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Assessing Flight Initiation Distance and Behavioural Tolerance of an Alien Invasive Species, the Sacred Ibis (*Threskiornis aethiopicus*), in Northern Adriatic Coasts (Italy): Implications for Management of Invasive Waterbirds

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Abstract

The Sacred Ibis *Threskiornis aethiopicus* is an invasive alien species (IAS) that has become established in many European countries. Because of its invasive status and its frequent interactions with native species, understanding the behavioural tolerance of this species to human disturbance is relevant for both conservation and management. Here, we analysed Flight Initiation Distances (FID) of *T. aethiopicus* recorded between 2012 and 2025 across the northern Adriatic coast. The dataset ($n = 72$) included approaches on foot and by boat in six habitat types (artificial saltmarshes, farmlands, brackish ponds, freshwater wetlands, saltmarshes, tidal flats). Mean FID was 41 m ($SD = \pm 24$); it was affected mainly by group size, whereas habitat, season and approach mode had no clear effect. A cross-species analysis of mean FID versus body mass indicated that, for its size, *T. aethiopicus* has a much shorter FID than expected from the allometric relationship observed in 20 other waterbirds species for which FID was also collected ($n = 1505$) at the same sites. The results suggest partial habituation to anthropized environments and a limited flight response compared to native species. These findings may support management actions aimed at monitoring and controlling the expansion of the species while mitigating disturbance to native assemblages.

Keywords: flight initiation distance; human disturbance; invasive species; Lagoon of Venice; Po Delta

1. Introduction

The Sacred Ibis *Threskiornis aethiopicus* is native to sub-Saharan Africa and parts of the Middle East but has been introduced accidentally or intentionally in several European countries since the late twentieth century [1–4]. Feral populations derived from escapes from zoological gardens have established in France, Germany, Italy, Portugal, Spain, Switzerland, and the Netherlands [1,3,4]. Although originally introduced from captive collections, the species now occupies a variety of coastal habitats, including estuaries, lagoon systems and agricultural landscapes. Its ecological flexibility, broad diet and tolerance of human-modified environments have facilitated this expansion, raising management questions regarding its potential impacts on native bird assemblages and wetland ecosystems. *T. aethiopicus* is considered an invasive alien species (IAS) under EU Regulation 1143/2014 because of its potential to compete with native colonial waterbirds for nesting sites and food and direct predation on eggs and chicks.



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Debate persists, however, over the magnitude and consistency of such impacts. While some authors report predation on eggs or competition with native colonial waterbirds [5–7], one long-term study indicates that the species' effects may be limited, context-dependent or overestimated [8]. This author emphasises that diet composition is dominated by abundant invertebrate prey or garbage, and that interactions with sensitive species may be opportunistic rather than systematic. A recent study [9] concluded that there were no instances of predation by *T. aethiopicus* on heron species that shared the same colonies in Italy.

Another possible problem is due to the species acting as a bridge host in avian influenza transmission cycles. Due to the increasing overlap between *T. aethiopicus* occurrence and poultry farming areas [10], along with its scavenging behaviour, continued surveillance has been claimed as essential to assess its epidemiological role in spreading avian influenza [11].

All these issues highlight the need for empirical field-based studies that focus on behavioural mechanisms underlying habitat use, disturbance responses and space-use patterns of *T. aethiopicus*.

Flight Initiation Distance (FID)—the distance at which an individual flees from an approaching threat—represents one of the most widely used behavioural metrics for assessing wildlife responses to disturbance [12–14]. FID provides a quantifiable measure of perceived risk and is increasingly used to inform spatial planning, buffer zones and management guidelines in coastal and wetland ecosystems [15–19]. However, FID is known to vary considerably among species, contexts and individuals, influenced by factors such as body size, group size, approach type and prior exposure to humans. Species with high behavioural plasticity, particularly those thriving in human-dominated landscapes, may exhibit weak or context-dependent differences in FID across habitat categories, consistent with habituation to recurrent disturbance and flexible risk assessment [20–22]. Previous studies on waterbirds in the North Adriatic have revealed substantial inter-specific variation in FID linked to foraging guild, body size and habitat [23–25].

Despite the growing distribution of *T. aethiopicus* in Europe, empirical data on its FID and on the determinants of escape behaviour remain extremely scarce. The few available studies on *T. aethiopicus* in Europe have focused primarily on diet, breeding dynamics and population trajectories in non-native ranges [2–4,8,26], whereas behavioural responses to disturbance—in particular FID—have received very little direct attention and are usually mentioned only incidentally within broader disturbance or community-level analyses [19,21].

Along the northwestern Adriatic coasts, the species has become increasingly common in lagoons, fish farms, agricultural mosaics and peri-urban wetlands; in the Veneto region, the first confirmed nesting event occurred in 2020 [27], and in 2025 at least 1500 pairs were nesting (Valle & Scarton, pers. obs.).

These features make this region highly suitable for examining fine-scale behavioural responses, including variation in Flight Initiation Distance (FID) across environmental and social contexts. The combination of ecological adaptability and expanding distribution underscores the relevance of studying disturbance responses for informing management within coastal areas. Moreover, no management measure has been adopted so far in the Veneto region; thus, the behaviour of the species has not been externally modified over this time period.

With the present study we want to partially fill this gap by providing a detailed assessment of FID in *T. aethiopicus* across a variety of coastal habitats along the northern Adriatic coast.

In detail, we:

- (1) describe variation in FID across six habitat categories;
 - (2) test the influence of social, environmental and observational predictors using a multi-variate framework;
 - (3) compare the local observed values with the few available from international studies.
- By clarifying the behavioural responses of this species to disturbance, our findings aim to support evidence-based management of this invasive species in human-dominated coastal ecosystems.

2. Materials and Methods

2.1. Study Area

The study area comprised the coastal zone of the Veneto region (NE Italy), spanning over a length of about 130 km from north (45.883° N, 13.027° E) to south (44.813° N, 12.427° E; Figure 1). This area includes a complex mosaic of habitats, such as saltmarshes, tidal flats, freshwater ponds, fish farms, small, vegetated islands, and intensively farmed landscapes. Besides the largest wetland systems in all the Mediterranean, the coastal area includes large towns and industrial sites, with a long history of intensive human management [28]. FIDs were mostly collected in the Lagoon of Venice (55,000 ha) and the Po Delta (61,000 ha), two large brackish wetland complexes, with additional data coming from the coastal plain. The study area is characterised by a temperate sub-continental climate, moderated by marine influence. Mean annual air temperatures typically range from 10 to 14 °C, with relatively mild winters (0–4 °C), warm summers exceeding 20 °C and annual precipitation typically between 800 and 1100 mm [29].

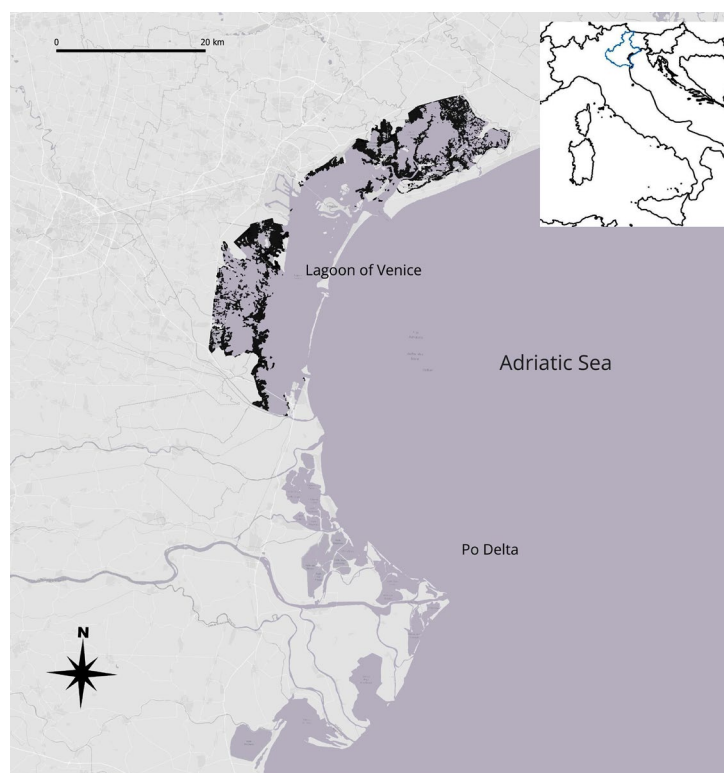


Figure 1. Map of the study area, with the location of the Lagoon of Venice and the Po Delta highlighted.

Field observations were conducted across representative sites spanning the full range of habitats exploited by *T. aethiopicus* in the region. All sites were accessed by foot or by boat under safe weather conditions, and surveys were distributed across seasons to include both breeding and non-breeding individuals or groups. The open landscape, extensive

visibility and predictable patterns of human presence make the northern Adriatic wetlands an appropriate system for studying FID and disturbance-related behaviours.

2.2. Data Collection

Seventy-two FID measurements were collected between 2012 and 2025 by one of the authors using a standardised protocol consistent with [23,24]. Surveys were conducted from two hours after sunrise to two hours before sunset, excluding the central hours of the day during summer months, as well as foggy or rainy conditions. No observation was taken when other boats, vehicles or people were present within 300 m of the focal birds. No management or control measure has been adopted in the area during the study period; thus, the behaviour of *T. aethiopicus* did not change. For approaches on foot, the observer walked slowly and directly toward the birds at a constant speed of 1–2 km/h. For approaches by boat, the observer and a driver advanced directly toward the focal individual or group at 7–10 km/h; all boats used were of similar length (about 7 m) and produced an engine noise of approximately 85 dB at 1 m. Distances were measured with a Leica Rangemaster LAF 900 rangefinder; in group observations (i.e., two or more birds) FID was defined as the distance at which the first individual initiated flight or walked away.

Starting Distance (SD) or Alert Distance (AD) were not recorded. Although SD and FID are typically strongly and positively correlated [14], all approaches occurred in open, unobstructed landscapes where the influence of SD on FID is expected to be limited [16]. For each FID event, the following variables were recorded:

- habitat category, grouped in six classes: natural saltmarshes and tidal flats, artificial saltmarsh (also called dredge islands [30]), brackish ponds (within fish farms), freshwater ponds/wetlands, farmland fields (mostly ploughed), and small vegetated islands;
- approach method: on foot or by boat;
- presumed breeding status: breeding (i.e., adult birds observed between April and July 2020–2025) or non-breeding (other months, or any month if before 2020, the date of the first confirmed nesting event in the study area);
- group size: number of individuals present within approximately a 30 m radius of the focal bird.

2.3. Statistical Analyses

We evaluated the factors influencing Flight Initiation Distance (FID) in *T. aethiopicus* using standard procedures in behavioural ecology and wildlife disturbance research [13,14,31]. All records with complete information on FID, group size, habitat, approach method and breeding status were retained for analysis. Because raw FID values were right-skewed and deviated from normality—patterns widely reported in escape-distance studies—initial comparisons among habitats were performed using the Kruskal–Wallis test. When relevant, pairwise contrasts were explored using Wilcoxon rank-sum tests with Bonferroni correction.

Because the authors do not routinely use R for statistical computing, analyses were conducted through an AI-assisted workflow using ChatGPT v. 5.2 (OpenAI) to generate Python v 3.11 and R code for data filtering, descriptive statistics and regression modelling. The use of large language models (LLMs) for coding and analytical assistance in ecology is increasingly discussed in the scientific literature, with emphasis on both potential and misuse [32–36]. In the present study, the LLM served strictly as a coding assistant: all analytical choices, data validation and interpretation remained under the authors' full responsibility. The complete *T. aethiopicus* dataset and the script used to reproduce the analyses are provided as Supplementary Materials.

FID was analysed in four sequential steps:

1. Descriptive statistics. Mean, variance, median, 25th–75th percentiles and range were computed for the full dataset. Habitat-specific summaries were then produced for the six habitat categories used in the study (Table 1).
2. Comparisons among habitats. Because the dataset was right-skewed, heteroscedastic and unbalanced across habitat classes, we tested for differences using the Kruskal–Wallis H statistic ($\alpha = 0.05$).
3. Multivariate model of predictors of escape behaviour. To evaluate the joint influence of social, environmental and observational factors, we fitted a multiple linear regression model to log-transformed FID values. OLS (Ordinary Least Squares) regression—i.e., a linear model estimated by minimising the sum of squared residuals—was used to quantify the effects of predictors on log-transformed FID. Both FID and group size were transformed using $\log_{10}$ to approximate normality and stabilise variance, following best practices in behavioural and ecological regression modelling [37].

Table 1. Descriptive statistics of Flight Initiation Distance (FID, m) by habitat.

Habitat	<i>n</i>	Mean (m)	SD	Median	Min	Max
Artificial saltmarshes	17	35.7	14.5	35	14	62
Brackish ponds	5	29.8	10.1	27	17	42
Farmlands	31	45.4	24.8	40	12	120
Freshwater ponds	2	39.5	7.8	39.5	34	45
Natural saltmarshes and tidal flats	12	41.3	37.3	27.5	16	150
Small islands	5	45.2	17.6	45	18	65

The model structure was:

$$\log_{10}(\text{FID}) = \beta_0 + \beta_1 \log_{10}(\text{Group size}) + \text{Habitat} + \text{Approach method} + \text{Status} + \varepsilon.$$

Group size was treated as a continuous covariate and $\log_{10}$ -transformed prior to analysis, whereas categorical predictors (habitat, approach method and status) were included as fixed effects and dummy-coded automatically. Model residuals were inspected visually and via Shapiro–Wilk and Breusch–Pagan tests to evaluate normality and homoscedasticity; diagnostics indicated acceptable fit on the transformed scale. Model evaluation followed information-theoretic principles using Akaike’s Information Criterion.

4. Cross-species scaling (body mass vs. FID). To contextualise the behavioural responses of *T. aethiopicus*, FID measurements (boat and on foot combined) from 20 additional waterbird species (71 records on average, range 10–350) were extracted from the broader dataset held by the authors (1505 records). All measurements were collected by the same observer within the same regional and temporal context as the present study. Body mass values for each species were retrieved from the Swiss Ornithological Institute database (www.vogelwarte.ch, accessed on 26 November 2025). A log–log regression quantified scaling between body mass and FID, allowing the position of *T. aethiopicus* to be interpreted relative to community-level expectations.

All analyses were performed in Python v 3.11 using pandas, numpy and statsmodels. Effect sizes are reported as regression coefficients with associated *p*-values.

3. Results

3.1. Descriptive Statistics of FID Across Habitats

A total of 72 valid FID measurements were included in the analysis. Across all observations, FID showed a mean of 41.2 m (SD = 23.9 m), median 36.5 m, and a range of 12–150 m. When summarised by habitat category ($n = 6$), substantial variability was present within each group, and distributions overlapped widely (Table 1). While some habitats contained small samples (e.g., freshwater ponds, brackish ponds, small islands), the overall pattern was consistent: no habitat showed different FID relative to the others (Kruskal–Wallis test: $H = 3.52$, $df = 5$, $p = 0.620$). Pairwise Wilcoxon tests, adjusted for multiple comparisons, likewise revealed no significant contrasts among habitats (all raw p -values = 0.095–0.958; Bonferroni-corrected $\alpha = 0.0033$). Taken together, the descriptive statistics indicate that habitat type does not exert a measurable influence on escape behaviour in this population of *T. aethiopicus*, with birds responding similarly across both natural and anthropogenic wetland environments. To evaluate the combined effects of social, environmental and observational factors, a multiple linear regression model was fitted to log-transformed FID values. The model included $\log_{10}$ (group size), habitat (six categories), approach method (foot, boat) and status (breeding, non-breeding) as predictors.

3.2. Predictors of FID

The overall model explained a modest proportion of variance ($R^2 = 0.162$; adjusted $R^2 = 0.056$). Among all predictors, log-transformed group size was the only variable significantly associated with FID ($\beta = 0.1536$, $p = 0.020$; Table 2). On the original scale, this corresponds to a 43% increase in FID for each tenfold increase in group size, consistent with enhanced detection or collective vigilance in larger groups.

Table 2. Multivariate regression results, including regression coefficients, standard errors, t-values and p -values for all predictors. Significant values are marked in bold.

Predictor	Estimate (β)	SE	t	p -Value	95% CI
Intercept	1.51	0.09	16.86	<0.001	[1.33, 1.69]
$\log_{10}$ (Group size)	0.15	0.06	2.39	0.02	[0.02, 0.28]
Habitat: Brackish_pond	−0.09	0.13	−0.69	0.50	[−0.34, 0.16]
Habitat: Farmland	0.02	0.09	0.27	0.79	[−0.15, 0.20]
Habitat: Fresh_water_pond	0.09	0.17	0.54	0.59	[−0.24, 0.42]
Habitat: Saltmarsh_tidalflat	−0.01	0.09	−0.12	0.91	[−0.19, 0.16]
Habitat: Small_island	0.13	0.13	1.06	0.29	[−0.11, 0.38]
Approach_method: Boat	−0.05	0.08	−0.56	0.58	[−0.21, 0.12]
Status: Breeding	−0.07	0.08	−0.88	0.38	[−0.222, 0.087]

None of the categorical predictors yielded significant coefficients. All habitat contrasts relative to the reference category had wide confidence intervals that spanned zero (p -values 0.29–0.90), indicating no measurable habitat-level contribution after accounting for social effects. Similarly, approach method ($p = 0.581$) and status ($p = 0.384$) did not improve model fit or explain additional variation. Overall, these results demonstrate that social context, represented by flock size, was the only reliable predictor of escape distance, while habitat, approach type and reproductive status did not contribute measurably to variation in FID.

3.3. FID–Body Mass Relationship and Comparative Positioning of *T. aethiopicus*

A significant positive relationship emerged at the community level: $\log_{10}(\text{FID}) = 0.33 \log_{10}(\text{weight}) + 0.97$, $R^2 = 0.50$, indicating that heavier species among those considered here generally maintain greater escape distances (Figure 2). However, *T. aethiopicus* deviates markedly from this trend. Given its mean body mass (ca. 1500 g), the

scaling equation would predict an FID close to ca. 112 m, whereas the observed mean value was only ca. 41 m; *T. aethiopicus* therefore stands well below the regression line, displaying a substantially lower-than-expected escape distance for a bird of its size.

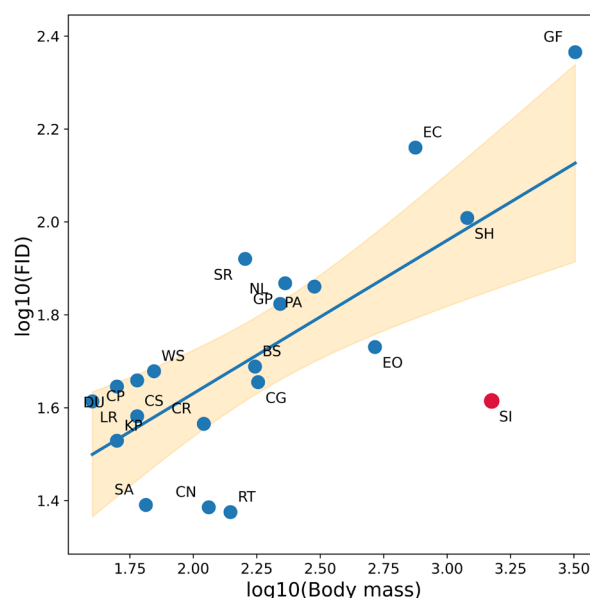


Figure 2. Log–log relationship between species-level mean body weight and flight initiation distance (FID, boat and on foot combined) for North Adriatic waterbirds. Points represent mean values per species, and the regression line is fitted across all species. Species codes: BS Black-winged Stilt, CG Common Greenshank, CR Common Redshank, CP Common Ringed Plover, CS Common Sandpiper, SH Common Shelduck, CN Common Snipe, DU Dunlin, EC Eurasian Curlew, EO Eurasian Oystercatcher, GF Greater Flamingo, GP Grey Plover, KP Kentish Plover, LR Little Ringed Plover, NL Northern Lapwing, PA Pied Avocet, RT Ruddy Turnstone, SI Sacred Ibis, SA Sanderling, SR Spotted Redshank, WS Wood Sandpiper. The shaded area represents the 95% confidence interval (CI) of the regression.

4. Discussion

4.1. Behavioural Tolerance and Habitat Use

T. aethiopicus in North Adriatic lagoons shows a mean FID, elicited by boat or on foot approaches, of approximately 41 m. This value is substantially shorter than that reported for large waterbirds occurring in the same region, such as *Numenius arquata* (often FID > 130 m) or *Phoenicopterus roseus* (FID > 200 m), and more similar to that of many smaller resident species, whose FIDs commonly fall around 20–40 m [23,24]. Such moderate escape distances are indicative of partial habituation to human presence and are consistent with the species' frequent use of artificial ponds, drainage channels and urbanised wetland margins [3,4].

Although descriptive summaries suggested somewhat longer FIDs in open farmland and natural tidal flats and shorter distances near artificial or aquaculture ponds, the multivariate model did not detect significant habitat effects once group size was accounted for. In practical terms, *T. aethiopicus* responded similarly across all habitats sampled, at least within the range of disturbance conditions represented in this study. Broad within-habitat variability combined with weak between-habitat differentiation seems typical of disturbance-tolerant species with high behavioural plasticity and repeated exposure to human activity [20].

Group size exerted a mild but consistent influence on FID, with larger flocks initiating flight at greater distances. Although the magnitude of this effect was moderate, it was statistically robust and indicates a socially mediated component of escape behaviour.

Taken together with the relatively low R^2 of the multivariate model, these results indicate that individual experience, local disturbance regimes and other unmeasured factors likely play an important role in shaping escape behaviour in *T. aethiopicus* of the North Adriatic lagoons. Environmental context and approach mode (by boat vs. on foot) did not exert a measurable influence within the range of habitats sampled, and breeding status was likewise non-informative. Given the moderate sample size and unbalanced distribution among habitats, non-significant results should be interpreted as lack of evidence for strong effects rather than definitive evidence of absence.

Overall, *T. aethiopicus* exhibited no statistically detectable variation in FID across habitat types, reinforcing the view of a generalist and behaviourally tolerant species capable of maintaining foraging activity under frequent human disturbance. This behavioural tolerance is consistent with the species' invasive success and its ability to exploit a wide range of wetland environments across the Western Palearctic [3,6].

4.2. Social and Environmental Drivers of Escape Behaviour

Our results identify flock size as the only significant social driver of escape responses in *T. aethiopicus*. Larger groups initiated flight at greater distances, in line with theoretical expectations of group-mediated vigilance, improved threat detection and alarm propagation [38]. Nevertheless, the effect of group size on FID has been shown to vary widely across species and contexts, with positive, negative or null relationships reported in the literature [13,17,19,38,39]. The moderate positive association observed here is therefore best interpreted as a context-dependent outcome reflecting socially mediated detection in a gregarious, disturbance-tolerant species.

Although statistically significant, the effect of group size was moderate in magnitude, and a substantial proportion of variation in FID remained unexplained. This outcome seems common in behavioural studies, where local disturbance history, individual experience and fine-scale environmental conditions can strongly influence escape responses [13,14].

This pattern suggests a high degree of behavioural flexibility and habituation to recurrent human activity, rather than habitat-specific risk assessment [14,19].

Likewise, no detectable differences were found between approach types (on foot vs. by boat). Differences in escape responses among disturbance stimuli have been documented in several bird species, with pedestrians, bicycles and motor vehicles eliciting different FIDs depending on species and context [19,40–42]. The absence of differences in the present study suggests limited discrimination among disturbance modes, likely reflecting habituation to frequent and repeated exposure to both types of human activity.

4.3. Comparisons with Other Studies

Our results are broadly consistent with published behavioural studies on the species. In France [8] described *T. aethiopicus* as exhibiting generally moderate wariness and a high degree of tolerance to human presence, with behavioural responses varying only weakly across habitats and colony sites. Studies examining community interactions further indicate that the species may coexist with native colonial birds [26] without necessarily inducing strong displacement responses, supporting the idea that behavioural tolerance—rather than acute avoidance—characterises its interactions with disturbance stimuli [5].

Comparative analyses and reviews of FID determinants in birds consistently identify body size as an important predictor of escape distance, with larger species tending to initiate flight at greater distances, although this relationship may be modulated by disturbance history and ecological context [13,14]. Our community-level analysis confirms this general allometric pattern across waterbirds but also highlights a marked deviation for *T. aethiopicus*. Given its body mass (ca. 1500 g), the species would be expected to show substantially

longer escape distances than those observed. Instead, its mean FID (ca. 41 m) lies well below the value predicted by the scaling relationship, placing *T. aethiopicus* consistently under the regression line.

This divergence indicates that, while the overall body mass–FID relationship holds at the community level, *T. aethiopicus* exhibits a lower-than-expected escape response for its size, consistent with elevated behavioural tolerance and reduced sensitivity to human disturbance. Such under-reaction relative to allometric expectations has been reported for other generalist or human-tolerant species and may contribute to *T. aethiopicus*' ability to exploit anthropogenic wetlands and persist in highly disturbed coastal systems [20,22].

Several small-bodied shorebird species, including Sanderling *Calidris alba*, Common Sandpiper *Actitis hypoleucos* and Ruddy Turnstone *Arenaria interpres*, also fall below the lower 95% confidence interval of the body mass–FID regression we obtained. These species are known to forage extensively in highly disturbed coastal and recreational habitats, where repeated exposure to humans most likely promotes tolerance and reduced escape distances. The position of these species as well below the regression line therefore likely reflects behavioural plasticity and habituation, a pattern consistent with previous studies on generalist and human-tolerant waders [19,22].

4.4. Management Implications

Our results indicate that *Threskiornis aethiopicus* displays a generally low and only moderately variable flight initiation distance, with no statistically detectable differences among habitats and values substantially lower than expected for a bird of its body mass. The absence of habitat-specific escape thresholds supports the interpretation of *T. aethiopicus* as a disturbance-tolerant generalist in coastal and wetland ecosystems. When considered alongside the broad inter-population variability documented elsewhere—such as higher mean FID values reported in South African wetlands (ca. 69 m) [21] and much shorter distances observed in African urban contexts (ca. 20 m) [22]—this pattern highlights pronounced behavioural plasticity, allowing the species to maintain foraging activity under contrasting levels of human pressure.

From a management perspective, these findings may have three main practical implications.

1. Buffer zones based on FID alone may have limited effectiveness

Given that FID values are relatively low across environments and do not vary systematically with habitat type, simple spatial exclusion based on fixed buffer distances is unlikely to deter *T. aethiopicus* effectively in the absence of complementary measures. As a precautionary reference, maintaining a minimum approach distance of approximately 50 m would be expected to reduce repeated flushing events in many situations, thereby limiting short-range displacement of birds between nearby sites. This aspect is particularly relevant where repeated disturbance could cause birds to move from natural or semi-natural wetlands towards nearby sensitive areas, such as poultry farms, where contact with domestic birds may increase the potential risk of pathogen transmission. However, such a threshold cannot be considered a reliable containment tool on its own.

Although FID provides a quantifiable and widely used behavioural metric, its application as a stand-alone management instrument appears limited for this species. Escape distances are moderate and only weakly context-dependent, indicating that individuals do not markedly adjust their responses to disturbance according to the environmental setting in which it occurs. Consequently, exclusion zones derived solely from FID are likely to prevent flushing only under relatively idealised conditions, such as predictable approach trajectories, low background disturbance and good visibility.

In real-world management scenarios, multiple interacting factors—including group size, visibility, observer behaviour and repeated exposure to disturbance—likely shape

escape responses. These interactions may lead either to earlier-than-expected flushing or, conversely, to progressive habituation and reduced escape distances following repeated non-threatening stimuli.

For these reasons, FID-based distancing rules should be interpreted primarily as behavioural guidelines rather than as effective containment strategies. More robust management outcomes are likely to require additional or complementary actions, such as temporal access restrictions during sensitive periods, targeted deterrence where colony establishment is undesired, or habitat management measures aimed at reducing local suitability. While FID can help define zones where disturbance is less likely to elicit immediate escape, it does not inherently induce spatial avoidance in adaptable and disturbance-tolerant species such as *T. aethiopicus*.

2. Behavioural tolerance may favour persistence under control efforts

A large-bodied species that consistently initiates flight at relatively short distances may be particularly capable of coexisting with human presence, recreational activities and routine management operations. Such behavioural tolerance can reduce the immediate effectiveness of disturbance-based deterrents, as repeated non-lethal stimuli may fail to elicit sustained avoidance responses. As a result, strategies based primarily on displacement or exclusion through human disturbance are unlikely to produce long-term reductions in site use by this species.

In this context, population-level interventions are generally considered more reliable than behavioural deterrence alone. For *T. aethiopicus*, management experiences across Europe indicate that measures targeting reproduction and demographic processes—such as nest removal, egg sterilisation, and, where legally permitted, targeted removal—are more effective in limiting population growth than reliance on disturbance alone [4], in line with broader EU management principles for invasive alien species [43].

3. Group size as an operationally relevant predictor

Group size was the only behavioural variable with measurable predictive value in explaining variation in FID. Although the effect was moderate in magnitude, the positive association indicates that approaches toward larger aggregations are more likely to trigger earlier flight responses. Ongoing population growth is therefore expected to increase the operational relevance of this factor. In Italy, for example, the number of *T. aethiopicus* counted at winter roosts in the north-western Po Plain increased from a few tens of individuals to 10,880 birds by 2019 [3], implying a progressive shift towards larger and more frequent flocks.

From a practical standpoint, management actions conducted near feeding flocks or mixed-species assemblages should therefore anticipate a higher probability of flushing events as flock size increases, even if absolute escape distances remain relatively short. Incorporating information on group size into operational planning may improve the predictability of behavioural responses and help minimise unintended disturbance to non-target native species occurring in the same habitats.

Overall, the evidence supports a view of *T. aethiopicus* as behaviourally tolerant, flexible and potentially resistant to disturbance-based exclusion regimes. Management strategies should thus prioritise integrated control frameworks, combining population-level interventions, spatial planning and long-term monitoring, rather than relying solely on human presence or active flushing as deterrent mechanisms. Continued behavioural monitoring remains essential to assess whether FID shifts over time in response to sustained management pressure or changes in local human–wildlife interactions.

From an operational and regulatory perspective, the results above presented highlight both structural constraints and practicable opportunities for management. High

behavioural tolerance and rapid habituation shown by *T. aethiopicus* likely reduce the long-term effectiveness of deterrence strategies based solely on repeated disturbance, particularly in open coastal systems where human activity is already pervasive, such as the northern Adriatic coasts. This limits the reliability of FID-based buffer zones as stand-alone tools for spatial exclusion. However, the relatively low variance of FID across habitats and the consistent effect of flock size provide a basis for risk-based management, whereby intervention thresholds and control efforts can be prioritised in areas hosting large aggregations or in proximity to sensitive receptors (e.g., poultry farms, colonies and roosts of native species). Integrating FID-derived behavioural metrics with demographic control measures, spatial planning and targeted surveillance may therefore improve predictability and efficiency of IAS management, while reducing unintended impacts on native waterbird assemblages.

5. Conclusions

This study provides an updated and comprehensive assessment of escape behaviour in *T. aethiopicus* within the wetlands and coastal lagoon systems of the northern Adriatic. Based on 72 focal observations, flight initiation distances were generally moderate and broadly consistent with those reported for other European populations. However, when interpreted in a comparative context, the species exhibited escape distances substantially lower than expected for a bird of its body mass, indicating reduced sensitivity to human approach relative to allometric expectations.

The analyses identify flock size as the only consistent predictor of FID, with larger groups initiating flight at greater distances, in accordance with general antipredator and vigilance theory. In contrast, habitat type, approach method and breeding status did not measurably influence escape behaviour, even within a multivariate framework. This lack of context-specific modulation indicates that *T. aethiopicus* responds in a largely uniform manner across heterogeneous environments, supporting the view of a behaviourally flexible and disturbance-tolerant species that readily exploits human-modified landscapes.

From a management perspective, these behavioural traits are particularly relevant in the context of an invasive alien species. The combination of moderate escape distances, weak habitat dependence and limited discrimination among disturbance types implies that FID-based exclusion or deterrence measures are unlikely to produce sustained spatial avoidance. Although a precautionary buffer of approximately 50 m may reduce repeated flushing in some situations, FID alone cannot be relied upon to prevent site use or limit displacement towards other sensitive areas. Management strategies based solely on minimum approach distances are therefore unlikely to be effective in isolation.

More broadly, the results highlight how behavioural tolerance and plasticity may facilitate persistence and spread under human pressure, potentially undermining disturbance-based control efforts. In this sense, escape behaviour provides not only insight into species ecology, but also a diagnostic indicator of the likely effectiveness—and limitations—of disturbance-based management tools.

Overall, this work contributes novel, fine-scale behavioural evidence directly relevant to the management of a rapidly expanding non-native waterbird. By linking escape behaviour to allometric expectations and operational constraints, it provides an empirical basis for proportionate, evidence-based management strategies aimed at balancing conservation objectives with the realities of increasingly human-dominated coastal ecosystems in which *T. aethiopicus* is now firmly established.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/coasts6010004/s1>.

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