EFFECTIVENESS, EFFICIENCY, AND SAFETY OF CENSUSING EURASIAN OYSTERCATCHERS *HAEMATOPUS OSTRALEGUS* BY UNMANNED AIRCRAFT

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ABSTRACT

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Censusing oystercatcher *Haematopus* spp. can be difficult. Challenges often arise from difficulties with site access and the need to avoid disturbing nesting birds. Unmanned aerial systems are increasingly used in conservation and ecological research. The present study evaluated the effectiveness, managerial efficiency, and safety of the use of unmanned aerial vehicles (drones) to count Eurasian Oystercatchers *Haematopus ostralegus* breeding at the Po Delta in northeast Italy. Flights encountered 142 oystercatcher pairs, in contrast to the 135 pairs that were counted through traditional ground census. Combining the results from both methods, 140 breeding pairs of oystercatchers (110 confirmed, 30 probable) were located. The mean time required to census with the drone was far less than that required to census by ground (5.6 ± 5.7 min vs. 37 ± 38 min, respectively, for our study area). This corresponds to an expenditure of 3 708 € for ground census vs. 460 € for drone census, leading to a cost reduction of 88 %. No apparent negative effects on nesting pairs or clutches were observed. Our major findings were as follows: 1) compared with traditional ground census, using drones in waterbird counts saved time and money; 2) there was no significant difference in overall counts between drone and observer counts; and 3) despite their advantages, drones are associated with an increased disturbance response among Eurasian Oystercatchers—often leaving nests exposed and vulnerable to depredation—and this should be carefully considered when selecting a study approach.

Key words: breeding, drones, Eurasian Oystercatcher, *Haematopus ostralegus*, Po Delta

INTRODUCTION

The Eurasian Oystercatcher *Haematopus ostralegus* is one of the best-studied waders (see Goss-Custard 1996, Schwemmer *et al*. 2016 for a review), with the European population recognized as *H. o. ostralegus*. This species breeds primarily along coastal beaches, shorelines, and saline lakes in the Western Palearctic (van de Pol *et al.* 2014). According to BirdLife (2018a), the size of the European population increased from the 1960s and 1990s, then declined at a rate exceeding 40 % over the next three generations. This species' population size was recently estimated at approximately 284 000–354 000 pairs, and was given "Vulnerable" status because of the sharp decline in bird numbers where this species was formerly abundant (BirdLife International 2015, 2018b). A portion of this population inhabits Mediterranean coastlines, totalling 300–341 pairs in 1998 (Valle & Scarton 1998). In Italy, Eurasian Oystercatchers are confined to the northwestern Adriatic coasts, probably numbering about 300 pairs (pers. obs.); therefore, this species is classified as "Near Threatened" on the recent Italian Red List (Peronace *et al*. 2014). A long-term census of breeding oystercatchers has been conducted since 1991 in this area (Scarton *et al.* 1998), showing steady and ongoing population growth and expansion (Scarton & Valle 2017).

Censusing waterbirds is often difficult. Challenges arise for several reasons, most notably problematic site access (due to large mudflats, soft soil, frequent occurrences of tidal channels, time constraints due to low tides etc.) and the need to avoid disturbing nesting birds (Carney & Sydeman 1999, Drever *et al.* 2015). Difficulties with site access may reduce census efficiency, leading to population underestimates, whereas disturbances from researchers may lead to breeding failure (Beale & Monaghan 2004, Gill 2007, Carey *et al*. 2009). It is known that young oystercatchers receive reduced parental care at sites that are frequently disturbed, leading to lowered breeding success (Verboven *et al*. 2001, Verhulst *et al*. 2001). Traditional ground counts of nesting Eurasian Oystercatchers involve field biologists searching for nests, which leads to the incubating bird flying away and making alarm calls. This behaviour is often, but not always, accompanied by the bird circling the intruder until the person is 80–100 m from the nest (pers. obs.).

Unmanned aerial vehicles (UAVs, or drones) are increasingly used in conservation and ecological research, with a growing body of evidence suggesting that drones cause less disturbance than traditional monitoring methods. Moreover, trials using fake birds showed that UAV counts of seabird colonies are more precise than traditional ground counts (Grémillet *et al.* 2012; Hodgson *et al*. 2016, 2018; McEvoy *et al*. 2017). Data on disturbance caused by drones are only available for a few species, and little work has gone into evaluating new types of anthropogenic disturbances or assessing their associated risks (for reviews, see Borelle & Fletcher 2017, Hodgson & Pin Koh 2016; see Valle & Scarton 2018 for an analysis of flight initiation distances of 27 species nesting along the northern Adriatic Sea).

Although drones allow for inexpensive and rapid data collection, these benefits should not be prioritized over their potential risks for disturbance; further studies on the response of birds to UAVs is urgently needed for more species than those studied so far (Hodgson & Pin Koh 2016). The aims of the current study were to evaluate the effectiveness, managerial efficiency, and safety of UAV-conducted bird counts—relative to traditional census methods—on a population of Eurasian Oystercatchers. As far as we know, this is the first time that the efficiency of drone-conducted censusing has been assessed for this species.

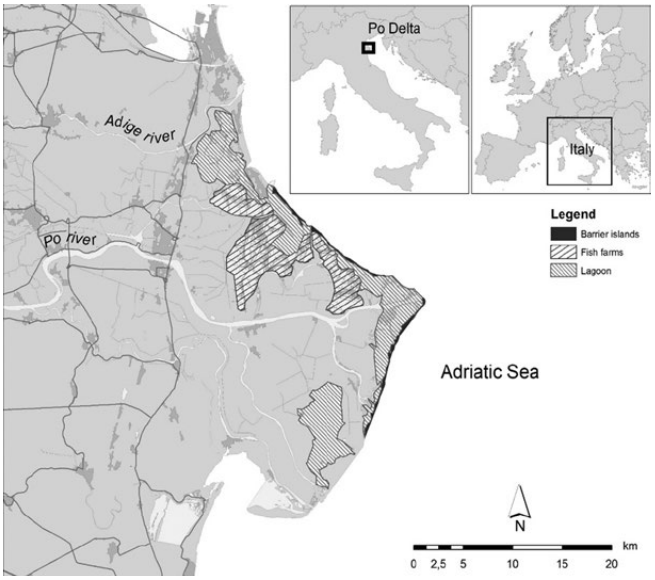

Fig. 1. Study area in the Po Delta (northern Adriatic coastline, Italy), where drone and ground counts of breeding Eurasian Oystercatchers were compared from April to June 2017; artificial islands are not shown for reasons of scale.

STUDY AREA

This project was conducted in the Po Delta, on the northwestern coast of the Adriatic Sea, between the mouths of the Adige (45°09′N, 12°20′E) and Po di Volano rivers (44°46′N, 12°15′E; Fig. 1). Due to its avian importance, the area became a Special Protection Area (IT3270023 Delta del Po) under the European Union 147/09 Birds Directive, one of the oldest EU legislations on the environment and a cornerstone of the EU's environmental protection policy.

Twenty barrier islands, including 10 artificial islands and two peninsulas, were present in the study area, each 0.5–6.9 km long and no wider than 500 m. Four barrier islands were connected to the mainland by bridges or sea-walls, and were otherwise separated from the mainland by shallow lagoons ranging from a few hundred meters to several kilometres wide. Distance from the mainland ranged from 0 (attached) to 0.7 km. The maximum tidal amplitude was ~ 100 cm. Habitats were characterized by sandy or muddy beaches and low dunes covered with psammophilous vegetation, mainly European Searocket *Cakile maritima*, Sea Holly *Eryngium maritimum,* and Marram Grass *Ammophila arenaria*. Sun-bathing and fishing by humans heavily disturb some of the islands in late spring and summer. Many possible predators of oystercatcher eggs and chicks were present, including Yellow-legged Gulls *Larus michahellis*, Marsh and Montagu's Harriers *Circus aeruginosus* and *Circus pygargus*, Eurasian Magpies *Pica pica*, and Hooded Crows *Corvus cornix* (Valle & Scarton 1999). The occurrence of breeding Yellow-legged Gulls was recorded during field activities.

METHODS

Surveys

Each island was visited three times between 1 April and 30 June 2017, between 07h00 and 14h00, each time in excellent

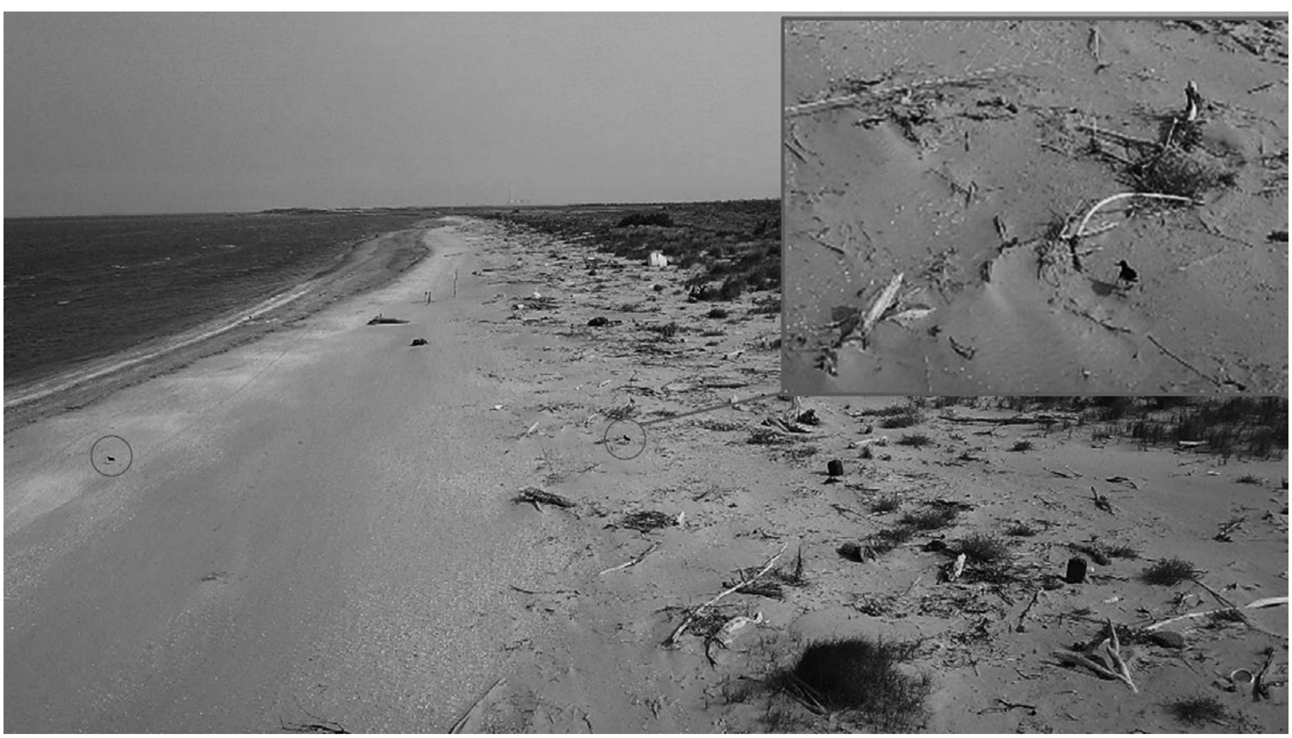

Fig. 2. A confirmed oystercatcher nesting pair during a drone count, including a bird flushing off the nest.

meteorological conditions (wind speed < 10 km/h; no clouds). Two planned drone surveys were cancelled due to unfavourable winds and precipitation. Both "probable" (pairs holding territory) and "confirmed" (pairs with eggs) nesting pairs were considered; definitions follow Hagemeijer & Blair (1997).

Human observation method

Two researchers reached each island by boat: one walked through the whole area with binoculars or a telescope looking for incubating or displaying adults and searching for nests; the other travelled to the other half of the island, left the boat, and searched for birds in the opposite direction. The first researcher then travelled to the end of the island by boat and met the second researcher, minimizing disturbance by reducing the total duration of their stay.

Drone counts

Our drone censuses were performed using systems and operational factors that were likely to minimize the negative impacts on waterbirds. These included standoff distances for operators and the use of smaller, low-visibility, low-noise vehicles (Borelle & Fletcher 2017). In our approach, two researchers surveyed the whole area by boat, one steering and the other piloting the drone. The latter flew over the barrier and artificial islands 100 m from the boat, 20–30 m above ground level (agl; the range needed for visual resolution), at a speed of 25 km/h. Drone distance was greater than the mean oystercatcher flight initiation distance of 43 ± 19.5 m for an approaching boat (Scarton 2018). At 20–30 m agl, our drone captured an area that covered the entire strip width of suitable habitat on all islands. We used a small drone (DJI Mavic Pro), at an approximate cost of 1 200 € (US$1 370), with the following parameters: weight 734 g, maximum speed 60 km/h, sensor 1/2.3″, lens 28 mm (35 mm format equivalent) f/2.2, field of view 78.8°, distortion < 1.5 %, focus from 0.5 m to ∞, video recording modes C4K (4096 × 2160 24p), 4K (3840 × 2160 24/25/30p), and noise 70.0 dB(A). Counts of oystercatchers were then made from recorded videos viewed on a personal computer by two different observers. Each count was followed by a ground census conducted within 72 h of the drone census; this included an assessment of possible predation due to drone disturbance. We recorded behavioral responses of oystercatchers, both in the field and later from videos, as follows: 1) bird flushing from the nest (confirmed nesting pair; Fig. 2); 2) bird flushing far from the nest but reacting to the drone and actively chasing, following, or preceding it (probable nesting pair; Fig. 3); and 3) birds flushing out of sight of the drone, then following and chasing it, as determined by periodic 360° rotations (at 30 sec intervals) to detect birds flying beside the drone (probable nesting pair; Fig. 3). Our drone research activities complied with the current laws in Italy.

Safety for birds

Disturbance of nesting birds during each flight, as well as during each ground survey, was estimated by: 1) the length of time that oystercatcher alarm displays occurred during drone/researcher presence in each 250-m sector; and 2) the maximum distance from the nest, or from the point the bird flew away, observed for at least one bird of the pair.

Costs

Managerial efficiency (the output a method creates relative to the effort expended, using the least amount of input to achieve the highest amount of output) was measured and was limited to human labor costs; the initial costs of the drone and the training/certifications required for drone operation were excluded. Hourly

Fig. 3. Probable nesting pairs of breeding Eurasian Oystercatchers in the Po Delta during a drone count: birds flushing far from the nest but reacting to the drone and actively preceding (A) or chasing (B) it, and/or birds flushing out of sight of the drone, following and/or chasing it (C).

costs were estimated at 60 and 40 €/h for a senior and junior researcher, respectively. The analysis did not include the costs of two cancelled drone flights.

Statistical analyses

We divided the shoreline of the barrier island into 333 sectors, each 250 m long, for a total surveyed coastline of ~ 83 km, and the presence-absence and number of pairs was calculated for each sector. Results from each method were compared to a "gold standard", obtained by combining both methods. Subsequently, sensitivity (the proportion of actual positives that were correctly identified as such), specificity (the proportion of actual negatives that were correctly identified as such), and positive and negative predictive values (proportions of positive and negative results that were true-positive and true-negative results, respectively) were calculated for ground and drone counts (Allouche *et al.* 2006). Furthermore, a kappa test was used to test the hypothesis that agreement between the two methods was greater than chance. The following coefficient of agreement ranges were used: 0–0.20 (poor), 0.21–0.40 (fair), 0.41-0.60 (moderate), 0.61–0.80 (substantial), and 0.81–1.00 (nearly perfect) (Landis & Koch 1977). To calculate the mean time needed to census each island, each island was divided into sub-islands, with sub-islands defined by a channel deeper than 100 cm. This resulted in 30 barrier sub-islands and 20 reclaimed sub-islands, with the total strips of suitable habitat ranging from 0.2–7.6 km (1.9 ± 1.9 km) in length. Differences in mean values were analyzed using paired or unpaired *t*-tests. Differences in count data were tested using a χ^2 test. Categorical data are presented as numbers (percent), and continuous data are means ± 1 SD. All tests are two-tailed, and a value of $P < 0.05$ was considered significant. Analyses were performed using SPSS software for Mac, release 20.0, SPSS Inc., Chicago, USA.

TABLE 1
Comparison of drone vs. traditional counts of Eurasian Oystercatchers in the Po Delta in 2017

	Drone count	Ground count	Combined count
Oystercatcher breeding pairs (*n*)	142	135	140
- Certain breeding pairs (*n*)	68	106	110
- Probable breeding pairs (*n*)	74	29	30
Sensitivity (%)	96.1	95.6	-
Specificity (%)	97.4	100	-
Positive predictive value (%)	96.1	100	-
Negative predictive value (%)	98.2	97.8	-

RESULTS

Effectiveness

Drone flights counted 142 Eurasian Oystercatcher pairs, versus a count of 135 from ground surveys. One hundred and forty breeding pairs (110 confirmed, 30 probable) were ascertained along the surveyed coastline by combining results from both methods, as specified below (see also Table 1, Fig. 4). Four pairs were missed by drone surveys, whereas six pairs were not confirmed/detected during ground surveys. Ground counts missed five pairs. Overall, the population occurred within 108 sectors: 82 sectors contained one pair; 21 sectors, four sectors, and one sector contained two, three, and four pairs, respectively. These values allowed for slightly better sensitivity and inferior specificity for drone surveys compared to ground counts. No significant differences were found in the number of breeding pairs found by the two methods ($t = 20.721$), and the average coefficient of agreement between the methods was "nearly perfect" (Cohen's kappa = 0.905). Otherwise, the ratio of probable to confirmed nests was different between the two methods, with drones providing a higher number of probable pairs (74/68) in comparison with ground counts (29/106) ($c_2 = 30.5$, $P < 0.001$; Table 1, Fig. 4).

Managerial efficiency

The mean time spent to census an island (both barrier and artificial) with a drone (5.6 ± 5.7 min) was far less than that required for census by traditional methods (37 ± 38 min) (paired *t*-test: $P < 0.001$). Similar differences were observed for drone and traditional methods in the time required to census both barrier islands (7.5 ± 6.5 min vs. 49.5 ± 43.3 min; paired *t*-test, $P < 0.001$) and dredge islands (2.8 ± 1.9 min vs. 18.5 ± 12.7 min; paired *t*-test, $P < 0.001$). The mean speed of researchers during traditional census methods (i.e., walking along the shoreline) was 3.0 km/h compared

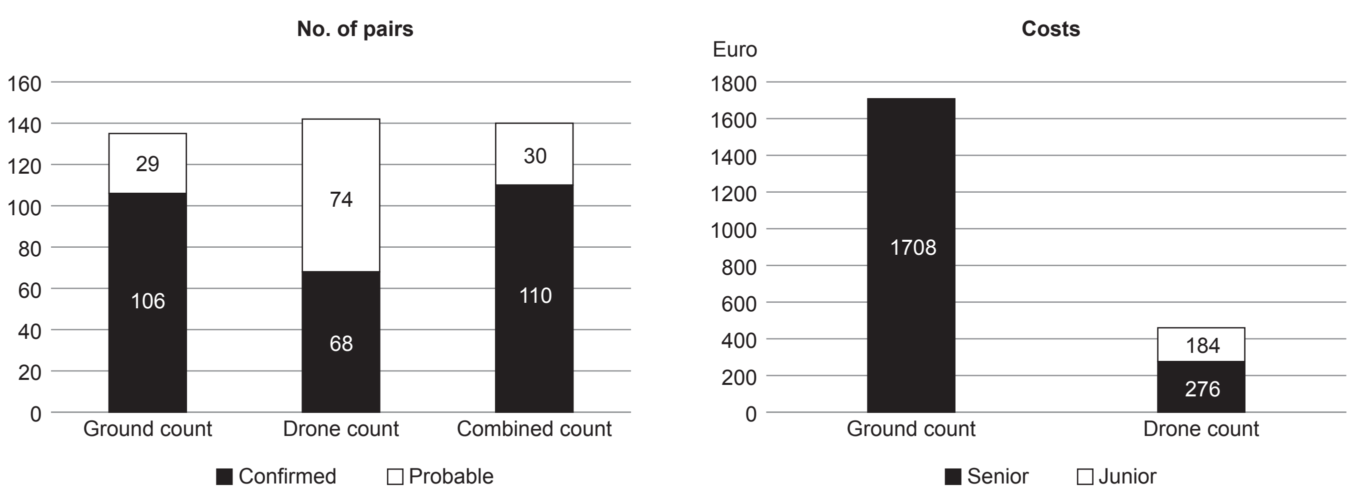

Fig. 4. Counts and total expenditure of funds for traditional vs. drone censuses of breeding Eurasian Oystercatchers in the Po Delta, Italy.

with 25 km/h by the drone. Overall, 30.9 h were spent surveying the whole area using the traditional approach vs. 4.6 h using the drone (- 85 %). This corresponded to an expenditure of 3 708 € vs. 460 € for the traditional vs. drone approach, respectively, corresponding to a cost reduction of 88 % (Fig. 4). This result was due to both a reduction in the time spent surveying and to the employment of a senior plus a junior researcher (as a boat driver) with the drone approach, compared with the need for two senior researchers using the traditional method (Fig. 4).

Disturbance

The time spent by the observer in each sector was far longer during ground counts than during drone surveys: 228 ± 40 sec vs. 49 ± 51 sec (range: 190–370 sec vs. 10–380 sec, respectively; paired t-test, $P < 0.001$). However, drones disturbed birds in a significantly different way than did ground surveys. During drone surveys, birds moved farther away from nests than they did during ground surveys: 143 ± 191 m vs. 75 ± 27 m (range: 0–1 300 m vs. 30–200 m, respectively; paired t-test, $P < 0.001$); frequently, alarmed birds (up to 17 altogether) followed and chased the drone (Fig. 3). In the absence of individually-ringed birds we could not determine if only one member of the pair followed the drone while the remaining member of the pair guarded eggs and chicks. The time spent far from the nest and the maximum distance away were greater in the presence of gulls (57 ± 60 sec, 166 ± 209 m) than in their absence (37 ± 31 sec, 108 ± 153 m; unpaired t-test, $P < 0.05$ and $P < 0.05$, respectively). These values were inversely correlated with the presence and numbers of breeding gulls during drone surveys (Linear Regression, Beta = -0.221, $P < 0.05$; and Beta = -0.240, $P = 0.05$, respectively), but not during ground counts (Beta = 0.800, $P = 0.425$). Island type did not influence our findings; for barrier and artificial islands, there were no differences in the maximum distance from the nest during ground counts (75 ± 24 m vs. 74 ± 32 m, respectively; unpaired t-test, $P = 0.973$) or in the time (119 ± 124 sec vs. 190 ± 273 sec, respectively; unpaired t-test, $P = 0.504$) and distance (47 ± 41 m vs. 54 ± 67 m, respectively; unpaired t-test, $P = 0.068$) of drone surveys. Finally, no nests were deserted and no clutch predation was observed in the 72 h after the drone surveys, as determined by subsequent ground counts.

DISCUSSION

Several studies have shown the usefulness of drone censusing—in terms of both efficiency and the amount of disturbance—for the fine-scale monitoring of nesting waterbirds such as Black-headed Gulls *Chroicocephalus ridibundus* (Sardà-Palomera *et al*. 2012), Slender-billed Gulls *Chroicocephalus genei* (Díaz-Delgado *et al*. 2017), gulls *Larus* spp., murres *Uria* spp. (Brisson-Curadeau *et al*. 2017), and Common Terns *Sterna hirundo* (Chabot *et al*. 2015). Our study confirmed the utility of drones for surveying nesting Eurasian Oystercatchers, allowing us to perform an accurate count along an 80-km section of coastline.

Drone counts allowed us to detect more (+ 5 %) breeding pairs than ground counts, and number of pairs estimated by drones (142) was almost equal to the estimate obtained by combining both methods (140). Our results agree with those reported by Chabot *et al*. (2015) for their surveys of nesting Common Terns (drones detected 94 % of the pairs counted by ground counts); Hodgson *et al.* (2018), who, using fake birds, found that drone surveys were 43 % to 96 % more accurate than ground counts; and Israel & Reinhard (2017), who surveyed Northern Lapwings and detected, by drone, 93 % of nests counted by ground counts. Nevertheless, these results refer to colonial nesting waterbirds; for non-colonial species, such as the Eurasian Oystercatcher, data have been lacking.

Disturbance caused by drones has been tested for various species. In general, it has been observed that birds react only when drones are very close to the nesting individual or nest (Brisson-Curadeau *et al*. 2017, Chabot *et al*. 2015). However, different responses among species to an approaching drone have been found by some authors (Brisson-Curadeau *et al*. 2017, Borrelle & Fletcher 2017). Interestingly, Valle & Scarton (2018) found differences among species and, in the same species, among individuals of different status (e.g., nesting or non-nesting). At our study site, all nesting individuals flushed from their nests when the drone flew over, even during test flights at an altitude of > 50 m above surface level; this behaviour is the same as that usually adopted when a pedestrian or a boat approaches an oystercatcher's nest (Scarton 2018).

Remarkably, compared to ground counts, our drone surveys significantly increased the time that Eurasian Oystercatchers spent away from their nests. This could potentially affect nesting success through predation of unattended nests or chicks, as indicated in some studies (Brisson-Curadeau *et al.* 2017). Therefore, the significantly longer time spent far from the nest when Yellow-legged Gulls were present is a matter of concern; in the Po Delta, the oystercatcher and the gull select the same nesting habitat (Valle & Scarton 1999), and the gull population has been increasing over the last 20 years (RV pers. obs.). Although the time needed for drone surveys is far less than for a ground count, and no chick or egg predations were noticed during drone surveys among the nests, our findings indicate that care should be taken when drone flights are used to survey oystercatcher pairs near gull colonies.

Weather conditions may heavily affect wildlife monitoring operations; along the coast, wind and rain can hinder surveys. This is an especially important consideration if only a few days are available to complete surveys (e.g., McClelland *et al*. 2016). Conversely, in our study area, as well as at many Mediterranean sites, fine days without rain are common; winds usually become stronger in the late morning to early afternoon, so drone surveys in the early morning often allow for good results.

CONCLUSIONS

The major findings of our study are as follows: 1) using drones in waterbird counts can save time and money compared to traditional ground census approaches; 2) there are no significant differences in overall count results between drone and observer counts; and 3) despite their advantages, drones are associated with an increased disturbance response among Eurasian Oystercatchers, and this should be carefully considered when selecting a study approach.

This is the first time, as far as we know, that the efficiency of drone-conducted censuses have been assessed for Eurasian Oystercatchers. Having effectively censused oystercatchers along an 80-km-long stretch of coast in just two days, our results indicate that, in the Po Delta as well at other coastal protected areas, drone counts can reduce survey costs by 88 % compared with traditional ground-based counts. Using drones, we recommend the following precautions: 1) launching at a distance of 150 m from the nesting site to be investigated; 2) flying at an altitude 20–30 m agl (the range needed for visual resolution); 3) flying over the nesting site for < 1 min; and 4) if large gulls or other possible predators are nesting close by, carefully observing possible predation during temporarily unattended nests of the targeted species and, if this is the case, suspending flights.

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