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Environmental characteristics of shallow bottoms used by Greater Flamingo *Phoenicopterus roseus* in a northern Adriatic lagoon

Okoljske značilnosti plitvin, ki jih uporablja plamenec *Phoenicopterus roseus* v severnojadranski laguni

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Since the beginning of this century, Greater Flamingo *Phoenicopterus roseus* flocks have been observed regularly when feeding in the large extensions of shallow bottoms in the Lagoon of Venice (NE Italy), the largest lagoon along the Mediterranean. Nowadays thousands of flamingos are present throughout the year. Between 2013 and 2017 I collected data on the environmental features of the shallow bottoms used by feeding flocks, along with measurements of flight initiation distance (FID) of Greater Flamingo in response to the approach of boats and pedestrians. Shallow bottoms were shown to be used when covered with approximately 10 to 60 cm of water. All the feeding sites were in open landscapes, with low occurrence of saltmarshes in a radius of 500 m. The bottoms were barely covered with seagrasses (<4% of the surface around the survey points) and were mostly silty. Feeding flocks were on average 1.2 km far from the nearest road or dyke, while the mean distance from channels that could be used by boats was about 420 m. The mean FID caused by boats or pedestrians was 241 m ± 117 m (N = 31, ± 1 SD) without significant differences between those for the two disturbance sources. The use of shallow bottoms by the Greater Flamingo appears governed primarily by the tidal cycle, but boat disturbance probably modifies this effect. According to FID values, a set-back distance of 465 m is suggested to reduce the disturbance caused by boats and pedestrians to the flamingo feeding flocks.

Key words: buffer zone, flight initiation distance, Lagoon of Venice, tidal flats, waterbirds
Ključne besede: zaščitni pas, ubežna razdalja, Beneška laguna, plitvine, vodne ptice

1. Introduction

In the lagoon of Venice (Italy), Greater Flamingos *Phoenicopterus roseus* were observed irregularly until the end of the 80s, mostly during late summer and autumn (Bon *et al.* 2004). Eventually they became more common, but it is only since 2007 that they began to be found regularly during mid-January IWC counts showing an almost regular increase until January 2016, when 7,000 birds were counted (Bon & Scarton 2012, Basso & Bon 2016). Given that, during the 2014–2016 winter, the Po delta hosted on average about 3,000 birds (Associazione Sagittaria *pers. comm.*) and the Friuli-Venezia Giulia wetlands about 500 birds (Regione Friuli-Venezia Giulia & Astore *unpubl.*), the Lagoon of Venice is nowadays the most important wintering site along the Adriatic coast north of the Po river.

In the Lagoon of Venice, the Greater Flamingo exploits both the fish farms surrounding the lagoon and the large extensions of tidal flats and shallow bottoms occurring outside the fish farms. The Greater Flamingo has been referred to as an ecosystem engineer (Gayet *et al.* 2012) since, due to its feeding behaviour, it mobilises large quantities of surficial sediments, due to both trampling and active filtering. The species feeds mostly on aquatic invertebrates, such as insects, crustaceans, molluscs, annelids, microalgae and plant material (Rodríguez-Pérez *et al.* 2007). Despite its major feeding habitats being salt ponds and other hypersaline environments, tidal flats, freshwater wetlands and periodic wetlands are also exploited regularly (Yohannes *et al.* 2014). The use of feeding habitats by the Greater Flamingo has been studied in detail at several Mediterranean wetlands (Tourenq *et al.* 2001, Amat *et al.* 2005, Béchet *et al.* 2009, Hamza *et al.* 2014, Yohannes *et al.* 2014, Hamza & Selmi 2015), while data for the Adriatic wetlands are lacking completely.

When feeding on large tidal flats, which are used also by clam harvesters and by fishermen, and are adjacent to deeper channels regularly used by commercial and leisure boats, in the Lagoon of Venice the Greater Flamingo is exposed to disturbance by Man. The possible effects of disturbance are disruption of regular behaviour of birds, causing the temporary or permanent abandonment of feeding, resting and nesting sites (Fitzpatrick & Bouchez 1998, West *et al.* 2002, Beale & Monaghan 2004). In the Lagoon of Venice, it has recently been estimated that at least 40,000 boats circulate each year, used for professional fishing, goods and tourist transportation and for leisure activities (Ministero delle Infrastutture e dei Trasporti 2017). About 600 of these boats are devoted to the professional harvest of the Manila Clam *Ruditapes philippinarum*. Due to their small size and low draft, these boats navigate for most of the year not only along channels but also on shallow bottoms, close to the tidal flats used by Greater Flamingos for resting or feeding. Moreover, an increasing number of wildlife watching boat tours are operating, and, for these boat tours, the Greater Flamingo flocks are clearly a sought-after target.

The flight initiation distance (FID), i.e. the point at which the bird flushes or otherwise moves away from the approaching disturbance source, is a well-known metric used to measure disturbance effects (Whitfield *et al.* 2008). The use of set-back distances and buffer zones, calculated on the base of FIDs, is often suggested as a mean of reducing disturbance of birds caused by human activities (Chatwin *et al.* 2013, Whitfield & Rae 2014, Koch & Paton 2014). Despite the Greater Flamingo being considered as a species highly sensitive to disturbance by Man, no measurements of FID have so far been available for Mediterranean wetlands.

The aims of this paper are the following: 1) a preliminary analysis of several morphological and biological characteristics of the tidal flats and shallow bottoms used by the Greater Flamingo in the Lagoon of Venice; 2) the proposition of set-back distances for this species, based on FID measurements made in 2013–2017, as a possible way to reduce disturbance caused by boats and pedestrians to the flamingo flocks.

2. Study area and methods

The Lagoon of Venice is the largest coastal lagoon in the Mediterranean; it covers an area of 55,000 ha along the Adriatic Sea, with its centre at 45°26′ N, 12°19′ E. A large part of the lagoon consists of an open water body about 37,000 ha in size, of which 5,000 ha are tidal flats less than 0.5 m deep and exposed regularly during low tides. 26,000 ha of these are shallow bottoms (0.5–1 m deep) and 6,000 ha are deeper channels (Solidoro *et al.* 2010). Saltmarshes, 3,800 ha in size, and dredge islands (artificial intertidal sites made with dredged sediments: Scarton & Montanari 2015) of 1,300 ha comprise the remaining area, along with small islands and the historical towns of Venice, Burano and Murano. Fish farms, completely surrounded by dykes and where tidal influx is regulated by the owners, occupy 9,000 ha along the lagoon borders. The climate is temperate, with a mean annual value of 14.5°C and a mean rainfall of 800 mm per year; the excursion during spring tide is about 1 m, one of the highest values in the whole Mediterranean (Solidoro *et al.* 2010). For its ornithological value, being probably the most important waterbird wintering site in the Mediterranean and one of the most important breeding sites in Italy, the whole lagoon was declared a Special Protection Area (IT 3250046 Laguna di Venezia) in 2007 according to the Birds Directive 2009/147/EC.

In the Lagoon of Venice, the Greater Flamingo regularly uses fish farms and tidal flats for feeding and resting; it is quite common to see flocks of flamingos commuting between fish farms and the lagoon shallow bottoms outside them. In order to characterise lagoon bottoms used by Greater Flamingos, between January 2014 and June 2017 I recorded from boats, or vantage points along the lagoon borders, the position of Greater Flamingo flocks (N = 21; Figure 1) occurring on shallow bottoms. Only feeding groups of at least ten birds were considered. In a radius of 500 m around the estimated position of the flamingos, the following biological and morphological data were assessed by a geographic information system (GIS) platform (Arc-GIS 9.x, ESRI, Redlands, CA) and, using recent thematic maps freely available for downloading (www.atlantedellalaguna.it):

- bathymetry, expressed on the Venice local datum;
- percentage of area covered with saltmarshes; the percentage of area covered with submerged aquatic vegetation (*Ruppia* sp. and *Zostera noltei)* (updated in spring-summer 2017);
- mean yearly water salinity; grain size of surface sediment, expressed as percentage of sand, silt and clay;
- distance of the flock from the closest possible source of disturbance such as roads, bridges and dykes;
- distance from the closest navigable channel, i.e. deeper than 1 m.

Hourly tidal levels for the 2016, chosen as a reference year for the whole period and measured at Venice town tidal gauge, were downloaded from the Venice Municipality web site (www.comune.venezia.it).

I also collected 31 measurements of FID between May 2013 and June 2017 by approaching Greater Flamingos, either on foot (N = 10) or by boat (N = 21). In the first case, I walked slowly at a constant speed through saltmarshes, dredge islands and exposed tidal flats towards the birds. I then measured the distance between me and the birds, as soon as they began to move away; care was taken not to cause flamingos to flyaway by ending the approach to avoid unnecessary disturbance. Distances were estimated using a rangefinder Leica Rangemaster LAF 900 (accuracy ± 1 m); no observation was made if there were other boats or people within 500 m of the targeted birds. In the second case, a 7 m fiberglass boat with a 140-horsepower outboard motor was used; two people were always aboard, a driver and the author. The boat approached the birds at a speed between about 4 and 5 knots, until they began to move away. The noise emission from the engine was about 85 dB(A). The boat used was of the same type as that owned by many professional shell fishermen. Distance from the birds was measured with the rangefinder. Observations always took place between 07:00 and 15:00 hours, avoiding foggy or rainy days. I visited multiple sites throughout the lagoon to avoid problems of bias, habituation and autocorrelation in the response of birds (Rodgers & Schwikert 2002). Data were not normally distributed, nor could they be normalised using standard methods. Non-parametric tests were used, such as Spearman rank correlation (r_s) and Mann-Whitney tests. Means ± SD are reported for ease of interpretation; for the same reason, the regression line is shown in the scatterplot. Numerical and statistical analyses were performed using the software Statistica vers. 7.2. Following Laursen *et al.* (2005), the mean FID plus 2 SD was used as a conservative set-back distance.

3. Results

Statistics for the 21 sites where Greater Flamingos were observed are shown in Table 1. The mean depth of the feeding sites, not including channels >1 m in depth, was about 60 cm below mean sea level; the feeding sites thus expand from truly intertidal tidal flats to the upper subtidal bottoms. During field observations, flamingos were never observed feeding on completely emerged tidal flats while, on several occasions, the birds were feeding with water at breast height. It is estimated that 10 to 60 cm of water above the bottom is the preferred range.

Table 1: Statistics for selected environmental variables of lagoon sites (radius of 500 m; N = 21) used by feeding Greater Flamingos *Phoenicopterus roseus*. SAV – submerged aquatic vegetation.

Tabela 1: Statistika izbranih okoljskih spremenljivk za posamezne lokacije v laguni (polmer 500 m; N = 21), kjer so se prehranjevali plamenci *Phoenicopterus roseus*. SAV – potopljeno vodno rastlinje

	Depth below sea level/ Globina pod morsko gladino	Saltmarsh area / Površina slanih travnikov	SAV	Sand/ Pesek	Clay/ Ilovica	Silt/ Mulj	Salinity/ Slanost	Distance from roads and bridges/ Razdalja do cest in mostov	Distance from channel >1 m deep (m)/ Razdalja do kanalov, globljih od 1 m
	(m)	%	%	%	%	%	ppt	(m)	
Mean	-0.64	13.9	3.8	12.3	21.1	66.5	28.7	1156	416
Min	-1.12	0	0	2	10.4	34.1	23.5	150	170
Max	-0.41	46.3	50	55.4	33.8	76.1	32.4	2600	1200
SD	0.18	14.6	12.4	12.1	4.6	9.8	2.1	744	230

Considering the mean depth of feeding sites in Table 1, the water column range and the tidal observations for the year 2016, the potentially suitable bottoms are not available (i.e., because water is too high or too low) for at least 57% of the whole year.

The feeding sites were all located along the western and northern sectors of the Lagoon of Venice; lagoon bottoms in the eastern and southern sectors are usually deeper, being between −1 m and −2 m, thus completely unsuitable for the flamingos to feed (Figure 1). Nevertheless, the flamingos appeared to use only a part of the whole potentially suitable area of shallow bottoms (dark grey in Figure 1).

All 21 feeding sites were in open landscapes, with low occurrence of saltmarshes in a radius of 500 m; the bottoms were barely covered with seagrasses and mostly silty. The flocks were, on average 1.2 km from the nearest road, bridge or dyke, while the mean distance from channels that could be used by boats was about 420 m, with a minimum of 150 m. Mean annual water salinity in the feeding sites was that of brackish waters, as in most of the Lagoon of Venice.

The mean FID measured was 242 m ± 117 m (N = 31, ± 1 SD), with a minimum of 85 m and a maximum of 570 m. Birds moved away earlier if a boat was approaching (260 m ± 100 m, N = 21) instead of a pedestrian (204 m ± 144 m, N = 10), but these differences were at the threshold of significance ($P = 0.07$). Larger flocks moved earlier than smaller ones, with a highly significant increase in FID (Spearman r = 0.68, $P < 0.001$; Figure 2). No correlation was observed between FID values and date, expressed as days from 1 Jan (Spearman r = 0.25, $P > 0.05$). Using the values of mean FID and SD reported above, the resulting set-back distance is 465 m.

4. Discussion

For a few years, Greater Flamingos have been observed regularly in the Lagoon of Venice, feeding or resting in the large extensions of shallow bottoms. The presence of thousands of Greater Flamingos should promote studies dealing with the possible effects of intertidal sediment properties and biological characteristics on Greater Flamingo activity (see for a review Gayet *et al.* 2012 and Gihwala *et al.* 2017), as well as conservation actions aimed at reducing disturbance to the flocks occurring in this highly anthropised lagoon.

The preliminary results presented in this work show that the flocks did not use lagoon bottoms that emerged during the low tides. Instead, they

Figure 1: Location of sites where Greater Flamingo *Phoenicopterus roseus* feeding flocks were recorded (white dots): in dark grey the area of shallow bottoms between 0 and –1 m below sea level

Slika 1: Lokacije, kjer so bile zabeležene jate plamencev *Phoenicopterus roseus* med prehranjevanjem (bele pike). S temno sivo so označene plitvine med 0 in 1 m pod morsko gladino

used the still submerged sites, with an estimated water column of between 10 and 60 cm. This range agrees with results from other Mediterranean wetlands, as in southern Tunisia (Boukhriss *et al.* 2007).

During the frequent field surveys I have made over the last years, I observed flamingos leaving the intertidal sites when water became too high, due to the incoming tide, or when it was too low, due to the receding tides. Birds were then flying towards the privately-owned fish farms, where water levels are strictly regulated by the owners and are far less variable than those outside. In the Lagoon of Venice, fish farms host the majority, about 80%, of wintering birds, at least during daytime when IWC counts are carried out (Scarton & Bon 2009). These anthropogenic wetlands also hosted a similar percentage of the breeding population estimated in the whole lagoon in 2012–2014, for 26 waterbird species (Scarton 2017). Fish farms along the NW Adriatic coasts are used intensively for hunting, during a few days per week; outside the hunting season (August–January) the overall disturbance is low. As observed elsewhere for other man-made wetlands (Fasola & Ruiz 1996, Ramírez *et al.*

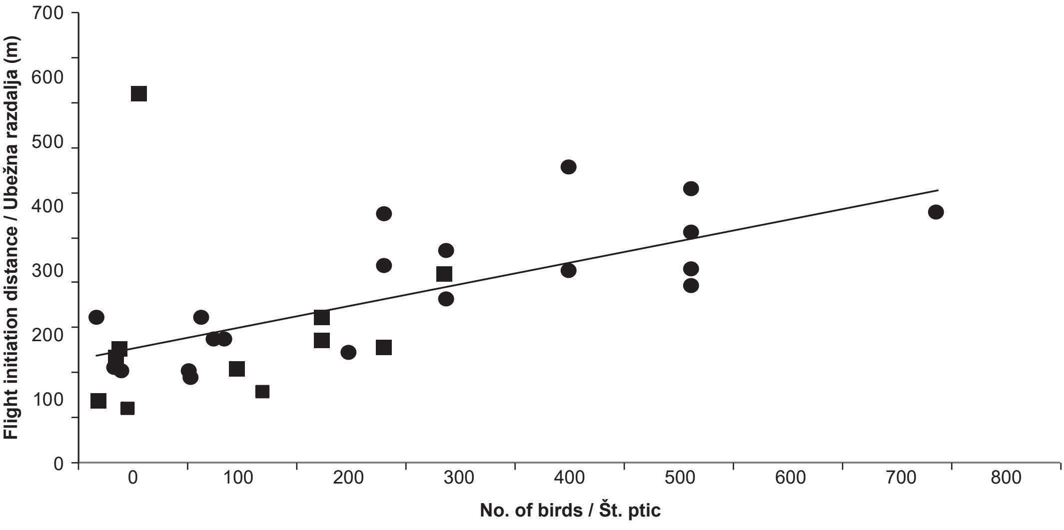

Figure 2: Flight initiation distance (m) versus flock size: response to disturbance caused by a pedestrian (square) or a boat (circle)

Slika 2: Ubežna razdalja (m) glede na velikost jat: motnja s strani pešca (kvadrat) ali plovila (krog)

2012), the NW Adriatic fish farms probably play an important role as alternative feeding, resting and nesting habitats for waterbirds; nevertheless, more detailed studies are needed to elucidate this topic.

The sites used by the Greater Flamingos had scarce seagrass coverage, as for most tidal flats and part of the shallow bottoms occurring in the Lagoon of Venice. Here, the denser and larger seagrass beds can be found either in deeper bottoms or along channels, on the margin between the channels and the adjacent tidal flats. The former is not suitable for Greater Flamingos due to its excessive depth, while the second is probably too close to the navigation channels, that are frequently used by boats. It is likely that Greater Flamingos avoid shallow bottoms close to the channels for this reason, although these bottoms are in principle suitable as feeding habitats. Disentangling the effects of tides from those of man-made disturbance is thus another topic for study. Moreover, other landscape characteristics are known to affect the occurrence of feeding Greater Flamingos, such as openness of the site, presence of wooded margins and distance to natural marshes (Tourenq *et al.* 2011) and should be investigated for a better understanding of the ecology of this species in the North Adriatic.

Disturbance to waterbirds, including flamingos, due to boats used for birdwatching tours has been studied in Spain, South Africa, and South America (Galicia & Baldassare 1997, McFadden *et al.* 2017, De Blocq Van Scheltinga 2017). All the studies found negative effects, i.e. displacement of birds occurring near the channels used by boats. As reported in Galicia & Baldassarre (1997), the Greater Flamingo has a feeding time exceeding 50% of the whole day; thus, disturbance made from boats could reduce its feeding time in tidal flats, forcing birds to leave what are otherwise suitable feeding habitats. The impact of boat traffic on Greater Flamingos and on other waterbirds that use tidal flats is virtually unknown in northern Adriatic wetlands; the first data about FID in six species of non-breeding waders presented in a recent study failed to observe differences between boat and pedestrian disturbance (*own data*).

The possible impact of clam harvesting on Greater Flamingo feeding also deserves attention. It must be noted that, at other coastal sites, the species did not appear to be disturbed by clam collectors walking on tidal flats, as was reported by Hamza & Selmi (2015) for the Gulf of Gabes, Tunisia, or by Khaleghizadeh (2010) for the Bandar Abbas coast, Iran, where flamingos allowed people to approach to about 50 m. Nevertheless, in the Lagoon of Venice the professional clam harvesting is carried out mostly using boats, which navigate not only through the deep channels but in the large shallow bottoms as well. Given the high gregariousness of the species and the population size of flamingos in the Lagoon of Venice, even a single event of disturbance can force a significant proportion of the birds present in the whole lagoon to abandon their feeding sites.

Disturbance to waterbirds caused by roads and other man-made structures have been studied elsewhere (Burton *et al.* 2002, Godinho *et al.* 2017), but there appears to be nothing specific to Greater Flamingo, apart from a paper by Yosef (2000), who showed that birds were disturbed more by all-terrain vehicles than by joggers. The observations of flocks presented here, from two long bridges with intensive traffic that crosses the lagoon, were always at a distance of at least 150 m, despite the shallow bottoms having similar morphological characteristics closer to the bridges. It is thus likely that, in my study site, Greater Flamingo did not feed at less than 150 from car traffic.

Overall, the FID measurements made in this study indicate that about 250 m is the distance at which birds begin to react, by moving away, to the occurrence of boats or pedestrians. The finding that larger flocks have larger FIDs than smaller groups or than single birds is certainly not a novelty, explained with the effects of many eyes scanning for predators (Møller 2015); moreover, large flamingo flocks are more likely made by a greater proportion of adults, which are more vigilant than young (Boukriss *et al.* 2007). The increase in FID observed here may have important consequences for conservation measures, indicating that large flocks should be regarded as particularly prone to disturbance. Few data on FID are available in the literature. Only for related flamingo species did Coetzer & Bouwman (2017) report a mean FID of 157 m for the Lesser Flamingo *P. minor*, while Galicia & Baldassare (1997) reported American Flamingos *P. ruber ruber* (now *P. ruber*) flying in response to boat disturbance of between 50 and

100 m. Both these values are much smaller than those observed in the Lagoon of Venice, which may indicate lower habituation to human disturbance in the latter site.

The adoption of new rules, that include the duty to maintain a distance of at least 400 m from flamingo flocks, is thus recommended in the Lagoon of Venice and, probably, at other northern Adriatic wetlands. At the same time, an information campaign among the many people who use boats for leisure (anglers, hunters) or work (tourist and goods transport boat pilots) should also be launched to increase awareness about the possible direct and indirect effects of the boat traffic on the Greater Flamingo and other waterbirds.

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Povzetek

Od začetka tega stoletja se jate plamencev *Phoenicopterus roseus* redno prehranjujejo v plitvinah Beneške lagune (SV Italija), največje sredozemske lagune. Tisoči osebkov se tam zadržujejo vse leto. Med letoma 2013 in 2017 sem zbiral podatke o okoljskih značilnostih plitvin, kjer se jate prehranjujejo in meril ubežne razdalje jat pred pešci in plovili. Plamenci so se prehranjevali v plitvinah, kjer je bila višina vode 10–60 cm. Vsa prehranjevališča so bila v odprti krajini z majhnim deležem slanih travnikov v polmeru 500 m; dno je bilo večinoma muljasto, z majhnim deležem pokritosti z algami (< 4 % površin). Jate so bile v povprečju 1,2 km oddaljene od najbližje ceste oziroma nasipa, povprečna razdalja od plovnih kanalov pa je bila 420 m. Povprečna ubežna razdalja pred ladjami ali plovili je bila 241 ± 117 m (N = 31, ± 1 SD), brez pomembnih razlik med obema viroma motenj. Na prisotnost plamencev vpliva predvsem bibavica, verjetno pa so motnje s strani plovil dodaten dejavnik. Glede na izmerjene ubežne razdalje svetujem določitev razdalje 465 m kot prag za zmanjševanje motenj s strani pešcev in plovil.

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