Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Perspective

The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: Insights from the first European locked down country

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ABSTRACT

The COVID-19 pandemic zoonosis has determined extensive lockdowns worldwide that provide an unprecedented opportunity to understand how large-scale shifts of human activities can impact wildlife. We addressed the impacts of the COVID-19 lockdown on wildlife in Italy, the first European country that performed a countrywide lockdown, and identified potentially beneficial and negative consequences for wildlife conservation and management. We combined a qualitative analysis of social media information with field data from multiple taxa, data from citizen science projects, and questionnaires addressed to managers of protected areas. Both social media information and field data suggest that a reduction of human disturbance allowed wildlife to exploit new habitats and increase daily activity. The field data confirmed some positive effects on wildlife conservation, such as an increase in species richness in temporarily less-disturbed habitats, a higher breeding success of an aerial insectivorous bird, and reduction of road-killing of both amphibians and reptiles. Despite some positive effects, our data also highlighted several negative impacts of the COVID-19 crisis on wildlife. The lower human disturbance linked to lockdown was in fact beneficial for invasive alien species. Results from questionnaires addressed to managers of protected areas highlighted that the COVID-19 lockdown interrupted actions for the control of invasive alien species, and hampered conservation activities targeting threatened taxa. Furthermore, the reduction of enforcement could cause a surge of illegal killing of wildlife. The COVID-19 crisis, besides having deep socio-economic impacts, might profoundly affect wildlife conservation, with potentially long-lasting effects.

1. Introduction

Almost every nation in the world is being or going to be challenged by the pandemic zoonosis identified as Coronavirus disease (COVID-19). The etiologic agent is a novel zoonotic coronavirus, SARS-CoV-2, that determines severe respiratory symptoms (Cascella et al., 2020). The origin of the disease is uncertain: like many other coronaviruses, SARS-CoV-2 likely originated in bats, but research is ongoing to investigate if the virus has been transmitted to humans directly from bats or through intermediate hosts (Wu et al., 2020). Although emerging pathogens that affect humans are rarely considered as invasive organisms, SARS-CoV-2 shows several traits typical of invasive species (e. g. quick adaptation to new environments/hosts, quick spread, large-scale geographic dispersal via human transportation networks) (Nunez et al., 2020). SARS-CoV-2 was first isolated in China, during December 2019 (Kraemer et al., 2020), and its rapid subsequent spread has enormously affected people's daily lives and public health systems (Baloch et al., 2020).

The majority of governments around the globe has responded to the spread of the disease by declaring national emergencies and creating more or less extensive lockdowns to facilitate social distancing (Karnon, 2020). These lockdowns have had severe societal and economic effects. Lockdown impacted the shape of human displacements worldwide, with deep consequences on many behaviours, from daily activity to

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social dynamics (Ji et al., in press; Krause et al., 2020). Such sudden changes of human activities at a global scale have potentially major effects on the environment, and provide an unprecedented opportunity to understand how large-scale shifts of human activities can impact on wildlife (Corlett et al., 2020; Rutz et al., in press).

Until now, multiple studies have assessed how changes in climate and in environmental conditions affected the spread and the dynamics of viral diseases potentially dangerous for humans and wildlife (Foley et al., 2015; Ramasamy and Surendran, 2012). Yet the reverse, i.e. the effect that a human pandemic may have on the environment and wildlife, is a novel and understudied topic. Unsurprisingly, the pandemic is determining reductions in air and water pollution, especially in those countries which have been heavily impacted by COVID-19 - such as China and Italy - because industry, traffic, public transportations and aviation have grinded to a halt. For instance, scientists first observed a decrease in greenhouse gas emissions in China, where the pandemic started (Dutheil et al., 2020). This period of global slowing of actual human activities has recently been defined as an “anthropause” (Rutz et al., in press). The impacts of reduction of human activities are not limited changes in emissions; worldwide newspapers and social media started to pop up posts and news about unprecedented wildlife sightings in urban areas (Rutz et al., in press), often claiming that “nature just regains its space” (Elliot, 2020; The Economist, 2020).

However, negative effects are also possible (Zhang et al., 2020), yet very limited information is available on this. Considering that lockdowns stopped many actions normally performed for the conservation of native wildlife and for the management and control of alien invasive species (IAS), we hypothesise that lockdowns may also have negative impacts on conservation, besides the supposed benefits claimed by the media.

Italy has been the first non-Asian country to experience a severe COVID-19 outbreak, and to establish strictly enforced country-wide lockdown measures (Remuzzi and Remuzzi, 2020). On March 11, 2020, severe restrictions to movements and economic activities were enforced, and a complete ban of recreational, touristic, and non-essential economic activities was established (McKibbin and Fernando, 2020; Paterlini, 2020; Remuzzi and Remuzzi, 2020) followed by impressive reduction of roadside traffic (Pepe et al., 2020). Such stringent lockdown measures were confirmed until May 4, 2020, when restrictions started to be progressively lifted. Such a lockdown implied almost two months of unprecedented reduction of human disturbance throughout the country during a critical period for many wildlife species, which were starting their spring reproductive activities after winter.

To qualitatively assess effects on wildlife, we first performed a survey of news published by online magazines and social media, reporting observations both from Italy and worldwide. Second, we analysed empirical data, comparing the activity, spatial distribution, abundance, breeding success, and mortality of multiple wildlife species recorded during the lockdown, with those recorded at the same sites during previous years. Third, we analysed questionnaires submitted to managers of protected areas to understand how the lockdown has impacted practical conservation actions. Our study unveils the complexity of COVID-19 lockdown impacts on wildlife, and identifies both potentially beneficial and negative effects (Fig. 1).

2. The good: effects of reduced human disturbance on spatial or ranging behaviour, breeding success, and mortality

2.1. Changes of wildlife activity during the lockdown observations from the media

From the beginning of March until April 23, 2020, we performed a broad survey of online newspapers, Facebook and Instagram posts linking observations of wildlife to COVID-19 lockdown for Italy and other countries (Supplementary 1). On the basis of 102 news/posts related to 156 observations that embrace 73 species/taxa and some descriptions of general patterns, it appears that the lockdown triggered both the exploitation of novel/unusual habitats and an increase of daily activity of otherwise nocturnal/crepuscular species, as evidenced by 83 observations related to observations of animals in Italy (Fig. 2). The pattern is confirmed not only for Italy but also for other 25 countries for which news were reported by Italian media (Supplementary 2). Most news reported unusual sightings in urban environments (Supplementary 2). Although most observations referred to species that frequently occur in urban areas, such as the red fox *Vulpes vulpes* and the wild boar *Sus scrofa*, some provided indications of urban areas exploitation by less common species, such as the wolf *Canis lupus* and deer (fallow deer *Dama dama*, red deer *Cervus elaphus* and roe deer *Capreolus capreolus*). Moreover, many reports suggested a change in daily activity, whereby normally nocturnal species were frequently observed during daytime (Fig. 2).

2.2. Activity and abundance changes during the lockdown: evidence from field data

Records from the media were not quantitative. Therefore, we supported these reports with quantitative field data for some birds and mammals (Fig. 3A). First, we analysed data from a long-term citizen-science project (Supplementary 1) that is monitoring the distribution of the crested porcupine *Hystrix cristata*, a widespread large-sized rodent (Mori et al., 2018; Mori et al., 2013). Crested porcupine records within human settlements are rare and generally attract newspapers and public attention, although this species often occurs in suburban areas and urban parks (Grano, 2016; Lovari et al., 2017; Santini et al., 2019). We compared the number of records (confirmed by pictures) of porcupines in March–April between the years 2011–2019 and 2020 throughout Italy, and we also noted those in urban areas. Despite the lockdown, the total number of records of porcupines in 2020 was similar to that of the previous years, suggesting that the survey effort did not markedly change among years. However, the proportion of records in urban areas increased remarkably in 2020 compared to previous years (Fig. 3B), whereas the number of observations in non-urban settings did not change (likelihood ratio test, $\chi^2 = 8.21$, d.f. = 1, one-tailed $P = 0.002$).

Second, we surveyed the breeding activity of the Kentish plover *Charadrius alexandrinus*, a wading bird species of European conservation priority (Annex I of the EU Birds Directive 2009/147/EC), along a highly anthropized and touristic littoral strip, the 13 km-long Cavallino-Treporti peninsula (Venice, Northern Italy; Fig. 3C; Supplementary 1). This species commonly breeds on the inner portion of sandy beaches and is highly sensitive to human disturbance, which can considerably reduce breeding output (Gomez-Serrano and Lopez-Lopez, 2014; Pietrelli and Biondi, 2012). During 2016–2019, between 9 and 13 pairs built their nest along the beach in the period March 1–April 25, mostly in the few less disturbed stretches of the beach. During 2020, 9 nests were built on the beach, but several nests were built in areas where pairs never settled in 2016–2019, leading to a significantly more even spread of nests along the beach in 2020 compared to previous years (Fig. 3C). The median nearest-neighbour distance of nests during 2016–2019 was 278 m ($N = 44$ nests) and 1080 m in 2020 ($N = 9$) (Mann-Whitney U test, Z = 2.84, one-tailed $p = 0.002$).

Third, we obtained information on the occurrence of waterbird species at a small (7.4 ha) artificial lake near Mantua (Northern Italy; Supplementary 1). This small lake is included within a local protected area, whose shores are widely used for recreational activities (e.g. outdoor sports, fishing). Waterbirds were counted at this site during four census sessions in April 2019, and the count was repeated at the same dates in 2020. Overall, only 2 species were observed in 2019, while 10 species were observed in 2020. The abundance (maximum number of individuals observed across the four census sessions) of these 10 species was remarkably larger in 2020 compared to 2019 (Wilcoxon matched-pairs test, Z = 2.83, one-tailed $p = 0.002$) (Fig. 3D). A few

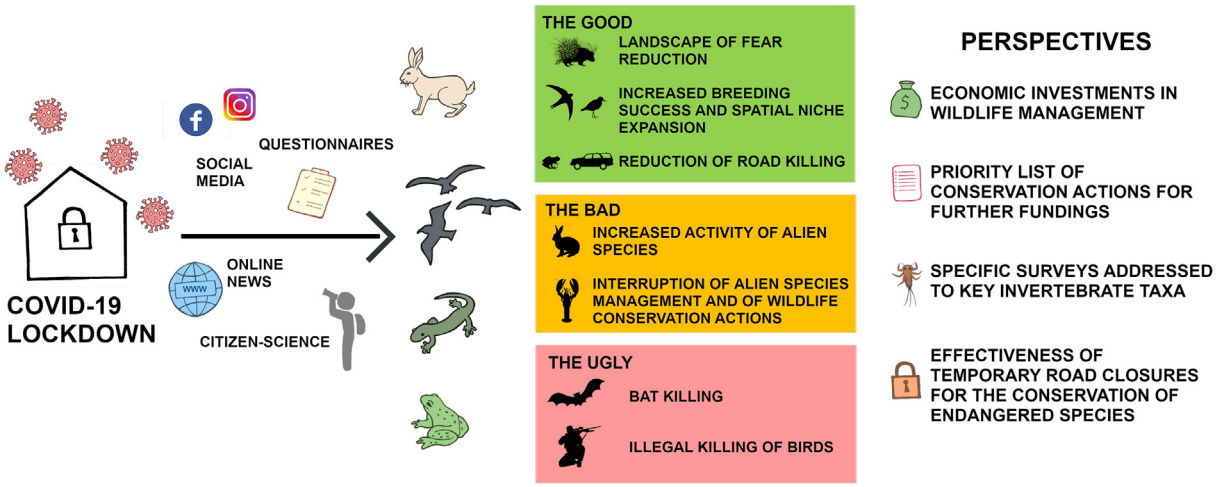

Fig. 1. The main effects of COVID-19 lockdown on wildlife, and the perspectives for its management. The assessment of the effects COVID-19 lockdown was performed using multiple tools (analysis of media news, field records and questionnaires sent to managers of protected areas).

species that were rarely observed in this area since several years (Grattini and Nigrelli, 2019), such as the crested grebe *Podiceps cristatus* (never observed breeding since 1999 despite regular monitoring; Grattini, 2000) and the little grebe *Tachybaptus ruficollis*, were found to breed in the area during April 2020 (Grattini and Nigrelli, 2019).

2.3. Broad-scale changes in landscape of fear: fact or fiction?

These findings suggest that rapid large-scale decreases in human disturbance have led to rapid changes in the human-induced landscape of fear (Bleicher, 2017; Lodberg-Holm et al., 2019) generated by human infrastructures, activities and widespread presence, with animals showing up in unusual places that are normally perceived as too dangerous. A similar effect could potentially explain the increase in daily

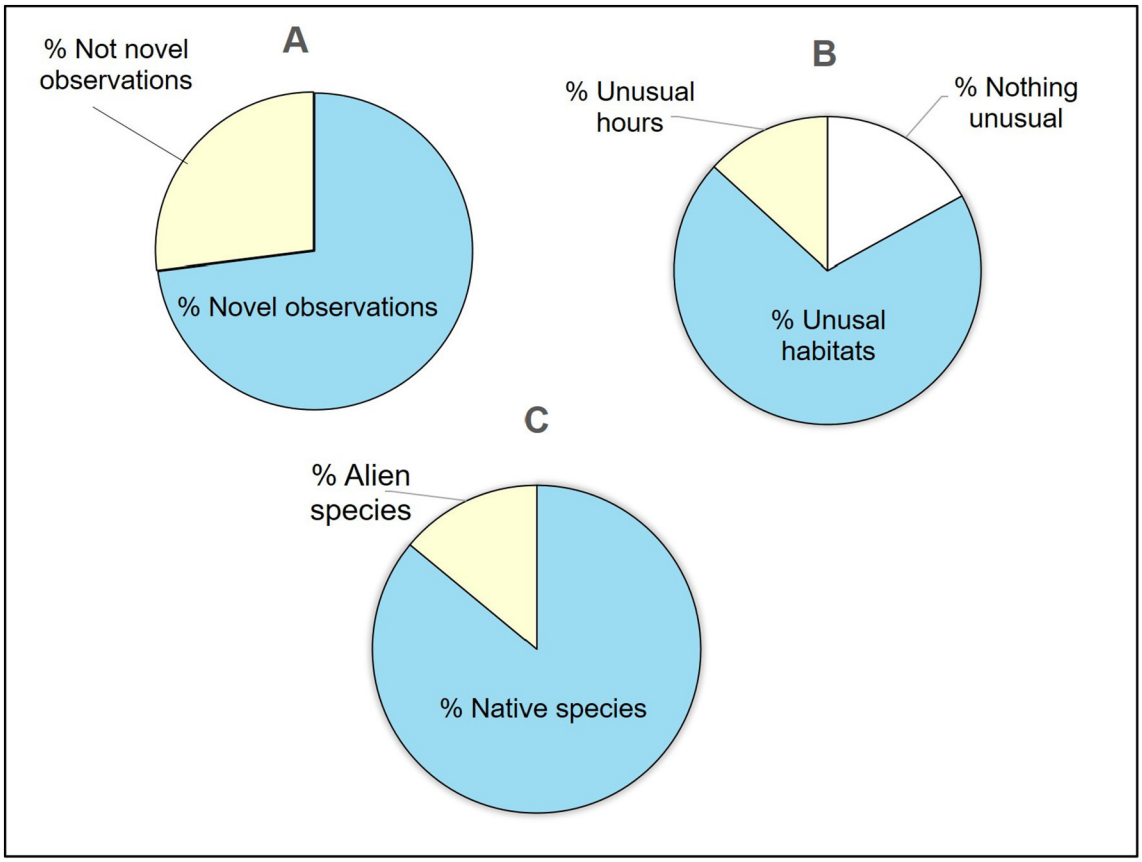

Fig. 2. Overview of 83 wildlife observations in Italy reported by online news/posts. A: Novelty of the observations; comparison between online observations that have been published exclusively during COVID-19 lockdown in Italy and observations that have been reported online by news and social posts before 2020. B: Proportion of observations related to the occurrence of wildlife in unusual habitats, unusual time of day or in habitats usually known to be exploited by the species to which the observation is referred. C: Proportion of observations reporting alien species vs. sightings of native species.

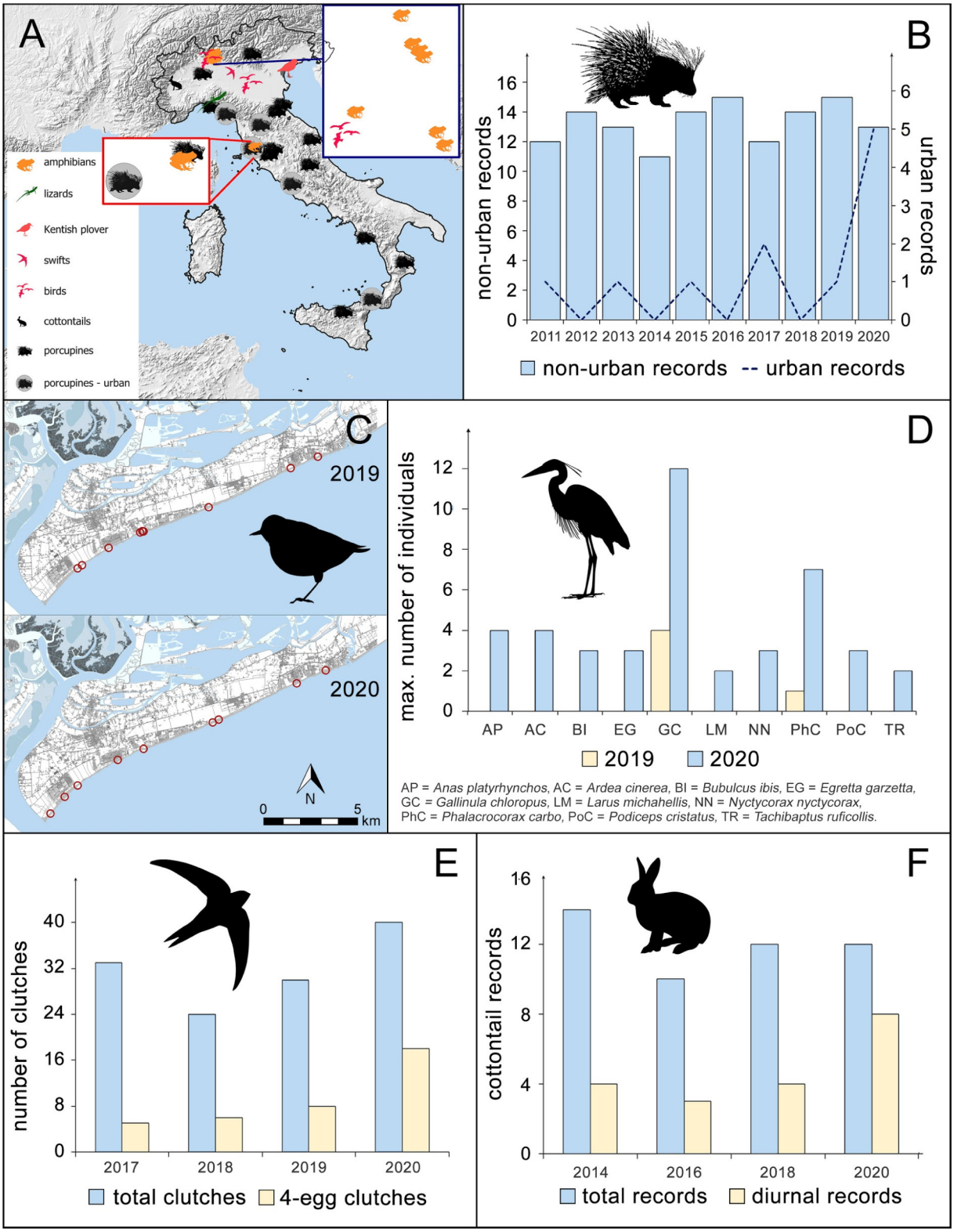

Fig. 3. Changes in activity, distribution and breeding success of some vertebrate species during the Italy 2020 COVID-19 lockdown compared to previous years. A: Map of Italy showing the geographic locations where quantitative data used to assess lockdown effects have been collected; symbols refer to the different taxa. B: Citizen-science records of crested porcupines between March and April 2011–2020 in Italy; bars represent records in non-urban areas, dotted lines show the number of urban records. C: Position of Kentish plover nests (open red circles) along the Cavallino-Treporti peninsula (Venice, northern Italy) during March–April 2019 (upper panel) and 2020 (lower panel) (n = 9 nests in both years); the data collected in 2020 show a spread toward the highly touristic and normally unsuitable Punta Sabbioni area (on the south-west of the peninsula), which was never occupied in previous years of monitoring (2016–2019). D: Maximum number of individuals of 10 waterbird species counted during April 2019 and 2020 at an artificial lake that is normally subjected to recreational disturbance (near Mantua, northern Italy). E: Number of clutches of the common swift during 2017–2020 at a colony site near Brescia (northern Italy), showing an increase of the frequency of 4-egg clutches in 2020 (45%) compared to previous years (2017–2019, 15–27%). F: Number of cottontail records at the Lingotto railway station (Turin, Northern Italy) in March–April, showing an increase of diurnal records in 2020 compared to previous years. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

activity of animals that are normally active during the night or at twilight.

However, it must also be noted that some news that used positive words to convey information on lockdown effects actually described observations of wildlife that does not occur during the lockdown period only. Once that we detected a post for a certain Italian locality, we verified if similar observations had been reported for the same locality and the same habitat also before 2020 (see Supplementary 1 for details). This was indeed the case for 27% of wildlife observations (Fig. 2A; Supplementary 2). Hence, the societal emphasis on the lockdown may have sometimes led to inappropriate connections, still the increased detection of wildlife due to changes in behaviour was likely substantial.

Nevertheless, we wish to point out that detection rates can be highest during a lockdown, even in the absence of variations in daily activity and in human-induced landscape of fear. This is clearly exemplified by acoustic surveys of singing birds. Noise and other disturbances determined by human activities may in fact reduce bird detectability by lowering observers' ability to hear a call or song (Brambilla et al., 2020; Kissling et al., 2010; Pacifici et al., 2008). Therefore, the strong reduction of background noise caused by e.g. road traffic may result in increased detection rates and/or detection distance, especially in noisy environments such as urban areas. Moreover, the increase in urban sightings of wild species could also be due to increased observation effort. Many people (e.g. birdwatchers, amateur and professional wildlife biologists) have been spending an unprecedented amount of time at home looking for birds and wildlife in general, increasing survey efforts in urban areas. We obtained empirical evidence for both of these effects. At an urban site regularly surveyed during all the springs 2011–2020 (Cantù, Northern Italy; Supplementary 1), common pheasant *Phasianus colchicus* and marsh tit *Poecile palustris* were never detected, and short-toed treecreeper *Certhia brachydactyla* was detected only once during the breeding season in 2011–2019, despite they have been regularly breeding some hundreds of meters far from the monitoring site. All those species were heard in 2020 during the lockdown, likely thanks to the strong reduction in background noise. The possible link between the increase of sampling efforts in urban areas and the variety of species observed in towns is exemplified by the observations recorded at the same site. Here, the number of bird records collected in the period March 9–April 26 ranged between 453 and 774 in 2011–2019, whereas it was definitely larger in 2020 (1627 detections). Similarly, the number of bird species (total, $N = 89$) observed each year during the same period varied between 28 and 38 in 2011–2019 but peaked to 77 in 2020, being highly correlated with the sampling effort expressed as the number of observations collected. For species that are detected mainly based on acoustic surveys, like birds, the strong increase of observation effort during the lockdown could explain a substantial part of the increase in species richness and in first sightings of many species in urban areas.

Likewise, many data on medium- and large-sized mammal species recorded during COVID-19 lockdown do not necessarily represent changed patterns of behaviour or distribution. Mammals like cetaceans and carnivores may rapidly catch the human affective sphere, stimulating positive emotions (e.g. Colléony et al., 2017; Glikman et al., 2012), thus their images are widely used to communicate a reassuring sense of re-expanding nature. In fact, even though observations of roe deer, wild boar and grey wolf have most likely effectively increased in urban areas (Supplementary 2), a lot of pictures have been described as unusual findings linked to the lockdown but actually were false, being both recorded in other periods and for other localities/habitats (e.g. Daly, 2020). This highlights the complexity of using social media posts to assess actual wildlife distribution or activity patterns.

2.4. Lockdown effects on breeding success

The reproduction and abundance of aerial insectivorous birds, like swallows and swifts, is negatively impacted by industrial air pollution, either directly and/or indirectly (Newman et al., 1985). We monitored the breeding success of a widespread aerial insectivorous Afro-Palearctic migratory bird, the common swift (*Apus apus*) at a breeding site in northern Italy, where up to 80 pairs breed each year in nestboxes (Supplementary 1). Common swifts arrive at the colony in late March-early April, and begin laying eggs in the second half of April (Rubolini et al., 2007). By the beginning of May about half of the breeding pairs at the study colony have completed laying their eggs. Female swifts lay a single clutch of 2–4 eggs per breeding season (modal clutch = 3 eggs) (Brichetti and Caffi, 1995). The reproductive investment of swifts is affected by local aerial insect abundance (Cucco and Malacarne, 1996), and air pollution, especially nitrogen dioxide, can negatively impact on insect biomass (e.g. Campbell and Vallano, 2018) or directly impair the fitness of birds via inhalation exposure (Sanderfoot and Holloway, 2017). We compared the clutch size of those clutches that were completed up to early May 2020 with clutches laid in 2017–2019 (see Supplementary 1). Like many other locked down areas, northern Italy has experienced a huge decrease of several air pollutants in March–April 2020, including nitrogen dioxide, benzene and sulphur dioxide (Buonocore, 2020; Muhammad et al., 2020). We therefore predicted larger clutch size in 2020 compared to previous years. Indeed, the frequency of 4-egg clutches during 2020 was remarkably higher (45%) compared to 2017–2019 (15%–27%) (Fig. 3E) (likelihood ratio test, $\chi^2 = 6.87$, d.f. = 1, one-tailed $P = 0.009$).

These findings parallel recent studies reporting beneficial effects of reduced fishing and boat disturbance on the breeding success of sea turtles in Thailand, India and Florida, caused by the lockdown (Bates et al., 2020; Kotala, 2020; The Guardian, 2020).

2.5. Road traffic reduction and decrease of road-killing

The strong road traffic reduction during lockdowns is expected to decrease the ecological impacts of roads on wildlife populations, especially for those species that are highly impacted by road-killing. For instance, to reach breeding sites, amphibians often perform massive migrations during which road-killing determines high mortality rates (Beebee, 2013). We compared the number of road-killed amphibians during the spring breeding migration at 8 sites in Italy where toad crossing rescue occurs (Bonardi et al., 2011) and that were surveyed both during 2019 and 2020 (Supplementary 1). At all sites, local police reports indicate an 80–100% reduction in the traffic amount during night hours (N. Fumagalli, pers. comm.). Across all sites, 408 common toads (*Bufo bufo*) and 16 agile frogs (*Rana dalmatina*) were found dead in 2019, whereas only 38 common toads and no agile frogs were found dead in 2020 (Supplementary 3). The decrease of the number of road-killed amphibians across sites was significant (median mortality per site, 2019: 53 individuals, 2020: 1 individual; Wilcoxon matched-pairs test, $Z = 2.31$, one-tailed $P = 0.010$), and at some sites no dead amphibians were detected. The traffic reduction and the low mortality during the lockdown suggest that the number of breeders that could reach breeding sites in 2020 was higher than in previous years.

Furthermore, in April 2020, we surveyed three 300 m transects of a road in Liguria (Northern Italy; Supplementary 1) for which data on road-killed lizards (common wall lizards *Podarcis muralis* and western green lizard *Lacerta bilineata*) were recorded during April 2019. The total survey effort was similar between years and in both years we detected a total of 25 basking lizards. However, mortality in 2019 was 10-fold higher (number of detected dead lizards: 11 in 2019, 1 in 2020). Even though these data are sparse, they consistently show that lockdown-related traffic reductions constituted a positive event for the many wildlife species that are negatively affected by road-killing, with possibly broader population-level consequences (Trombulak and Frissell, 2000).

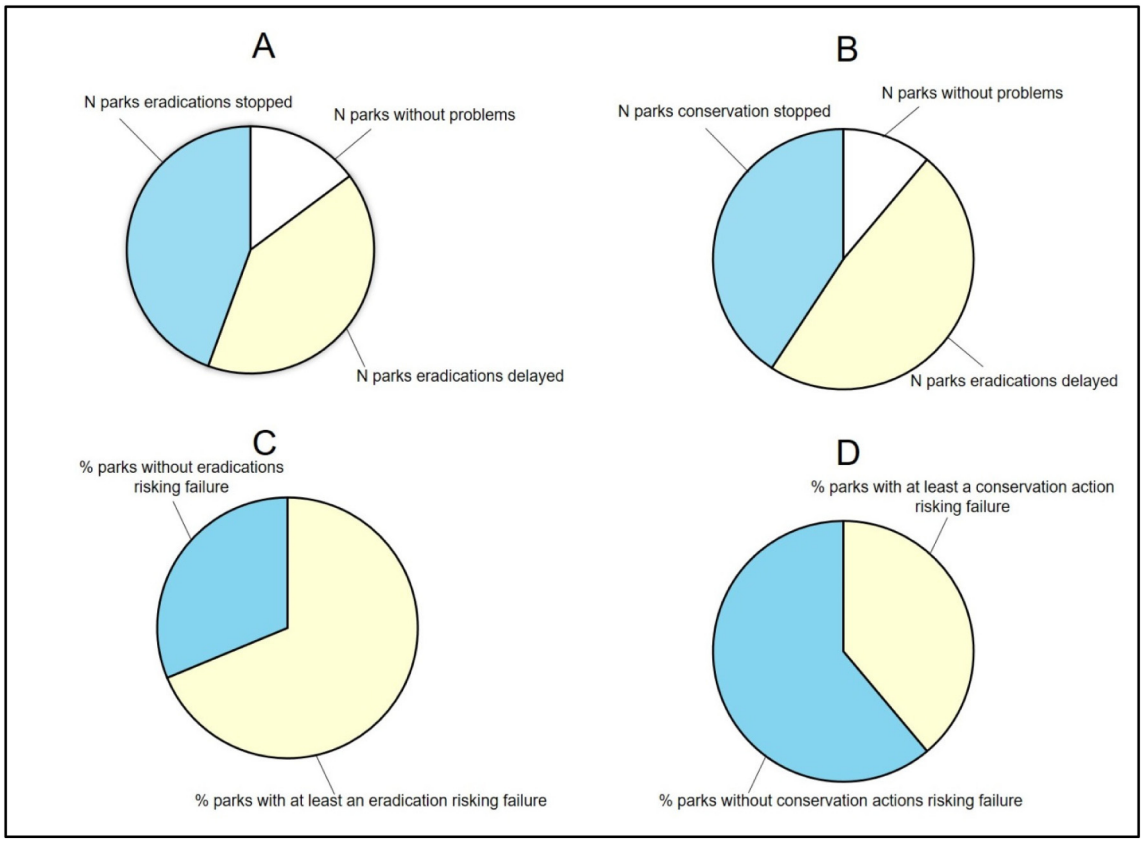

Fig. 4. Answers to the questionnaire submitted to the managers of Italian protected areas (n = 26 answers). A: Percentage of protected areas where alien species eradication actions have been stopped, delayed or unaffected during the COVID-19 lockdown (some protected areas had both delayed and stopped actions). B: Percentage of protected areas where wildlife conservation actions have been stopped, delayed or unaffected during COVID-19 lockdown (some protected areas had both delayed and stopped actions). C: Percentage of protected areas with ongoing eradication actions risking or not risking failure as a consequence of the COVID-19 lockdown. D: Percentage of protected areas with ongoing wildlife conservation actions risking or not risking failure as a consequence of the COVID-19 lockdown.

3. The bad: lockdown may favour the spread of alien or problematic species and delay conservation initiatives

Despite some positive effects, our data also highlighted several negative impacts of the COVID-19 crisis on wildlife. First of all, 14% of the news describing increased wildlife activity referred to alien species (even though often enthusiastically claiming that 'nature was coming back'). These news generally focused on urban habitats and described either alien species occurring in agricultural environments, like the Indian peafowl *Pavo cristatus*, or well-established alien species that became more active during daytime like the coypu *Myocastor coypus* (Supplementary 2).

3.1. Increased activity of alien species

An increase in daytime activity of alien species was confirmed by our observations of the Eastern cottontail *Sylvilagus floridanus*. This species has been introduced to Italy from North America for hunting purposes (Dori et al., 2019); it is mostly a solitary species, although small groups can be observed at low levels of disturbance. Eastern cottontails can also thrive in urban areas, and several urban populations occur both in the native and in the introduced range (Baker et al., 2015; Hunt et al., 2014; Santini et al., 2019). Lord (1961, 1964) reported that the activity of Eastern cottontails peaks at dusk and dawn, with inactive animals concealing in the vegetation during daytime. We monitored the behaviour and number of individuals of Eastern cottontails in an urban area (Piedmont, northern Italy; Supplementary 1). A similar monitoring effort has been applied to count cottontails in this area in 2014, 2016, 2018 and 2020 (24 h per week, in four six-hours periods, for two weeks/year in the breeding period, i.e. in March–April). In each season, 11–15 records were collected and group-size did not vary across years. In March–April 2020, cottontails were observed more frequently during daytime (late morning, between 11:00 and 14:00) compared to previous years. In 2020, the frequency of diurnal records strongly increased compared to previous years (likelihood ratio test of the hypothesis that the frequency of diurnal records was greater in 2020 compared to previous years: $\chi^2 = 4.85$, d.f. = 1, one-tailed $P = 0.014$) (Fig. 3F).

3.2. Reduction of management actions

Alien species are not only favoured by an increase of habitat availability and daily activity, but likely also by the suspension of ongoing eradication and containment activities. To investigate whether this was actually the case, we submitted a questionnaire to Italian protected areas managers. We addressed the questionnaire to 17 Italian National Parks and to 37 Regional Parks of Lombardy and Piedmont, the Italian regions that were most heavily affected by the COVID-19 February–March outbreak (Gatto et al., 2020; Supplementary 3), as well as to the Lombardy Region environmental management authority. We obtained feedback from 26 protected areas managing authorities. Eradication actions of alien species were ongoing in 62% of the protected areas and involved both terrestrial and freshwater vertebrates. 75% of the protected areas with ongoing control actions reported an interruption of the activities; 69% the necessity to delay them and 44% dreaded failure of initiated actions due to the COVID-19 lockdown (Fig. 4). Considering that the interruption of these actions took place during the breeding season of most alien species, and that many

invasive species have high fecundity rates (Capizzi et al., 2014; Masutti and Battisti, 1990), it is likely that their populations will increase more than expected, possibly overcoming the effects of past and current control strategies. Some of the interviewed managers also reported the risk of their sites to be invaded by alien species from surrounding sites because of the lack of barrier effect normally played by roads. Others underlined that the lack of control of problematic mammals like wild boars *Sus scrofa* could increase the disturbance of sites hosting endangered animals and plants. In addition, the interruption of ongoing rat eradications on islands likely limited nesting success of seabird species of conservation concern (Yelkouan shearwater *Puffinus yelkouan*, Scopoli's shearwater *Calonectris diomedea*), as suggested to occur e.g. in the Tremiti islands (L. Gaudiano, pers. comm.; cfr. Capizzi et al., 2010).

The reduction of alien species eradication activities was paralleled by a reduction of conservation actions toward native species. From our survey on protected areas, 69% of management authorities reported that actions for the conservation of threatened native species were ongoing. 61% of them had to stop these actions during lockdown, 72% reported a delay, and 61% expressed the concern that the ongoing actions had a high risk of failure because of the lockdown (Fig. 4). For instance, the latter was the case with actions aimed at building new water bodies for breeding amphibians and dragonflies. Securing funding for wildlife conservation has always been challenging (Iacona et al., 2018; Pineda-Vazquez et al., 2019), and a failure of already initiated actions, combined with the risk of reduced funding during the coming years (Corlett et al., 2020) raises special concern on the long-term success of many conservation actions in protected areas.

4. The ugly: lockdown may foster illegal killing and persecution of wild species

During the lockdown, large parts of the countryside were missing careful patrolling and monitoring from either scientists, rangers or hikers. This severely reduced the likelihood of detecting threats (Corlett et al., 2020), and probably fostered opportunities for shooting or poisoning endangered wildlife species. This was testified by a resurgence of illegal killing of birds during spring migration in many traditional Italian strongholds, such as some Tyrrhenian islands and the Straits of Messina, but also in some areas of northern and central Italy, as reported by different media (Supplementary 2). These data reflect a worldwide pattern as different NGOs underlined that in both African (e.g. Uganda, south Africa and Kenya) and Asian (especially India) countries, poaching of wild animals has more than doubled during lockdowns (Athumani, 2020; Badola, 2020). Italian media also reported the direct killing of bats in Asia as a consequence of SARS-Cov-2 fear of contagion, together with cases of illegal killing of bats in Eurasia, South America and Africa. Dedicated surveys will be needed to assess the impact of persecutions and illegal hunting on these species.

Media also highlighted the unusual behaviour of 'tourist-reliant' primates at some Asian localities where tourism collapsed (Supplementary 2), evidencing how the sudden changes in touristic exploitation may affect wildlife populations.

5. Lockdown effects: the overall picture and future perspectives for wildlife conservation

The combination of online media survey, questionnaires and first-hand field data showed the impacts of COVID-19 pandemic on wildlife can be multifaceted. It might be argued that some case studies have a limited geographical and taxonomic extent, which would reduce the generality of our conclusions. However, the different case studies showed a coherent pattern across multiple vertebrate species, and were in agreement with known impacts of human disturbance on species activity and mortality (Beebee, 2013; Liddle, 1997). This suggests that our observations were not anecdotal, and might point to broad-scale patterns (Fig. 3A), likely occurring in many areas affected by lockdowns. The COVID-19 pandemic was an unexpected emergency, and this hampered the a-priori definition of targeted monitoring programs aiming at investigating its impacts on wildlife. Nevertheless, comparing the 2020 dynamics with observation performed during previous years is an effective and efficient approach to measure the impact of an unprecedented event (e.g. surveillance monitoring; Wintle et al., 2010).

The media and part of monitoring data often suggested positive effects of COVID-19 lockdowns, which may however be labile and of limited extent. Our data allowed us to identify some perspectives for wildlife management and conservation in the near future (Fig. 4). First, every country experiencing extended lockdown periods should plan investments toward wildlife management to avoid the loss of benefits derived from ongoing conservation or management actions obtained in previous years. Funding is needed for both monitoring and direct conservation actions. Monitoring is particularly necessary for native and alien target species for which long-term data are available, to test if and to what extent lockdowns affected trends. Furthermore, dedicated monitoring of habitats for which there are indications of industrial pollution decrease like rivers, streams and urban coasts can provide exceptional information of the rate and extent of the recovering possibilities of these environments. For conservation actions, a priority list of projects most suffering from the COVID-19 crisis is required. It is possible that projects losing conservation effectiveness due to lockdowns might be abandoned to favour those currently showing the highest possibility of success. COVID-19 spread among humans was attributed to a wet-market where wildlife was sold, and over-exploitation is just one of the many impacts human activities have on wildlife. The COVID-19 crisis might have deep economic and societal impacts. However, the global environmental crisis is not over and remains a major threat for human societies and wellbeing. Forgetting the environmental crisis and stopping the ongoing conservation actions could have deep impacts for the years to come.

Second, records in the media are biased toward more charismatic and visible taxa, i.e. vertebrates (especially large mammals and birds) (Batt, 2009). Only 1% of the observations from the news survey referred to invertebrates. These were the description of an octopus *Octopus vulgaris* active in a harbour and of a barrel jellyfish *Rhizostoma pulmo* swimming in Venice canals (Supplementary 2). This may reflect the generally limited interest toward invertebrates in news items (Cardoso et al., 2011), similarly to scientific research on biodiversity and conservation (Kellert, 1993). Some news reported a decrease of pollution levels in freshwater, brackish and marine habitats that could favour many invertebrates, and a news item hypothesized the increase in pollinator species in urban areas because vegetation along roadsides was not managed during lockdowns (Supplementary 2). Due to the limited time of lockdowns and the likely rebound of activities that will follow, it is however unlikely that these effects will last long. Generally overlooked before and along the crisis (Manenti et al., 2019), the negative trends of invertebrates incur the risk of going largely unnoticed afterwards. Specific surveys and further research should be performed to address the population status of key aquatic and terrestrial invertebrates, such as pollinators and freshwater insects (Seibold et al., 2019; van Klink et al., 2020).

Third, the COVID-19 lockdown is an unplanned experiment of how stopping or limiting human activities can affect wildlife (Bates et al., 2020; Rutz et al., in press). Our surveys confirm that limitations of road traffic, even during short periods can provide major benefits to amphibians migrating to spawning grounds. Road closures, if carefully focused, could be replicated also in the future for the conservation of endangered amphibian or reptile species.

Paradoxically, the general lockdown occurring in many countries limits the possibility of performing exhaustive and quantitative analyses of the effects of lockdown himself. Nevertheless, the combination of media information and sparse monitoring data provides a clear idea of the complexity of lockdown impacts on the many facets of

biodiversity. Such information needs to be quickly recorded and catalogued globally (Bates et al., 2020), to develop rapid response plans to current and future challenges for wildlife conservation, as already going on for medical and economic topics. In the long-term, the lockdown could have strong economic and social consequences, potentially undermining our possibility to perform effective management and conservation actions (Corlett et al., 2020). However, keeping targets of biodiversity conservation must remain a key priority for the governments, shall we want to preserve the processes sustaining the functioning of the biosphere.

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Declaration of competing interest

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