Bologna, Italy
[c] Baltic Seabird Project, Sanda Västerby 568, 623 79 Klintehamn, Sweden
[d] Stockholm Resilience Centre, Stockholm University, Sweden

A R T I C L E I N F O

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A B S T R A C T

Altered human presence, which resulted from COVID-19 lockdowns, led to instant and wide-ranging effects on wildlife across the globe. While humans have gradually reappeared in nature after the lockdowns, it has remained unclear how persistent these lockdown effects have been on ecosystems. We have earlier reported an unexpected chain of events linked to the closing of the tourist traffic to an iconic seabird island in the Baltic Sea. When tourists disappeared, the number of white-tailed eagles rose dramatically, which had strong negative effects on breeding common murres. Using data from the first post-lockdown season (2021), when human presence increased, we document a sudden return to pre-lockdown conditions with fewer eagles, lowered disturbance of murres and recovered murre productivity. However, eagle disturbances of murres remained in an isolated part of the island, revealing that the interaction between humans, eagles and seabirds occur at a small geographical scale. This suggests that small-scale mediation of human behavior can be effective in mediating animal behavior and thereby allow for co-existence between seemingly conflicting conservation goals.

1. Introduction

A social-ecological systems perspective is increasingly advocated in the conservation field (Mace, 2014; Miller et al., 2012; Sala and Torchio, 2019). The necessity of such integrated perspective was highlighted by the COVID-19 lockdown, which demonstrated the tremendous and sometimes unexpected effects humans have on global wildlife (e.g. Bates et al., 2021; Corlett et al., 2020; Manenti et al., 2020; Montgomery et al., 2021). The effects of human disappearance on species and ecosystems due to lockdowns were sometimes very fast – ranging from days to weeks – but as humans start reappearing in nature, the persistency of these effects have remained unclear.

We have earlier reported an unexpected chain of events linked to the closing of the tourist traffic to Stora Karlsö, an iconic seabird island in the Baltic Sea. As tourists disappeared, the number of non-breeding white-tailed eagles *Haliaeetus albicilla* increased sevenfold. Their presence and frequent hunting attempts disturbed breeding common murres *Uria aalge* and led to the worst breeding season ever recorded on this island (Hentati-Sundberg et al., 2021). The recovery of sea eagles (including bald eagle, *Haliaeetus leucocephalus*) have been a steady process across the northern hemisphere in recent decades (Eakle et al., 2015; Evans et al., 2009; Herrmann et al., 2011; Krüger et al., 2010; Mougeot et al., 2013; Winder and Watkins, 2020). The return of sea eagles is a remarkable nature conservation achievement, parallel to the widespread recoveries of e.g. marine and terrestrial top-predators (Can et al., 2014; Magera et al., 2013; Mech, 2017). The northern hemisphere sea eagle recovery has however had the side effect of negative impacts on another highly valued group of animals – aquatic birds (Cruz et al., 2019; Hipfner et al., 2012; Horton, 2014; Ward Myran, 2021). In the Baltic Sea, the increasing white-tailed eagle population has recently been shown to negatively impact several seabird species, including Caspian terns (Lötberg et al., 2022) and common eiders (Öst et al., 2018). On Stora Karlsö, however, no long-term impact from the increasing white-tailed eagle population occurred until the COVID-19 lockdown. The lock-down removed the concealed guarding effect of tourists, and resulted eagle disturbance impacting Stora Karlsö's seabirds (Hentati-Sundberg et al., 2021).

Human – nature interactions, similar to other complex adaptive systems, often change in a nonlinear fashion (Folke et al., 2004; Levin, 2002; Rocha et al., 2015; Scheffer and Carpenter, 2003; Sugihara et al., 2012). Similarly, ecosystems that undergo substantial shifts may not bounce back after the drivers have been returned to previous levels. This

* Corresponding author at: Biocentrum, Sveriges lantbruksuniversitet, 750 07 Uppsala, Sweden.
E-mail address: jonas.sundberg@slu.se (J. Hentati-Sundberg).

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type of change is often termed hysteresis, meaning that a system's history shapes is current state of a system (Hobbs, 2007; Michaels et al., 2020; Nyström et al., 2012; Suding and Hobbs, 2009; Van Meerbeek et al., 2019). In the case of COVID-19 lockdown effects on wildlife, a hysteresis could occur if animals would habituate to the temporarily changing conditions under the lock-down period, thereby weakening the species interactions (Gaynor et al., 2021). We used the 'natural experiment' of COVID lockdown and release, to test whether Stora Karlsö's seabird colonies are experiencing hysteresis, and formulated three contrasting hypotheses: (A) No habituation: eagles would disappear as tourists return, and seabird productivity would return to normal; (B1) Habituation in one species: eagles would habituate to human presence and continue to impact seabirds; and (B2) Habituation in two species: eagles would habituate to human presence but seabirds would also habituate to eagles, potentially allowing for co-existence. Here, we report on our findings from the first post-lockdown season in 2021, when tourists were again allowed on the island, although in limited numbers. By comparing seabird behavior and productivity and eagle numbers and behavior before, during and after the lockdown, we provide insights on the interactions between these two species and humans.

2. Material and methods

We studied common murres and sea eagles (white-tailed eagle, *Haliaeetus albicilla*) on the island of Stora Karlsö, Baltic Sea, Sweden (57°17′1 N, 17°58′2E). The paper focusses on three consecutive years – 2019 (pre-lockdown), 2020 (lockdown) and 2021 (post-lockdown) but additional data from earlier years are included for comparison. We performed daily monitoring of common murres in a fixed study plot in the largest sub-colony on the northwestern part of the island (Fig. 1, area A) and noted presence of eggs and chicks, from which we calculated number of breeding attempts, phenology and breeding success. We used a CCTV camera system in the same area to study disturbances from eagles on an area with approximately 40 pairs of common murres, filming continuously throughout the breeding seasons. Disturbances were defined as occasions when murres synchronously left the breeding ledges. For each disturbance event, we noted time, number of birds before the disturbance, and the return of birds at two-minute intervals after the disturbance until 85 % of the birds were again present. The detailed analysis methods are reported in Hentati-Sundberg et al., 2021.

In 2021, the eagles present on the island were counted daily from the end of April until mid-July by 1–2 dedicated eagle observers. Near-daily observations of eagle numbers between mid-July and the end of August were recorded by the island warden. In 2021, in a small common murre sub-colony on the southwestern side of the island (Fig. 1, area C), a time-lapse camera (Brinno TLC200) was installed, taking an image every minute during the period 17 May – 28 June. The footage was analyzed in a similar manner as the CCTV footage with regards to disturbance events (described above). In 2021, white-tailed eagles made their first breeding attempt on Stora Karlsö in at least 150 years. The area around the nest (Fig. 1, Area E) were inspected for bone remains after the breeding season.

3. Results

The number of visiting tourists in the post-lockdown season recovered but was lower than before the pandemic due to remaining restrictions to avoid crowding on the tourist boat (Fig. 1, inset graph). The number of eagles on the island were lower in the post-lockdown season than during lockdown but higher than any time before the pandemic (Average max number observed per month 1.93, 19.3 and 10.3, for the pre, during and post lockdown periods, respectively, Fig. 2a). Specifically, the period just before the onset of the tourist traffic and a short period in the end of the summer stand out as having unusually many eagles in the post-lockdown season (Fig. 2b). In 2018, a pair of white-tailed eagles starting to build a nest on the southern part of the island,

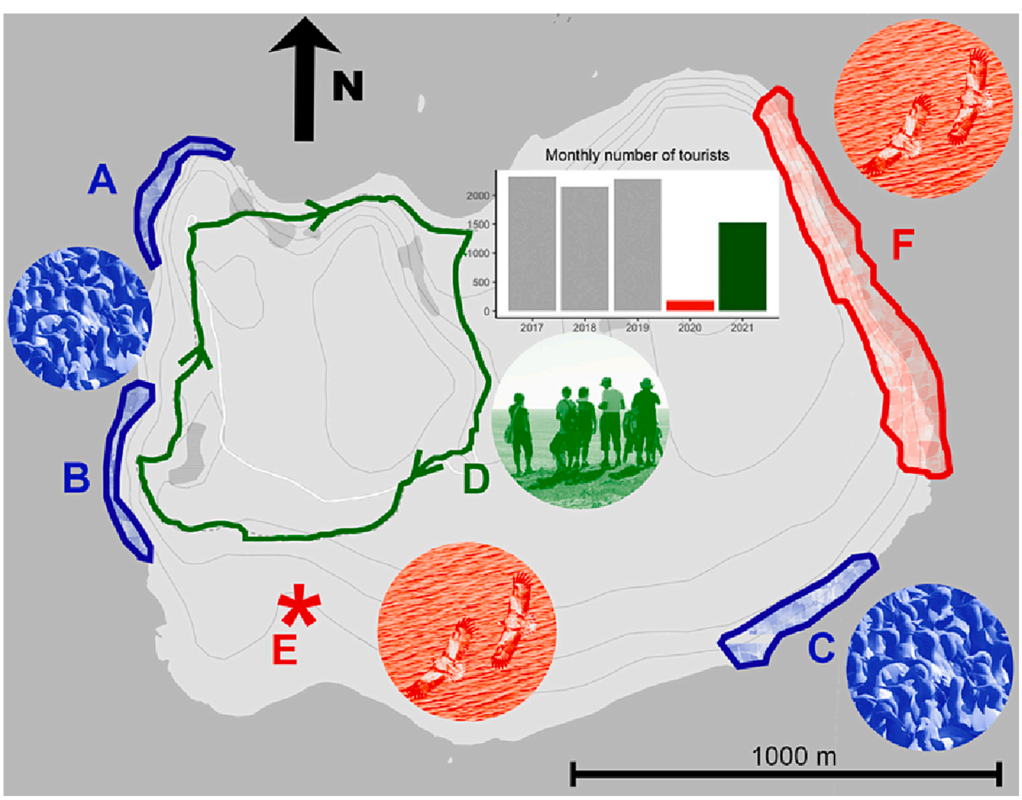

Fig. 1. Map of Stora Karlsö. (A-C) the Common murre colonies, (D) the tourist walking path, (E) approximate position of the eagle nest, and (F) the main location for immature roosting eagles. Inset graph shows average number of tourists in May and June in 2017–2021.

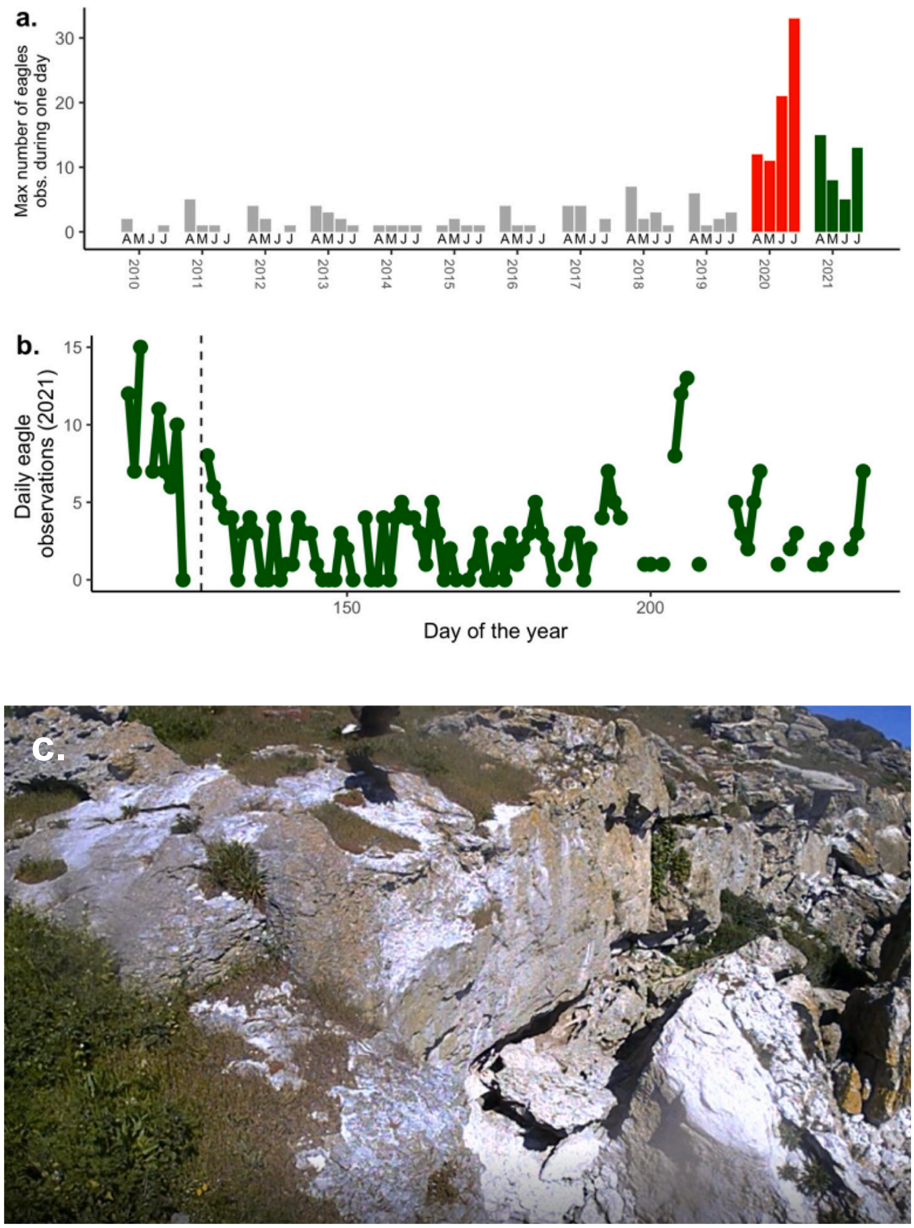

Fig. 2. Eagles, before, during and after the COVID-19 lockdown. (a) Max number of eagles per month in 2010–2021. Letters under bars denote month (April, May, June, July). Color denotes before, during and after the COVID-19 lockdown. (b) Max number of eagles observed per day in 2021. Vertical dashed line denotes the start of the tourist traffic in early May. (c) Eagle captured on time lapse camera May 19th 2021, in sub-colony C (see Fig. 1).

and in 2021, they made their first known breeding attempt, producing one chick that died in the middle of May. Based on analysis of bone remains, common murres were the eagles' most common target species, followed by razorbills and common eiders (Table 1). One of the adult eagles from the pair is depicted in Fig. 2c, flying over the sub-colony C.

The timing and duration of eagle disturbances on common murres in the main colony A (Fig. 1) was on a similar level in the post-lockdown as in the pre-lockdown seasons – markedly lower than during the lockdown (Fig. 3). However, in the smaller sub-colony C, located at the south-western corner of the island (Fig. 1), regular disturbances continued until June 1st, on average 54 min day^{-1}, which significantly more than the 5.6 min day^{-1} disturbance level at the main colony (95 % boot-strapped confidence interval for the difference between locations: 15.1–84.0 min day^{-1}), but still only a fraction of the 212 min day^{-1} recorded in the main colony during the lockdown (Fig. 3c).

Phenology and productivity in common murres were back on the long-term average level in the post lock-down period (Fig. 4). Median egg laying day in the first post lockdown year was 140.7 (SD = 4.89) which is eight days earlier than the 148.8 (SD = 6.53) observed during the lockdown and in line with the long-term trend for phenology (Fig. 4a). Productivity (hatching success) was 0.75 in the first lockdown year which near the long-term average for the period before the lock-down (0.76) and significantly higher than the record low 0.59

Table 1
Bone remains found around the eagle nest, August 2021.

Species	Number of inds.
Common murre *Uria aalge*	12
Razorbill *Alca torda*	4
Common eider *Somateria mollissima*	4
Velvet scooter *Melanitta fusca*	2
Great cormorant *Phalacrocorax carbo*	1
Herring gull *Larus argentatus*	1
Mountain hare *Lepus timidus*	1

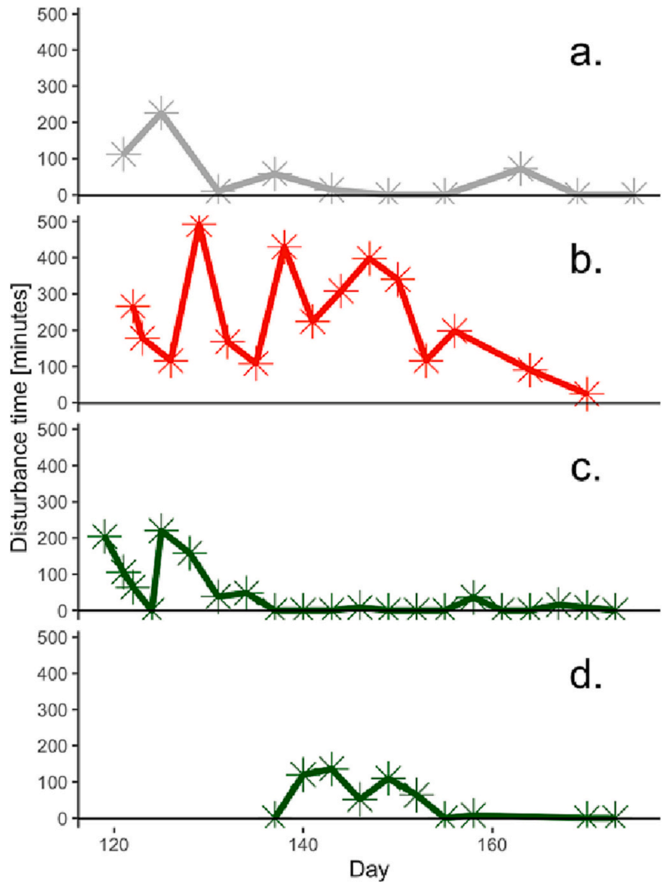

Fig. 3. Daily disturbance rates of common murres in the main sub-colony. (a) before (2019), (b) during (2020), and (c) after (2021) the COVID-19 lockdown, and (d) Disturbance rate in 2021 in the southwestern sub-colony C, close to the eagle nest.

observed during the lock-down (bootstrapped 95 % confidence interval for the difference between during and post lockdown 0.034–0.30) (Fig. 4b).

4. Discussion

When tourists returned to Stora Karlsö in early May 2021, although in limited numbers, eagle numbers declined and murre phenology and productivity returned to pre-lockdown levels. Accordingly, our data from the first post-COVID-19 lockdown season indicate a nearly linear dynamic in the interaction between tourists, eagles and seabirds – the instant system flip observed during the lock-down was reversed – supporting our hypothesis A. However, we cannot rule out that habituation in the studied species occurs at a slower pace. Studies of bald eagles have demonstrated both short-term habituation in behavior to regular disturbance activities (Stalmaster and Newman, 1978) as well as intergenerational habituation in nest site selection (Guinn, 2013). On the other hand, it is currently unclear whether murres have the same potential for habituation to eagle disturbances. A limited number of studies done so far have not found any clear signs of habituation of murre responses to human disturbances (Brisson-Curadeau et al., 2017; Olsson and Gabrielsen, 1990).

Despite there being fewer tourists in 2021 than in a normal year (Fig. 1), eagle numbers declined and remained low for the most part of the season, albeit higher than any time before the pandemic (Fig. 2a). A higher eagle observation effort in 2021 compared to earlier years (daily walks across the island) suggest that the observed decline compared to the COVID-19 lockdown year is robust. The timing of the decline also matches with the onset of the tourist traffic in early May (Fig. 2b). In the middle of the summer in 2021, we observed a new peak of white-tailed eagles, with up to 13 individuals. We speculate that these are juvenile individuals that disperse after fledging from the nearby island of Gotland, which hosts approx. 60 breeding pairs of white-tailed eagles (J. Månsson, Gotland County Administrative Board, pers. comm.).

Whereas the rate of disturbance on common murres decreased, and laying date and breeding success recovered in the tourist accessible main colony A, disturbance levels remained at a level about ten times higher in the southeastern sub-colony C that is close to the newly established eagle nest and the main roosting area for young eagles (Fig. 1). The fact that we have never observed an eagle successfully hunt a common murre, but murres nevertheless being the main prey item found around the nest (Table 1), gives a complementary indication of interactions between murres and eagles at a small (within island) geographical scale. Such micro-scale interactions between tourist presence, eagle behavior and murre productivity suggests conservation policies that are spatially fine-tuned may be able to meet seemingly conflicting goals. While the long-term and wide-ranging increase of white-tailed eagles could pose an existential threat to seabird populations (Hipfner et al., 2012), local management measures such as tourist presence, even within a 2.5 km^2 island, could possibly mitigate the conflict and promote co-existence. Other examples of such small-scale conservation measures have been proposed and applied with varying success for conserving biodiversity within urban areas (Garrard et al., 2018), mitigating human-carnivore conflicts (McManus et al., 2015), excluding seals from critical recruitment areas of endangered salmons (Graham et al., 2009) and reducing conflict between avian predators and captive honey bees (Goras et al., 2022). The common denominator for these examples is that strategic human interventions are used to conserve highly valued services in highly impacted ecosystems, rather than conserving pristine species assemblages or habitats. With seabirds being affected by multiple human induced threats including climate change, fisheries and invasive species (Dias et al., 2019), we argue that managing eagle disturbance is a reasonable strategy in present-day seabird conservation, in ecosystems that are far from the state where the interacting species once evolved. Management measures in this context could be as simple as allowing rather than preventing humans to visit conservation areas.

The COVID-19 lockdowns put the role of humans in ecosystems in a flashlight (Bates et al., 2021; Corlett et al., 2020). To paraphrase Bates et al., the role of humans as biodiversity custodians shall not be underestimated – and based on our own experience, we call for further attempts to utilize human presence as a strategic conservation measure. More research integrating animal and human behavior can help suggest policies for achieving complex and seemingly conflicting conservation goals (Berger-Tal et al., 2016; Gaynor et al., 2021; Miller et al., 2012), with humans taking an informed and active role as stewards (Chapin et al., 2010), or indeed, custodians (Bates et al., 2021). The ultimate goal of such endeavors may not be the conservation of species or ecosystems as such, but a sustainable co-existence of humans and nature, manifested through dynamic social-ecological interactions, learning and adaptation (Keith et al., 2011; McCarthy and Possingham, 2007).

Author statement

The work is all original research carried out by the authors. All authors agree with the contents of the manuscript and its submission to the journal. No part of the research has been published in any form elsewhere. The manuscript is not being considered for publication elsewhere while it is being considered for publication in this journal. All sources of funding are acknowledged in the manuscript. All appropriate ethics and other approvals were obtained for the research.

Declaration of competing interest

The authors declare no competing interest.

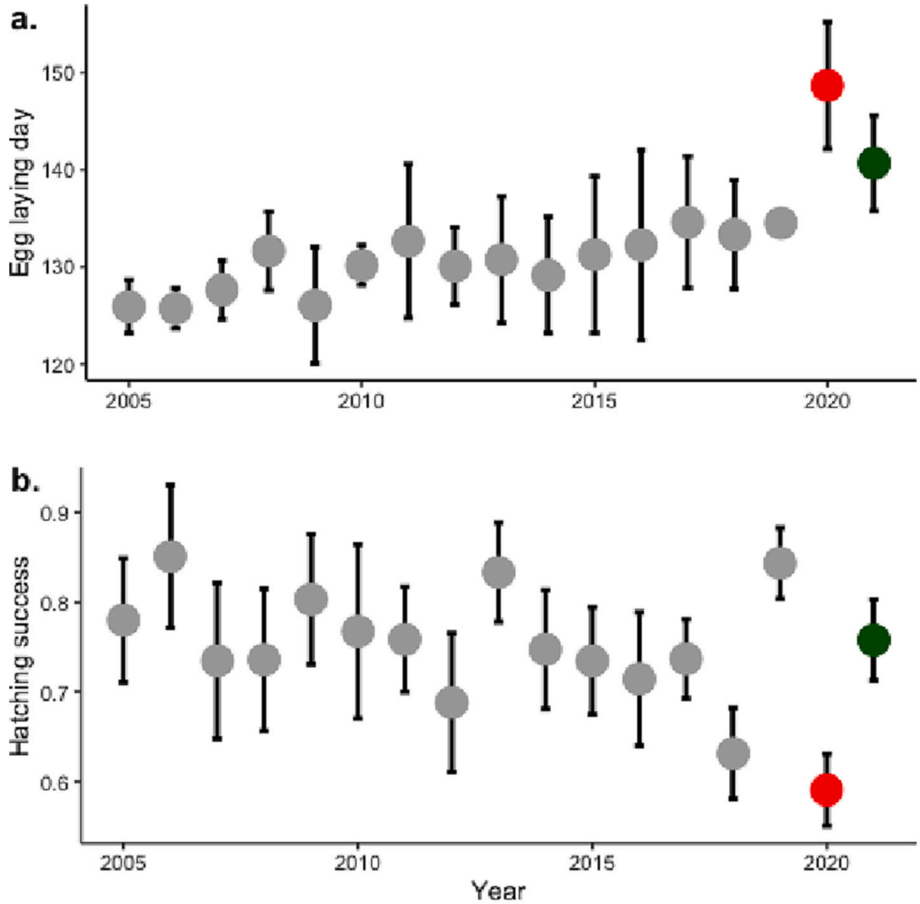

Fig. 4. Common murre performance. (a) Egg laying date, and (b) Hatching success of common murres 2005–2021, with period before, during and after the COVID-19 lockdown indicated as grey, red, and green, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Data availability

Data will be made available on request.

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